Report

# Hydrogeological Assessment for Cloudbreak Water Management Scheme

Technical Services

**December 2013**
**CB-RP-HY-0019**

Fortescue
The New Force in Iron Ore

| | | | | |
|---|---|---|---|---|
| | **Hydrogeological assessment for the Cloudbreak Water Management Scheme** | | **CB-RP-HY-0019** | |
| **Revision Number** | **2** | | **20/12/2013** | |
| **Status** | **IFU - ISSUED FOR USE** | | | |
| **Author** | Fuli Wang, Paul Ricketts | Signature | 25/10/2013 | |
| **Checked** | Paul Ricketts | Signature | 16/12/2013 | |
| **Approved** | Bobak Willis Jones | Signature | 20/12/2013 | |
| **Confidentiality** | **PUBLIC USE (ACCESS TO ALL)** | **Publish on Extranet** | ☐ Yes | ☒ No |
| **Review Date** | **22/11/2013** | | | |

**Revision History** *(to be completed for each version retained by Document Control)*

| Author | Checker | Approver | Rev No. | Status | Issued Date |
|---|---|---|---|---|---|
| **Bobak Willis-Jones** | **Jed Youngs** | **Doug Brown** | 1.2 | **IFU** | 5/11/2010 |
| **Fuli Wang** | **Paul Ricketts** | **Bobak Willis Jones** | 2 | **IFU** | 20/12/2013 |

## EXECUTIVE SUMMARY

Fortescue Metals Group's (Fortescue's) Cloudbreak iron ore mine (Cloudbreak) is within the Pilbara region of Western Australia. Cloudbreak is located approximately 30 kilometres west of Fortescue's Christmas Creek mine, 80 kilometres south west of Nullagine and approximately 120 kilometres north of Newman (Figure 1). The Cloudbreak iron ore mine has been operating since 2008, and is currently approved to ship iron ore, via a rail link, from Port Hedland (Figure 1 and Figure 2).

About 90% of iron ore at Cloudbreak is below the watertable, and mine dewatering is undertaken to minimise water ingress into mining pits. Below watertable mining commenced in July 2008, current mine dewatering and associated water management activities are approved under Ministerial Statement 899 (MS899) granted in 2012[1], controlled action EPBC 2005/2205 granted in July 2006 and EPBC 2010/5696 granted in November 2012. Key characteristics of the project stated in MS899, controlled actions EPCB 2005/2205 and EPBC 2010/5696 and the recently approved applications under section 45C and 46 of the *Environmental Protection Act 1986* limit groundwater abstraction to 100 GL/a and injection to 95 GL/a.

Knowledge developed during operations has improved the understanding of the hydrogeological conditions. On this basis the Life of Mine (LOM) plan (FMG, 2010d) has been reassessed, identifying dewatering and injection requirements up to 150 GL/a. The level of groundwater impact, in the shallow alluvial aquifer, at the fringe or within the Fortescue Marsh is within the range predicted in the previous assessment (FMG, 2010d).

Dewatering will be achieved through advance dewatering methods and operational dewatering methods. Dewatering may significantly exceed mine water use requirements, and any surplus (the difference between abstraction water and mine water use) may be transferred to Christmas Creek if required or will be returned to compatible aquifers through injection to preserve water resources and to minimise environmental impacts (groundwater level drawdown/mounding). This process of groundwater abstraction and injection is referred to as the Cloudbreak water management strategy.

The hydrological setting of the project area is characterised by three broad hydrological regimes; a topographic driven flow regime; a density driven flow regime; and the Fortescue Marsh regime which cycles between a recharge and discharge feature in accordance with flooding and drying cycles. Detailed understanding of these flow regimes and the interaction between the flow regimes has been developed based on nearly 10 years of investigations and operations in the region.

Empirical evidence, in particular the demonstrated ability of *T. indica subsp. bidens* to tolerate drought and other stressors, and numerical simulation of soil water dynamics and plant water

---

[1] MS899 supersedes the conditions of Statement 721 which was published on 24th April 2006, changed on September 2005, 12th July 2010 and 10th June 2011.

uptake by samphire vegetation on the fringe of the Fortescue Marsh (HYDRUS) suggest that the ecological water requirements of the fringing samphire communities are wholly or predominantly met by surface inputs (Equinox Environmental, 2012).

A density-driven flow and transport numerical groundwater model was developed and calibrated in the FEFLOW modelling platform for the purpose of conceptual design of the dewatering and injection system and predicting groundwater level conditions. The results of the numerical modelling, including sensitivity and uncertainty analysis has shown;

- The average annual dewatering volume is predicted to be up to 110 GL/a over the LoM period.
- The peak annual dewatering volume is predicted to be up to 168 GL/a (realistic requirement likely to be up to 150 GL/a).
- Maximum watertable drawdown along the Fortescue Marsh fringe[1] is predicted to be up to 1.7 m.
- Maximum watertable mounding along the Fortescue Marsh fringe is predicted to be up to 1.8 m.
- Injection of surplus water into suitable aquifers minimises the long term impacts of drawdown at the watertable.
- With the cessation of dewatering, groundwater level drawdown in the mining area decreases from over 50 m at the end of mining (2024) to about 5 m, after ten years (2034), and to about 3 m after 20 years (2044).

An eco-hydrological study (Equinox Environmental, 2012) has provided confidence that prolonged dry conditions and drawdown, of up to 3 m, will not significantly affect samphire survival and health. Other potential groundwater system impacts associated with the Cloudbreak Project water management strategy, such as disruption to the surface flow regime, watertable mounding (due to injection) and water quality changes, are also not predicted to be significant.

Modelling results suggest that the Cloudbreak water management scheme can operate independently. However, the adaptive management strategy of Cloudbreak would be strongly enhanced (enable greater flexibility to distribute injection) by adopting an integrated water management approach with Christmas Creek.

[1] Watertable measurements and predictions at the fringe of the Fortescue Marsh relate to monitoring locations CBFMM01_s to CBFMM08_s (excluding CBFMM03_s)

## TABLE OF CONTENTS

## List of Tables

## LIST OF FIGURES

## LIST OF APPENDICES

# 1. INTRODUCTION

Fortescue Metals Group's (Fortescue's) Cloudbreak iron ore mine (Cloudbreak) is within the Pilbara region of Western Australia. Cloudbreak is located approximately 30 kilometres west of Fortescue's Christmas Creek mine, 80 kilometres south west of Nullagine and approximately 120 kilometres north of Newman (Figure 1). The Cloudbreak iron ore mine has been operating since 2008, and is currently approved to ship iron ore, via a rail link, from Port Hedland (Figure 1 and Figure 2).

About 90% of iron ore at Cloudbreak is below the watertable, and mine dewatering is undertaken to minimise water ingress into mining pits. Below watertable mining commenced in July 2008, current mine dewatering and associated water management activities are approved under Ministerial Statement 899 (MS899) granted in 2012[2], controlled action EPBC 2005/2205 granted in July 2006 and EPBC 2010/5696 granted in November 2012. Key characteristics of the project stated in MS899, controlled actions EPBC 2005/2205 and EPBC 2010/5696 and the recently approved applications under Section 45C and 46 of the *Environmental Protection Act 1986* (EP Act) limit groundwater abstraction to 100 GL/a and injection to 95 GL/a. Knowledge developed during operations has improved the understanding of the hydrogeological conditions. On this basis the Life of Mine (LOM) plan (FMG, 2010d) has been reassessed, identifying dewatering and injection requirements up to 150 GL/a. The level of groundwater impact, in the shallow alluvial aquifer, at the fringe or within the Fortescue Marsh is within the range predicted in the previous assessment (FMG, 2010d).

## 1.1 Scope of works

This report presents the updated detailed hydrogeological assessment for the proposed LOM plan. Specifically this document includes a description of;

- Site specific hydrogeological data and the conceptual model for the groundwater and surface water hydrology.
- The development of a numerical model.
- The groundwater abstraction and injection management strategy.
- The results of dewatering and injection simulations, including volumes and water level changes.
- The method and results of sensitivity and uncertainty analysis.

Revision of concepts, parameters and other changes from the previous assessment (FMG, 2010d) are highlighted through this document.

[2] MS899 supersede the conditions of Statement 721 which was published on 24th April 2006, changed on September 2005, 12th July 2010 and 10th June 2011.

## 1.2 Previous studies at Cloudbreak

Hydrogeological assessments undertaken both pre and post commencement of dewatering and injection operations at Cloudbreak are outlined in Table 1. These assessments have been used, in conjunction with those from adjacent sites (Christmas Creek) and regional knowledge (Section 1.3), to inform the conceptual hydrogeological understanding for this assessment.

**Table 1: Previous groundwater investigations at Cloudbreak**

| Project/Reference | Scope | Outcomes |
|---|---|---|
| Hydrogeology report<br>(Aquaterra, 2005) | • 2 test production bores.<br>• Groundwater model developed.<br>• Dewatering assessment conducted. | • Conceptual model and numerical model utilising 'average' Pilbara hydraulic parameters.<br>• Predicted dewatering requirements of up to 12 GL/a over life of mine. |
| Hydrogeology assessment<br>(FMG, 2009) | • To support change to Ministerial Statement.<br>• Increase dewatering to 25 GL/a and injection to 18 GL/a. Included.<br>• Review of short term dewatering and injection requirements.<br>• Hydrological Impact assessment. | • Updated conceptual hydrogeology and short term dewatering requirements.<br>• Key updates include significant increase of hydraulic conductivity parameters and inclusion of density coupling in groundwater flow modelling. |
| Geochemical Assessment<br>(FMG, 2007) | • Measurement of groundwater quality parameters and sampling of groundwater from proposed mine dewatering borefield.<br>• Chemical analysis of groundwater samples.<br>• Assessment of likely changes to the groundwater composition and mineral precipitation due to mixing of water types, using aqueous geochemical modelling software PHREEQC.<br>• Documentation of methodologies, results, conclusions and recommendations. | • Information on the borefield and aquifer geochemistry.<br>• Precipitation of secondary minerals in the injection bore and the receiving aquifer is unlikely to be significant: calcite and dolomite were already oversaturated in the receiving aquifer. Si is unchanged, Gypsum was and remains after mixing with the injected water, under-saturated in the aquifer.<br>• The potential for bio-fouling to occur is low, due to the presence of iron-precipitating bacteria, oxygen and ferrous iron. |
| Geochemical Assessment<br>(MWH, 2009) | • Predicted geochemical interactions for re-injection of saline abstraction water into the saline Oakover Formation and in surface storage facilities.<br>• 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.<br>• The most likely mineral precipitates for the South Transfer Pond are Ca-Mg carbonates, amorphous silica, and ferric oxyhydroxide according to geochemical modelling results.<br>• 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, sulphate, and silica minerals (except Mn and Fe oxyhydroxides) and therefore limits potential for geochemical fouling. |
| Saline Injection Trial<br>(FMG, 2010b) | • Assessment of a 6-month saline injection trial.<br>• Summary of the operations, groundwater levels, water | • Proof of concept has been achieved.<br>• Environmental impact consistent with predictions.<br>• Injection of saline water has not impacted the upper, brackish aquifers except in isolated sites |

| Project/Reference | Scope | Outcomes |
|---|---|---|
| | quality data, and vegetation monitoring.<br>• Hydrogeological assessment of these data, hydrogeological characterisation of the saline injection area, numerical model assessment.<br>• Commitments assessment.<br>• Compliance assessment. | thought to relate to bore construction.<br>• Telemetry system control being developed.<br>• Hydrogeological characterisation of the saline injection area and validation of the model in this area were limited due to limited aquifer response.<br>• Progress in the assessment of clogging potential of saline reinjection. |
| Cloudbreak Triennial Aquifer Review<br>(FMG, 2010c) | • Three year summary of groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | Presentation of monitoring data and assessment to verify the conceptual hydrogeological model for the Cloudbreak site. |
| Cloudbreak FY11 Dewatering and injection program<br>(FMG, 2013b) | • Groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | • 98 production bores and 51 injection bores were active during the reporting period.<br>• 24.9 GL abstraction during reporting period.<br>• 14.2 GL injection during the reporting period.<br>• No Class 2 trigger exceedances (environmental significant) were recorded. |
| Saline Injection Trial – Stage 2 Close Out Report<br>(FMG, 2012a) | • Updated report to cover full length of saline injection trial and early operation.<br>• Summary of the operations, groundwater levels, water quality data, and vegetation monitoring.<br>• Hydrogeological assessment of these data, hydrogeological characterisation of the saline injection area, numerical model assessment.<br>• Commitments assessment.<br>• Compliance assessment. | • Injection has been demonstrated to be a feasible strategy for managing excess water.<br>• Groundwater monitoring indicated a limited hydrogeological response to injection.<br>• Operations will cause minimal impact (drawdown/mounding) to groundwater levels in the shallow aquifer at the Fortescue Marsh, predicted to be within the maximum permissible impact of <1m as set out in the PER document (FMG, 2010d).<br>• Injected saline water has not impacted the upper, brackish watertable aquifers.<br>• The primary clogging mechanism for injection bore has been identified as physical clogging by introduced sediment and debris. |
| Cloudbreak FY12 Dewatering and injection program<br>(FMG, 2013b) | • Groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | • 159 production bores and 53 injection bores were active during the reporting period.<br>• 31.7 GL abstraction during reporting period.<br>• 20.3 GL injection during the reporting period.<br>• No Class 2 trigger exceedances (environmental significant) were recorded. |
| Cloudbreak Triennial Aquifer Review<br>(FMG, 2013b) | • Three year summary of groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | Presentation of monitoring data and assessment to verify the conceptual hydrogeological model for the Cloudbreak site. |
| Aquifer reviews | • As part of licencing conditions for the Cloudbreak 5C licence. Frequency FMG have produced a series of monitoring summaries and aquifer reviews:<br>• Annual during the mine- | Descriptions of volumetric data (abstraction, injection, mine water use), groundwater level data and groundwater quality data. |

| Project/Reference | Scope | Outcomes |
|---|---|---|
| | construction phase (the 2006 and 2007 licence periods);<br>• Quarterly and annual since dewatering operations commenced in mid-2008. | |
| Cloudbreak FY13 Dewatering and injection program (FMG, 2013b) | • Groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | • 151 production bores and 48 injection bores were active during the reporting period.<br>• 59.4 GL abstraction during reporting period.<br>• 45.7 GL injection during the reporting period.<br>• No Class 2 trigger exceedances (environmental significant) were recorded. |
| University of Western Australia (UWA).<br>Ongoing research and investigation into the Fortescue Marsh. | Research projects, investigation works and publications into the dynamics and processes within and adjacent to the Fortescue Marsh, (Skrypek G., 2013). | • Fortescue Marsh is currently recharged by occasional floodwater.<br>• Salt in the Marsh is concentrated by evaporation of rainfall.<br>• Brackish waters mainly reflect modern recharge.<br>• Saline water reflects mixing between modern and old waters.<br>• Deep saline groundwater beneath Fortescue Marsh developed under different climatic regime and accumulated over the last 40,000 to 700,000-years. |

## 1.3 Previous studies at adjacent sites

The conceptual understanding of the Cloudbreak hydrogeological setting has also been supported by extensive hydrogeological work undertaken at Fortescue's adjacent mine site, Christmas Creek, and other relevant regional studies. Table 2 summarises the works that have contributed to the regional geological and hydrogeological understanding of Cloudbreak, and the hydrological functioning of the Fortescue Marsh.

**Table 2: Previous groundwater investigations at Christmas Creek and other sites**

| Project/Reference | Scope | Outcomes |
|---|---|---|
| Hydrogeology report (Aquaterra, 2004) | • Drilling (four 150mm ND test production bores).<br>• Pumping tests (24 to 48 hour duration).<br>• Develop a numerical model (based on steady-state calibration and hydraulic properties from other Pilbara sites). | • Marra Mamba Formation (MMF) hydraulic conductivity of 0.5 m/day.<br>• Saline gradient toward Fortescue Marsh identified.<br>• Dewatering requirement 1.15 GL/a for 60 metre deep pits.<br>• Remote water supply needed to meet 11.4 GL/a demand.<br>• No impact on vegetation or Fortescue Marsh groundwater anticipated.<br>• Salinity increase through up-coning or ingression not anticipated. |
| Hydrogeology assessment (FMG, 2009) | • Drilling (14 production bores, three multi-level monitoring bores).<br>• Pump test assessments. | • Improved regional-scale and mine-scale stratigraphic data.<br>• Mineralised MMF hydraulic conductivities in the order of 10 to 200 m/day, therefore greater dewatering rates.<br>• The Oakover Formation's presence and aquifer properties identified.<br>• Cloudbreak-style water management solutions proposed. |

| Project/Reference | Scope | Outcomes |
|---|---|---|
| Bore Completion report<br>(FMG, 2010) | • Drilling (10 test production bores, 12 multi-level monitoring bores).<br>• Test-pumping (up to seven days duration).<br>• SkyTEM geophysical survey.<br>• Geochemical aquifer characterisation.<br>• Numerical model development. | • Mineralised MMF hydraulic conductivities up to 311 m/day.<br>• Oakover Formation hydraulic conductivities of similar magnitude to Mineralised MMF.<br>• Variable connection between the Oakover Formation and Mineralised MMF; connection between these two units appears to be stronger than that at Cloudbreak.<br>• Saline interface further defined from SkyTEM data; discrete saline pathways identified.<br>• Cloudbreak-style water management solutions proposed. |
| Hydrogeological assessment in support of Fortescue's Christmas Creek API submission (FMG, 2010a) | • FEFLOW modelling.<br>• Ongoing drilling and testing data. | • Natural watertable fluctuation at the fringe of Fortescue Marsh predicted to be up to 3m following large rainfall events.<br>• Abstraction up 50 GL/a required to deliver the mine plan presented.<br>• Watertable change due to mining was predicted to be in the order of 1 m. |
| Christmas Creek FY11 Dewatering and injection program.<br>(FMG, 2013a) | • Groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | • 29 production bores and 4 injection bores were constructed during the reporting period.<br>• 0.9 GL abstraction during reporting period.<br>• No injection during the reporting period.<br>• No Class 2 trigger exceedances (environmental significant) were recorded. |
| Hydrogeological assessment in support of Fortescue's API submission<br>(FMG, 2013e) | • FEFLOW modelling.<br>• Ongoing drilling and testing data.<br>• Updated mine plan and project expansion. | • Natural watertable fluctuation at the fringe of Fortescue Marsh predicted to be up to 3m following large rainfall events.<br>• Abstraction up 110 GL/a required to deliver the mine plan presented.<br>• Watertable change due to mining was predicted to be in the order of 2.3 m. |
| Christmas Creek FY12 Dewatering and injection program.<br>(FMG, 2013a) | • Groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | • 65 production bores and 15 injection bores where constructed during the reporting period.<br>• 10.2 GL abstraction during reporting period.<br>• 1.3 GL injection during the reporting period.<br>• No Class 2 trigger exceedances (environmental significant) were recorded. |
| Vegetation dependence on shallow groundwater study.<br>(Equinox Environmental, 2012) | Investigation into the impact of drawdown upon groundwater dependent vegetation. | Groundwater drawdown up to 3m, for prolonged periods of time, does not adversely impact the ability for samphire vegetation to acquire water. |
| Christmas Creek April 2013 Quarterly groundwater monitoring summary<br>(FMG, 2013a) | Christmas Creek groundwater monitoring review for quarter (Feb 2013 to April 2013) | • 64 production bores and 21 injection bores were operational during the reporting period.<br>• 9.5 GL abstraction during reporting period.<br>• 4.6 GL injection during the reporting period.<br>• No Class 2 trigger exceedances (environmental significant) were recorded. |
| Christmas Creek FY13 Dewatering and injection program<br>(FMG, 2013a) | • Groundwater abstraction, injection and monitoring.<br>• Hydrogeological assessment of data.<br>• A compliance assessment against the regulatory commitments. | • 73 production bores and 29 injection bores were constructed during the reporting period.<br>• 34.4 GL abstraction during reporting period.<br>• 17.4 GL injection during the reporting period.<br>• No Class 2 trigger exceedances (environmental significant) were recorded. |

# 2. EXISTING ENVIRONMENT

## 2.1 Location

The Cloudbreak project area is located in the eastern Chichester Range within an escarpment that gently slopes down to the Fortescue Marsh to the south (Figure 1). The Cloudbreak mine site is located approximately 30 kilometres west of Fortescue's Christmas Creek mine, 80 kilometres south west of Nullagine and approximately 120 kilometres north of Newman (Figure 1).

## 2.2 Topography

The regional topography is dominated by the Chichester Range (immediately to the north) and Hamersley Range to the south. These features are separated by the Fortescue Marsh, which forms the terminating point for the Upper Fortescue River catchment. The Upper Fortescue River flow northwards from Ethel Creek Station and then northwest past Roy Hill Station, before entering into Fortescue Marsh on its eastern margin.

The topography of Cloudbreak is gently sloping from north to south, with a relief ranging from 500 to 600 m AHD in the Chichester Ranges and 400 to 450 m AHD in the Fortescue Valley. The Chichester Range and the major drainage system of the Upper Fortescue catchment both trend west-northwest to east-southeast.

## 2.3 Climate

The climate of the Pilbara region is classed as subtropical to dry being, characterised by very low rainfall, high daytime temperatures in summer and low winter minima (Gentilli, 1972). The region is defined by two distinct seasons; a dry winter season and a wet summer season. Rainfall during summer is typically associated with tropical cyclones and local thunderstorms. Winter rains are infrequent, with typically one or two falls of 20 to 30 mm per year. The average annual rainfall is around 320mm per year. Annual pan evaporation is about 3500 mm (Bureau of Meteorology, 1977).

Monthly average temperature, rainfall and evaporation data for the region are presented in Table 3. Rainfall data recorded at Cloudbreak and for BoM site at Newman are presented in Figure 4.

Normal maximum temperature ranges are 35 to 40 degrees Celsius ($^{o}$C) in summer and 24 to 28 $^{o}$C in winter. Most summer rainfall is from scattered thunderstorms and occasional tropical cyclones.

For the period 1907 to 2012, the mean annual rainfall recorded at Bonney Downs (Site 004006), Figure 1, was 310mm, compared to 406mm over the last 10 years (2002 to 2012). Five of the last ten years have recorded annual rainfall in excess of 400 mm, with only two years recording less than 200mm.

**Table 3: Average monthly temperature, evaporation and rainfall**

| Month | Mean temperature ( C)[3] | | Average rainfall (mm/month) | | Cloudbreak rainfall (mm/month)[4] | | Pan evaporation (mm/month)[5] |
|---|---|---|---|---|---|---|---|
| | Daily max | Daily min | Roy Hill[6] | Bonney Downs[7] | 2011 | 2012 | |
| Jan | 39.5 | 25 | 45 | 57.2 | 95.7 | 409.1 | 390 |
| Feb | 37 | 23.9 | 58 | 77 | 178 | 13 | 310 |
| Mar | 35 | 21.5 | 45 | 40.7 | 44 | 42.5 | 290 |
| Apr | 31.7 | 17.3 | 22 | 19.6 | 29 | 1.4 | 205 |
| May | 27.3 | 11.6 | 19 | 18.1 | 17 | 0 | 138 |
| Jun | 23.1 | 6.8 | 18 | 14.2 | 17.5 | 0 | 100 |
| Jul | 23 | 5.9 | 11 | 14.9 | 22.9 | 0 | 110 |
| Aug | 25.8 | 7.5 | 6 | 7.7 | 0 | 0 | 165 |
| Sep | 30.5 | 11.8 | 2 | 3.4 | 0 | 0 | 230 |
| Oct | 35 | 17.2 | 5 | 4.9 | 0 | 9 | 315 |
| Nov | 37.4 | 20.6 | 8 | 10.5 | 55.2 | 82.75 | 380 |
| Dec | 38.9 | 23.6 | 24 | 37.4 | 13 | 0 | 405 |
| *Annual:* | 32 | 16.1 | 261 | 310 | 472.3 | 557.75 | 3038 |

## 2.4 Hydrology

### 2.4.1 Regional Hydrology

The Chichester operations are located in the vicinity of the Fortescue Marsh in the upper Fortescue River catchment. 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 between December to April and can produce very large runoff events. The period between July to November typically has relatively low rainfall, although significant runoff events during this time can occur.

The Goodiadarrie Hills, about 60 km east from the town of Wittenoom, effectively cut the Fortescue River into two separate river systems. West from the Goodiadarrie Hills, the Lower Fortescue River Catchment drains to the coast, whereas east from the hills the Fortescue Marsh receives drainage from the upper Fortescue River catchment. The alluvial outwash fan from the

[3] Bureau of Meteorology, Newman Station, 1971-2010
[4] Cloudbreak rainfall data, recorded on site by Fortescue
[5] Interpolated from Bureau of Meteorology 1961-1990 spatial evapotranspiration dataset
[6] Bureau of Meteorology, Roy Hill Station 0050523, 1961-1990
[7] Bureau of Meteorology, Bonney Downs Station 004006, 1907-2012

Weeli Wolli Creek system abutting the Goodiadarrie Hills is believed to be partially responsible for obstructing the Fortescue River and forming the Fortescue Marsh.

The Fortescue Marsh forms an extensive intermittent wetland (located on the floor of the Fortescue Valley) occupying an area around 100 km long by typically 10 km wide. The Fortescue Marsh is listed in the directory of Important Wetlands (Env, 2001) and is listed by the Department of Environment and Regulation (DER) as a Priority 1 Priority Ecological Community. The Fortescue Marsh has an elevation of around 400 m AHD. To the north, the Chichester Plateau rises to over 500 m AHD, whereas to the south the Hamersley Range rises to over 1,000 m AHD. 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 Marshes at the main drainage inlets, whereas for the larger events the whole marsh area may flood.

On the southern and northern flanks of the Fortescue Valley, numerous creeks discharge to the Fortescue Marsh. Rainfall runoff from the valley sides initially drains down gradient as overland flow before concentrating in defined flow channels. In this process, surface retention, vegetation, infiltration and other mechanisms absorb water from the runoff stream. In steep areas, the runoff processes are rapid with relatively low losses, and defined drainage channels are typically in close proximity. In the lower slope areas, the runoff processes are slow with relatively higher losses and greater distances between defined drainage channels.

Where defined drainage channels from the steeper slopes enter the lower slope areas, the channels typically have a reduced discharge capacity and in many instances become less defined, braided, or may even completely disperse in flat areas. In these reducing slope channels, runoff tends to overspill the main channel flow zones and spread over a wider front. In some of the lower slope areas, vegetation communities (scrub and Mulga woodlands) have developed. These are dependent on seepage water provided by the overland flow process. In these areas, the overland flow process has been termed sheet-flow. Conversely, the Fortescue River, Weeli Wolli Creek, and other main channels entering the Marshes typically support Eucalyptus woodlands on their banks and floodplains.

Surface water runoff to the Fortescue Marsh is of low salinity and turbidity, though the runoff turbidity significantly increases during peak periods of flooding. Following a significant event that floods the whole marsh area, the ponded water may be over 4 m deep in the lower elevation marsh areas. Water stored on the Fortescue Marsh slowly dissipates through the processes of seepage and evaporation. During the evaporation process, the water salinity levels increase and as the ponded areas recede, traces of surface salt can be seen. During the seepage process, as the ponds evaporate, increasingly more saline water is believed to seep into the valley floor alluvial deposits.

### 2.4.2 Localised/Site Hydrology

Surface water flows at the Chichester Operations have previously been characterised as one of several modes, summarised as follows:

- 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. Naturally, flows are generally convergent 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 Fortescue 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 superficial fresh aquifer replenished by more frequent smaller flows.

- Diverging Flow. Diverging flow zones 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 slope of terrain and the size of the flows generated by a catchment (i.e. the greater the flow, the more well defined the channel is further downstream). Banded grove-intergrove vegetation patterns typical of sheet flow areas are not normally found downstream of areas where diverging flows intersect with sheet flow zones. Sheet flow zones form in ‘fan’ like terrain.

- 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, causing sheet flow zones to be maintained over large areas. The banded Mulga (Acacia aneura) formations common throughout the study area, are part of an ecological response to the sheet flow patterns.

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

The Cloudbreak mining footprint is typically located in the channel flow and diverging flow zone. None of the Cloudbreak operations are located within either the Hillslope runoff or Sheetlow Zones.

### 2.4.3 Fortescue Marsh surface water balance

In June 2012 Worley Parsons prepared the Fortescue Marsh Catchment Water Balance Study (Worley Parsons, 2012). As part of this study a water balance model was constructed to assess:

- Rainfall directly on the water surface of the Fortescue Marsh
- Runoff inflows to the Fortescue Marsh
- Evaporation losses from the water surface of the Fortescue Marsh.

A daily rainfall runoff model was established and used to estimated surface runoff into the Marsh. There are four stream flow gauging stations within Weeli Wolli Creek and one stream flow gauging station on the Fortescue River. A rainfall runoff model was established and calibrated for each of these catchments. These gauging stations are all located to the south of the Fortescue Marsh in hilly terrain. The calibrated model parameters were found to be similar for each of these gauging stations.

Median parameters from these gauged catchments were applied to the ungauged catchments draining the Chichester East Hamersley Ranges, which were considered to have similar terrain and hydrologic properties. These computed flows were input to the water balance model. The gauged flows for Weeli Wolli Creek (measured at Waterloo Bore) were also entered into the water balance model. (Note that Waterloo is located approximately 30 km south of the Marsh and Weeli Wolli Creek traverses an alluvial fan between Waterloo and the Marsh incurring significant transmission losses during low flows. However, during major inflow events it was considered that transmission losses would be minor.)

The gauging station on the Fortescue River is located at Newman, just upstream of Opthalmia Dam which was constructed in 1981. Opthalmia Dam has a storage capacity of 32 GL, and has only overflowed three times since construction. There is no stream flow gauge downstream of Opthamia Dam and so flows downstream of the dam were estimated by use of the Source Catchments model[8] (Worley Parsons, 2012). This model utilized observed stream flows at Newman and then simulated the storage behaviour of the dam to compute the spills which were then entered into the water balance model.

The water balance model was run for the period from 1/12/1984 to 30/04/2011 for the natural pre-development scenario with no mines at Cloudbreak, Christmas Creek or Roy Hill and with the remainder of the catchment in current conditions in place. Figure 44, shows the annual

[8] Source Catchments is a rainfall runoff modelling package developed by eWater CRC

volume of water entering the Fortescue Marsh for this scenario. Total annual flows into the Fortescue Marsh have been predicted to range between <50 GL/a to 1400 GL/a depending on climatic variation, (Worley Parsons, 2012)

### 2.4.4 Cultural significance

Semi-permanent water bodies along the shores of the Fortescue Marsh are culturally significant areas. These water bodies, known as Yintas (Goode, 2009), are located at low points in the surface topography of the marsh. Each Yinta is associated with local catchments that drain from the Chichester Range.

Aboriginal heritage surveys associated with the Chichester Range operations (Chichester Range operations refer to mining activities at both the Cloudbreak and Christmas Creek mine sites) have been undertaken since late 2003.

## 2.5 Geology

The main iron ores of the Hamersley Province are hosted with in the Archean to Palaeoproterozoic volcanic and sedimentary sequence of the Mount Bruce Supergroup (MBS). The MBS spans a time interval of over 400 million years (Ma), from greater than 2770 Ma to near 2350 Ma. The MBS rests unconformably on 3.50 to 2.80 billion year old (Ga) granitoids and greenstones that occupy the northern half of the Pilbara Craton. The MBS comprises late Archean metasediments and metavolcanics of the Fortescue Group, unconformably overlain by early Proterozoic metasediments of the Hamersley Group, which in turn are conformably overlain by siliclastics, carbonates and basalts of the Turee Creek Group.

This section describes the geology of the north eastern margin of the basin, which is directly relatable to the Cloudbreak mine.

### 2.5.1 Stratigraphy, structure and mineralisation

The local geology is dominated by the Fortescue Group and the lower part of the Hamersley Group, the Marra Mamba Formation (MMF). The mineralisation of the Chichester Range is confined to the Nammuldi Member, the lowermost unit of the MMF, overlying the black shales of the Jeerinah Formation at the top of the Fortescue Group. Beneath the Fortescue Valley the MMF is conformably overlain by the Wittenoom Formation of the Hamersley Group.

The MMF (and Wittenoom Formation where present beneath the Fortescue Valley) is unconformably overlain by younger Tertiary to Quaternary deposits. The Oakover Formation comprises a sequence of lacustrine carbonate, silcrete and mudstone rocks that have been deposited in the palaeodrainage of the Fortescue Valley. The Fortescue Valley is covered by a thick (up to 50 m) blanket of Tertiary colluvial scree slopes (close to the range) and flood plain alluvial sediments. A summary of the generalised stratigraphy is presented in Table 4.

**Table 4: Cloudbreak Generalised stratigraphy**

| Age | Group/Formation/Member | | | Stratigraphy Code[9] | Stratigraphy Description | Geological Description |
|---|---|---|---|---|---|---|
| Cenozoic | Tertiary alluvium | | | Ta | Tertiary alluvium | Variable clast composition |
| | Tertiary detritals | | | Tdi | Tertiary detrital | Immature |
| | | | | Tds | | Semi-mature |
| | | | | Tdm | | Mature |
| | Tertiary Clay | | | Te | Tertiary clay | Layer forms semi aquitard above the Oakover Formation |
| | Oakover Formation | | | To | Oakover | Calcrete, silcrete and calcareous sediments |
| **Unconformity** | | | | | | |
| Archean | Hamersley Group | Hardcap | | Hc | Hardcap | Commonly vuggy hard 'ore' with moderate GGM or VGH) |
| | | Wittenoom Formation | | WD | Dolomite | Varies between fresh to fractured and/or weathered |
| | | Marra Mamba Formation | Nammuldi Member | MuX | Ore Body | Bedded iron mineralisation, Goethitic & hematitic shales, chert and BIF. Ore body aquifer |
| | Fortescue Group | Jeerinah Formation | Roy Hill Shale | Jr | Roy Hill Shale | Commonly leached kaolonitic or black shale when fresh |
| | | | | Fj | Jeerinah Formation | Dolomites, volcanics, sandstones, conglomerates |

Regionally, the Chichester Range has gentle dips, usually less than 5°S, marking the onlap of the Hamersley Basin onto the Pilbara Craton. However, the gentle regional southerly dip of the Nammuldi Member at Cloudbreak has been offset by north-south to northeast-southwest trending faults. This is further overprinted by low amplitude (<20 m), long wavelength (200 to 800 m), north-south to northeast-southwest trending and south southwest plunging folds. This folding is interpreted to be the result of waning phases of deformation in the underlying Pilbara Craton (Hannon, 2005) and (Thorne, 2008).

Small amplitude folds developed at Christmas Creek, and elsewhere along the Chichester Range, have influenced both the development and preservation of mineralisation. The formation of high-grade ore is controlled by northeast-southwest trending faults and folds. Synclines appear to have focused supergene fluids resulting in their preferential mineralisation compared to adjacent anticlines. Subsequent erosion, controlled in part by the same structures, led to the broad stripping of anticlines and also the local removal of synclines along drainage channels.

[9] Stratigraphy codes defined in Table 4 represent Fortescue's interpretation and nomenclature.

The majority of mineralisation developed in the Chichester Range occurs as a sub-horizontal sheet of typical supergene martite-goethite and martite-ocherous goethite enrichment, overprinting hypogene microplaty hematite, which locally persists below the martite-goethite sheet. Hypogene enriched microplaty hematite mineralisation is structurally controlled, while supergene enriched mineralisation is very extensively developed as a sheet continuing for kilometres under recent cover. The majority of the mineralisation is typically a mixture of goethite, martite and hematite in varying amounts, similar to other Marra Mamba ores in the Hamersley Basin.

## 2.6 Hydrogeology

Groundwater dynamics in the Cloudbreak area are strongly controlled by stratigraphy, topography, mineralisation, structure and density (related to groundwater salinity). This section provides a description of the hydrogeology with consideration for hydraulic characteristics, groundwater recharge, throughflow, storage, discharge, quality and density. A conceptual hydrogeological cross section is provided in Figure 3

### 2.6.1 Hydrostratigraphy

The main hydrostratigraphic units and their characteristics are described below and are summarised in Table 5. A major finding after the submission of the previous PER report (FMG, 2010d) is the widespread existence of Tertiary clay, which overlies the Oakover Formation and functions as an aquitard between the Oakover Formation aquifer and the shallow aquifer.

#### Jeerinah Formation (Roy Hill Shale)

The Roy Hill Shale is generally considered to have low transmissivity; however permeability can be enhanced along the interface with the overlying Marra Mamba Formation (MMF) and predominantly north east to south west orientated fault zones. Additionally, a number of stratigraphic horizons within the Roy Hill Shale (located north of the MMF outcrop) have been found to have moderate permeability associated with bedded cherts which have undergone brittle deformation. Groundwater quality in the Roy Hill Shale, beneath the ore body, is generally saline to hypersaline.

#### Marra Mamba Formation

The distribution of permeability and storage in the MMF is influenced by lithological characteristics, faulting and secondary geochemical processes. In the upper part of the Nammuldi Member, supergene mineralisation processes have formed a broad sub-horizontal aquifer with high permeability and storage characteristics. Although this alteration has developed over a large lateral extent of the Chichester Ranges, later erosion (by drainage features) of the anticlines and in some places synclines has resulted in lateral discontinuity of the aquifer. The supergene zone diminishes to the south, which also results in lower permeability and storage.

The lower part of the Nammuldi Member is dominated by chert and has not undergone the same alteration to form an extensive aquifer. Zones of high permeability are associated with fracture zones, which based on regional structural interpretation, are dominantly developed in a north east to south west orientation. Permeability is expected to persist more extensively to the north and south along these features than the aquifer associated with the supergene mineralisation of the Nammuldi Member. Structural features that have been the focus of sub-vertical hypogene mineralisation can display higher permeability.

Groundwater quality is generally brackish in the upper part of the Nammuldi Member and becomes more saline within the lower part.

### Wittenoom Formation

The Wittenoom Formation conformably overlies the MMF in the area of the Fortescue Valley. It comprises calcitic dolomite, with minor interbedded chert and shale and volcaniclastic sandstone. Lithological logging suggests that where fresh, it is crystalline, massive in nature, and has low intergranular permeability. Local permeable zones may be developed along fault zones.

### Tertiary Calcrete and Silcrete (Oakover Formation)

The Oakover Formation is approximately 20 m thick and continuously developed beneath the Tertiary clay at about 50 metres below ground level (m bgl). The Oakover Formation onlaps with the MMF at its northern extent and extends beneath the Fortescue Marsh to the south, where it overlies the Wittenoom Formation.

Within the project area the Oakover Formation consists of calcretised and silicified carbonate formation, which typically has karstic characteristics that result in secondary permeability and enhanced storage properties. It is poorly developed or absent to the east, towards the Roy Hill deposit.

Regionally the Oakover Formation is described as a sequence of Tertiary lacustrine carbonate, silcrete and mudstone rocks deposited in the palaeodrainage of the Fortescue River Valley (Clout, 2011). Fortescue's definition for the Oakover Formation may only comprise a section of the larger formation identified within the Fortescue Valley.

### Tertiary Clay

Beneath the mixed Tertiary detritals and alluvial sedimentary sequence within the Fortescue Valley, there is a clay layer. The homogeneous nature of the clay suggests deposition within a lacustrine environment. It is typically 10 to 20 metres thick and continuous across the Christmas Creek and Cloudbreak project areas. At its northern limit, the Tertiary clay overlies the MMF (Figure 18). The clay is considered an aquitard that results in confining conditions for the Oakover Formation.

Evidence of significant clay layers has been identified from drilling completed within and to the south of the Fortescue Marsh by Rio Tinto Iron Ore, UWA and others (Skrypek G., 2013).

### Tertiary Detrital and Alluvium

Detrital and alluvial deposits cover the Tertiary clay, MMF and Fortescue Valley. Hydraulic characteristics are often variable due to the nature of deposition in alluvial fans and flood plains. Areas of low to moderate yield and storage are associated with chert and reworked MMF gravels that have been deposited proximal to source. More distal deposits comprise clayey (variable) magnetite pisolitic gravels that have lower permeability. Recent work, (Equinox Environmental, 2012), has shown the importance of varying conditions of the detritals and alluvium deposits in controlling near surface and groundwater processes, in particular, at the Marsh fringe.

- Tertiary alluvium– variable hydraulic conductivity and storativity as influenced by depositional heterogeneity, substrate geology and particle size distribution. Aquifers within the Tertiary depositional sequence are semi-confined to unconfined. Fortescue bore records show that the watertable at the fringe of the marsh fluctuate in the order of 2 to 3 m under natural conditions, and are responsive to significant rainfall events. However, the response of shallow watertable to rainfall rapidly diminish moving further north from the marsh boundary.

- Tertiary Detritals - thick unit of detrital and alluvial sediments with moderate permeability. Basal layers are of low permeability layer with significant clay lenses prominent in the deeper profile near the Fortescue Marsh. These overlie the Oakover Formation, and at their northern extent onlap the Marra Mamba Formation. These layers are believed to impede vertical water transfer between the surficial and deeper groundwater systems.

**Table 5: Summary of geological and hydro-stratigraphic framework**

| Fortescue Stratigraphy Code | Stratigraphy Description[10] | Hydrogeological Characteristics |
|---|---|---|
| Ta | Tertiary alluvium | Detrital and alluvial sediments, ranging from proximal cobble to pebble, alluvial fans to distal silty and clayey flood plain deposits. Basal layers can have well-rounded hematite and magnetite pisoliths in clay matrix. |
| Tdi | Tertiary detrital | |
| Tds | | |
| Tdm | | |
| Te | Tertiary clay | Consolidated red-brown clay, highly plastic, cohesive. Forms aquitard overlying Oakover Formation |
| To | Oakover Formation | Zones of re-precipitated calcium carbonate and silica developed within Fortescue Valley.<br>Can be karstic creating zones of high permeability.<br>Confined aquifer conditions developed beneath Tertiary clay. |
| WD | Wittenoom Formation | Generally massive dolomite, localised permeability associated with fault zones. Upper zone generally weathered and clay-dominant. Conformably overlies the MMF, only present to the south of the mineralised MMF |
| Hc | Hardcap | Cherty shale and ferruginous chert, intrusive hypogene hematite deposits and post-depositional supergene geochemical alteration and iron |

[10] Refer to Table 4

| Fortescue Stratigraphy Code | Stratigraphy Description[10] | Hydrogeological Characteristics |
|---|---|---|
| | | enrichment zones.<br>Noticeably vuggy and porous, high porosity and permeability. Generally thin and discontinuous unit. |
| MuX | MMF | – Hematite zones; massive, friable, foliated, intrusion and precipitation of iron rich fluids along fault zones.<br>Interpreted to have high porosity (micro-scale), but tends to have low to moderate permeability. |
| | Mineralised MMF | Goethite, martite and hematite zones; secondary alteration and mineralisation. Complex overprinting of primary deposits by secondary processes.<br>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 lower (non-mineralised) | Ferruginous bedded chert and iron formation, generally very low storage and low permeability with higher permeability associated with NE – SW fault zones |
| Jr | Royhill shale | Upper weathered zones can have moderate permeability. Lower, unweathered zones represent a thick unit with generally low permeability. Enhanced permeability zones associated with cross cutting fractures and cherty interbeds. |

### 2.6.2 Hydraulic Properties

The results of hydraulic testing from previous field programs are summarised in Table 6. Table 6 provides summary data for borefields and hydrostratigraphic units. These data are derived from ongoing operations being referenced in (FMG, 2013), (FMG, 2013a), (FMG, 2013b), (FMG, 2013e) and (FMG, 2010d).

### 2.6.3 Hydrostratigraphic connectivity

Knowledge of connectivity between hydrostratigraphic units is of particular importance for this assessment. The significance and interpreted nature of the connectivity between the hydrostratigraphic units is described below:

**Tertiary alluvium and Tertiary Detritals**

The Tertiary alluvium and Tertiary Detritals contain a significant proportion of clay sediments deposited in overlapping lenses such that the vertical conductance between the watertable and groundwater occurrence in the deeper parts of the Tertiary detritals is low.

**Tertiary Detrital (detrital) and Oakover Formation**

The presence of the thick clay layer (Tertiary clay) between the Oakover Formation and the Tertiary detritals is observed[11] to limit fluxes between these aquifer systems. This is significant as the Oakover Formation will be subject to pressurisation and depressurisation at different stages during the LOM, and the low connectivity due to the presence of the clay layer will inhibit manifestation of pressure changes in overlying detrital and alluvial aquifer zones.

**Tertiary Detrital (alluvium and detrital) and Mineralised MMF**

Tertiary detritals/alluvium overlying the MMF are saturated and therefore require dewatering where the mine plan requires access to the ore body. They also represent a store of water in water supply areas. The Tertiary detritals/alluvium has low hydraulic conductivity, and is often separated from the underlying MMF by the presence of Tertiary clay, making it inefficient to abstract groundwater directly from the aquifer; as such, there is a reliance on leakage being induced by abstracting from the underlying MMF.

Dewatering operations, at both Cloudbreak and Christmas Creek, has shown that leakage from the Tertiary detritals and alluvium overlying the ore body occurs in response to lowering the piezometric head in the MMF.

**Oakover Formation and Mineralised MMF**

The connectivity between the mineralised MMF and Oakover Formation is an important factor in determining the flux of high salinity groundwater to the mine pits and abstraction borefields. The connectivity between these aquifers may be direct, in areas where the Oakover Formation overlies the mineralised MMF; or indirect via NE-SW orientated fracture zones through the Wittenoom Formation and unmineralised MMF. The connectivity, as assessed by investigations and piezometric response to dewatering, is variable with the possibility of indirect pathways being the more prevalent means of connection.  Greater connection in some areas, are considered a factor contributing to increased dewatering rates in this assessment.

[11] Injection of saline water into the Oakover Formation has pressurised the Oakover aquifer.  This has resulted in an increase in monitoring bore water level in the Oakover Formation.  This rise in water level has not been observed in monitoring bores screened across the watertable within the Tertiary alluvium at coincidental locations.

**Table 6: Hydraulic assessment results by aquifer and borefield**

| Aquifer | Area | B[12] (m) | K[13] | | T[14] | | S[15] | | 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[16] | Hillside West | 2 to 50 | 2 to 1055 | 140 | 70 to 20000 | 3115 | $6.2e^{-4}$ to $1.8e^{-1}$ | 4.53e-02 | 52 | 360 to 2880 | (FMG, 2010d) (FMG, 2013a) (FMG, 2013b) |
| | Hillside East | 12 to 48 | 2 to 214 | 37 | 33 to 8145 | 1101 | $1.2e^{-4}$ to $5e^{-4}$ | 6.52e-2 | 22 | 90 to 2880 | |
| | Cockatoo Pit | 28 to 35 | 1 to 42 | 17 | 30 to 1400 | 560 | $4.2e^{-5}$ to $7.8e^{-2}$ | 2.00E-02 | 3 | 1440 | |
| | Cocos Pit | 16 to 60 | 0.2 to 160 | 37 | 8 to 4600 | 1200 | $2.7e^{-5}$ to $8.7e^{-2}$ | 6.70E-03 | 39 | 360 to 2160 | |
| | Brampton | 10 to 60 | 2 to 770 | 120 | 14 to 11500 | 3600 | $2.4e^{-4}$ to $8.9e^{-2}$ | 8.66e-03 | 133 | 60 to 2880 | |
| | Hook Pit | 11 to 42 | 2 to 500 | 90 | 7 to 10000 | 3400 | $1.48e^{-10}$ to $8e^{-2}$ | 6.1E-3 | 126 | 150 to 14400 | |
| | Hayman Pit | 8 to 50 | 4 to 220 | 10 | 7 to 7500 | 3500 | $7.9e^{-7}$ to $6.3e^{-3}$ | 2.5e-03 | 40 | 360 to 2880 | |
| | Hamilton | 9 to 36 | 2 to 38 | 14 | 11 to 1100 | 520 | $2.7e^{-4}$ to $2.0e^{-3}$ | 1.00E-03 | 33 | 720 to 2880 | |
| | 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 | 84 | 180 to 2880 | |
| Tertiary Detritals | Regional | 5 to 20 | 0.2 to 8 | 4 | 1 to 210 | 130 | - | - | 3 | 1440 | (Aquaterra, 2005) (FMG, 2010d) |
| Oakover Formation | Saline reinjection area | 8 to 48 | 81 to 1333 | 380 | 2480 to 25000 | 6805 | $1.7e^{-4}$ to $8.0e^{-2}$ | 2.11e-4 | 41 | 120 to 720 | (FMG, 2010d) (FMG, 2013a) (FMG, 2013b) |

[12] Aquifer thickness (m)
[13] Hydraulic Conductivity (m/day)
[14] Transmissivity ($m^2$/day)
[15] Aquifer stativity (dimensionless) (not assessed where no monitoring bore data are available)
[16] All includes both the mineralised and un-mineralised MMF. However, the bore may not screen the entire non-mineralised sequence.

**Roy Hill Shale and MMF**

The degree of hydraulic connection between the Roy Hill Shale and the MMF is important to understand with respect to geotechnical issues and the potential for up-welling of saline water. Observations from operations and investigations at Cloudbreak have shown that abstraction from the MMF does induce depressurisation of the Roy Hill Shale during the latter stages of the dewatering program. It is conceivable that decreasing the overlying pressure in the Roy Hill Shale by dewatering and mining may result in the opening of fine fractures and facilitate greater vertical leakage of water. The Roy Hill Shale has a typically low storage and contributing only a small volume of groundwater though upward leakage.

### 2.6.4 Groundwater Levels and Flow

Baseline[17] (2007) groundwater levels in the Tertiary detrital and the MMF[18] measured in hydraulic head[19] and freshwater equivalent head[20] , respectively, are shown in Figure 5 and Figure 6. Groundwater gradients are relatively shallow from the mining area to the Fortescue Marsh in both the Tertiary detrital and MMF. When measured piezometric head in the hypersaline Oakover Formation are converted to fresh water equivalent a pressure gradient can be observed in the opposing direction to the topographical driven gradient from the Chichester Ranges into the Fortescue Valley. Isotopic analysis (Skrypek G., 2013) has suggested the dominant process at the Marsh fringe is vertical with a low horizontal component of groundwater flow.

Seasonal fluctuations in water levels are observed to vary across the site and in different hydrostratigraphic units. Figure 7 shows ponding of water observed across the Fortescue Marsh, following a significant rainfall event in late February 2009[21], and the locations of reference monitoring bores from the Cloudbreak monitoring network and two University of Western Australia research sites[22]. Interpretation of this data and operational monitoring provides the following conclusions:

- Cloudbreak and Christmas Creek monitoring bore data, for all hydrostratigraphic units, display a general groundwater level recession between 2006 and 2010, related to below-average rainfall.

---

[17] Baseline data taken prior to dewatering activities commenced in 2008.

[18] The Oakover Formation and MMF are considered as a single unit for the purpose of generating contours shown in Figure 6.

[19] A combined measure of the elevation and the water pressure at a point in an aquifer which represents the total energy of the water

[20] Hydraulic head is dependent on density (salinity) of water. To compare one or more hydraulic heads they need to be standardised to a constant density. This is usually to their fresh water head, i.e. the hydraulic head if all water bodies had a salinity and hence density of fresh water.

[21] Interpreted from Landsat imagery (Appendix 1).

[22] Data is available for the Cloudbreak and UWA monitoring bores, shown on Figure 7, from 2006 onwards.

- Groundwater recession between 2006 and 2007 was approximately 1 m and approximately 0.5 to 1 m from 2007 to early 2010, within the Tertiary detrital/alluvium. The recession trend was punctuated by a rainfall event in early 2009 and subsequent groundwater recharge.
- Since 2010, a number of large rainfall events resulted in variable Tertiary detrital/alluvium water levels across Cloudbreak and Christmas Creek. Since 2010, Tertiary detrital/alluvium groundwater levels adjacent to the Fortescue Marsh have shown annually fluctuations of up to 2m.

Ponding on the Fortescue Marsh, related to high intensity rainfall, is directly related to Tertiary alluvium groundwater level responses observed within and at the fringe of the Fortescue Marsh. The control exerted, on groundwater levels, by ponding within the Marsh is reduced with distance from the Marsh. These trends are supported by the following observations:

- Significant rainfall and flooding of the Fortescue Marsh between January and March 2006 (380 mm rainfall recorded at Newman) resulted in the cessation of the long-term Tertiary detrital/alluvium groundwater level recession.
- Subsequent smaller rainfall events resulted in a groundwater level rise (130mm) between March and April 2007. Notably, Tertiary alluvium groundwater level increases were only observed in monitoring bores located adjacent to the Fortescue Marsh.
- Tertiary alluvium groundwater level increases in the order of 0.5 m, adjacent to the Fortescue Marsh, were observed in response to a rainfall event (105 mm in one day) in early 2009. This rainfall event caused significant ponding on the Fortescue Marsh[23] which is clearly visible from Landsat imagery and was recorded at two UWA research sites within the margin of the Fortescue Marsh (see Figure 7). The westernmost site (Site B) recorded ponding of approximately 0.5 m above ground level (406.8 m AHD)
- The easternmost site (Site A) recorded ponding of approximately 0.2 m above ground level (405.8).
- Tertiary alluvium groundwater level increases, at the fringe of the Marsh, were observed following Cyclone Heidi (Jan 2012) at both Cloudbreak and Christmas Creek. The increase observed varied spatially along the Marsh and was directly related to proximity and localised/regional ponding.
    - Cloudbreak bores, being located distal from the Marsh, showed a delayed and small increase in groundwater level (0.3 – 1 m). Most pronounced variations were observed closest to the Marsh and adjacent to areas of previous ponding (Historical Landsat data, Appendix 1).
    - Christmas Creek bores[24] showed a rapid increase in groundwater level (0.5-1.5 m) in the month following Cyclone Heidi. Water level fluctuation was most

[23] This ponding event was localised and appears to be related to discharge from discrete catchments in the Chichester Range.
[24] Monitoring bores CBFMM01_s – CBFMM08_s (excluding CBFMM03_s).

pronounced at CCFMM03, adjacent to a creek line, with a relatively subdued response to the east and west.

Further information regarding long-term groundwater trends is developed from the modelled groundwater levels under various climatic conditions (Section 5.6).

### 2.6.5 Groundwater Quality

Groundwater in the Cloudbreak region ranges from marginal/brackish (<1,500 milligrams per litre [mg/L] Total Dissolved Solids [TDS]) in shallow recharge areas to hypersaline at depth and close to the Fortescue Valley (>150,000 mg/L TDS). Hypersaline groundwater has evolved through evapo-concentration beneath the Fortescue Marsh, over prolonged periods of time and potentially under different climatic regimes over periods of up to 700,000 years (Skrypek G., 2013).

The distribution of brackish and saline water within the Cloudbreak area is shown schematically in Figure 3. Baseline salinity levels in the Tertiary detrital and the MMF are shown in Figure 9 and Figure 10. Baseline salinity in both the Tertiary detrital and MMF increases with proximity to Fortescue Marsh and are generally aligned with the alignment of the Marsh fringe. Salinity concentrations in Tertiary detrital and MMF vary between 25,000 us/cm (south of the active mining area) to 150,000 us/cm (at the Marsh fringe). Isotopic analysis (Skrypek G., 2013) of shallow groundwater beneath and adjacent to Fortescue Marsh shows the predominance of vertical recharge in their development with limited horizontal groundwater flow.

The composition of 135 groundwater samples have been plotted on a Piper diagram (Figure 8) for classification of water types). It illustrates two dominant water types and a definite mixing trend. The majority of waters plot in the high Na-Cl-$SO_4$ window with variability between end members, resulting in two predominant types:

- Na-Cl-$SO_4$
- Na-Cl

The Na-Cl and Na-Cl-$SO_4$ 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-$SO_4$. 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.

The spatial distribution of groundwater salinity was assessed via a SkyTEM[25] airborne electromagnetic survey. Data-inversion was carried out using the Laterally-Constrained Inversion (LCI) method. Field data was filtered and then modelled 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 provided as slices through specific hydrogeological surfaces, including 5 m below the watertable (Figure 12) and the top of the ore zone (Figure 11). This approach has assisted in mapping the position of the salt interface and developing the following concepts:

- The heterogeneity of the saltwater interface, in particular associations with structural lineaments and other preferential flow paths.
- Brackish water forms a lens in the MMF and Tertiary detritals/alluvium overlying saline groundwater near the Chichester Ranges.
- Salinity increases towards the Marsh in all hydrostratigraphic units, and
- Saline zones beneath the ore zone may be disconnected from principal flow mechanisms (‘fossil’ groundwater).

### 2.6.6 Density Driven Flow

Density gradients due to salinity difference are an important driving force of groundwater flow. Density contrast between saline groundwater beneath and adjacent to the Fortescue Marsh and fresher groundwater along the flanks of the Chichester Ranges has resulted in a saline transition zone. Stratigraphy, structure, hydraulic head and salinity concentration influence the extent and nature of the saline transition zone. The saline interface may, naturally, move seasonally owing to changes in hydraulic head conditions.

When comparing pressure conditions between fresh and saline aquifers, the piezometric head[19] measured in a saline aquifer must be converted to a fresh water equivalent head to account for the pressure exerted by the overlying column of saline water. The measured piezometric heads can be converted to equivalent freshwater head via the following density-conversion equation[26]:

$$equivalent\ head = measured\ head\ \times \frac{(0.0007723 \times S) + 997.31}{1000}$$

When measured piezometric head in the hypersaline Oakover Formation are converted to fresh water equivalent a pressure gradient can be observed in the opposing direction to the topographical driven gradient from the Chichester Ranges into the Fortescue Valley (Figure 3).

[25] SkyTEM is a helicopter-mounted, time domain electromagnetic (TDEM) system. The SkyTEM survey was conducted by Geoforce Pty Ltd over an eight-day field program in September 2009. The surveyed area extended from the Fortescue Marsh boundary to the Chichester Range, from Christmas Creek in the East to Cloudbreak in the West.

[26] Where S is salinity (mg/l) as adapted from (Bear, 1972)

### 2.6.7 Groundwater Recharge

Primary mechanisms for groundwater recharge are:

- Infiltration recharge from direct rainfall and local stream flow on MMF outcrop and Tertiary detritals/alluvium.
- Infiltration recharge, into Tertiary detritals, associated with ponding on the Fortescue Marsh.
- Inflow from aquifers within the Fortescue Group located to the north of the project area.

Direct rainfall recharge to the Tertiary detritals/alluvium and MMF aquifers is considered to be low in the Cloudbreak area, reflecting the low rainfall and high evaporation of the region (see Section 2.3).

Recharge is enhanced in creeks and areas of stream flow. Areas of outcrop and subcrop with drainage incisions can have direct connection between surface water and underlying permeable lithologies.

### 2.6.8 Groundwater Discharge

Based on the evolution of groundwater within the upper Fortescue Valley the groundwater system beneath the Fortescue Marsh is considered a closed system with limited outflow to the west beneath the Goodardarie Hills. Discharge is therefore interpreted to only occur through evaporation and evapotranspiration processes beneath and fringing the Marsh. Discharge would be greatest when water levels are high, following recharge events and lowest after a prolonged dry period when the extinction zone for evaporation or evapotranspiration (from the watertable) is reached.

### 2.6.9 Hydrogeological setting comparison

Table 7 provides a comparison of the hydrogeological setting at Cloudbreak with respect to that of the nearby Christmas Creek and Roy Hill projects in order to provide a regional context.

**Table 7: Hydrogeological setting comparison**

| Aspect | Cloudbreak | Christmas Creek | Roy Hill (Hancock , 2009) |
|---|---|---|---|
| **Drawdown Footprint** | | | |
| Operational Dewatering strike length | ~30 km | ~30 km | ~35 km |
| Distance from the Fortescue Marsh boundary | 4 - 6 km | 7 - 9 km | 5 - 10 km |
| **Ore Body Parameters** | | | |
| Mineralised Marra Mamba Formation | 30 to 100 m/day | 30 to 100 m/day | 7.5 m/day |
| Oakover Formation | 50 to 300 m/day | 200 m/day | Up to 5 m/day |
| Regional hydraulic connection | Discrete zones of connection between MMF and Oakover Fm. | Regional connection between MMF and Oakover Fm. | Oakover Fm. not present to the south of Roy Hill. |
| **Numerical modelling** | | | |
| Estimated annual abstraction rate | Up to 100[27] GL/a (dewatering) | Up to 110 GL/a (dewatering) | 22 GL/a (dewatering) |
| Basis for assessment | Pumping tests and calibration against over 36 months of operational data | Pumping tests and calibration against over 18 months of operational data | 10 pump tests of up to 4 days duration. |
| Modelling approach | FEFLOW density-coupled model; 11 model layers, BASD (moving mesh) saturated flow parameters | FEFLOW density-coupled model; 11 model layers, BASD (moving mesh) saturated flow parameters | MODFLOW Finite difference model; 6 model layers. Further details (e.g. density coupling) unknown |
| Water excess management approach | Reinjection to compatible aquifers (all excess water) | Reinjection to compatible aquifers (all excess water) | Evaporation pond(s); salt encapsulation. |

## 2.7 Flora and Fauna

### 2.7.1 Flora and Vegetation

Eight broad vegetation formations have been described for the Project Area, comprising 21 vegetation communities ( (ENV, 2011) and (Mattiske, 2005)) (Table 8).

No Threatened Ecological Communities are known to occur in the Project Area (ENV, 2011). The Fortescue Marsh Priority 1 Priority Ecological Community (PEC) is known to occur in the Project Area, though outside of the mine disturbance footprint (ENV, 2011). The Fortescue Marsh is characterised by its collection of endemic *Eremophila* and Samphire species as well as populations of Priority flora occurring on the fringe of the Fortescue Marsh. The Samphire (*Tecticornia* species) vegetation communities 12, 13, 22, 25 and 26 that are recorded within the Project Area are considered to be representative of the PEC (ENV, 2011).

[27] 100GL as defined within (FMG, 2010d). This assessment predicts abstraction up to 150GL.

**Table 8: Vegetation communities occurring within Cloudbreak**

| Broad Vegetation Formation | Vegetation Community No. | Vegetation Community Description |
|---|---|---|
| Creek line and drainage lines – Coolibah and River Red Gum dominated | 1 | Open Woodland of *Eucalyptus victrix,* E. *camaldulensis* with pockets of *Acacia coriacea* subsp. *pendens* over *Grevillea wickhamii* subsp. *aprica*, *Petalostylis labicheoides* and *A. tumida* over *Triodia longiceps*, *Chrysopogon fallax, Themeda triandra* and *Aristida* species. |
| Creek line and drainage lines – Mulga dominated | 2 | Low Woodland to Low Open Forest of *Acacia aneura* var. *aneura*, *A. citrinoviridis*, *A. pruinocarpa* over *A. tetragonophylla* and *Psydrax latifolia* over *Chrysopogon fallax*, *Stemodia viscosa*, *Blumea tenella*, *Themeda triandra* and species of *Triodia* and *Aristida*. |
| Creek line and drainage lines – other *Acacia* dominated | 8 | Closed Scrub to Tall Shrubland of *Acacia pruinocarpa*, *A. tumida*, *A. ancistrocarpa*, *A. maitlandii*, *A. kempeana*, *A. tetragonophylla* with occasional *Eucalyptus gamophylla* and *Corymbia deserticola* over *Triodia epactia*, *Themeda triandra* and *Aristida* species. |
| | 9 | Closed Scrub to Shrubland of *Acacia ancistrocarpa*, *A. maitlandii*, *A. kempeana*, *A. monticola* with occasional *Eucalyptus gamophylla* and *Corymbia deserticola* over *Senna* species, *Triodia basedowii* and *Aristida* species. |
| Flats and broad plains containing Mulga | 3 | Low Woodland to Low Open Forest of *Acacia aneura* var. *aneura*, *A. pruinocarpa*, *A. tetragonophylla*, *A. tenuissima*, *Grevillea wickhamii* subsp. *aprica*, *Psydrax latifolia* over *Dodonaea petiolaris* and species of *Triodia* and *Aristida*. |
| | 4 | Low Open Woodland of *Acacia aneura* var. *aneura*, *A. pruinocarpa*, *A. xiphophylla*, *A. victoriae* over *A. tetragonophylla*, *Psydrax latifolia* and *Psydrax suaveolens* over *Ptilotus obovatus* and species of *Maireana* and *Sclerolaena*. |
| | 10 | Low Open Woodland of *Acacia xiphophylla*, *Acacia victoriae*, *Acacia aneura* var. *aneura* over *Acacia tetragonophylla*, *Ptilotus obovatus*, *Senna* species and species of *Maireana* and *Sclerolaena*. |
| Flats and broad plains without Mulga | 15 | Low Open Woodland of *Acacia victoriae*, *A. xiphophylla* over *Ptilotus obovatus*, *Senna* species and species of *Maireana* and *Sclerolaena.* |
| Ranges, hills and hillslopes | 7 | Hummock Grassland of *Triodia basedowii* with emergent patches of *Eucalyptus gamophylla*, *E. leucophloia*, *Corymbia deserticola* over *Acacia ancistrocarpa*, *A. sclerosperma* subsp. *sclerosperma*, *A. kempeana*, *A. arida*, *Grevillea berryana*, *G. wickhamii* subsp. *aprica*, *Calytrix carinata* over *Goodenia stobbsiana* and mixed Poaceae species. |
| | 16 | Hummock Grassland of *Triodia basedowii* with pockets of *Triodia epactia* and *T. lanigera* with emergent patches *of Eucalyptus leucophloia*, *Corymbia deserticola* over *Acacia ancistrocarpa*, *A. hilliana*, *A. acradenia*, *A. pyrifolia*, *Hakea lorea* subsp. *lorea* over *Goodenia stobbsiana* and mixed *Senna* species. |
| | 17 | Hummock Grassland of *Triodia basedowii* with areas of *T. epactia* and *T. lanigera* with emergent patches of *Eucalyptus leucophloia*, *Corymbia deserticola* over *Acacia ancistrocarpa*, *A. pyrifolia*, *Hakea lorea* subsp. *lorea* over *Goodenia stobbsiana* and mixed *Senna* and *Ptilotus* species. |
| | 18 | Hummock Grassland of *Triodia angusta* with emergent patches of *Eucalyptus leucophloia* over *Acacia ancistrocarpa*, *A. pyrifolia*, *Hakea lorea* subsp. *lorea* over *Goodenia stobbsiana* and mixed *Senna* and *Ptilotus* species. |
| Fringes of Samphire flats containing Samphire | 12 | Low Halophytic Shrubland of *Tecticornia auriculata* and *T. indica* subsp. *leiostachya* with associated *Maireana* species and *Atriplex flabelliformis* with *Muehlenbeckia florulenta* with patches of *Acacia victoriae* and *A. sclerosperma* subsp. *sclerosperma.* |
| | 13 | Low Halophytic Shrubland of *Tecticornia auriculata*, *T. indica* subsp. |

| Broad Vegetation Formation | Vegetation Community No. | Vegetation Community Description |
|---|---|---|
| | | *leiostachya*, *T. halocnemoides* subsp. *tenuis* with patches *of Frankenia species*. |
| | 22 | Low Shrubland of *Tecticornia indica* subsp. *bidens* and *Nicotiana occidentalis* over grasses with occasional stands of *Sesbania cannabina* and *Cullen cinereum*. |
| | 25 | Low Shrubland of *Tecticornia auriculata*, *T. indica* subsp. *bidens* and *Frankenia ambita* over *Eragrostis dielsii*. |
| | 26 | Low Shrubland of *Muellerolimon salicorniaceum* and *Tecticornia indica* subsp. *bidens*. |
| Fringes of Samphire flats without Samphire | 11 | Hummock Grassland of *Triodia angusta* with patches of *Acacia victoriae*, *A. aneura* var. *aneura*, *A. xiphophylla over Atriplex codonocarpa*, *Eremophila cuneifolia* and mixed Chenopodiaceae species. |
| | 14 | Hummock Grassland of *Triodia angusta* with patches of *Acacia victoriae* over *Atriplex codonocarpa* and mixed Chenopodiaceae and Poaceae species. |
| | 20 | Scrub of *Acacia sericophylla* over *Muellerolimon salicorniaceum*, *Nicotiana occidentalis* and *Mimulus gracilis*. |
| | 27 | Low Shrubland of *Maireana carnosa*, *Atriplex codonocarpa* and *Sclerolaena cuneata* over *Eragrostis dielsii* and *Trianthema turgidifolia*. |

No Declared Rare Flora/Threatened flora species are known to occur within the Project Area. However, eight Priority flora taxa have been recorded ( (Biota, 2004); (Mattiske, 2005), (Mattiske, 2007); (ENV, 2011); (Astron, 2012) and (Astron, 2012a)) as follows:

- *Eremophila spongiocarpa* (Priority 1);
- *Nicotiana heterantha* (Priority 1);
- *Gymnanthera cunninghamii* (Priority 3);
- *Phyllanthus aridus* (Priority 3);
- *Rostellularia adscendens* var. *latifolia* (Priority 3);
- *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) (Priority 3);
- *Eremophila youngii* subsp. *lepidota* (Priority 4); and
- *Goodenia nuda* (Priority 4).

The vegetation of the Project Area has previously been described to be in variable condition. Vegetation in best condition, rated as ‘Excellent’ is mostly in the broad vegetation formations of ‘Fringe of Samphire flats’, ‘Creek and drainage lines’ and ‘Ranges, hills and hillslopes’. Vegetation categorised as being in Good condition, exhibiting the effects of grazing pressure and fire, and is mostly found in the broad vegetation formations of ‘Broad flats and plains’ (ENV, 2011).

### 2.7.2 Fauna

Six broad fauna habitats have been identified within the Project Area (Ecologia, 2010) and (Ecologia, 2011):

- Low halophytic shrubland;
- Hummock grassland on fringe of Fortescue Marsh;
- Low Mulga, Snakewood and other Acacia woodlands;
- Spinifex covered hills and ranges;
- Creek and wells with Acacia shrubland and/or Eucalypt woodland; and
- Rocky escarpments.

The potential fauna assemblage for the region comprises 34 native and nine introduced mammal species, 165 bird species, 100 reptile species and five amphibian species (Ecologia, 2011). A total of 14 native and three introduced mammal species, 63 bird, 47 reptile and one amphibian species have been previously recorded in the Project Area (Ecologia, 2011). Fifteen species of conservation significance have been recorded within the Project Area (either directly or through secondary evidence) (FMG, 2011).

A total of 685 invertebrate specimens have been recorded in the Project Area, of which one is confirmed, one is likely, and five are potential Short Range Endemic (SRE) species (FMG, 2011). These potential SREs include mygalomorph spiders, millipedes, scorpions and pseudoscorpions.

### 2.7.3 Fortescue Marsh

Work recently completed by Equinox Environmental (Equinox Environmental, 2012) provides a consolidated summary of knowledge gained from studies relating to ecohydrology of the Fortescue Marsh. (Equinox Environmental, 2012) also describes a conceptual ecohydrological model of the Fortescue Marsh fringe and discusses potential indirect impacts to the Fortescue Marsh and fringing areas, Figure 13.

Supported by empirical evidence from multiple studies, the Fortescue Marsh conceptual ecohydrological model indicates that the water balance dynamics of the marsh are principally controlled by surface water inflows from the greater marsh catchment, as dictated by episodic flooding events. The flood events replenish a shallow aquifer system in the Tertiary sediments beneath the marsh, which is gradually depleted by direct surface evaporation and evapotranspiration by the fringing vegetation communities. In periods of prolonged drought, the shallow watertable reaches a pseudo-steady state set by the evaporation extinction depth in the lowest parts of the marsh basin. The fringing vegetation is dominated by samphire communities which exhibit zonal species distribution patterns influenced by soil water and salinity dynamics, depth to watertable and flooding frequency (Equinox Environmental, 2012).

A vertical 2-dimensional variably-saturated model (HYDRUS) was used to simulate soil water dynamics and plant water uptake by samphire vegetation on the fringe of the Fortescue Marsh (Equinox Environmental, 2012). In combination with empirical observations, in particular the demonstrated ability of *T. indica* subsp. *bidens* to tolerate drought and other stressors, the findings of the modelling study suggest that the ecological water requirements of the fringing samphire communities are wholly or predominantly met by surface inputs. The findings also provide confidence that drawdown, of up to 3 m, will not significantly affect samphire survival and health. Other potential groundwater system impacts associated with the Cloudbreak Project water management strategy, such as injection mounding and water quality changes, are also not predicted to be significant.

Mining and infrastructure development associated with the Cloudbreak Project will disturb the surface flow regime north of the Fortescue Marsh, within a zone of relatively stable channel systems occasionally separated by sheetflow areas. The divergent channel drainage network downstream from these areas will remain largely unaffected by mining disturbances. Assuming effective implementation of the Cloudbreak Life of Mine Surface Water Management Plan (FMG, 2013f), minimal disruption to the downstream flow regime at the marsh fringe is expected. Where changes to the flow regimes of individual drainage outlets occur, these are predicted to be modest and will not significantly affect the ecological water requirements of the Fortescue Marsh samphire communities.

## 2.8 Aboriginal heritage

There is a long history of Aboriginal habitation in the vicinity of Fortescue Marsh. A number of ethno-archaeological sites (mainly stone artefact scatters) have been identified 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.

## 2.9 Pastoral bore 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 9. 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 12 to 18 years ago, which has anecdotally been attributed to the upstream development of Opthalmia Dam.

**Table 9: Pastoral groundwater bores**

| Station Bore Name | Pastoral Station | Easting (GDA94, Zone 50) | Northing (GDA94, Zone 50) | Water Quality (TDS in mg/L) |
|---|---|---|---|---|
| Walla Bore | Mulga Downs | 710,020E | 7,534,549N | Unknown |
| Kardardarrie Bore | Mulga Downs | 714,520E | 7,534,070N | 5,000 mg/L |
| Thieves Bore | Mulga Downs | 722,537E | 7,534,269N | 2,500 mg/L |
| Moojari Bore | Mulga Downs | 727,900E | 7,531,200N | 2,000 to 2,500 mg/L |
| Minga Well | Mulga Downs | 733,719E | 7,529,737N | 1,100 to 1,700 mg/L |
| Outcamp Well | Hillside | 760,711E | 7,521,638N | Unknown |
| Mulinyury Bore | Hillside | 756,803E | 7,522,730N | Unknown |

# 3. CLOUDBREAK OPERATIONS

## 3.1 Groundwater management strategy

The groundwater management approach developed for Cloudbreak has been successfully implemented since 2008 and has since been expanded to the Christmas Creek operation. The strategy has been developed to meet requirements of the mine and Fortescue Marsh Management objectives (EPA, 2013). Key components of the groundwater management approach include:

- Advance dewatering and operational dewatering methods for multiple water quality streams;
- Managed aquifer recharge of brackish and saline water, including recovery of brackish water;
- Mine to mine transfer of brackish water to meet inter-mine water demands; and
- Mine to mine transfer of saline water (adaptive management strategy).

The Groundwater management strategy has been enhanced with the connectivity of the Cloudbreak and Christmas Creek brackish systems, which enables maximum beneficial use of brackish water abstracted during dewatering. Fortescue has recently obtained approval for transfer of saline water between Cloudbreak and Christmas Creek which will enable redistribution of saline injection across 90km of Oakover aquifer strike, significantly enhancing the adaptive management approach to management of groundwater drawdown and or mounding impacts in the alluvial aquifer.

A summary of objectives and management strategies is presented in Table 10 and briefly described below.

**Table 10: Water management objectives and strategies**

| Objectives | Strategies |
|---|---|
| <u>Cloudbreak</u><br>• Prevention of disruption to mining due to water.<br>• Conservation of groundwater resource.<br>• Completion of water management operations in a cost-effective manner. | • Inclusion of water management as a key parameter in the mine planning process.<br>• Adoption of Managed Aquifer Recharge (MAR) as the principal excess water management method. |
| <u>Fortescue Marsh Management Objectives</u><br>• Minimisation of impacts associated with discharge of excess water to the environment.<br>• Minimisation of Groundwater Dependent Ecosystem (GDE) impact due to operational groundwater level change.<br>• Prevention of aquifer contamination.<br>• Sustainable use of groundwater resource. | • Operation of separate water management conveyance systems for brackish and saline water.<br>• Banking (storing) brackish groundwater for future recovery.<br>• Targeted injection of excess water to reduce drawdown footprint.<br>• Injection of saline groundwater into compatible saline quality aquifer(s).<br>• Adoption of a flexible water conveyance system |

| Objectives | Strategies |
|---|---|
| • carbon-efficient construction and operation.<br>• Minimisation of ground clearing requirement.<br>• Minimisation of closure legacy. | that enables the redistribution of water as required to manage potential impacts.<br>• Adoption of mine site surface water diversion strategies to minimise disruptions to volume of surface water flow from the Chichester Range to the Fortescue Marsh. |
| Social<br>• Minimisation of impact to cultural values.<br>• Minimisation of impact to other stakeholders. | • Continued pursuit of process-improvement strategies for water management.<br>• Continued development and implementation of Fortescue's groundwater management framework. |

## 3.2 Operations management

The following regulation applies to abstraction and injection operations:

- Groundwater abstraction is regulated under Section 5C of *the Rights in Water and Irrigation* (RIWI) *Act 1914* by the Department of Water (DoW). The applicable groundwater instrument is groundwater licenses GWL166200 and GWL 166354, which has an abstraction entitlement of 100 GL/a. Operational commitments applicable to the licence, including monitoring and reporting commitments are documented in the *Cloudbreak Groundwater Operating Strategy*. (FMG, 2013d)

- Groundwater injection is regulated under Part V of the EP Act, by the Department of Environmental Regulation (DER). The applicable licence instrument is L8199/2007/2. Operational commitments applicable to L8199/2007/2, including monitoring and reporting commitments are documented in the *Cloudbreak Water Management Scheme* (FMG, 2013c).

Reporting, to the DoW, is undertaken quarterly to demonstrate compliance with the operating strategy and to inform of groundwater impacts. The most recent quarterly monitoring summary covers the period from 1 February 2013 to 30 April 2013 (FMG, 2013). A triennial review summarising data up to July 2013 was submitted in September 2013 (FMG, 2013b).

Groundwater monitoring is undertaken by a dedicated Cloudbreak Monitoring and Compliance team. Groundwater levels, salinities and abstraction volumes are measured monthly (or at more frequent intervals).

A brief summary of performance against Fortescue Marsh management objectives and the Cloudbreak Operating strategy is outlined below.

## 3.3 Operations performance summary

To date, Fortescue has been compliant with all requirements of the Operating Strategy (FMG, 2013d) and Water Management Scheme (FMG, 2013c). No significant impacts have been recorded and adaptive management solutions have been implemented to ensure continuing success of operations (FMG, 2013b).

Mining below watertable has progressed in several mine pits spanning approximately 17km of the mineralised Marra Mamba Formation (MMF). Water quality permitting this groundwater is used for ore processing and dust suppression; excess brackish water has been transferred to Christmas Creek and or injected to the east and west of the below watertable mining area (but within the same aquifer) and saline groundwater has been injected to the Oakover Formation located to the south of the below watertable mining area (and north of the Fortescue Marsh). In the 2013 period, some brackish groundwater was abstracted from previous brackish injection areas to supplement brackish supply for the mine site.

A total of 24,928,000kL; 31,697,000 kL; and 59,388,000 kL were abstracted for the 2010, 2011 and 2012 licence periods respectively. Of the total abstraction, mine site water use and injection comprised 30% and 57% respectively for 2010; 24% and 64% respectively for 2011; and 10% and 77% for 2012.

Water level changes due to dewatering and injection activities have followed the expected trends, being summarised as;

- The piezometric level has been lowered in the MMF aquifer and overlying Tertiary detrital/alluvial aquifer in the below watertable mining (and dewatering) area.
- The piezometric level has risen and subsequently started to recede in the MMF aquifer and overlying Tertiary detrital/alluvial aquifer in the brackish injection area to the east and west of the below watertable mining area in response to periods of injection and abstraction.
- Piezometric levels have risen in the Oakover Formation in the saline injection area and to a lesser extent in the near marsh area.
- Piezometric levels in the shallow Tertiary alluvial aquifer (overlying the Oakover Formation) in the saline injection area and near marsh areas have displayed cyclical periods of rise and fall in response to climatic induced groundwater recharge events.

The salinity of groundwater abstracted from dewatering operations has increased in response to depletion of the brackish water resource in the dewatering area; salinity has remained relatively constant in the MMF in the brackish injection zones; and salinity has remained relatively stable in the Oakover Formation and overlying detrital and alluvial aquifer in the saline injection and near-marsh areas.

# 4. CONCEPTUAL HYDROGEOLOGICAL MODEL

Extensive hydrological data developed from site and regional investigations, and operations (Sections 1 & 3) have been synthesised to inform the conceptual hydrogeological model for Cloudbreak. The conceptual model forms the basis of the numerical modelling. The hydrogeological setting can be classified based on the dominant flow processes into three regimes:

- Topographic driven groundwater flow system of the Chichester Range.
- Density driven groundwater flow system of the Upper Fortescue Valley.
- Surface water driven Fortescue Marsh and peripheral shallow groundwater system.

Characteristics of each of these systems and the relationship between the flow systems are described below and in Figure 3. Elements of the conceptual model which are represented in the numerical modelling study are summarised in Table 11, including key revisions from the previous LOM assessment (FMG, 2010d).

## 4.1 Topographic driven groundwater flow system of the Chichester Range

Rainfall and stream flow on the upper and lower slopes of the Chichester Ranges infiltrate the soil and recharge the MMF directly or through Tertiary detritals/alluvium. The mineralised MMF is the main aquifer in this part of the flow system. The mineralised MMF is bounded below by the lower MMF and Jeerinah Formation and overlain by saturated Tertiary detritals/alluvium.

Groundwater flow is generally in a south to south westerly direction towards the Fortescue Marsh. The hydraulic gradient is very low due to the opposing density driven flow system, a small amount of discharge for limited periods is expected to occur by evapotranspiration at the Fortescue Marsh.

Seasonal groundwater trends are generally subdued due to the low infiltration rate, high storage of Tertiary detritals/alluvium and low rate of discharge from the system.

## 4.2 Density driven groundwater flow system of the Upper Fortescue Valley

The hypersaline environment of the Upper Fortescue Valley groundwater system creates a density driven flow system that directly opposes the topographic driven flow system. Evidence suggests that hypersaline conditions developed due to a constriction of the regional groundwater flow system at the Goodardarie Hills, as well as a long period of evapo-concentration of flood waters on the Fortescue Marsh.

The Oakover Formation is the main aquifer in this part of the flow system. The Oakover Formation is bounded below by the Wittenoom Formation and overlain by a homogeneous clay layer which in turn is overlain by saturated Tertiary detritals/alluvium.

The opposing density driven and topographic driven flow systems result in the formation of a dynamic saline interface, which extends over many kilometres between the Fortescue Marsh and the lower slopes of the Chichester Ranges, and is present throughout the flow system. Changing pressure conditions within each part of the system create a dynamic interface, the distribution of which reflects hydrostratigraphic connectivity and dispersion characteristics of the aquifer system.

Direct connectivity between the mineralised MMF and the Oakover Formation is variable and indirect connectivity is locally enhanced through north east to south west fault zones in underlying MMF and Wittenoom Formation.

## 4.3 The Fortescue Marsh and peripheral shallow groundwater system

The upper groundwater system of the Upper Fortescue Valley is associated with the Fortescue Marsh, which is the discharge point for the Upper Fortescue surface water catchment. The Upper Fortescue catchment covers an area of 30,000 km$^2$. Runoff following major rainfall events in the catchment result in significant flooding on the Fortescue Marsh.

The extreme variability of hydrological dynamics that occur between flood and prolonged dry periods can be described by three dynamic phases and are illustrated in Figure 13:

### 4.3.1 Flood phase

Following major rainfall events catchment runoff enters the Fortescue Marsh and forms a lake or series of lakes. Lake volumes in excess of 300 GL have been calculated. Under this condition, the surface water and shallow groundwater become connected as surface water infiltrates and raises the groundwater level to the surface. The capacity of the groundwater system beneath the Fortescue Marsh to receive water is generally low as the watertable is normally around 1 or 2 m below ground surface. The fresh surface water infiltrating the unsaturated zone is quickly salinized due to abundance of salts in the soil profile (Skrypek G., 2013). The elevated head associated with the lake creates a hydraulic gradient away from the Fortescue Marsh and groundwater flows into the adjacent alluvium.

Flooding within the Fortescue Marsh has been observed to have an influence on shallow groundwater (Tertiary detrital/alluvium) levels up to 2 km from the fringe of the Marsh.

### 4.3.2 Inter-flood phase

Between flooding events, referred to as the inter-flood period (Figure 13), rainfall and catchment runoff is generally low and evaporation exceeds the direct rainfall on the Fortescue Marsh. The lake is reduced over time through evaporation. At this stage, hydraulic gradients developed by the interplay of the topographic and density driven flow systems resumes, and evaporative discharge through and fringing the lake continues to lower the watertable.

### 4.3.3 Prolonged dry phase

Following an extended period of low rainfall, the Fortescue Marsh may reach the 'prolonged dry' condition (Figure 13). If the dry period progresses for a prolonged period the watertable level will fall below the evaporative extinction depth and discharge will diminish.

**Table 11: Conceptual model summary**

| Element | Description | Key change from previous LOM assessment (FMG, 2010d) |
|---|---|---|
| **Model Framework** | | |
| Domain | The model domain covers an area of approximately 2745 $km^2$. | Slightly smaller area |
| Hydrogeological units | See Section 2.6.1 | No change |
| Hydraulic properties | See Section 2.6.2 | No change to calibrated model properties. |
| Salinity | Groundwater salinity ranges between fresh (<500 mg/L) and hypersaline (up to 150,000 mg/L) | No change |
| Model boundaries | Northern boundary. Though the MMF is truncated where it outcrops in the Chichester Range, this does not represent the northern boundary of the hydrogeological system. Groundwater occurrence within the underlying Jeerinah Formation (Roy Hill Shale) is connected with the MMF. However, the connection (between MMF & Roy Hill Shale) is constrained to discrete fracture zones and thus groundwater flow across the northern boundary is believed to be negligible, i.e., the northern boundary can be approximated as a no-flow boundary.<br>The southern boundary is located at such a large distance away from the Cloudbreak mine site that groundwater levels along the boundary would not be affected by mine dewatering or water injection..<br>The eastern boundary is beyond the eastern extent of the operation, and groundwater flow is considered to be parallel to this boundary.<br>The western boundary is beyond the western extent of the operation, and groundwater flow is considered to be parallel to this boundary.<br>The model base is at a selected level below the groundwater flow system.<br>The model top is represented by groundwatertable or surface watertable over the Fortescue Marsh during the period of surface ponding. | No change |
| **Groundwater Recharge** | | |
| Chichester Range recharge | Recharge due to infiltration of rainfall is estimated to range between 0.2 to 3% of rainfall (approximately 0.5 GL/a 6 GL/a). | No change |
| Fortescue Marsh | After a prolonged dry period in which water levels below the | No change |

| Element | Description | Key change from previous LOM assessment (FMG, 2010d) |
|---|---|---|
| recharge | Fortescue Marsh decline to 3 m below the surface, the occurrence of a significant ponding event (over 600 $km^2$) could recharge the groundwater system by approximately 30 GL of water.<br>Groundwater recharge related to flooding can be predicted based on correlation between observed flooding and rainfall records. | |
| **Groundwater Discharge** | | |
| Evaporation and evapotranspiration | Evaporation and evapotranspiration principally occur in the Fortescue Marsh area, where the depth to watertable is shallowest. Potential evapotranspiration rates in the region are as high as 3,000 mm/year. This rate is expected to exponentially decline as depth to watertable increases (to a maximum depth of 3 metres). | Zone of evaporation and evapotranspiration amended based on topography rather than simply the prescribed boundary of Fortescue Marsh |
| **Groundwater Flow** | | |
| Hydraulic gradient and through flow (topographic-driven flow) | Groundwater flow through the Chichester Range aquifer system is considered to be equivalent to catchment recharge. Chichester Range groundwater through flow is low compared to the Fortescue Marsh's recharge and evapotranspiration fluxes, as it is constrained by the presence of dense water beneath the Fortescue Marsh. Topographic driven flow from the Chichester Ranges tends to flow through shallow stratigraphy towards the watertable beneath the Fortescue Marsh | No change |
| Salinity and density gradients (density-driven flow) | High salinity water has a higher density than fresh water, and resultant density gradients have an important influence on groundwater flow.<br>The density value at 150,000 mg/L is 1.114kg/L. | No change |
| **Anthropogenic** | | |
| Pastoral bores | Several pastoral bores are located in the project area. These bores pump shallow groundwater around watertable and groundwater drawdown due to these bores is usually small. | No change |
| Cloudbreak dewatering | Mining pits are located at areas with mineralised MMF. | No change |
| Cloudbreak injection | The injection of brackish groundwater will occur laterally into MMF; the injection of saline groundwater will be to the south of mine pits into the Oakover Formation aquifer. | No change |
| Christmas Creek operations | Christmas Creek mining operations are located to the east of Cloudbreak and some dewatering and injection activities at Christmas Creek may affect groundwater flow at the Cloudbreak site. | No change |

## 4.4 Water Balance

A conceptual water balance for each of the Fortescue Marsh phases is presented in Table 12. The water balance is for illustrative purposes and represents broad average recharge conditions, whereas recharge (especially related to the Fortescue Marsh) is event based.

- On an annual basis recharge to the groundwater system beneath the upper and lower slopes of the Chichester Ranges is estimated to be approximately 0.5 GL/a based on average rainfall conditions, an estimated 3% of rainfall recharging the aquifer system and the aerial extent of the Christmas Creek domain.
- Under flooded conditions, the groundwater system is being recharged. The lake, or open water, formed on the Fortescue Marsh following significant rainfall (average lake volume of around 300 GL) results in around 30 GL of water entering the shallow groundwater system.
- Under interflood conditions, the groundwater system is still receiving around 0.5 GL of recharge from the Chichester Ranges; however, discharge (evaporative) through and fringing the Fortescue Marsh is dominant.
- Under the prolonged dry condition, the system is effectively static (not receiving recharge or discharging).

**Table 12: Simplified analytical water balance**

| | Recharge (GL/a) | Discharge (GL/a) |
|---|---|---|
| **Flooded Condition** | | |
| Chichester Ranges | 6 | 0 |
| Fortescue Marsh (groundwater system) | 30 | 0 |
| **Net** | **36** | |
| **Interflood Condition** | | |
| Chichester Ranges | 0.5 | 0 |
| Fortescue Marsh (groundwater system) | 0 | 30 |
| **Net** | **29.5** | |
| **Prolonged Dry Condition** | | |
| Chichester Ranges | 0 | 6 |
| Fortescue Marsh (groundwater system) | 0 | 0 |
| **Net** | **-6** | |

# 5. GROUNDWATER MODELLING ASSESSMENT

## 5.1 Modelling objectives and scope

A computer based, numerical groundwater flow and transport model has been developed for the Cloudbreak project area for the purpose of predicting groundwater level conditions and conceptual design of the dewatering and injection system.

This section describes the following key components of this assessment:

- Construction of a numerical groundwater flow and transport model.
- Calibration.
- Simulation of dewatering and injection and prediction of water level change.
- Uncertainty analysis.
- Model limitations.
- Where relevant, updates to the model since the previous Cloudbreak LOM assessment (FMG, 2010d) are noted.

## 5.2 Numerical model construction

### 5.2.1 Numerical model complexity

Within the context of the Australian Groundwater Modelling Guidelines (SKM & NGRT, 2012), 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.

### 5.2.2 Model software selection and code settings

To select suitable modelling software, several criteria were used:

- The software should have the function of simulating density driven flow and transport, since density-driven flow and salt transport is a major feature of the aquifer system.
- The model domain, which is very large (2745 $km^2$) to achieve the goal of assessing environmental impacts, has to be discretised efficiently with the total number of elements (largely determining computer running time) being at a reasonable level.
- The software should industry recognised and technically well supported.

FEFLOW software (version 6.0) was determined to rate highly against the criteria and was selected as the preferred modelling code.

The following solver and code settings were adopted:

- Default iterative non-symmetrical equation solver 'preconditioned Lanczos-type BICGSTAPB'.
- Default convergent form transport equations.
- Non-Fickian dispersion law.
- Extended Boussinesq approximation to density dependence.
- Neglect fluid viscosity effects on conductivity.
- The predictor-corrector, automatic, time-stepping system utilising the Forward Adams-Bashford/backward trapezoid rule.
- Default Euclidean L2 integral Root Mean Square (RMS) error norm with a convergence criteria of 0.0005.
- 'Full upwinding' techniques were applied to dampen oscillations.

### 5.2.3 Numerical mesh and numerical layers design

#### Model domain

The model domain (Figure 14) covers the Fortescue Marsh and the mining area as well as extending in all directions to locations where no flow boundary conditions are valid assumptions. The total model area is about 2745 km$^2$.

#### Model layer structure

The hydrostratigraphy represented in the model is listed in Table 13 and shown graphically in Figure 15. An additional numerical layer (Layer 1) is used in the model to represent open water in Fortescue Marsh. This layer has a porosity of 1 and a large conductivity of 8640 m/day to simulate surface water ponding that may occur after significant rainfall events.

#### Spatial discretisation

Each numerical layer within the FEFLOW model is discretised into triangles with variable element sizes throughout the model domain. The finite element mesh was refined in and around the proposed mining area (Figure 14) with elemental side length down to 50 m.

Discretisation parameters were selected on the basis of the ability of the mesh to represent the curvature in the watertable and corresponding groundwater heads at depth. The gradation in element size from small to large radiating out from the mining regions is considered appropriate. Figure 15 shows the distribution of hydrogeological units in a vertical cross section of the model.

**Table 13: Model layers**

| Numerical Model Layer Number | Description |
|---|---|
| 1 | Fortescue Marsh Open Water |
| 2 | Tertiary Detrital |
| 3 | Tertiary Clay |
| 4 | Oakover Formation |
| 5 and 6 | Wittenoom Formation |
| 7 | Hardcap: Depleted Marra Mamba Formation (MMB) |
| 8 | Mineralised MMB: above the Economical Ore Base |
| 9 | Mineralised MMB: below the Economical Ore Base |
| 10 | Fractured MMB |
| 11 | Un-mineralised MMB |
| 12 | Jeerinah Formation (Roy Hill Shale) |

### 5.2.4 Model parameters

The values and distribution of model hydraulic properties have been developed from field based aquifer testing (see Section 2.6.2) and model calibration (undertaken for borefield planning and design purposes) at both Cloudbreak and Christmas Creek. Initial hydraulic parameter values used in the model are presented in Table 14.

Model calibration undertaken as the operation has progressed has assisted in constraining parameters determined from aquifer tests, particularly vertical conductivity and specific yield parameters, which are inherently difficult to determine from relatively short duration tests.

**Table 14: Initial model hydraulic parameters**

| Hydrostratigraphic unit | Hydraulic conductivity | | | Specific yield | Specific storage coefficient |
|---|---|---|---|---|---|
| | $K_h$ (m/s) | $K_h$ (m/day) | $K_h/K_z$ | | |
| Marsh water body | $1.0 \times 10^{-1}$ | 8640.0 | 1 | 1.0 | $10^{-5}$ |
| Tertiary Detrital | $2.48 \times 10^{-5}$ | 2.15 | 50 | 0.04 | $10^{-4}$ |
| Alluvial clay | $1.16 \times 10^{-7}$ | 0.01 | 10 | 0.01 | $10^{-4}$ |
| Oakover Formation | $2.31 \times 10^{-3}$ | 200.0 | 10 | 0.04 | $10^{-4}$ |
| Wittenoom Formation | $1.16 \times 10^{-5}$ | 1.0 | 10 | 0.005 | $10^{-5}$ |
| Hardcap | $1.16 \times 10^{-6}$ | 0.1 | 10 | 0.03 | $10^{-5}$ |
| Mineralised Marra Mamba Formation | $6.94 \times 10^{-4}$ | 60.0 | 50 | 0.03 | $10^{-5}$ |
| Fractured Marra Mamba Formation | $5.78 \times 10^{-5}$ | 5.0 | 10 | 0.03 | $10^{-5}$ |
| Un-mineralised Marra Mamba Formation | $5.78 \times 10^{-6}$ | 0.5 | 50 | 0.01 | $10^{-5}$ |
| Roy Hill Shale | $1.16 \times 10^{-7}$ | 0.01 | 10 | 0.001 | $10^{-5}$ |

### 5.2.5 Boundary conditions for groundwater flow

All boundary conditions used in the current numerical model are the same as those used in the previous hydrogeological assessment (FMG, 2010d) Table 15.

**Table 15: Numerical model boundary conditions**

| Boundary | Boundary Type | Description of hydrogeological representation |
|---|---|---|
| Western | No flow Boundary | For simplicity, the western and eastern boundaries are represented as no flow boundaries.<br>• Under natural flow conditions, the assumption of a no flow boundary is considered appropriate as natural groundwater flow is roughly parallel to these boundaries.<br>• Under mining conditions, no flow boundary conditions are also considered appropriate as they are located significant distances from active areas of mining (over 6 km to the western boundary |
| Eastern | No flow Boundary | |

| Boundary | Boundary Type | Description of hydrogeological representation |
|---|---|---|
| | | and over 10 km from the eastern boundary).<br>If any significant drawdown is predicted along these boundaries, it would represent the worst case scenario that might occur as long as no significant drawdown is caused by the neighbouring mining activity. |
| Northern | No flow boundary | The northern boundary is aligned with the surface water catchment divide within the Chichester Ranges. Groundwater flow is expected to closely follow topography and therefore the selected alignment represents a natural groundwater divide. Drawdown impacts are not expected to extrapolate to this boundary thereby not influencing the natural groundwater flow regime. |
| Southern | Constant head boundary | The southern model boundary is located to the South of the Fortescue Marsh and is at least 29 km away from mining pits and at least 27 km away from proposed injection wells. Boundary heads were assigned based on measured groundwater levels nearby the boundary. |

### 5.2.6 Recharge

Recharge is the component of direct rainfall or surface water flowing across the land surface that infiltrates to the watertable. The model area was divided into seven recharge zones as described in Table 16 and presented in Figure 16.

Recharge zones are mostly the same as those in the previous PER model, except that the Marsh recharge zone was extended to include some lowland area to the Northwest of the Fortescue Marsh (see Figure 16).

**Table 16: Numerical model recharge zones**

| Recharge zone | Name | Description |
|---|---|---|
| 1 | Southern TD recharge zone | The zone is covered with Tertiary Detritals and the land surface is flat or with a gentle slope. It receives moderate recharge. |
| 2 | Weeli-Wolly Creek zone | This is used to represent recharge from Weeli Wolly Creek. It is high recharge zone. |
| 3 | Fortescue Marsh recharge zone | This zone is the lowland area of the Fortescue valley. It receives direct rainfall recharge as well as surface runoff from the large catchment. Watertable rises to |

| Recharge zone | Name | Description |
|---|---|---|
| | | above ground surface when flooding occurs. Note that most of the recharge in this zone stores above the ground surface (part of model domain) and leaves from the model through evaporation. |
| 4 | Southern Bedrock recharge zone | The zone is mostly covered with Roy Hill Shales. It receives little recharge due to the low permeability and the steep slope ground surface. |
| 5 | Northern TD recharge zone | The zone is covered with Tertiary Detritals and the land surface is flat or with a gentle slope. It receives moderate recharge. |
| 6 | Northern MMF recharge zone | The zone is mostly covered with mineralised MMF. It receives significant recharge from direct rainfall and surface runoff from upslope area. |
| 7 | Northern bedrock recharge zone | The zone is mostly covered with Roy Hill Shales or un-mineralised MMF. It receives little recharge due to the low permeability and the steep slope ground surface. |

### Recharge rate for catchment zones (all zones except the Marsh zone)

It was assumed that recharge occurs only when the monthly rainfall is 50 mm or over and the recharge rate is proportional to the monthly rainfall. The recharge coefficient was determined through model calibration.

### Recharge rate for the Fortescue Marsh

The recharge over the Fortescue Marsh is calculated as:

Equation 1 $$Recharge = POW \times Repot$$

Equation 2 $$Repot = F \times Raflood - Epan$$

Equation 3 $$POW = \begin{cases} 0 & HMSE > 407 \\ \frac{(407 - HMSE)}{2} & 405 \leq HMSE \leq 407 \\ 1 & HMSE < 405 \end{cases}$$

Where,

- POW represents the potential of receiving recharge that is assumed to be inversely proportional to ground surface elevation, i.e., the lower the surface ground the larger the potential to receive water from surface runoff.

- Repot is the potential net recharge.
- F is the coefficient to be calibrated and is related to stream flow entering Fortescue Marsh from the greater catchment region in flooding events.
- Raflood is the moving average (over 3 months) of measured monthly rainfall events that are greater than 90mm/month.
- Epan is the average monthly rate of pan evaporation (mm/month).
- HMSE is the land surface elevation ().

From Equation 3, the following conclusions can be drawn.

- Low ground areas receive more recharge than high ground areas in the Fortescue Marsh.
- The actual recharge rate is equal to the potential net recharge rate in areas where the land surface elevation is less than 405 m AHD and decreases with increasing land surface elevation.
- In areas with ground surface elevations greater than 407 m AHD, the actual recharge equals zero.

The approach used for calculating catchment and Marsh water recharge are the same as used in the previous hydrogeological assessment (FMG, 2010d).

### 5.2.7 Evapotranspiration

Evaporation is the sum of evaporation and plant transpiration direct from the watertable or surface water feature. Evapotranspiration is not significant over the upper and lower slopes of the Chichester Ranges owing to the depth to the watertable and nature of plant assemblage's, which dominantly draw moisture from the soil profile. Evapotranspiration is the dominant process occurring within the Fortescue Marsh (Recharge Zone 3).

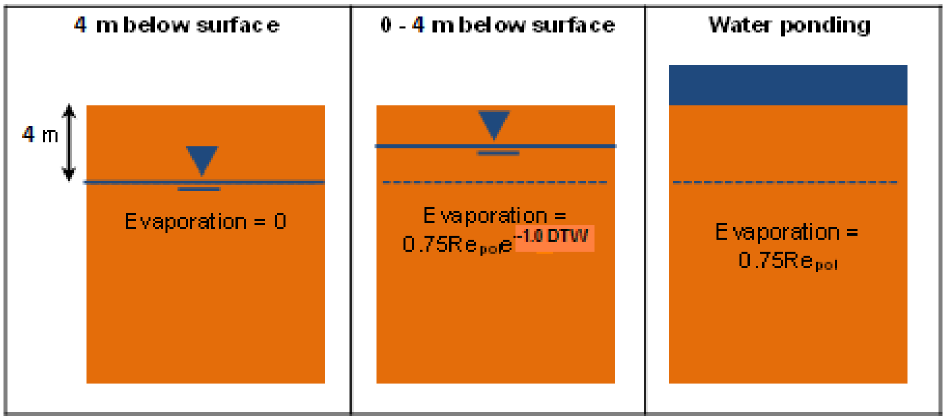
Evaporation is the discharge mechanism for open water occurring on the Fortescue Marsh and shallow groundwater beneath the Marsh. The application of evapotranspiration to the Fortescue Marsh is described below.

**Fortescue Marsh evaportranspiration**

In the model evaporation over Fortescue Marsh is calculated using the formulas outlined in Table 17. Under inter flood conditions, groundwater in the aquifer system flows towards the Fortescue Marsh area, where water flows out of the system through evapotranspiration. The rate of evapotranspiration is assumed to be proportional to the depth to groundwater. The rate of evapotranspiration declines exponentially with the increase in depth to groundwater. When the watertable reaches the extinction depth (assumed to be 3-4 m), the rate of groundwater evapotranspiration is assumed to be zero (prolonged dry period).

During flooding events, when the watertable is above the ground surface, the rate of evapotranspiration is assumed to be 75% of the potential evapotranspiration rate (about 3000 mm/year).

**Table 17: Fortescue Marsh evaporation algorithm**




## 5.2.8 Solute transport and density couple flow modelling

### Solute transport processes

Solute transport occurs in two ways, advection and hydrodynamic dispersion (Bear, 1972).

- Advection is the process by which a volume of water is transported through porous media, carrying with 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.
    - Mechanical dispersion is caused by spatial variations in velocity at various scales as a result of the tortuosity of porous media and heterogeneity of hydraulic conductivity.

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, the 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 density-driven groundwater flow. Given that the salinity gradient at Cloudbreak is large, density-driven flow may be a dominating process in some areas of the model domain.

Solute transport and density driven flow have been included in the numerical model, key solute transport parameters are listed in Table 18.

**Table 18: Solute transport parameters**

| Parameter | Value |
|---|---|
| Reference concentration ($C_o$) | 0 mg/L |
| Maximum concentration ($C_s$) | 150,000 mg/L |
| Density ratio ($\alpha$) | 0.114 ($\alpha$ = ($\rho_{max}$-$\rho_0$)/$\rho_0$, where $\rho_0$=1.0 and $\rho_{max}$=1.114 (the density of water at concentration of 150,000 mg/L) |
| Molecular diffusion coefficient | $10^{-9}$ $m^2/s$ |
| Longitudinal dispersivity ($\square_L$) | 200 m |
| Transverse dispersivity ($\square_T$) | 20 m |
| Effective Porosity | Sy (used to calculate pore velocity in the solute transport equation) |

## Boundary conditions for solute transport

For solving the transport equation, boundary conditions need to be specified (Table 19). Zero-solute fluxes were applied to all lateral boundaries since they are all no-flow boundaries. As the salt concentration of rain water is small compared to groundwater salinity, the top boundary with rainfall recharge was assumed to be zero solute flux boundary. Salt concentrations of groundwater underneath the Fortescue Marsh are very high, up to 150,000 mg/L, and are not likely to change significantly over the model simulation period. As a result, a constant concentration boundary condition (internal boundary condition) was applied to all nodes underneath the Fortescue Marsh.

**Table 19: Solute transport boundary conditions**

| Boundary Condition | Rationale |
|---|---|
| Zero solute flux on all lateral boundaries | These boundaries are either no flow boundaries or constant head boundary with very low salt concentration (southern boundary) |
| Zero solute flux on top of the model | Rain water salinity is close to 0 mg/L |
| The concentration at nodes underlying the Fortescue Marsh is constant at 150,000 mg/L. | The hypersaline groundwater body has been formed over geological time periods (Skrypek G., 2013). Groundwater salinity is unlikely to change significantly over the simulation time period (20 years). |

All boundary conditions for solute transport are the same as used in the previous hydrogeological assessment (FMG, 2010d).

## 5.3 Model calibration

### 5.3.1 Initial conditions

The initial head and salinity distributions were derived from a long-term (4500 year) simulation. This long term simulation modelled the evolution of an initially brackish aquifer system by applying a constant salinity boundary condition set at 150,000 mg/L at the Fortescue Marsh surface to represent evapo-concentration processes. The actual historical evolution of the current salinity distribution is currently hypothesised to be due to similar processes but may have taken place over 10,000 to 100,000's of years, with various inter-waning periods (Skrypek G., 2013). The process applied enables the derivation of a reasonable and stable spatial distribution of salinity to be used as the initial condition for the calibration model.

### 5.3.2 Transient calibration

Transient calibration was conducted by using monitoring bore records and Fortescue Marsh flooding records (interpreted from Landsat images) in the period from 1/01/1997 to 30/06/2013 (16.5 years). The period is divided into two stages, i.e., the pre-dewatering stage (from 1/01/1997 to 31/12/2007) and dewatering stage (from 1/01/2008 to 30/06/2013).

The evaluation criteria for the model included:

- Residuals between observed and simulated heads at monitoring bores.
- Correlation between simulated and measured hydrographs of head (representing groundwater hydraulic dynamics at selected monitoring bores).
- Consistency between modelled water balance and estimated water balance in the model conceptualisation stage.
- Correlation between simulated and observed salinity distribution in the model area.

Calibration results for the two stages are presented separately in the following sections.

#### Pre-dewatering calibration stage

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

- Model parameter values shown in Table 20. Calibrated parameters are consistent with calculated parameters, Table 14. The only change was to include a high permeable zone within the Tertiary Detrital layer, Appendix 3. Conductivity in this zone has been increased by a factor of 20.
- The average annual Fortescue Marsh catchment runoff and evapotranspiration are 306.9 and 345.8 GL/a (see Table 21), respectively. The runoff of 306.9 GL/a equals 5% of effective rainfall over the whole Fortescue catchment (30,000 km$^2$).

- Average Fortescue catchment rainfall recharge rate is 1.4% of total rainfall, or 2.5% of the effective rainfall (sum of rainfall in all months with rainfall over 50 mm).

**Table 20: Calibrated model hydraulic parameters**

| Hydro-stratigraphic unit | Hydraulic conductivity | | | Specific yield | Specific storage coefficient (1/m) |
|---|---|---|---|---|---|
| | $K_h$ (m/s) | $K_h$ (m/day) | $K_h/K_z$ | | |
| Marsh water body | $1.0 \times 10^{-1}$ | 8640.0 | 1 | 1.0 | $10^{-5}$ |
| Tertiary Detrital | $2.89 \times 10^{-5}$ | 2.15 | 20 | 0.04 | $10^{-4}$ |
| High permeable zone of Tertiary Detrital | $5.78 \times 10^{-5}$ | 50 | 20 | 0.04 | $10^{-4}$ |
| Alluvial clay | $1.16 \times 10^{-8}$ | 0.01 | 10 | 0.01 | $10^{-4}$ |
| Oakover Formation | $23.1 \times 10^{-4}$ | 200 | 10 | 0.04 | $10^{-4}$ |
| Wittenoom Formation | $0.35 \times 10^{-4}$ | 3 | 10 | 0.005 | $10^{-5}$ |
| Hardcap | $1.16 \times 10^{-6}$ | 0.1 | 10 | 0.03 | $10^{-5}$ |
| Mineralised Marra Mamba Formation | $6.94 \times 10^{-4}$ | 60 | 50 | 0.03 | $10^{-5}$ |
| Fractured Marra Mamba Formation | $5.78 \times 10^{-5}$ | 5.0 | 100 | 0.03 | $10^{-5}$ |
| Un-mineralised Marra Mamba Formation | $5.78 \times 10^{-6}$ | 0.5 | 50 | 0.01 | $10^{-5}$ |
| Roy Hill Shale | $1.16 \times 10^{-7}$ | 0.01 | 10 | 0.001 | $10^{-5}$ |

Simulated heads are compared with measured levels in Figure 17. The error between observed and simulated groundwater levels is in the range of -10.58 to 13.01 m. The average absolute error is 1.14 m, which is about 3.9% of the maximum difference (29.54 m) in observed groundwater levels.  Typically, an error less than 10% 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 5.8%, which is smaller than the value of 10% recommended by (SKM & NGRT, 2012).

Calibration of the model to the record of flooding for the Fortescue Marsh was undertaken for the period 1st January 1997 to 1st June 2011. The available rainfall data from Newman rainfall station was used as the primary time-varying model parameter for the Fortescue Marsh recharge formulation. The Fortescue Marsh runoff was adjusted to reproduce the observed Fortescue Marsh flood water levels.

The water balance of the calibrated model is shown in Table 21. Catchment rainfall recharge which refers to groundwater recharge is approximately 7.8 GL/a.

The water balance is dominated by surface water fluxes (340 GL/a) and evapotranspiration (341.7 GL/a) from the surface of the Fortescue Marsh. Water levels in the zone immediately beneath the marsh surface fluctuate by 1 to 4 m in response to cycles of flooding and evapotranspiration and the related groundwater storage change is small when compared to the surface water storage change. The small increase in groundwater storage change (6.1 GL/a) suggests that groundwater levels are slightly higher at the end than at the beginning of the model calibration period.

**Table 21: Model water balance in the calibration period**

| Model Input | | Model Output | Aquifer Storage Change (GL/a) |
|---|---|---|---|
| Catchment Recharge (GL/a) | Fortescue Marsh Recharge (GL/a) | ET[1] (GL/a) | |
| 7.8 | 340 | 341.7 | 6.1 |

The pre-dewatering calibration results are similar to the transient calibration results presented in the previous hydrogeological assessment (FMG, 2010d).

### Dewatering calibration stage

Recorded monthly pumping and injection rates were used as model inputs. Model parameters and recharge coefficients obtained from the pre-dewatering stage calibrations were used as initial parameters. In the dewatering stage calibration hydraulic parameters were adjusted to achieve reasonable fit with water levels, abstraction rates and injection rates. A scattergram for observed versus simulated water levels is presented in Figure 18. The results of the dewatering stage calibration are summarised as below:

- Simulated model abstraction was close to the actual abstraction (116.7 GL against 117.0 GL).
- The error between observed and simulated groundwater levels is in the range of -9.88 to 9.84 m. The average absolute error is 1.79 m.
- The ratio of the average absolute error to the maximum observed groundwater level difference (40.0 m) is 4.5%.
- The normalised Root Mean Squared error of the calibration is 5.9%, which is to that (5.8%) achieved in the pre-dewatering calibration.

As expected the average absolute error (1.79 m) is larger than that (1.14 m) achieved in the pre-dewatering calibration as groundwater levels are more dynamic under dewatering conditions. However, the ratio of the average absolute error to the maximum observed groundwater level difference is still significantly smaller than 10%, the commonly recommended guidance. All other calibration indicators are considered appropriate.

Hydrographs showing simulated and observed groundwater levels for both the pre dewatering and dewatering stage calibrations are presented in Appendix 4. The correlation between measured and simulated hydrographs at key locations is consistent, implying that the calibrated model has included the major processes and is representative of the groundwater system.

- The Fortescue Marsh zone is well calibrated to the magnitude, timing and absolute level of observed flooding events.
- The near marsh zone is well calibrated to the magnitude and timing of observed watertable change. Calibration to absolute levels could be improved with greater local refinement of the numerical model and density predictions, however the variation is generally less them one metre.
- The dewatering zone is generally well calibrated to the magnitude, timing and absolute level of observed water level changes in all horizons. Small scale structures and localised heterogeneity of the aquifer systems often result in individual poor calibration. Continual refinement of hydraulic parameters and understanding from operation will allow increased accuracy of calibration at a local scale.

During the dewatering stage calibrations, adjustments to some parameters were made:

- The specific yield of the mineralised MMF aquifer was increased from 0.03 to 0.04;
- Conductivity of the mineralised MMF aquifer was increased from 60 m/day to between 115 and 190 m/day in some pits area.
- Conductivity of the alluvial clay was reduced from 0.01 m/day to 0.001 m/day.

### 5.3.3 Calibration Summary

The updated groundwater model was calibrated against all available data at the end of June 2013. Calibration results are generally similar to those achieved in the calibration of the previous assessment (FMG, 2010d).

The MMF aquifer in the updated groundwater model is more continuous in the horizontal direction and deeper in some mining pits area compared to the 2010 assessment (FMG, 2010d). As a result the difference in abstraction volumes between model input (from measured data) and model result decreased from 11% in the 2010 assessment (FMG, 2010d) to 0.3% in this assessment. This demonstrates that the model structure provides a more accurate representation of reality.

In the dewatering stage calibrations it was found that the hydraulic conductivity of the ore body in some areas may be much higher than the average value calibrated in the pre dewatering calibration. Therefore, it is important to investigate the sensitivity of dewatering volumes to ore body conductivity when simulating mining operations.

## 5.4 Water management simulations

### 5.4.1 Mine plan and water management strategy

The basis for the model prediction is the Cloudbreak Life of Mine (LOM) Plan used within the 2010 assessment (FMG, 2010d). 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 simulated abstraction and injection program is in line with the Water Management Strategy outlined in Section 4.1, as such, the following key elements are represented in the model:

- Dewatering of below watertable resource areas in accordance with the mine sequence outlined in the mine plan.
- Provision of brackish water for mine water use requirements.
- The remaining dewatered groundwater is mainly saline water and thus injected to the Oakover Formation aquifer located to the south of the mining area.

Dewatering and injection is simulated in the following manner:

#### Dewatering

- Dewatering is simulated by applying seepage nodes to the bottom of mine pits.
- Mining pits are assumed to be mined over a period of one year.
- Mine site water use (supplied from the dewatering operation) is assumed to be 10 GL/a in the LOM period from 2014 to 2024.

#### Injection

- Yearly injection volumes were calculated by subtracting mine water usage from predicted dewatering volumes.
- The reinjection of saline water was modelled by injection through conceptual bores.

### 5.4.2 Setup of numerical simulations

#### Non-dewatering scenario

A non-dewatering simulation is conducted in order to provide a baseline from which groundwater level changes due to operation can be estimated. This simulation is run for the whole LoM period but without any dewatering or injection. This simulation therefore provides a prediction of the natural fluctuation and dynamics of the hydrogeological system without mining. Figure 19, Figure 20 and Figure 21 show the fluctuation of the watertable at key monitoring locations adjacent to Fortescue Marsh for the base, dry and wet rainfall simulations respectively.

### Dewatering and injection scenario

An initial dewatering only simulation (without injection) is conducted to provide an initial abstraction volume from which injection rates are estimated (abstraction less mine water use).

This injection volume is then applied in the second iteration of the scenario. Injection results in an increased in the abstraction rate due to recirculation of injected water to the abstraction point. The results of this simulation are used to revise the injection rate for the next simulation. This process is continued until abstraction is equivalent to the sum of mine water use and injection. Groundwater injection is adjusted spatially during this process to minimise water level impacts in areas sensitive to water level fall or rise.

The number and locations of injection bores in the model are conceptual only. In practice, bore locations and number of bores required will be determined by actual bore injection capacity.

### Post-mining recovery

Following cessation of mining in 2024, the numerical model was run without further dewatering and injection to simulate the rebound of groundwater levels. Further information is provided in Section 6.5 and Appendix 7.

## 5.4.3 Generation of synthetic rainfall sequences

To enable consideration of climate variation on the water level predictions rainfall data from the Newman rainfall station dating back to 1971 were used to create three rainfall sequences representing average, wet and dry climate scenarios, respectively. 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 an average rainfall sequence. 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, and 1980). Using 100 mm/month as the threshold value for Marsh flooding, there 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 (Table 22).

A stochastic method from the Stochastic Climate Library (SCL) (http://www.toolkit.net.au/scl) was used to generate 1000 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, and etcetera) as the historical data from which they are based. Each stochastic replicate (sequence) 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 the total rainfall over the period. The realisation at 5% ranking was used to generate the dry scenario. The driest continuous 14 years in the 5% ranking realisation was used for the dry scenario, which had five flood events (monthly rainfall >90 mm) in the prediction period (Table 21). The realisation at 95% ranking was used to generate the wet scenario. The wettest continuous 14 year period in this realisation was used for the wet scenario, which has 25 flood events (monthly rainfall > 100 mm) (Table 22).

**Table 22: Model generated monthly rainfall data used for groundwater model predictions**

| Average Scenario | | | Dry Scenario | | | Wet Scenario | | |
|---|---|---|---|---|---|---|---|---|
| Year | Month | Rainfall | Year | Month | Rainfall | Year | Month | Rainfall[28] |
| 1 | 3 | 122.8 | 3 | 4 | 101.6 | 1 | 2 | 142.5 |
| 3 | 3 | 122.8 | 12 | 2 | 278.9 | 1 | 12 | 249.5 |
| 4 | 2 | 124.6 | | | | 2 | 1 | 172.1 |
| 6 | 3 | 122.8 | | | | 2 | 2 | 179.0 |
| 7 | 3 | 122.8 | | | | 3 | 2 | 325.4 |
| 9 | 2 | 124.6 | | | | 4 | 1 | 294.1 |
| 11 | 2 | 124.6 | | | | 4 | 3 | 135.8 |
| 13 | 2 | 124.6 | | | | 5 | 1 | 228.1 |
| 14 | 2 | 112.9 | | | | 6 | 2 | 260.1 |
| | | | | | | 8 | 2 | 338.2 |
| | | | | | | 9 | 1 | 229.4 |
| | | | | | | 9 | 3 | 106.0 |
| | | | | | | 10 | 1 | 160.7 |
| | | | | | | 10 | 2 | 123.8 |
| | | | | | | 11 | 12 | 199.2 |
| | | | | | | 12 | 1 | 164.6 |
| | | | | | | 12 | 2 | 171.2 |
| | | | | | | 13 | 2 | 286.7 |
| | | | | | | 14 | 12 | 211.1 |
| | | | | | | 17 | 3 | 121.6 |

[28] Only rainfall events >=100mm/month are shown

## 5.5 Model limitations

All numerical groundwater models are representations of the natural groundwater system. As a result of assumptions used in model conceptualisation and numerical model construction, groundwater models are subject to various limitations when applied to make predictions. The following limitations of the Cloudbreak model are noted.

### 5.5.1 Heterogeneity of hydraulic parameters

The hydraulic conductivity of the MMF and Oakover Formation aquifers is spatial-variability; as such their representation in the model as largely homogeneous aquifers is a simplification of hydrogeological complexity. Groundwater levels at some localised areas may be either over-predicted or under-predicted. Numerical scenarios employing a broad parameter range for key hydraulic units have been conducted to assess the regional water level impact of these uncertainties. Monitoring and in some cases incorporation of additional detail to models through operations will be employed to manage local scale responses.

### 5.5.2 Duration of dataset

The groundwater monitoring bore dataset used for Cloudbreak model calibrations covers the period from 2006 to 2012. This is sufficient for a robust characterisation of the aquifer system under natural conditions. The calibration of the model under the mine dewatering condition (calibration stage 2 period) was limited to the active mine pits area.

The fluctuation of Fortescue Marsh water levels were verified by using Landsat-derived data, and direct measurements from Cyclone Heidi. The model will need to be further calibrated against additional direct measured Marsh water levels, as such data becomes available.

### 5.5.3 Limited resolution in salinity distribution

Simulation of salinity distribution has been undertaken to provide a broad representation of the density-driven flow mechanism. Salinity was not modelled with sufficient spatial resolution to accurately predict salinity distribution in the vertical direction. Therefore, the salinity in the shallow aquifer may be over predicted owing to numerical dispersion in the vertical direction.

A 2-D numerical modelling investigation for the Chichester Range (FMG, 2010e) demonstrated that groundwater salinity in the shallow aquifer, at the fringe of the Marsh, is little affected by mine dewatering and saline water injection. Initial operational data confirms this finding and will be updated with continued observation and monitoring data.

# 6. GROUNDWATER MODELLING RESULTS

## 6.1 Predicted Results - Base Scenario

The base scenario has been simulated using average climatic conditions. An initial simulation without dewatering or injection was completed followed by simulation incorporating dewatering and injection, again with the average climate conditions. Comparison of the two simulations enables assessment of mining impacts. Results of this assessment are presented below.

### 6.1.1 Predicted natural groundwater regime

Hydrographs[29] at seven key locations along the Fortescue Marsh fringe are shown in Figure 19 to Figure 21. These figures show:

- Groundwater levels on the margin of the Fortescue Marsh only respond following rainfall events of 100 mm/month or more. This is directly related to flooding and ponding of water on the surface of Fortescue Marsh.
- Groundwater levels on the margin of the Fortescue Marsh may naturally vary between surface and 3.2 m bgl at various times and locations.
- The expected natural change in water level at locations on the fringe of the Fortescue Marsh for the LoM period will depend on the rainfall sequence. The groundwater level may recede by up to 3 m after a long dry period; whilst a major rainfall event may result in groundwater level rise of up to 3 m.

The rate of groundwater evapotranspiration decreases with depth to watertable. Evapotranspiration (of groundwater) is therefore greatest when water levels are closest to ground surface without ponding of water on the surface of Fortescue Marsh, i.e. immediately following flooding events. These simulated natural conditions are consistent with observed baseline data available.

### 6.1.2 Predicted dewatering and injection volumes

Model predicted dewatering and injection volumes for the base scenario are presented in Table 23. The predicted average annual dewatering volume (no injection) over the period of 2014 to 2024 is 74 GL/a, which increases to 94 GL/a as surplus water is injected back to the aquifer system. Injection, results in an increase of approximately 27% in average annual dewatering volumes and up to 44% in an individual year (2023) at peak recirculation (Table 23). Peak dewatering rate has been simulated at 136 GL/a, which occurs in 2019.

[29] Hydrographs presented in Figure 19 to Figure 21 do not include abstraction or injection and represent the predicted natural groundwater levels without mining.

**Table 23: Model results – Base scenario**

| Year ending | Mine water use (GL/a) | Dewatering volume (GL/a) | | | Injection volume (GL/a) |
|---|---|---|---|---|---|
| | | Without injection | With injection | Increase due to Recirculation | |
| June 2014 | 10 | 99 | 108 | 9% | 98 |
| June 2015 | 10 | 43 | 58 | 33% | 49 |
| June 2016 | 10 | 78 | 95 | 22% | 81 |
| June 2017 | 10 | 91 | 122 | 34% | 111 |
| June 2018 | 10 | 28 | 31 | 9% | 21 |
| June 2019 | 10 | 98 | 136 | 39% | 128 |
| June 2020 | 10 | 66 | 75 | 14% | 63 |
| June 2021 | 10 | 105 | 133 | 27% | 120 |
| June 2022 | 10 | 50 | 61 | 22% | 53 |
| June 2023 | 10 | 63 | 91 | 44% | 82 |
| June 2024 | 10 | 93 | 125 | 35% | 114 |
| **Average Annual (GL/a)** | **10** | **74** | **94** | **27%** | **84** |
| **Total (GL)** | **110** | **814** | **1035** | | **920** |

The average annual dewatering rate increased from 63.5 GL/a predicted by the previous assessment (FMG, 2010d) to 94 GL/a by the updated groundwater model of this assessment. Similarly, the peak dewatering rate increased from 91 GL/a to 136 GL/a. The substantial increase in dewatering rates is due mainly to two changes in the model;

1. The mineralised MMF aquifer being more continuous in the horizontal direction and deeper in some pits area,
2. Better connections between the mineralised MMF aquifer and the Oakover Formation aquifer. These changes were made based on recent drilling data and operational data.

### 6.1.3 Predicted groundwater drawdown/mounding distribution

For the base scenario, the predicted drawdown and mounding impact (difference between simulated water levels under natural conditions and water levels under dewatering and injection conditions) at the end of each mining year is presented in Figure 22 to Figure 32. These figures also include the depth to watertable contours (m bgl).

Time series of drawdown and mounding at seven key monitoring bore locations along the Fortescue Marsh fringe are plotted in Figure 33. The locations of the key monitoring bores are shown on Figure 22 and their coordinates presented in Table 24.

**Table 24: Co-ordinates of the five key near-marsh monitoring locations**

| Site name | Location (MGA, Zone 50) | |
|---|---|---|
| | Easting | Northing |
| CBFMM01 | 720,703 | 7,531,612 |
| CBFMM02_s | 727,559 | 7,527,940 |
| CBFMM04 | 734,697 | 7,527,655 |
| CBFMM06_s | 740,436 | 7,524,558 |
| CBFMM05 | 746,758 | 7,523,454 |
| CBFMM07 | 751,176 | 7,521,806 |
| CBFMM08 | 755,273 | 7,520,434 |

The drawdown and mounding predictions illustrate the impact mining related dewatering and injection has on the watertable. Predicted drawdown and mounding shown in Figure 22 to Figure 32 indicate that:

- Watertable drawdown due to mine dewatering is restricted to the mining area. Small drawdown may extend towards the Fortescue Marsh.
- The maximum drawdown at the key monitoring locations (Table 24) is predicted to be about 0.9 m, occurred at CBFMM06_s in 2018.
- Watertable mounding is limited to small areas. The Oakover Formation is highly permeable and its storage capacity is much larger than the volume of injected water. The presence of the Tertiary clay also serves to mitigate pressure transmission to the watertable.
- The maximum watertable mounding at the key monitoring locations (Table 24) is 1.5 m, occurred at CBFMM05 in 2017.
- Saline water injection is an essential component for mitigating groundwater drawdown and impacts to the Fortescue Marsh. Modelling suggest that groundwater drawdown would be much larger without injection into the Oakover Formation.

The updated model predicts significantly larger abstraction volumes when compared to the previous assessment (FMG, 2010d). With the larger volumes the predicted maximum drawdown (0.9 m) and mounding (1.5) are slightly less (1 m maximum drawdown and 2 m maximum mounding) than predicted by the previous assessment (FMG, 2010d). This is due to the net abstraction from the system (difference between abstraction and injection volumes) being similar in both simulations and the presence of a lower permeability clay zone within the Tertiary detritals.

### 6.1.4 Predicted water demand and supply strategies

The assessment assumes mine water use (Table 25) will be met by the volume of brackish groundwater abstracted during mine dewatering. Based on an estimated brackish resource of 200 GL and remaining LOM water requirement of 110 GL this is plausible. However long term water quality is difficult to predict since the quality (salinity) of pumped groundwater is determined by multiple factors, such as locations of active mining pits relevant to saline water body, depth of dewatering bores, and bore field operation schedules, etc. The following approach to mitigating brackish water shortfalls from dewatering operations is recommended:

- Reduce brackish water demand where possible (water saving options are currently being assessed).
- Transfer water between Cloudbreak and Christmas Creek to balance brackish water demand (such transfers are currently being undertaken).
- Abstract 'banked' brackish groundwater previously injected.
- Assess water transfer options such as other proximal mine sites.
- Assess other brackish water supply options such as reverse osmosis (RO) treatment of abstracted water and/or supply from a remote borefield.

## 6.2 Numerical Model Sensitivity and uncertainty analysis

Sensitivity analysis has been undertaken to examine the model response to extreme values of the primary impact-determining parameters (SKM & NGRT, 2012). Five key parameters were selected to undertake the sensitivity study:

- Rainfall sequence;
- Hydraulic conductivity of the Oakover Formation;
- Hydraulic conductivity of the ore body (mineralised Marra Mamba Formation);
- Specific yield of the ore body; and
- Specific storage coefficient of the Oakover Formation.

For each parameter, two simulations were conducted by varying the parameter value used in the base scenario to an upper value and a lower value, respectively. The upper and lower values of each parameter are listed in Table 26. These values were chosen based on field data from both Cloudbreak and Christmas Creek, representing the end member values that may be reasonably expected.

### 6.2.1 Sensitivity analysis of dewatering volumes

Predicted dewatering volumes for all sensitivity simulations are summarised and compared to the base scenario results in Table 26 and summarised below;

The highest uncertainty in average and peak annual dewatering rates is associated with the hydraulic conductivity of the ore body.

- The average annual dewatering volume increased by 16.6% in the simulation with the upper conductivity value, but decreased by 12.0% in the simulation with the lower conductivity value.
- The peak annual dewatering volume increased by 23.5% for the high conductivity simulation and decreased by 16.9% for the low conductivity simulation.

The second most sensitive parameter is the conductivity of the Oakover Formation.

- With an upper conductivity value, the average and the peak annual dewatering volumes increased by 13.7% and 25%, respectively.
- The average and peak annual dewatering volumes decreased by 14.8% and 24.3%, respectively, when the lower end value was used,

Predicted dewatering volumes are slightly sensitive to climate condition.

- Under the wet climate condition average and peak annual dewatering volumes increased by 1.7% and 4.4%, respectively.
- Changing from the average climate condition to the dry climate condition didn't result in any significant change in the average or the peak annual dewatering volume (less than 1.5%).

Dewatering volumes are not sensitive to specific yield of the ore body or the specific storage coefficient of the Oakover Formation. Both average and peak annual dewatering volumes changed by less than 2.2% when the upper or lower end values of these two parameters were used,

Comparing the sensitivity study results to those reported in the previous PER model assessment, it was found that:

- The sensitivity of dewatering volume to Oakover formation conductivity increased substantially due to the increased connections between the two major aquifers in the current model with dewatering volume increased. The increase in dewatering volume due to the use of the upper end value of Oakover conductivity is substantially higher for the current model (13.7%) than for the previous PER model (3%). Similarly, the decrease in dewatering volume due to the adoption of the lower end value of the conductivity is much larger for the current model (14.8%) than for the previous PER model (1.4%).
- The change in dewatering volume due to the use of the upper end value of the conductivity of the mineralised MMF aquifer increased significantly from 11% for the previous PER model to 16.6% for the current mode.
- The change in sensitivity associated with other model parameter values is not significant.

### 6.2.2 Sensitivity analysis of drawdown/mounding

Hydrographs at selected key locations for dry and wet scenarios are shown and compared to those for the base scenario in Figure 36 to Figure 42. Groundwater levels under both natural and mining conditions are significantly affected by climate with watertable increase of up to 2.5 m following large rainfall events.

Hydrographs at selected key locations for investigated in the sensitivity study are presented in Appendix 5 and discussed below.

Maximum drawdowns and deviations of maximum drawdown at each of key locations over the whole mining period are summarised for all sensitivity simulations and the Base scenario. Maximum mounding and deviations of maximum mounding, over the whole mining period at key locations for climatic sensitivity simulations are summarised and compared to those from the Base scenario in Table 28.

- The largest drawdown of all simulations occurred in the scenario with the wet climate condition at six out of seven key locations[30], and in the scenario with upper end value of the ore body conductivity at one key location (CBFMM04).
- The largest mounding (1.8 m) of all simulations occurred in the scenario with the wet climate condition at key location CBFMM04.
- The largest drawdown of all sensitivity simulations (1.68 m), which is 0.78 m larger than the maximum drawdown (0.9 m) in the base scenario, occurred at the key location CBFMM06_S in the simulation under the wet climate condition.
- Based on calculated maximum drawdown deviations (Table 26), groundwater drawdown is most sensitive to the climate data with the average deviation of the seven key locations being 0.47 m under the wet climate scenario.
- The sensitivity of groundwater drawdown to other model parameters is less significant (average deviation less than -0.15 m) and does not show significant variations among these parameters (average deviation in the range of 0.03 to -0.14).

In summary, groundwater drawdown/mounding are generally less sensitive to model parameters than dewatering volumes. This is similar to the results presented in the previous PER report (FMG, 2010d).

[30] Drawdown is the variation between natural and simulated water levels at a given point in time. Although maximum impacts would be expected in dry conditions, impacts from mining (drawdown) may be of a greater magnitude when there is a greater volume of water to impact, i.e. during the wet scenario. Absolute water levels are lower in the dry scenario (Figures 36 to Figure 42), even though drawdown has been calculated to be lower.

## 6.3 Water balance analysis

The water balance of the simulated Base, Dry and Wet scenarios is summarised in Table 25 as average annual volumes over the life of mine (LoM). The results highlight:

- Under natural conditions (no mine dewatering) recharge is dominated by the Fortescue Marsh runoff (94% to 98% of the total recharge). Catchment recharge is small (between 2% and 6% of the total recharge). Evaporation is the only model output.
- Under mine dewatering conditions, water injection becomes a significant part of total model recharge being 18%, 41% and 68% of the total model input, respectively for the Wet, Base and Dry scenarios. Both evaporation and mine dewatering are important model output. There is more evaporation than dewatering in the Base and Wet scenarios, but less evaporation than dewatering in the Dry scenario.
- The net mine water use (the difference between dewatering and injection volumes) is about 10 GL/a during the life of mine.
- Change in aquifer storage is small compared to total model input in the Base and Wet scenarios (1% to 6% of the total model input), but increased to 11% to 18% of the total model input in the Dry scenario due to that the total model input in the Dry scenario is much smaller than those in the Base and Wet scenarios. In all scenarios, the change in aquifer storage is less than 0.3% of the total aquifer storage.

**Table 25: Model water balance in prediction period (2014 to 2024) for Base, Dry and Wet scenarios**

| Scenario | Water Management Option | Model inputs (GL/a)[31] | | | Model outputs (GL/a) | | Change in storage (GL/a) |
|---|---|---|---|---|---|---|---|
| | | Catchment Recharge | Fortescue Marsh Runoff | Water Injection | ET[32] | Mine Dewatering | |
| Base | No dewatering[33] | 4.4 | 115.0 | 0.0 | 123.2 | 0.0 | -3.8 |
| | Dewatering[34] | 4.4 | 115.0 | 83.6 | 119.1 | 94.1 | -10.2 |
| Dry | No dewatering | 2.5 | 37.0 | 0.0 | 46.6 | 0.0 | -7.1 |
| | Dewatering | 2.5 | 37.0 | 83.6 | 43.3 | 93.6 | -13.8 |
| Wet | No dewatering | 9.6 | 389.0 | 0.0 | 375.1 | 0.0 | 23.5 |
| | Dewatering | 9.6 | 389.0 | 85.7 | 385.6 | 95.7 | 3.0 |

[31] Average annual volume (GL/a)
[32] Evapotranspiration
[33] Natural conditions (with no mine dewatering)
[34] Water management, as outlined in Section 5.4

## 6.4 Cumulative impacts

The predicted drawdown and mounding at the end of LOM are shown in Figure 33 to Figure 35. This has considered and included predicted drawdowns associated with the Christmas Creek Operations, and other publicly-available drawdown predictions of water level impacts in the region, as detailed in Figure 43 and summarised below:

- The Hancock Prospecting PER document (Hancock , 2009) for the proposed Roy Hill project. This lies to the east of the Christmas Creek project.
- The Brockman Resources PER (Aquaterra, 2010) document for the proposed Marillana project. This lies on the southern side of the Fortescue Marsh.

### 6.4.1 Marillana 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 no overlap between the drawdown impacts associated with the Marillana Project and groundwater impacts associated with the Cloudbreak project.

### 6.4.2 Roy Hill project

The Roy Hill project, developed by Roy Hill Iron Ore Pty Ltd (RHIO), 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.

### 6.4.3 Christmas Creek project

The modelling results presented in Section 6.5.3 include proposed injection in the Hillside East injection area by the Christmas Creek operation. Fortescue have adopted an integrated Chichester Range approach to water management to support Fortescue Marsh management objectives.

**Table 26: Model results (abstraction volumes) from sensitivity study**

| Sensitivity case | Hydraulic parameter | | | | Average dewatering rate | | Peak dewatering rate | | Sensitivity ranking |
|---|---|---|---|---|---|---|---|---|---|
| | Oakover Formation | | MMF | | | | | | |
| | Kh (m/d) | Ss (1/m) | Kh (m/d) | Sy | GL/a | Change from base case | GL/a | Change from base Case | |
| ***Base Case*** | ***200*** | ***1.00E-04*** | ***60*** | ***0.04*** | **94.1** | **-** | **136** | **-** | |
| Wet | 200 | 1.00E-04 | 60 | 0.04 | 95.7 | 1.7% | 142 | 4.4% | 3 |
| Dry | 200 | 1.00E-04 | 60 | 0.04 | 93.6 | -0.5% | 138 | 1.5% | |
| High Oakover K | *400* | 1.00E-04 | 60 | 0.04 | 107.0 | 13.7% | 170 | 25.0% | 2 |
| Low Oakover K | *100* | 1.00E-04 | 60 | 0.04 | 80.2 | -14.8% | 103 | -24.3% | |
| High Ore Body K | 200 | 1.00E-04 | *120* | 0.04 | 109.7 | 16.6% | 168 | 23.5% | 1 |
| Low Ore Body K | 200 | 1.00E-04 | *30* | 0.04 | 82.8 | -12.0% | 113 | -16.9% | |
| High Ore Body $S_y$ | 200 | 1.00E-04 | 60 | *0.06* | 94.2 | 0.1% | 139 | 2.2% | 4 |
| Low Ore Body $S_y$ | 200 | 1.00E-04 | 60 | *0.02* | 93.1 | -1.1% | 137 | 0.7% | |
| High Oakover $S_s$ | 200 | *5.00E-04* | 60 | 0.04 | 93.5 | -0.6% | 138 | 1.5% | 5 |
| Low Oakover $S_s$ | 200 | *2.00E-05* | 60 | 0.04 | 93.6 | -0.5% | 137 | 0.7% | |

Table 27: Model results (drawdown change) from sensitivity study

| Sensitivity case | Hydraulic parameter | | | | Maximum Drawdown at Key Locations (m) | | | | | | | Deviation of Maximum Drawdown from the Base Scenario (m) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oakover Formation | | MMF | | | | | | | | | | | | | | | |
| | Kh (m/d) | Ss (1/m) | Kh (m/d) | Sy | CBFM 01 | CBFMM 02_S | CBFM M04 | CBFM M06_S | CBFMM 05 | CBFMM 07 | CBFMM 08 | CBFMM 01 | CBFMM 02_S | CBFMM 04 | CBFMM 06_S | CBFMM 05 | CBFMM 07 | CBFMM 08 |
| ***Base Case*** | ***200*** | ***1.00E-04*** | ***60*** | ***0.04*** | 0.08 | 0.37 | 0.76 | 0.90 | 0.73 | 0.54 | 0.14 | - | - | - | - | - | | |
| **Wet** | 200 | 1.00E-04 | 60 | 0.04 | **0.46** | **0.87** | 1.26 | **1.68** | **1.06** | **1.05** | **0.45** | 0.38 | 0.50 | 0.50 | 0.78 | 0.33 | 0.51 | 0.31 |
| Dry | 200 | 1.00E-04 | 60 | 0.04 | 0.10 | 0.46 | 0.62 | 0.93 | 0.62 | 0.50 | 0.17 | 0.02 | 0.09 | -0.14 | 0.03 | -0.11 | -0.04 | 0.03 |
| **High Oakover K** | ***400*** | 1.00E-04 | 60 | 0.04 | 0.30 | 0.39 | 1.48 | 0.69 | 0.00 | 0.24 | 0.00 | 0.22 | 0.02 | 0.72 | -0.21 | -0.73 | -0.30 | -0.14 |
| **Low Oakover K** | ***100*** | 1.00E-04 | 60 | 0.04 | 0.02 | 0.51 | 0.86 | 0.60 | 0.00 | 0.22 | 0.13 | -0.06 | 0.14 | 0.10 | -0.30 | -0.73 | -0.32 | -0.01 |
| **High Ore Body K** | 200 | 1.00E-04 | ***120*** | 0.04 | 0.15 | 0.60 | **1.52** | 0.80 | 0.00 | 0.22 | 0.00 | 0.07 | 0.23 | 0.76 | -0.10 | -0.73 | -0.32 | -0.14 |
| **Low Ore Body K** | 200 | 1.00E-04 | ***30*** | 0.04 | 0.01 | 0.32 | 1.01 | 0.71 | 0.00 | 0.28 | 0.17 | -0.07 | -0.05 | 0.25 | -0.19 | -0.73 | -0.26 | 0.03 |
| High Ore Body $S_y$ | 200 | 1.00E-04 | 60 | ***0.06*** | 0.08 | 0.46 | 1.17 | 0.65 | 0.00 | 0.18 | 0.10 | 0.00 | 0.09 | 0.41 | -0.25 | -0.73 | -0.36 | -0.04 |
| Low Ore Body $S_y$ | 200 | 1.00E-04 | 60 | ***0.02*** | 0.17 | 0.45 | 1.24 | 0.72 | 0.00 | 0.18 | 0.06 | 0.09 | 0.08 | 0.48 | -0.18 | -0.73 | -0.36 | -0.08 |
| High Oakover $S_s$ | 200 | ***5.00E-04*** | 60 | 0.04 | 0.01 | 0.39 | 1.17 | 0.67 | 0.00 | 0.19 | 0.07 | -0.07 | 0.02 | 0.41 | -0.23 | -0.73 | -0.35 | -0.07 |
| Low Oakover $S_s$ | 200 | ***2.00E-05*** | 60 | 0.04 | 0.00 | 0.42 | 1.23 | 0.72 | 0.00 | 0.23 | 0.07 | -0.08 | 0.05 | 0.47 | -0.18 | -0.73 | -0.31 | -0.07 |

Table 28: Model results (mounding change) from sensitivity study

| Sensitivity case | Hydraulic parameter | | | | Maximum Mounding at Key Locations (m) | | | | | | | Deviation of Maximum Mounding from the Base Scenario (m) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oakover Formation | | MMF | | | | | | | | | | | | | | | |
| | Kh (m/d) | Ss (1/m) | Kh (m/d) | Sy | CBFM 01 | CBFMM 02_S | CBFM M04 | CBFM M06_S | CBFMM 05 | CBFMM 07 | CBFMM 08 | CBFMM 01 | CBFMM 02_S | CBFMM 04 | CBFMM 06_S | CBFMM 05 | CBFMM 07 | CBFMM 08 |
| ***Base Case*** | ***200*** | ***1.00E-04*** | ***60*** | ***0.04*** | 0.6 | **0.3** | 1.4 | **1.5** | **1.1** | 0.8 | 1.3 | - | - | - | - | - | | |
| **Wet** | 200 | 1.00E-04 | 60 | 0.04 | **0.8** | 0.2 | **1.8** | 1.5 | 1 | 0.7 | 1.1 | 0.2 | -0.1 | 0.4 | 0 | -0.1 | -0.1 | -0.2 |
| Dry | 200 | 1.00E-04 | 60 | 0.04 | 0.7 | 0.3 | 1.6 | 1.5 | 1.1 | **0.9** | **1.4** | 0.1 | 0 | 0.2 | 0 | 0 | 0.1 | 0.1 |

## 6.5 Simulation of post-mining groundwater level recovery

Groundwater level recovery after mine closure was simulated over a range of time frames. In the mine area drawdown is predicted to recover from a maximum of around 50 m to around 6 m after 10 years and 3 m after 20 years.

The drawdown distribution for time increments following mine closure is shown in Appendix 7 and key changes are summarised below;

- One year after mining (2025) –Within the mining area drawdown has reduced significantly following 12 months on non-abstraction from over 50 m in 2024, Figure 32, to approximately 38 m in 2025. At the fringe of Fortescue Marsh there is little observed change between 2024 and 2025.
- Five years after mining (2029) – Drawdown within the mining area continues decreased significantly from 38 m in 2025 to 13 m in 2029. At the fringe of Fortescue Marsh drawdown has reduced slightly with only two of the key locations having drawdown over 1 m, but less than 1.5 m.
- Ten years after mining (2034) – Drawdown across all areas has reduced. Within the mining area drawdown is 6 m or less and at Fortescue Marsh is less than 1 m.
- Twenty years after mining (2044) – Drawdown has reduced further to less than 3 m within the area of mining, and to less than 0.5 m at monitoring locations at the fringe of Fortescue Marsh.
- Fifty years after mining (2074) – Drawdown across all areas is less than 2 m with very little impact at key monitoring locations at the fringe of Fortescue Marsh.

Following mining activities and the cessation of abstraction and dewatering the recovery of water levels will be highly dependent on rainfall.

# 7. CONCLUSION

## 7.1 Key changes from (FMG, 2010d)

Key changes from the conceptual model, interpretation and assessment for the previous PER assessment (FMG, 2010d) are summarised in Table 29.

**Table 29: Key assessment changes from (FMG, 2010d)**

| Element/Concept | Change | Assessment Implication |
|---|---|---|
| Hydraulic Parameters | Three additional years of observation and testing data was used to refine the range of hydraulic parameters for each of the model layers. | No change to pre dewatering calibration hydraulic parameters used in the numerical model. |
| Mineralised MMF | The MMF aquifer in the updated groundwater model is more continuous in the horizontal direction and deeper in some mining area compared to the 2010 assessment (FMG, 2010d). | Increase in dewatering abstraction volumes.<br><br>The difference in abstraction volumes between model input (from measured data) and model result decreased from 11% in the 2010 assessment (FMG, 2010d) to 0.3% in this assessment.<br><br>This demonstrates that the model structure provides a more accurate representation of reality than previous assessment (FMG, 2010d). |
| Recharge | The Marsh recharge zone was extended to include some lowland area to the Northwest of the Fortescue Marsh (see Figure 16). | Area of inclusion subjected to flooding events and evapotranspiration effects up to 3 m bgl. Predicted watertable in this additional zone therefore reflects cyclic events of Fortescue Marsh rather than regional groundwater. |
| Operational Data & Model Calibration | The updated groundwater model was calibrated against all available data at the end of June 2013. | In the dewatering stage calibrations it was found that the hydraulic conductivity of the ore body in some areas may be much higher than the average value calibrated in the pre dewatering calibration. This may result in an increase in dewatering volumes. |

## 7.2 Summary

Hydrogeological characteristics of the stratigraphy in the project area include:

- The project area is underlain by the Jeerinah Formation the upper-most formation of the Fortescue Group. The lithology is shale dominated creating low permeability conditions. Regional NE-SW fault systems and lithological variation can create zones of enhanced permeability.
- The Nammuldi Member of the Marra Mamba Formation (MMF) conformably overlies the Jeerinah Formation. This formation outcrops in the Chichester Ranges and dips gently southward beneath a blanket of recent cover. A broad blanket of supergene mineralisation (mineralised MMF) in the upper part of the Nammuldi Member has formed a laterally extensive and high permeability and storage aquifer along the strike of the Chichester Ranges. The aquifer is unsaturated to the north and the mineralisation and aquifer properties diminish to the south at around 4 to 8 km from the Fortescue Marsh. The lower part of the Nammuldi member is characteristically cherty and unaltered. Permeability is more constrained to sub vertical NE-SW trending fracture zones.
- The Wittenoom Formation overlays the MMF in areas south of where mineralisation occurs and is characteristically massive with low hydraulic conductivity. Regional NE-SW fault zones may have associated higher permeability.
- The mineralised MMF and Wittenoom Formation are unconformably overlain by a sequence of Tertiary detrital and alluvial sediments that thicken towards the south. The Tertiary sequence is characterised by; a lower calcrete and silcrete unit (Oakover Formation) with high permeability and storage; a clay aquitard (Tertiary clay), which overlays the Oakover Formation; and silts, sands and gravels (Tertiary Detritals) with generally low permeability. The shallow alluvial (watertable) layer is not a major aquifer due to its low permeability, but it is potentially environmentally important as it may be a source of water for vegetation in areas fringing the Fortescue Marsh.
- Groundwater salinity distribution in the mining area is brackish in the detrital aquifer and mineralised MMF; saline in the lower fracture dominated MMF; and becoming hypersaline in the Jeerinah Formation. Laterally towards the Fortescue Marsh, the saline interface occurs higher in the hydrostratigraphy with groundwater in portions of the alluvial, detrital and Oakover Formation being hypersaline near the Fortescue Marsh. The origins of saline water are associated with evapoconcentration and hydrological function within the closed basin.

The key regional groundwater and surface water hydrological regimes include:

- Topographic driven groundwater regime; in which rainfall and stream flow infiltration on the upper and lower slopes of the Chichester Ranges flows in a southward direction through the Tertiary Detritals, mineralised MMF and Oakover Formation.
- Density driven groundwater regime; in which high salinity groundwater beneath the Fortescue Valley results in a pressure gradient that directly opposes the topographic

driven regime. The interface of these two systems creates a saltwater interface that extends over many kilometres and is gradational throughout the flow system.

- The Fortescue Marsh regime; cycles periodically from a surface water dominated recharge system under flood conditions that recharges the shallow groundwater system, to a discharge regime where evapotranspiration is dominant.

A density-driven flow and transport numerical groundwater model was updated and calibrated in the FEFLOW modelling platform for the Cloudbreak project area. Calibration of steady state pre-mining conditions, short term aquifer tests and longer term operational conditions have validated the numerical model. The calibrated numerical model was used to predict groundwater dynamics in the LoM period by using various rainfall sequences (that is, Base [an average-probability rainfall sequence], Dry [5% probability extreme-dry rainfall sequence] and Wet [5% probability extreme-wet rainfall sequence] scenarios) that were generated based on historical rainfall records in the area.

Incorporating the baseline climatic conditions into a non-mining scenario, the model has simulated water levels in the alluvial aquifer adjacent to the Fortescue Marsh consistent with historical observed water level rise and fall in response to cycles of flooding evapotranspiration on the Marsh.

The proposed mine water management strategy for Cloudbreak is consistent with the strategy employed at Christmas Creek, and is designed to meet the mining requirements and Fortescue Marsh Management objectives. A cornerstone of the strategy is managed aquifer recharge.

Dewatering will be achieved through advance borefield abstraction and operational dewatering within pits as required. Dewatering may significantly exceed mine water use requirements, and any surplus (the difference between abstraction water and mine water use) will be returned to compatible aquifers through injection to preserve water resources and to minimise environmental impacts (groundwater level drawdown/mounding).

Excess brackish water will generally be injected into the along-strike mineralised Marra Mamba Formation aquifer for future use. Excess saline water will be injected into the naturally-saline Oakover Formation aquifer, south of mining areas, to reduce the dewatering drawdown footprint.

Groundwater dewatering volumes and drawdown/mounding predicted using the average rainfall updated calibrated model show that:

- The average annual dewatering volume is predicted to be 94 GL/a over the LoM period.
- The peak annual dewatering volume is predicted to be 136 GL/a (see statements below regarding dewatering-volume sensitivity).
- Groundwater drawdown along the Fortescue Marsh fringe is small (less than 1 m) over the LoM period.

- Groundwater mounding of the watertable along the Fortescue Marsh fringe is small (less than 1 m) over the majority of LoM period and 1.5 m for short periods of time at CBFMM04_s, CBFMM05_s and CBFMM08_s. It is believed this can be managed through optimisation of the Cloudbreak water management scheme.

The sensitivity of model predictions to climate conditions and key model parameters was investigated through numerical simulations. Results show that:

- Groundwater abstraction volumes are most sensitive to conductivities of ore body.
  - Average annual dewatering rates increasing by up to 16.6% (to about 110 GL/a, with ore body having the upper end value of conductivity).
  - Peak (as opposed to average) annual dewatering rates may increase by up to 23.5% (to about 168 GL/a).
- Groundwater drawdown at the watertable along the Fortescue Marsh fringe is moderately sensitive to climate conditions and conductivities of the ore body and the Oakover Formation.
  - Maximum watertable drawdown (as measured at the seven key near-marsh monitoring sites) may slightly increase from 0.9 m in the base scenario to about 1.68 m in the worst scenario with wet climate conditions.
  - Maximum watertable mounding (as measured at the seven key near-marsh monitoring sites) may slightly increase from 1.5 m in the base scenario to about 1.8 m in the worst scenario with wet climate conditions.
- The model is sensitive to the degree of connection between the Oakover Formation and MMF ore body aquifers. A high degree of connection is assumed for this modelling assessment; however, less connectivity will result in less drawdown and lower dewatering volumes.

To assess potential groundwater-quality impacts from the proposed water management scheme on the near-marsh environment, a 2-D numerical modelling assessment for the Chichester Range was undertaken (FMG, 2010e). This work concluded that the groundwater salinity of the shallow aquifer, adjacent to Fortescue Marsh, is little affected by mine dewatering and saline water injection.

Groundwater level recovery after mine closure was simulated over a range of time frames. In the mine area drawdown is predicted to recover from a maximum of around 50 m to around 6 m after 10 years and 3 m after 20 years.

Modelling results suggest that the Cloudbreak water management scheme can operate independently. However, opportunities to improve operational efficiencies and control of water levels near the Fortescue Marsh would be realised by adopting an integrated water management approach with Christmas Creek.

Inter-mine transfer has the opportunity to provide contingency options to mitigate potential shortfalls in the brackish water resource and near marsh watertable impacts. These contingencies are listed below in order of priority:

- Reduce brackish water demand where possible (water saving options are currently being assessed).
- Transfer water between Cloudbreak and Christmas Creek to balance brackish water demand (such transfers are currently being undertaken).
- Abstract ‘banked’ brackish groundwater previously injected.
- Assess water transfer options such as other proximal mine sites.
- Assess other brackish water supply options such as reverse osmosis (RO) treatment of abstracted water and/or supply from a remote borefield.

## 7.3 Future work

Ongoing hydrogeological assessment will assist in conceptual understanding and water management at Cloudbreak. Further investigations that could improve understanding and operational water management are outlined below.

- Ongoing hydrogeological investigations in areas of uncertainty to support ongoing development of the conceptual model particularly associated with Fortescue Marsh.
- Ongoing hydrogeological investigations of the Oakover Formation to confirm long term sustainable injection rates. Injection of saline water is an integral part of continued operations, contingency measures will be developed to reduce or limit injection of saline water and may include;
    - Ensure mine plans and hydrogeological assessments align with the long term capacity of the Oakover Formation.
    - Transfer of water between Cloudbreak and Christmas Creek to utilise the full strike length of Oakover Formation for injection.
    - Continued exploration of Oakover Formation to the west of Cloudbreak, south of areas of future mining.
    - Investigation and exploration of formations beneath the Oakover Formation which may be suitable for injection of surplus saline water.
    - Implement water saving measures within all areas of operation to determine if additional volumes of saline water can be utilised to reduce the demand on injection.
    - Consideration of a reverse osmosis (RO) plant which would utilise saline water and reduce demand on the Oakover Formation.

- Routine updating of the numerical model with findings of investigations and operational groundwater response to refine the model predictive capability.

.

## REFERENCES


Aquaterra. (2004). *east Pilbara Iron Ore Project, Hydrogeology report for the Public Environmental Review.* Perth: Aquaterra.

Aquaterra. (2005). *Hydrogeological report for Cloudbreak Public Envioronmental Review, Unpublished report.* Perth: Aquaterra.

Aquaterra. (2010). *Marillana Project Groundwater Study & Management Plan, PER supporting docuemnt prepared for Brockman Resources, Ref. 832G/G7154f.* Aquaterra.

Astron. (2012). *Cloudbreak Life of Mine Conservation Significant Flora Survey Phase 1. .* Astron, Unpublished report prepared for the Fortescue Metals Group Pty Ltd. .

Astron. (2012a). *Cloudbreak Life of Mine Conservation Significant Flora Survey Phase 2. .* Astron, Unpublished report prepared for the Fortescue Metals Group Pty Ltd.

Bear, J. (1972). *Dyanimcs of fluids in porous media.* New York, Am.: El764psevier Publishing Co., .

Biota. (2004). *Fortescue Metals Group Stage B Rail Corridor, Christmas Creek, Mt Lewin, Mt Nicholas and Mindy Mindy Areas Vegetation and Flora Survey, Report pRepared for Fortescue Metals Group.* Perth: Biota Environmental Sciences Pty Ltd .

Bureau of Meteorology. (1977). *Climatic Atlas of Australia.* Canberra: Australian Government Publishing Service.

Clout, J. (2011). *The Royhill Project.* AisiMM 3, 52-65.

Ecologia. (2010). *Cloudbreak Terrestrial Vertebrate Fauna Desktop Assessment. .* Ecologia, Unpublished report prepared for Fortescue Metals Group.

Ecologia. (2011). *Cloudbreak Level 2 Terrestrial Vertebrate Fauna Assessment. .* Ecologia, Unpublished report prepared for Fortescue Metals Group.

Env. (2001). *A Directory of Importnat Wetlands in Australia, Third Edition.* Environment Australia, ISBN 0 642 54721 1.

ENV. (2011). *Cloudbreak Flora and Vegetation Assessment.* ENV Australia, Unpublished reoprt prepared for Fortescue Metals Group Lts.

EPA. (2013). *Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area - Advice o fthe Environmental Protection Authority to the Minister for Environment under Section 16(e) of the EPA 1986.* Environmental Protection Authority, Report 1484.

Equinox Environmental. (2012). *Fortescue Marsh: Synthesis of Hydrological knowledge.* Perth: Equinox Environmental Pty Ltd.

Equinox Environmental Pty Ltd. (2012). *Fortescue Marsh, Synthesis of Hydrological Knowledge.* Perth: Equinox Environmental Pty Ltd.

FMG. (2007). *Pilbara Iron Ore and Infrastructure Projects< Draft, Re-injection Water Chemical Compatibility Study, 206-24-WR-RP-0001.* Perth: Fortescue Metals Group.

FMG. (2009). *Pilbara Iron Ore and Infrastructure Project, hydrogeolgoical Assessment.* Perth: Fortescue Metals Group.

FMG. (2009a). *Chichester Operations Surface Water Management Plan, 45-PL-EN-0015.* Perth: Fortescue Metals Group.

FMG. (2010). *Christmas Creek 2009 Bore Completion Report, Reference Code CC-RP-HY-0007.* Perth: Fortescue Metals Group.

FMG. (2010). *Hydrogeological Assessment for Cloudbreak Water Management Scheme.* Perth: Fortescue Metals Group.

FMG. (2010a). *Hydrogeological Assessment for the Christmas Creek Water Management Scheme, CC-RP-HY-0004.* Perth: Fortescue Metals Group.

FMG. (2010b). *Cloudbreak Saline Injection Trial Six Months Compliance Report, CB-RP-HY-0021.* Perth: Fortescue Metals Group.

FMG. (2010c). *Cloudbreak Operations triennial Aquifer Review: 1st August 2007 – 31 July 2010, CB-RP-HY-0023.* Perth: Fortescue Metals Group.

FMG. (2010d). *Hydrogeological Assessment for the Cloudbreak Water Management Scheme, CB-RP-HY-0019.* Perth: Fortescue Metals Group.

FMG. (2010e). *Modelling Two Dimensional Density Driven Flwo and transport under Mine Dewatering and Saline Water Injection Conditions.* Perth: Fortescue Metals Group.

FMG. (2011). *Cloudbreak Life of Mine - Public Environmental Review, April 2011. .* Perth: Fortescue Metals Group.

FMG. (2012). *Cloudbreak Saline Injection trial Stage 2 Close-out report, Water Management Department .* Perth: Fortescue Metals Group.

FMG. (2012). *Hydrogeological Assessment for the Christmas Creek Water Management Scheme Under Alternative Mining Sequence, CC-AS-WM-00001.* Perth: Fortescue Metals Group.

FMG. (2012a). *Cloudbreak Saline Injection trial Stage 2 Close-out report, Water Management Department, CB-RP-HY-0030.* Perth: Fortescue Metals Group.

FMG. (2012b). *Christmas Creek Groundwater Operating Strategy.* Perth: Fortescue Metals Group.

FMG. (2013). *Cloudbreak Groundwater Monitoring Summary (1 February 2013 to 31 April 2013).* Perth: Fortescue Metals Group.

FMG. (2013a). *Christmas Creek Triennial Groundwater Monitoring Review - August 2010 - July 2013, CC-RP-HY-0039.* Perth: Fortescue Metals Group.

FMG. (2013b). *Cloudbreak Triennial Groundwater Monitoring Review (August 2010 - July 2013), CB-RP-HY-0037.* Perth: Fortescue Metals Group.

FMG. (2013c). *Part V Licence (L8199/2007/2) Supporting Document, Cloudbreak Water Management Scheme.* Perth: Fortescue Metals Group.

FMG. (2013d). *Cloudbreak Groundwater Operating Strtaegy.* Perth: Fortescue Metals Group.

FMG. (2013e). *Hydrogeological Assessment of the Christmas Creek life of mine water management scheme.* Perth: Fortescue Metals Group.

FMG. (2013f). *Cloudbreak Life of Mine Surface Water Management Plan, CB-PL-EN-0023.* Perth: Fortescue Metals Group.

Gentilli, J. (1972). *Australian Climate Patterns.* Melbourne: Thomas Nelson - Austrlaian Government Publishing Service.

Goode, B. (2009). *Reort on the Ethnographic Aboriginal heritage Survey of the Christmas Creek Hydrological System, Western Australia, FMG Survey Request ETH_NYI_001, Prepared for Fortescue Metals Group ltd (FMG) and the Nyiyaparli Title Claimants.* Perth.

Hancock . (2009). *Roy Hill 1 Iton Ore Project Stage 1, Public Environmental Review Document.* Perth: Hancock Prospect Pty Ltd.

Hannon, E. K. (2005). *From Target Generation to Two Billion Tonnes in 18 Months - The re-invention fo the Chichester Range: in Iron Ore 2005 Conference, Perth WA, September 19-20, 2005.* Melbourne: The Australsian Institute of Mining and Metallurgy, pp 73-77.

Mattiske. (2005). *Flora and Vegetation on the Cloud Break and White Knight Leases.* Mattiske Consulting Pty Ltd , Unpublished report prepared for the Fortescue Metals Group Pty Ltd.

Mattiske. (2007). *Flora and Vegetation near Fortescue Marsh.* Mattiske Consulting Pty Ltd , Unpublished report prepared for the Fortescue Metals Group Pty Ltd.

MWH. (2009). *Technical Memorandum, Predicted geochemical interactions for re-injection of Fortescue abstraction water.* Perth: MWH.

SKM & NGRT. (2012). *Australian Groundwater Modelling Guidlines.* Waterlines Report Series No. 82, June 2012.

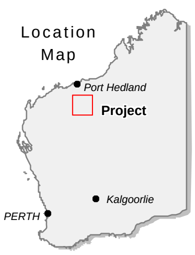
Skrypek G., D. S. (2013). *Geochemical and hydrological processes controlling groundwater salinity of a large inland wetland of north west Australia.* Chemical Geology 357 (2013) 164-177.

Thorne, W. H. (2008). *Banded Iron formation-related iron ore deposits of the Hamersley Province, Western Australia.* Perth: Economic Geology v.15.pp. 197-221.

Worley Parsons. (2012). *The Fortescue Marsh Catachemnt Water Balance Study, 301012-01527-SS-REP-0003.* Worley Parsons.

# Figure 1: Location Plan

This page has been left blank intentionally


Mine Sites
Towns
FMG Railway
Other Railways
Roads
Major Creek/Drainage

N

0 25 50
kilometres

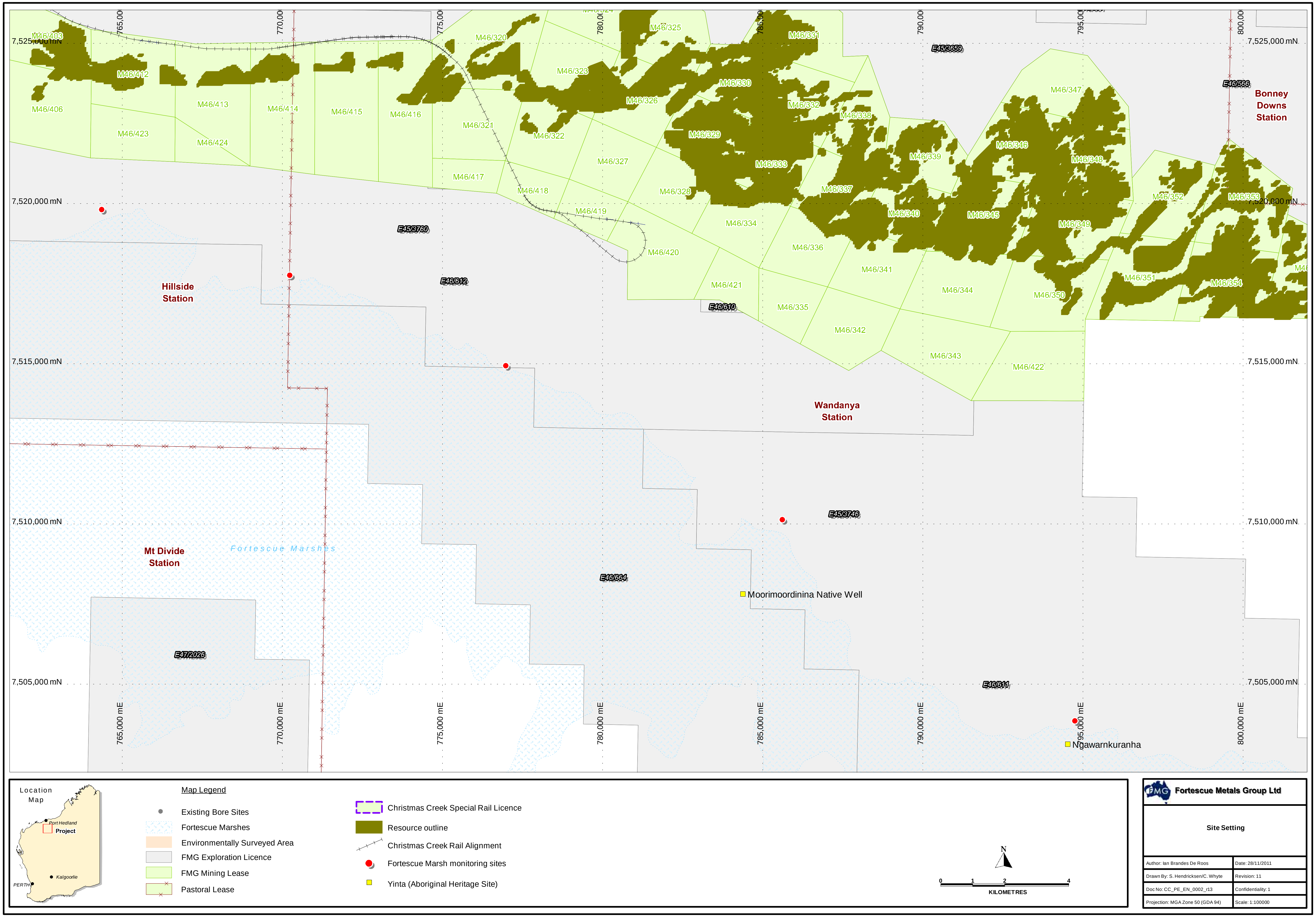
**Fortescue Metals Group Ltd**

**Site Location**

| | |
|---|---|
| Author: IBdR | Date: 27/05/2010 |
| Drawn By: SH | Revision: 5 |
| Doc No: GE_MP_HY_0005_Fig1 | Confidentiality: 1 |
| Projection: Longitude / Latitude (WGS 84) | Scale: 1:1750000 |

Figure 2: Site setting

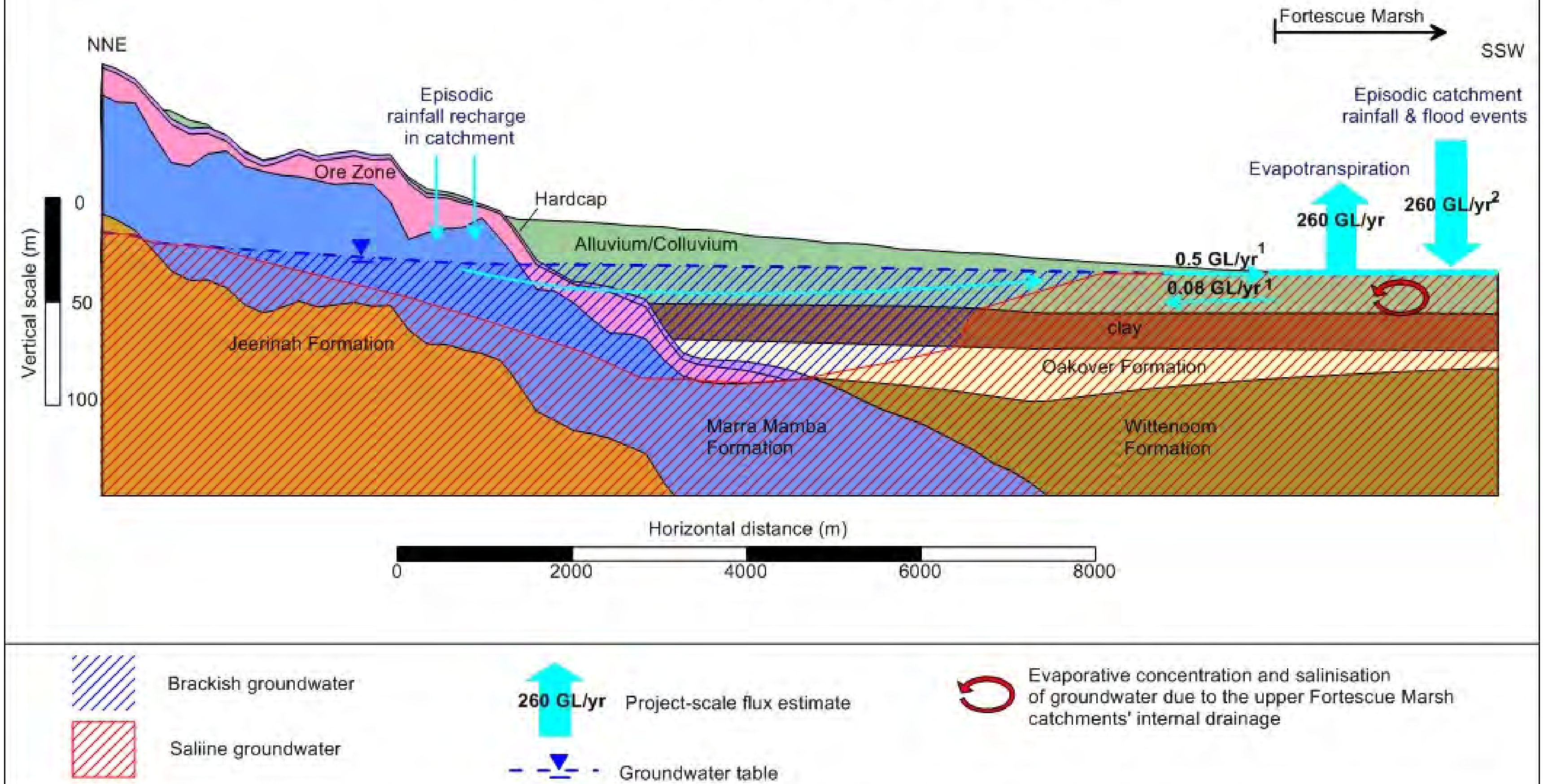
This page has been left blank intentionally



Bonney Downs Station
Hillside Station
Wandanya Station
Mt Divide Station
Fortescue Marshes
Moorimoordinina Native Well
Ngawarnkuranha
7,525,000 mN
7,520,000 mN
7,515,000 mN
7,510,000 mN
7,505,000 mN
765,000 mE
770,000 mE
775,000 mE
780,000 mE
785,000 mE
790,000 mE
795,000 mE
800,000 mE
M46/403
M46/406
M46/412
M46/413
M46/414
M46/415
M46/416
M46/417
M46/418
M46/419
M46/420
M46/421
M46/422
M46/423
M46/424
M46/320
M46/321
M46/322
M46/323
M46/325
M46/326
M46/327
M46/328
M46/329
M46/330
M46/331
M46/332
M46/333
M46/334
M46/335
M46/336
M46/337
M46/338
M46/339
M46/340
M46/341
M46/342
M46/343
M46/344
M46/345
M46/346
M46/347
M46/348
M46/349
M46/350
M46/351
M46/352
M46/353
M46/354
E45/3659
E45/3760
E45/3746
E46/566
E46/612
E46/610
E46/664
E46/611
E47/2026
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Map Legend
Existing Bore Sites
Fortescue Marshes
Environmentally Surveyed Area
FMG Exploration Licence
FMG Mining Lease
Pastoral Lease
Christmas Creek Special Rail Licence
Resource outline
Christmas Creek Rail Alignment
Fortescue Marsh monitoring sites
Yinta (Aboriginal Heritage Site)
N
0 1 2 4
KILOMETRES
Fortescue Metals Group Ltd
Site Setting
Author: Ian Brandes De Roos
Date: 28/11/2011
Drawn By: S. Hendricksen/C. Whyte
Revision: 11
Doc No: CC_PE_EN_0002_r13
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:100000

Figure 3: Conceptual Chichester cross section

This page has been left blank intentionally




Footnotes:

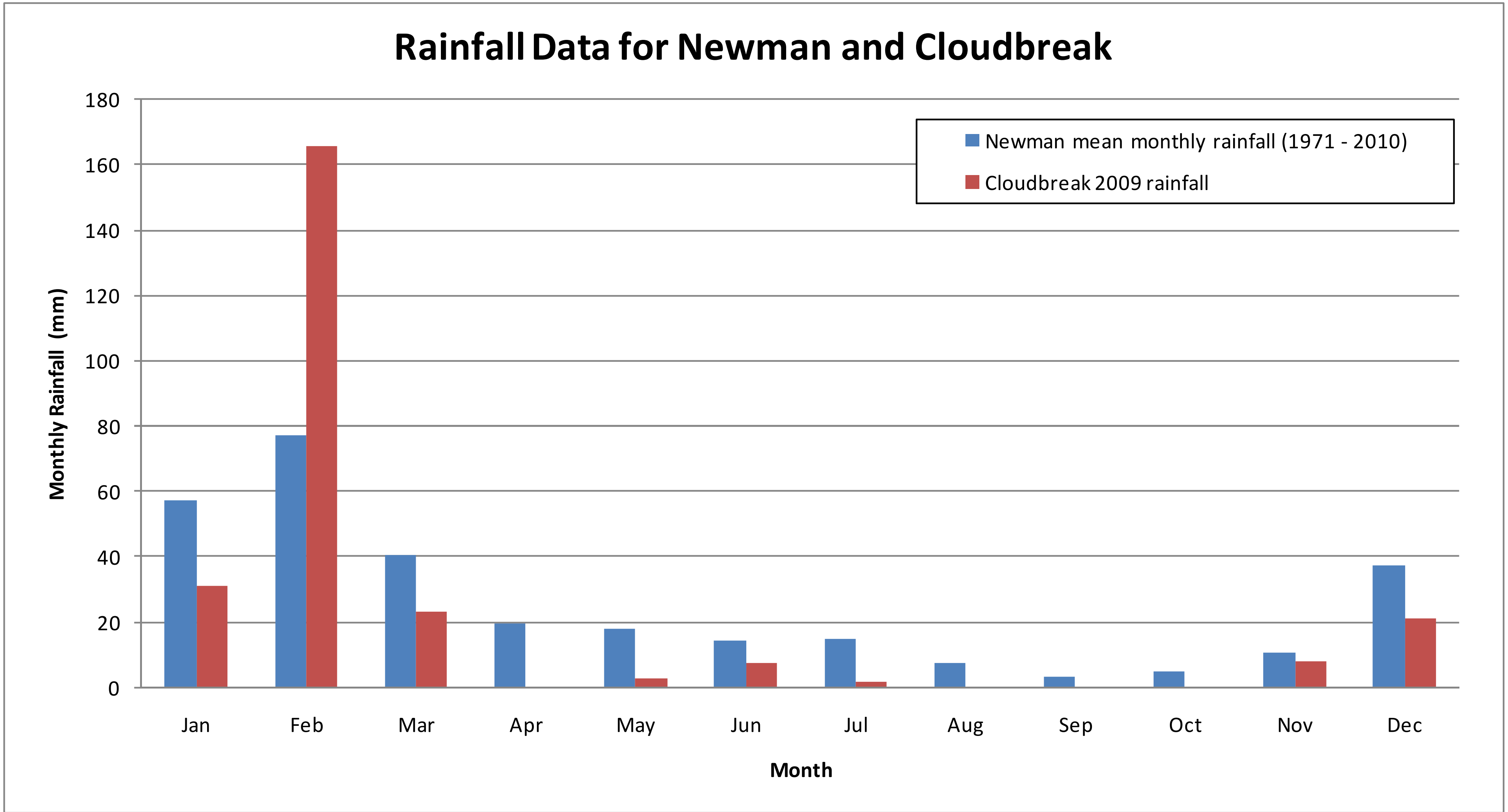
1 Annual groundwater discharge to the marsh and recharge from marsh flooding (average rates along the marsh edge, south of the Cloudbreak pits [about 36km strike length], calculated from a calibration numerical model with a simulation period from January 2007 to June 2011)

2 Based on Worley Parsons (2012): Cloudbreak Life of Mine Expansion - Fortescue Marsh Catchment Water Balance Study. Average inflow based on a water balance from 1984 to 2011. Other time periods will yield different average inflows.

| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Cloudbreak Conceptual Cross Section** | **Figure 03** |
| | | 07/11/2013 |

# Figure 4: Historical rainfall

This page has been left blank intentionally





Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

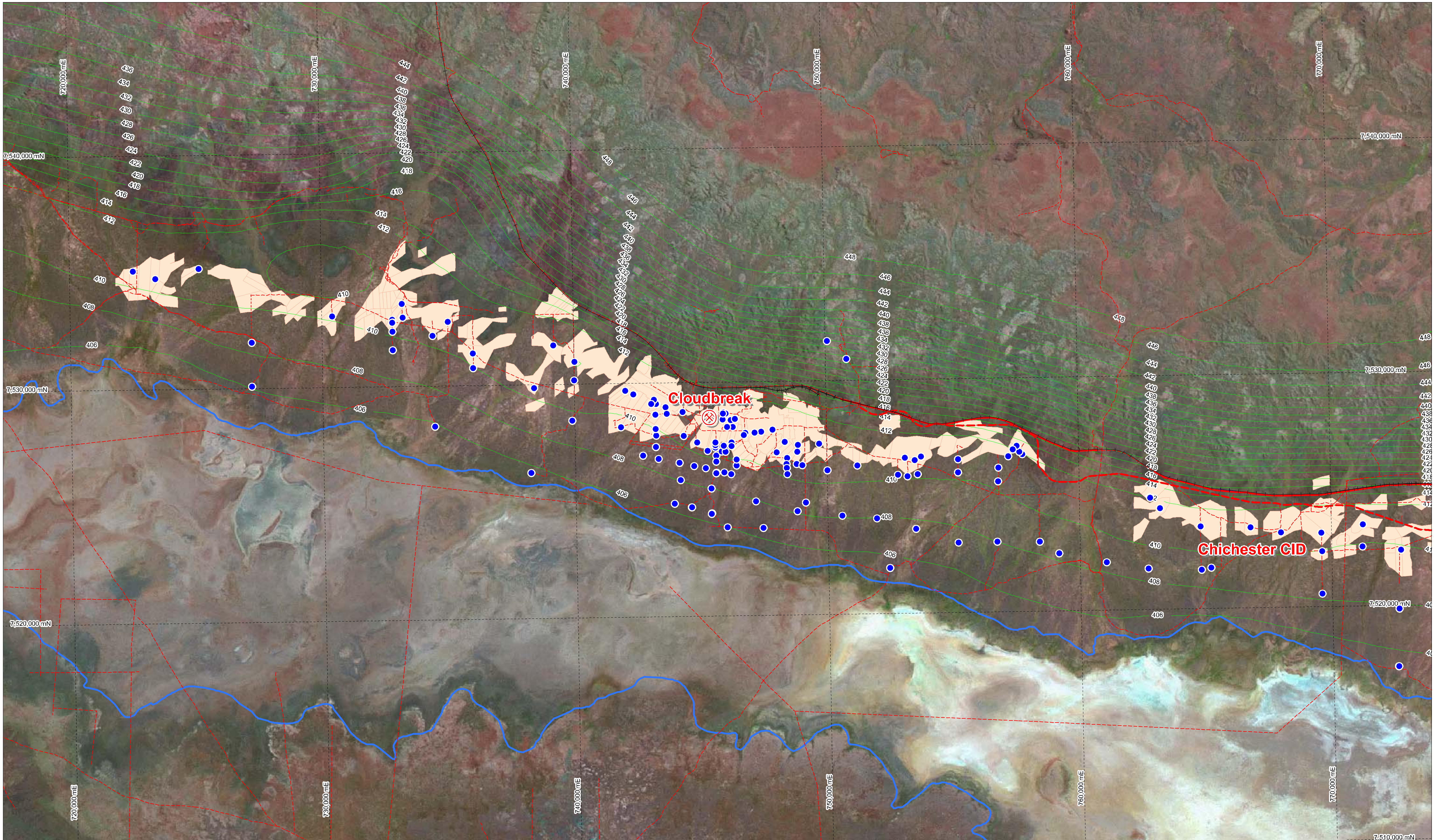

**Rainfall Data for Newman and Cloudbreak**

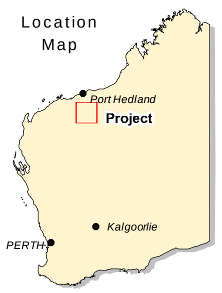
**Figure 04**

07/11/2013

# Figure 5: Baseline groundwater levels – Tertiary Detrital

This page has been left blank intentionally




Mine Sequence

Fortescue Marsh Boundary

Water Table Elevations (Late 2007)

Existing Roads/Tracks

Cloudbreak Monitoring Bores

N

0 1.25 2.5 5
kilometres

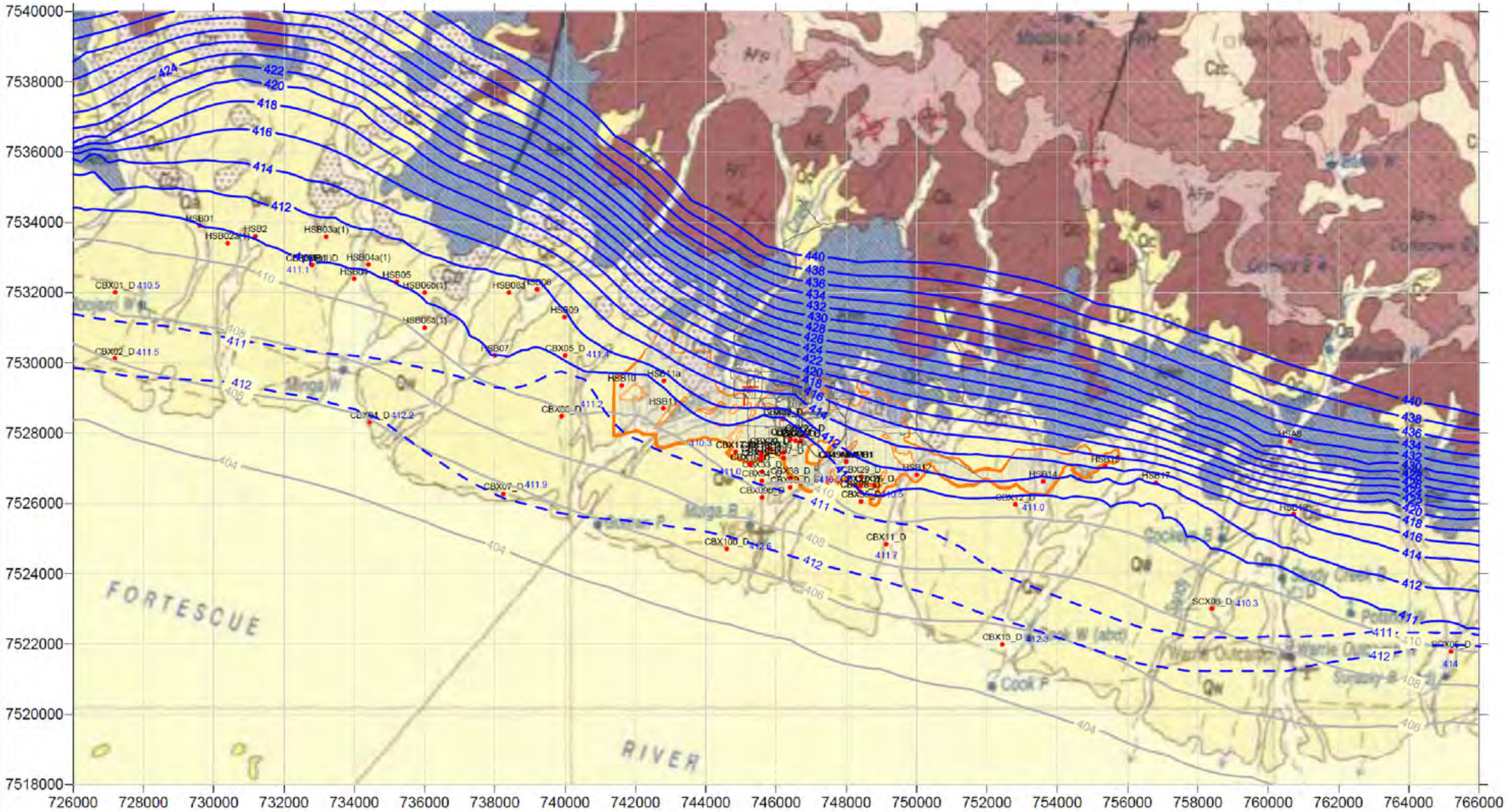
**Fortescue Metals Group Ltd**

## 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 6: Baseline groundwater levels (fresh water equivalence) – Marra Mamba Formation

This page has been left blank intentionally




## 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

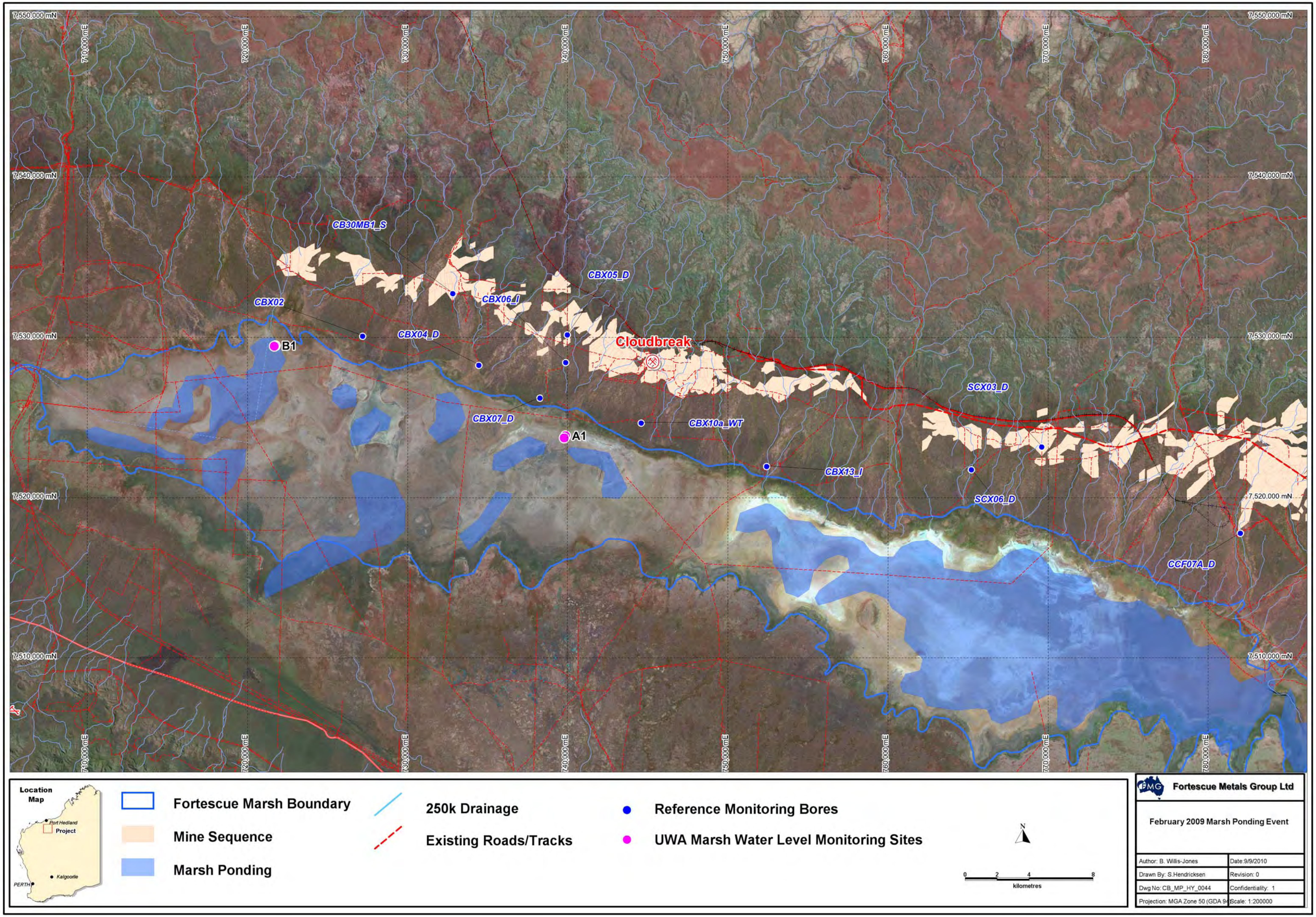
Report Title:

Hydrogeological assessment for Cloudbreak
Water Management Scheme

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

Figure 7: Fortescue Marsh ponding event

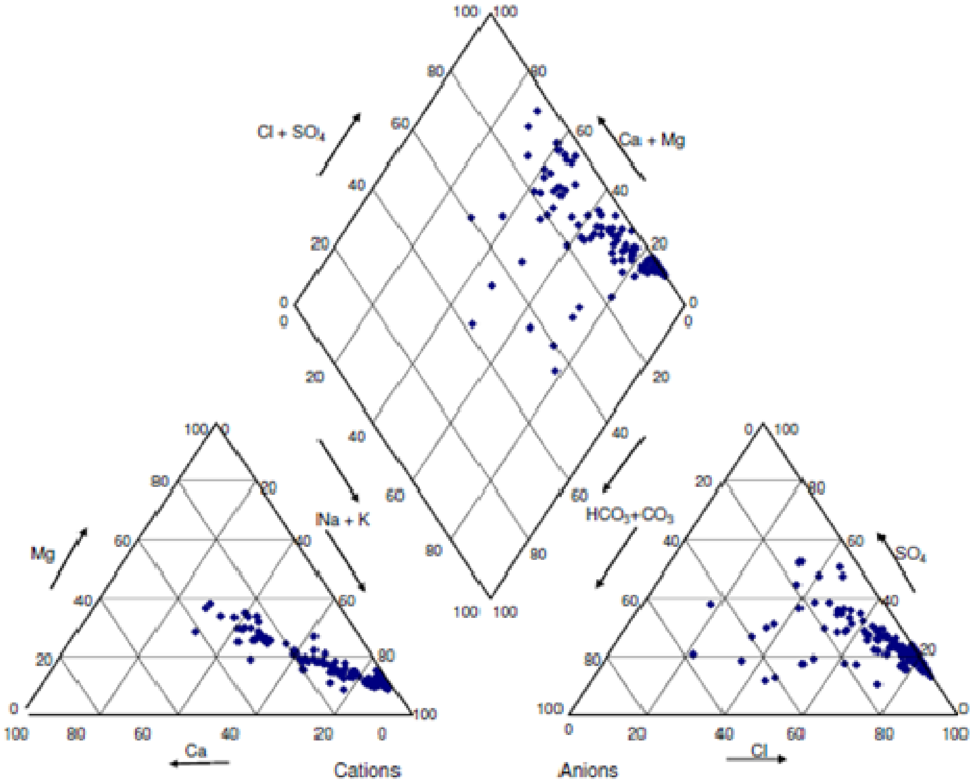
This page has been left blank intentionally



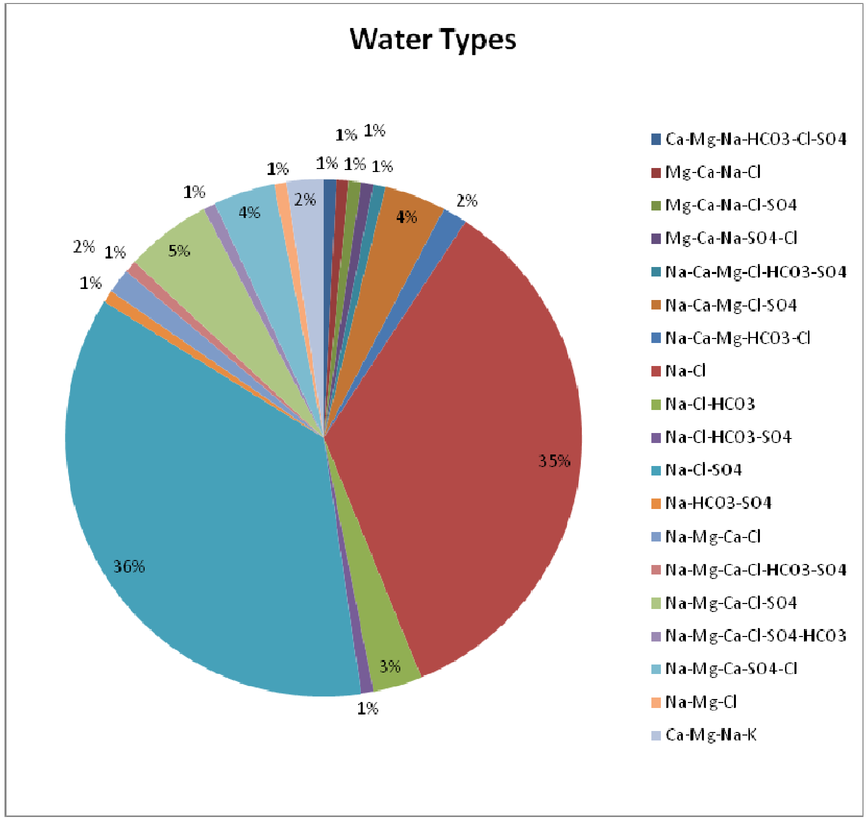
7,550,000 mN
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
710,000 mE
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
780,000 mE
CB30MB1_S
CBX05_D
CBX02
CBX06_I
CBX04_D
Cloudbreak
B1
SCX03_D
CBX07_D
CBX10a_WT
A1
CBX13_I
SCX06_D
CCF07A_D
Location Map
Port Hedland
Project
Kalgoorlie
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: Cloudbreak Water Types

This page has been left blank intentionally




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

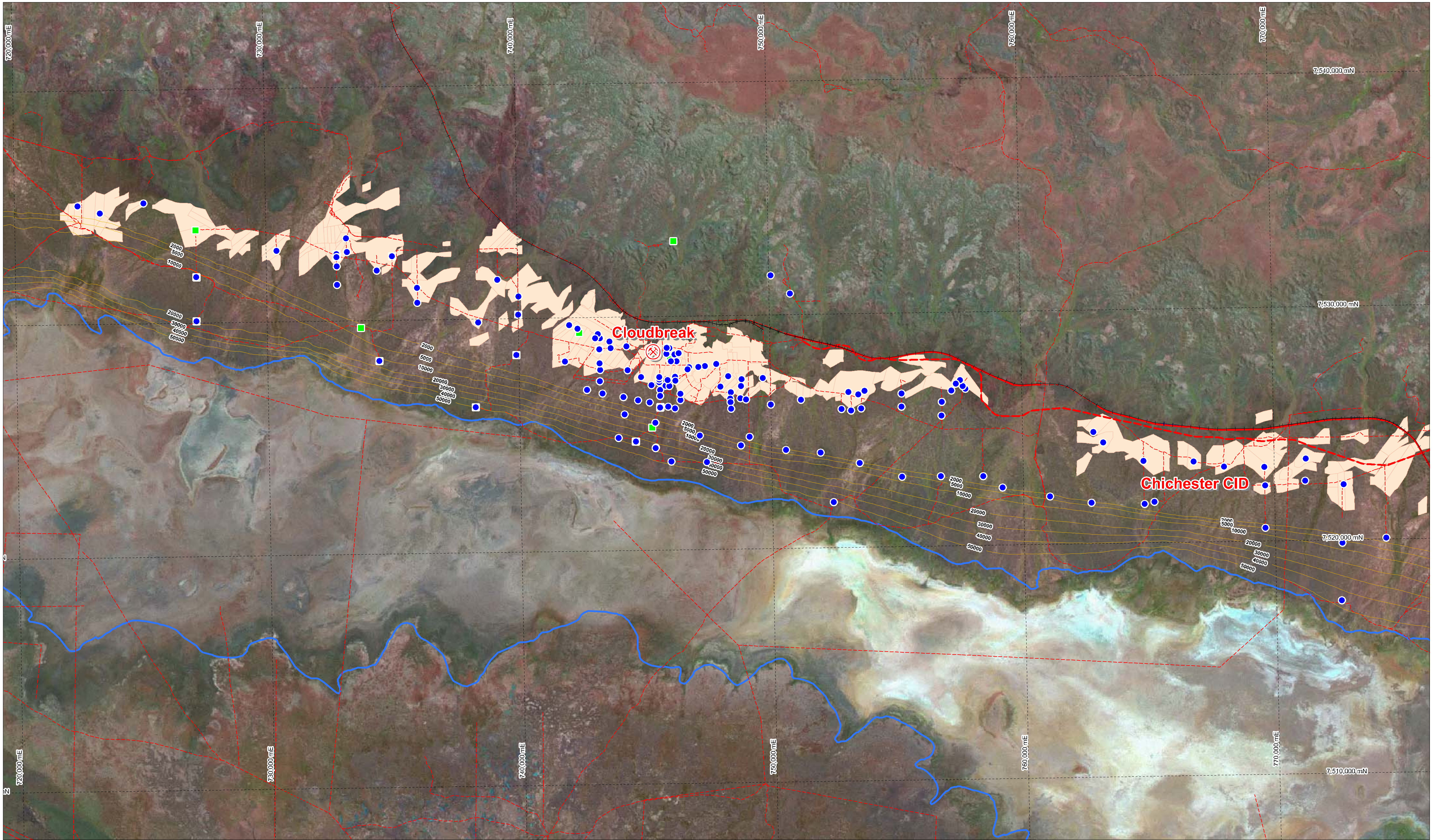



Water Types Based on Chemical Composition and Position on Piper Plot. Dominant Water Types 1) Na-Cl-SO4 (36%), 2) Na-Cl (34%), 3) Na-Mg-Ca-Cl-SO4 (5%), 4) Na-Mg-Ca-SO4-Cl (4%)

| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Water Types** | **Figure 08** |
|---|---|---|
| | | 07/11/2013 |

# Figure 9: Baseline E.C. – Tertiary Detritals

This page has been left blank intentionally




Mine Sequence

Fortescue Marsh Boundary

Salinity Upper TD3

Existing Roads/Tracks

Cloudbreak Monitoring Bores

Sampling Points

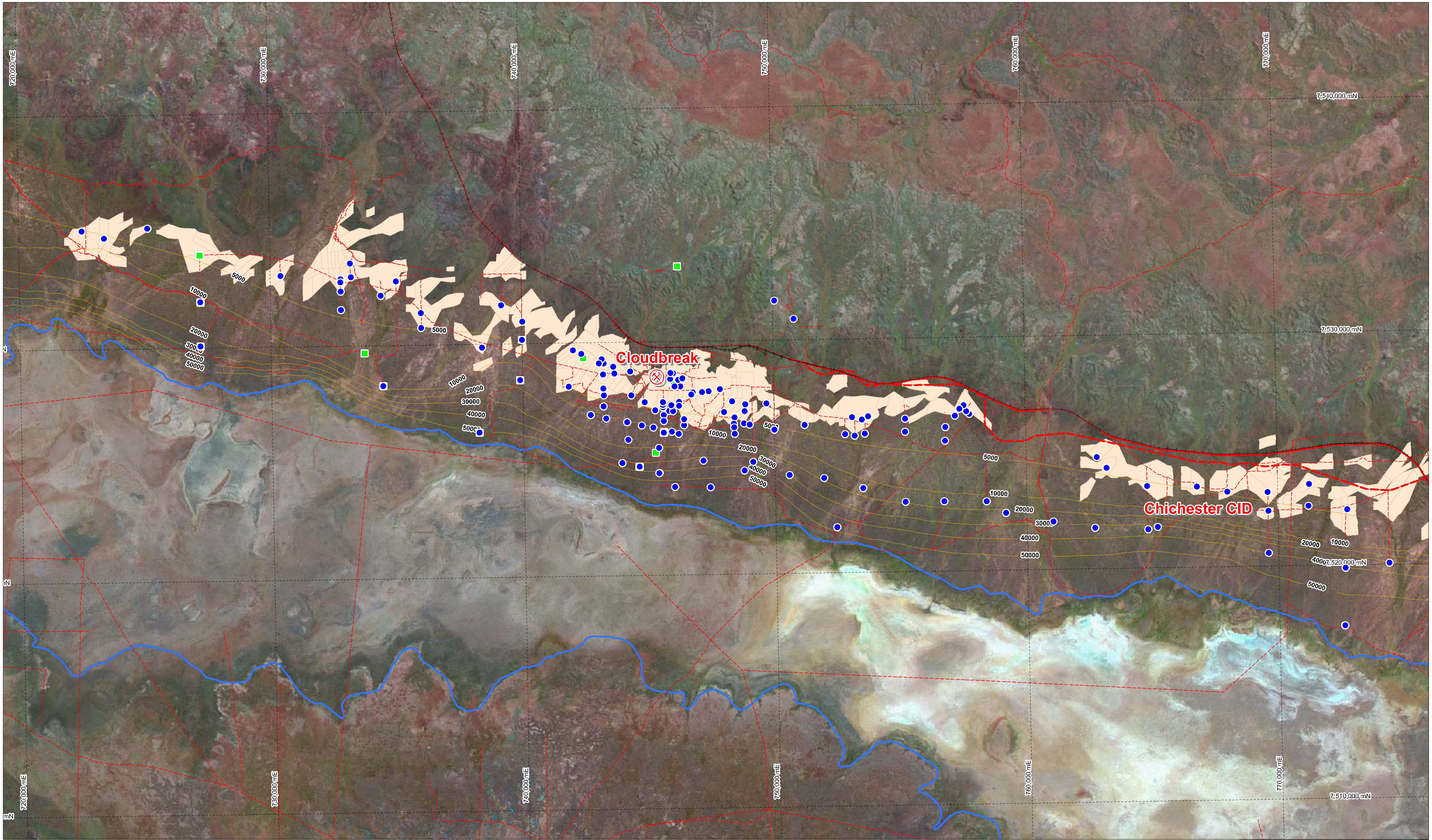
**Fortescue Metals Group Ltd**

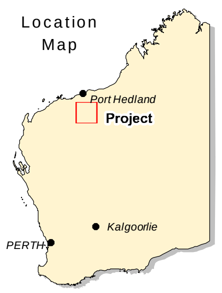
**Salinity Distribution in Upper Teriary Detritals (TD3) in mg/L**

| | |
|---|---|
| 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 10: Baseline E.C. – Marra Mamba Formation

This page has been left blank intentionally




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

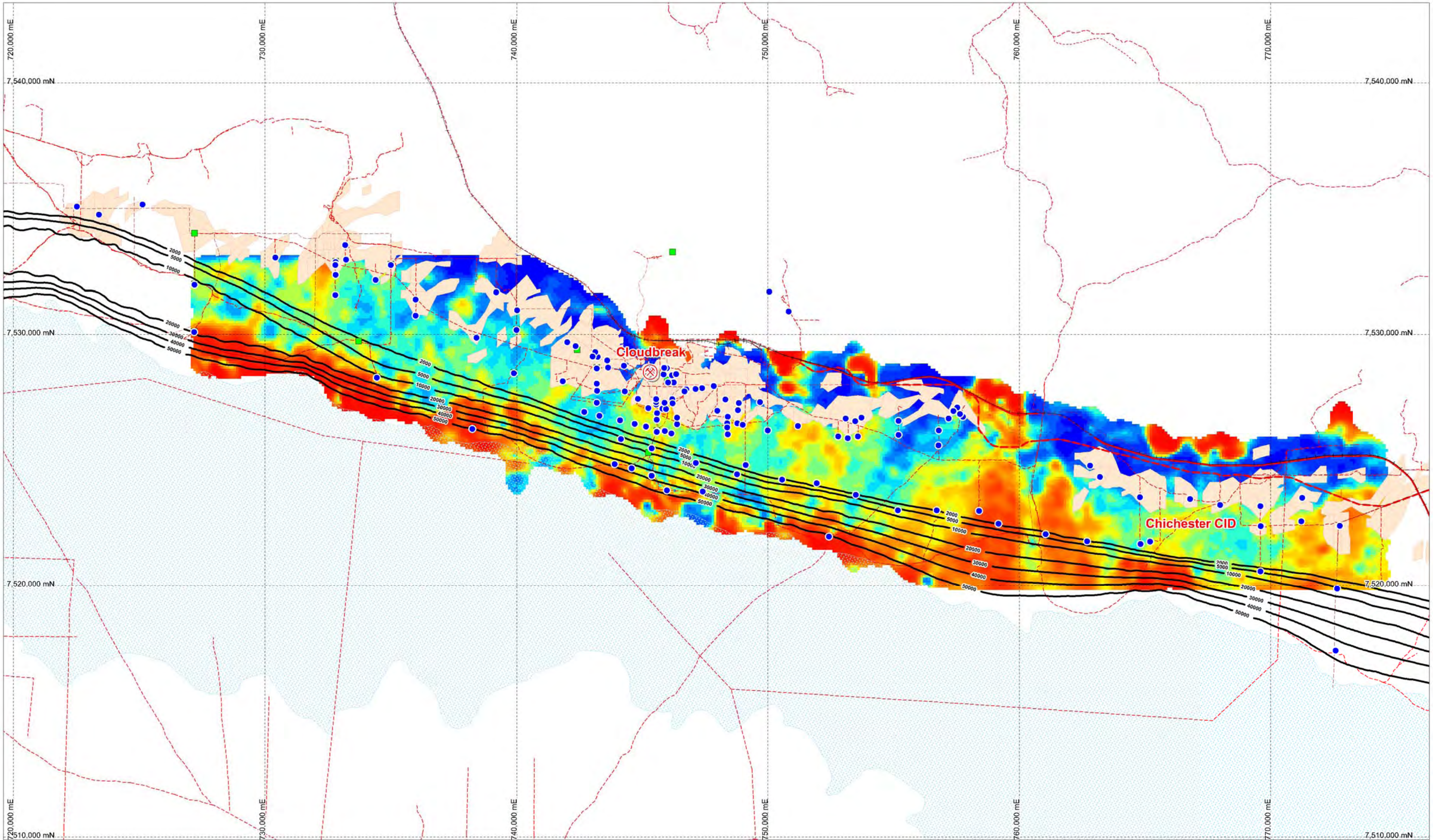
Fortescue Metals Group Ltd

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 11: Airborne EM conductivity – Marra Mamba Formation

This page has been left blank intentionally





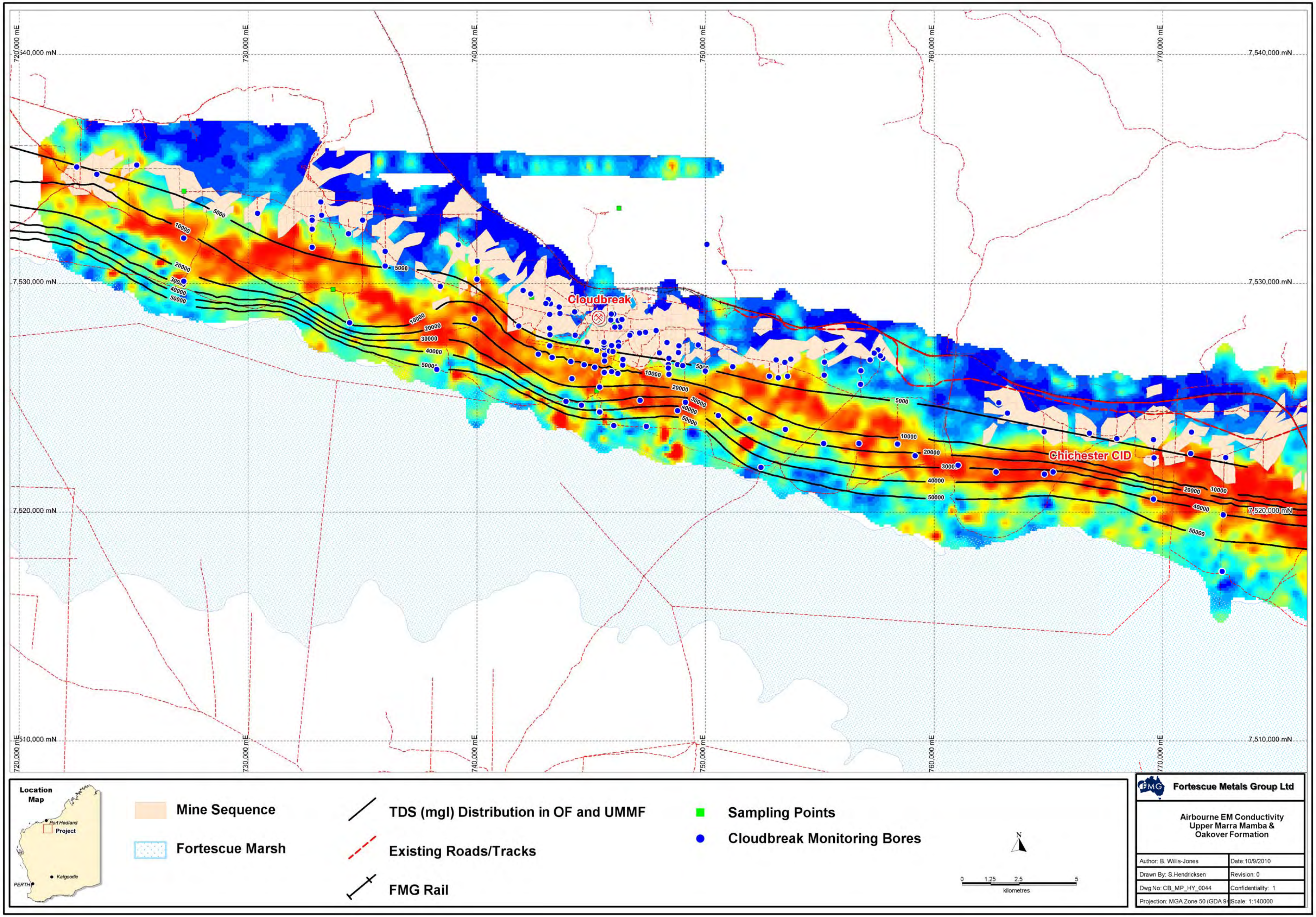

Fortescue Metals Group Ltd

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 12: Airborne EM conductivity – watertable minus five metres

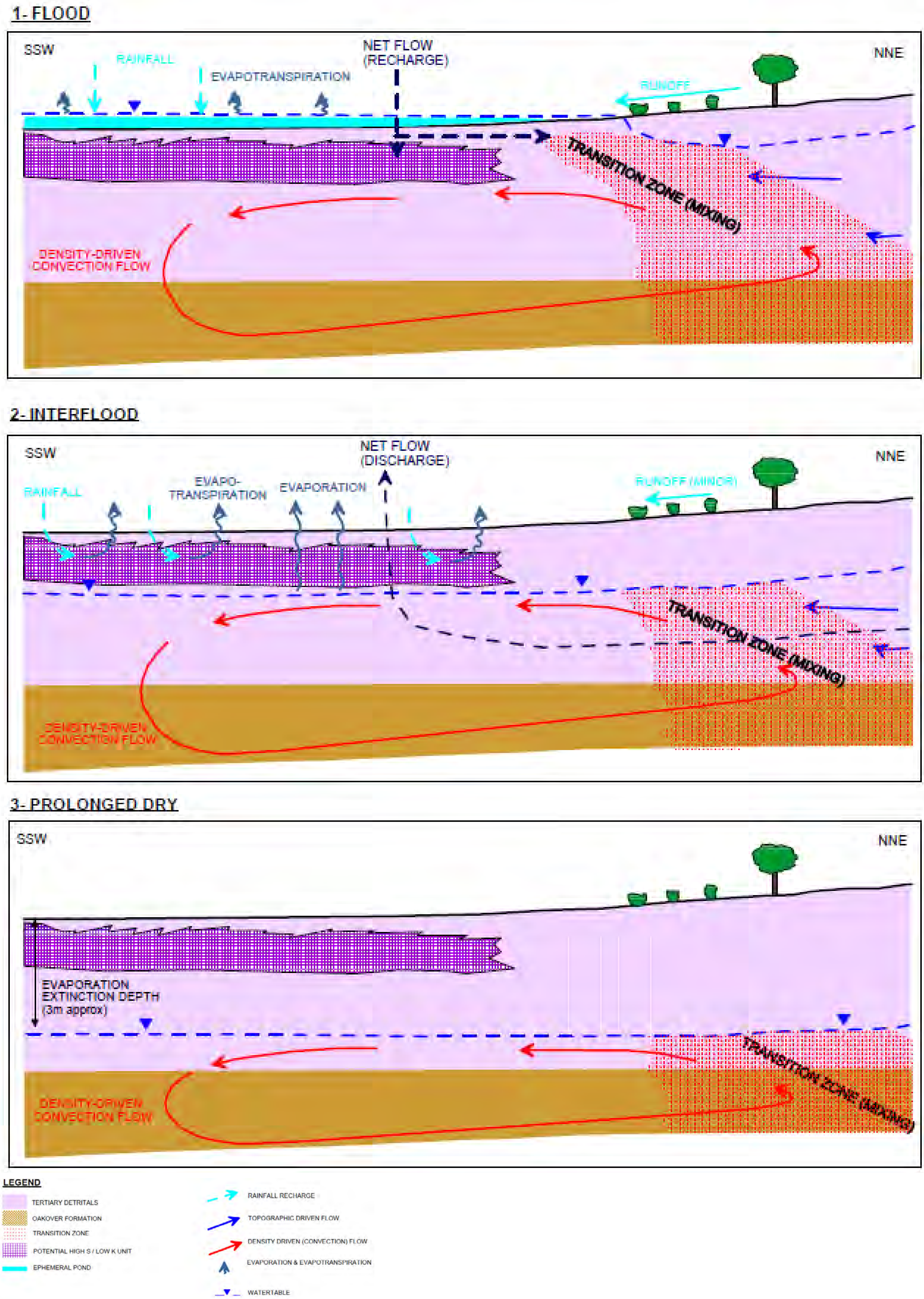
This page has been left blank intentionally



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
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 13: Fortescue Marsh conceptual section

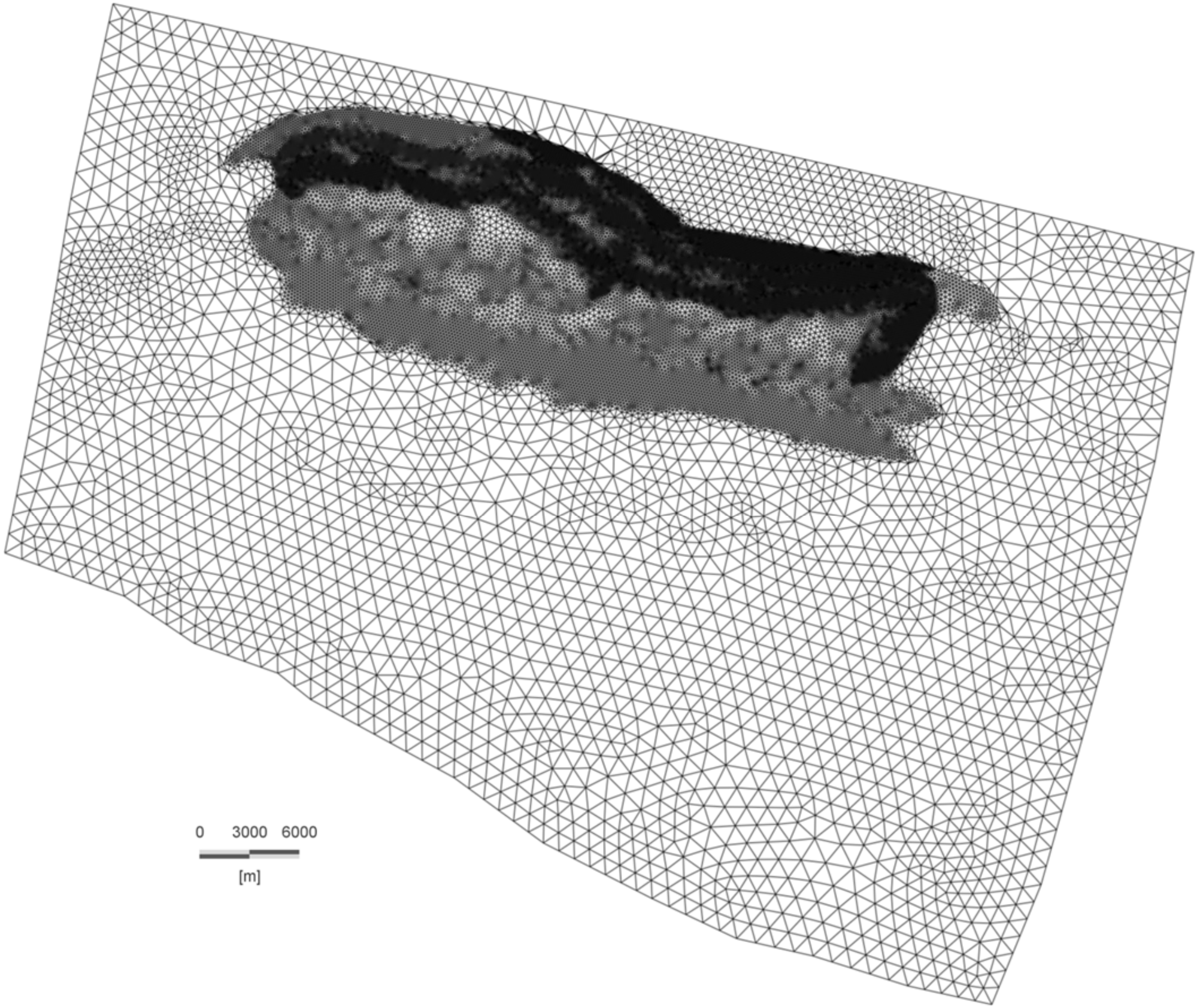
This page has been left blank intentionally




| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Fortescue Marsh Conceptual Hydrogeology** | **Figure 13** |
| | | 29/08/2013 |

# Figure 14: Model domain and boundary conditions

This page has been left blank intentionally




Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

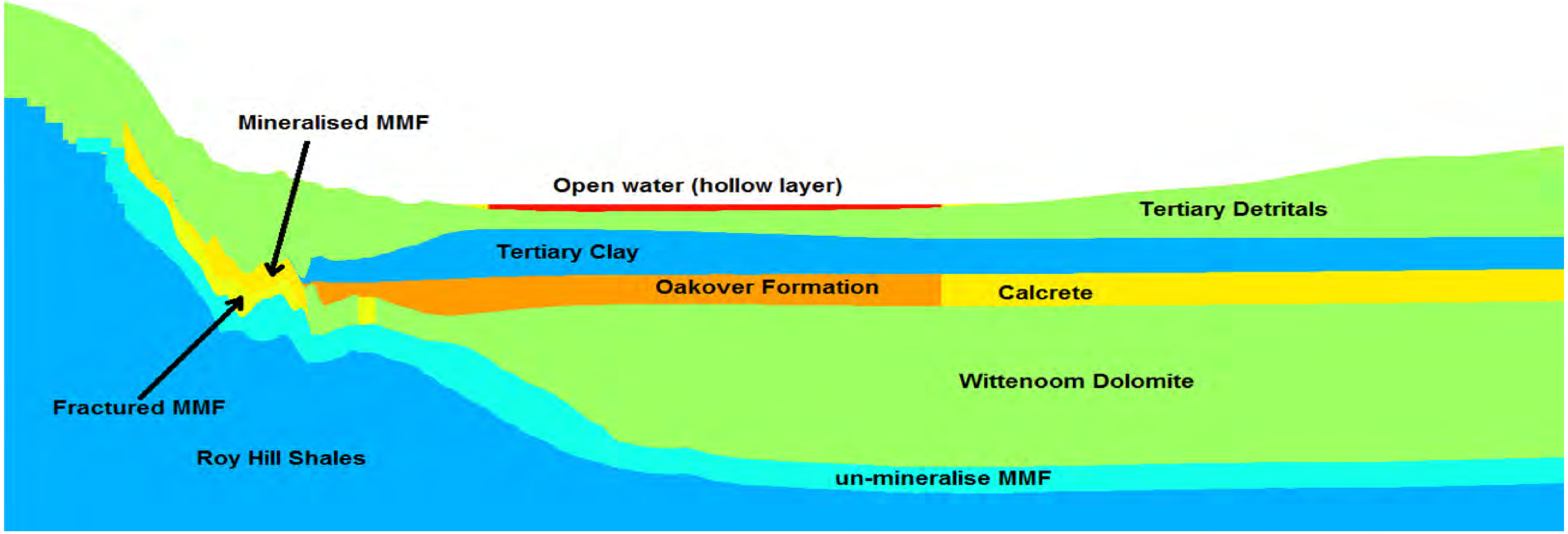
## Numerical Model Domain and Mesh

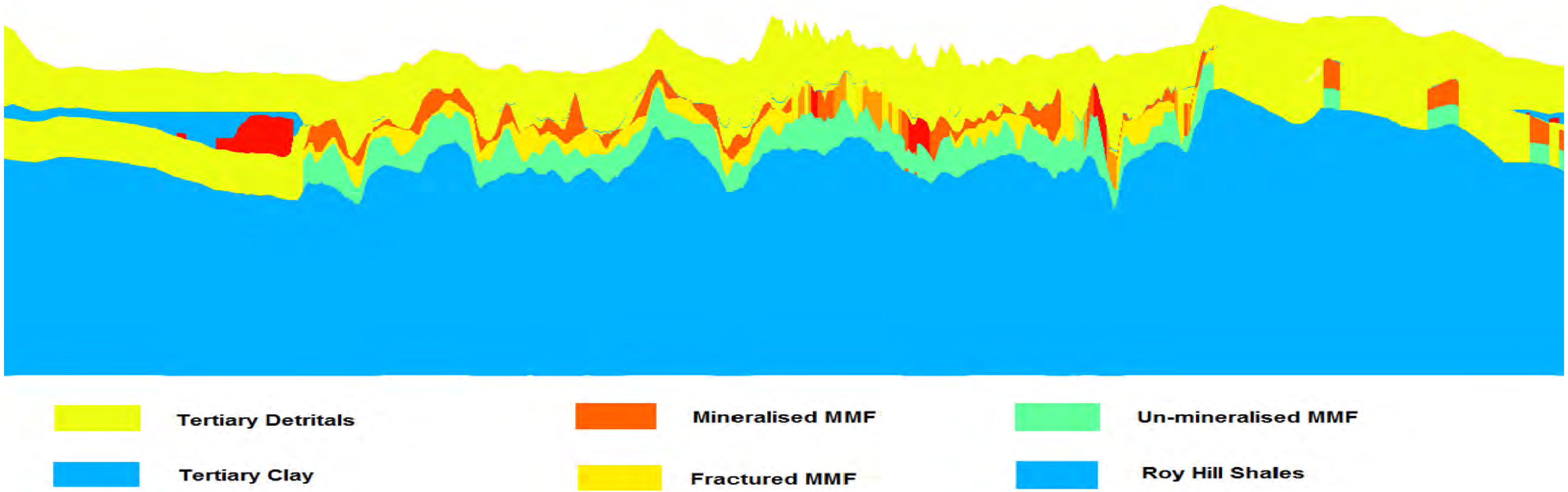
Figure 14

12/11/2013

# Figure 15: Model stratigraphic section

This page has been left blank intentionally

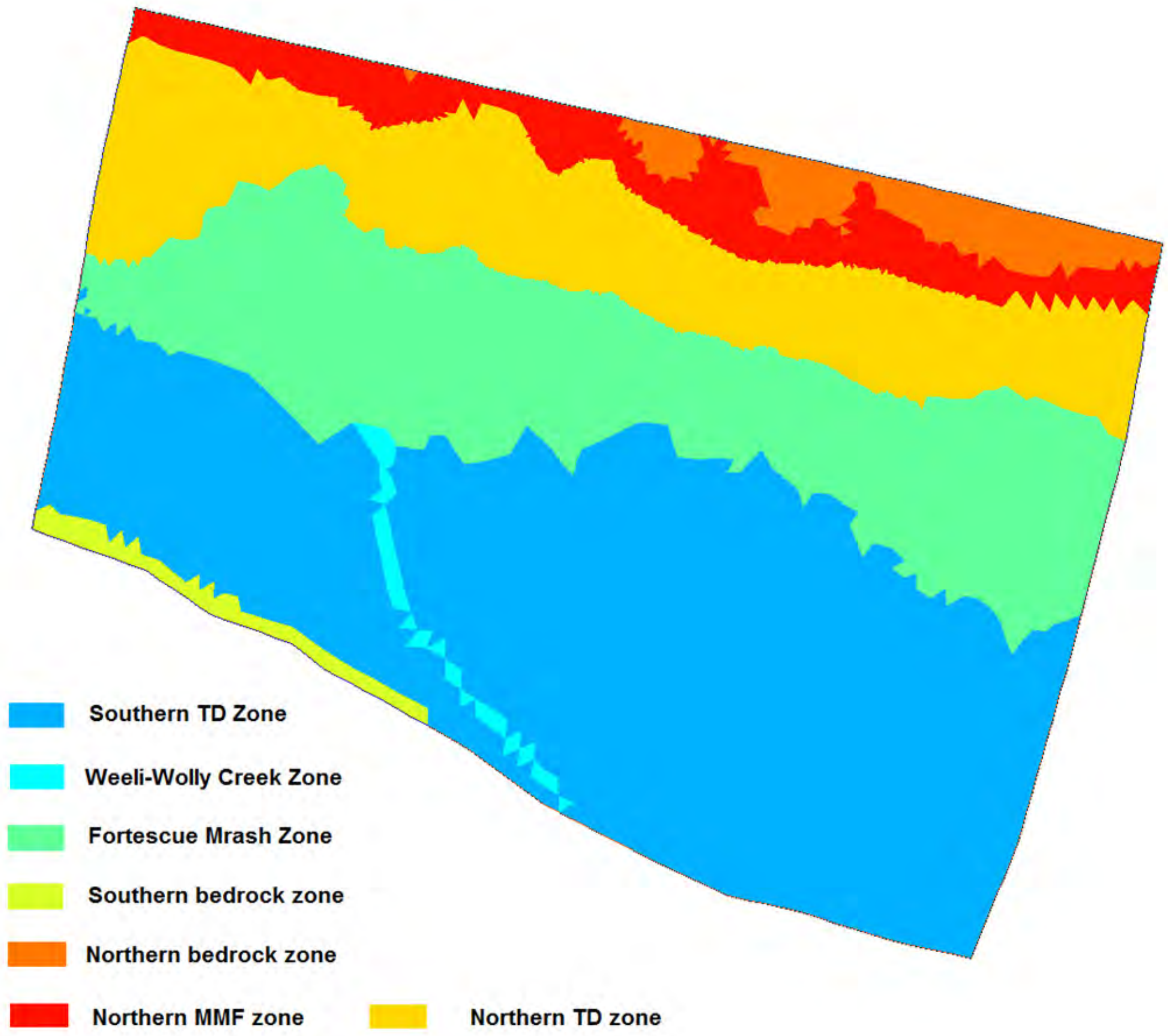



| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Numerical Model Cross Section** | **Figure 15** |
| | | 12/11/2013 |

Figure 16: Model Recharge Zones

This page has been left blank intentionally




Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

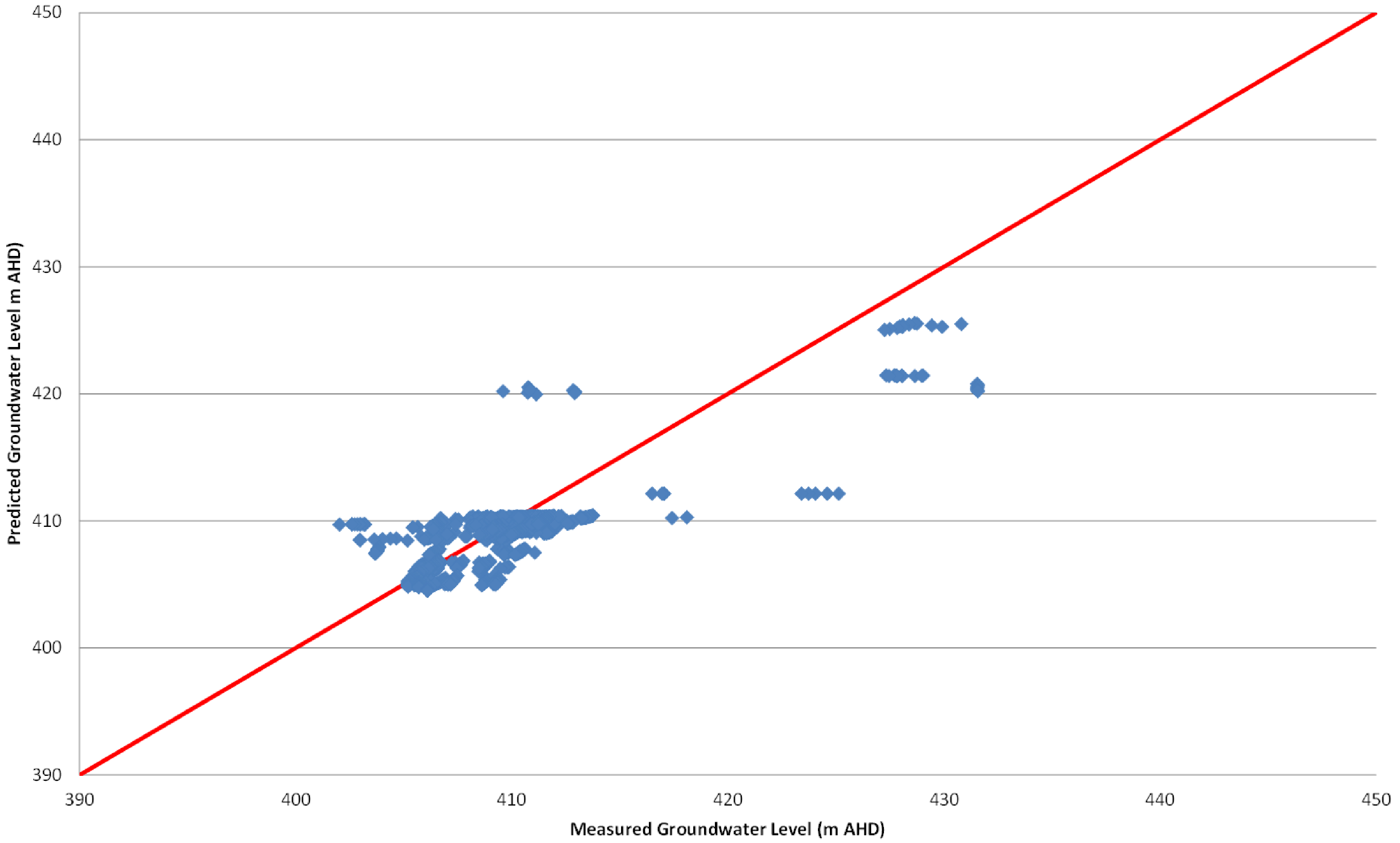
**Numerical Model Recharge Zones**

**Figure 16**

12/11/2013

Figure 17: Steady state calibration results: Measured v's model predicted groundwater levels

This page has been left blank intentionally





Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

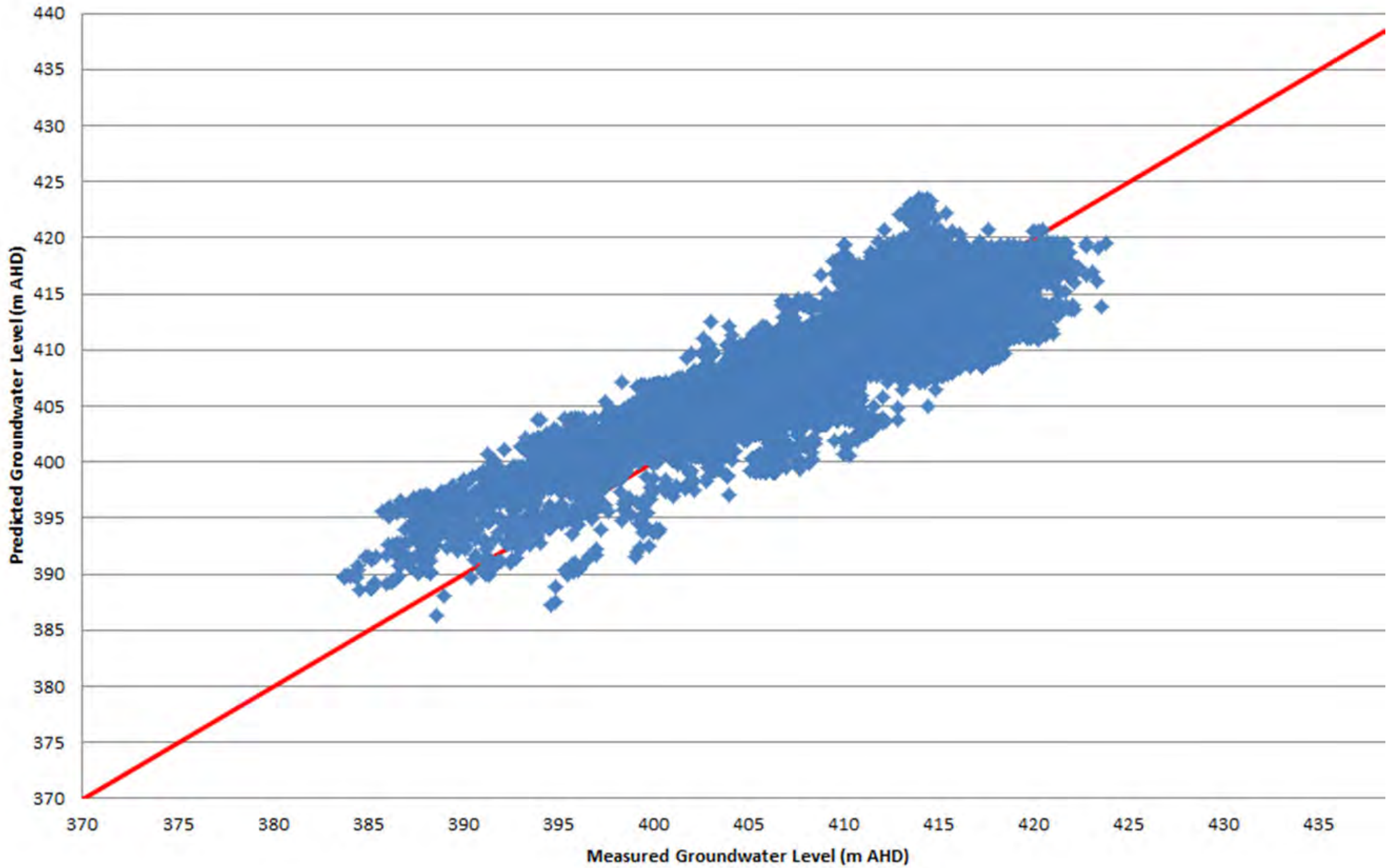

**Pre-dewatering Calibration Stage**

**Figure 17**

12/11/2013

# Figure 18: Transient calibration results: Measured v's model predicted groundwater levels

This page has been left blank intentionally





Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

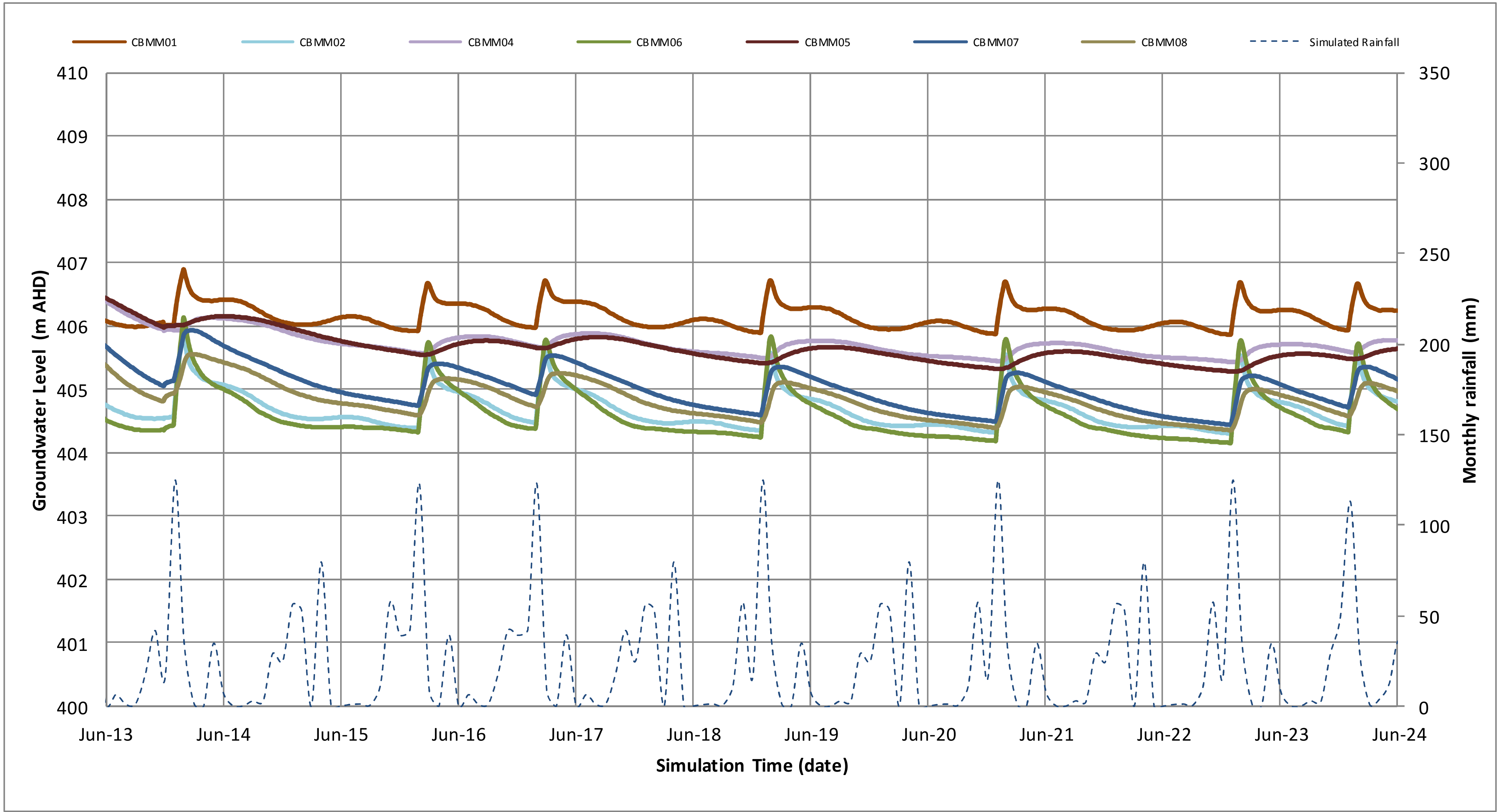

**Dewatering Calibration Stage**

**Figure 18**

12/11/2013

Figure 19: Hydrographs at five key locations for the base simulation without mining

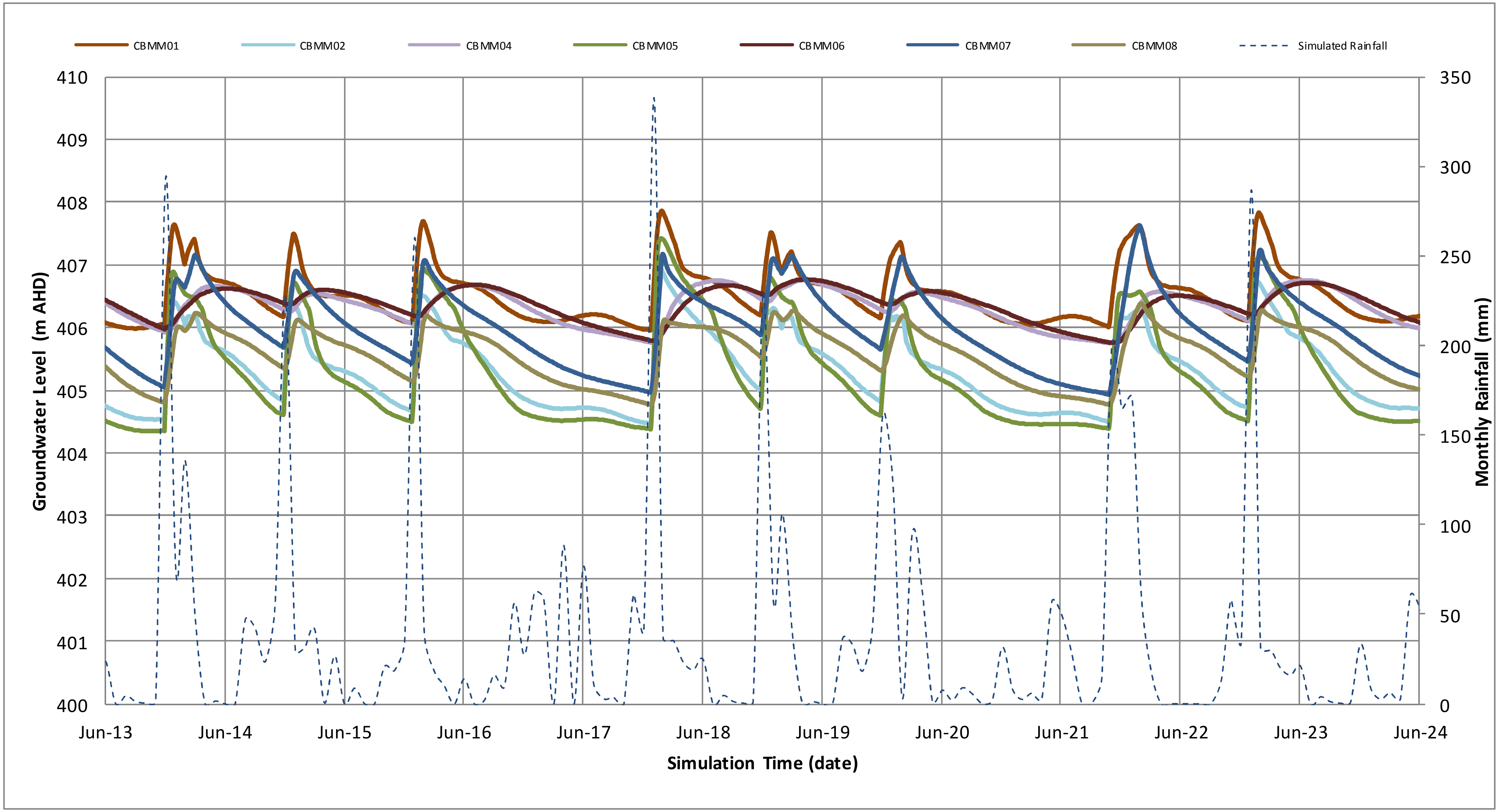
This page has been left blank intentionally




| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Hydrograph at key locations for the Base scenario without mine dewatering** | **Figure 19** |
|---|---|---|
| | | 07/11/2013 |

Figure 20: Hydrographs at five key locations for the dry simulation without mining

This page has been left blank intentionally




Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

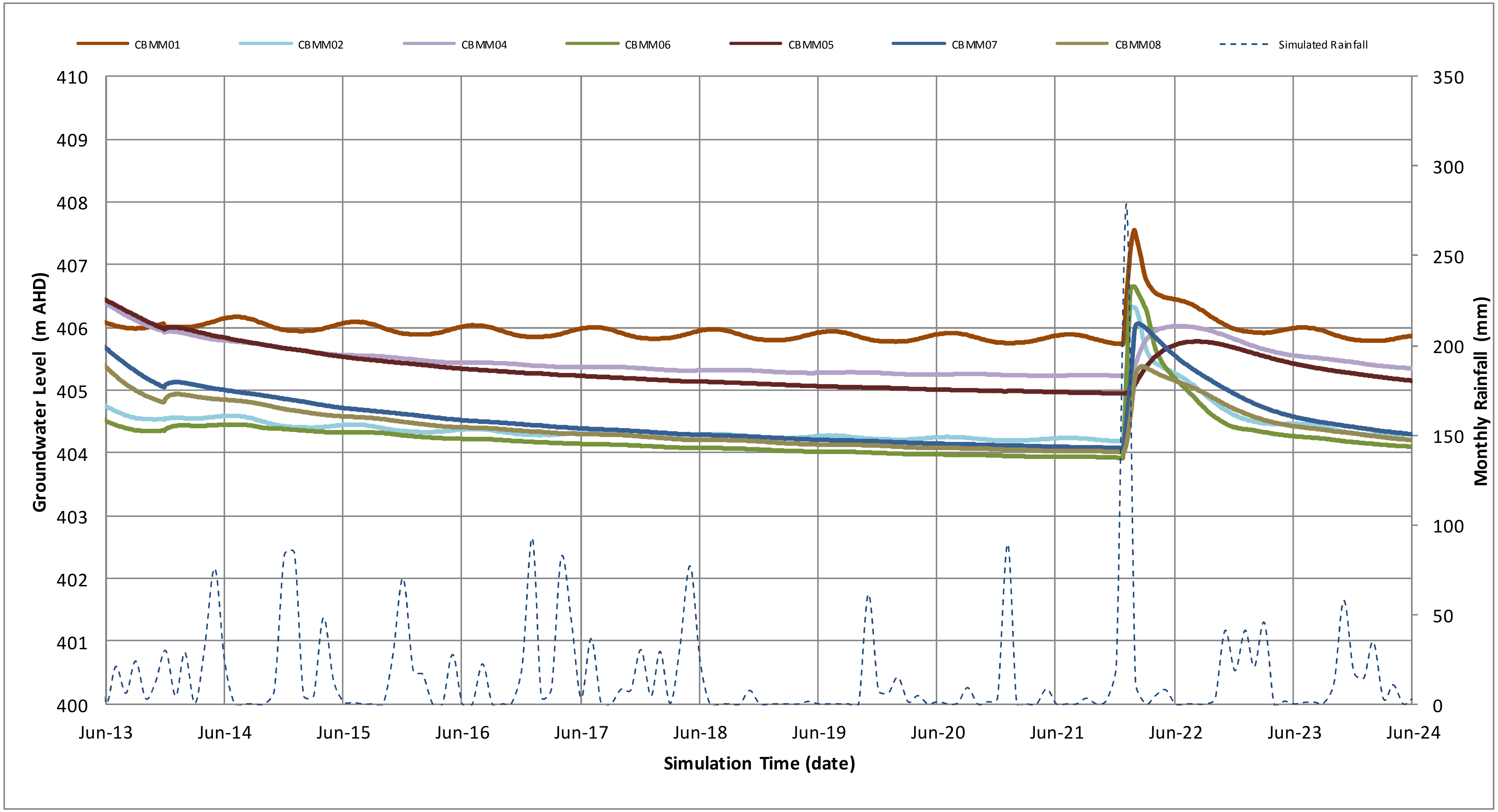
**Hydrograph at key locations for the Wet scenario without mine dewatering**

**Figure 20**

07/11/2013

Figure 21: Hydrographs at five key locations for the wet simulation without mining

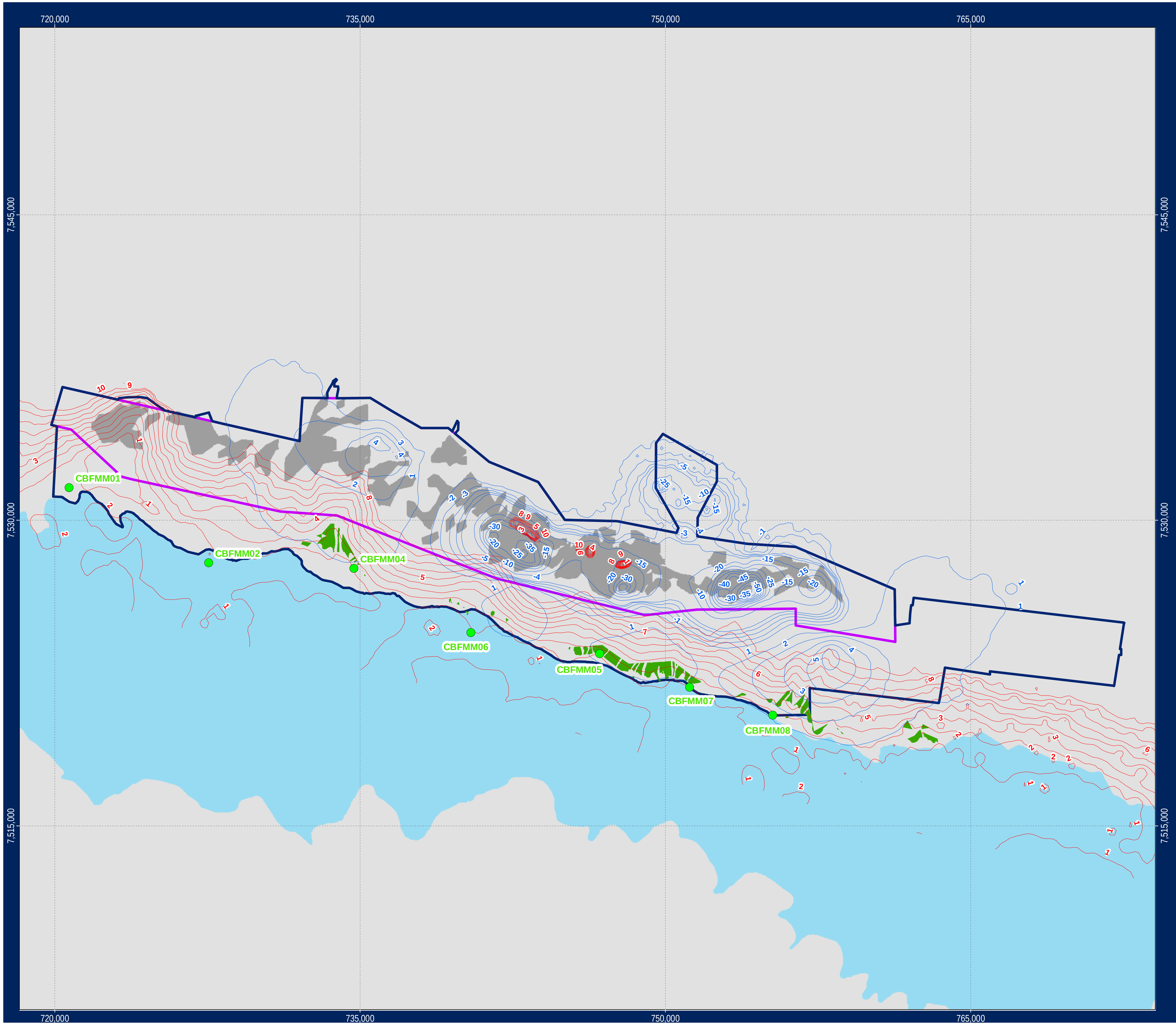
This page has been left blank intentionally

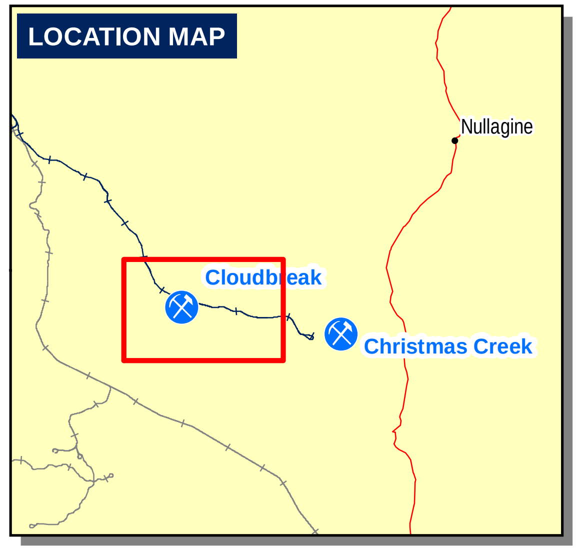



| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Hydrograph at key locations for the Dry scenario without mine dewatering** | **Figure 21** |
| | | 07/11/2013 |

Figure 22: Distribution of drawdown/mounding due to mining for the base simulation - 2014

This page has been left blank intentionally




## LEGEND

- MS 899 bores
- Change in watertable due to mining
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga - Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

## 2014

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.001_r0_2014

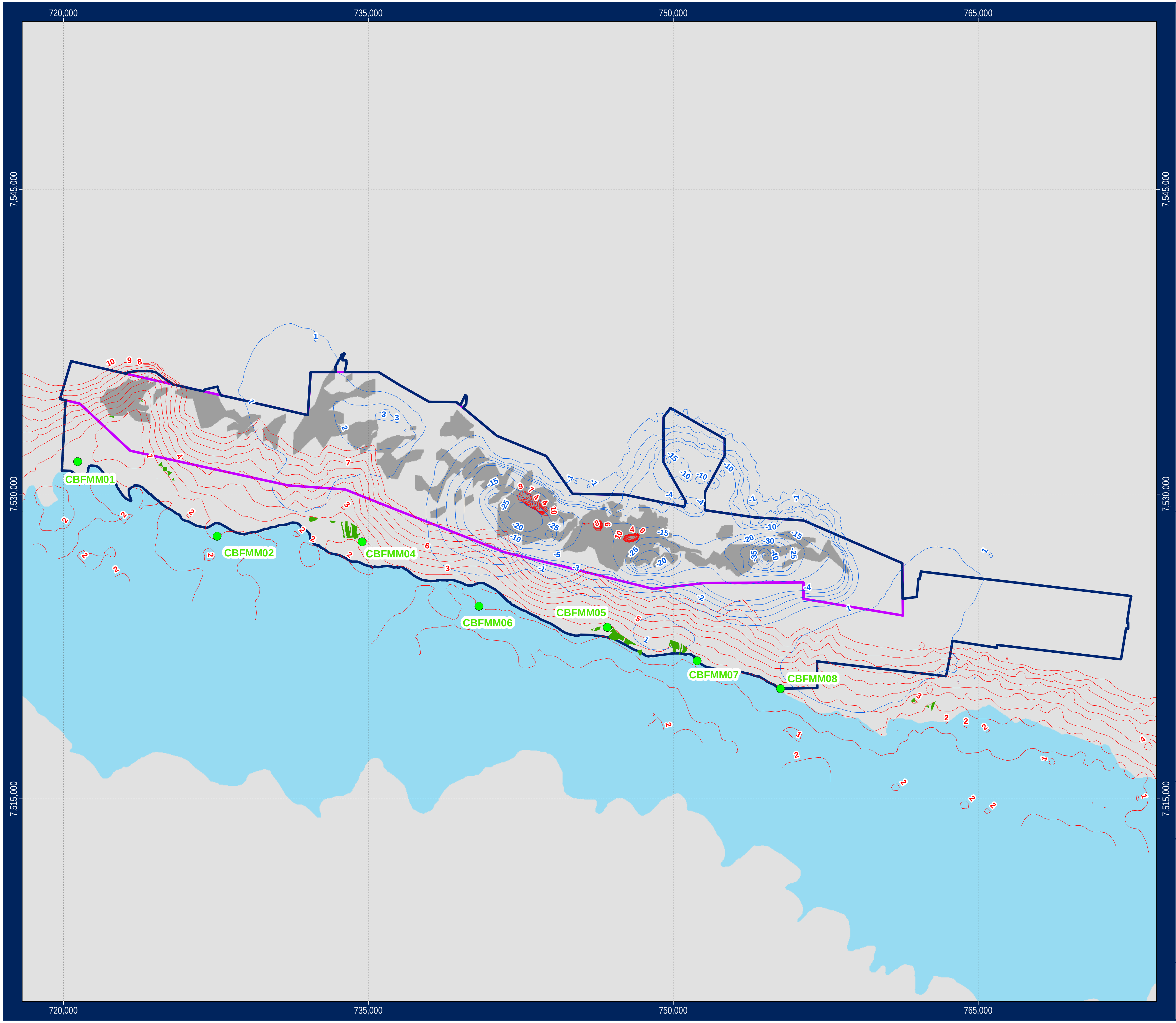
Date: 29/11/2013
Size: A3L
Revision: 0
Confidentiality: 1

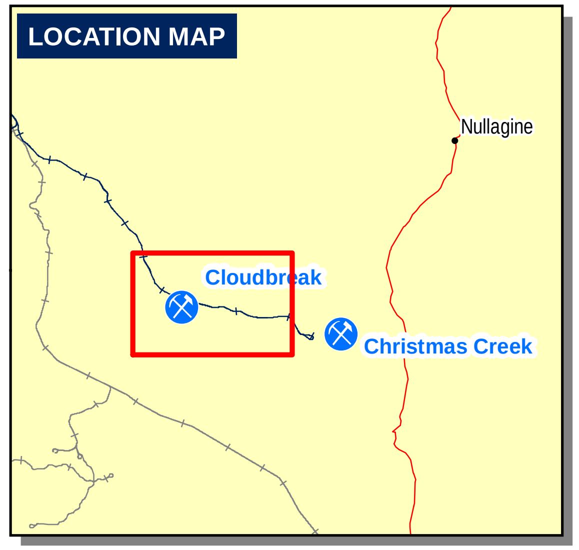


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 23: Distribution of drawdown/mounding due to mining for the base simulation - 2015

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

## 2015

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.002_r0_2015

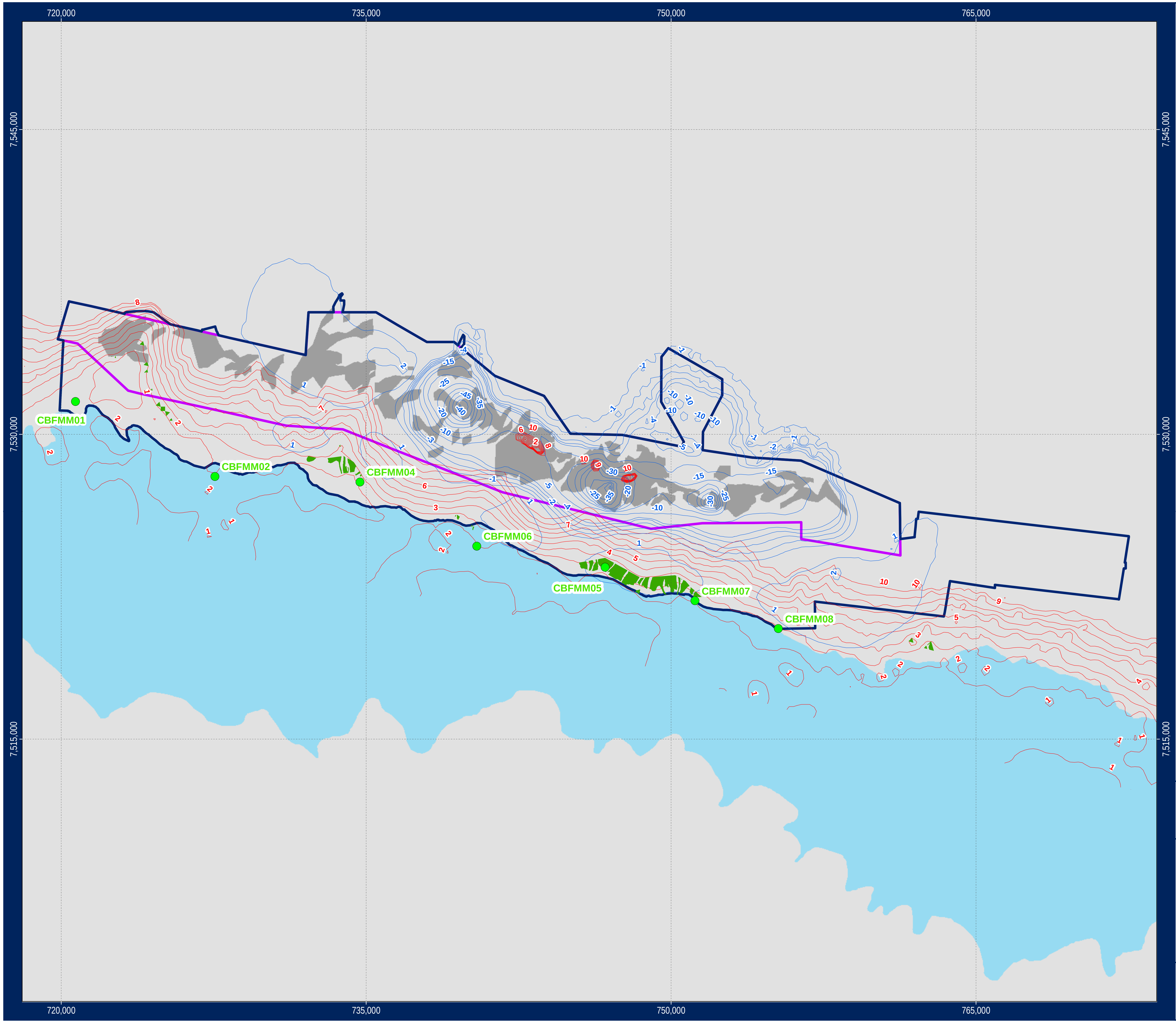
Date: 29/11/2013
Size: A3L
Revision: 0
Confidentiality: 1

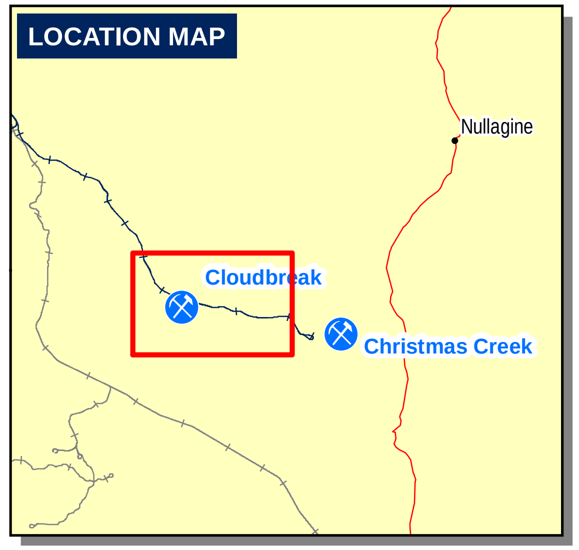


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 24: Distribution of drawdown/mounding due to mining for the base simulation - 2016

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

## 2016

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.003_r0_2016

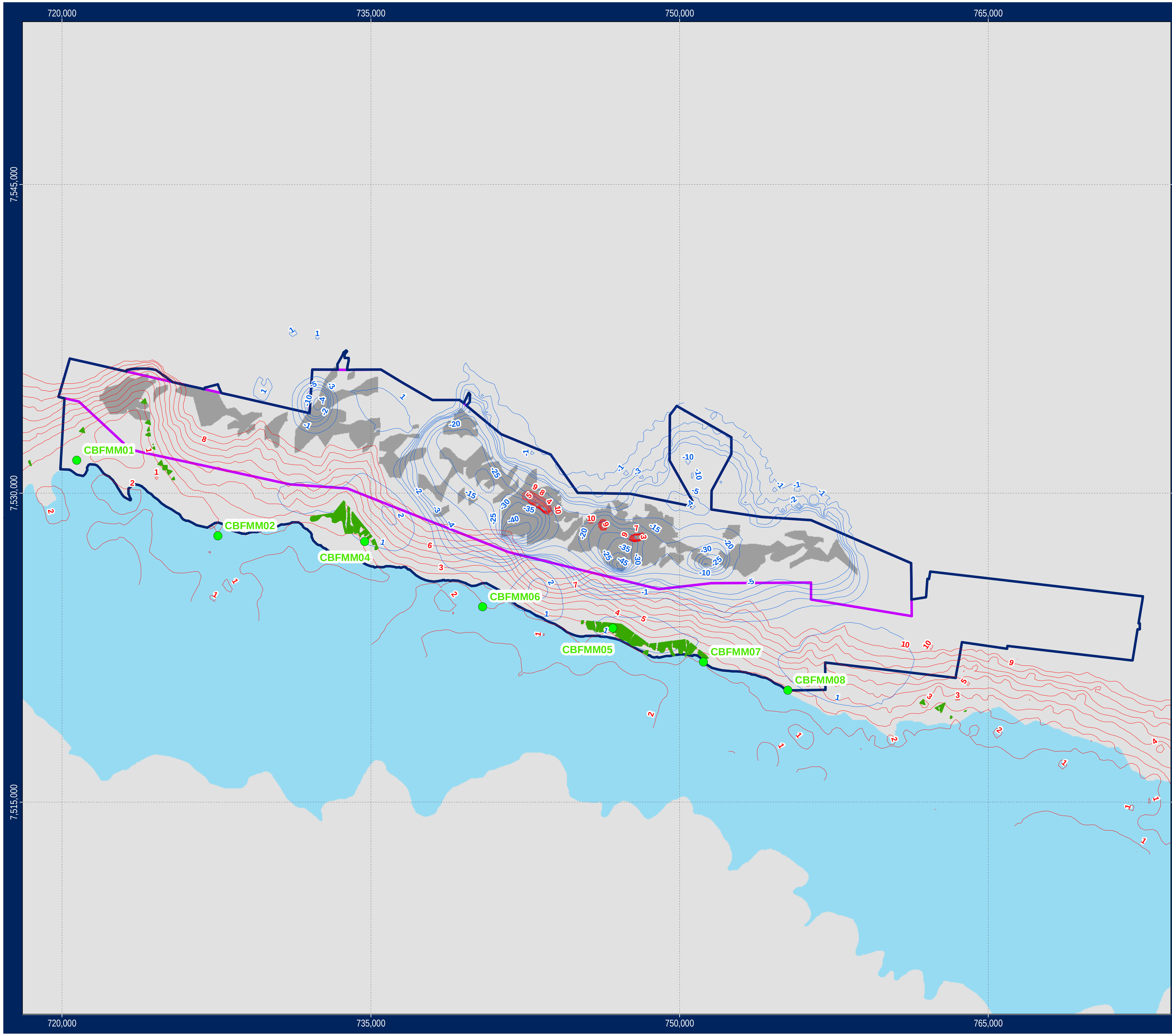
Date: 29/11/2013
Size: A3L
Revision: 0
Confidentiality: 1

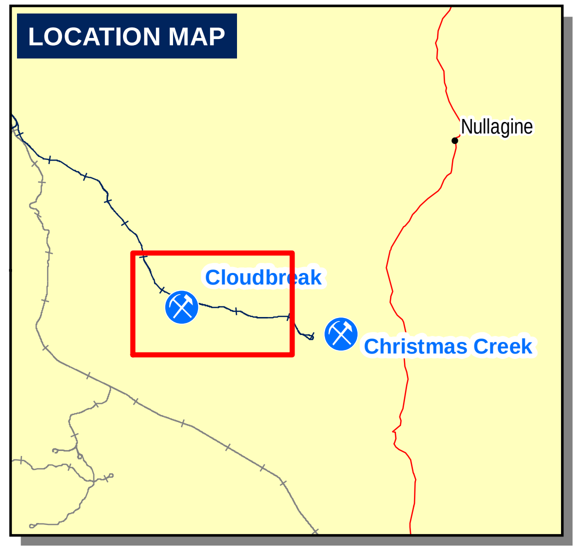


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 25: Distribution of drawdown/mounding due to mining for the base simulation - 2017

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

## 2017

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.004_r0_2017

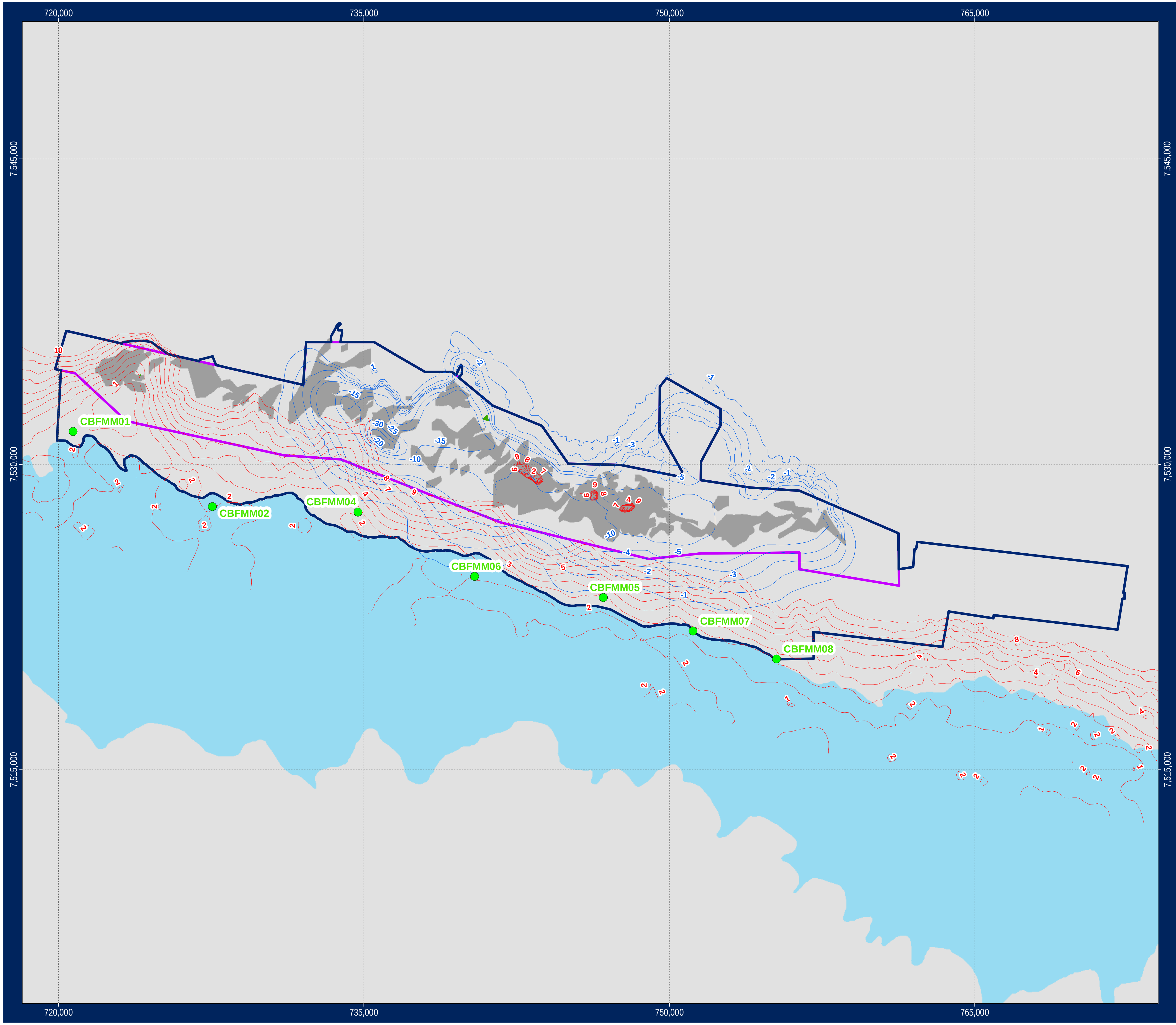
Date: 29/11/2013
Size: A3L
Revision: 0
Confidentiality: 1

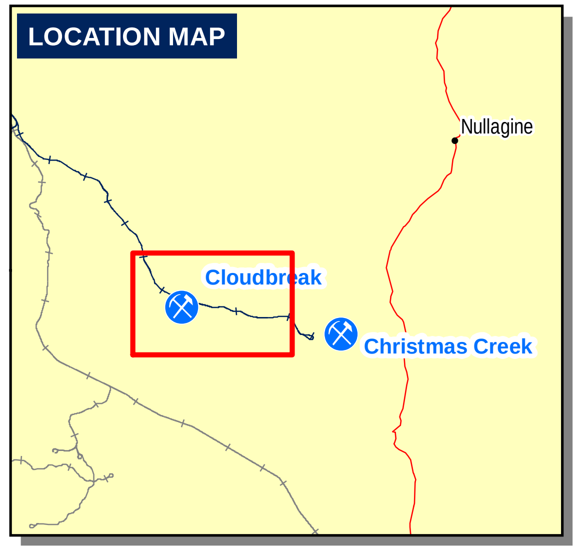


Fortescue Metals Group Ltd
The New Force in Iron Ore

# Figure 26: Distribution of drawdown/mounding due to mining for the base simulation - 2018

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga - Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

**2018**

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.005_r0_2018

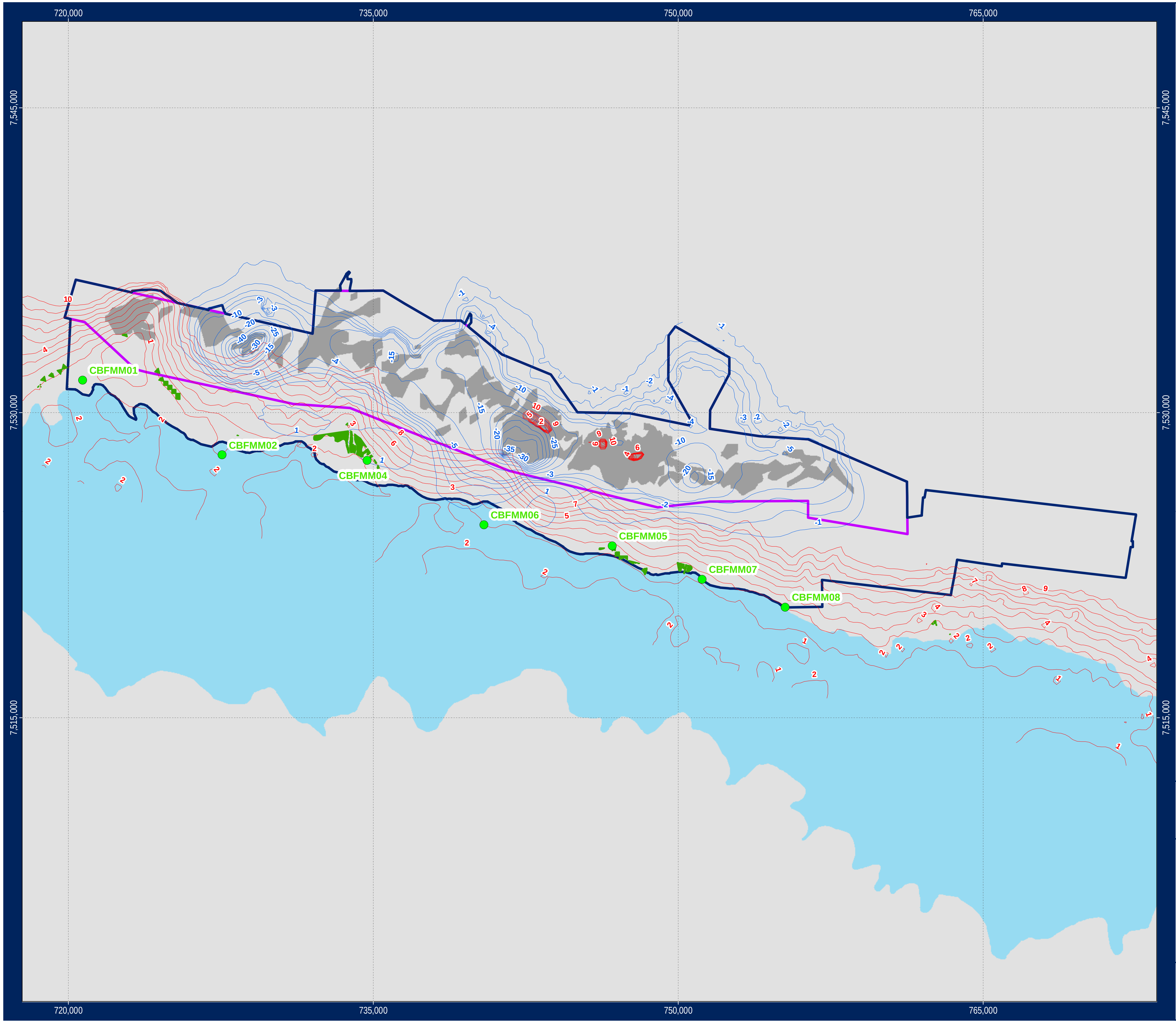
Date: 29/11/2013
Size: A3L
Revision: 0
Confidentiality: 1

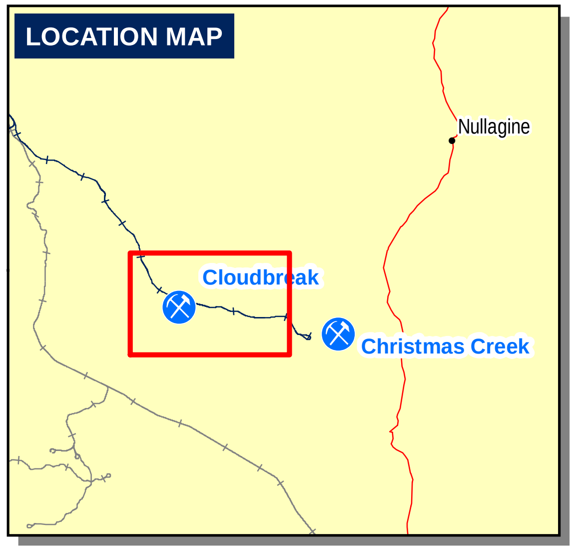


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 27: Distribution of drawdown/mounding due to mining for the base simulation - 2019

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

## 2019

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.006_r0_2019

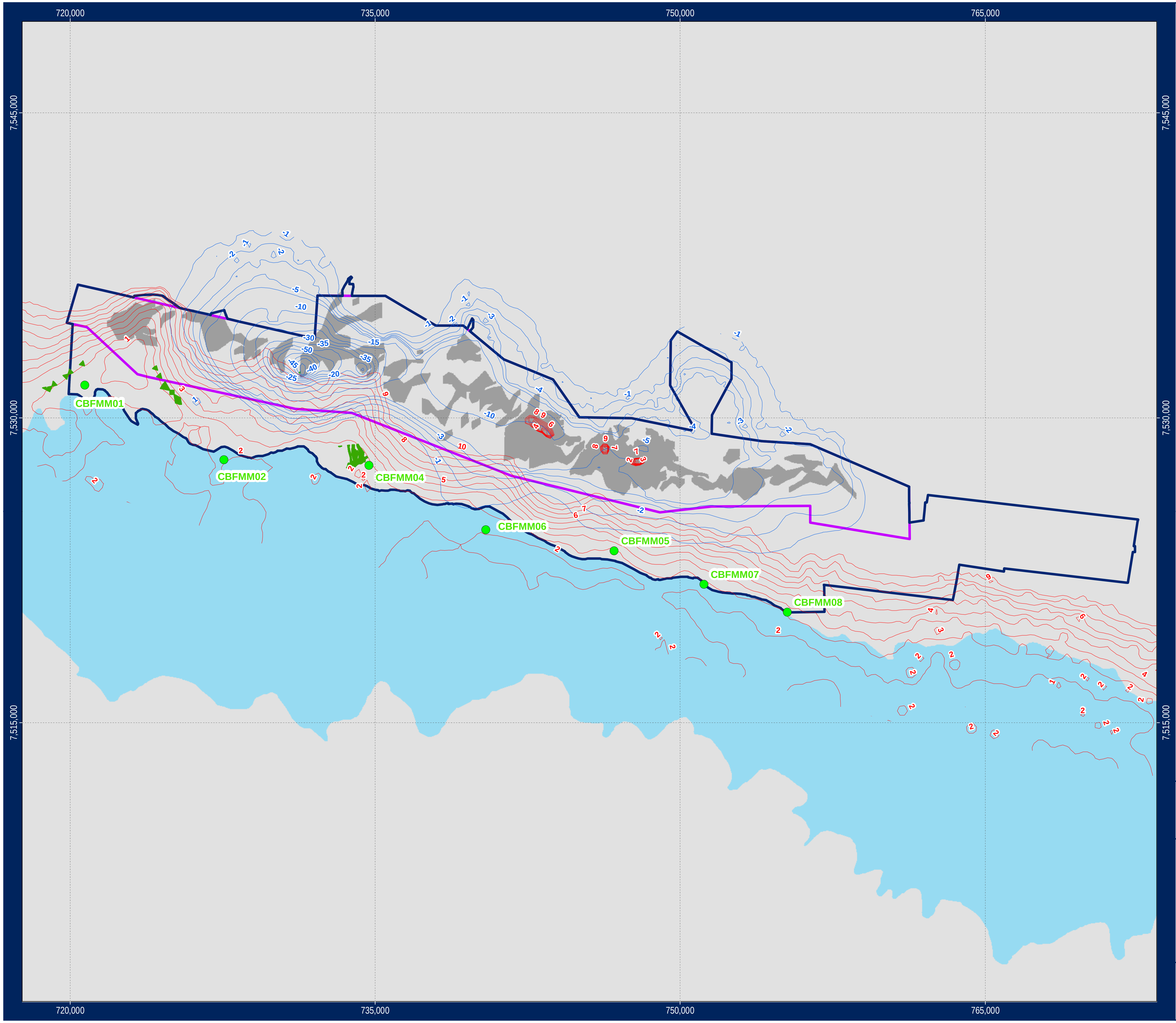
Date: 3/12/2013
Size: A3L
Revision: 0
Confidentiality: 1

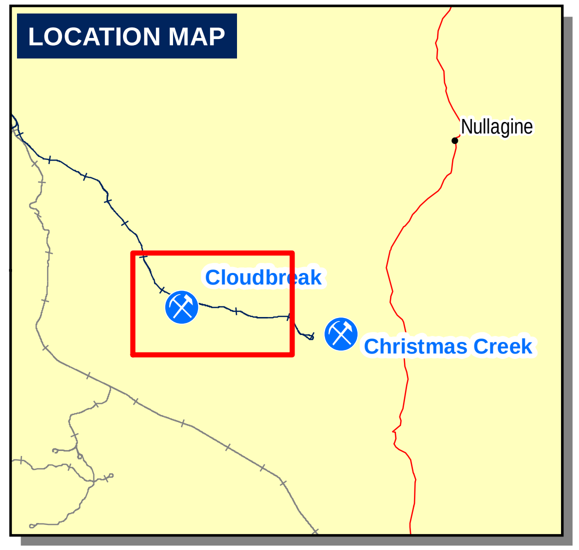


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 28: Distribution of drawdown/mounding due to mining for the base simulation - 2020

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

**2020**

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.007_r0_2020

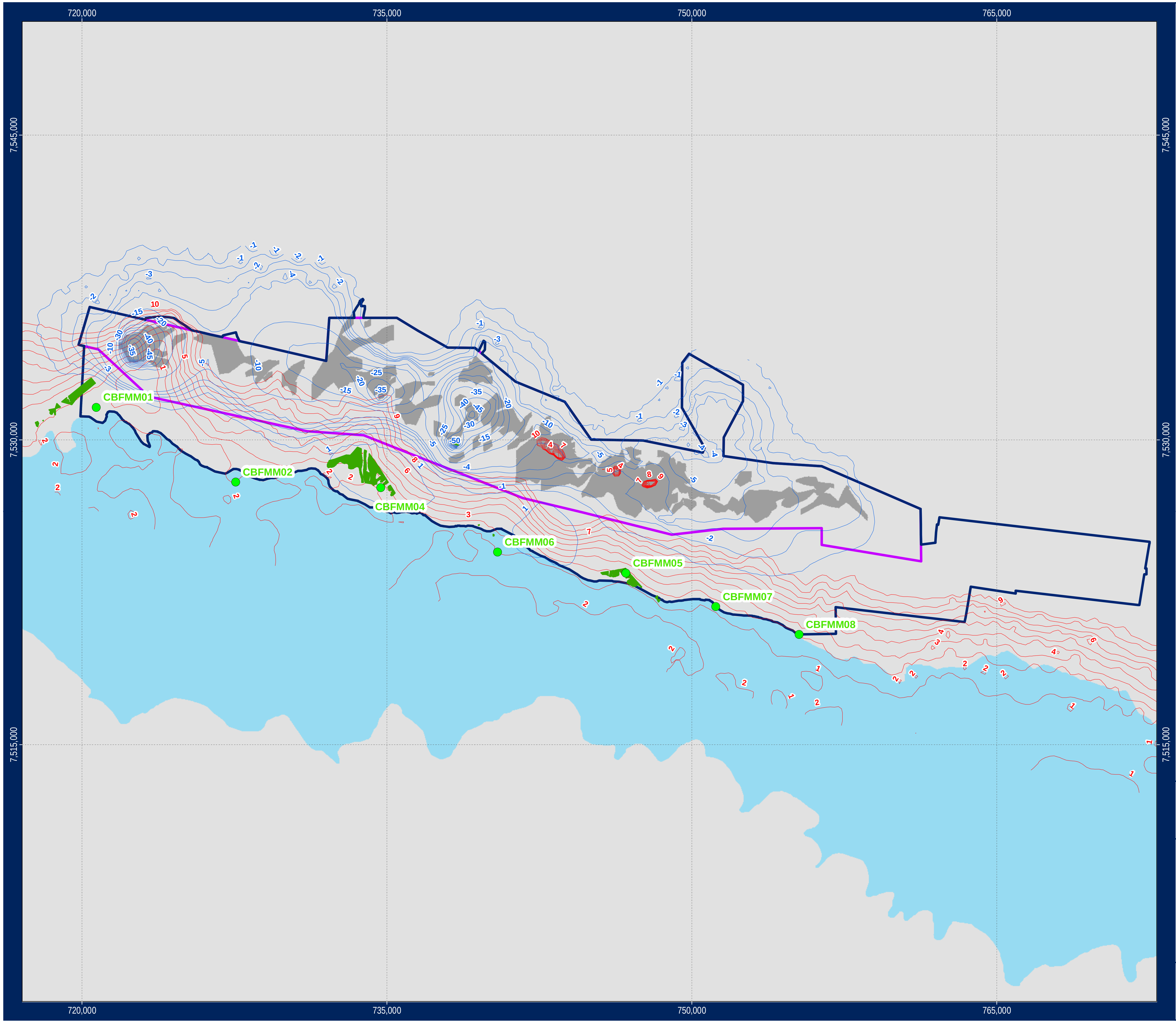
Date: 3/12/2013
Size: A3L
Revision: 0
Confidentiality: 1

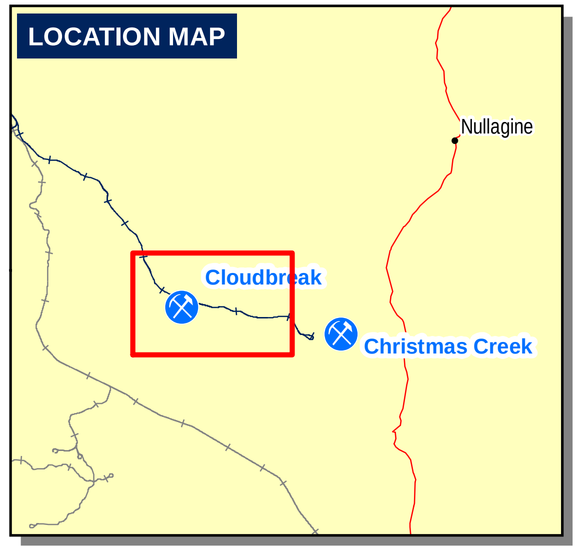


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 29: Distribution of drawdown/mounding due to mining for the base simulation - 2021

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

**2021**

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.008_r0_2021

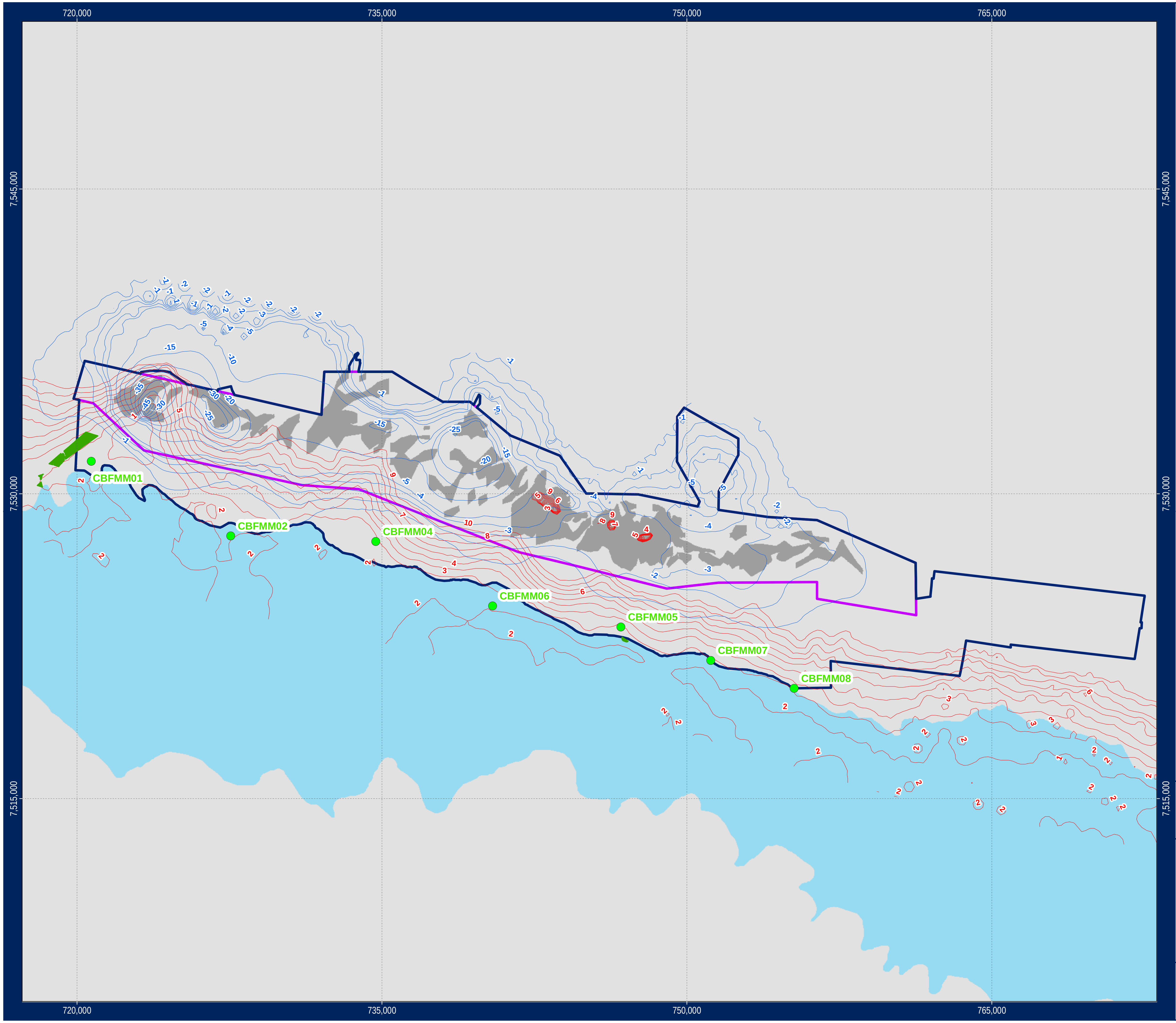
Date: 3/12/2013
Size: A3L
Revision: 0
Confidentiality: 1

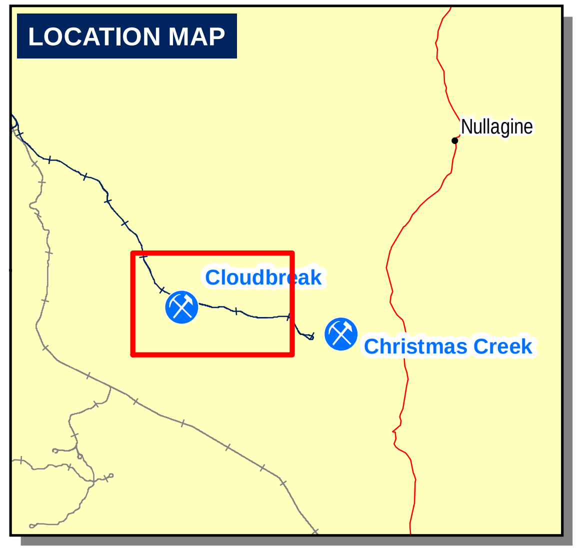


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 30: Distribution of drawdown/mounding due to mining for the base simulation - 2022

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

## 2022

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.009_r0_2022

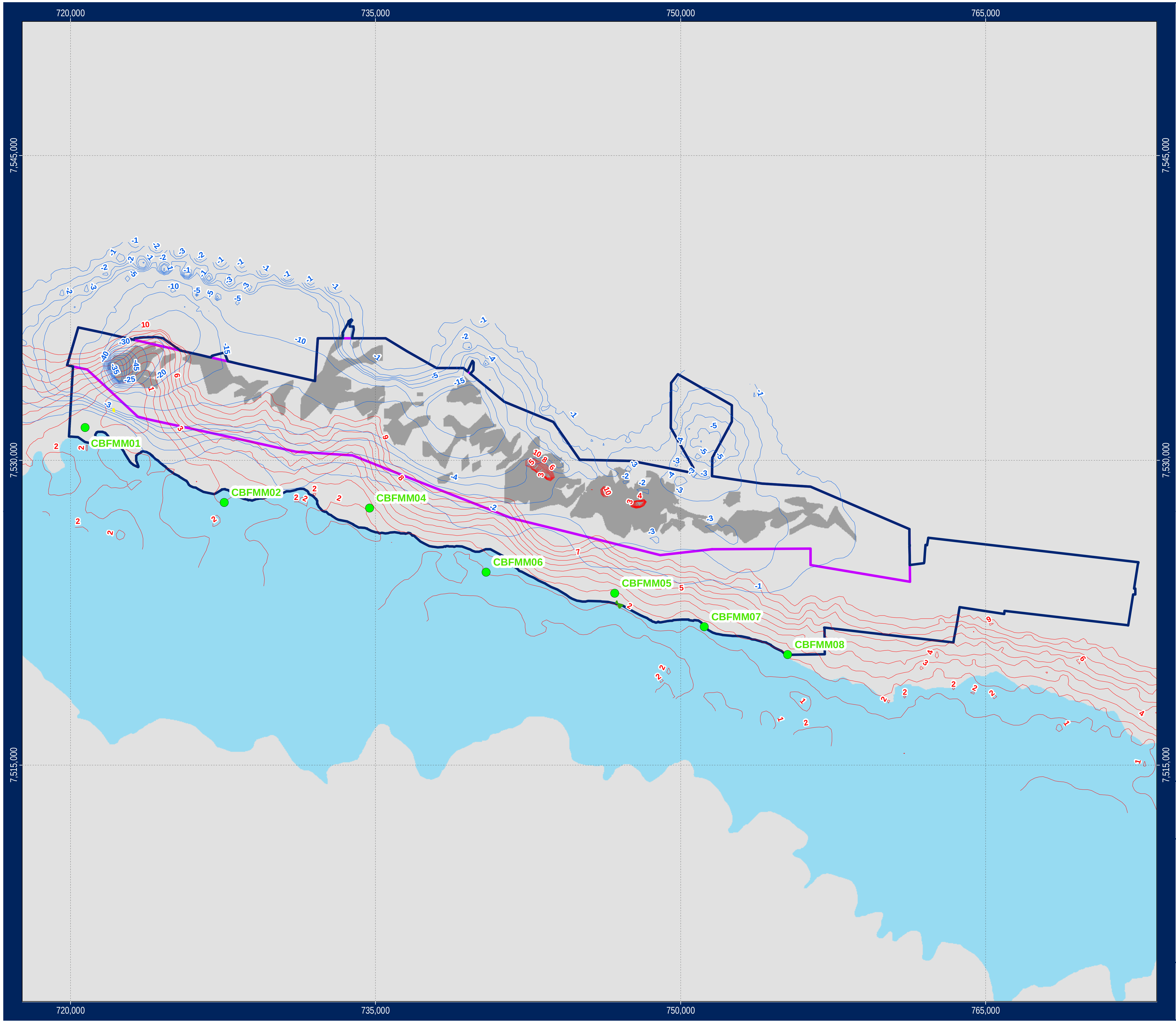
Date: 3/12/2013
Size: A3L
Revision: 0
Confidentiality: 1

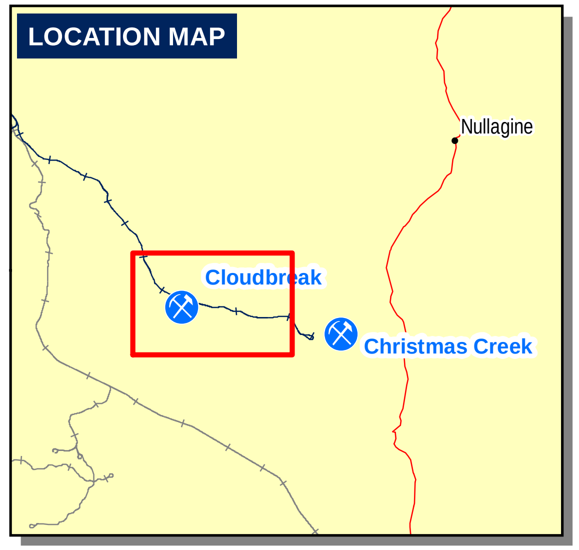


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 31: Distribution of drawdown/mounding due to mining for the base simulation - 2023

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Samphire – Drawdown greater than 3m in areas where the natural groundwater was 0-5 mbgl.
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced
from FMG (2013)

N

0 1 2 3 4 5
Kilometres

## 2023

Requested By: Paul Ricketts
Drawn By: A.Moore
Revised By: admoore
Approved By:
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.010_r0_2023

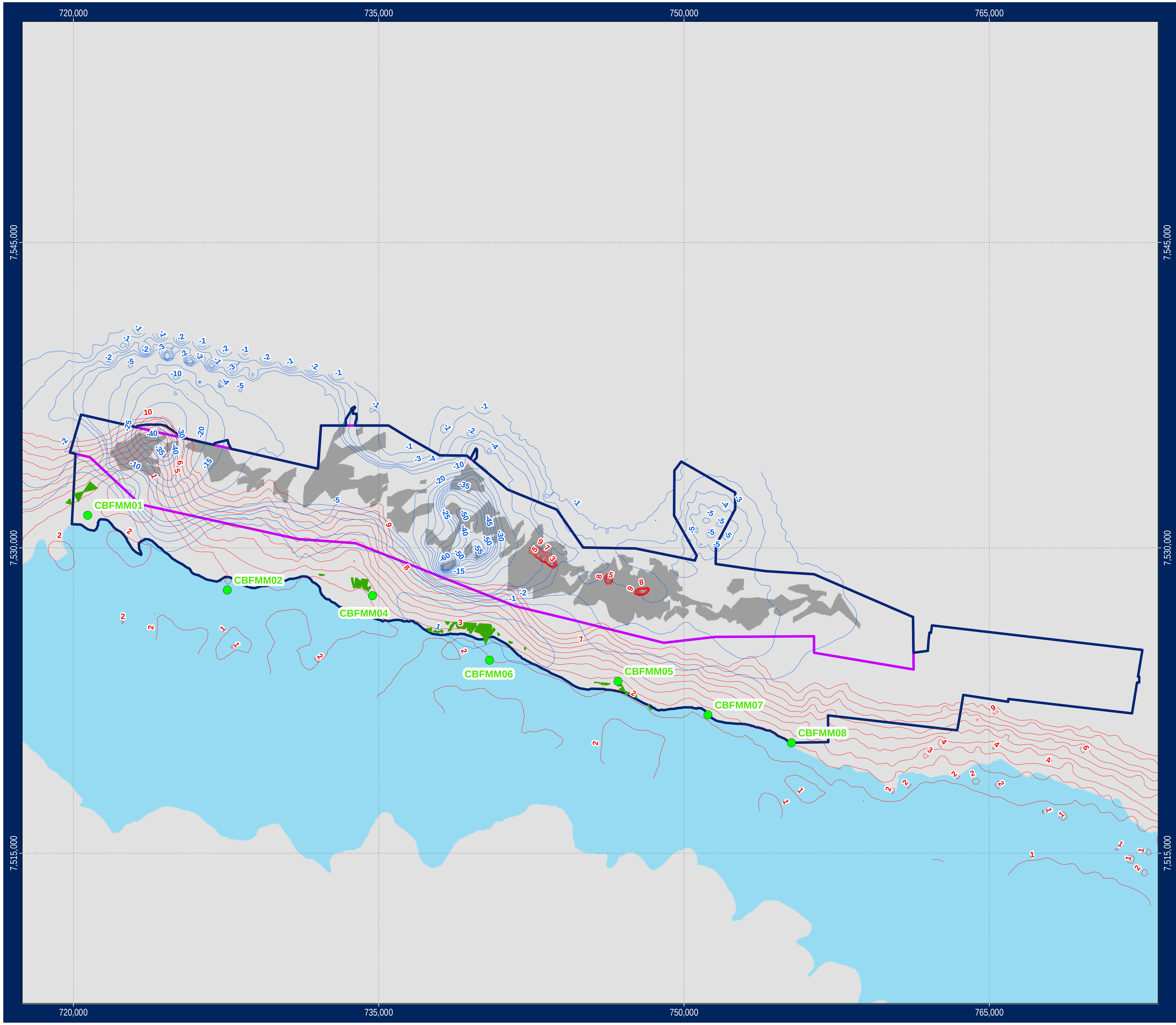
Date: 14/02/2014
Size: A3L
Revision: 0
Confidentiality: 1

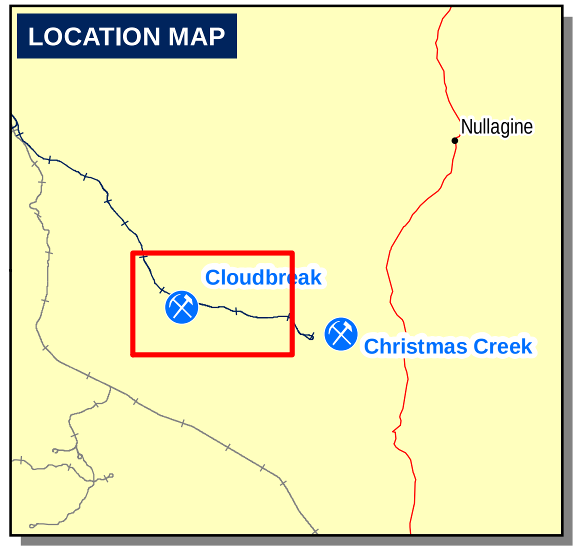


Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 32: Distribution of drawdown/mounding due to mining for the base simulation - 2024

This page has been left blank intentionally




**LEGEND**

- MS 899 bores
- Change in watertable due to mining.
- Depth to watertable (Natural) baseline_mbgl
- CB Mine Area - MS899
- CB Project Area - MS899
- Mine Plan
- Fortescue Marsh boundary
- Impacts to Mulga – Mounding within 2m of the ground surface where the natural groundwater was below 2mbgl.

Data Source(s):
Marsh data sourced from Enviro Australia,(2001).
Directory of Important Wetlands in Australia
Observation wells,mine plan data sourced from FMG (2013)

N

0 1 2 3 4 5
Kilometres

**2024**

| | |
|---|---|
| Requested By: Paul Ricketts | Date: 4/12/2013 |
| Drawn By: A.Moore | Size: A3L |
| Revised By: admoore | Revision: 0 |
| Approved By: | Confidentiality: 1 |

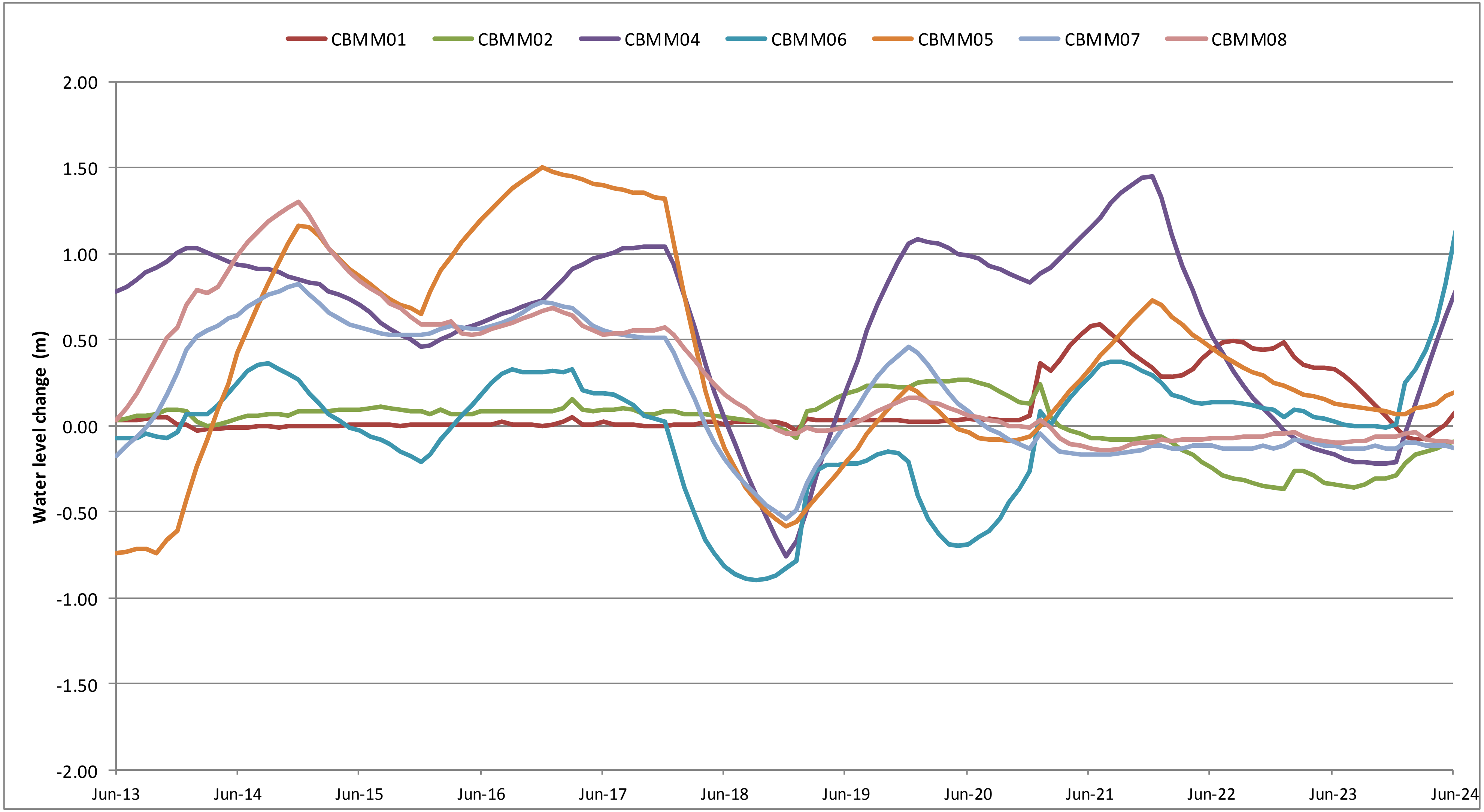
Scale: 1:180,000
Coordinate System: GDA 1994 MGA Zone 50
Document Name: CB_MP_HY_0073.011_r0_2024



Fortescue Metals Group Ltd
The New Force in Iron Ore

Figure 33: Groundwater level change at the seven key monitoring locations for the base simulation

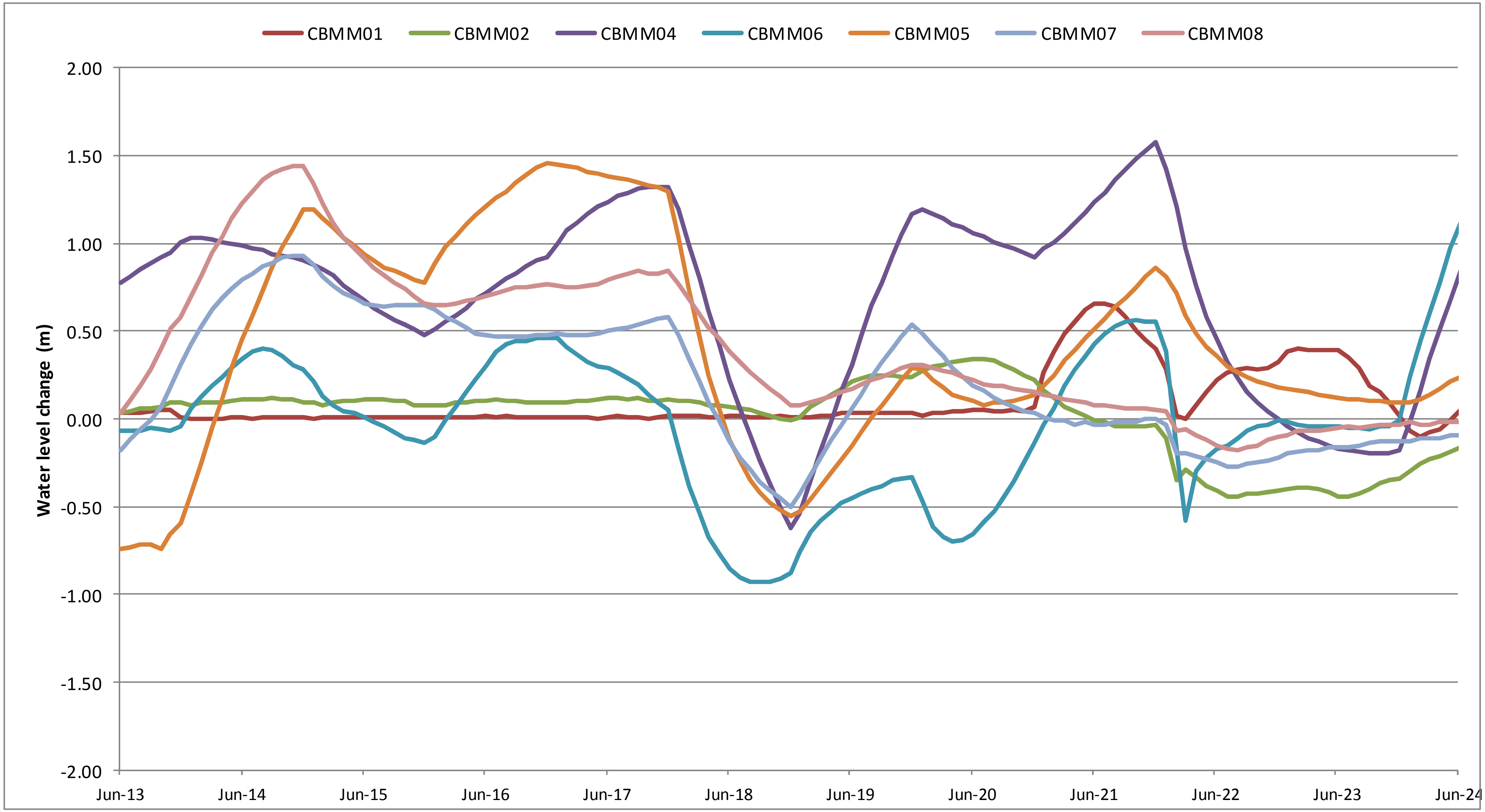
This page has been left blank intentionally




| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Groundwater level change (drawdown/mounding relative to natural conditions) at seven key locations—Base scenario** | **Figure 33** |
| | | 08/11/2013 |

Figure 34: Groundwater level change at the seven key monitoring locations for the dry simulation

This page has been left blank intentionally




Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

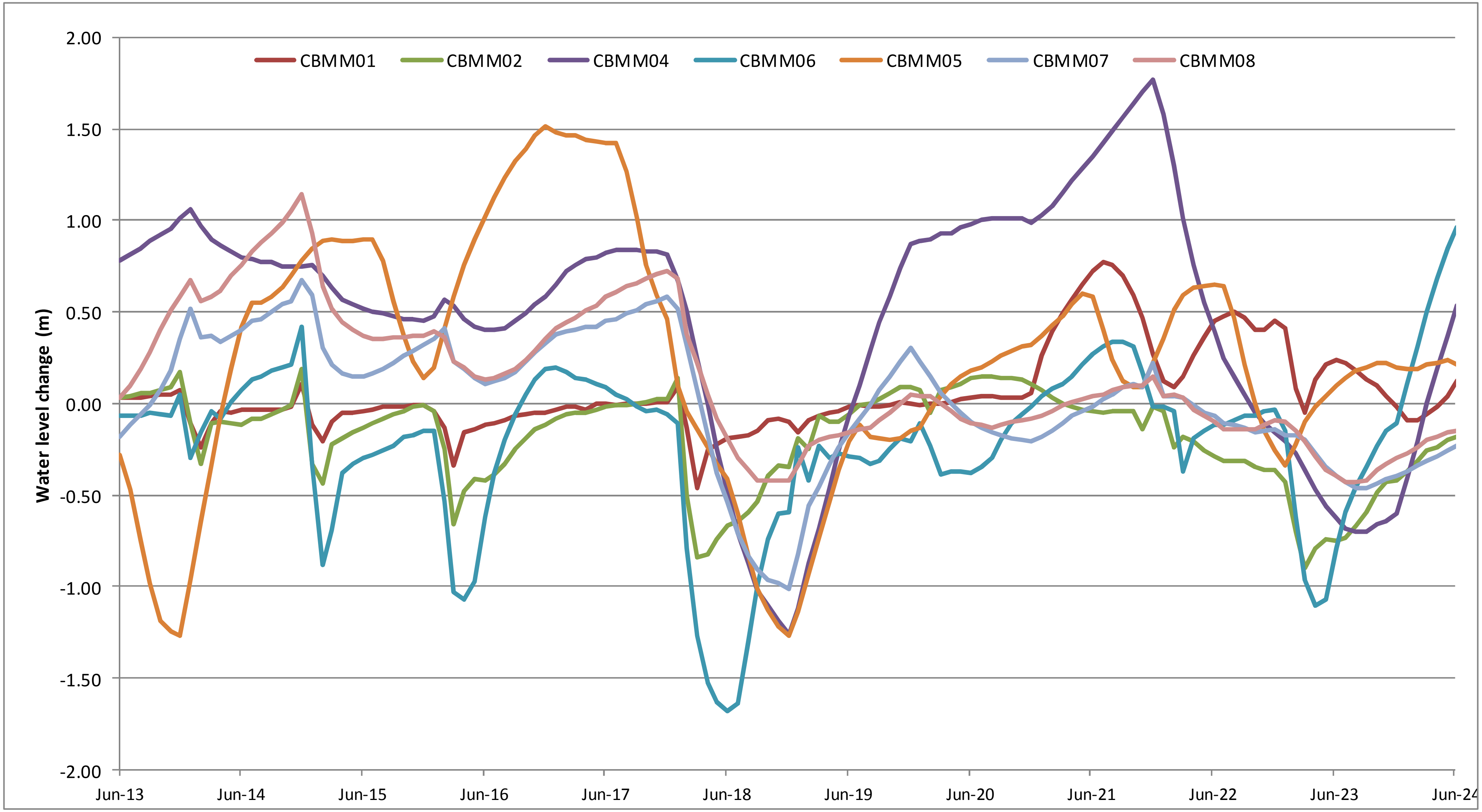
**Groundwater level change (drawdown/mounding relative to natural conditions) at seven key locations—Dry scenario**

**Figure 34**

08/11/2013

Figure 35: Groundwater level change at the seven key monitoring locations for the wet simulation

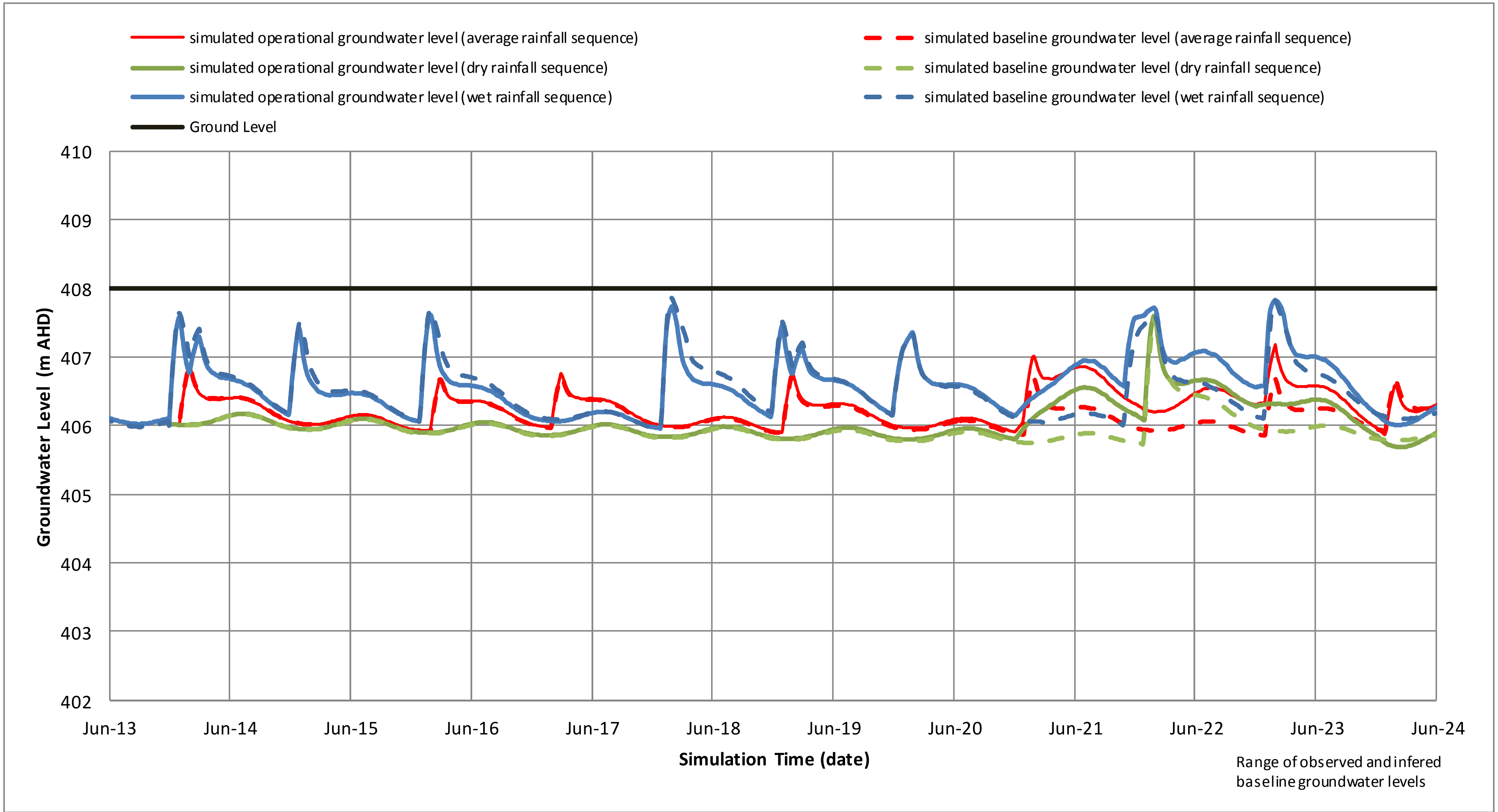
This page has been left blank intentionally




| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Groundwater level change (drawdown/mounding relative to natural conditions) at seven key locations—Wet scenario** | **Figure 35** |
| | | 08/11/2013 |

Figure 36: Hydrograph at CBFMM01_s, under natural and mining conditions for the Base, Dry and Wet simulations

This page has been left blank intentionally





Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

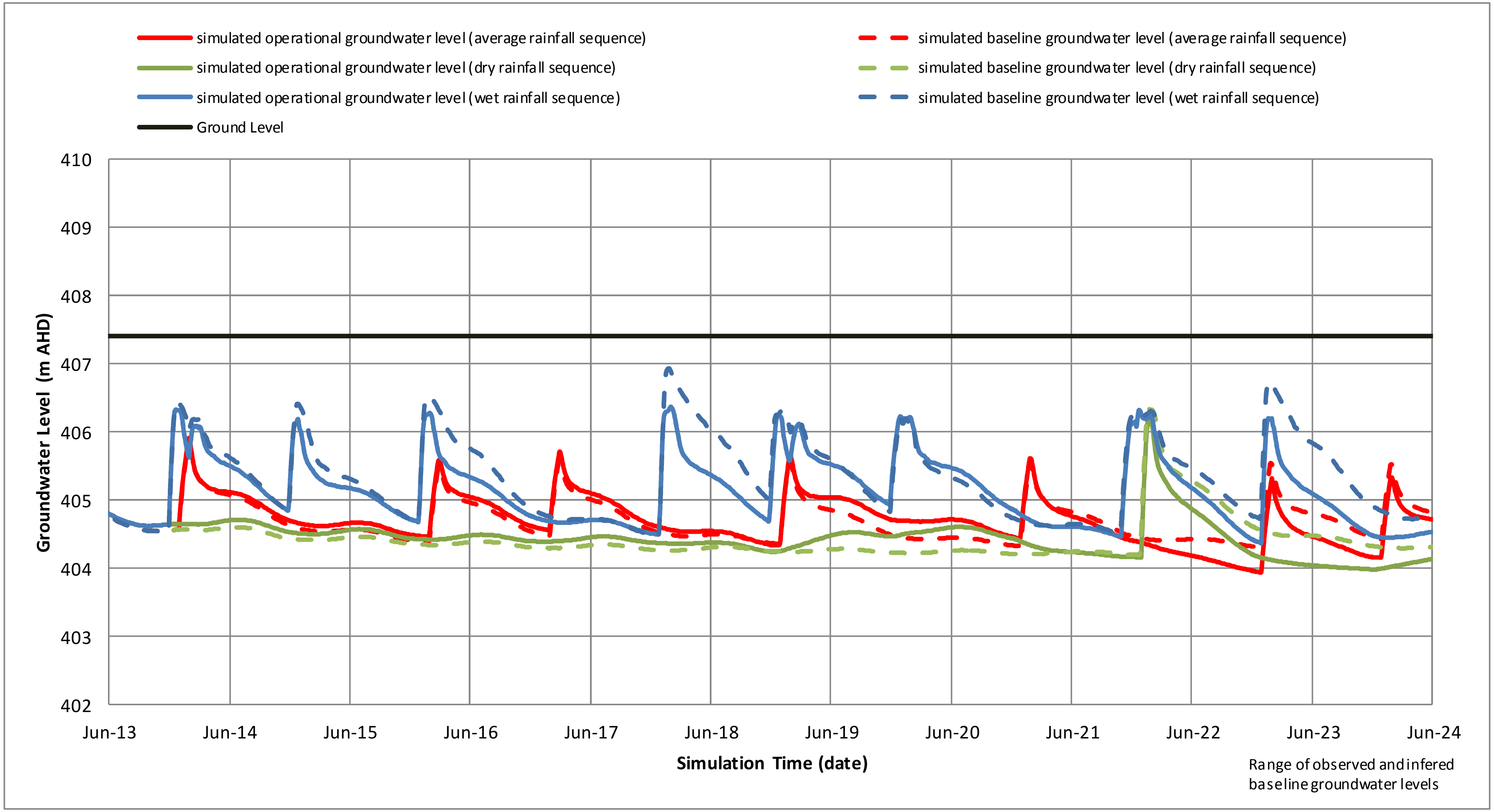

**Hydrographs at CBFM01 under natural (dashed lines) and mining (solid lines) conditions for Base, Dry and Wet scenarios**

**Figure 36**

11/11/2013

Figure 37: Hydrograph at CBFMM02_s, under natural and mining conditions for the Base, Dry and Wet simulations

This page has been left blank intentionally




Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

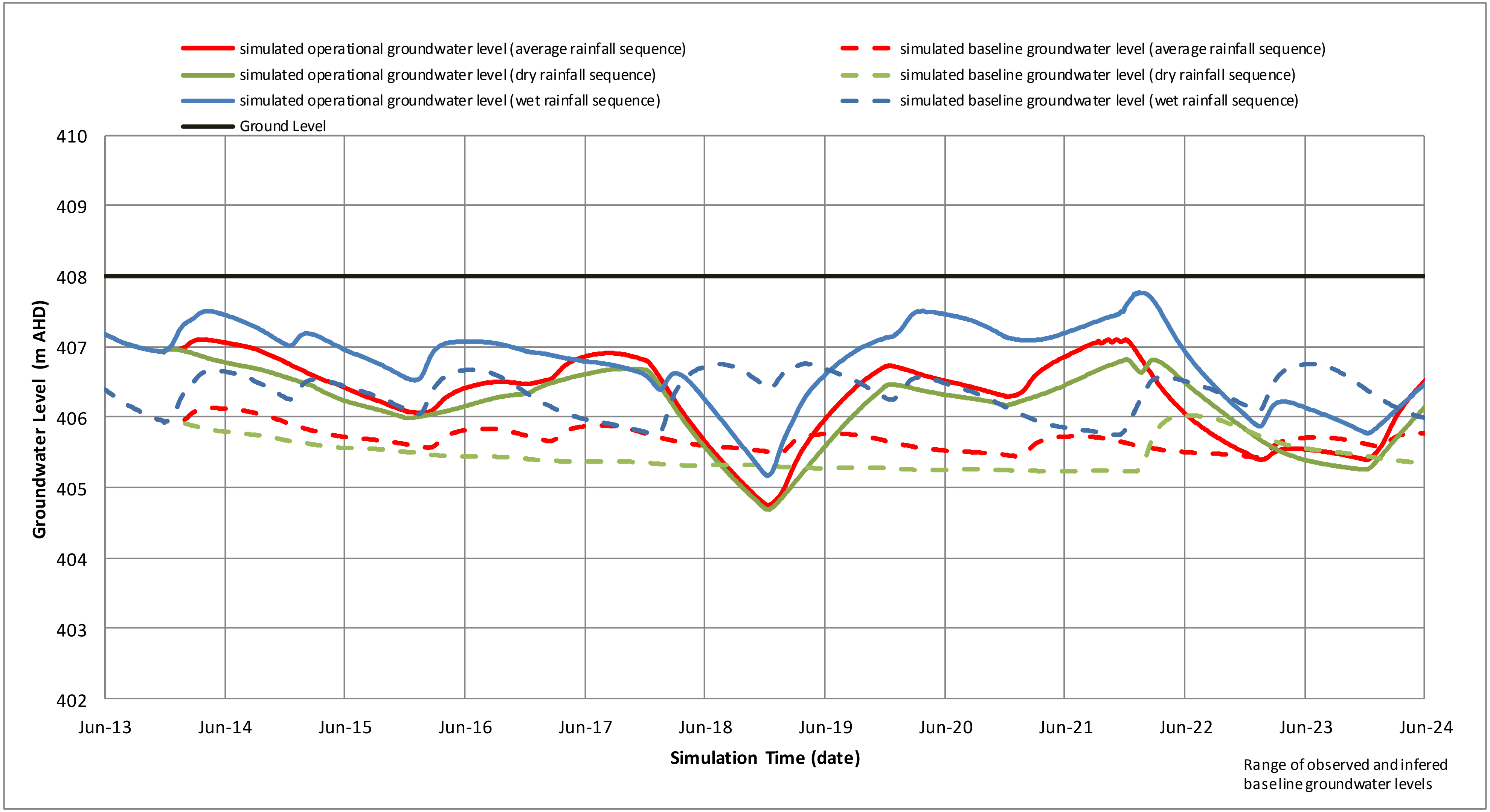
**Hydrographs at CBFM02 under natural (dashed lines) and mining (solid lines) conditions for Base, Dry and Wet scenarios**

**Figure 37**

11/11/2013

Figure 38: Hydrograph at CBFMM04_s, under natural and mining conditions for the Base, Dry and Wet simulations

This page has been left blank intentionally





Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

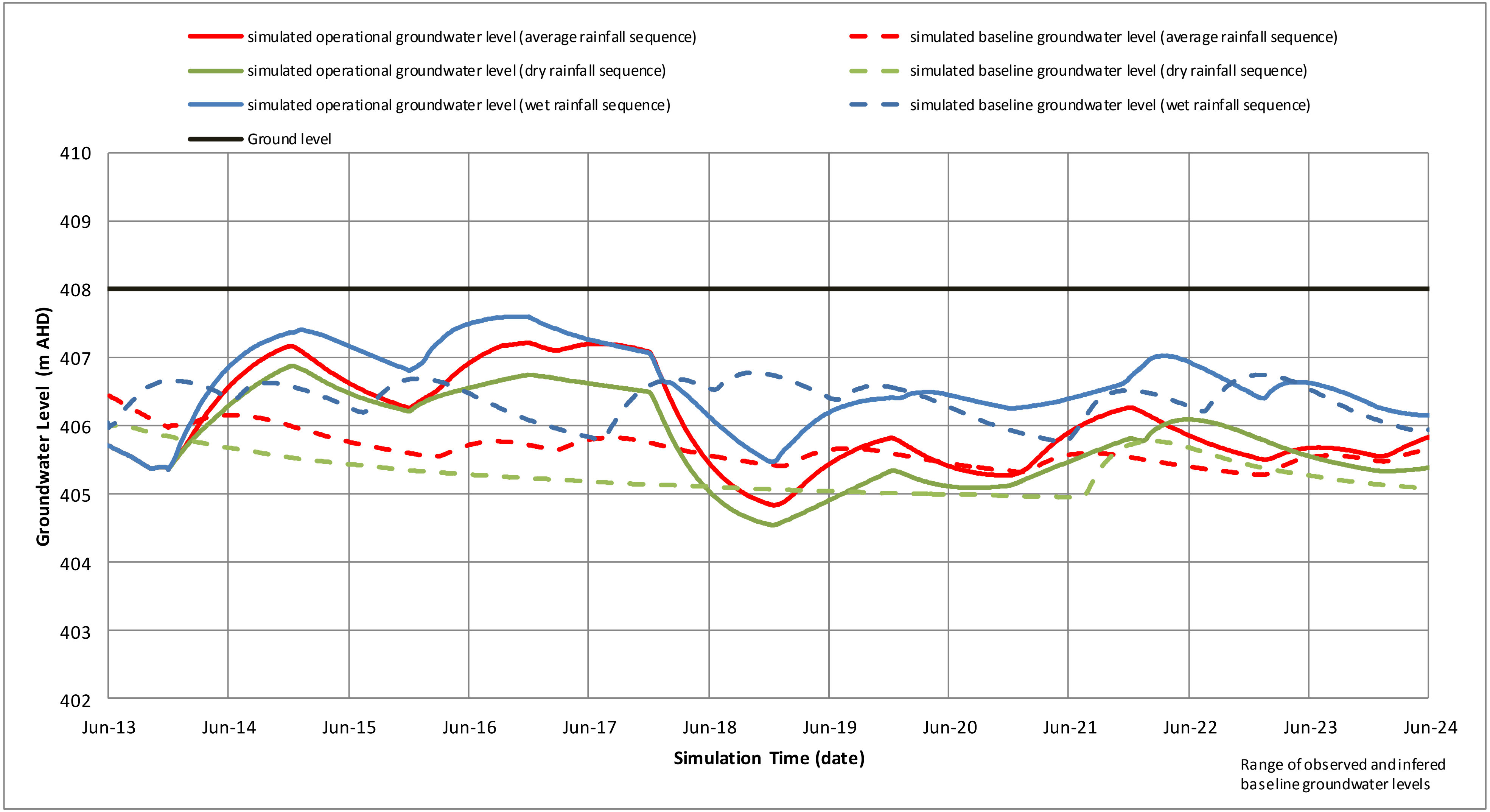

**Hydrographs at CBFM04 under natural (dashed lines) and mining (solid lines) conditions for Base, Dry and Wet scenarios**

**Figure 38**

11/11/2013

Figure 39: Hydrograph at CBFMM05_s, under natural and mining conditions for the Base, Dry and Wet simulations

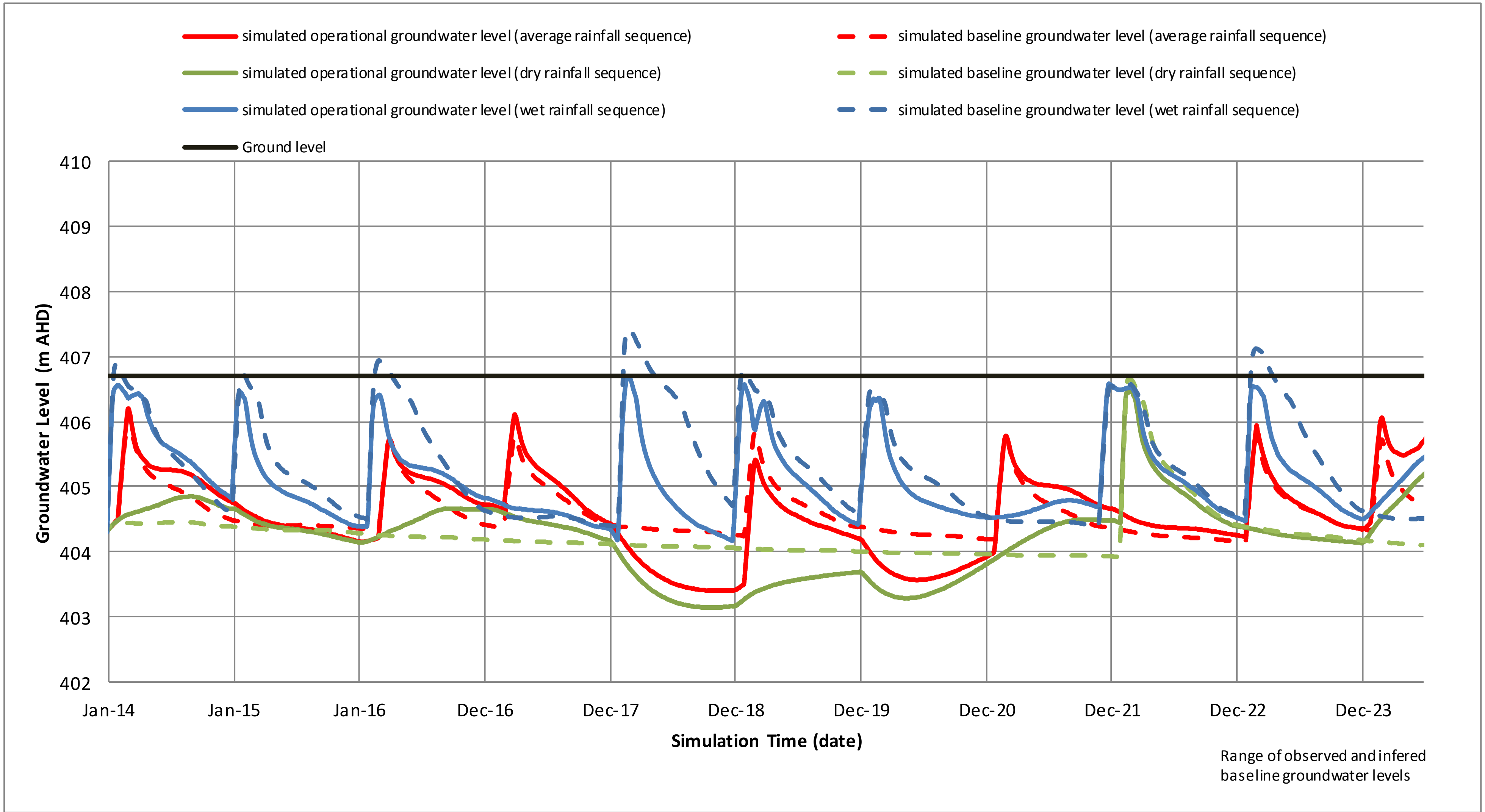
This page has been left blank intentionally




| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Hydrographs at CBFM05 under natural (dashed lines) and mining (solid lines) conditions for Base, Dry and Wet scenarios** | **Figure 39** |
| | | 11/11/2013 |

Figure 40: Hydrograph at CBFMM06_s, under natural and mining conditions for the Base, Dry and Wet simulations

This page has been left blank intentionally





Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

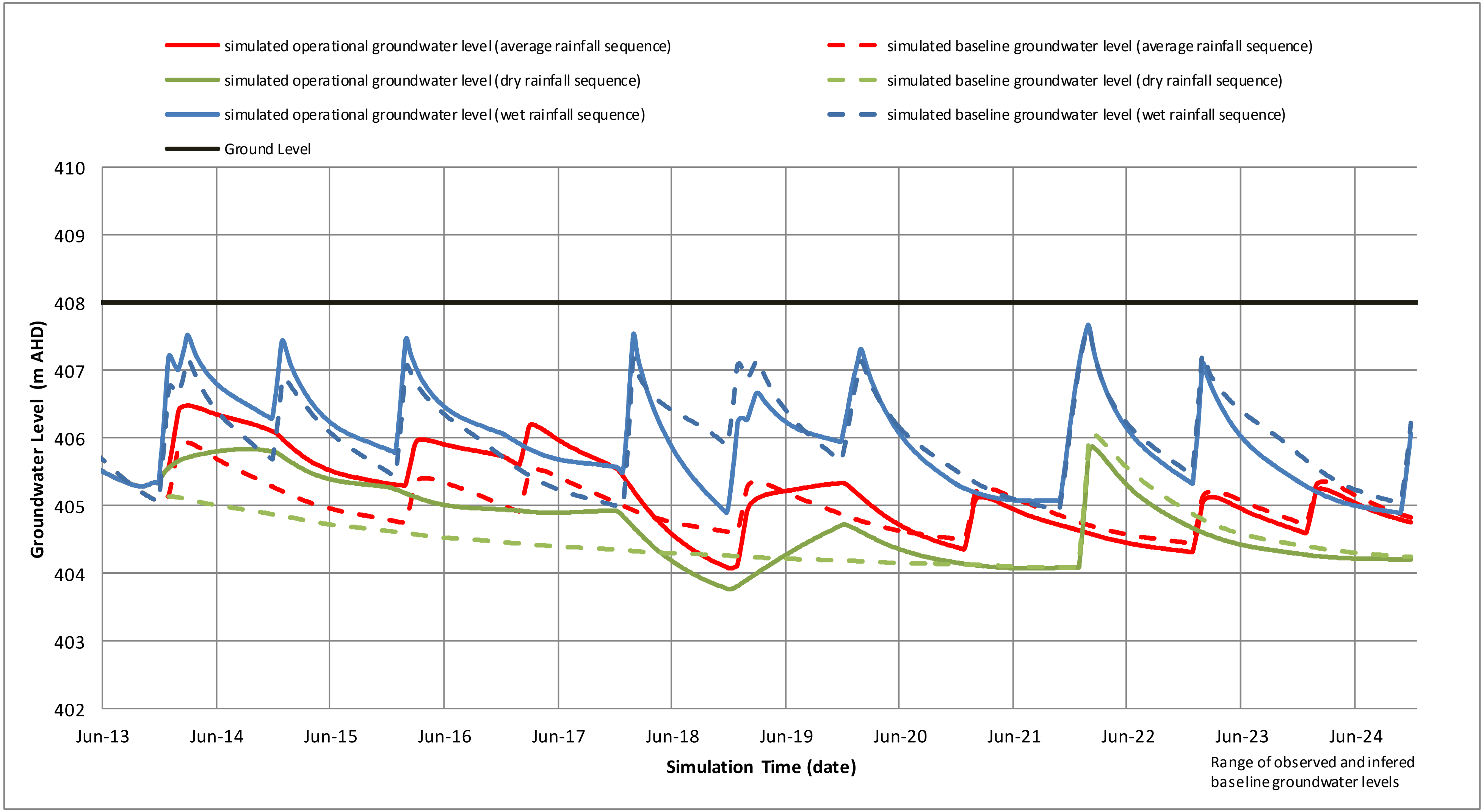

**Hydrographs at CBFM06 under natural (dashed lines) and mining (solid lines) conditions for Base, Dry and Wet scenarios**

**Figure 40**

11/11/2013

Figure 41: Hydrograph at CBFMM07_s, under natural and mining conditions for the Base, Dry and Wet simulations

This page has been left blank intentionally





Fortescue Metals Group Ltd
ACN: 002 594 872
87 Adelaide Terrace, East Perth
Western Australia 6004

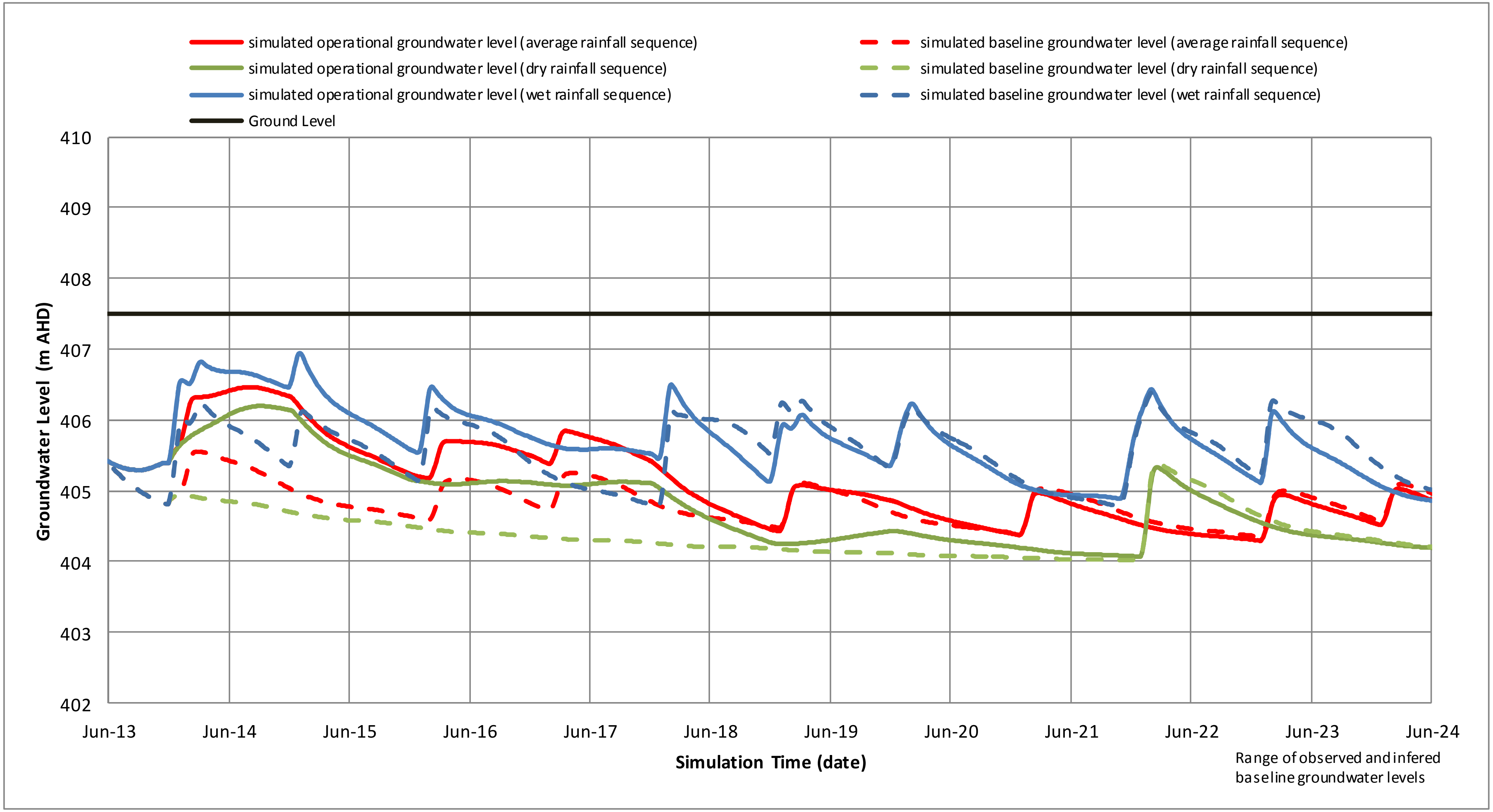

**Hydrographs at CBFM07 under natural (dashed lines) and mining (solid lines) conditions for Base, Dry and Wet scenarios**

**Figure 41**

11/11/2013

Figure 42: Hydrograph at CBFMM08_s, under natural and mining conditions for the Base, Dry and Wet simulations

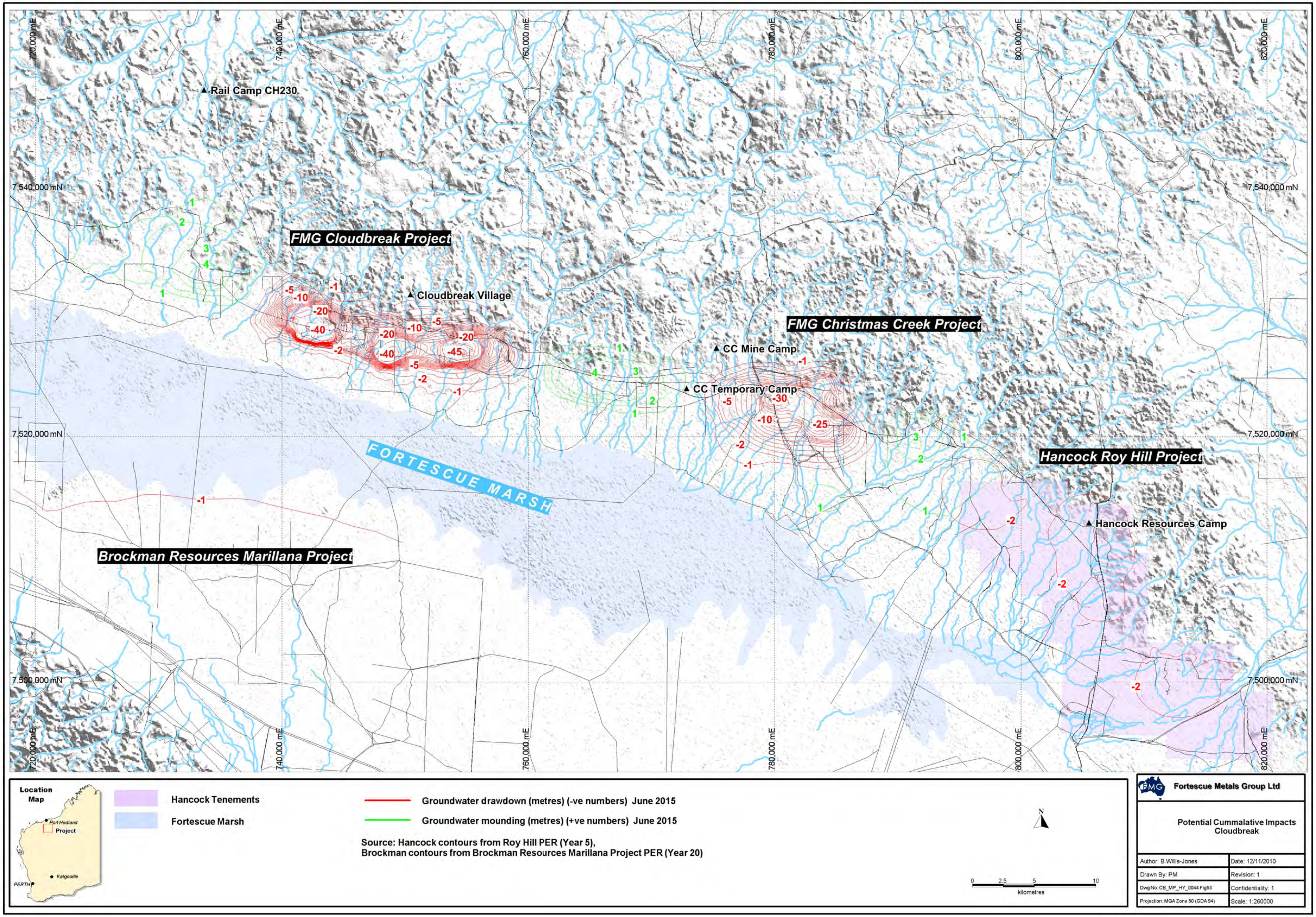
This page has been left blank intentionally




| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | **Hydrographs at CBFM08 under natural (dashed lines) and mining (solid lines) conditions for Base, Dry and Wet scenarios** | **Figure 42** |
| | | 11/11/2013 |

Figure 43: Cumulative impact on groundwater levels

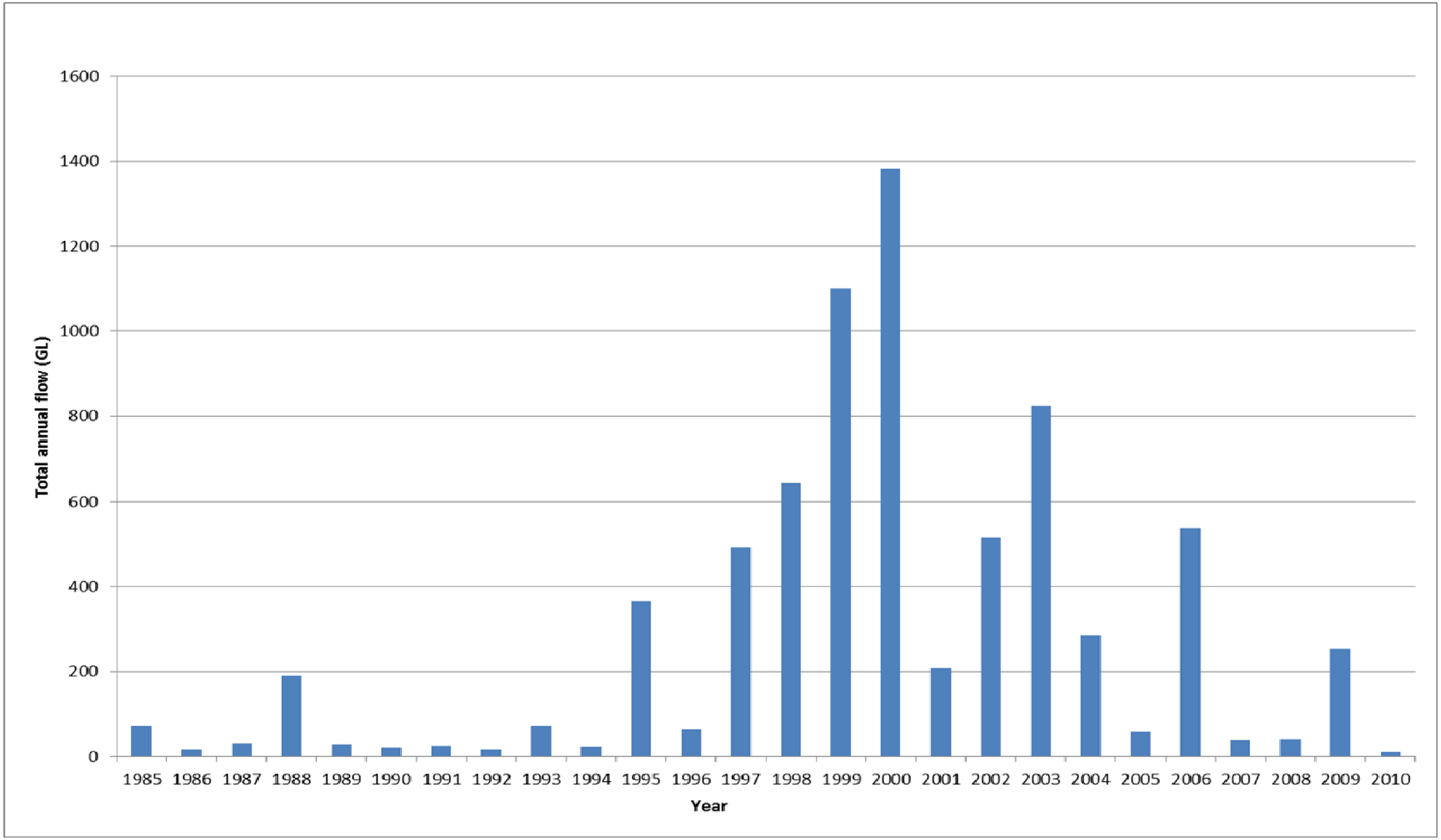
This page has been left blank intentionally



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
Rail Camp CH230
FMG Cloudbreak Project
Cloudbreak Village
FMG Christmas Creek Project
CC Mine Camp
CC Temporary Camp
FORTESCUE MARSH
Hancock Roy Hill Project
Hancock Resources Camp
Brockman Resources Marillana Project
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Hancock Tenements
Fortescue Marsh
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
Cloudbreak
Author: B.Willis-Jones
Date: 12/11/2010
Drawn By: PM
Revision: 1
Dwg No: CB_MP_HY_0044 Fig53
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:260000

# Figure 44: Fortescue Marsh Water Balance

This page has been left blank intentionally

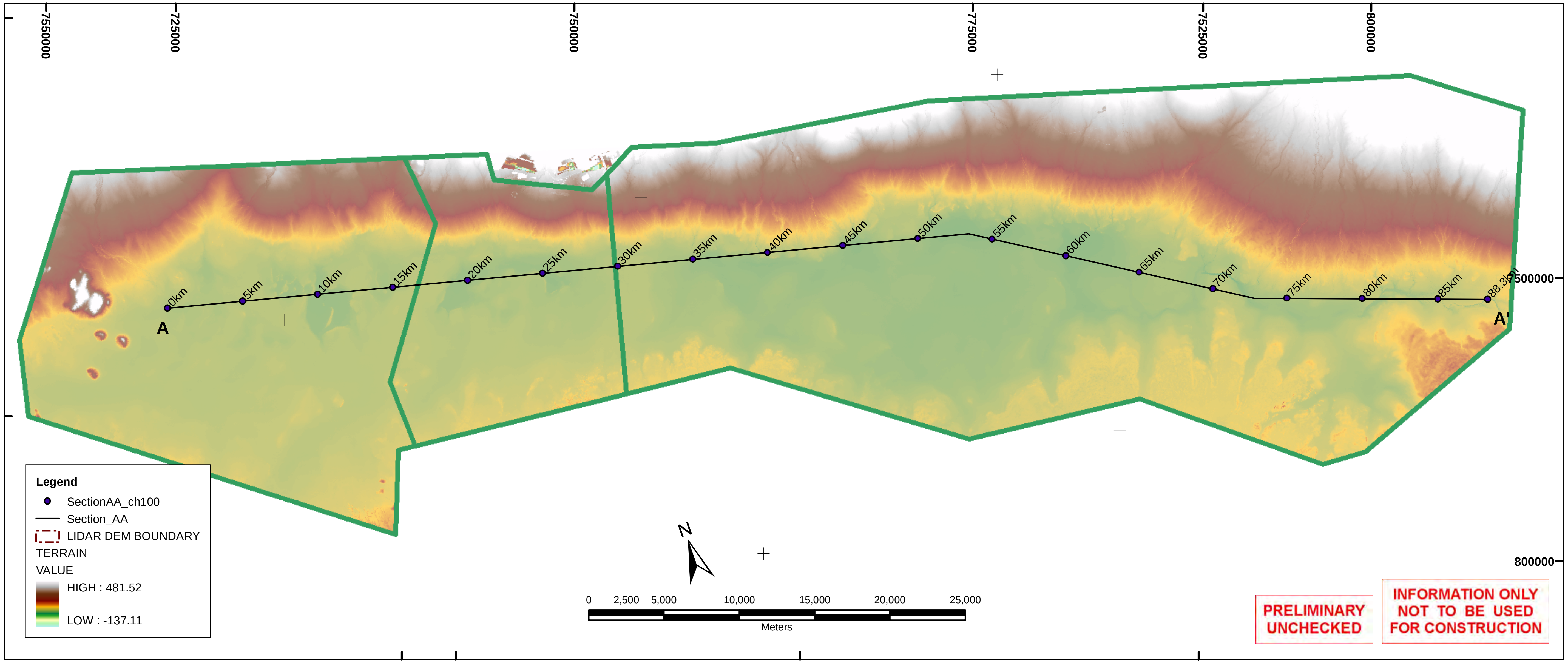


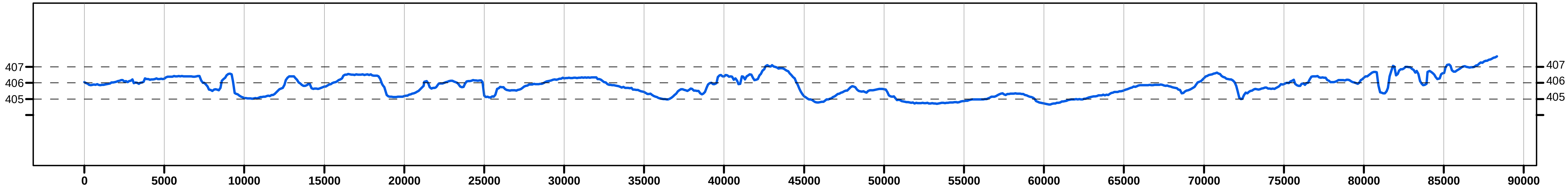

| | | |
|---|---|---|
| Fortescue Metals Group Ltd<br>ACN: 002 594 872<br>87 Adelaide Terrace, East Perth<br>Western Australia 6004 | Fortescue Marsh—Water Balance Model results (1985 to 2010) | **Figure 44** |
| | | 13/11/2013 |

# Appendix 1: Historical Landsat data

This page has been left blank intentionally

| 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 | - |




WorleyParsons EcoNomics

resources & energy


| WORLEYPARSONS PROJECT | SCALE | DATUM |
|---|---|---|
| 201012-00252 | 1:275,000 @ A3 | GDA_1994_MGA_Zone_50 |

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

NOTES

CLIENT

FMG

TITLE

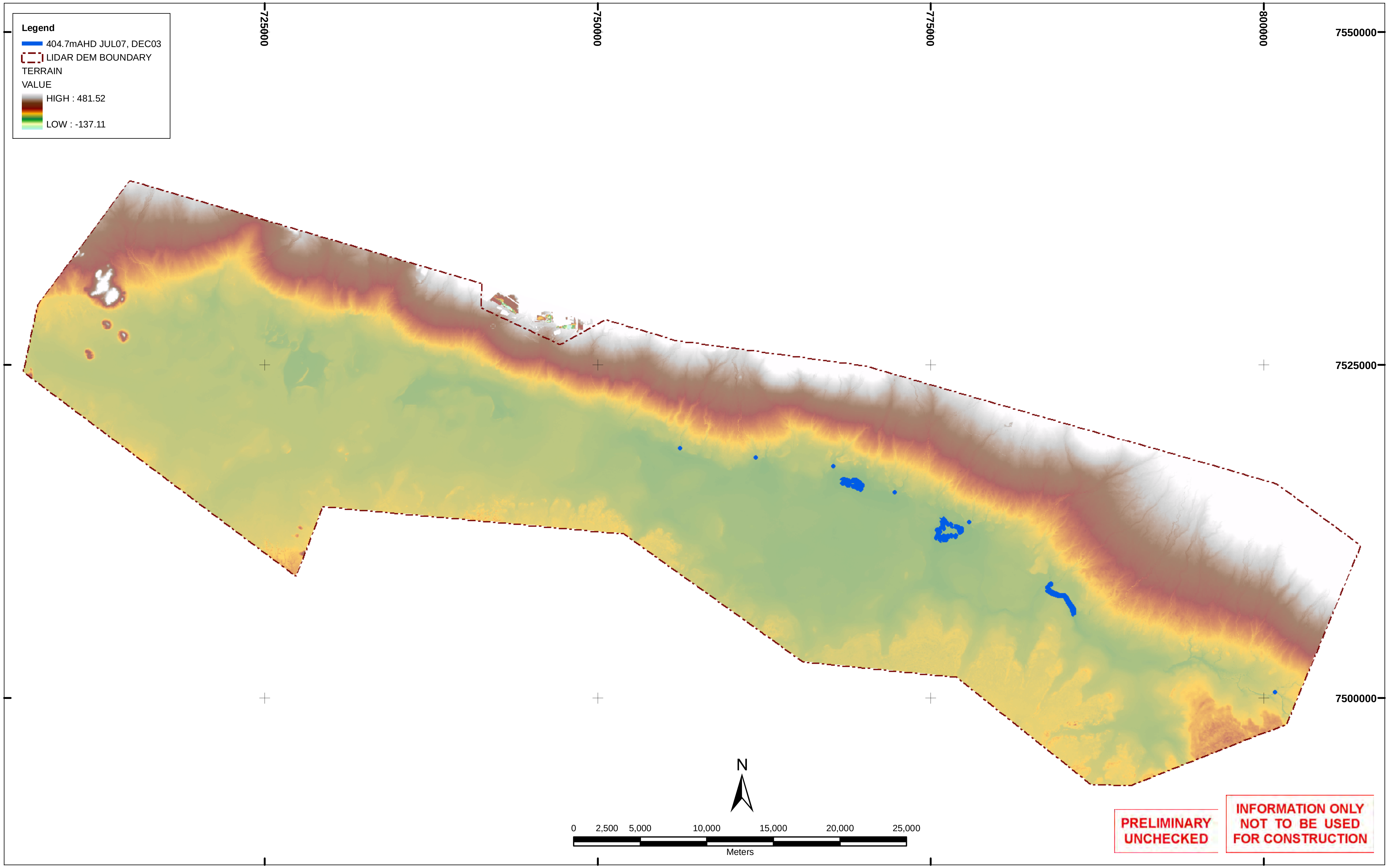
FORTESCUE MARSH
INUNDATION MAPPING
SECTION PROFILE A-A'

DRG NO 201012-00252-GIS-DSK-003

REV A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




**WorleyParsons** EcoNomics

resources & energy

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

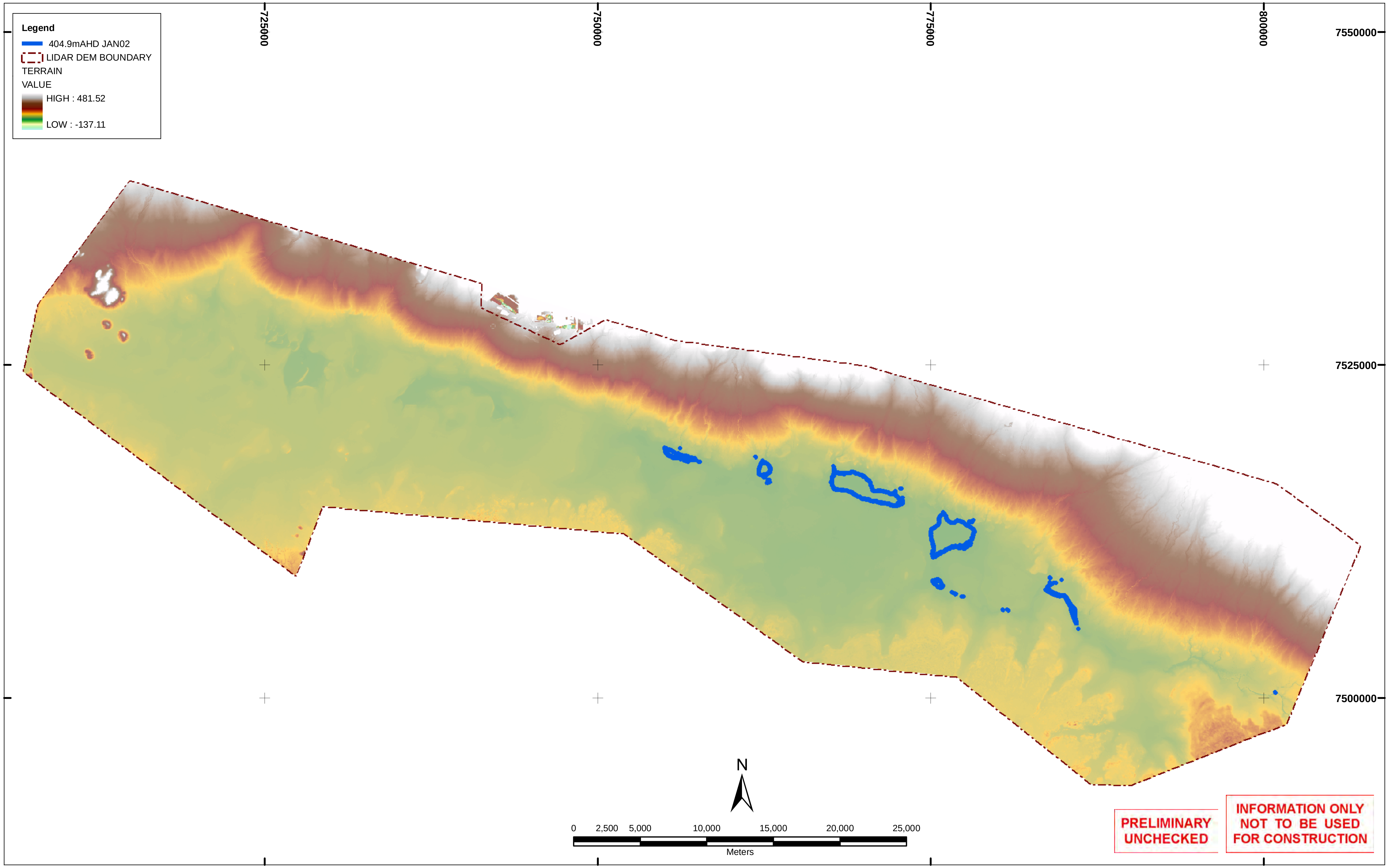
TITLE: FORTESCUE MARSH INUNDATION MAPPING 404.7mAHD JUL07, DEC03

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy


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 |

NOTES

CLIENT: FMG

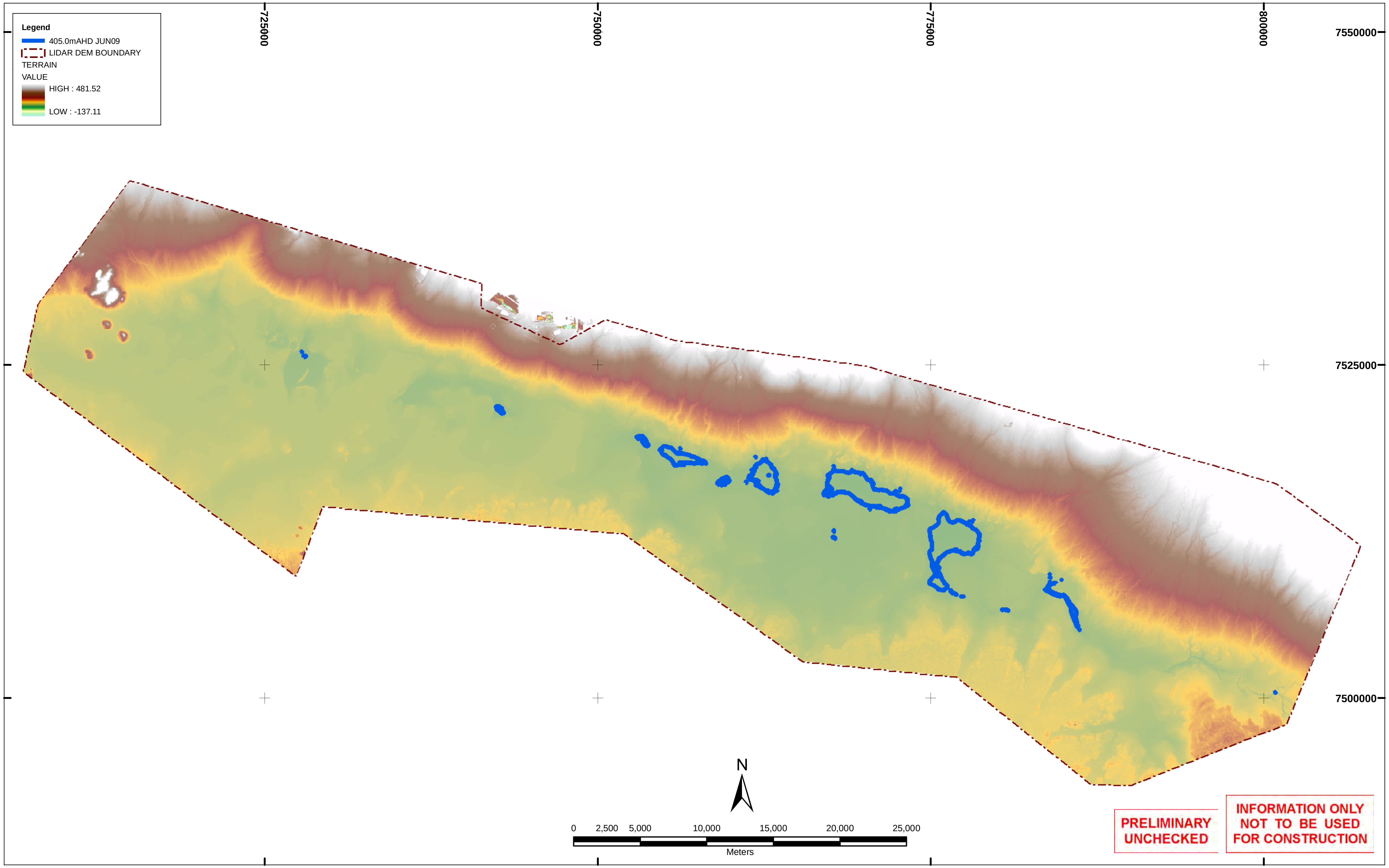
TITLE: FORTESCUE MARSH INUNDATION MAPPING 404.9mAHD JAN02

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy

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

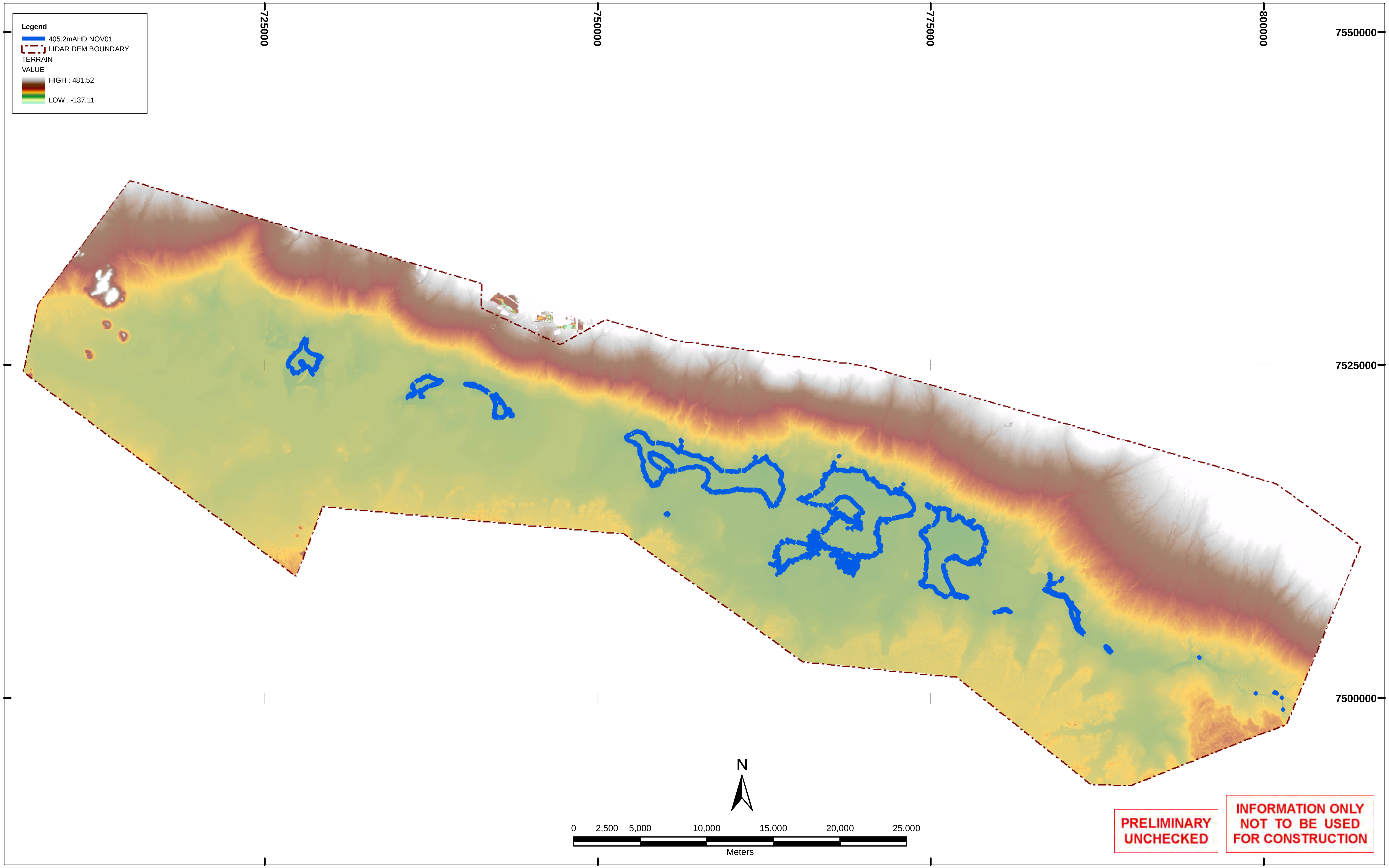
TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.0mAHD JUN09

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




**WorleyParsons** EcoNomics

resources & energy

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

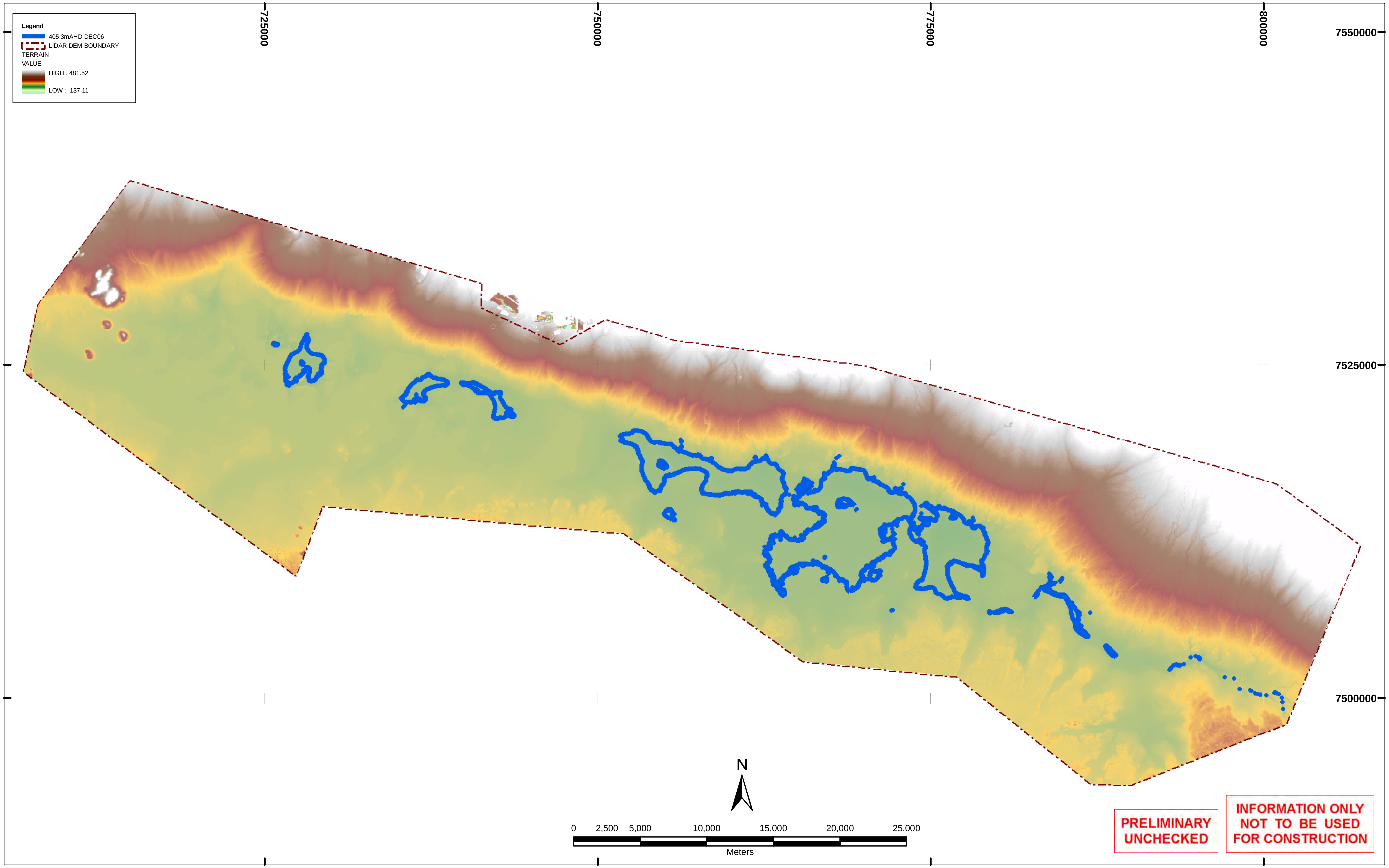
TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.2mAHD NOV01

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy

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

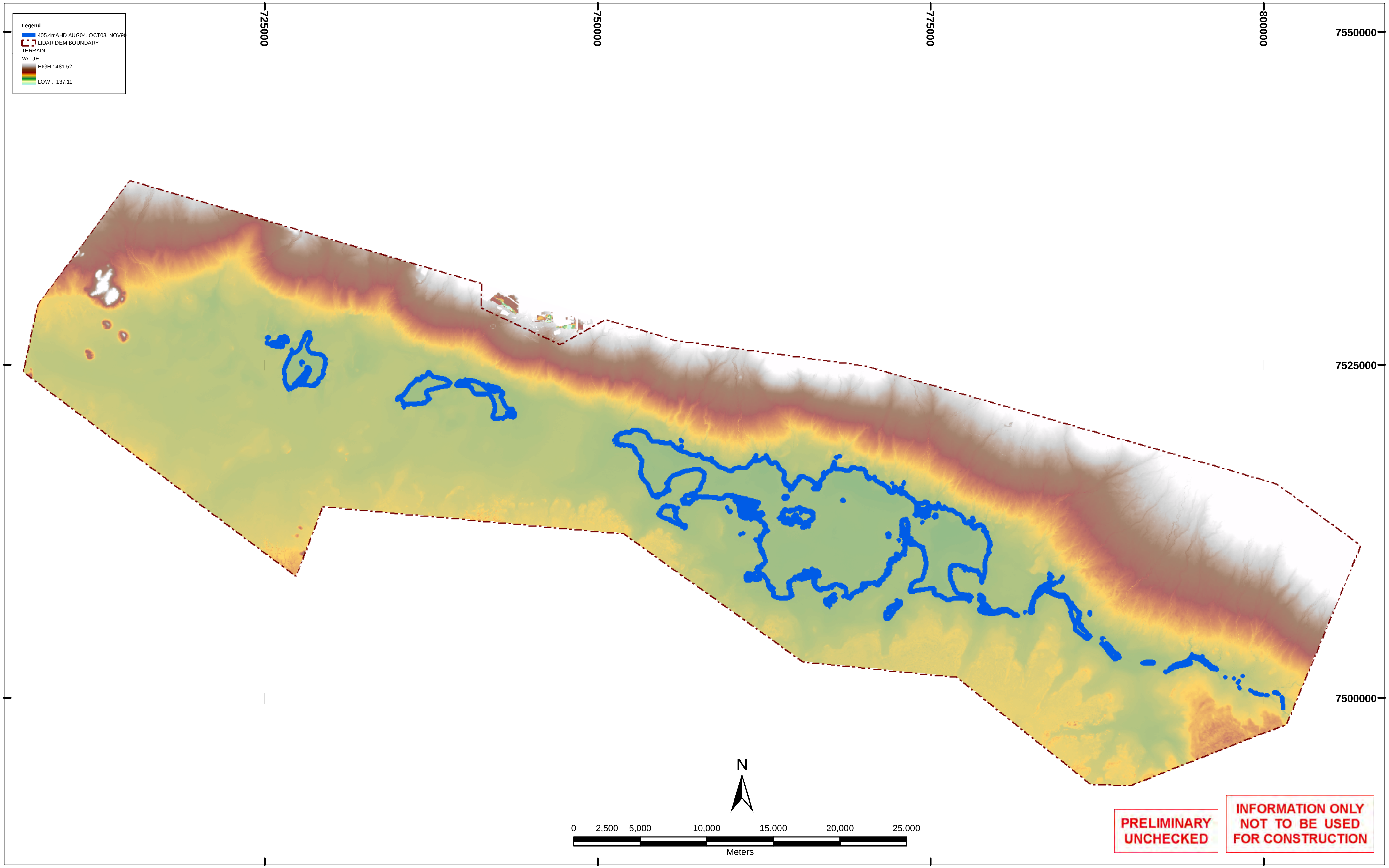
TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.3mAHD DEC06

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics

resources & energy

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

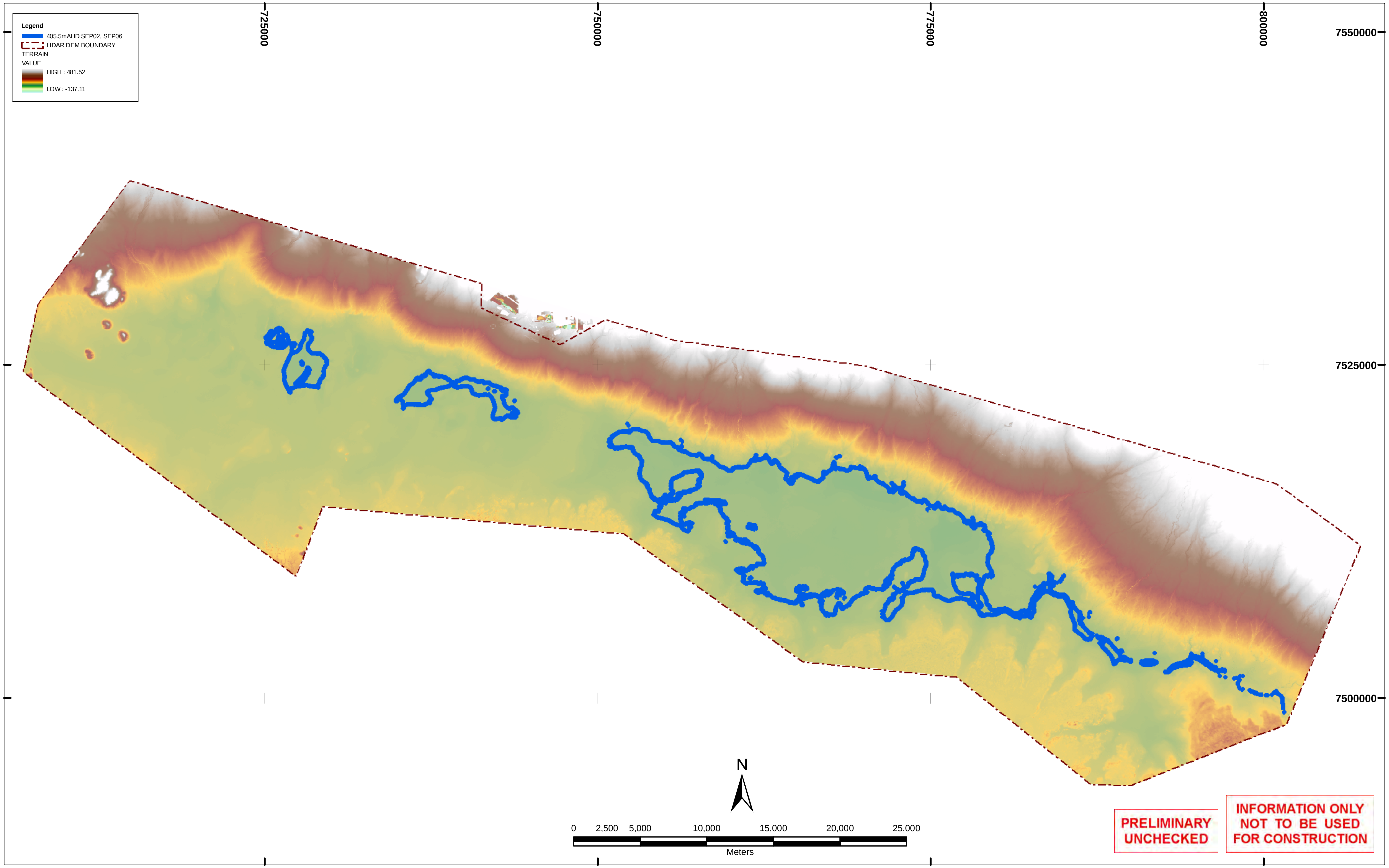
TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.4mAHD AUG04, OCT03, NOV99

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy


| | | | | |
|---|---|---|---|---|
| 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

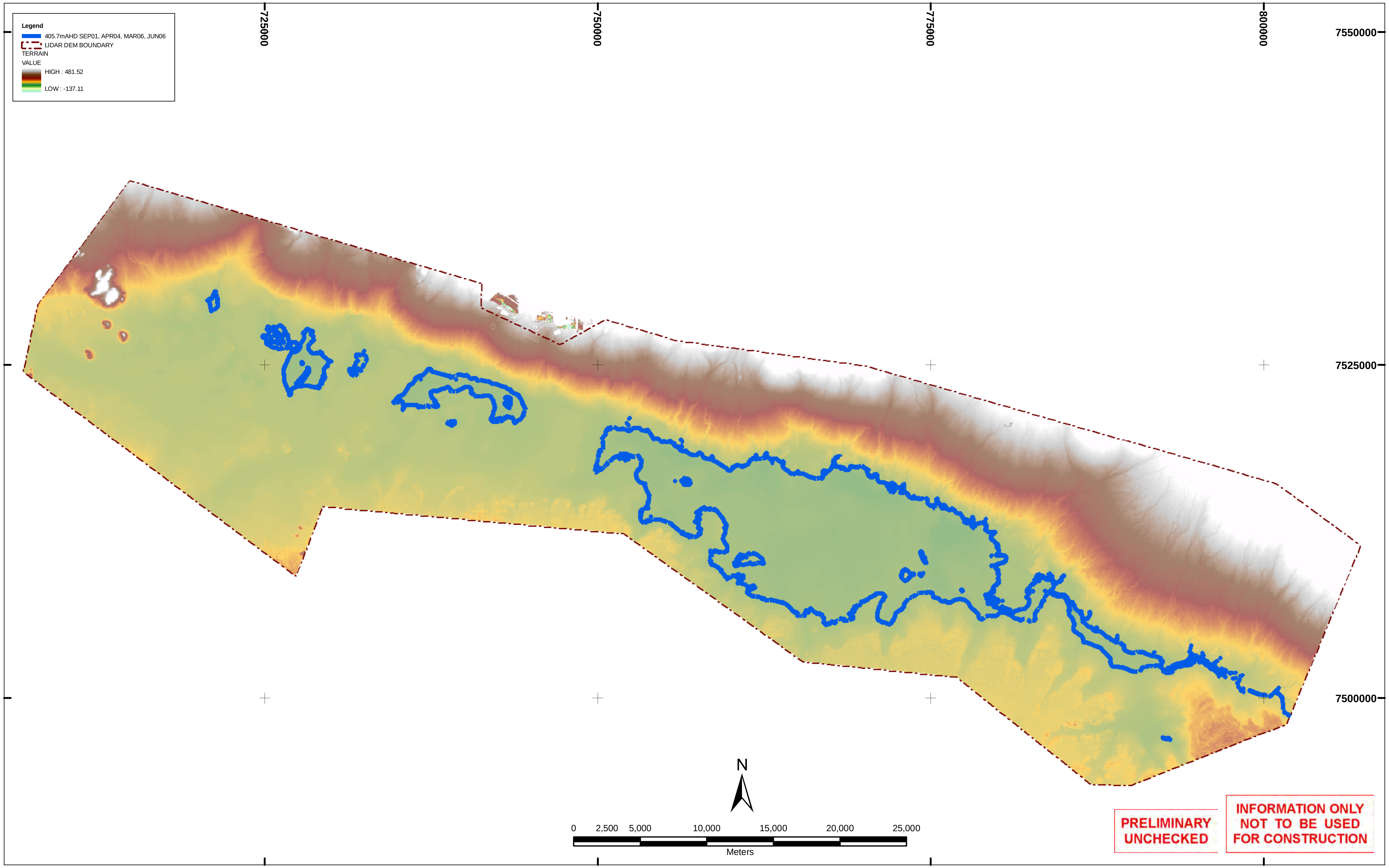
TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.5mAHD SEP02, SEP06

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy

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

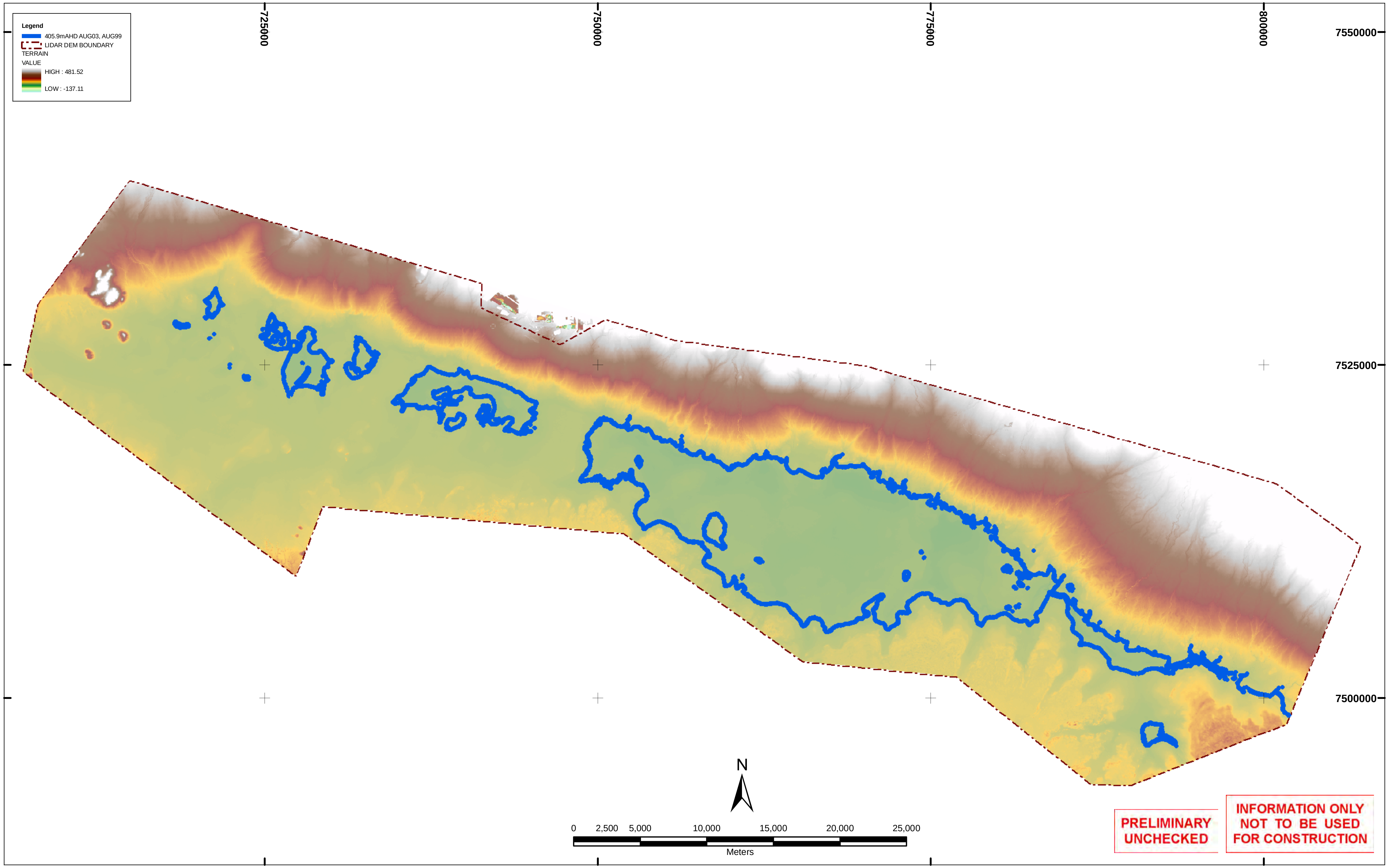
TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.7mAHD SEP01, APR04, MAR06, JUN06

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

REV: A

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.




WorleyParsons EcoNomics
resources & energy


| | | | | |
|---|---|---|---|---|
| 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

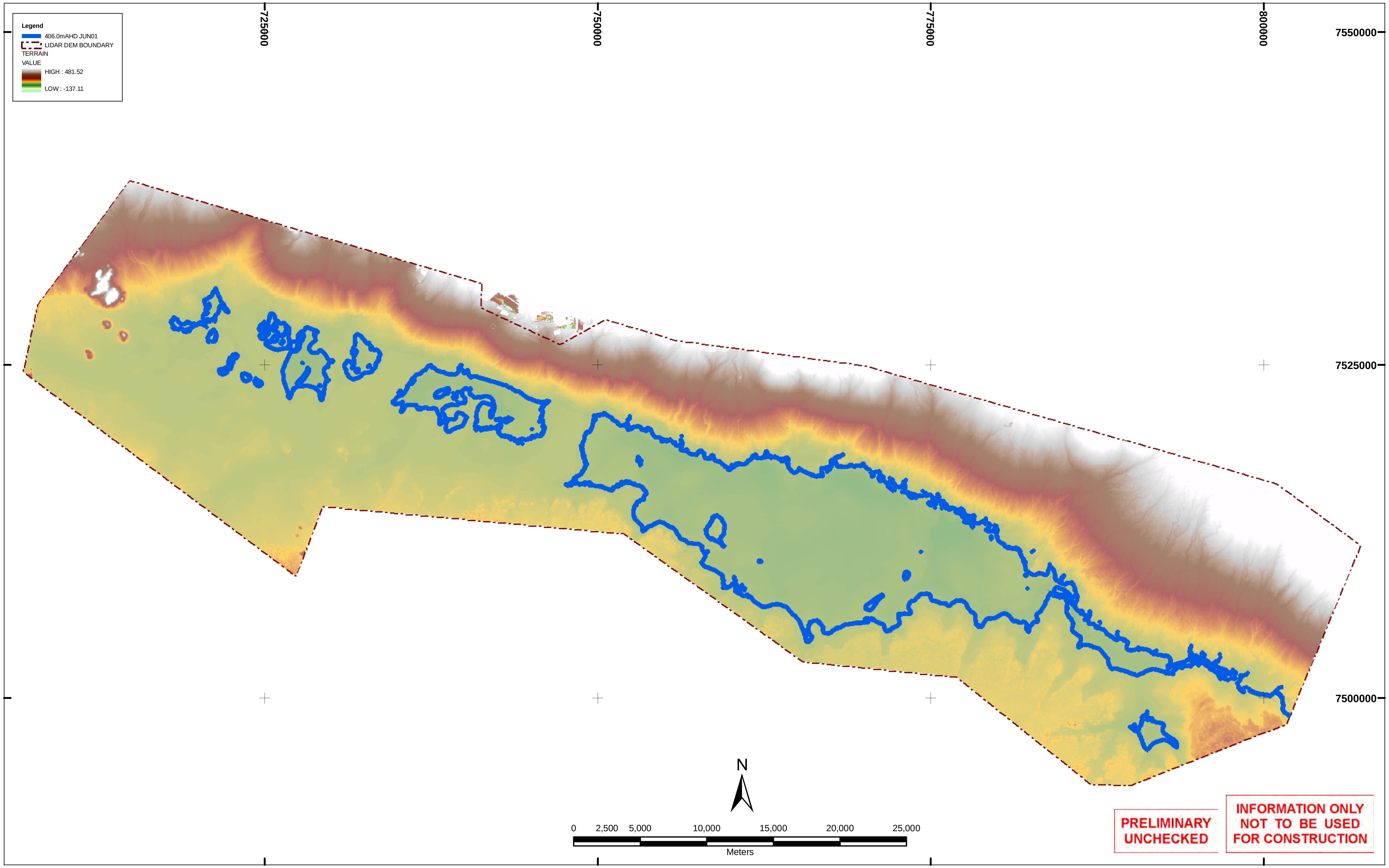
TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.9mAHD AUG03, AUG99

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

REV: A

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.




WorleyParsons EcoNomics

resources & energy

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 |

NOTES

CLIENT: FMG

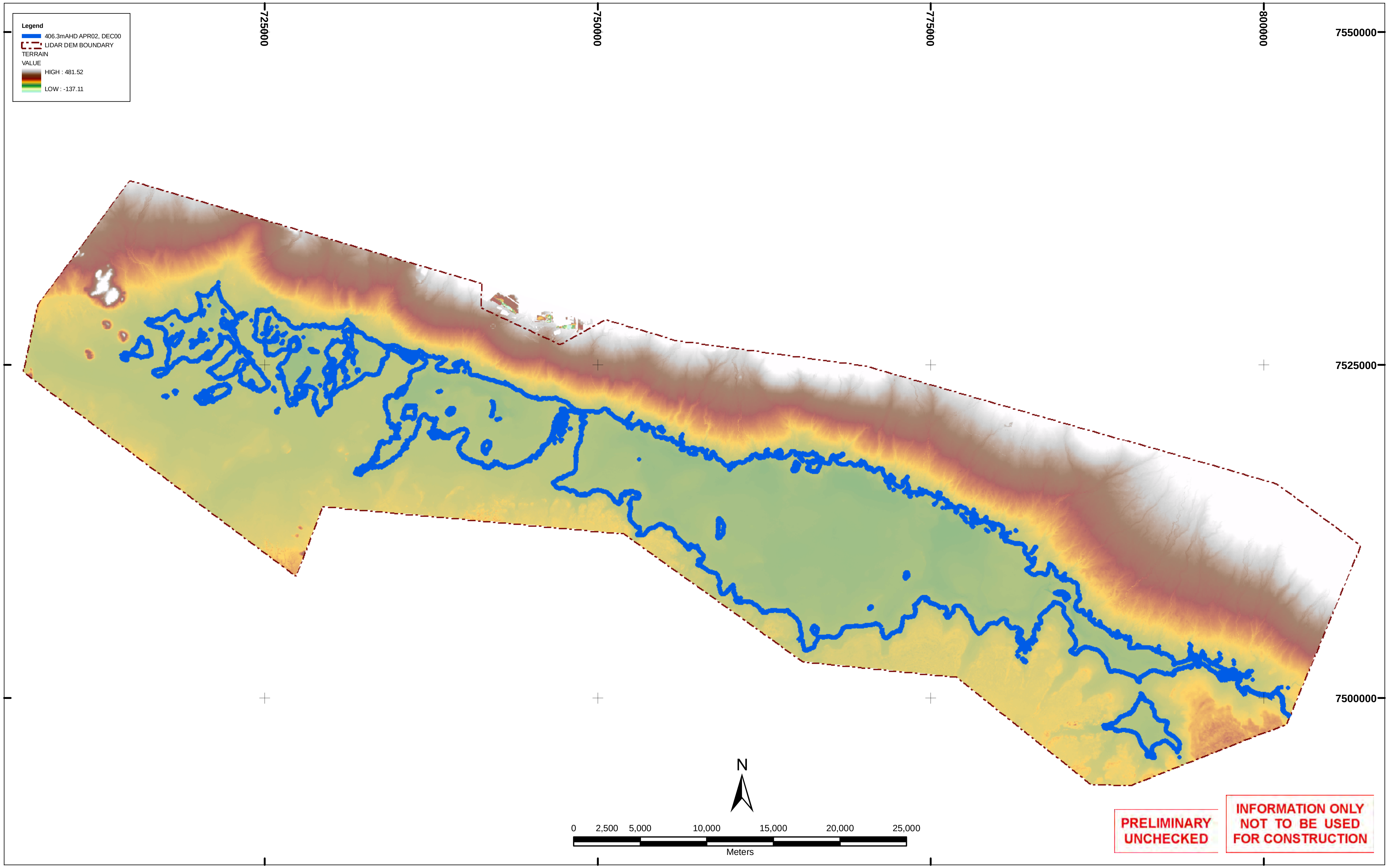
TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.0mAHD JUN01

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy


| | | | | |
|---|---|---|---|---|
| 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

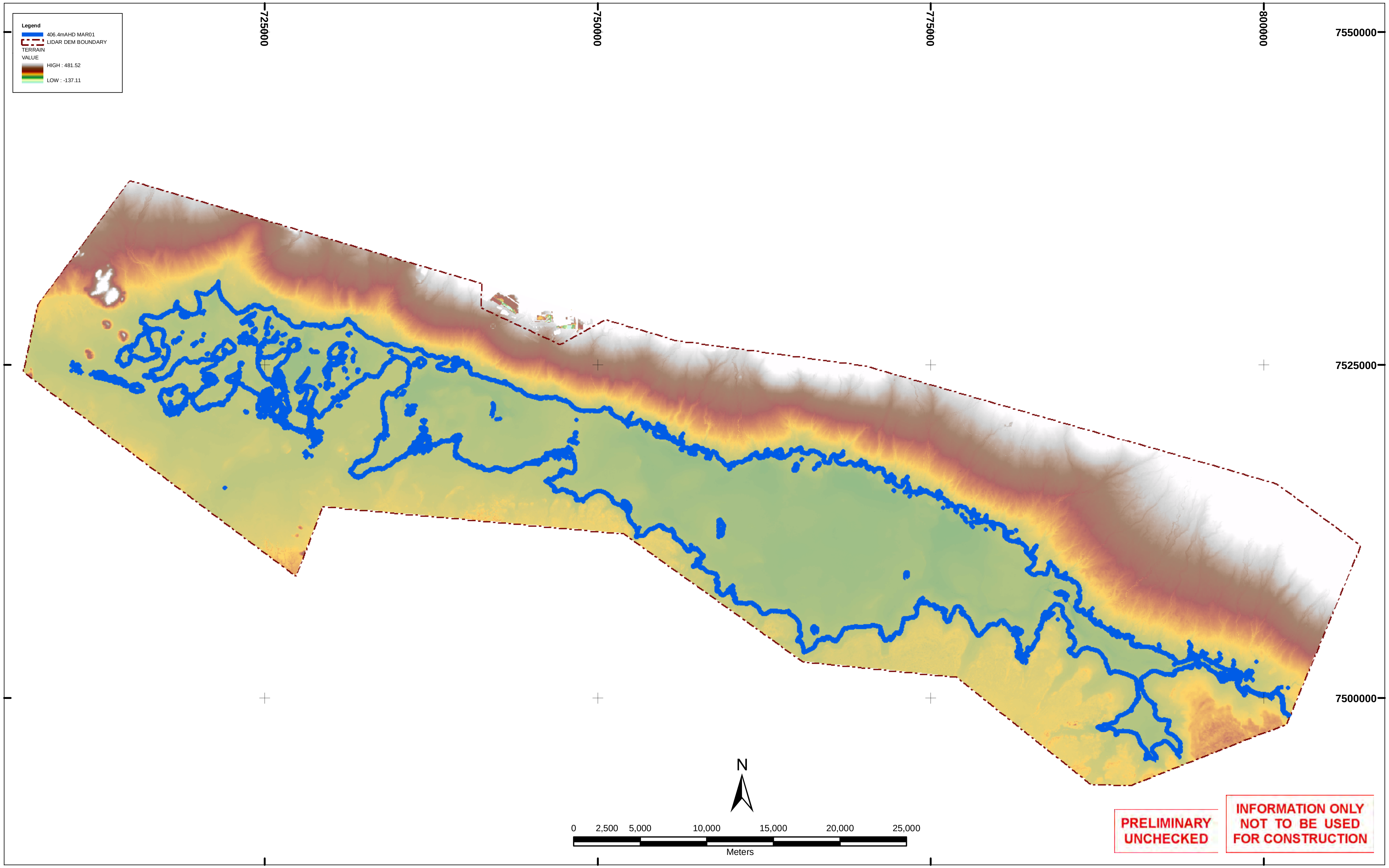
TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.3mAHD APR02, DEC00

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy


| | | | | |
|---|---|---|---|---|
| WORLEYPARSONS PROJECT: 201012-00252 | SCALE: 1:275,000 @ A3 | DATUM: GDA_1994_MGA_Zone_50 | | |
| A | ISSUED FOR INTERNAL REVIEW | | | 06.10.10 |
| REV | REVISION DESCRIPTION | DRN | CHK | DATE |

NOTES

CLIENT: FMG

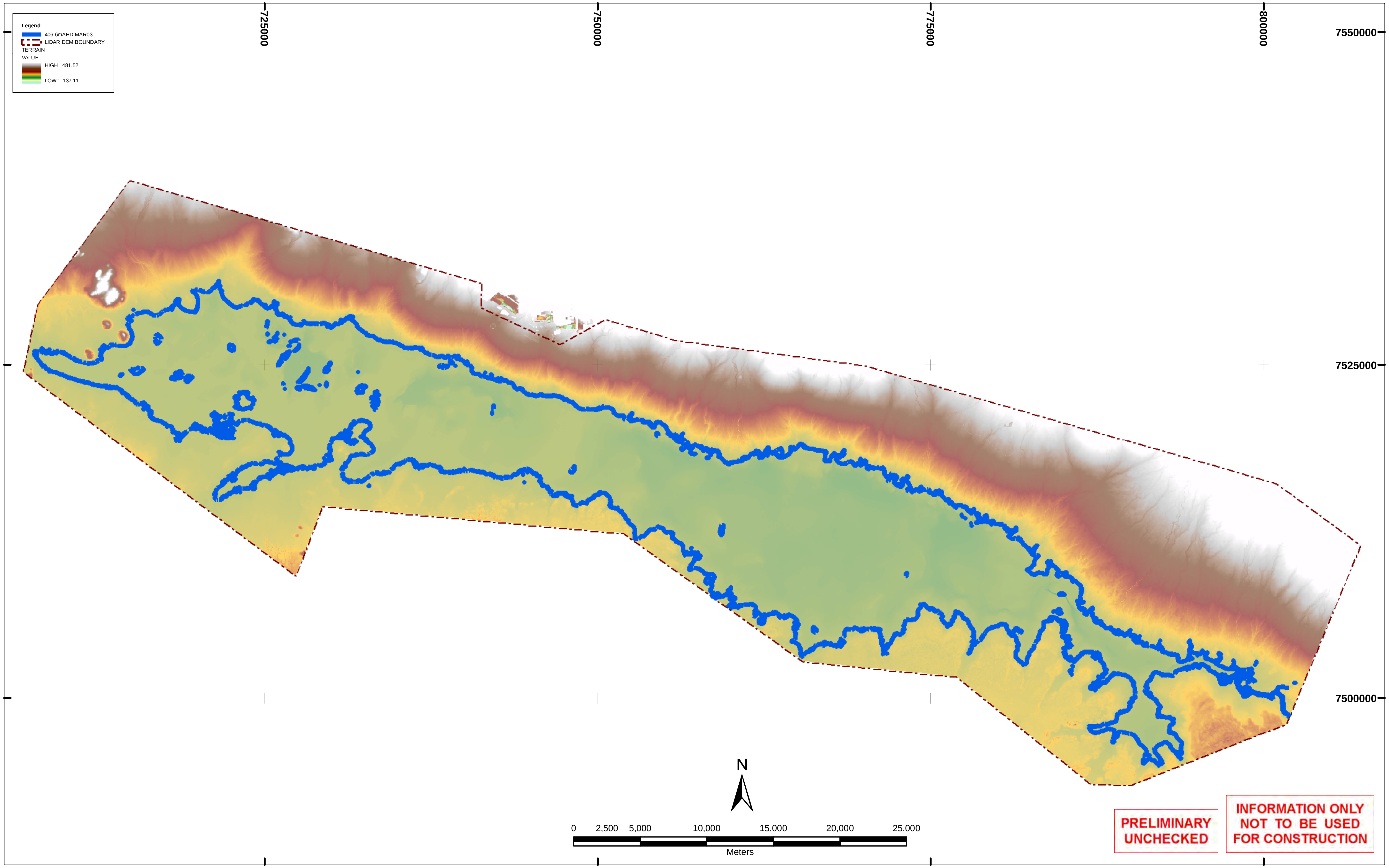
TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.4mAHD MAR01

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics

resources & energy

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

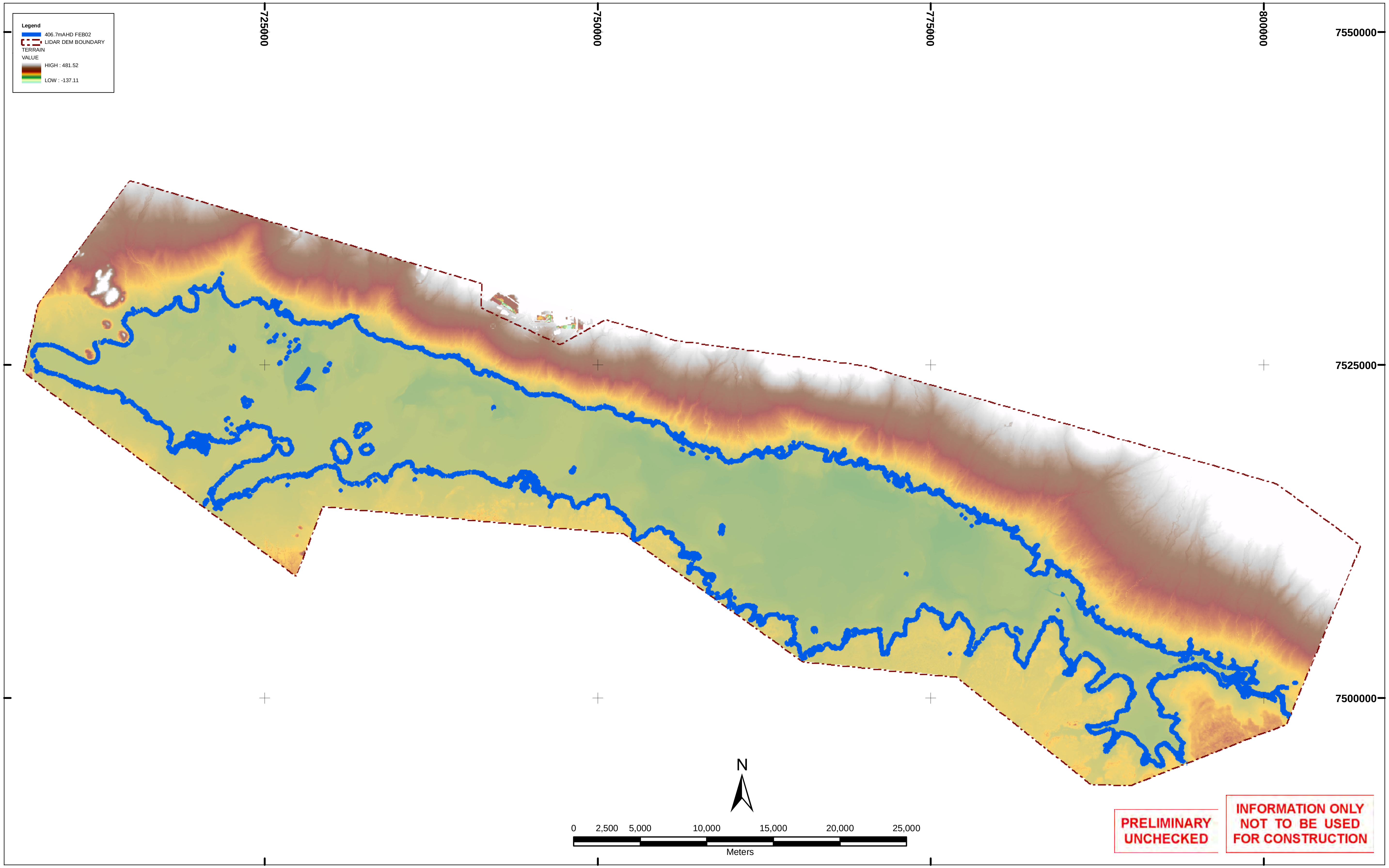
TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.6mAHD MAR03

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy

LOCALITY MAP

| WORLEYPARSONS PROJECT | SCALE | DATUM |
|---|---|---|
| 201012-00252 | 1:275,000 @ A3 | GDA_1994_MGA_Zone_50 |

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

NOTES

CLIENT
FMG

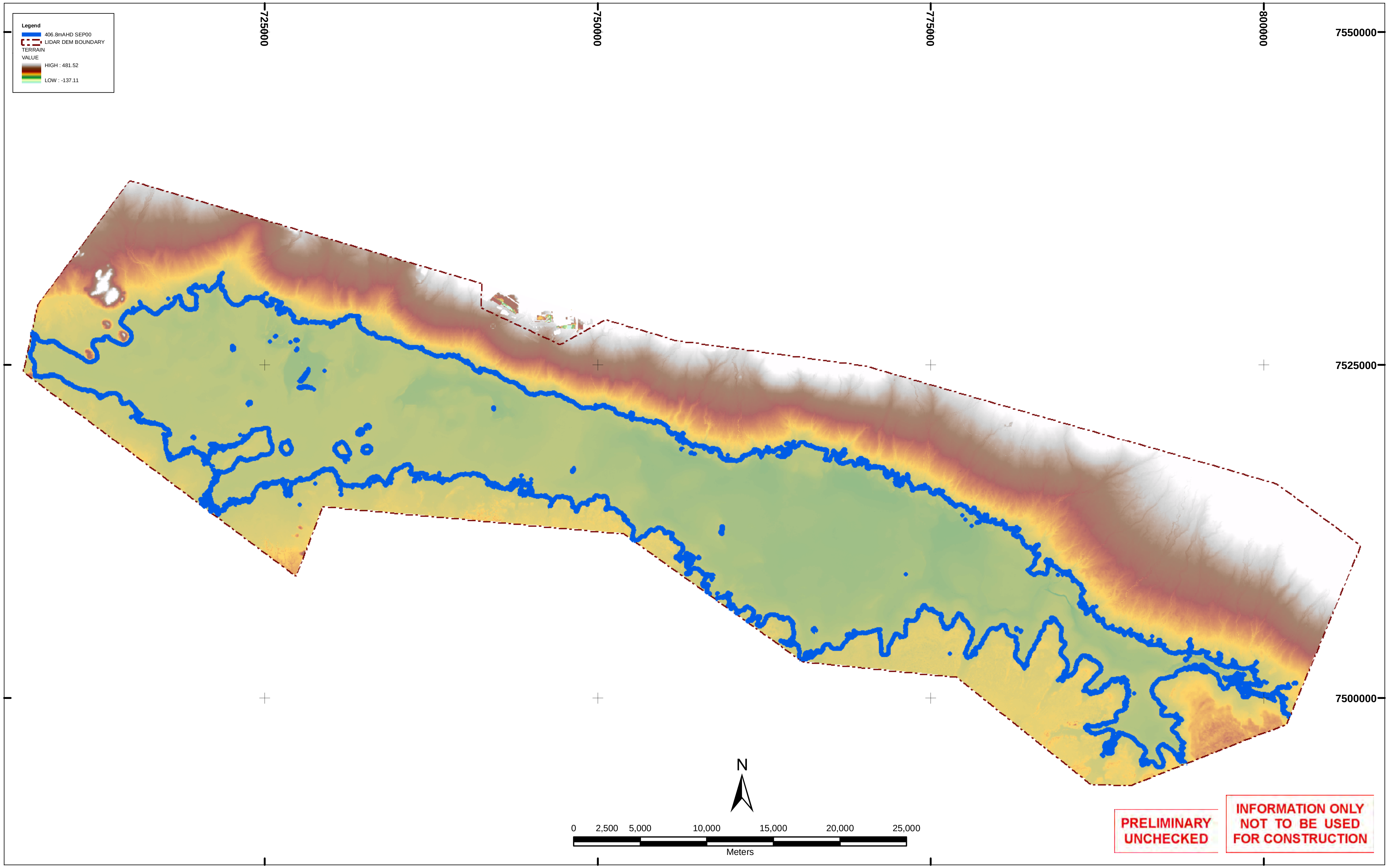
TITLE
FORTESCUE MARSH
INUNDATION MAPPING
406.7mAHD FEB02

DRG NO
201012-00252-GIS-DSK-002

REV
A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy

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

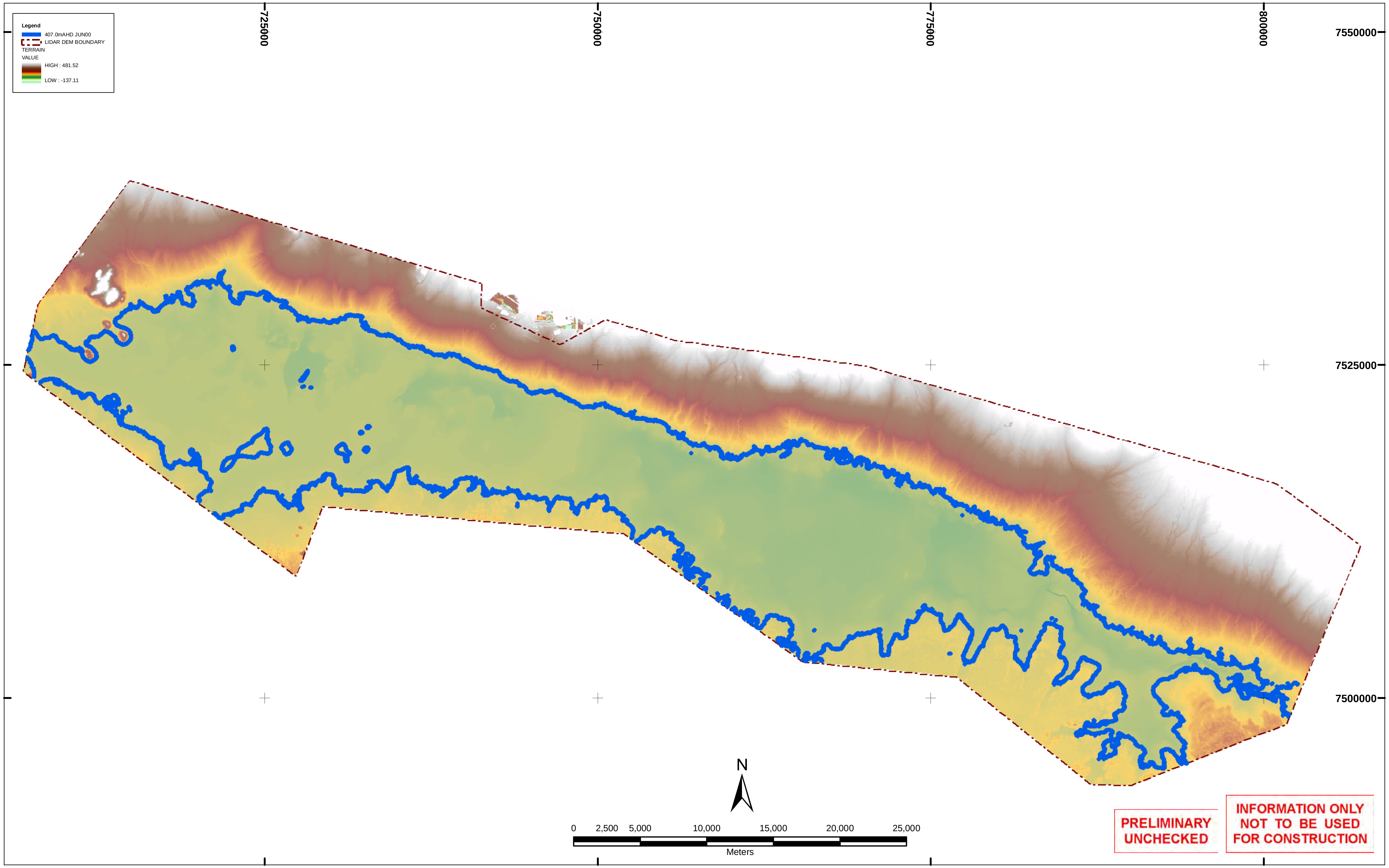
TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.8mAHD SEP00

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

REV: A

Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd




WorleyParsons EcoNomics
resources & energy


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| WORLEYPARSONS PROJECT: 201012-00252 | SCALE: 1:275,000 @ A3 | A | ISSUED FOR INTERNAL REVIEW | | | 06.10.10 | NOTES | CLIENT: FMG |
| | DATUM: GDA_1994_MGA_Zone_50 | REV | REVISION DESCRIPTION | DRN | CHK | DATE | | |

TITLE: FORTESCUE MARSH INUNDATION MAPPING 407.0mAHD JUN00

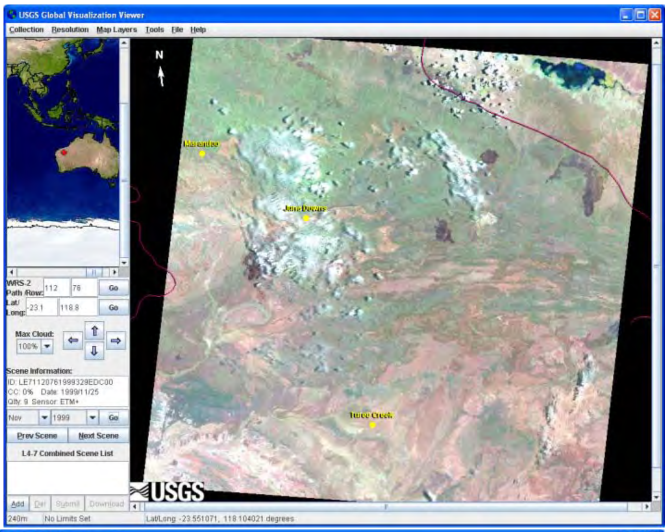
DRG NO: 201012-00252-GIS-DSK-002

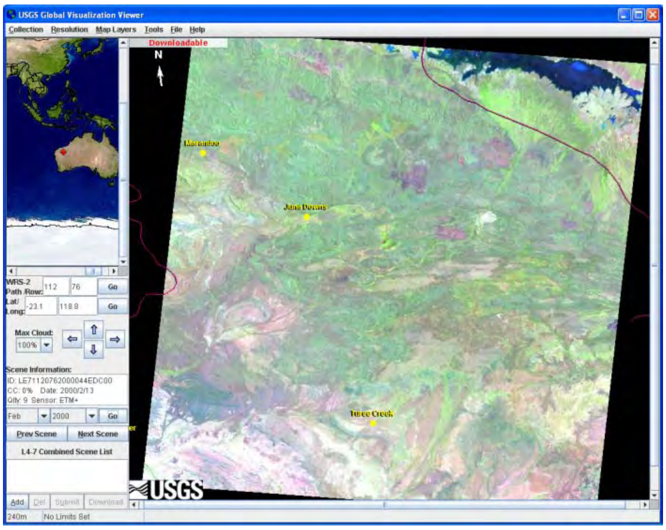
REV: A

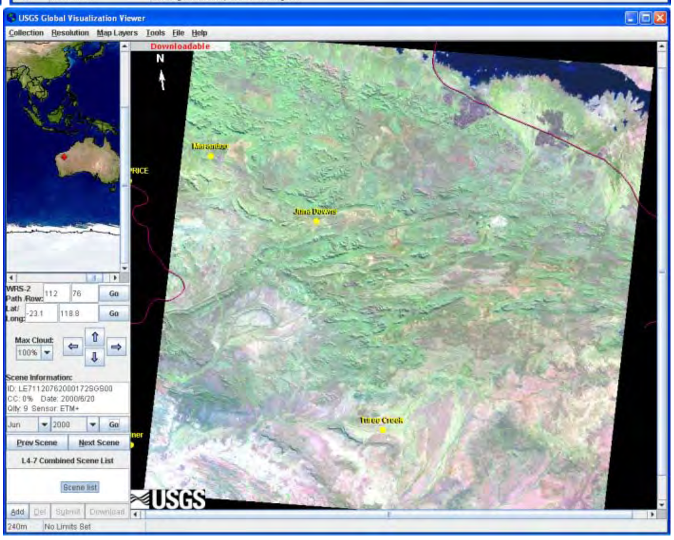
Produced by: daniel.hornby@worleyparsons.com - Geomatics W.A.

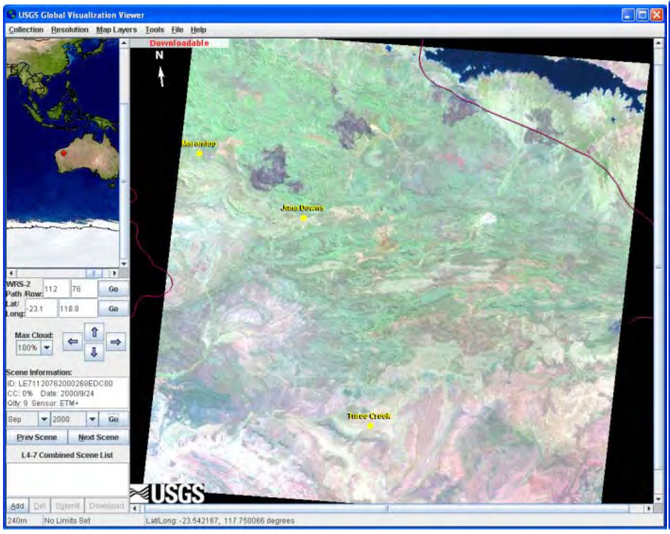
V:\201012-00252_FMG_FortescueMarsh\03Project\Workspace_SKT\201012-00252_GIS-DSK_002.mxd

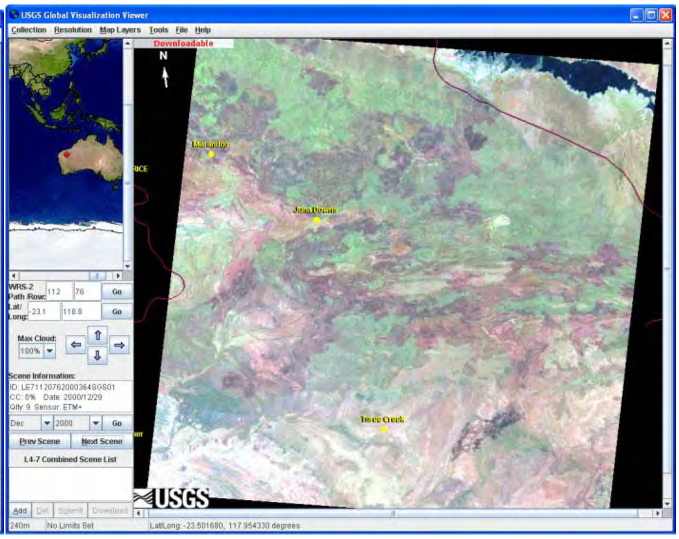
Aug 1999-Dec 2000

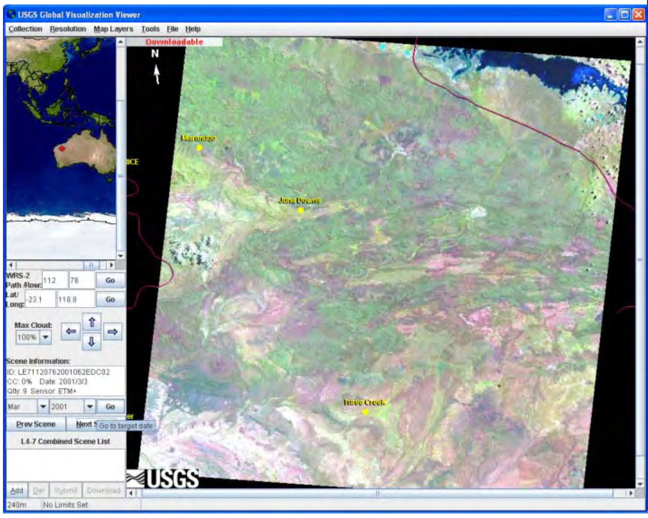



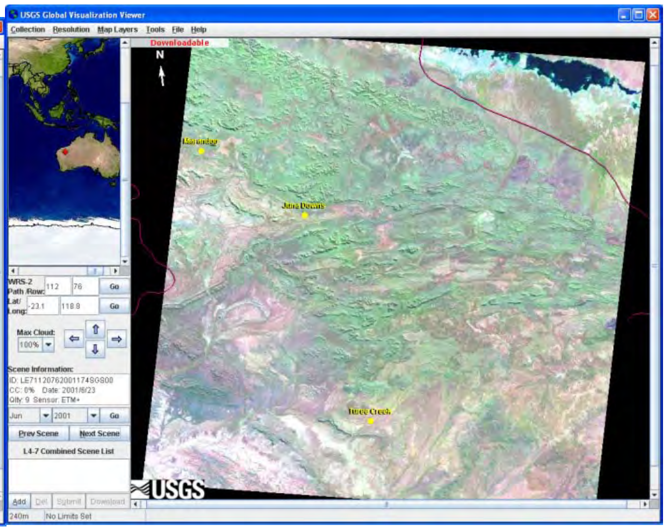



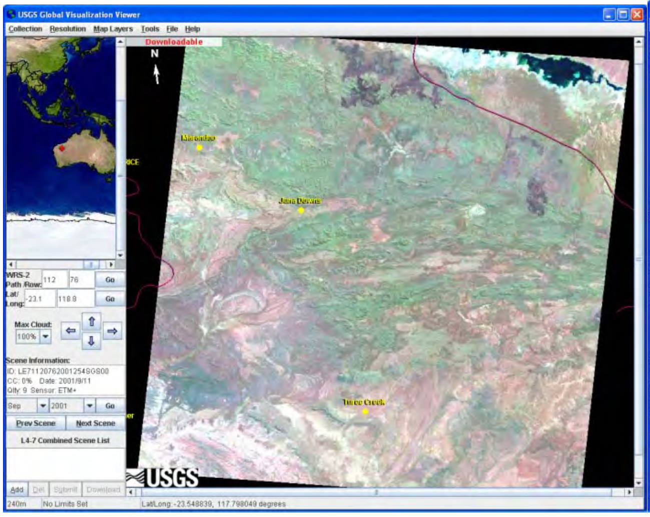



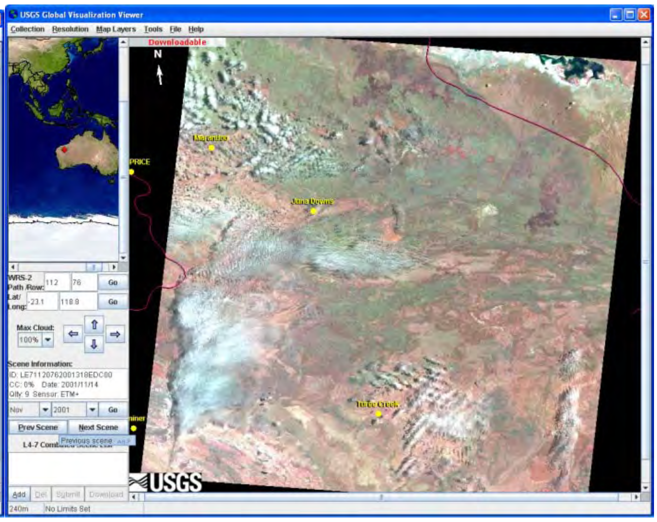



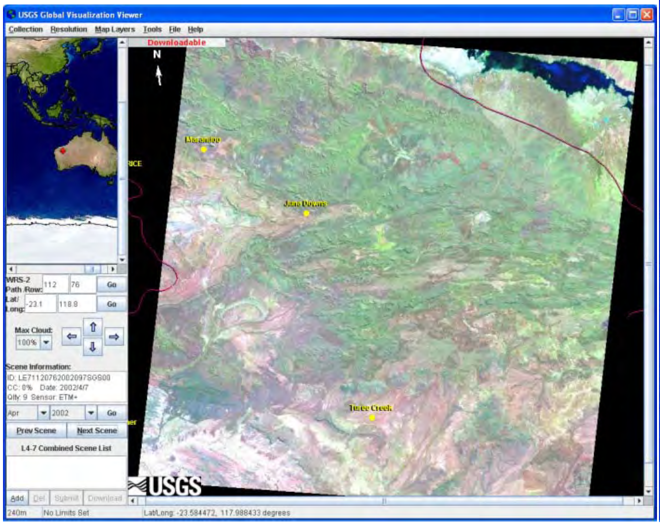
Mar 2001 – Sep 2002

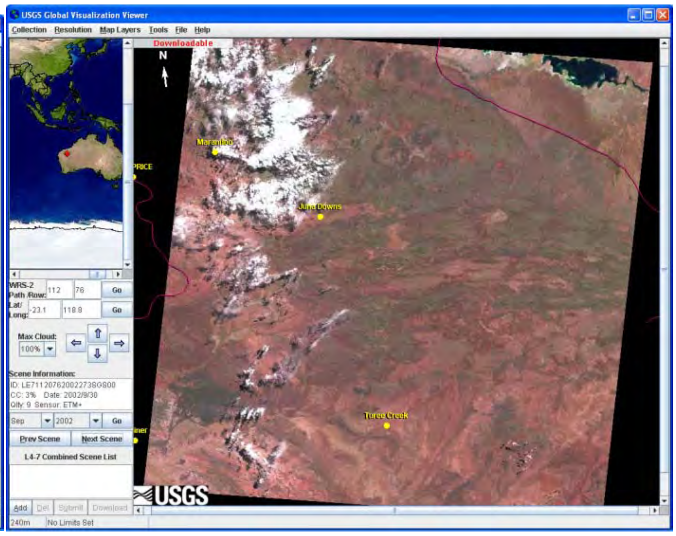


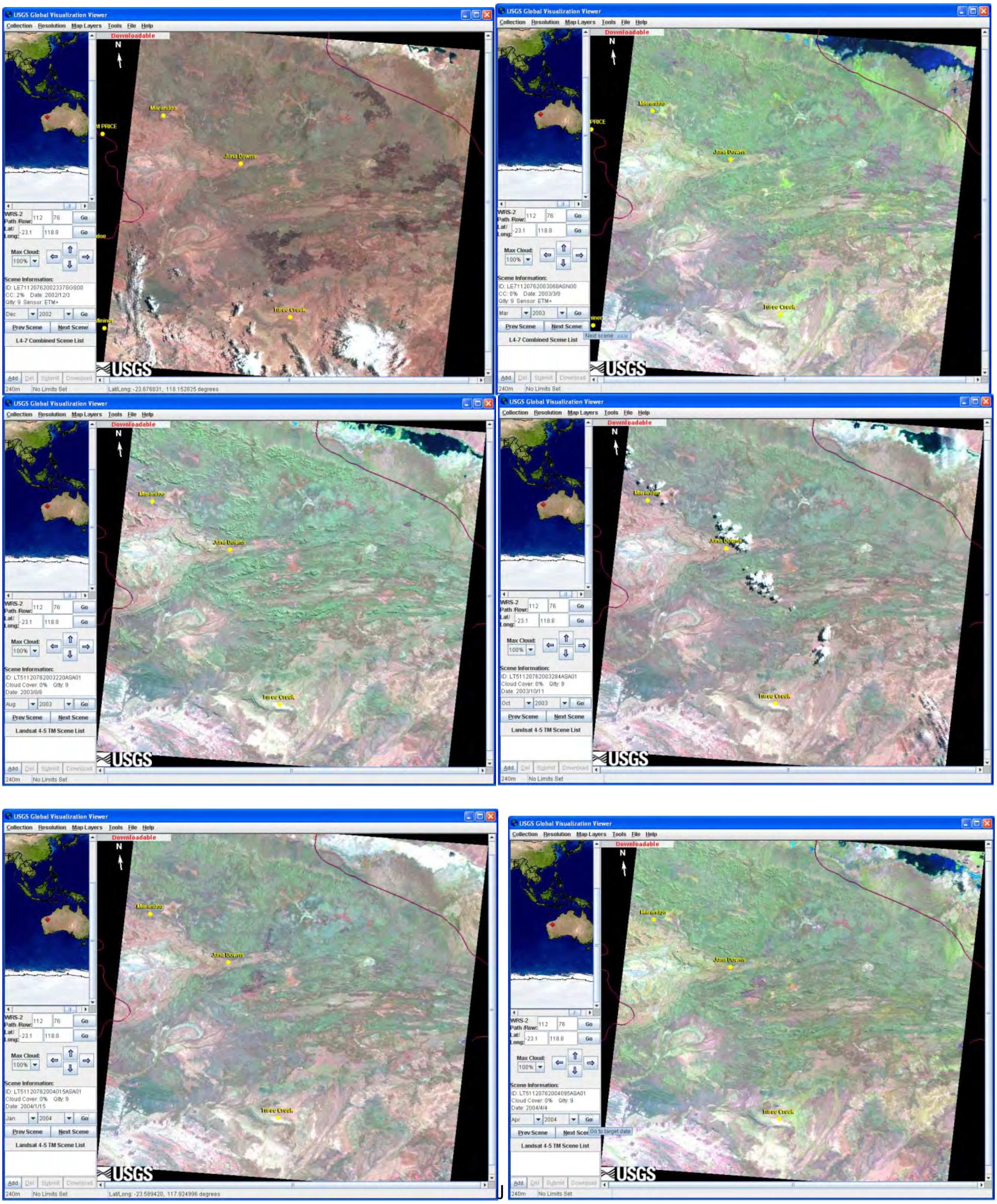



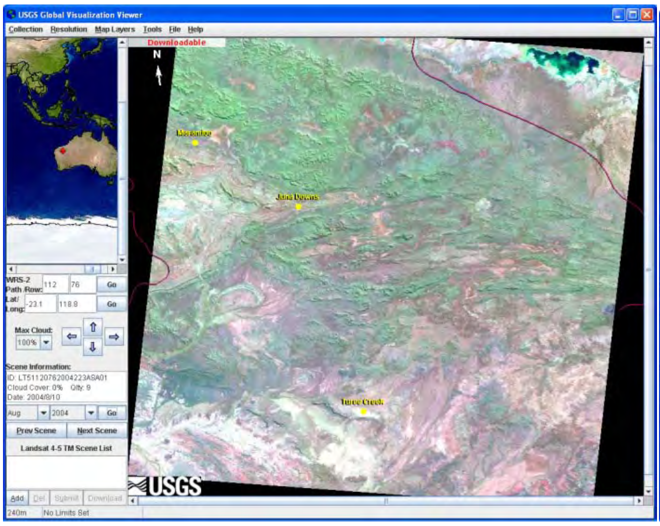



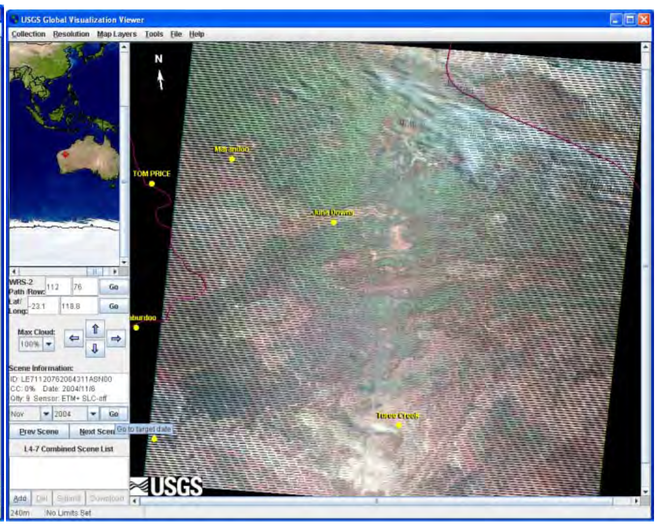



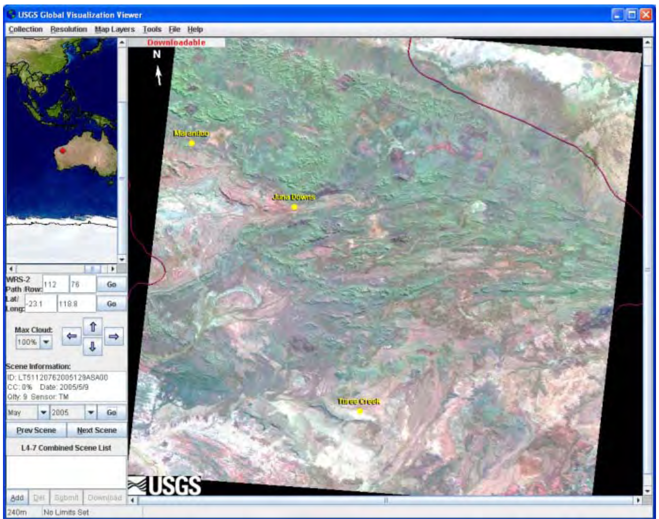
Dec 2002 – April 2004

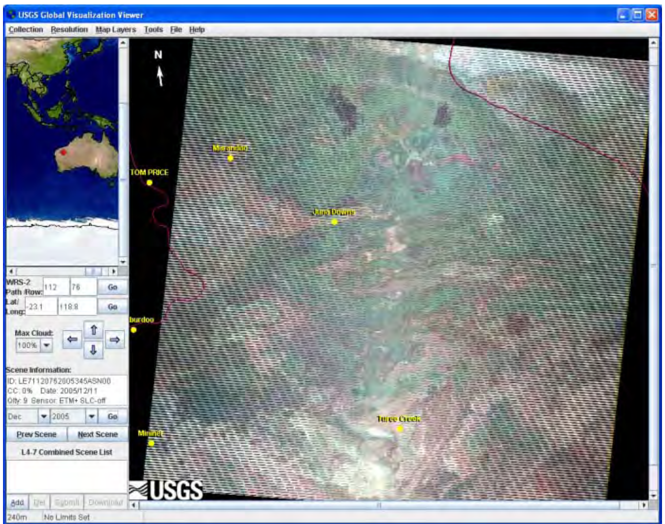


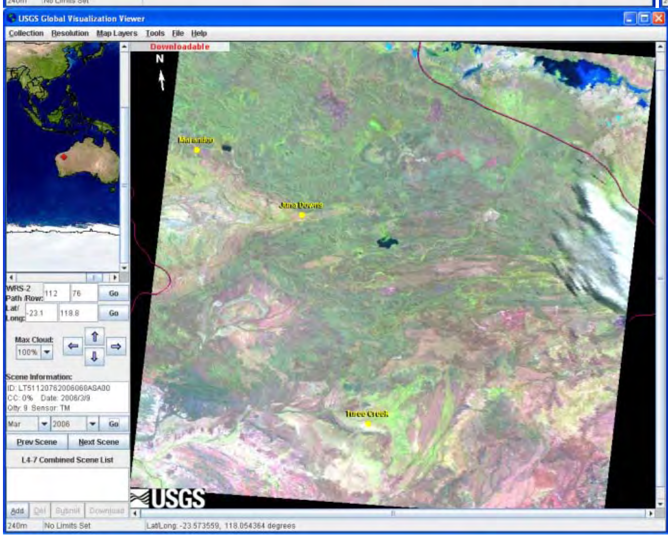
Aug 2004 – June 2006



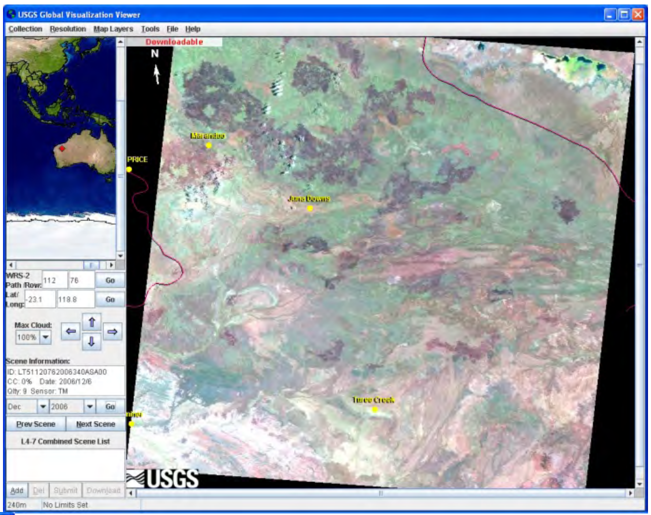



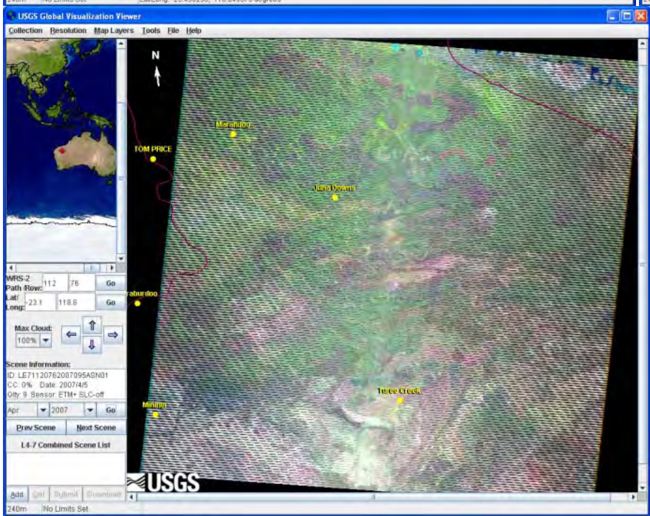



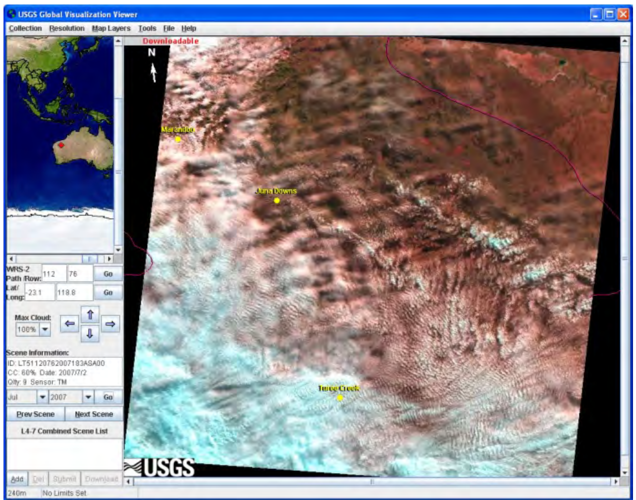



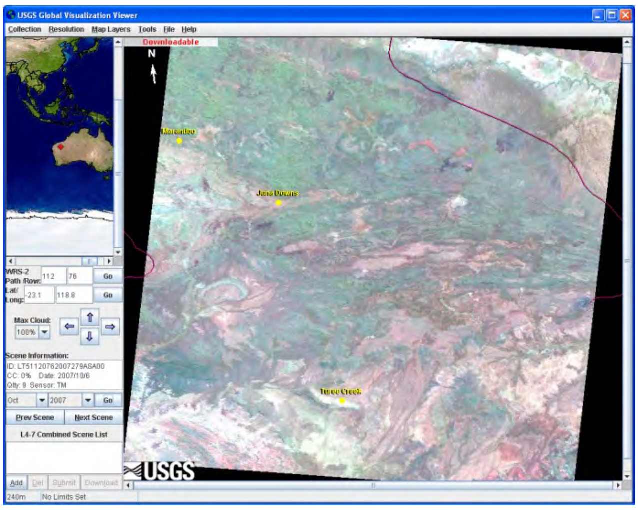



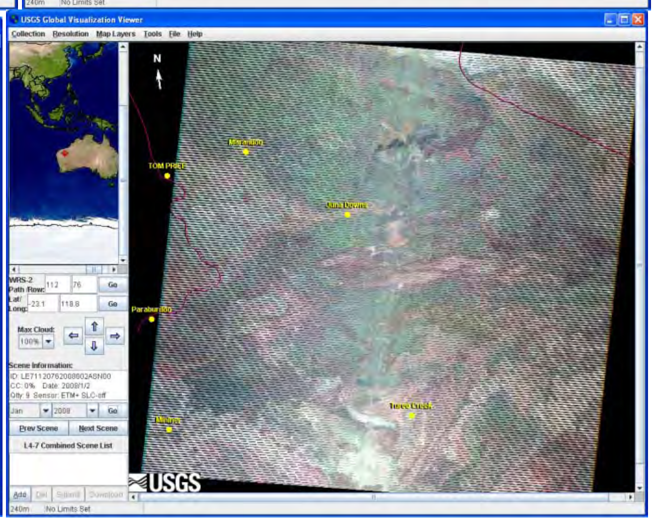

Sep 2006 – Jan 2008

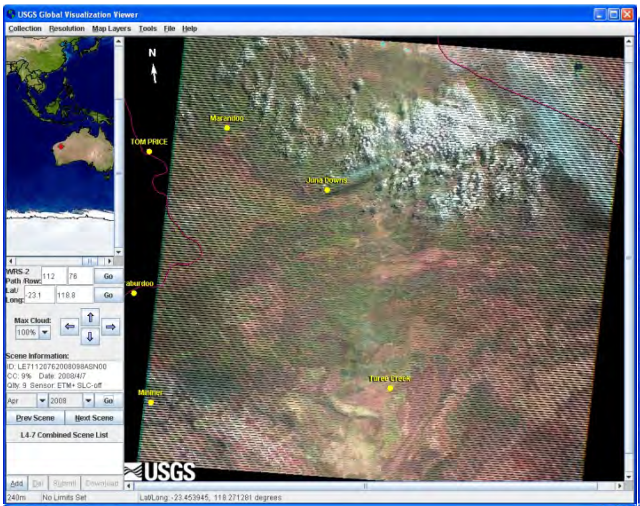



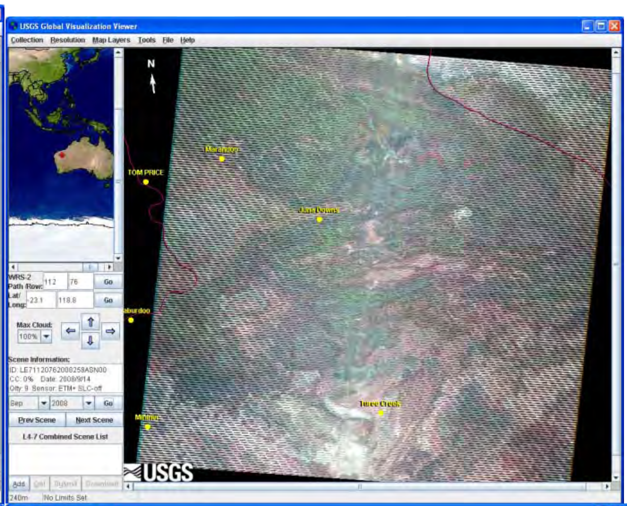



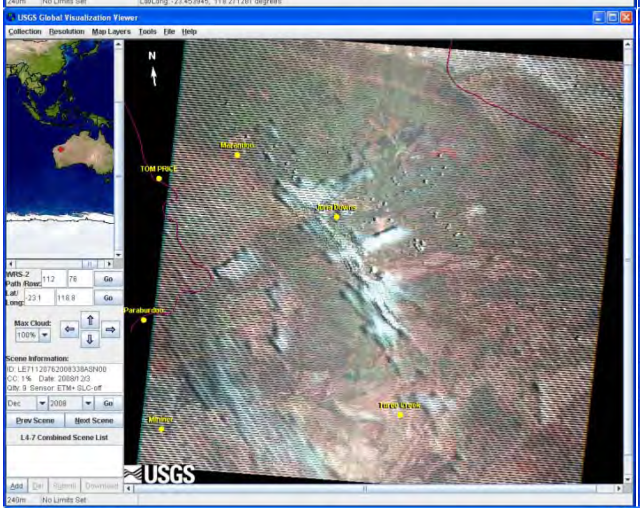



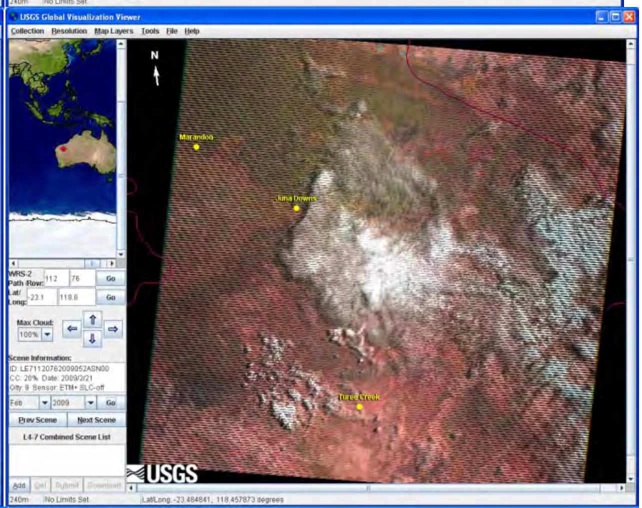



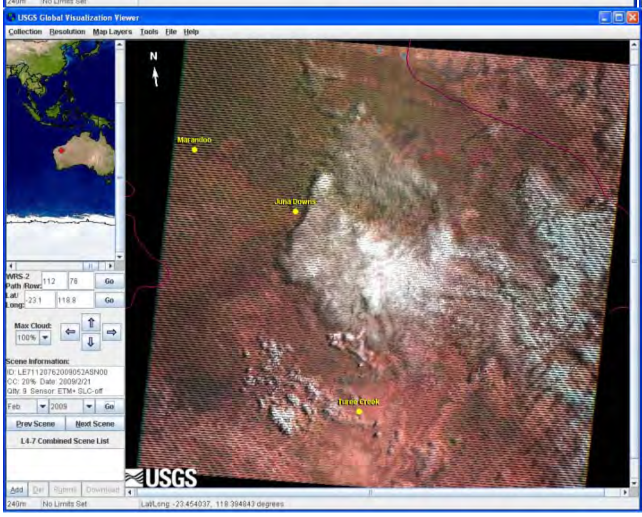
April 2008-June 2009

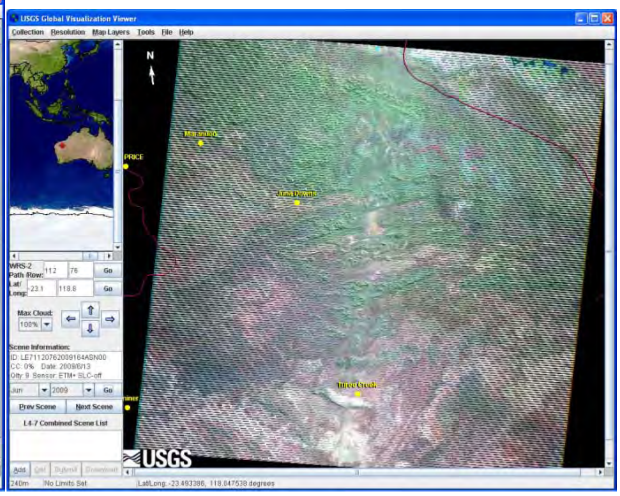


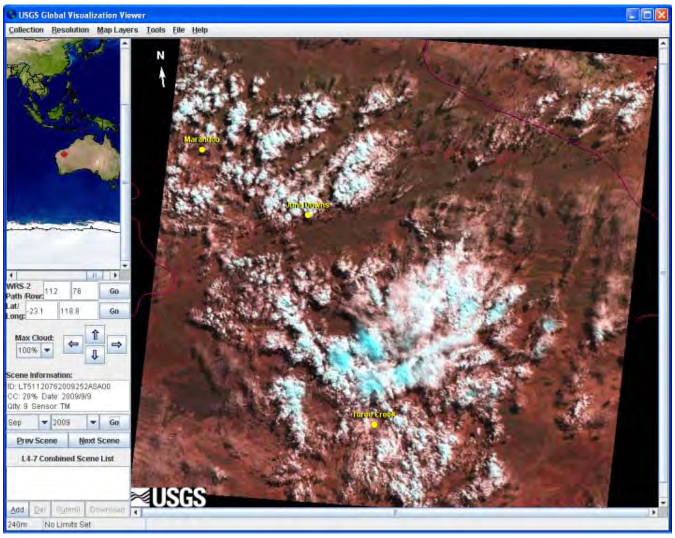



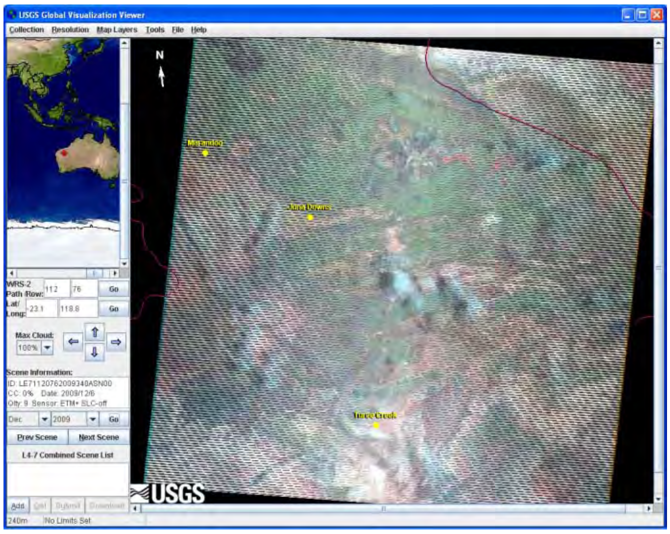



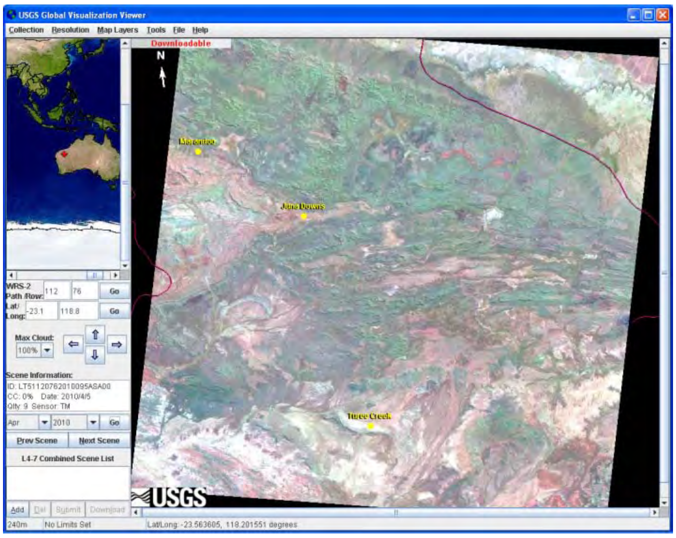



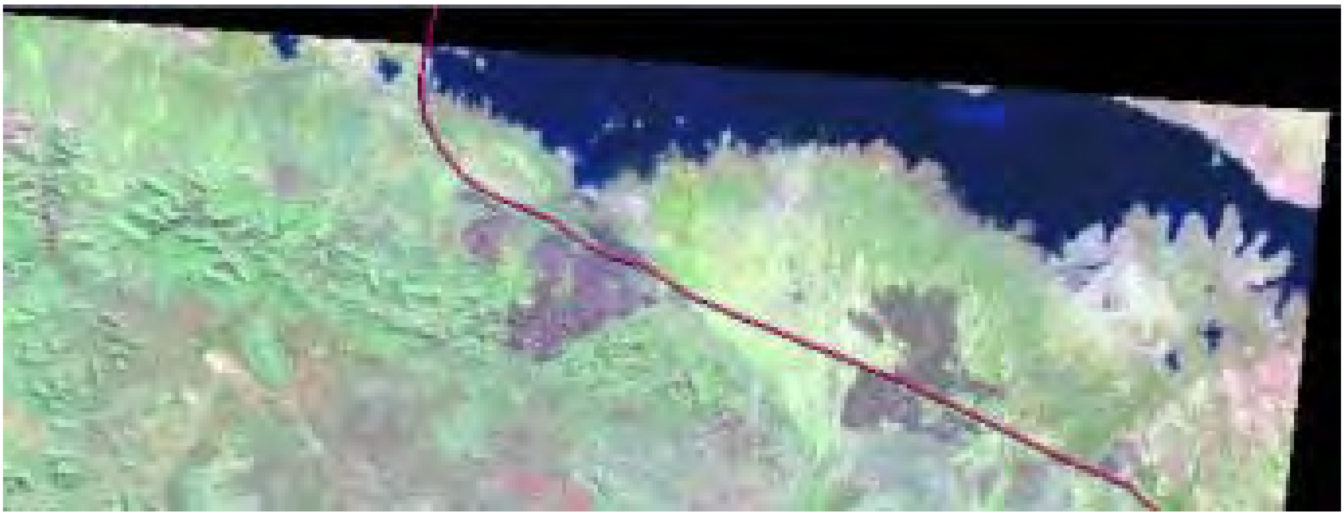



Sep 2009 – April 2010



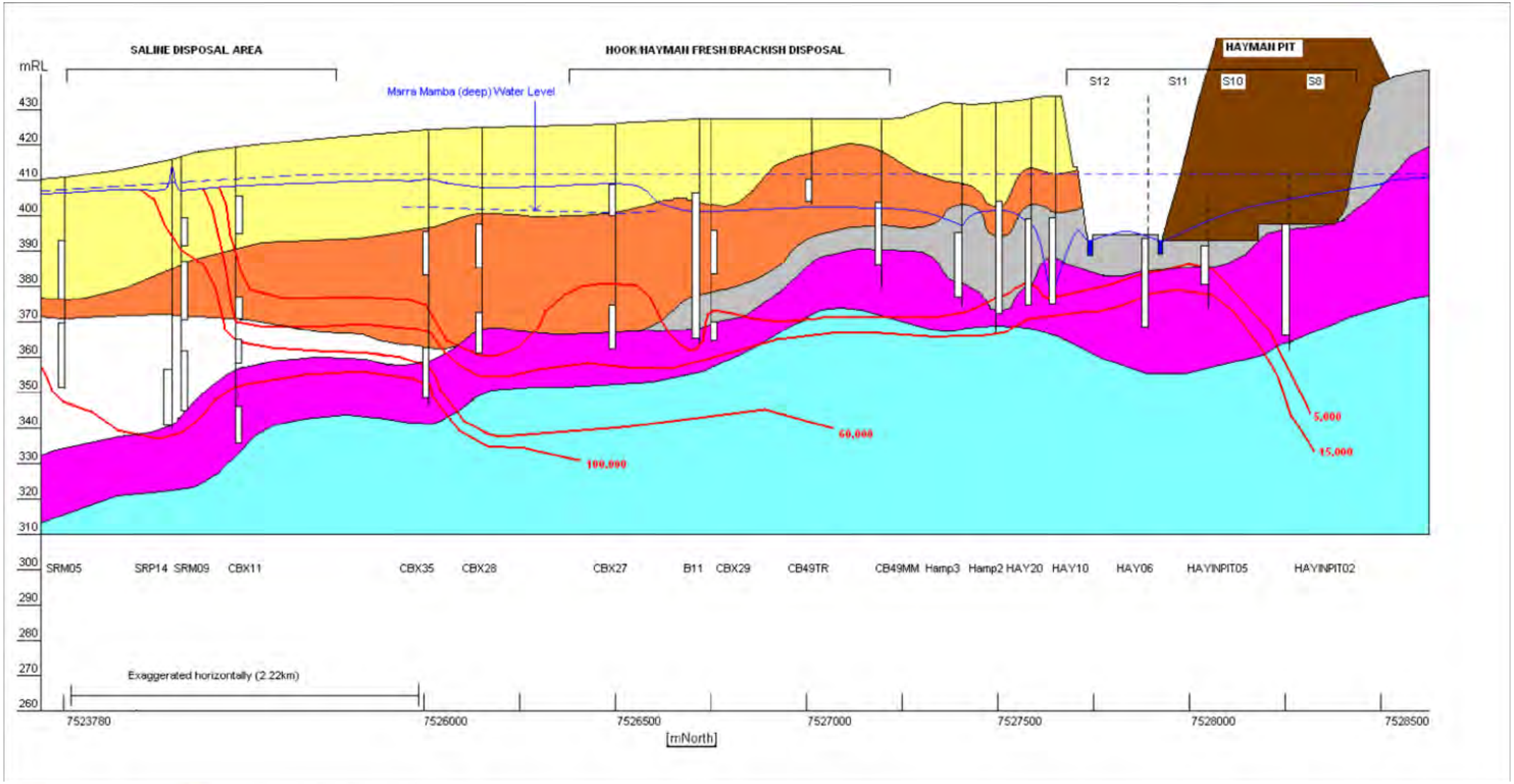





# Appendix 2: Geological cross sections

This page has been left blank intentionally




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

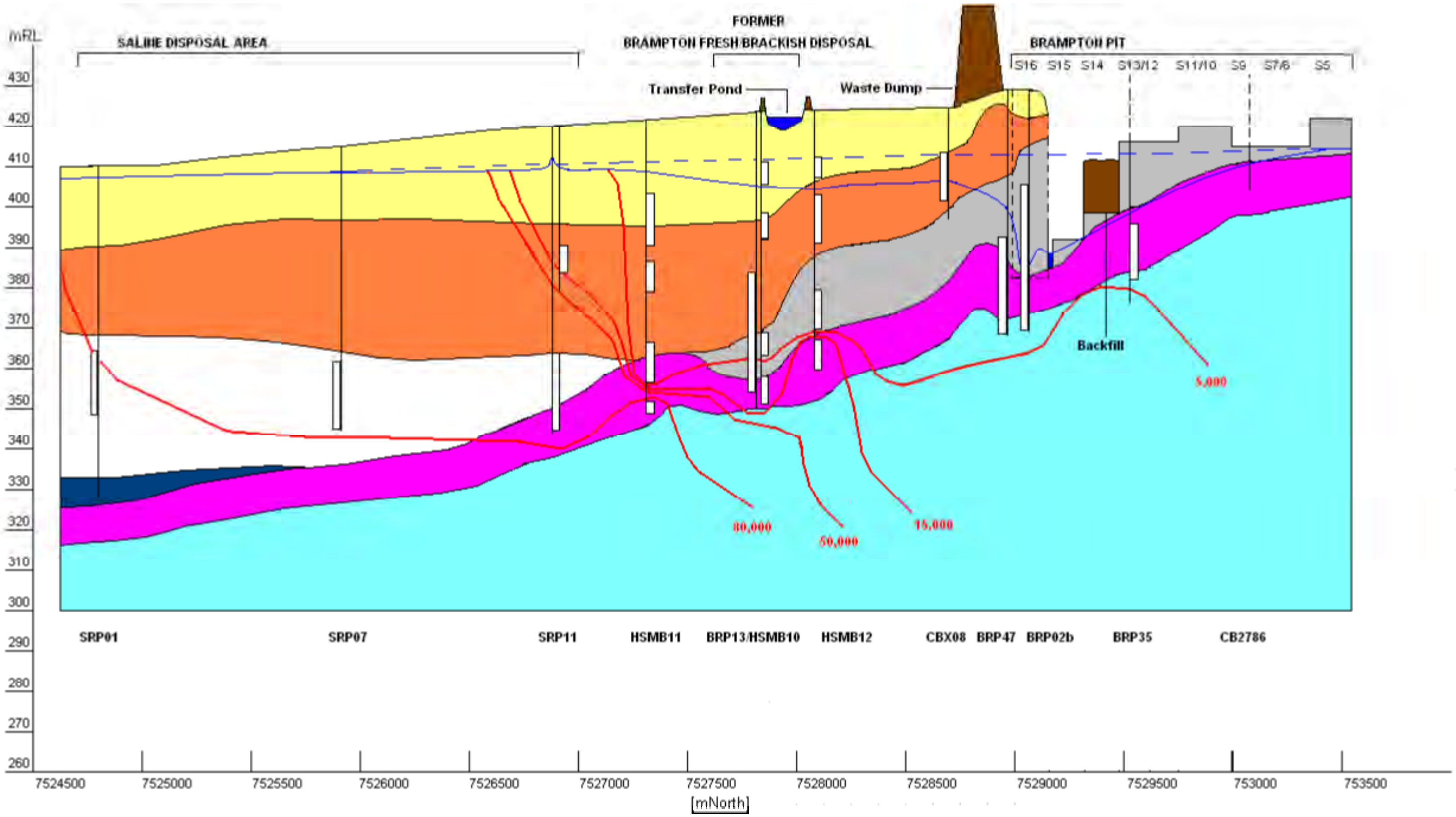
Equipotential electrical conductivity lines (uS/cm)

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 |




## CLOUDBREAK SECTIONS LEGEND

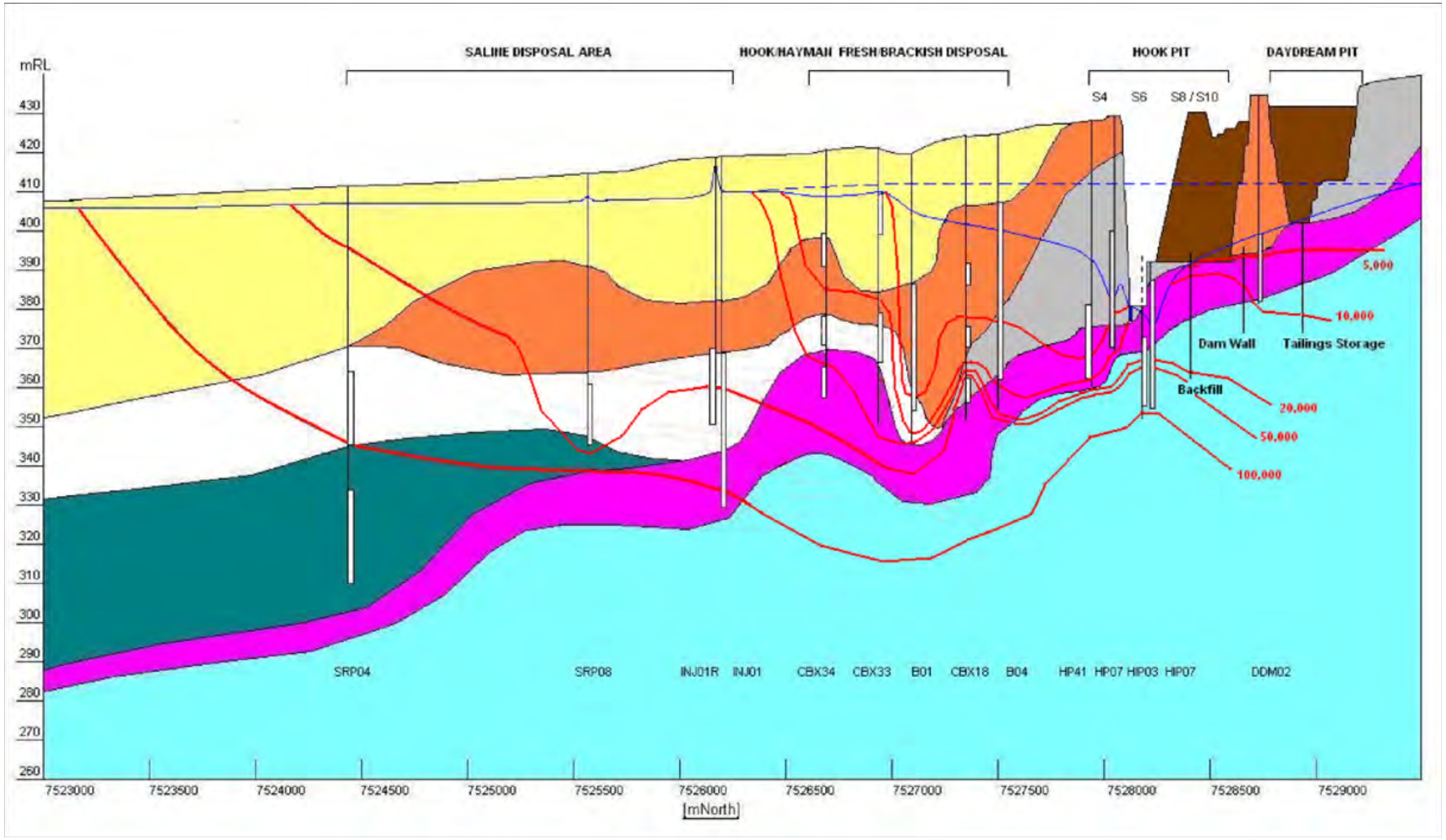
- Alluvium Ta (gravelly soils)
- Tertiary Detritals Tds (including hardcap Hc)
- Oakover Formation To (calcrete and silcrete/chalcedony)
- Mineralised Marra Mamba MUm/MUh (including transition zone MUt)
- Unmineralised Lower Marra Mamba MUb (Cherts/BIF)
- Wittenoom Formation (Dolomites and Shales)
- 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 - Brampton Pit | |
| Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme | |
| Author: | Date: |
| Drawn By: | Revision: |
| Drawing Ref: | Report Ref: |
| Scale: | Figure No: 13 |




## 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 | | FMG |
| Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme | | |
| Author: | Date: | |
| Drawn By: | Revision: | |
| Drawing Ref: | Report Ref: | |
| Scale: | Figure No: 12 | |

# Appendix 3: Numerical model hydraulic property zones and layer thicknesses

This page has been left blank intentionally

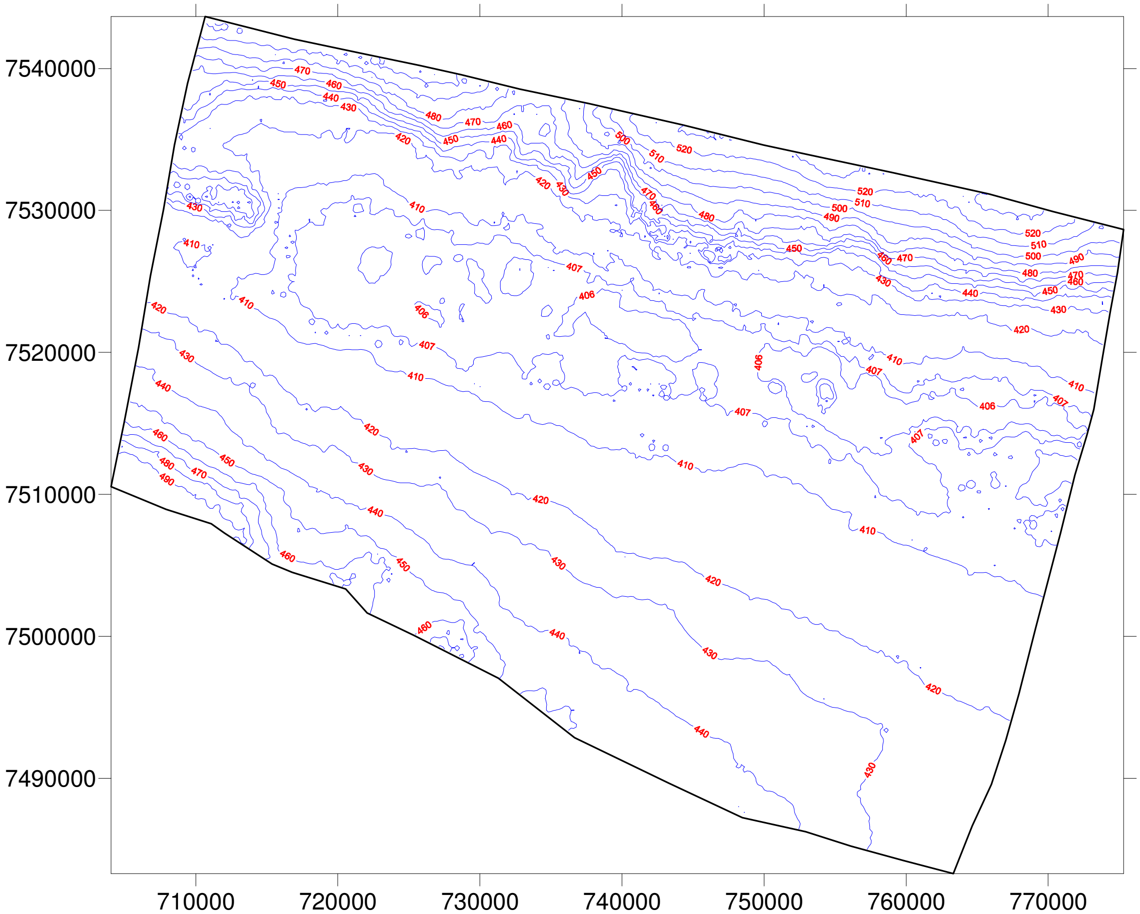



Figure 3.1: Elevation of ground surface.

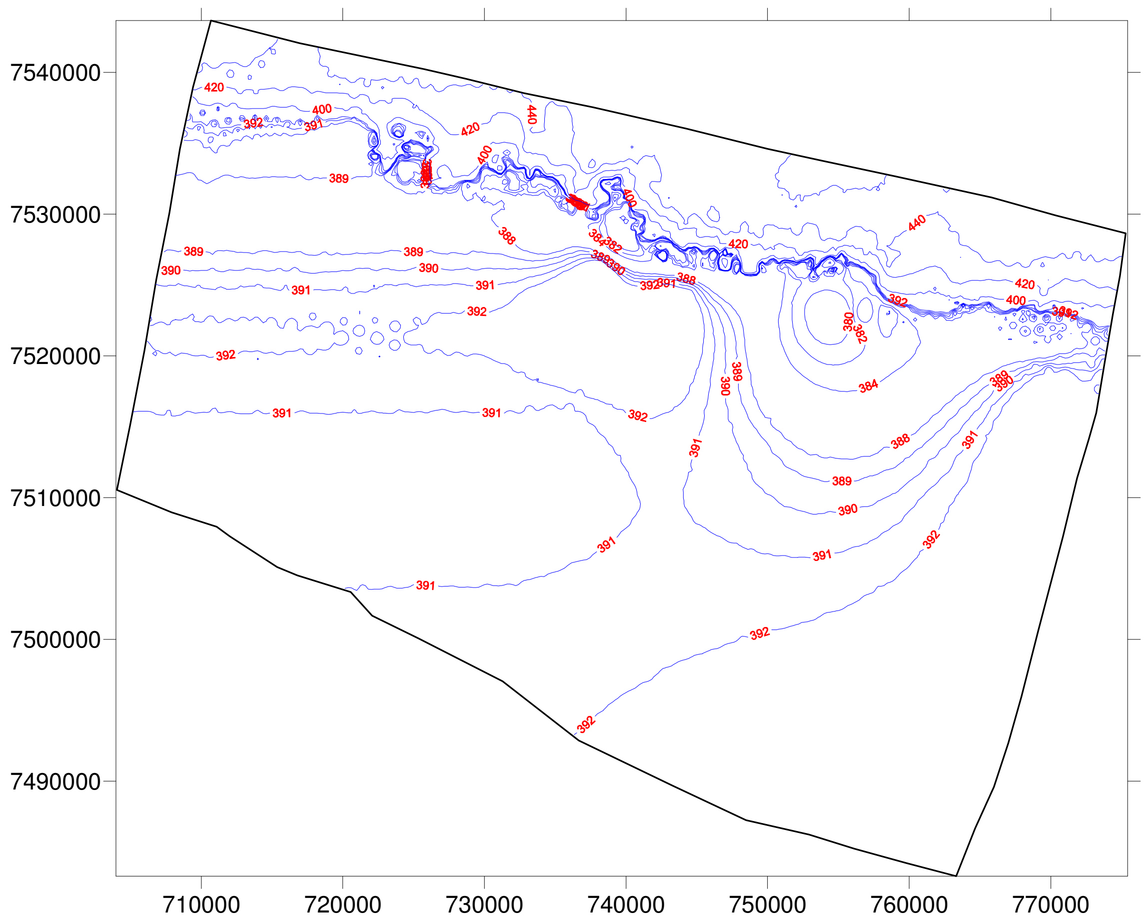



Figure 3.2: Elevation of slice 3 of the numerical model (base of Tertiary Detritals).

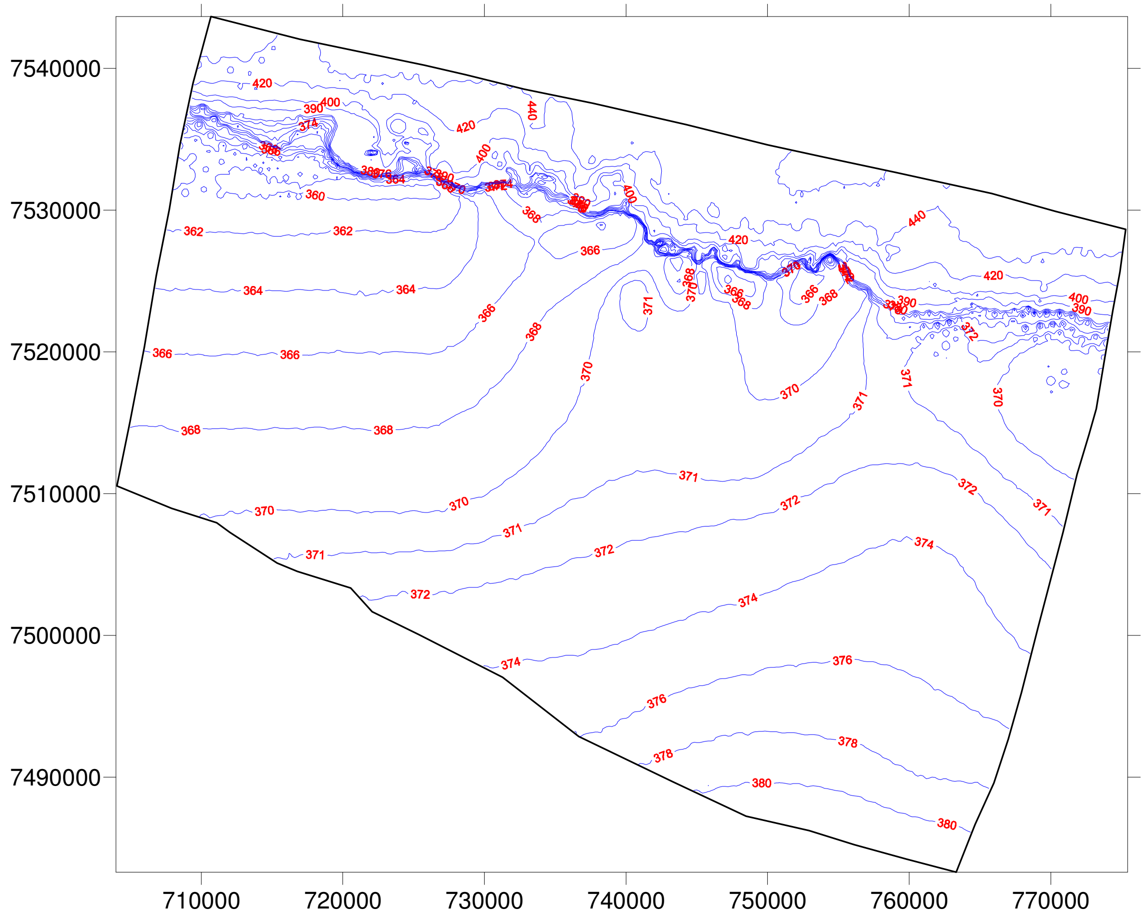



Figure 3.3: Elevation of slice 4 of the numerical model (base of Tertiary Clay).

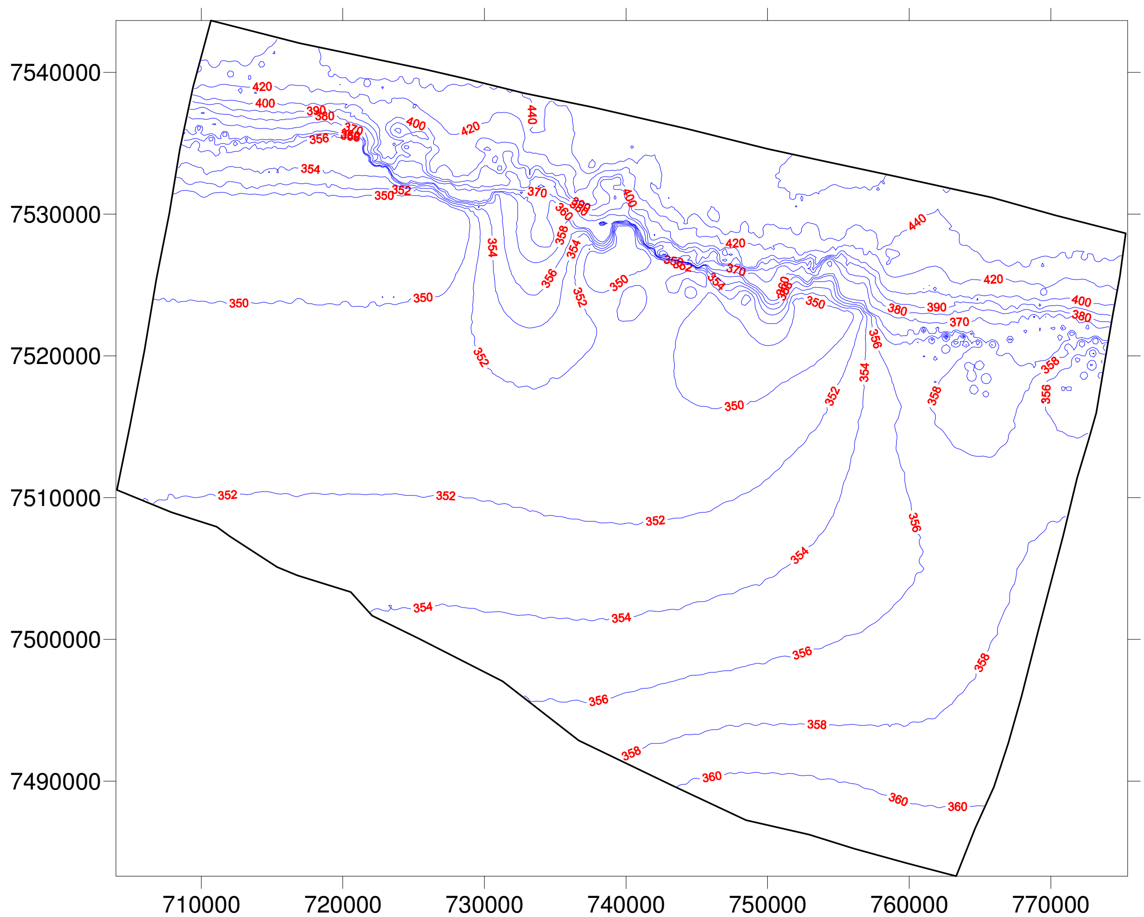



Figure 3.4: Elevation of slice 5 of the numerical model (base of Oakover formation).

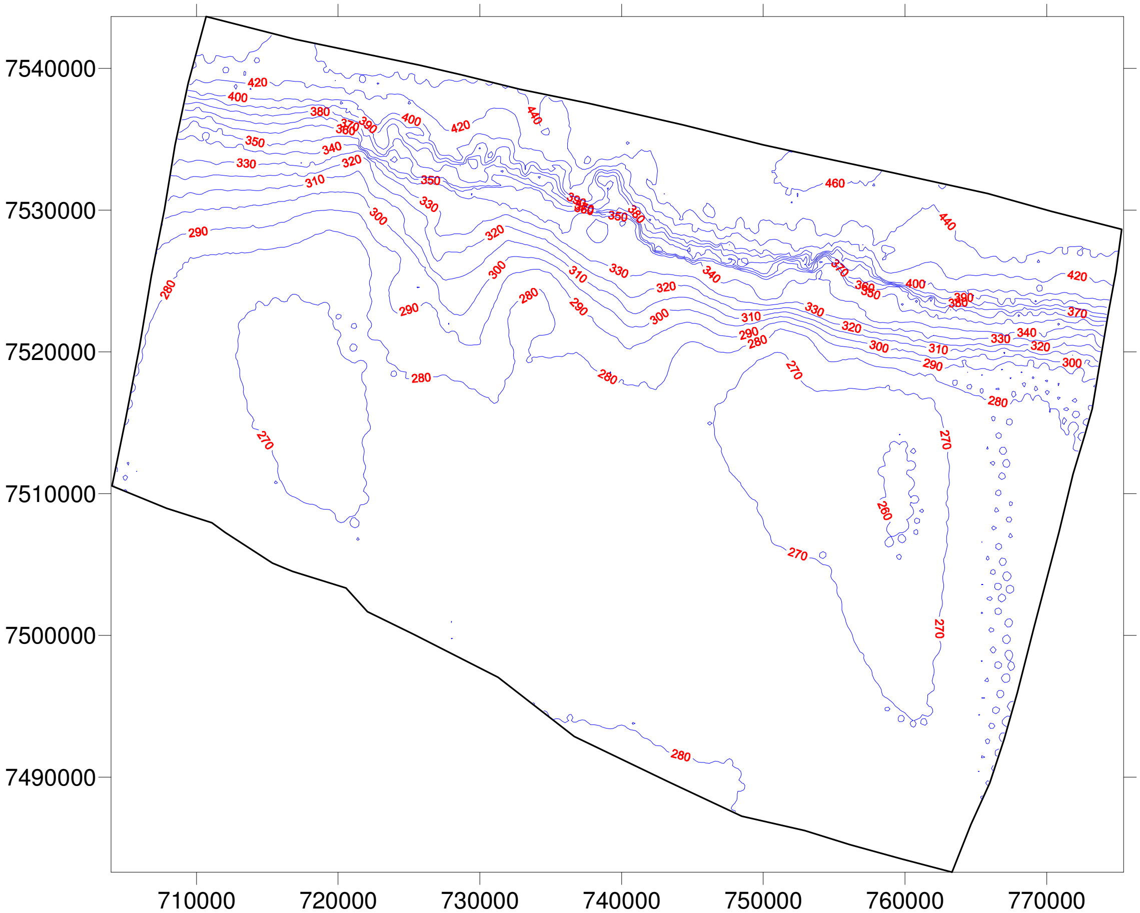



Figure 3.5: Elevation of slice 7 of the numerical model (base of Wittenoom Dolomite).

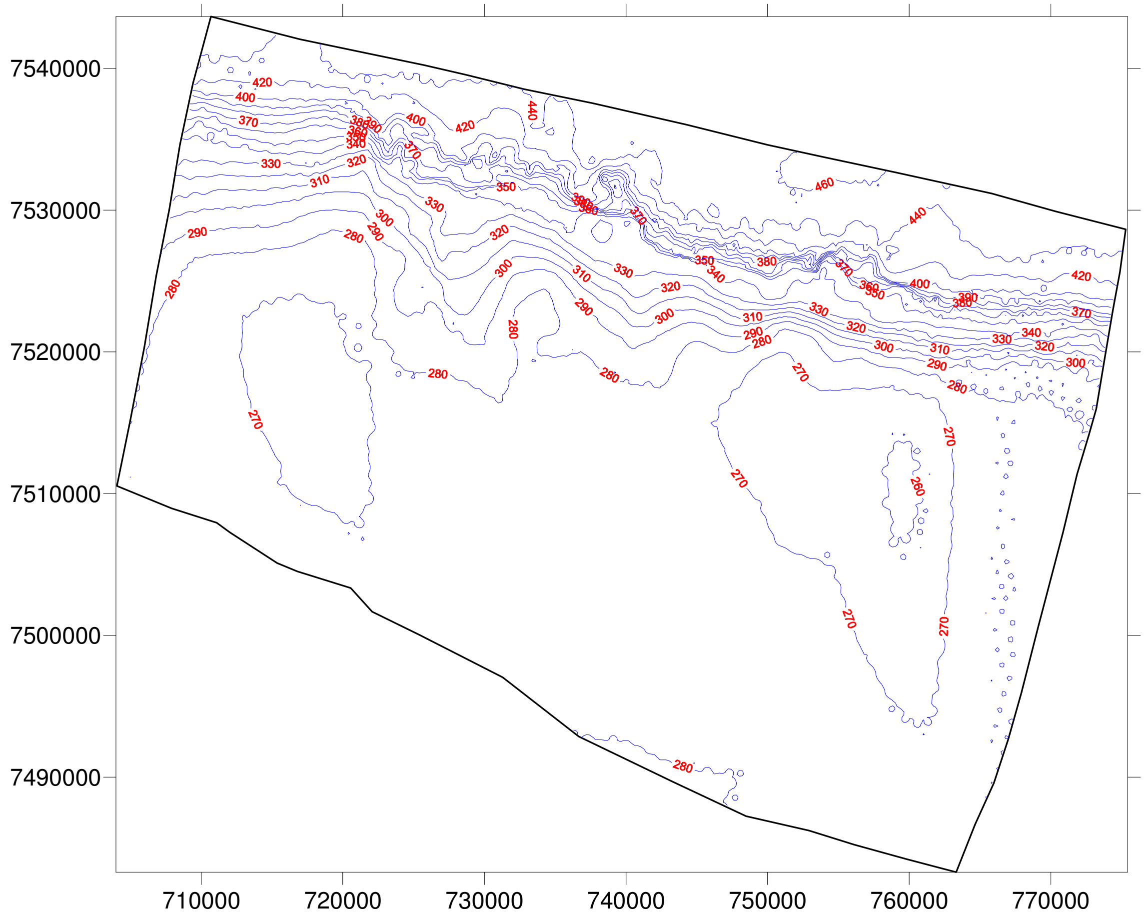



Figure 3.6: Elevation of slice 8 of the numerical model (base of Hardcap).

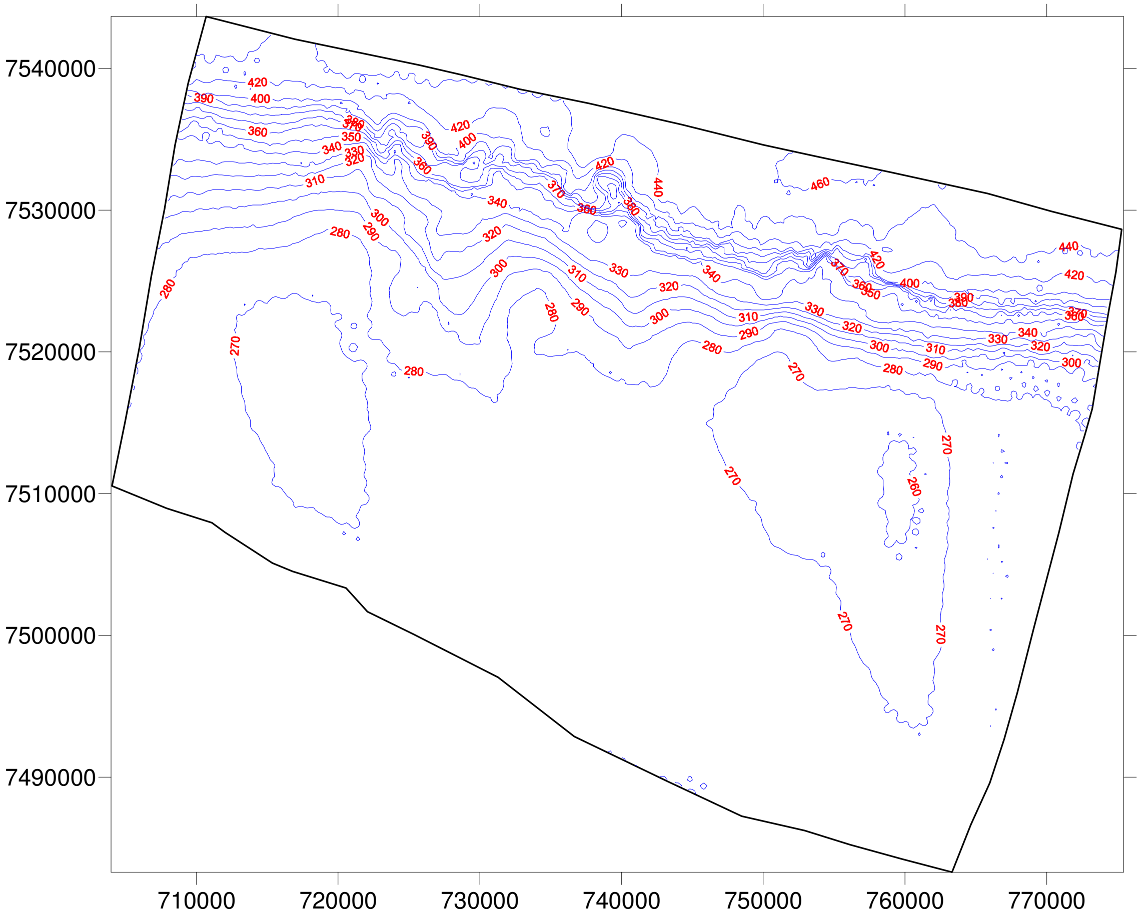



Figure 3.7: Elevation of slice 9 of the numerical model (base of Economic ore).

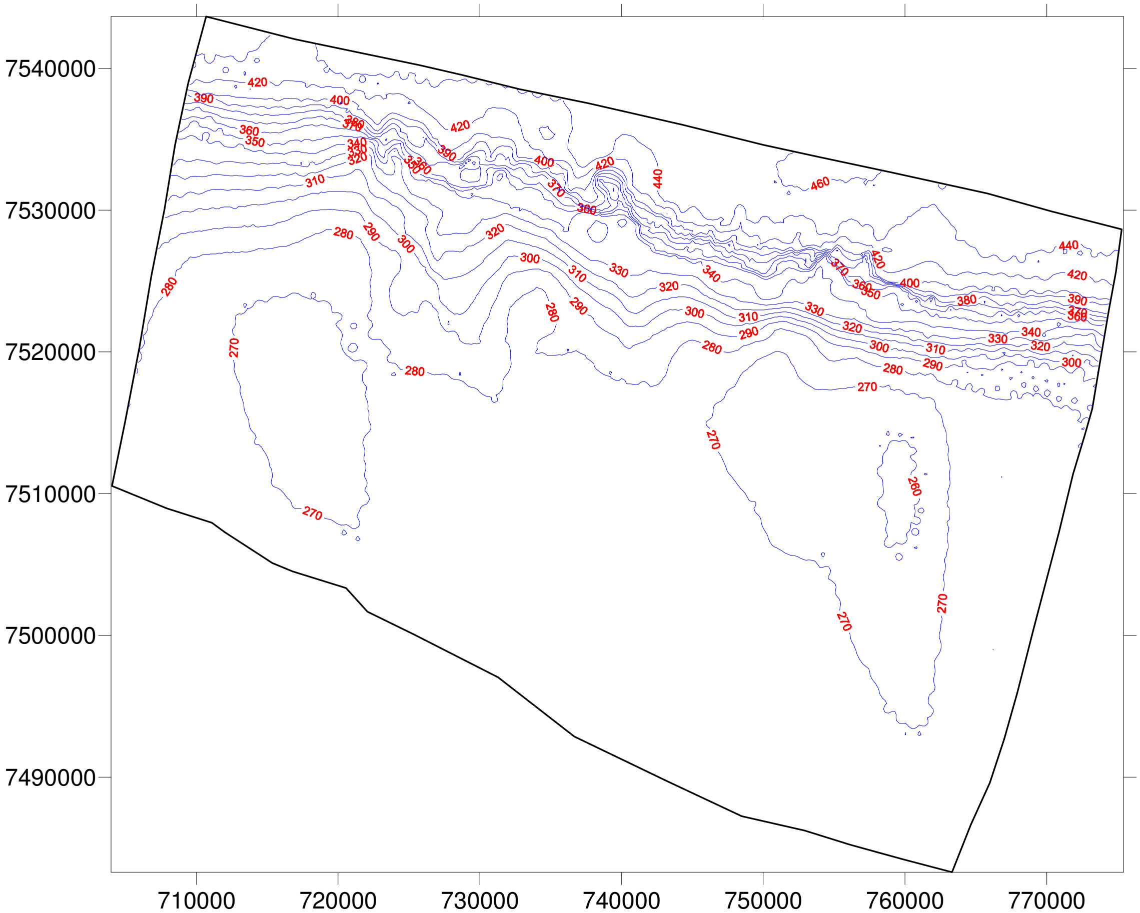



Figure 3.8: Elevation of slice 10 of the numerical model (base of mineralised MMF).

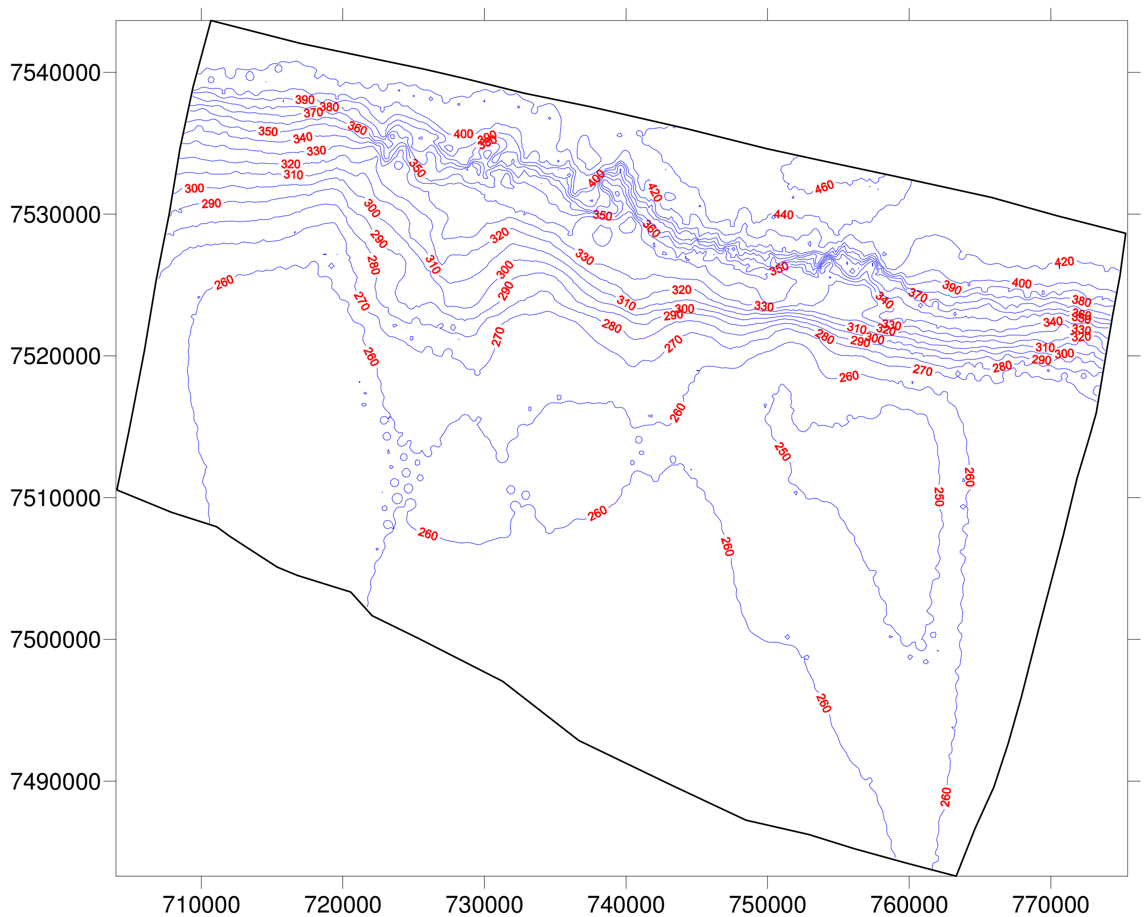



Figure 3.9: Elevation of slice 11 of the numerical model (base of fractured MMF).

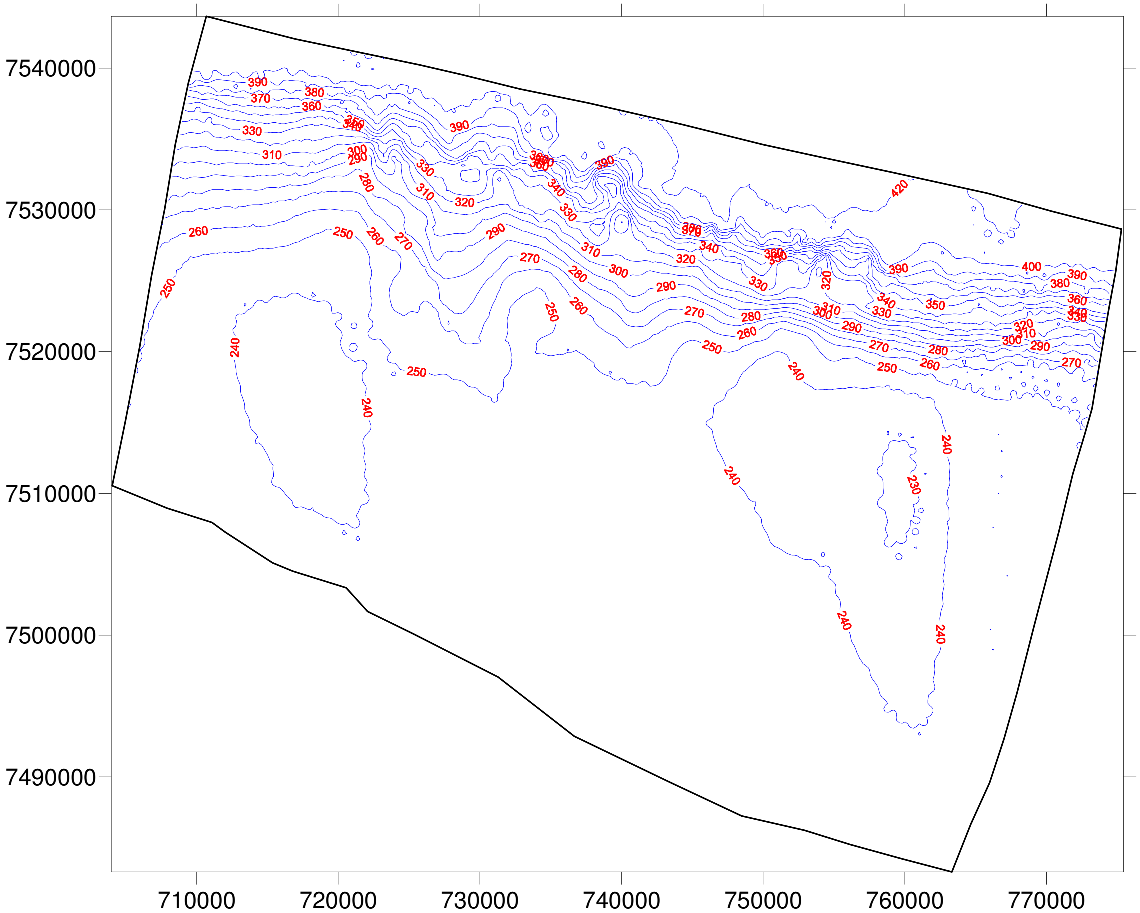



Figure 3.10: Elevation of slice 12 of the numerical model (base of un-mineralised MMF).

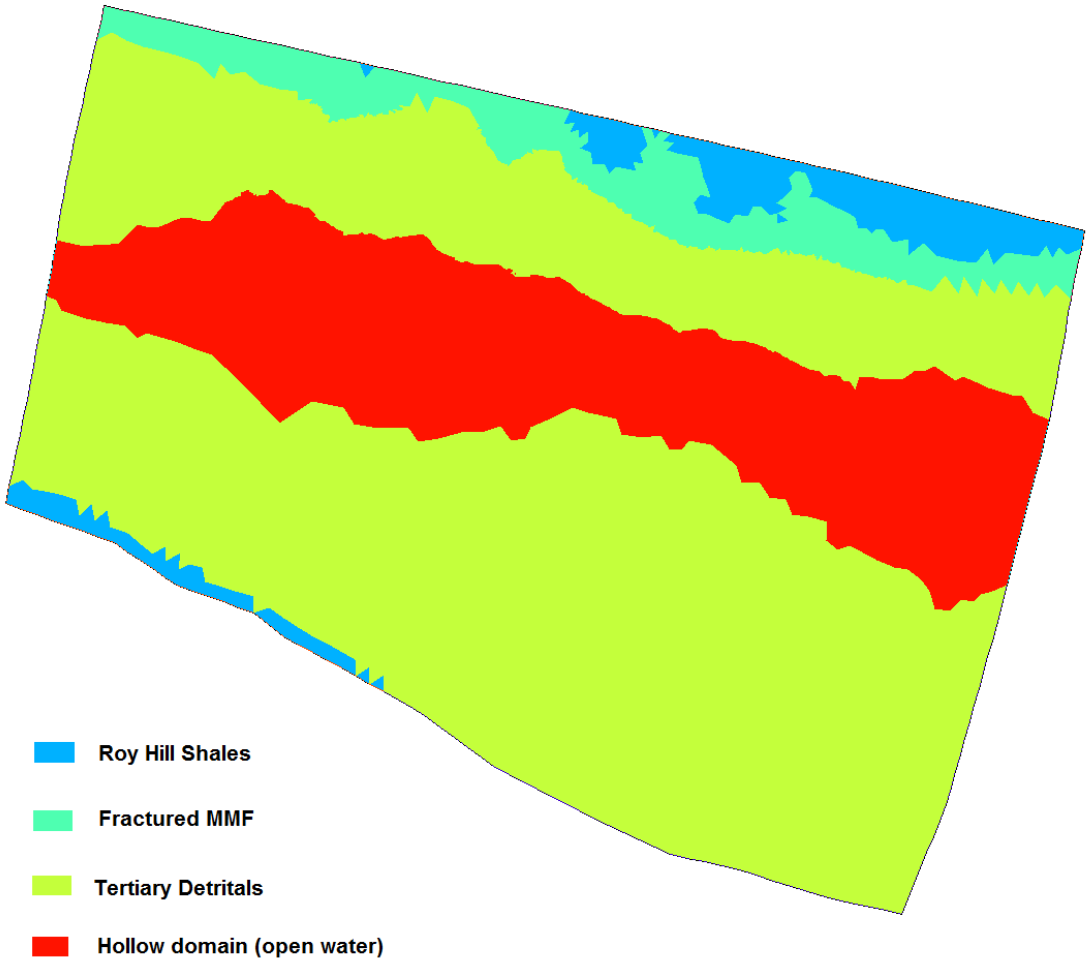



Figure 3.11: Hydraulic Property Distribution of Numerical Layer 1.


Figure 3.12: Hydraulic Property Distribution of Numerical Layer 2.

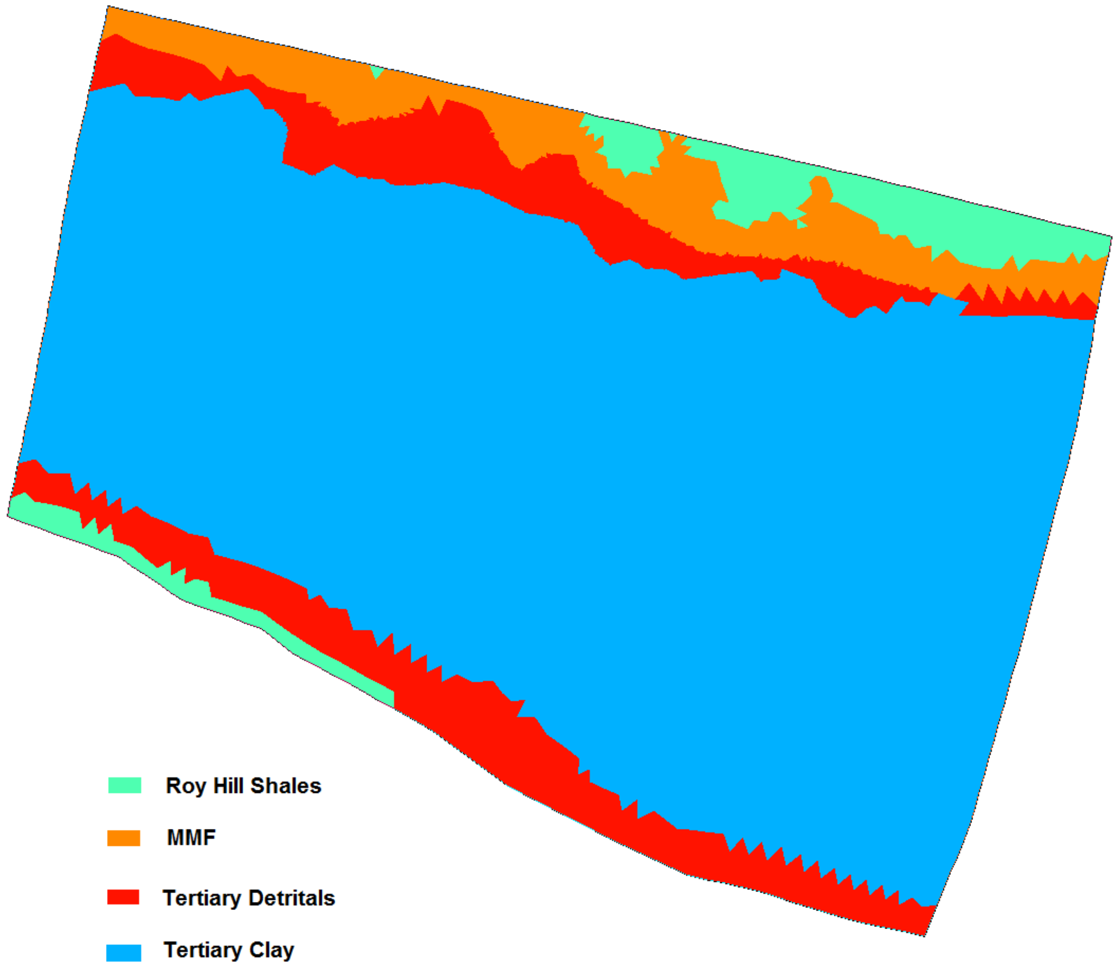



Figure 3.13: Hydraulic Property Distribution of Numerical Layer 3.

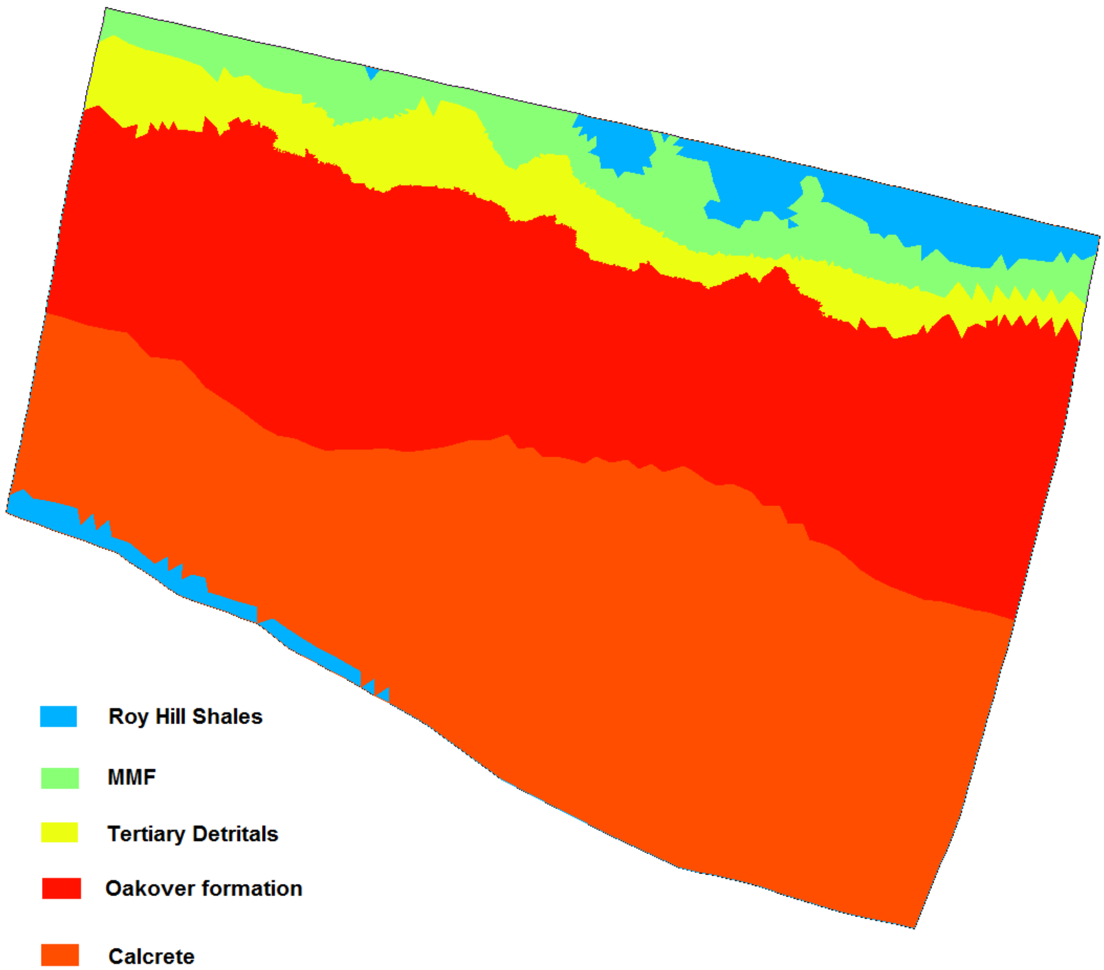



Figure 3.14: Hydraulic Property Distribution of Numerical Layer 4.

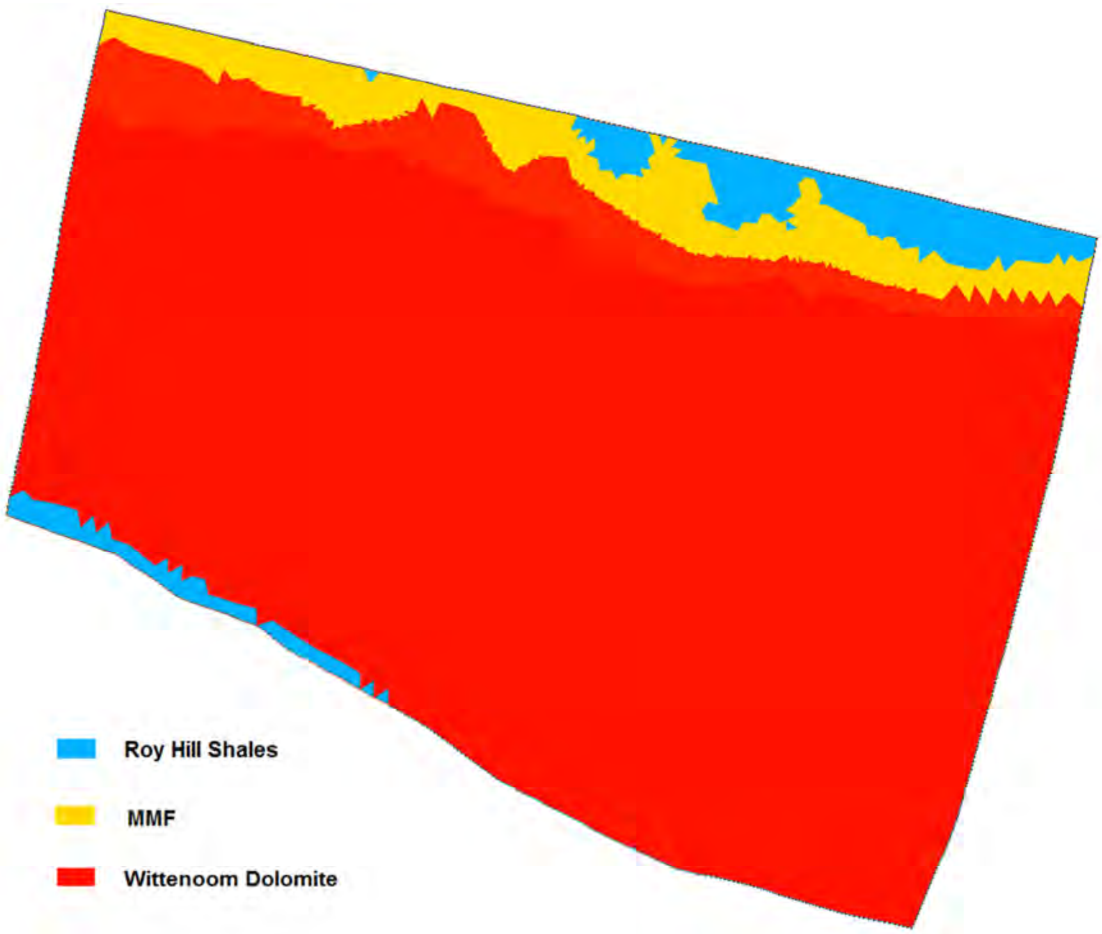



Figure 3.15: Hydraulic Property Distribution of Numerical Layers 5&6.

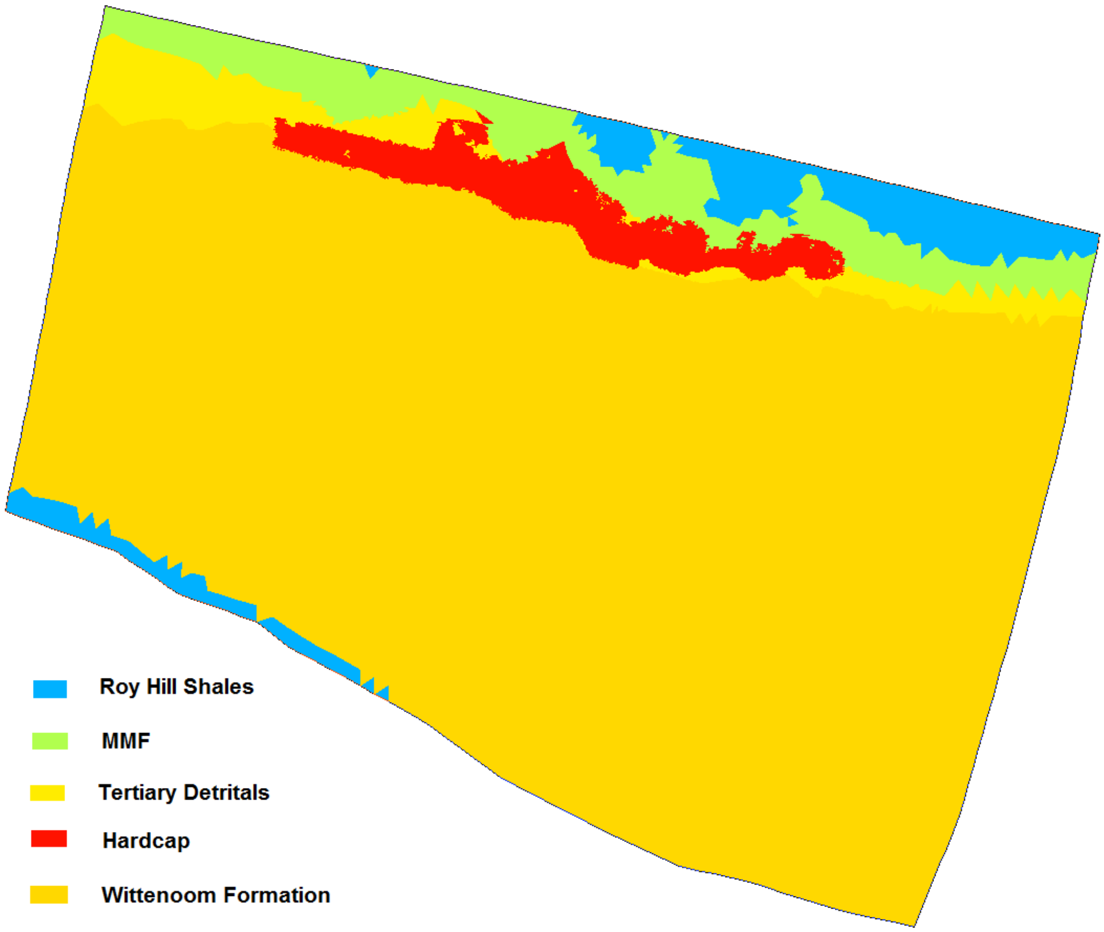



Figure 3.16: Hydraulic Property Distribution of Numerical Layer 7.

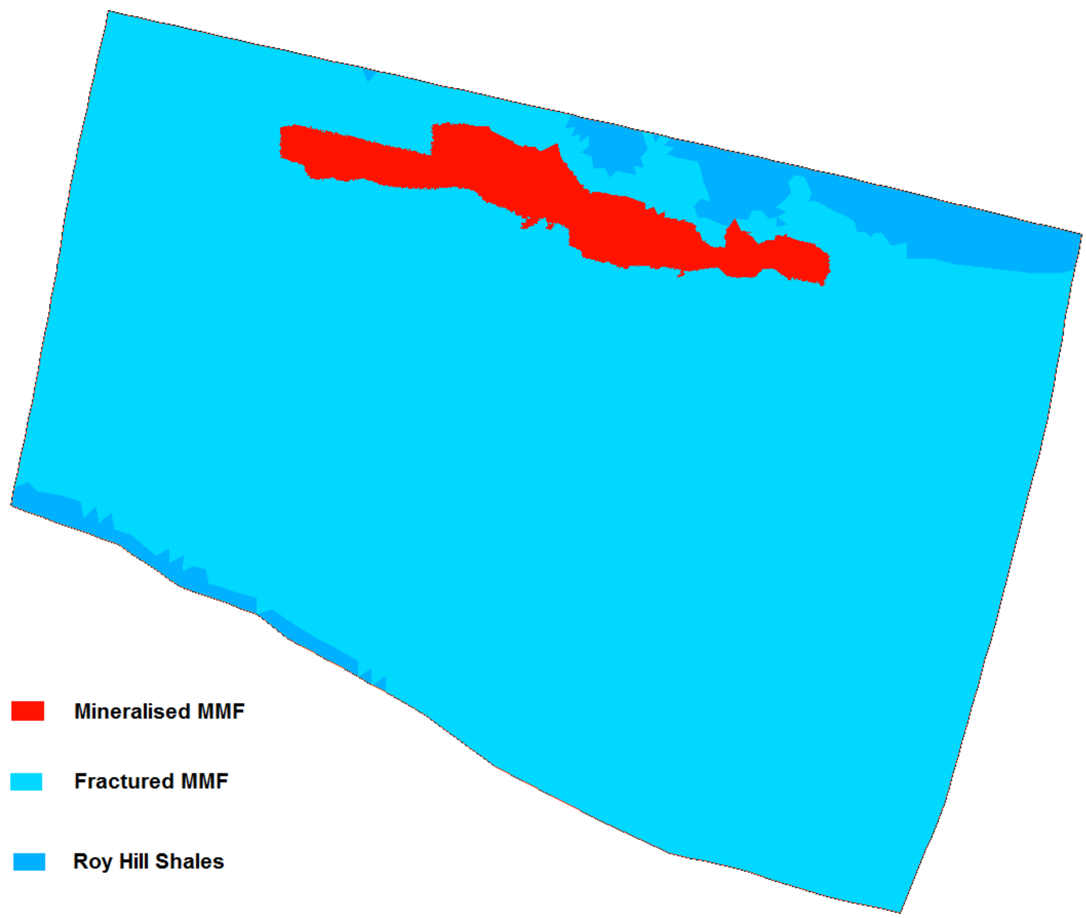



Figure 3.17: Hydraulic Property Distribution of Numerical Layers 8&9.

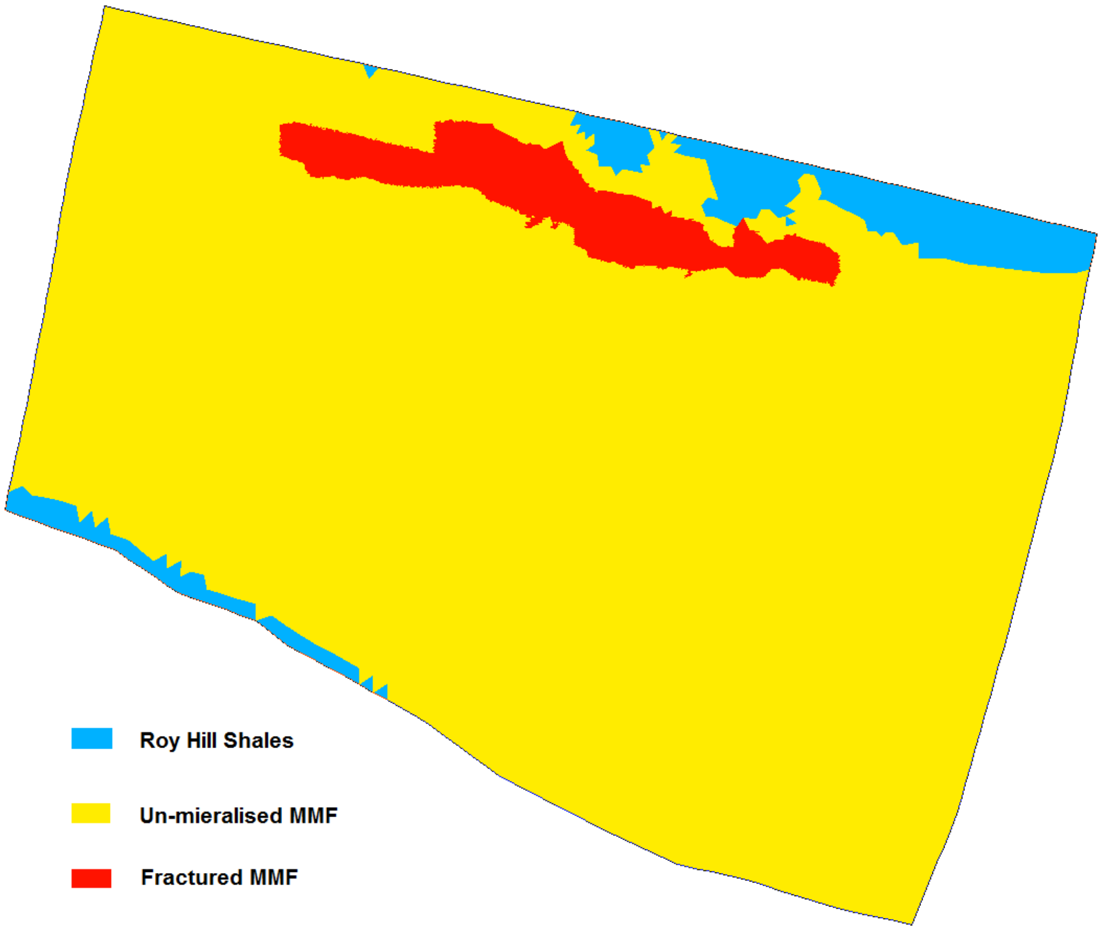
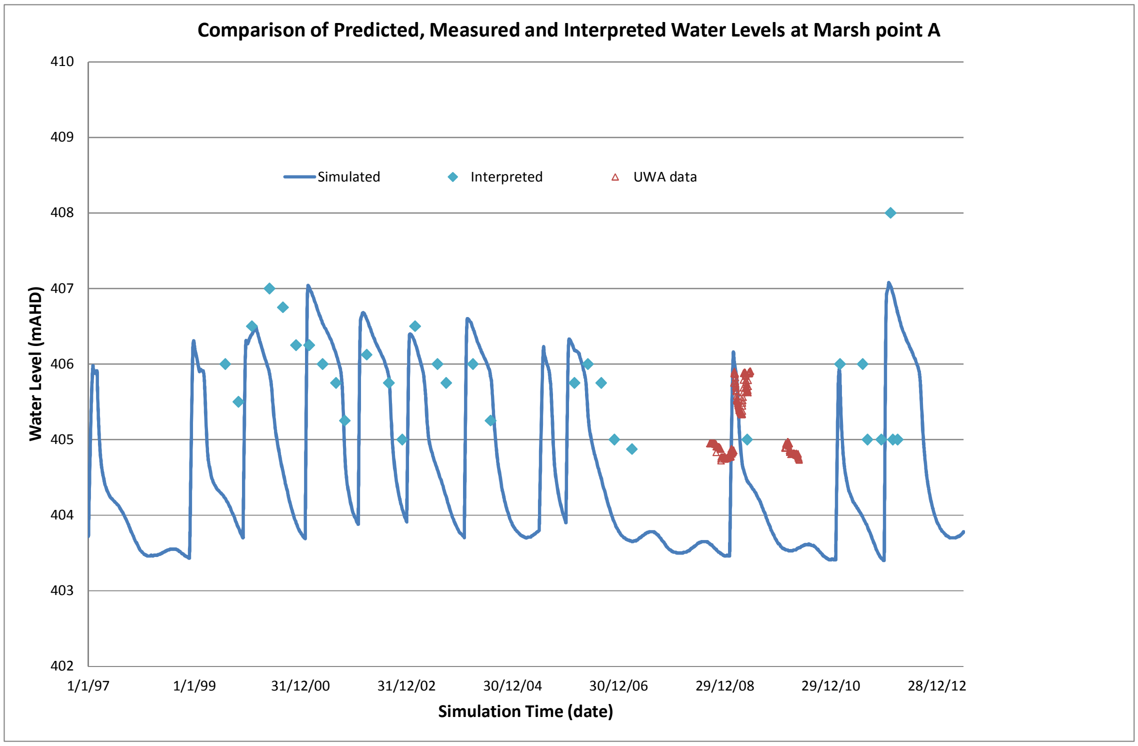


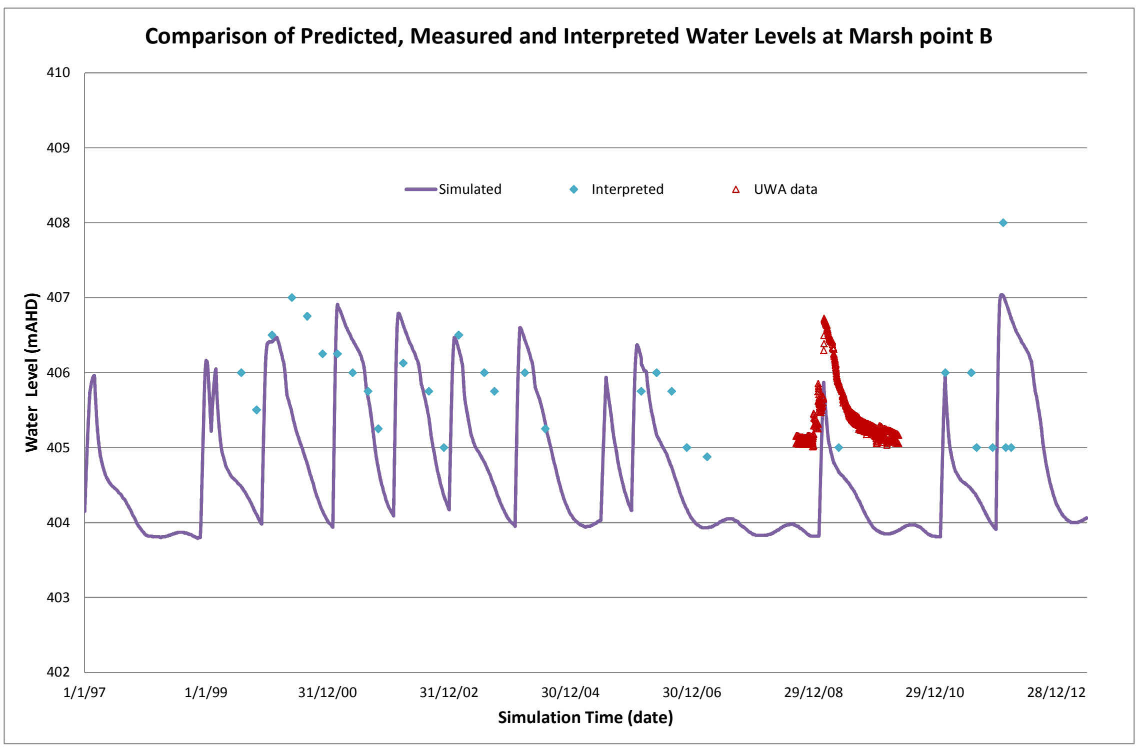

Figure 3.18: Hydraulic Property Distribution of Numerical Layer 10.

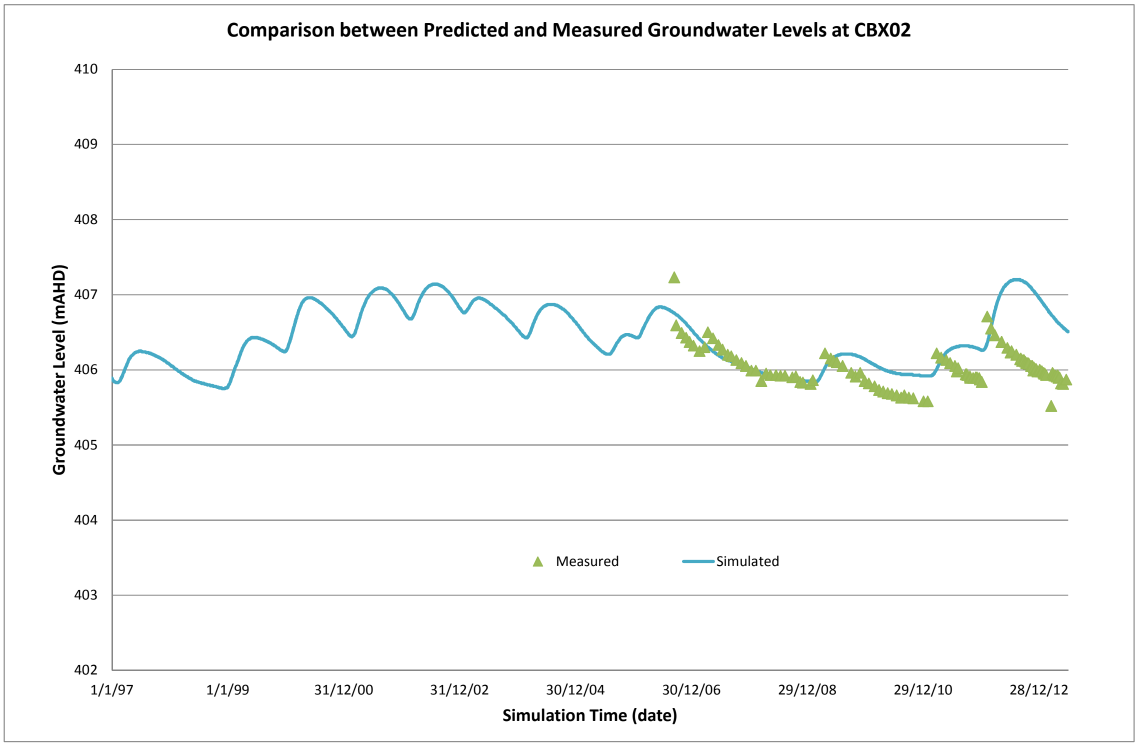

Figure 3.19: Hydraulic Property Distribution of Numerical Layer 11.

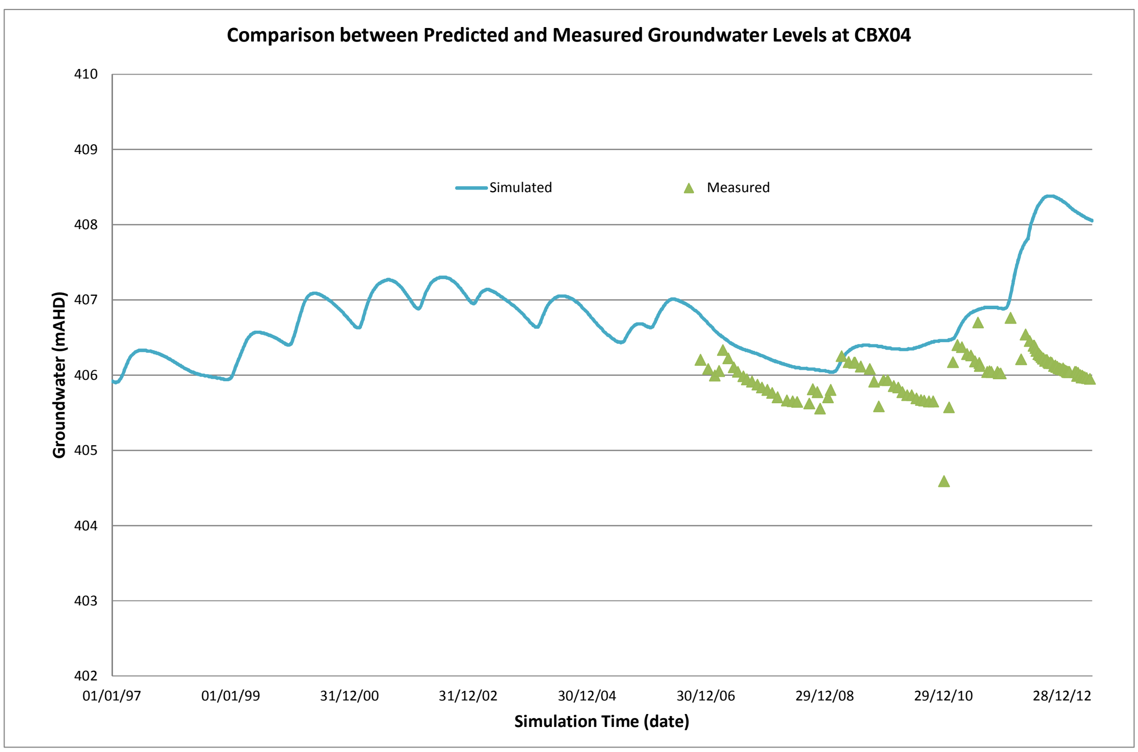
# Appendix 4: Numerical model calibration - Measured hydrographs at monitoring bores compared to those predicted by the calibrated model

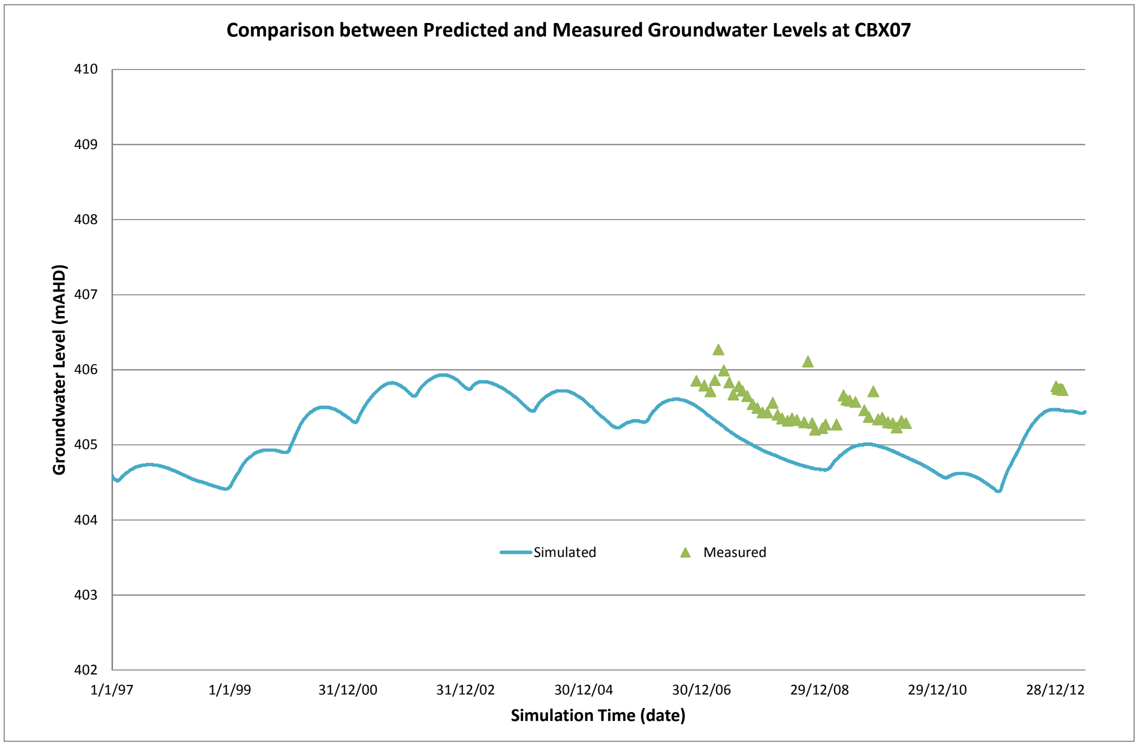
This page has been left blank intentionally

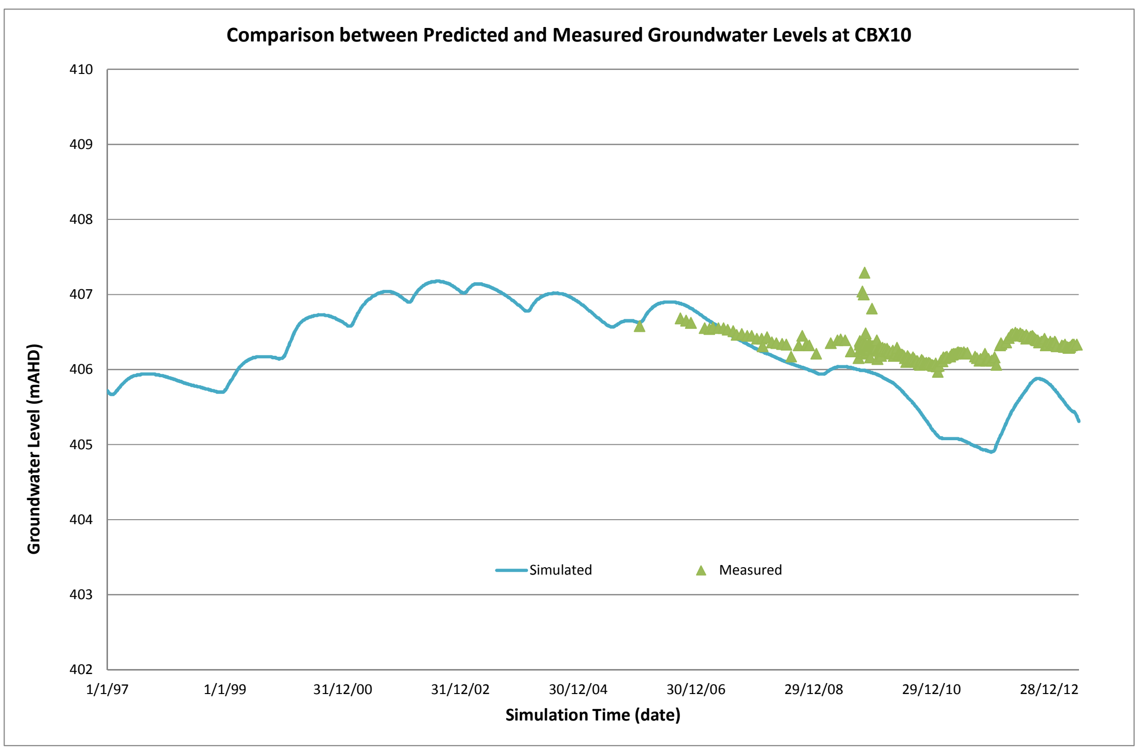

Comparison of Predicted, Measured and Interpreted Water Levels at Marsh point A
Simulated
Interpreted
UWA data
Water Level (mAHD)
410
409
408
407
406
405
404
403
402
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time (date)

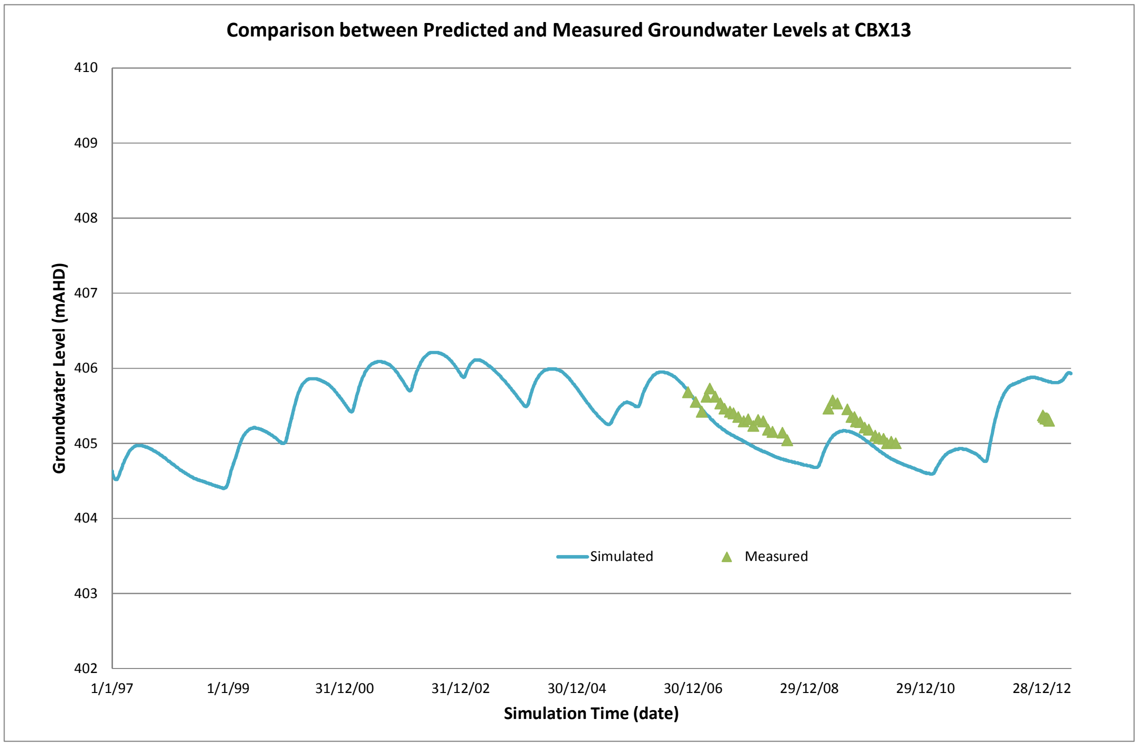

Comparison of Predicted, Measured and Interpreted Water Levels at Marsh point B
Simulated
Interpreted
UWA data
Water Level (mAHD)
410
409
408
407
406
405
404
403
402
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time (date)

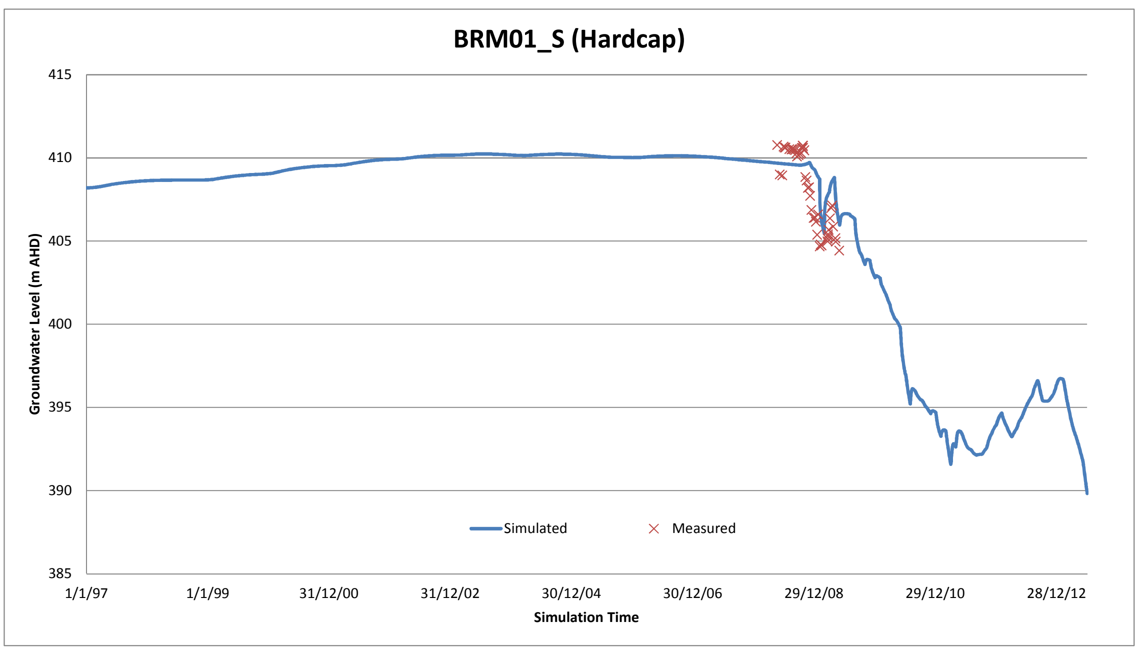

Comparison between Predicted and Measured Groundwater Levels at CBX02
410
409
408
407
406
405
404
403
402
Groundwater Level (mAHD)
Measured
Simulated
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time (date)

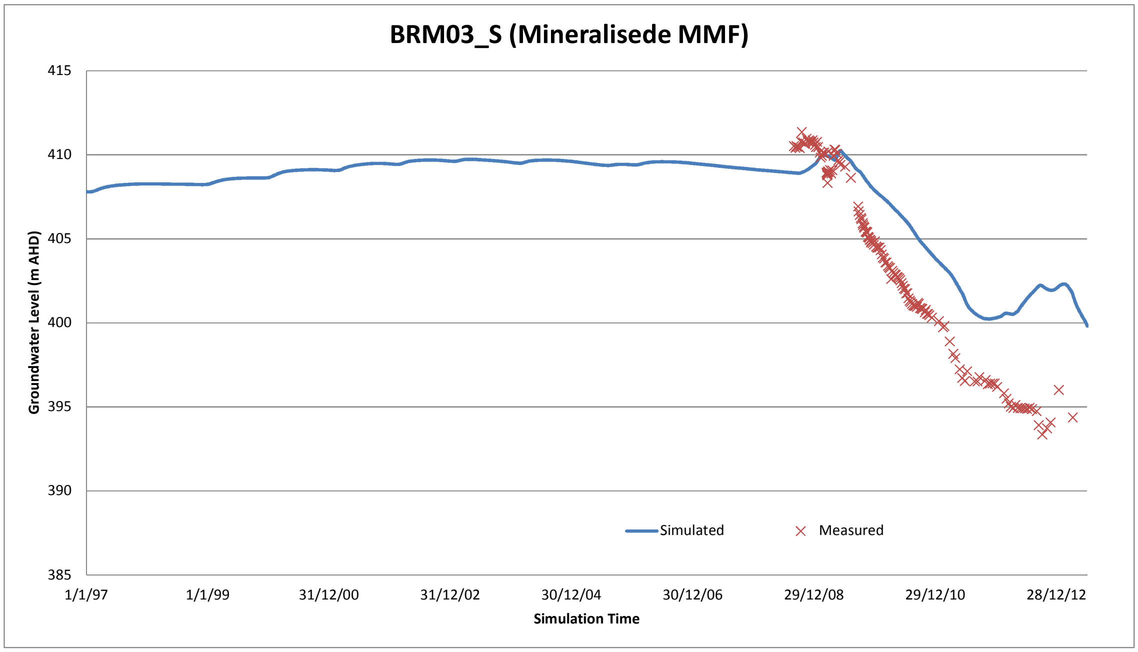

Comparison between Predicted and Measured Groundwater Levels at CBX04
410
409
408
407
406
405
404
403
402
Groundwater (mAHD)
Simulated
Measured
01/01/97
01/01/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time (date)


Comparison between Predicted and Measured Groundwater Levels at CBX07
410
409
408
407
406
405
404
403
402
Groundwater Level (mAHD)
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time (date)

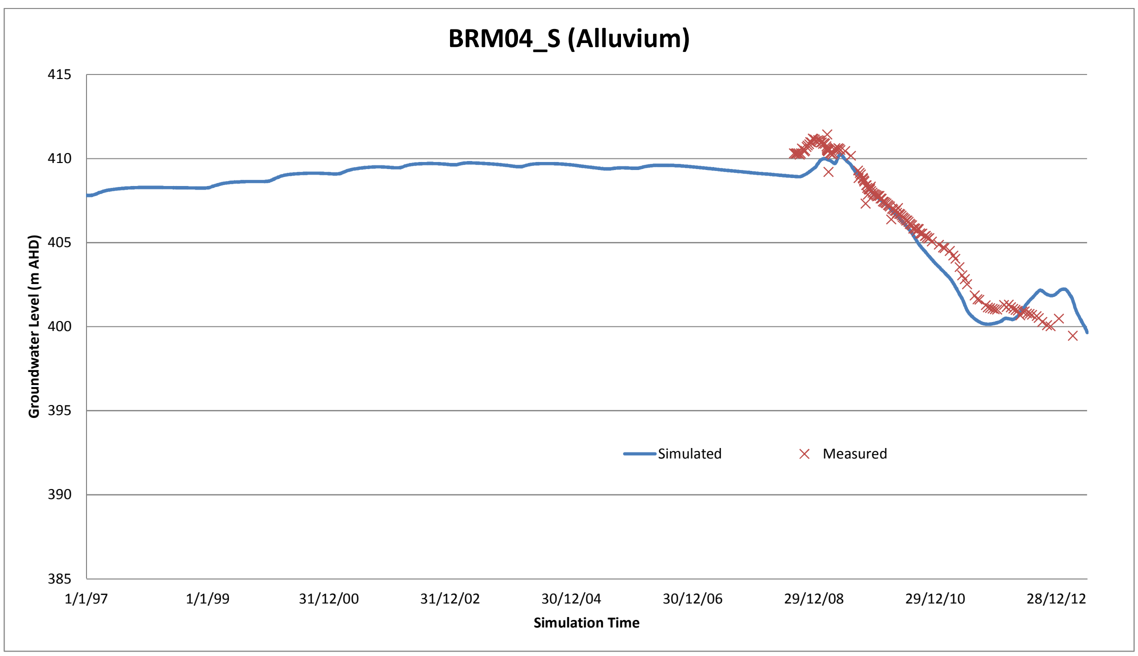

Comparison between Predicted and Measured Groundwater Levels at CBX10
410
409
408
407
406
405
404
403
402
Groundwater Level (mAHD)
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time (date)


Comparison between Predicted and Measured Groundwater Levels at CBX13
Groundwater Level (mAHD)
410
409
408
407
406
405
404
403
402
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time (date)

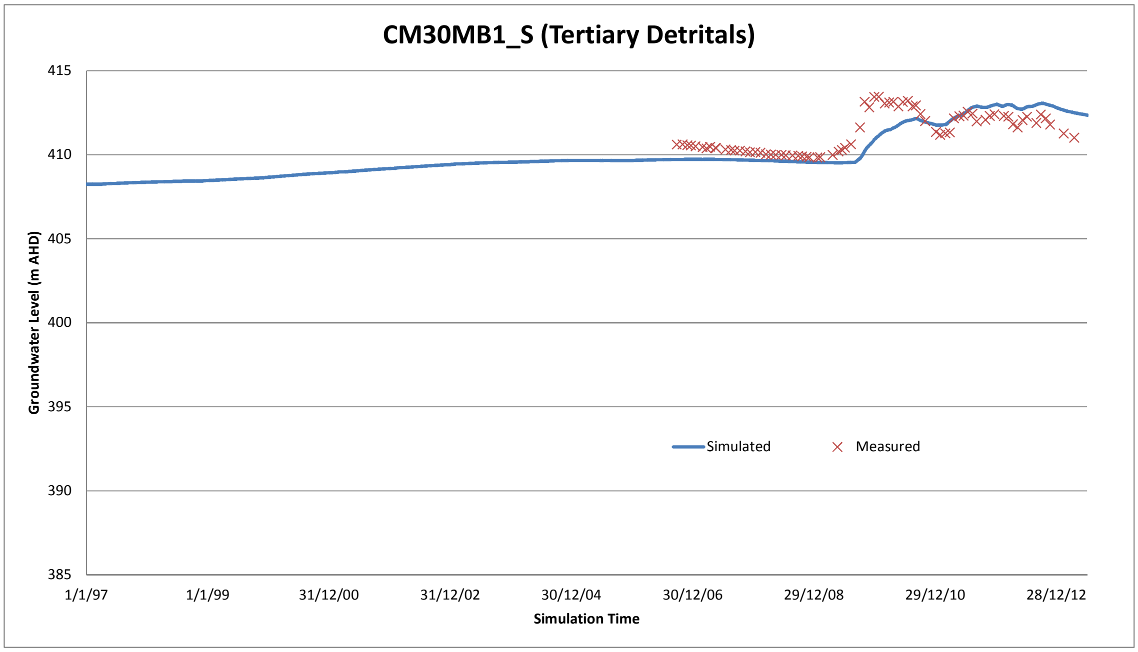

BRM01_S (Hardcap)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

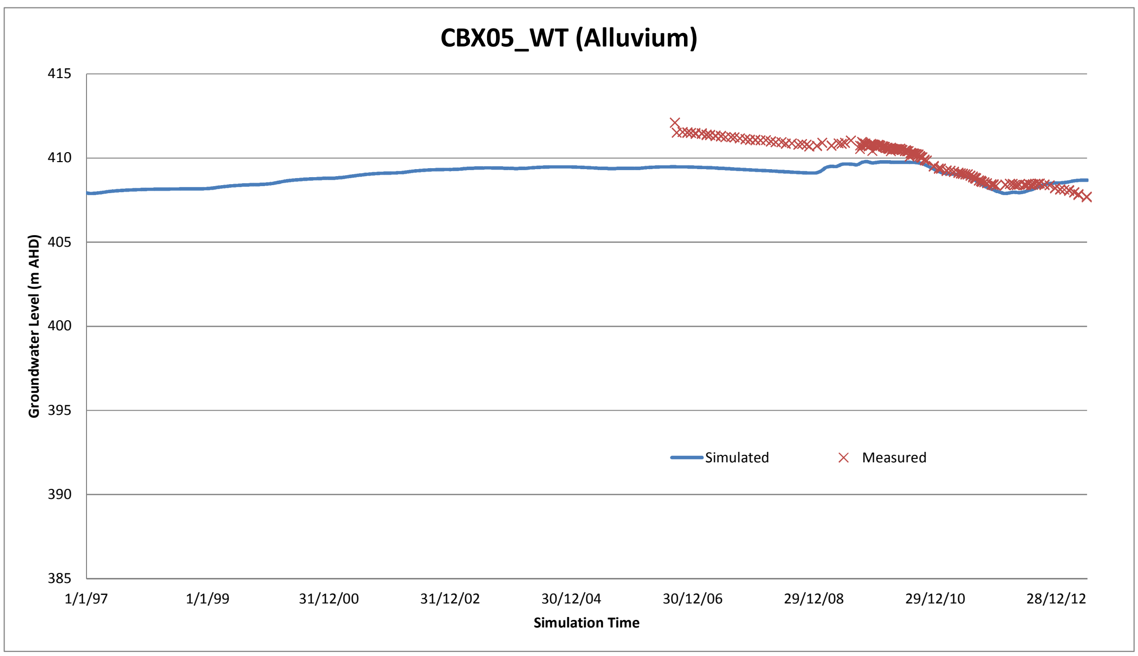


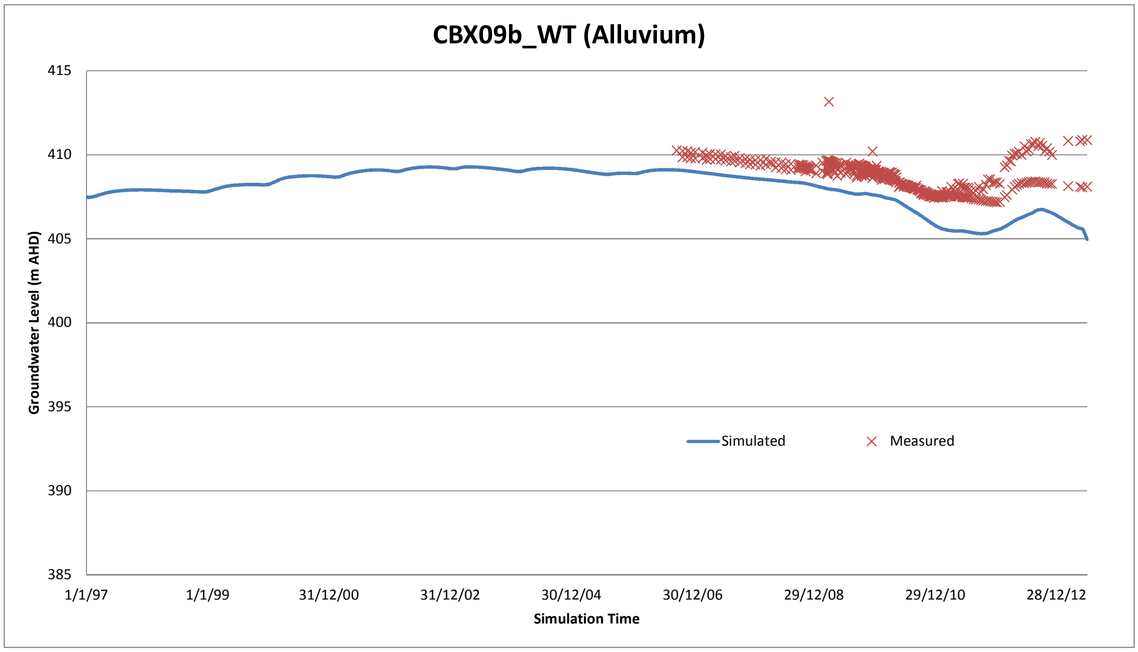
BRM03_S (Mineralisede MMF)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

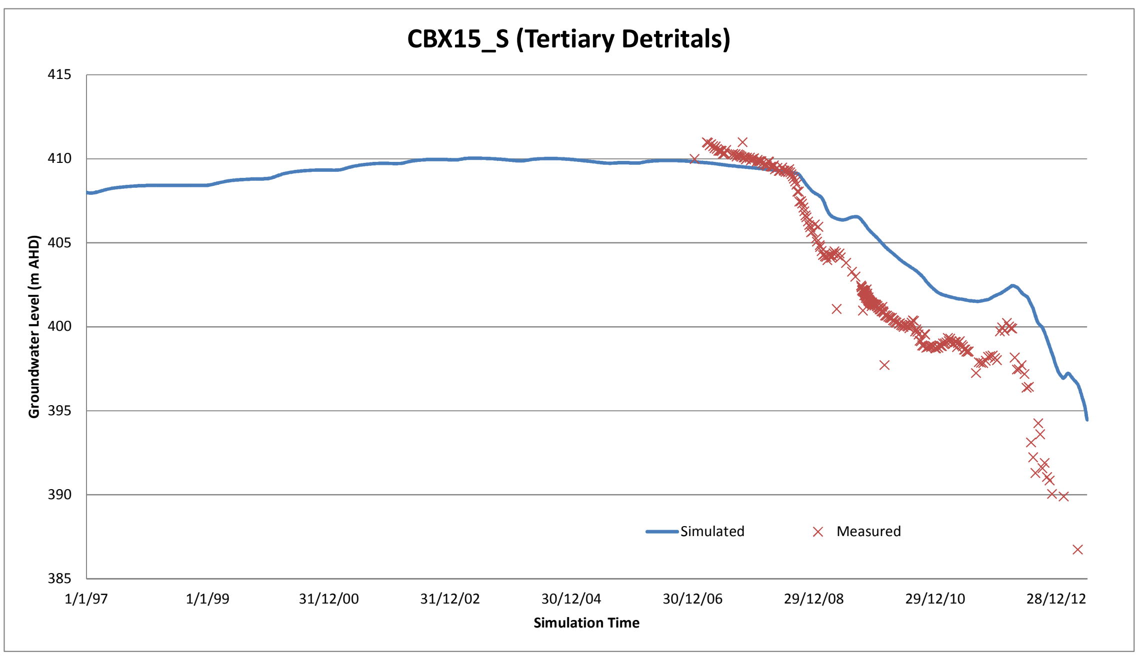



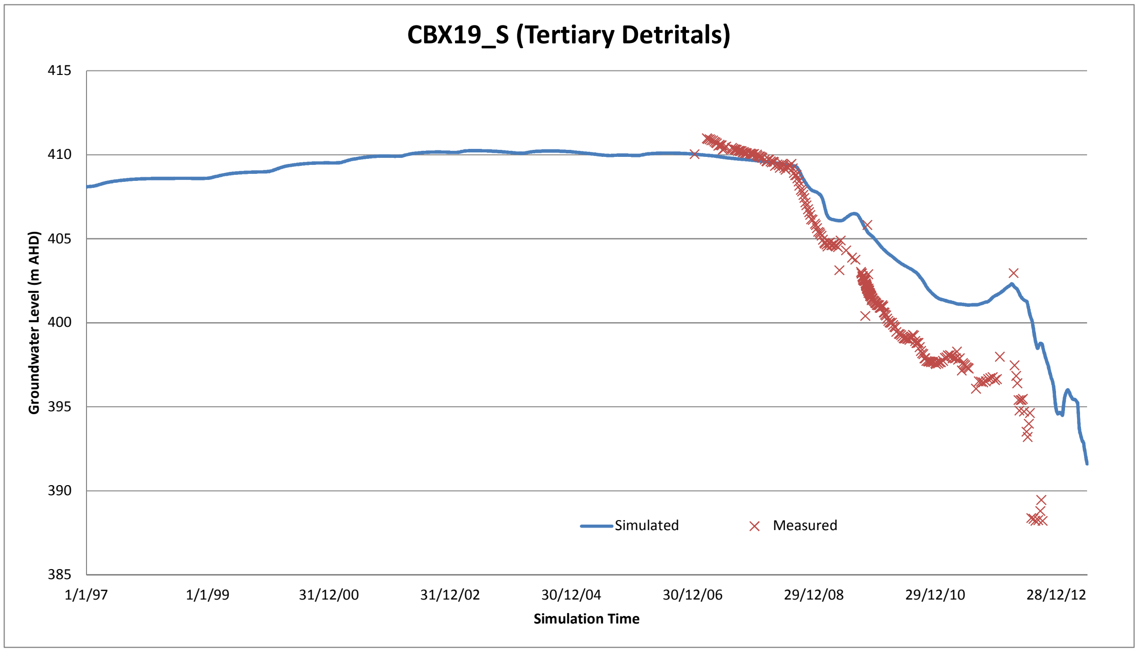
BRM04_S (Alluvium)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

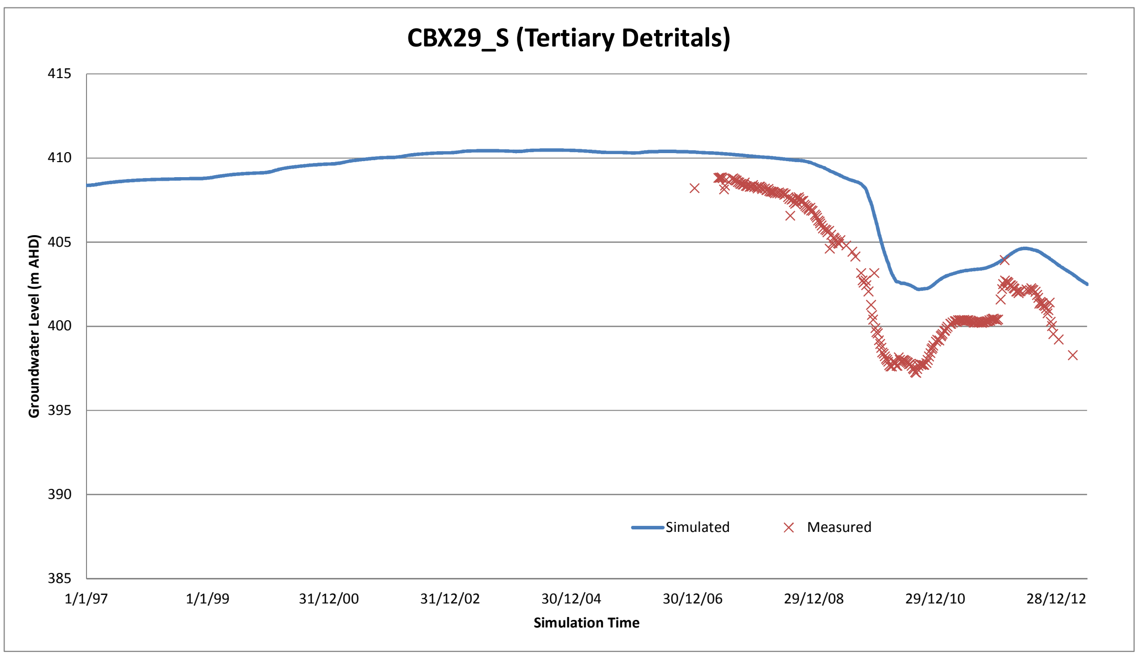

CM30MB1_S (Tertiary Detritals)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time
Simulated
Measured

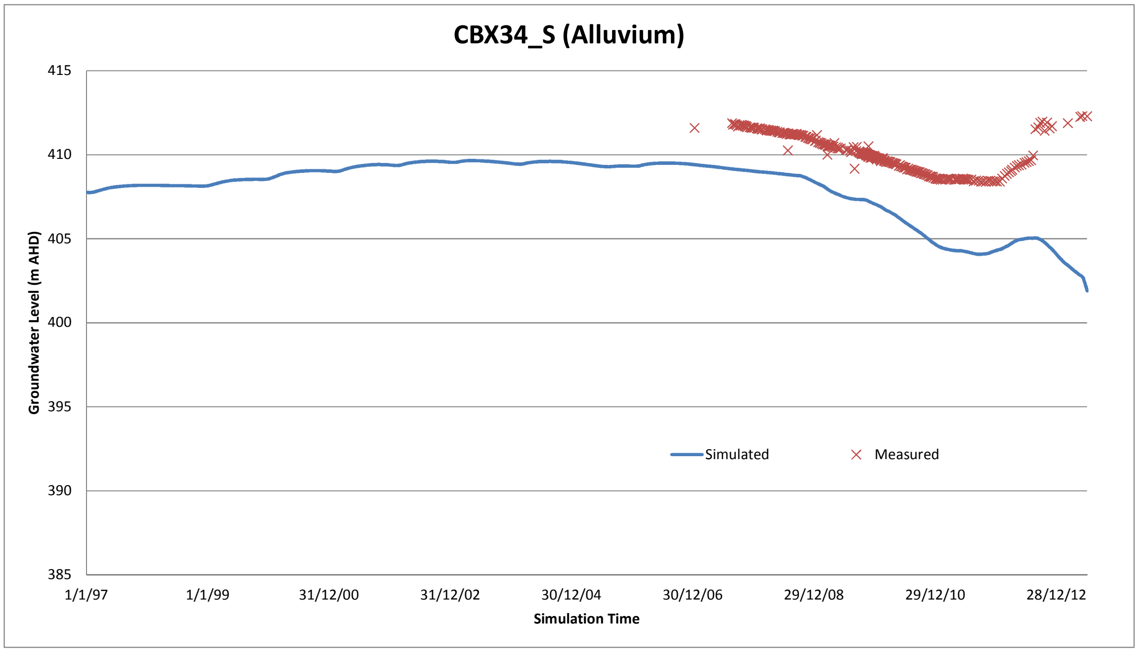

CBX05_WT (Alluvium)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time
Simulated
Measured

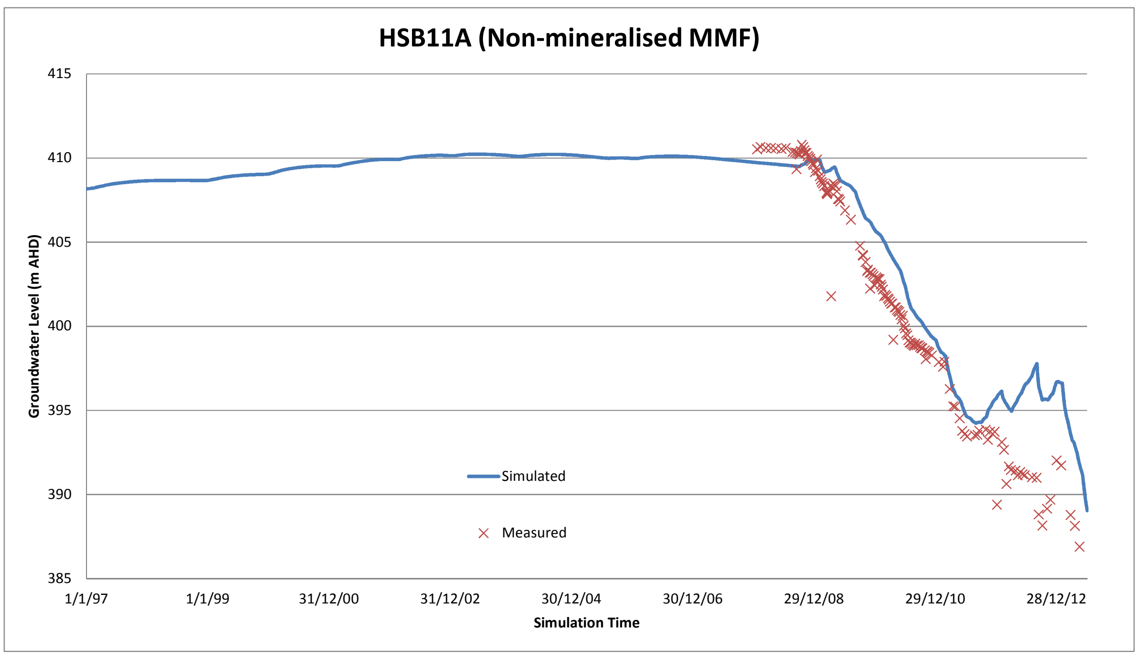

CBX09b_WT (Alluvium)
415
410
405
400
395
390
385
Groundwater Level (m AHD)
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time
Simulated
Measured

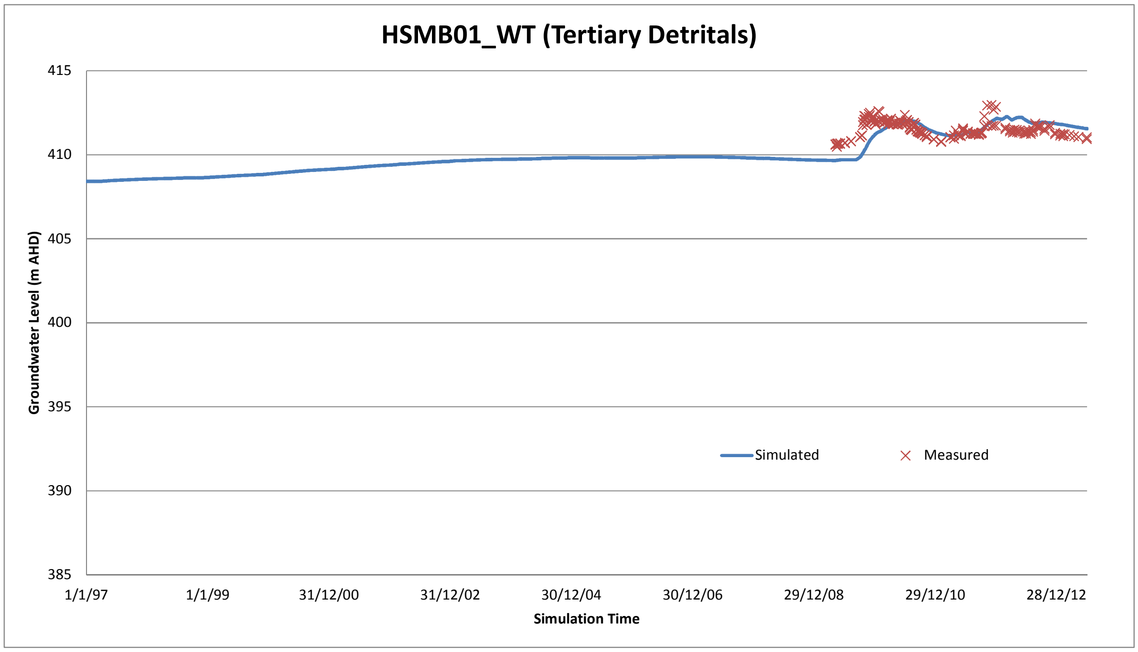

CBX15_S (Tertiary Detritals)
415
410
405
400
395
390
385
Groundwater Level (m AHD)
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time
Simulated
Measured

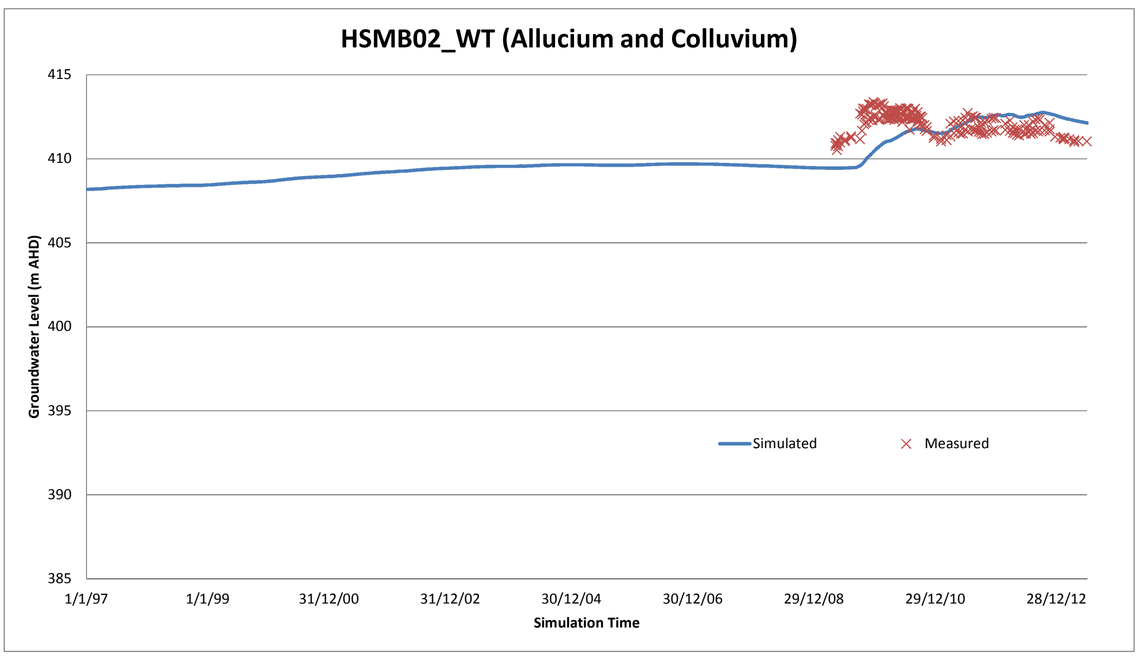

CBX19_S (Tertiary Detritals)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

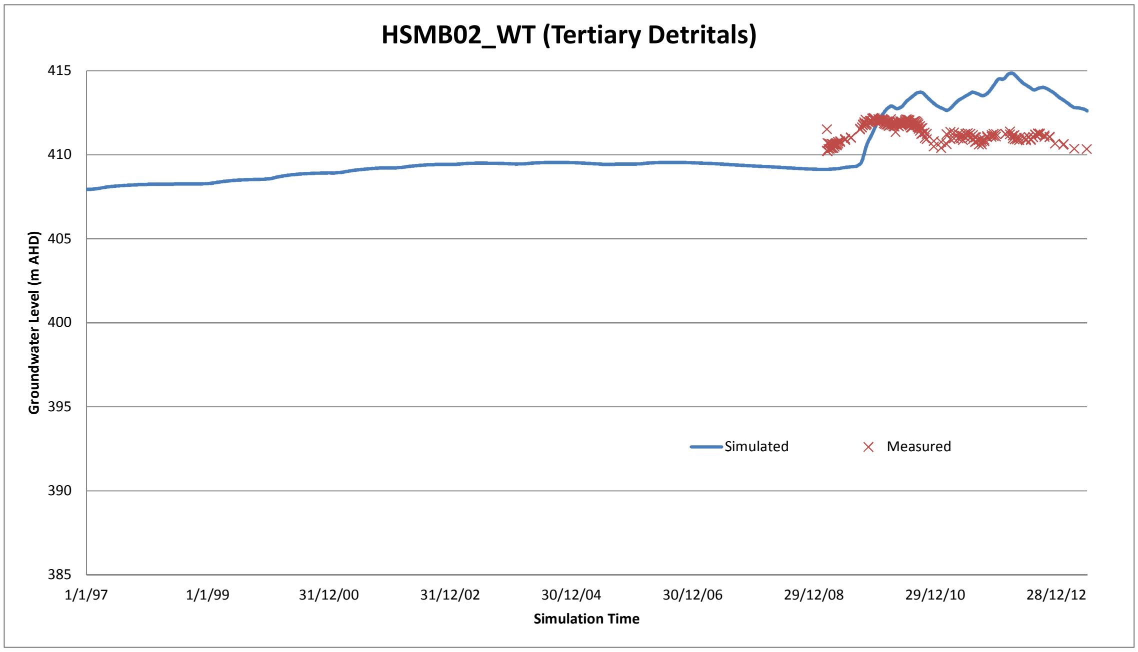

CBX29_S (Tertiary Detritals)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

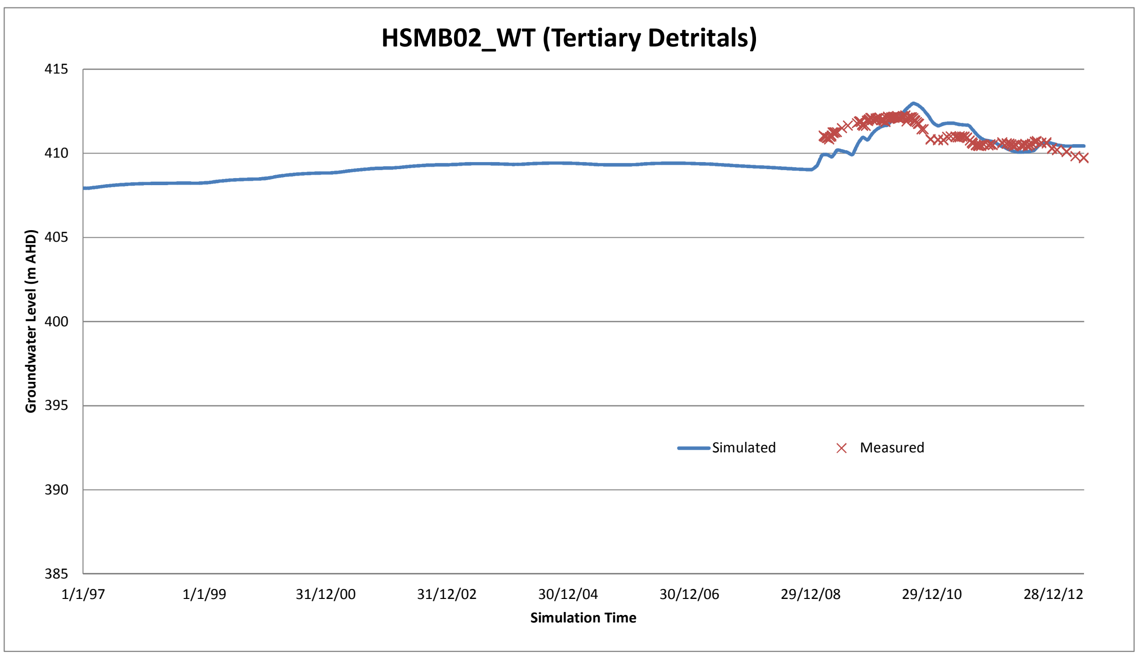

CBX34_S (Alluvium)
415
410
405
400
395
390
385
Groundwater Level (m AHD)
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time
Simulated
Measured

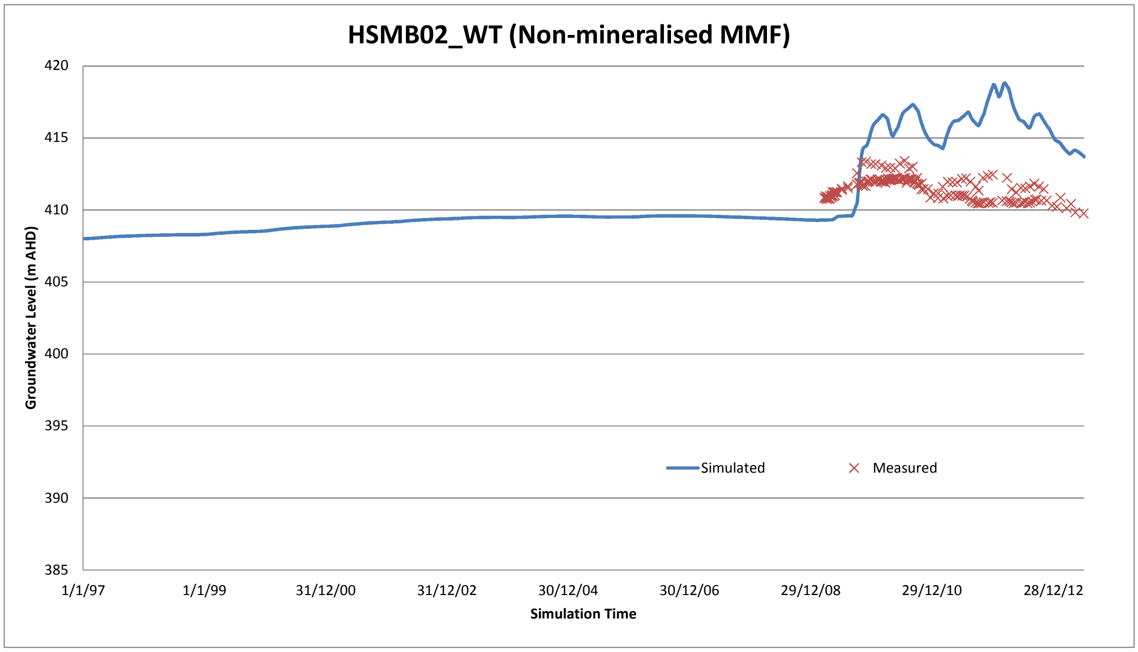

HSB11A (Non-mineralised MMF)
415
410
405
400
395
390
385
Groundwater Level (m AHD)
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time
Simulated
Measured

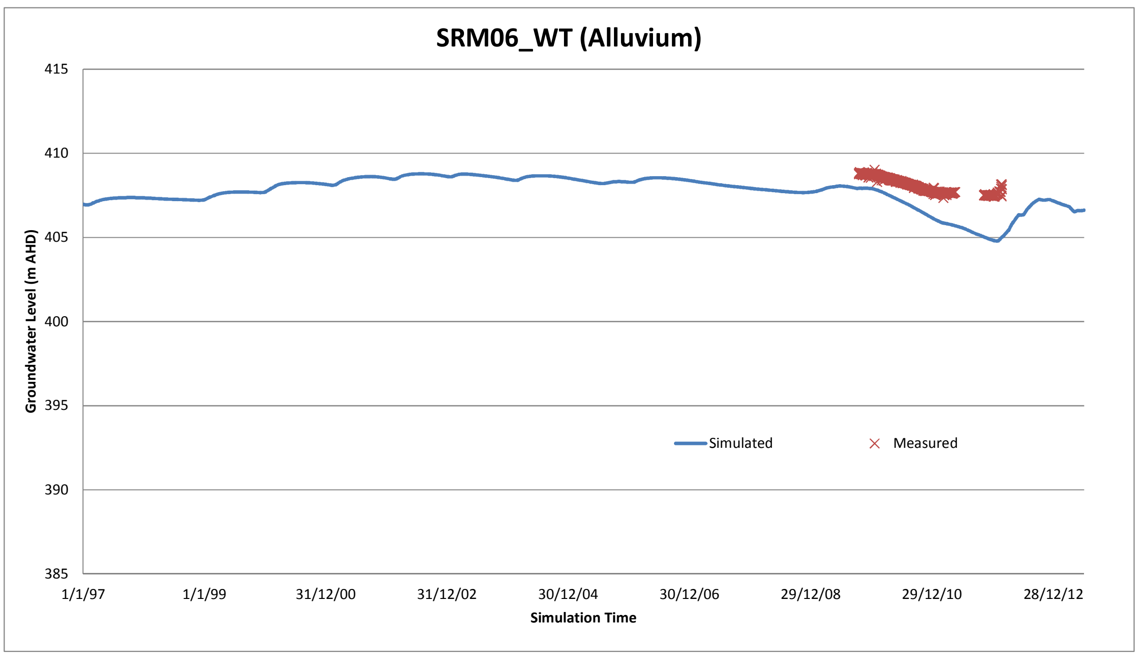

HSMB01_WT (Tertiary Detritals)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

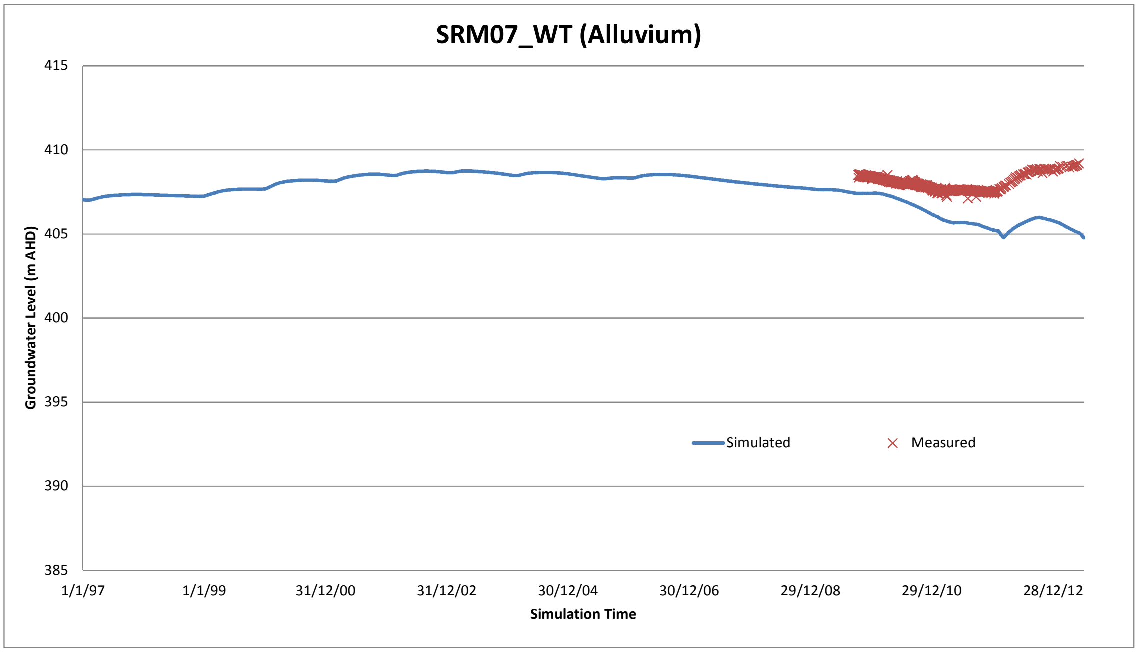

HSMB02_WT (Allucium and Colluvium)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time


HSMB02_WT (Tertiary Detritals)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time


HSMB02_WT (Tertiary Detritals)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time


HSMB02_WT (Non-mineralised MMF)
Groundwater Level (m AHD)
420
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

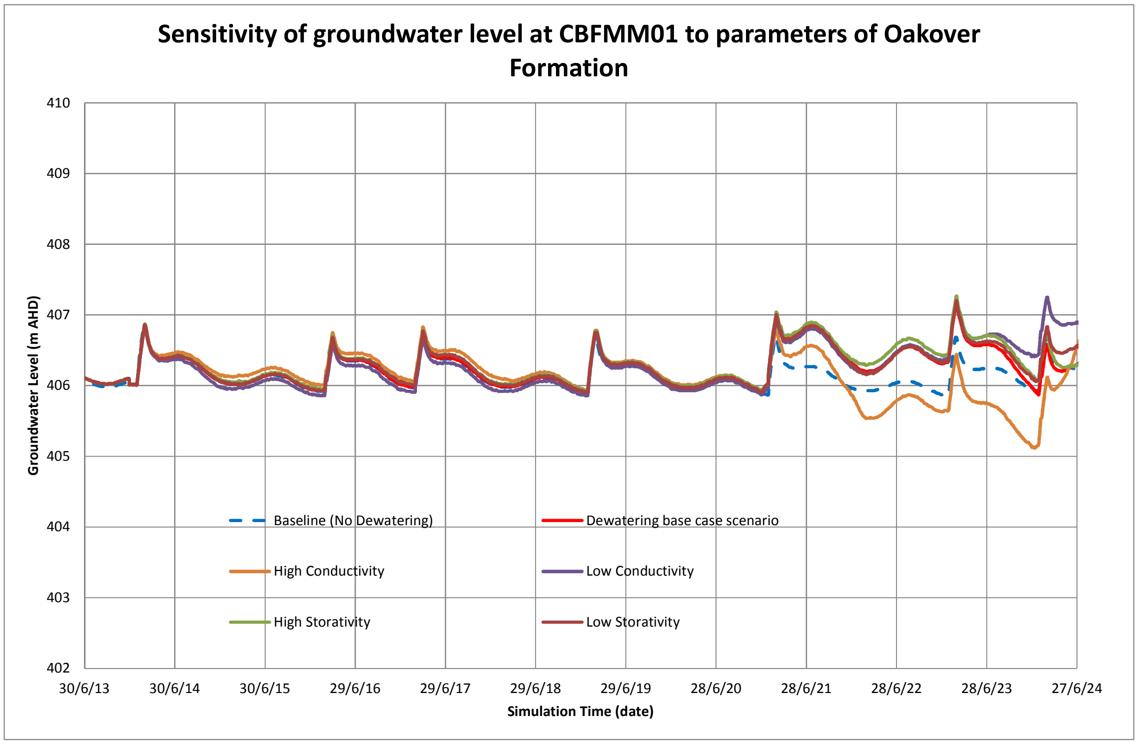

SRM06_WT (Alluvium)
Groundwater Level (m AHD)
415
410
405
400
395
390
385
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

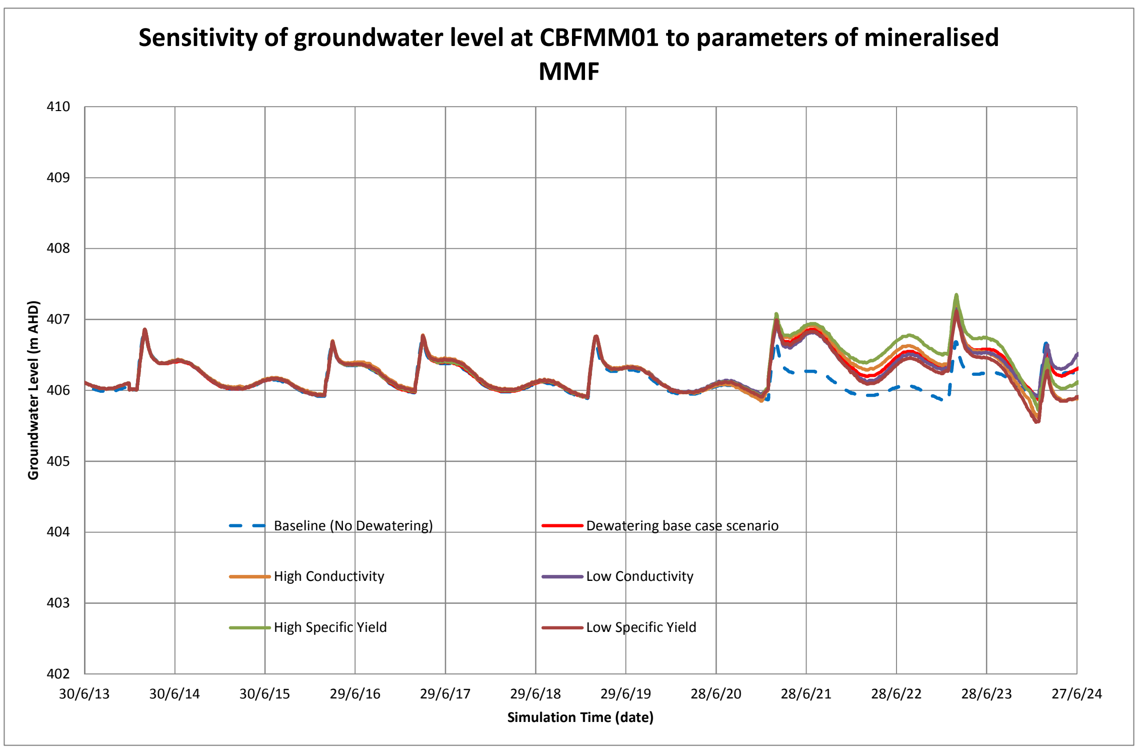


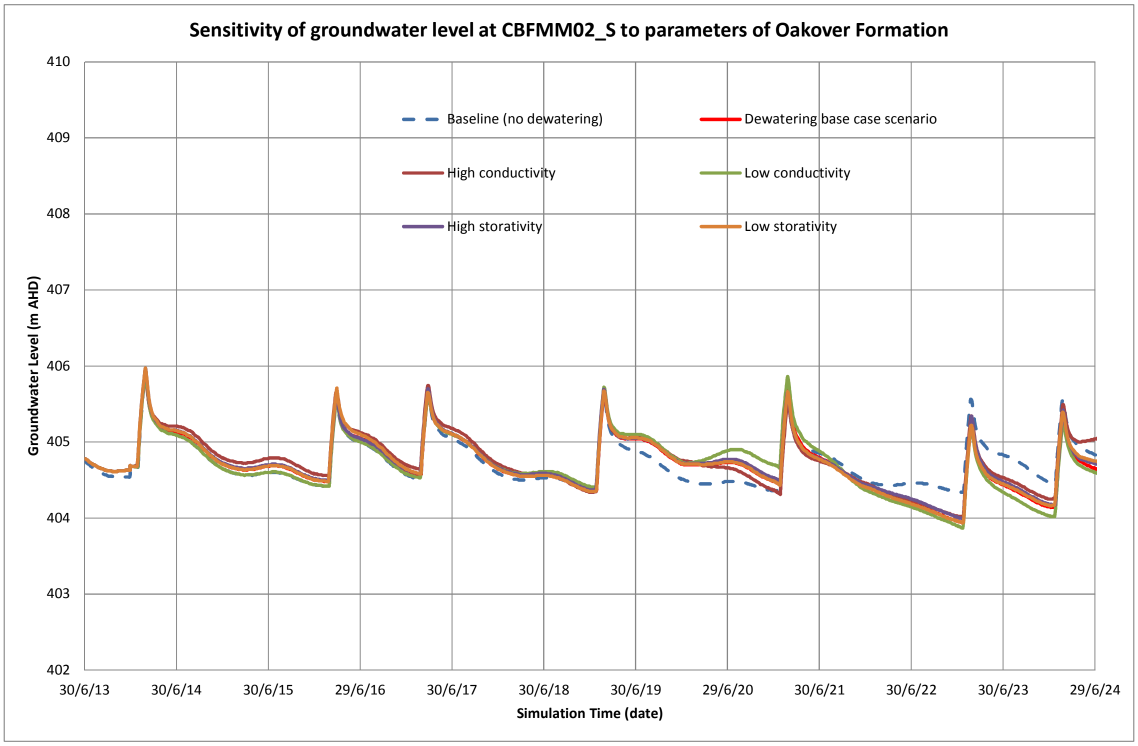
SRM07_WT (Alluvium)
415
410
405
400
395
390
385
Groundwater Level (m AHD)
Simulated
Measured
1/1/97
1/1/99
31/12/00
31/12/02
30/12/04
30/12/06
29/12/08
29/12/10
28/12/12
Simulation Time

# Appendix 5: Hydrographs at selected key locations from all sensitivity simulations

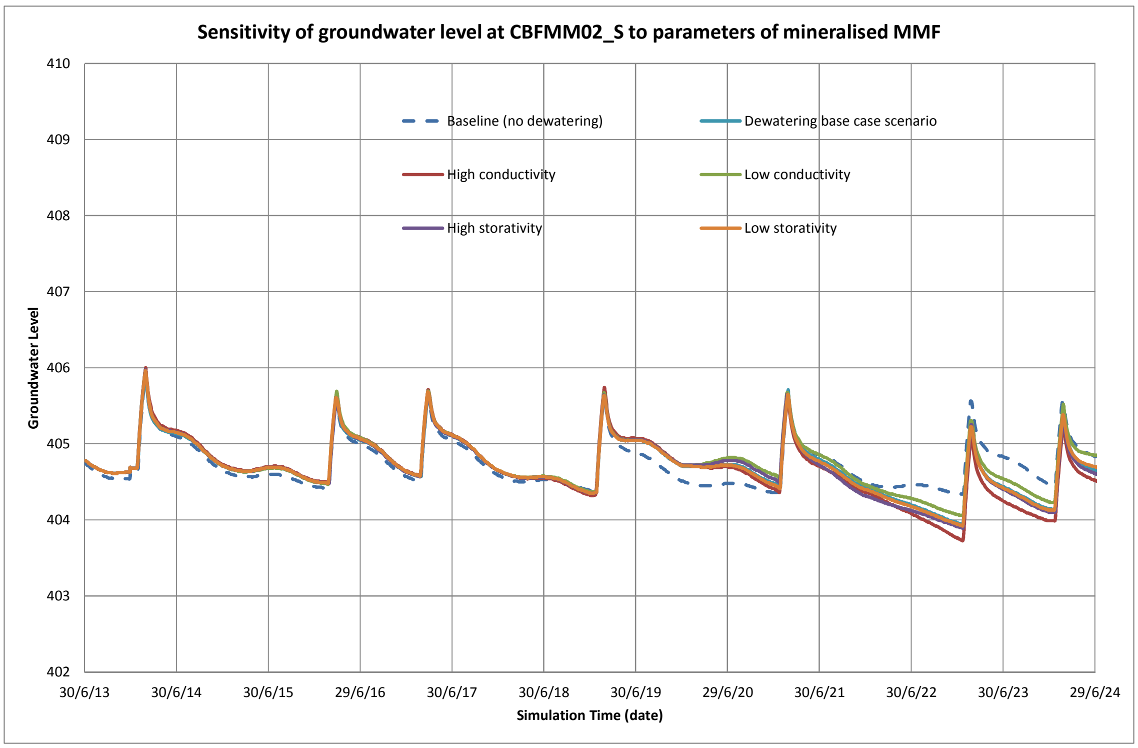
This page has been left blank intentionally


Sensitivity of groundwater level at CBFMM01 to parameters of Oakover Formation
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
Baseline (No Dewatering)
Dewatering base case scenario
High Conductivity
Low Conductivity
High Storativity
Low Storativity
30/6/13
30/6/14
30/6/15
29/6/16
29/6/17
29/6/18
29/6/19
28/6/20
28/6/21
28/6/22
28/6/23
27/6/24
Simulation Time (date)

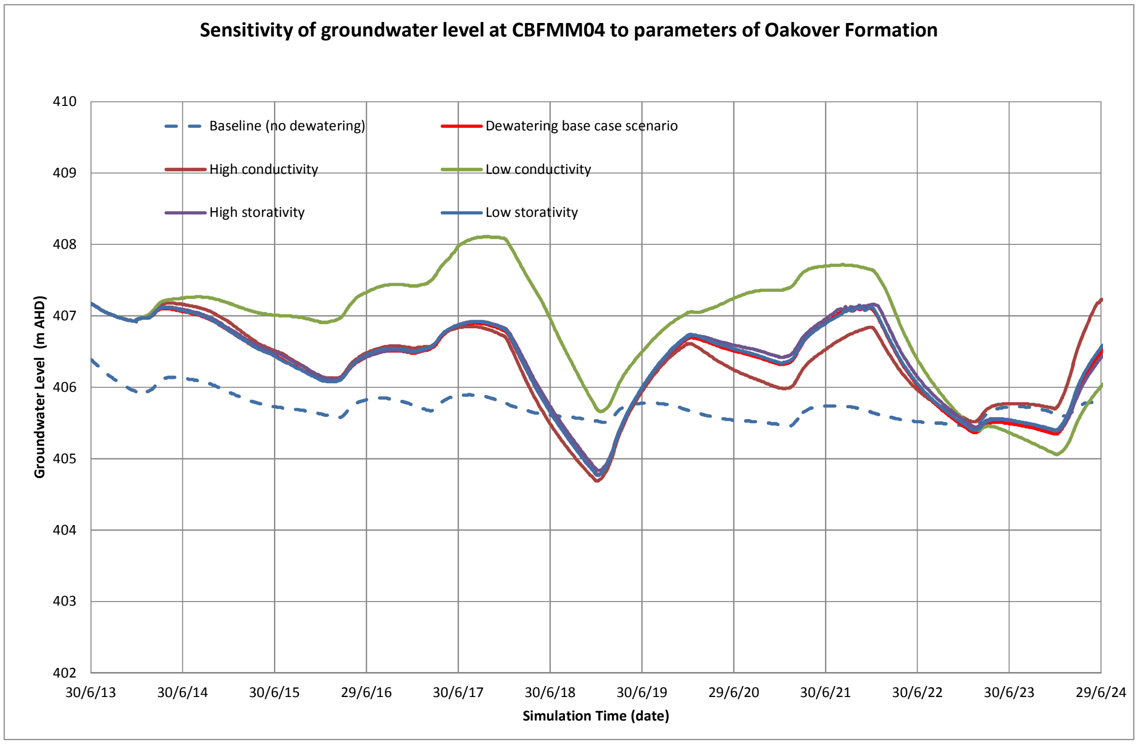

Sensitivity of groundwater level at CBFMM01 to parameters of mineralised MMF
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
Baseline (No Dewatering)
Dewatering base case scenario
High Conductivity
Low Conductivity
High Specific Yield
Low Specific Yield
30/6/13
30/6/14
30/6/15
29/6/16
29/6/17
29/6/18
29/6/19
28/6/20
28/6/21
28/6/22
28/6/23
27/6/24
Simulation Time (date)



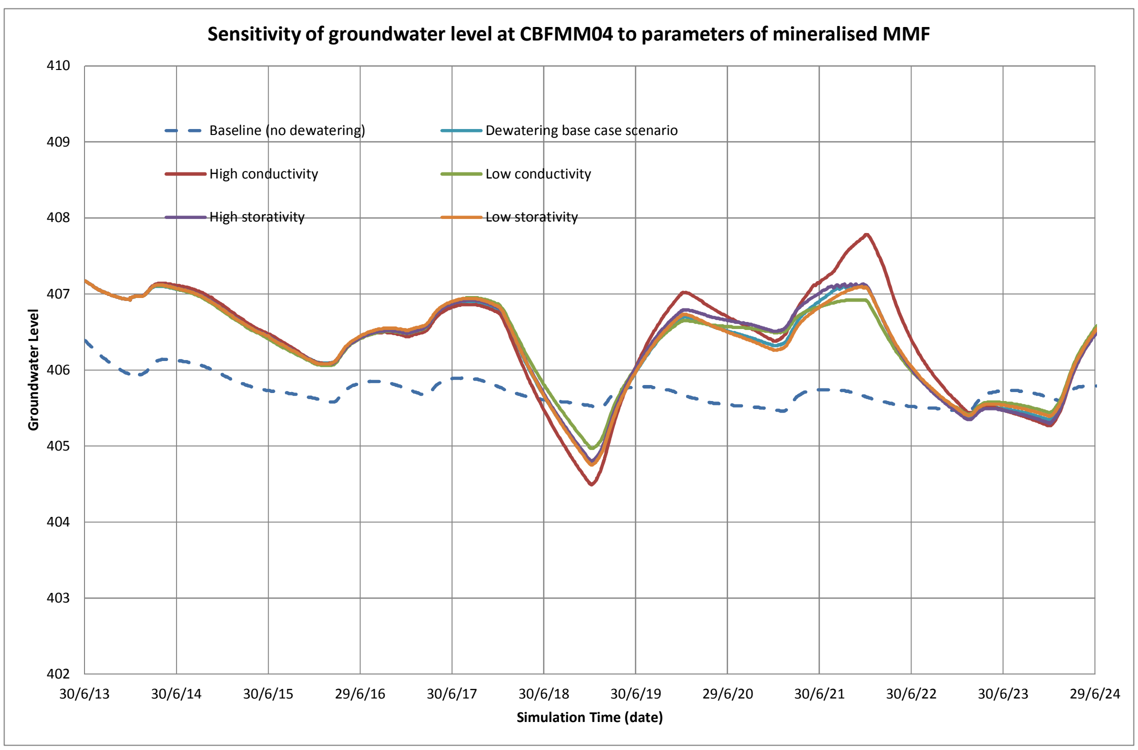
Sensitivity of groundwater level at CBFMM02_S to parameters of Oakover Formation
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

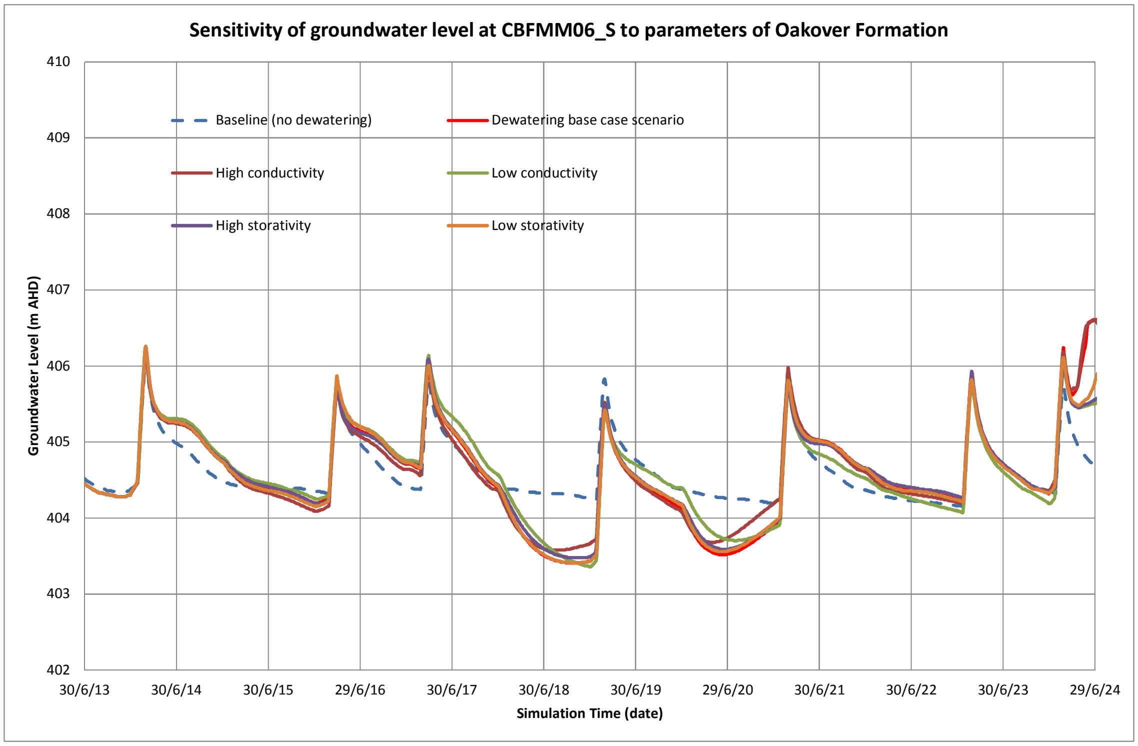
Sensitivity of groundwater level at CBFMM02_S to parameters of mineralised MMF
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

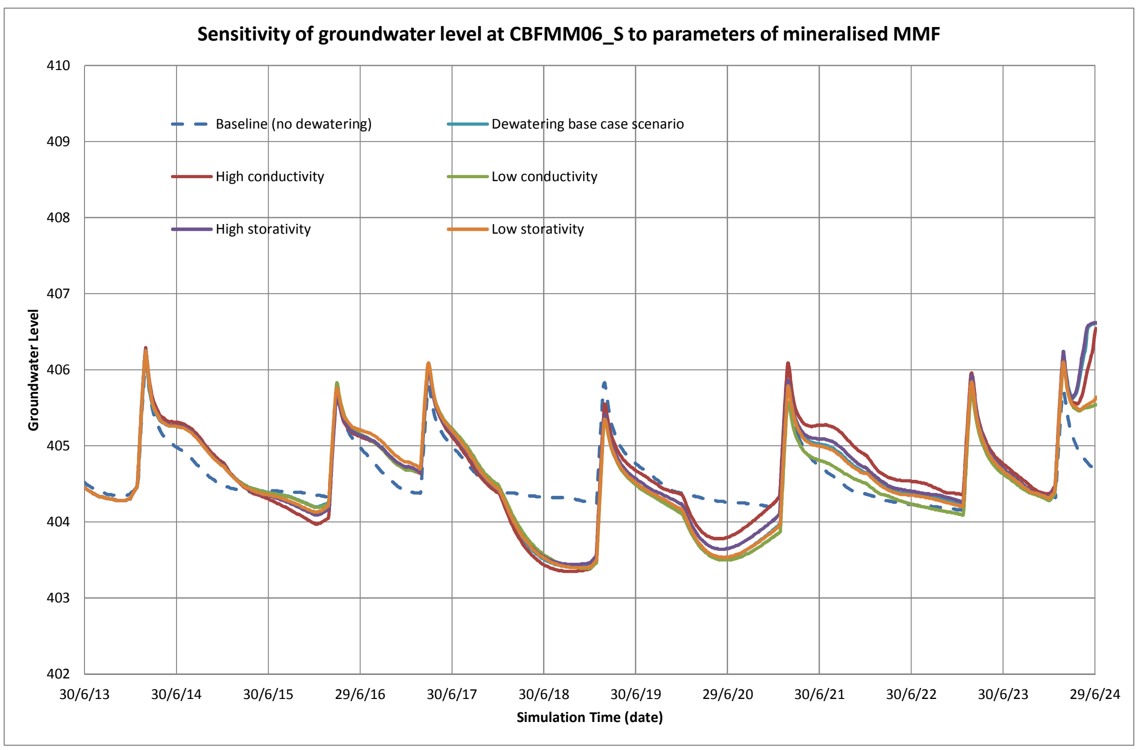


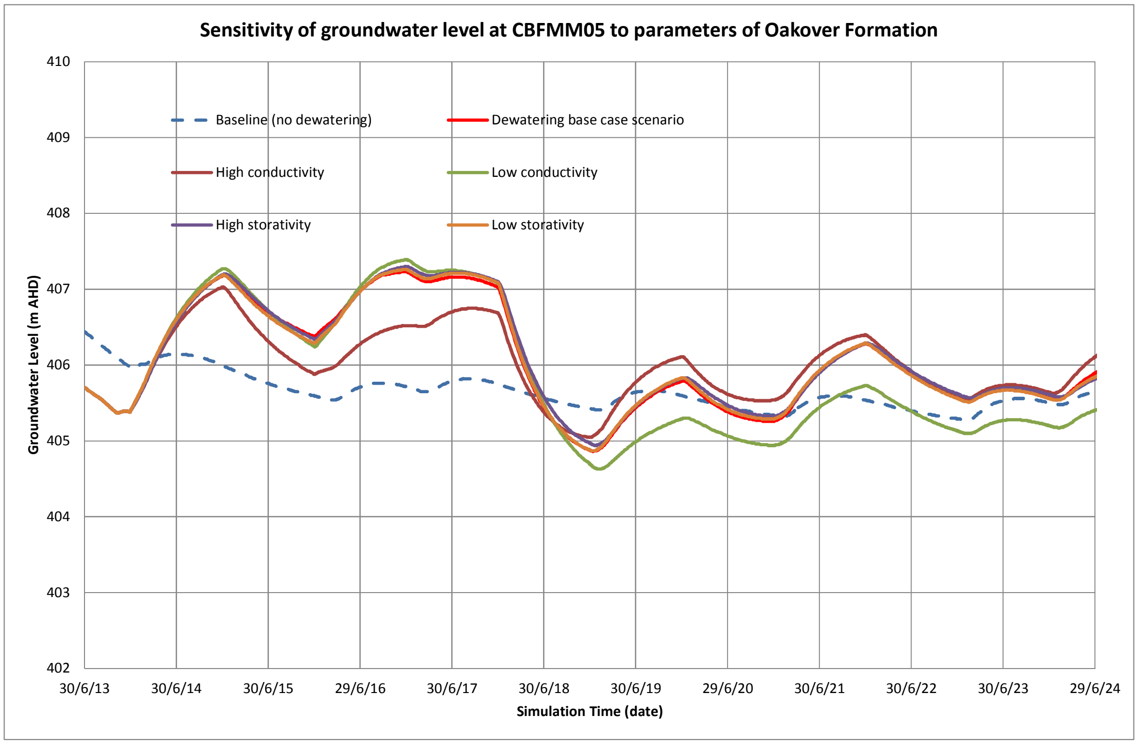
Sensitivity of groundwater level at CBFMM04 to parameters of Oakover Formation
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

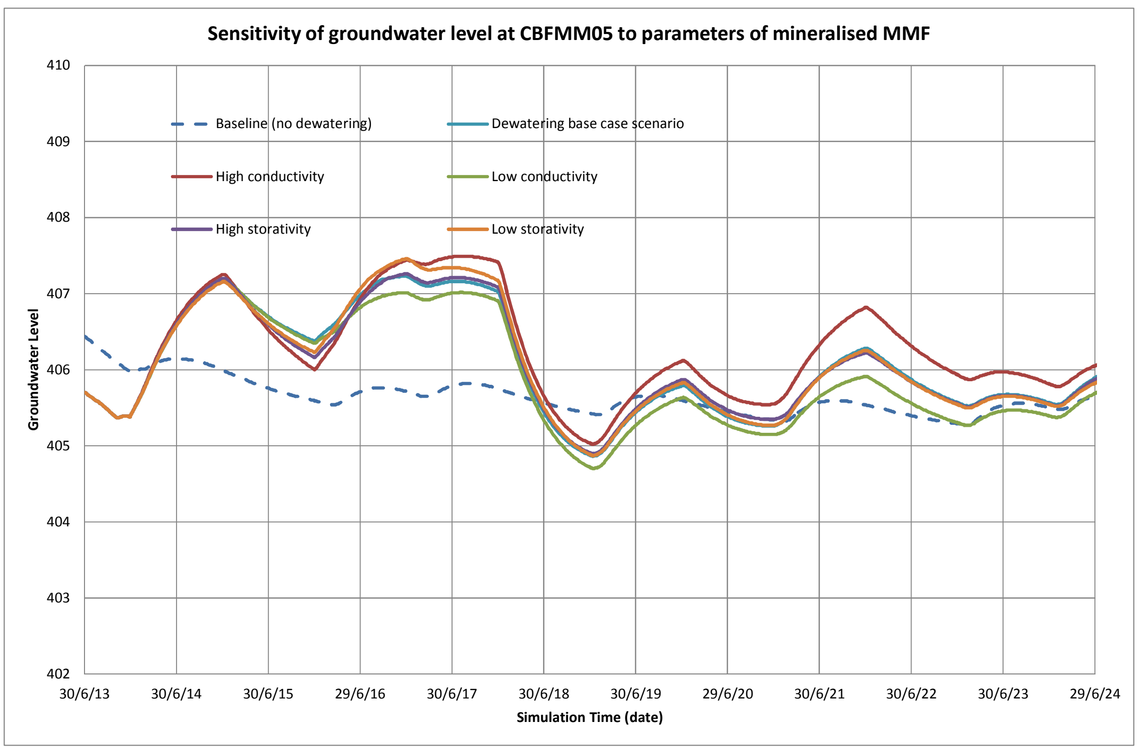



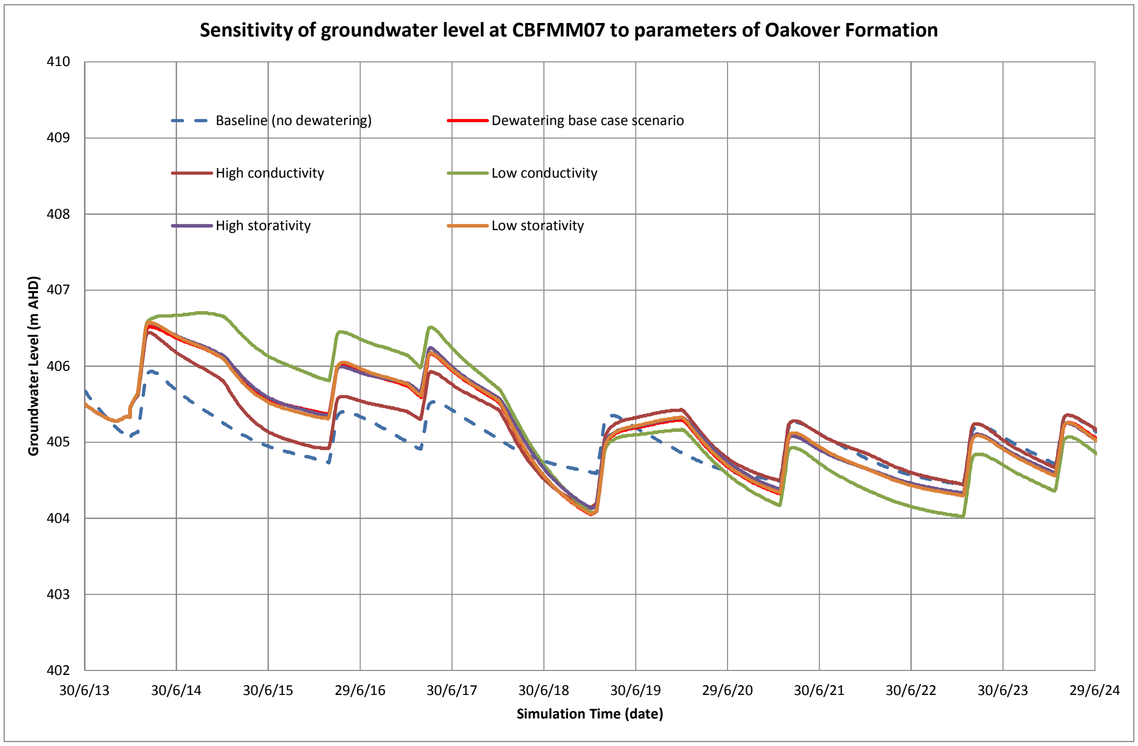
Sensitivity of groundwater level at CBFMM04 to parameters of mineralised MMF
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

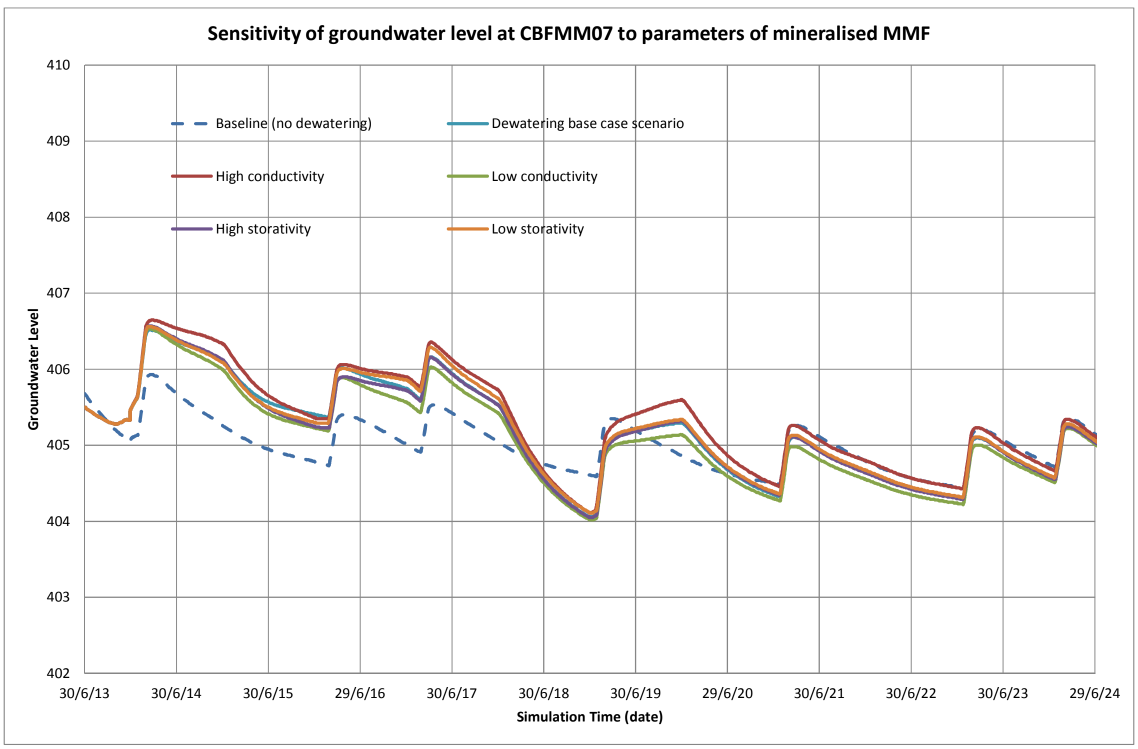

Sensitivity of groundwater level at CBFMM06_S to parameters of Oakover Formation
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

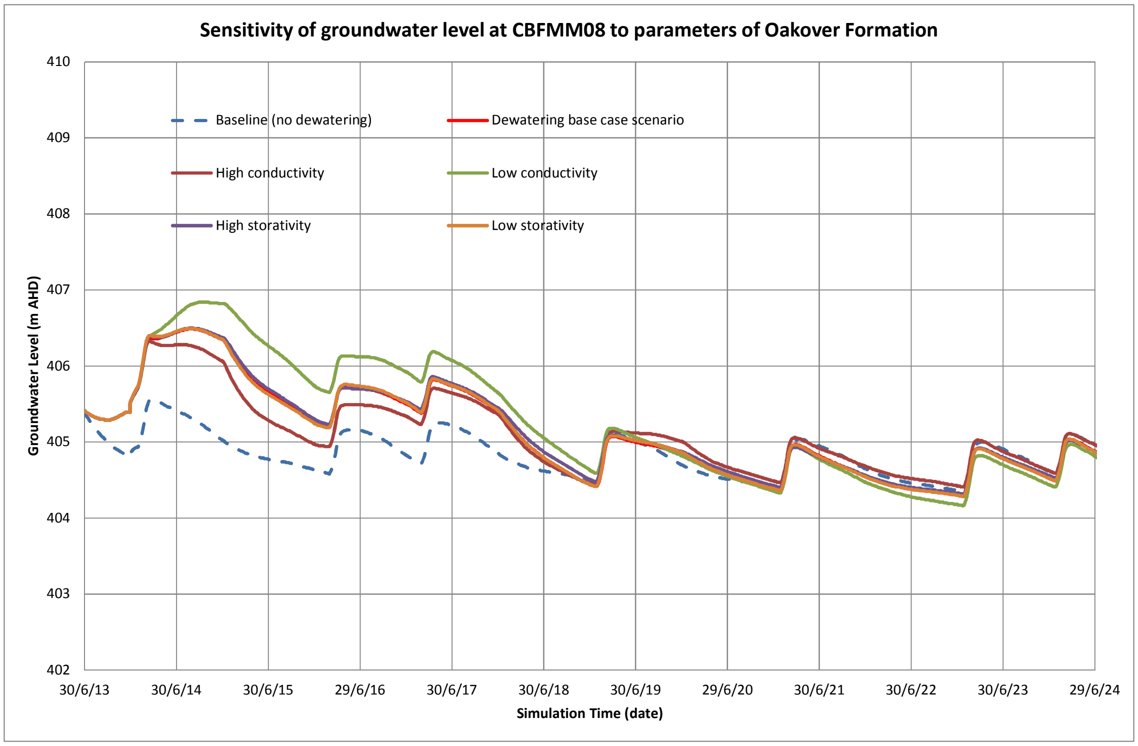

Sensitivity of groundwater level at CBFMM06_S to parameters of mineralised MMF
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)


Sensitivity of groundwater level at CBFMM05 to parameters of Oakover Formation
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

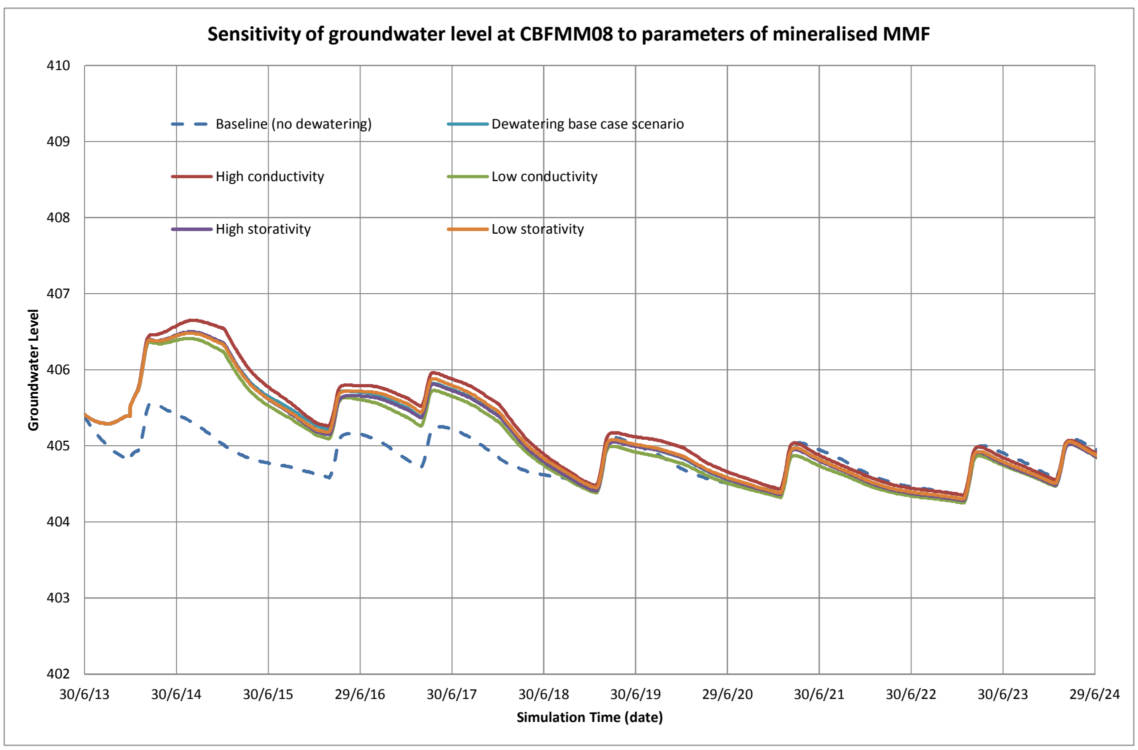

Sensitivity of groundwater level at CBFMM05 to parameters of mineralised MMF
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)


Sensitivity of groundwater level at CBFMM07 to parameters of Oakover Formation
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)


Sensitivity of groundwater level at CBFMM07 to parameters of mineralised MMF
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)



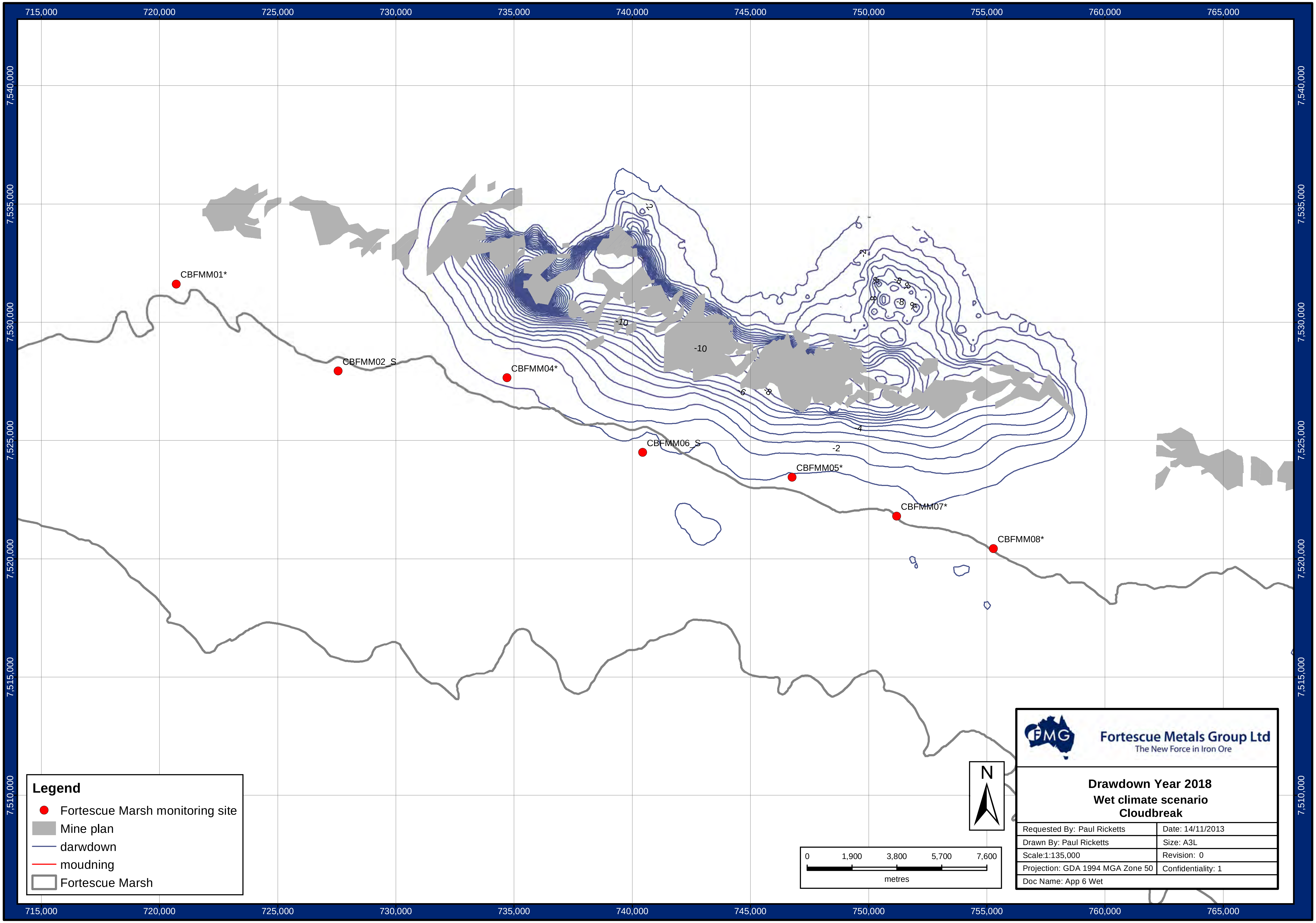
Sensitivity of groundwater level at CBFMM08 to parameters of Oakover Formation
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level (m AHD)
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

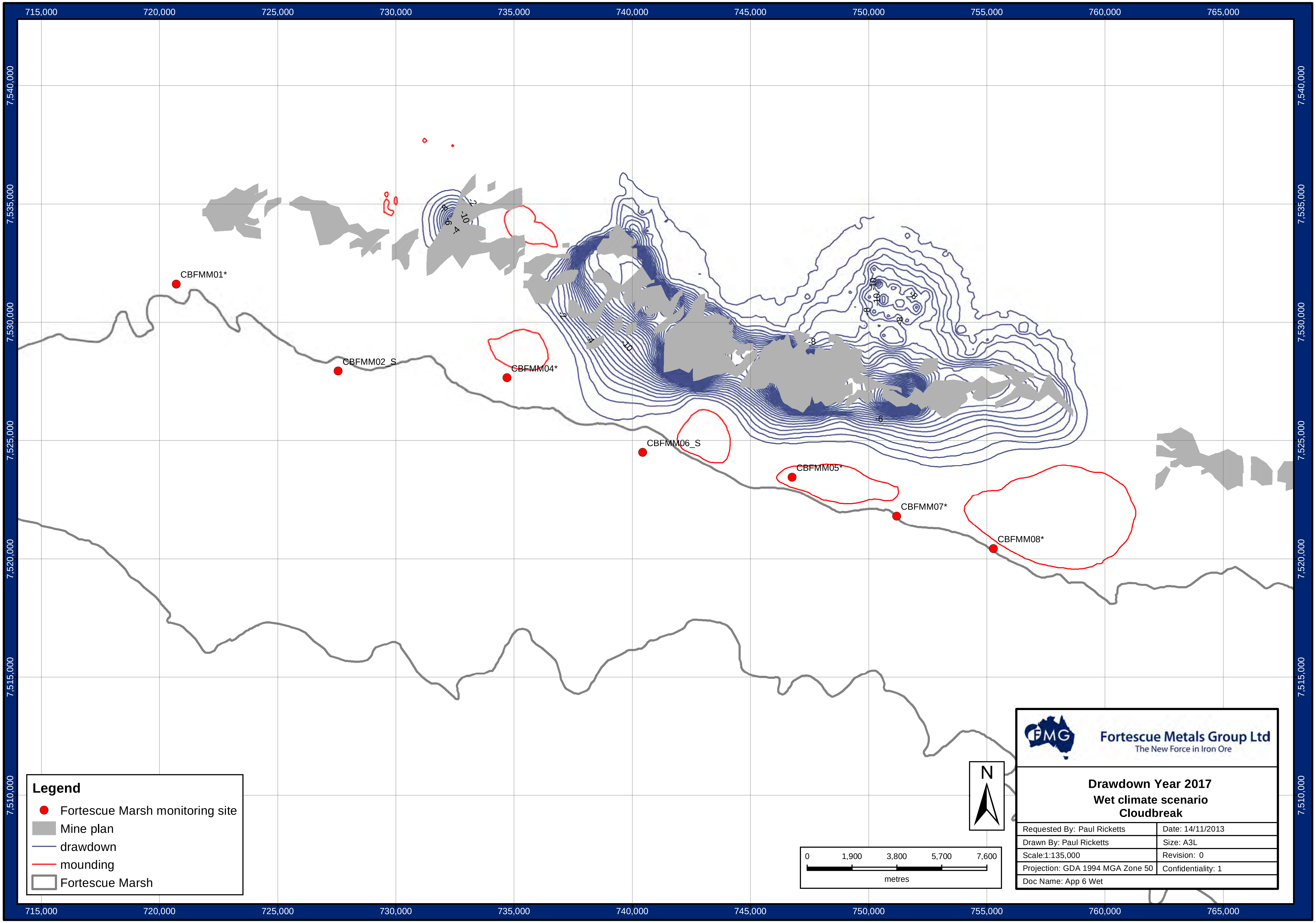
Sensitivity of groundwater level at CBFMM08 to parameters of mineralised MMF
Baseline (no dewatering)
Dewatering base case scenario
High conductivity
Low conductivity
High storativity
Low storativity
Groundwater Level
410
409
408
407
406
405
404
403
402
30/6/13
30/6/14
30/6/15
29/6/16
30/6/17
30/6/18
30/6/19
29/6/20
30/6/21
30/6/22
30/6/23
29/6/24
Simulation Time (date)

# Appendix 6: Distribution of drawdown/mounding and depth to groundwater predicted under dry and wet climatic simulations

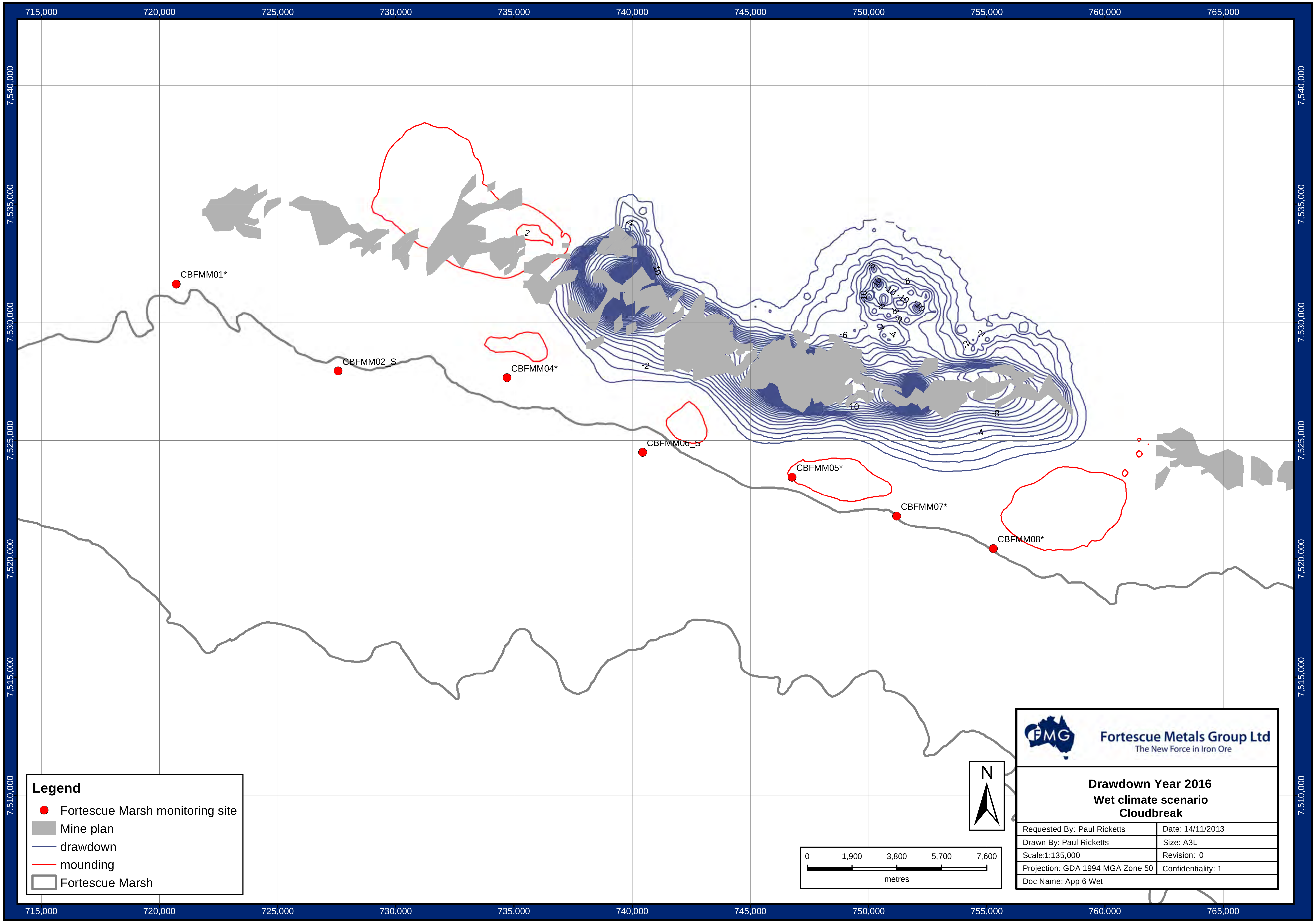
This page has been left blank intentionally

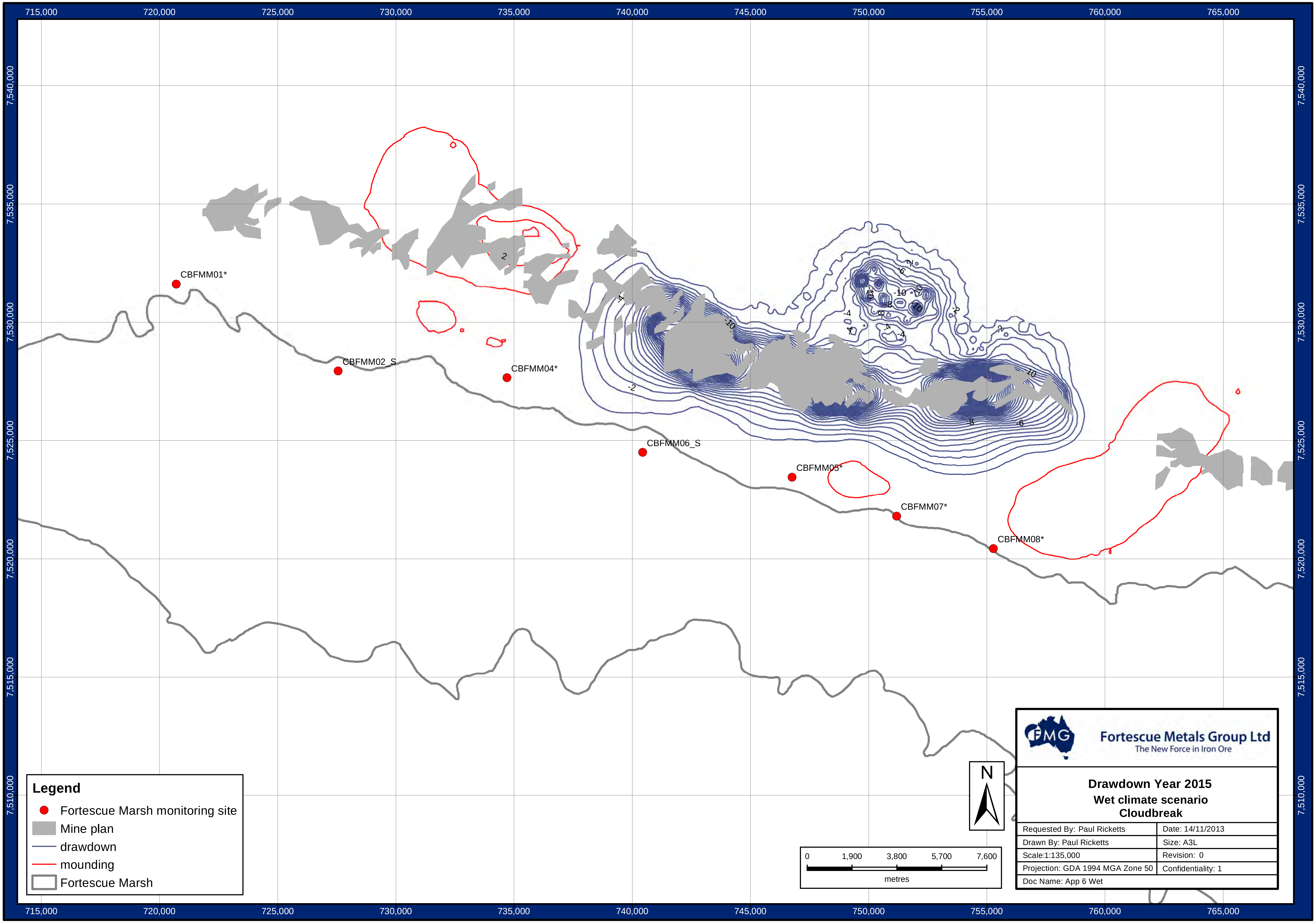


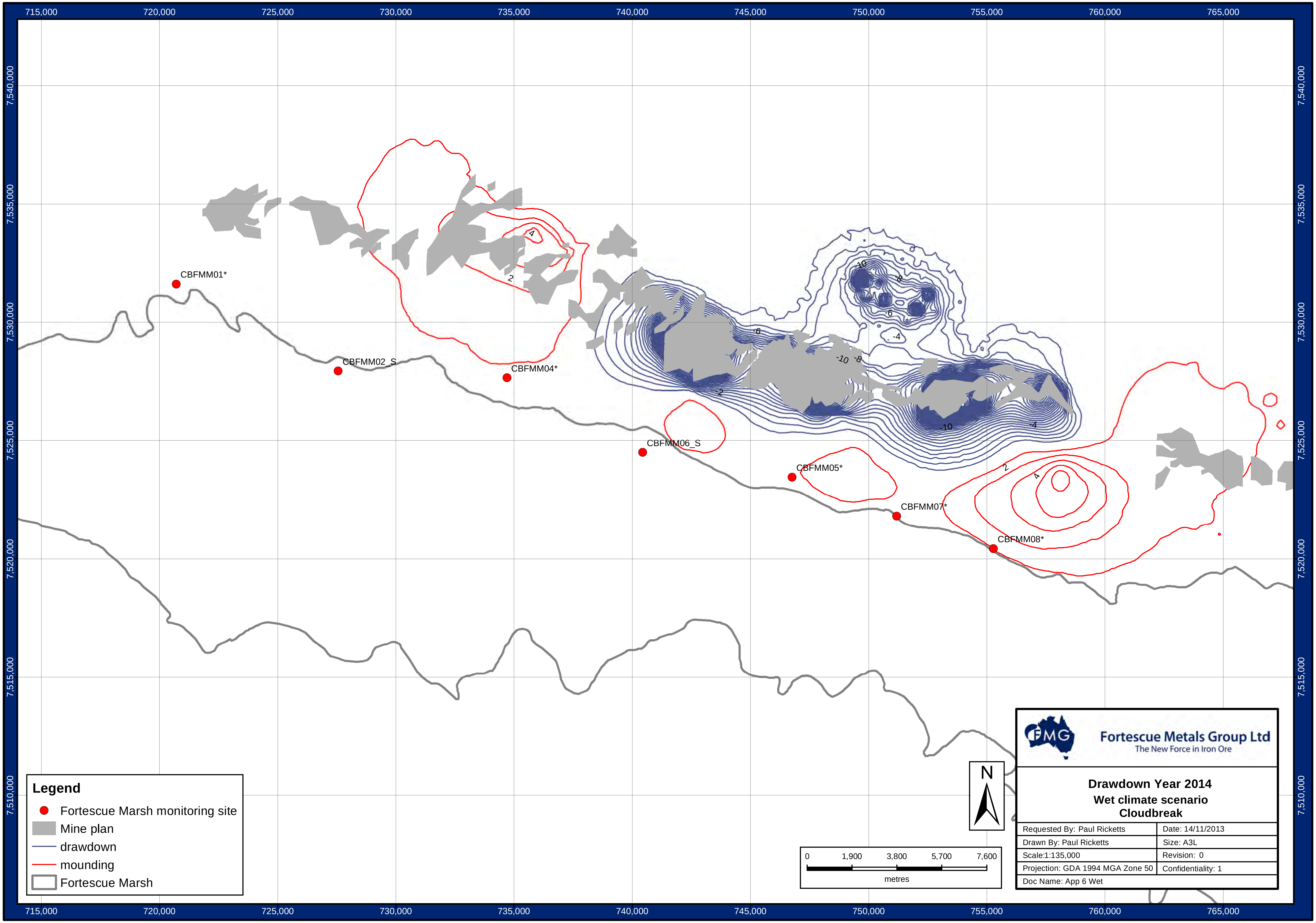
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-10
-10
-6
-8
-4
-2
-2
Legend
Fortescue Marsh monitoring site
Mine plan
darwdown
moudning
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2018
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet



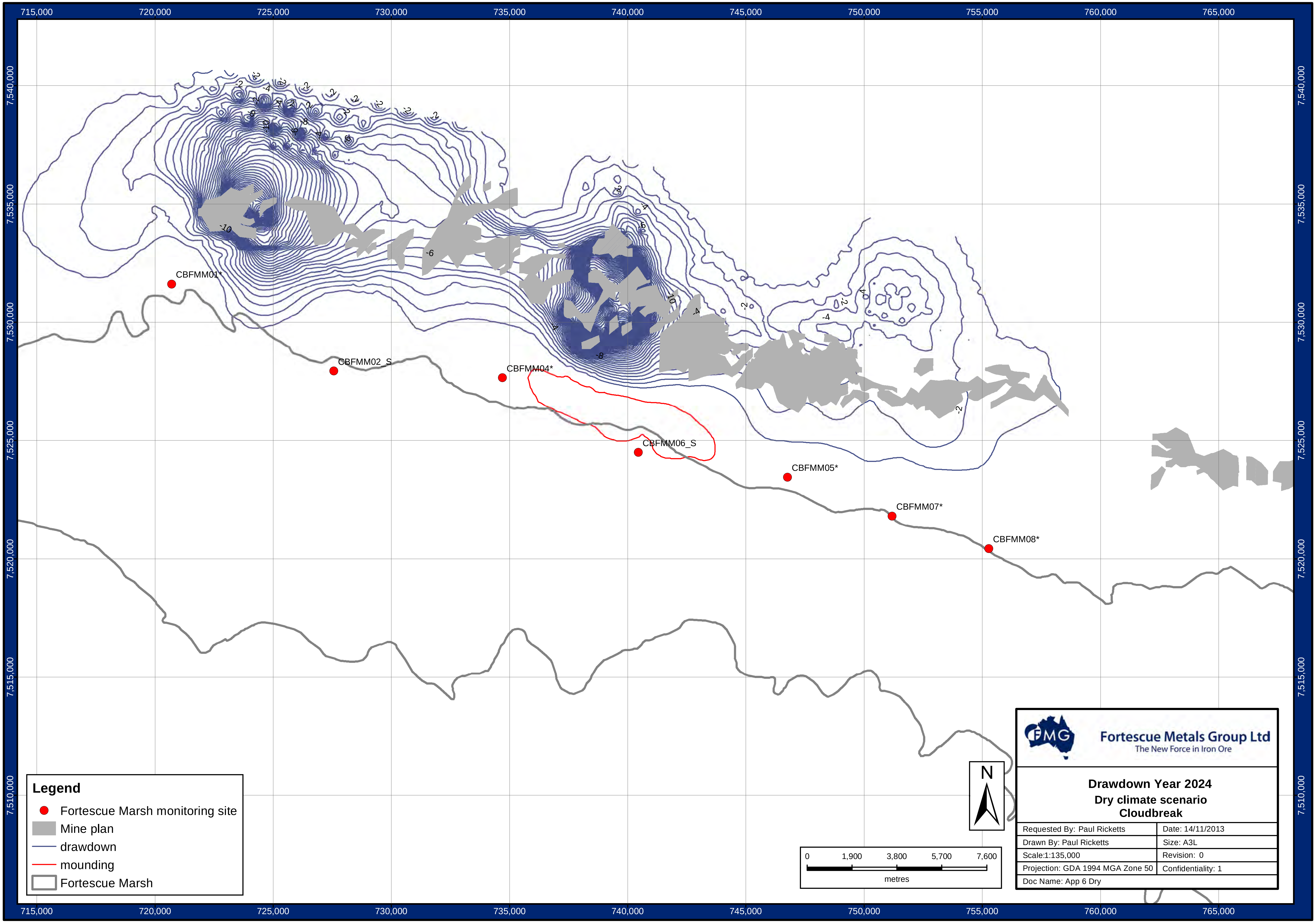
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2017
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet


715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2016
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet

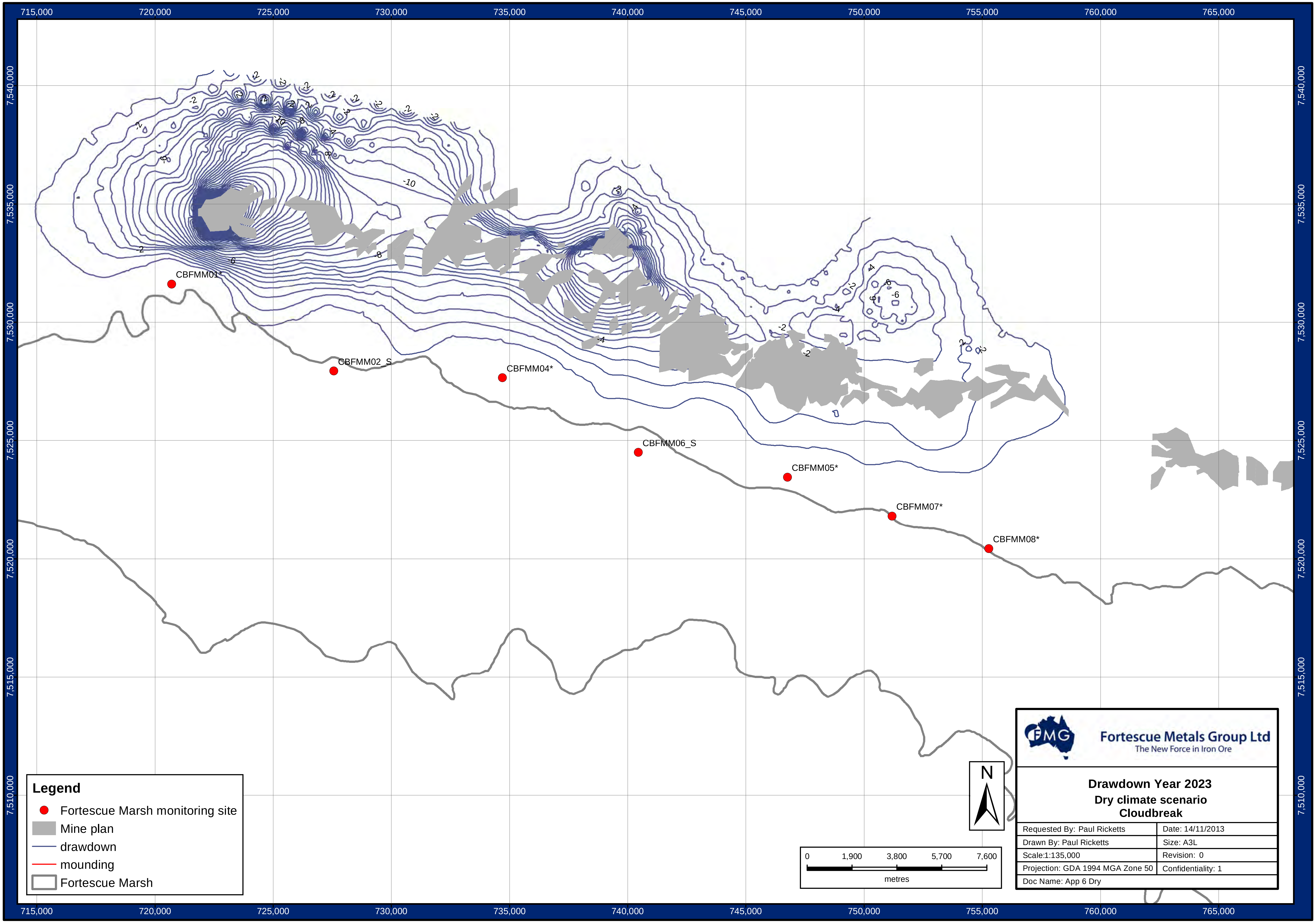

715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2015
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet



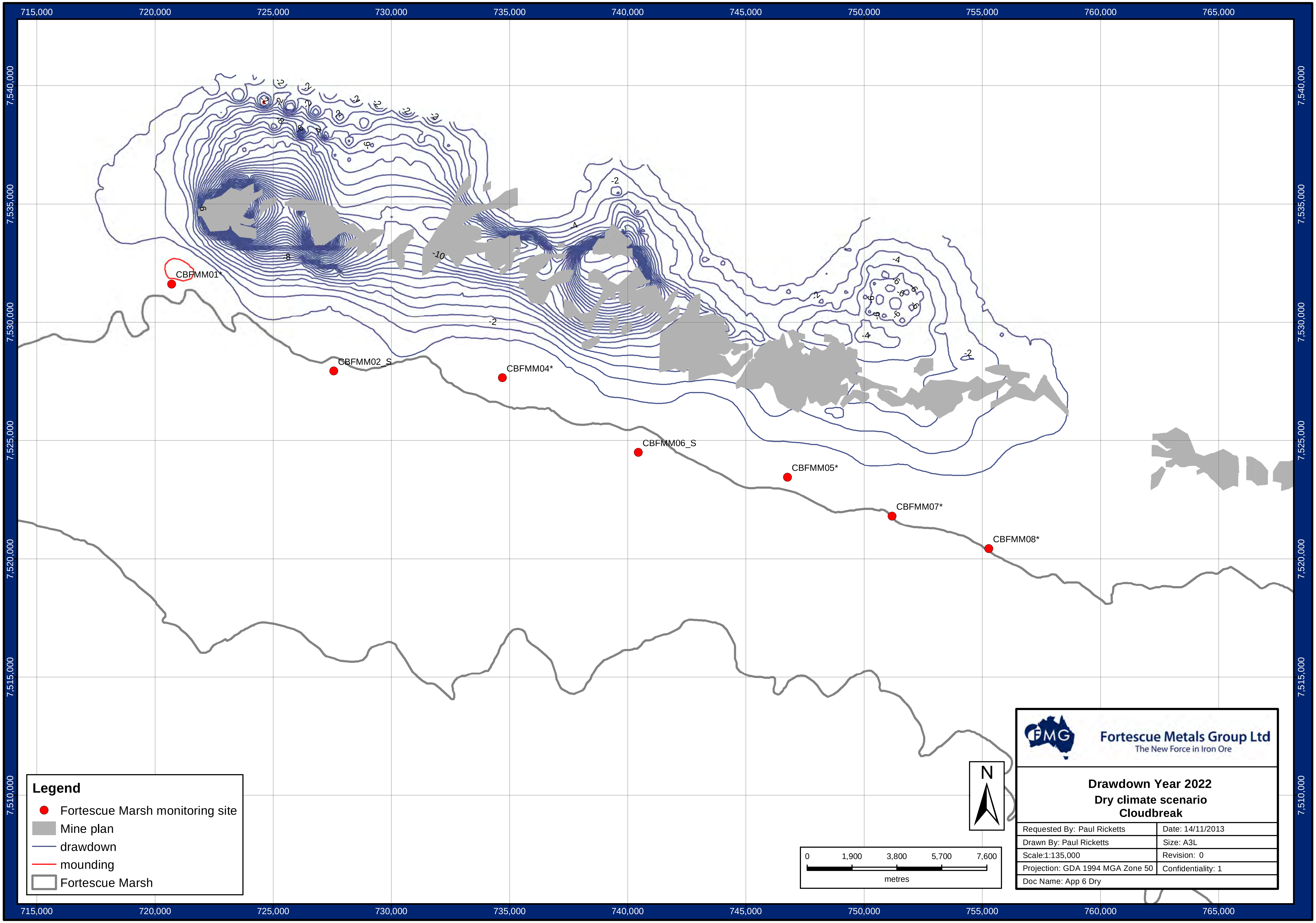
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2014
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet



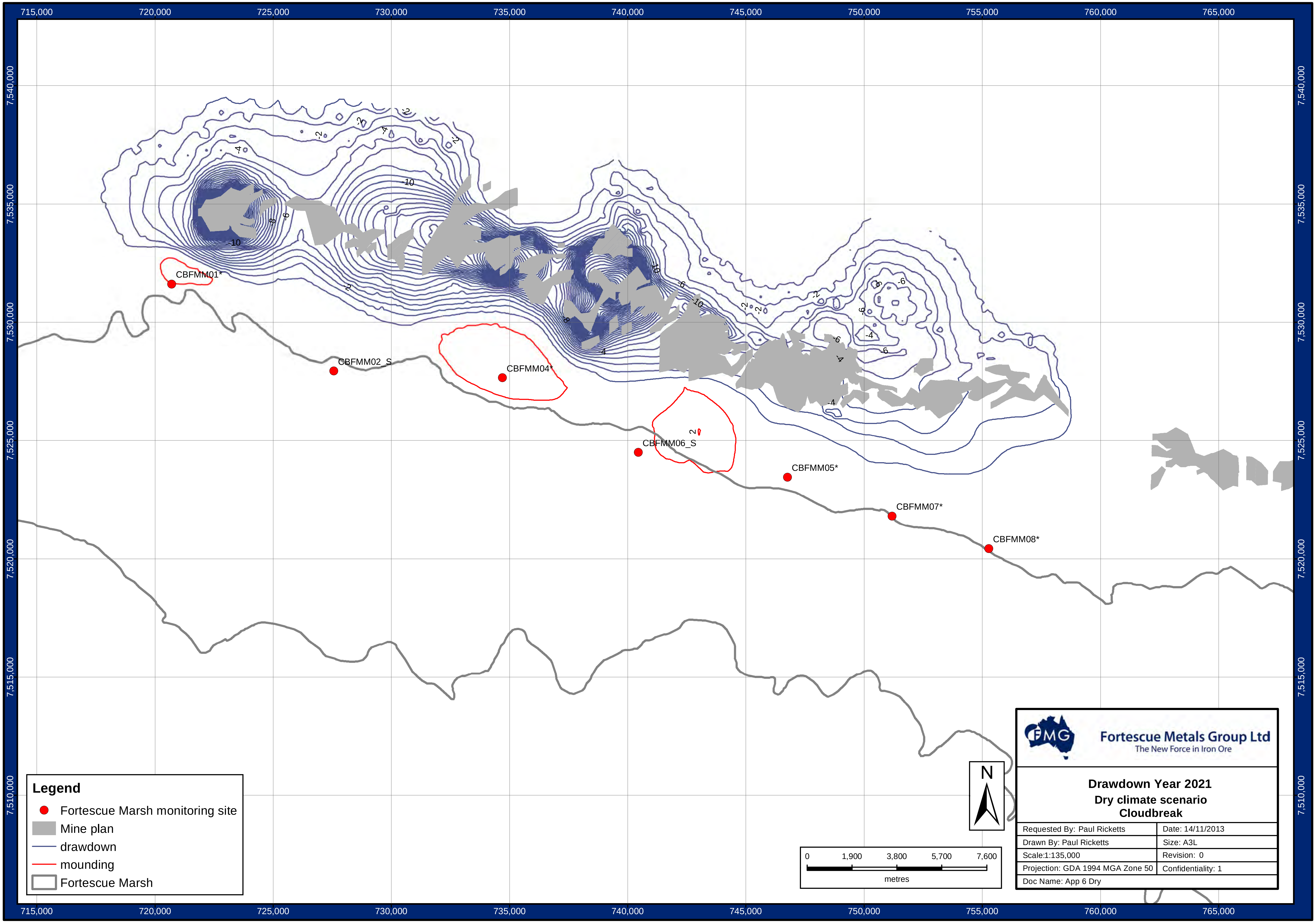
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2024
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



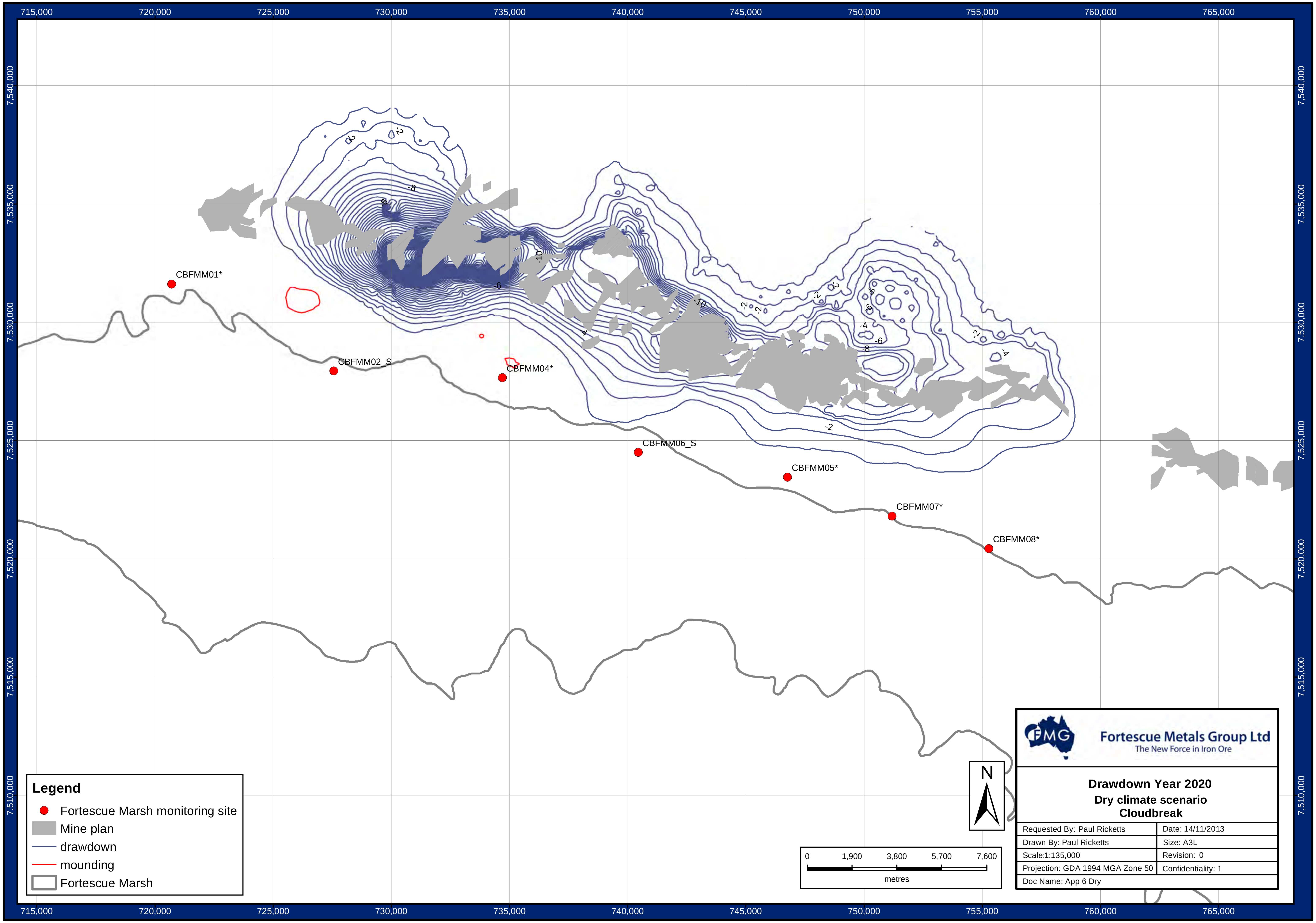
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2023
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



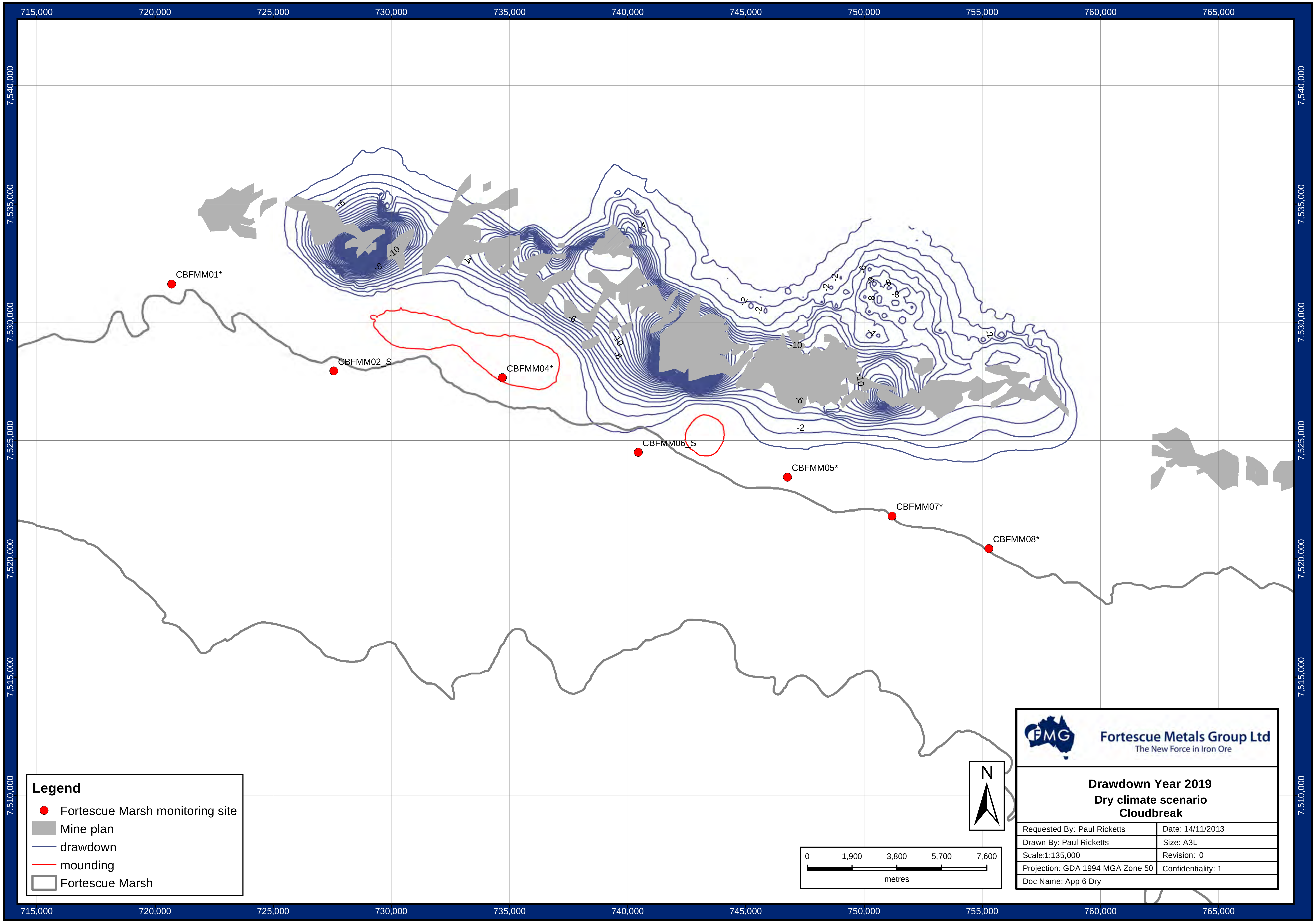
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2022
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



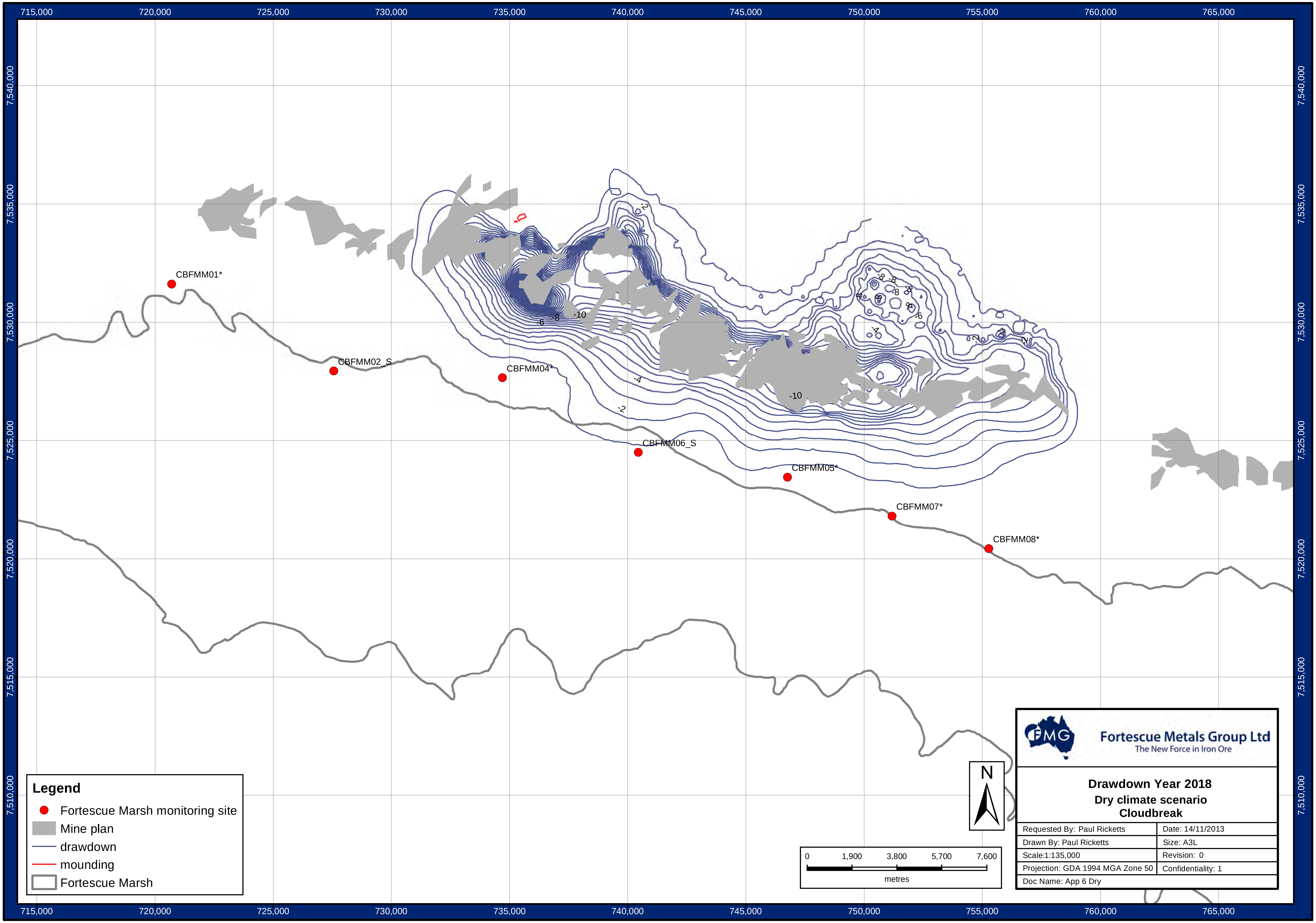
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2021
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



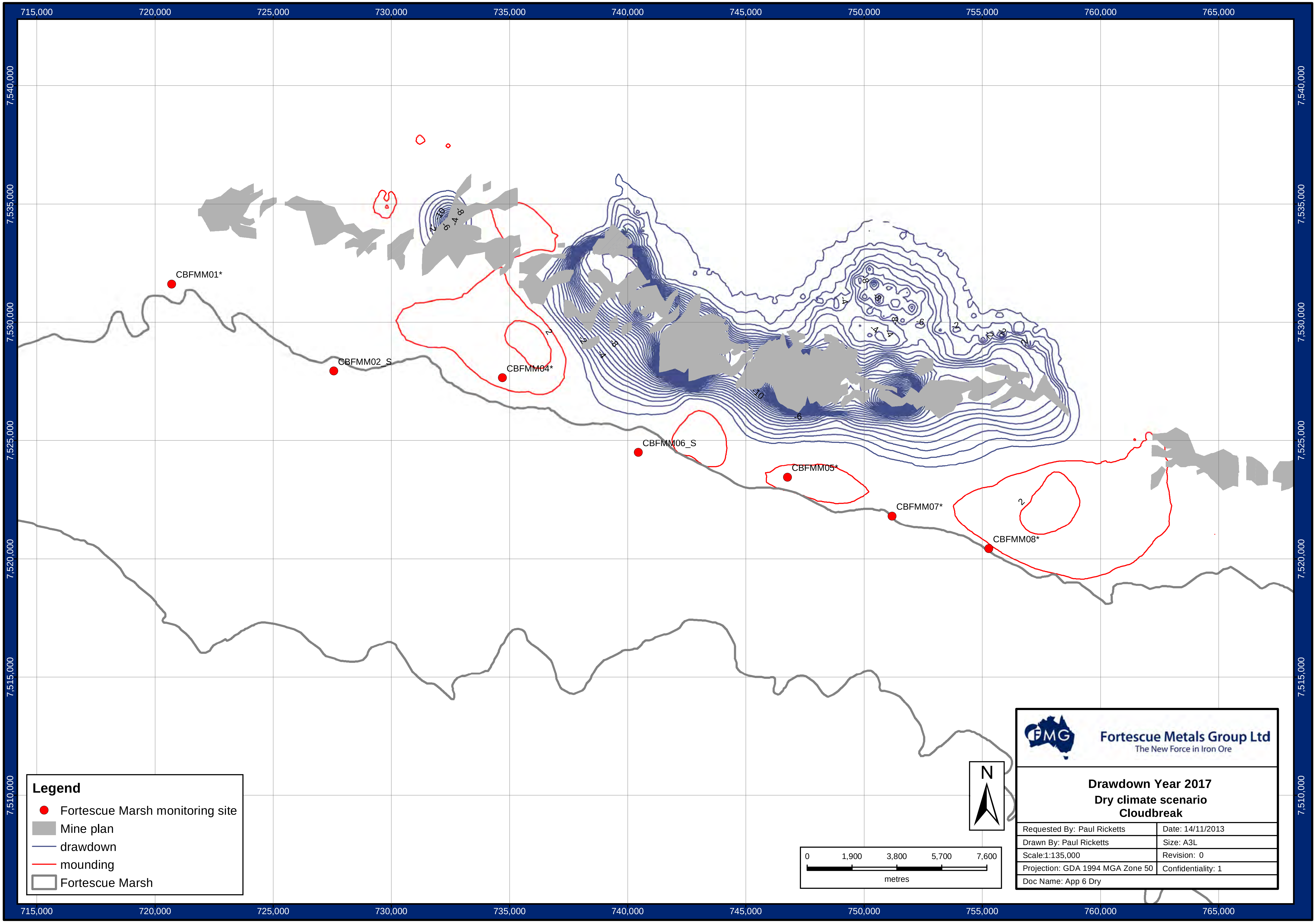
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2020
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



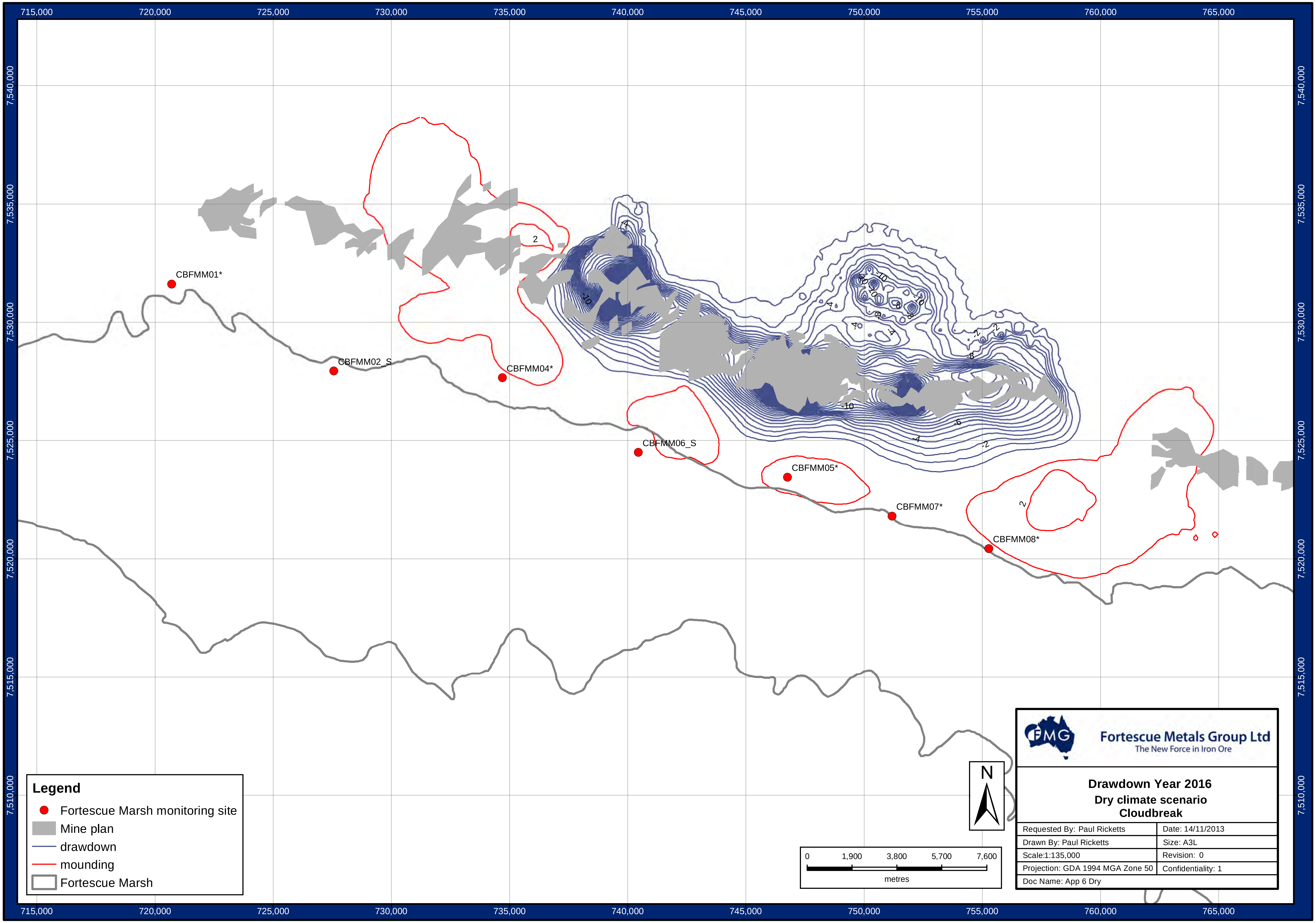
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
FMG
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2019
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



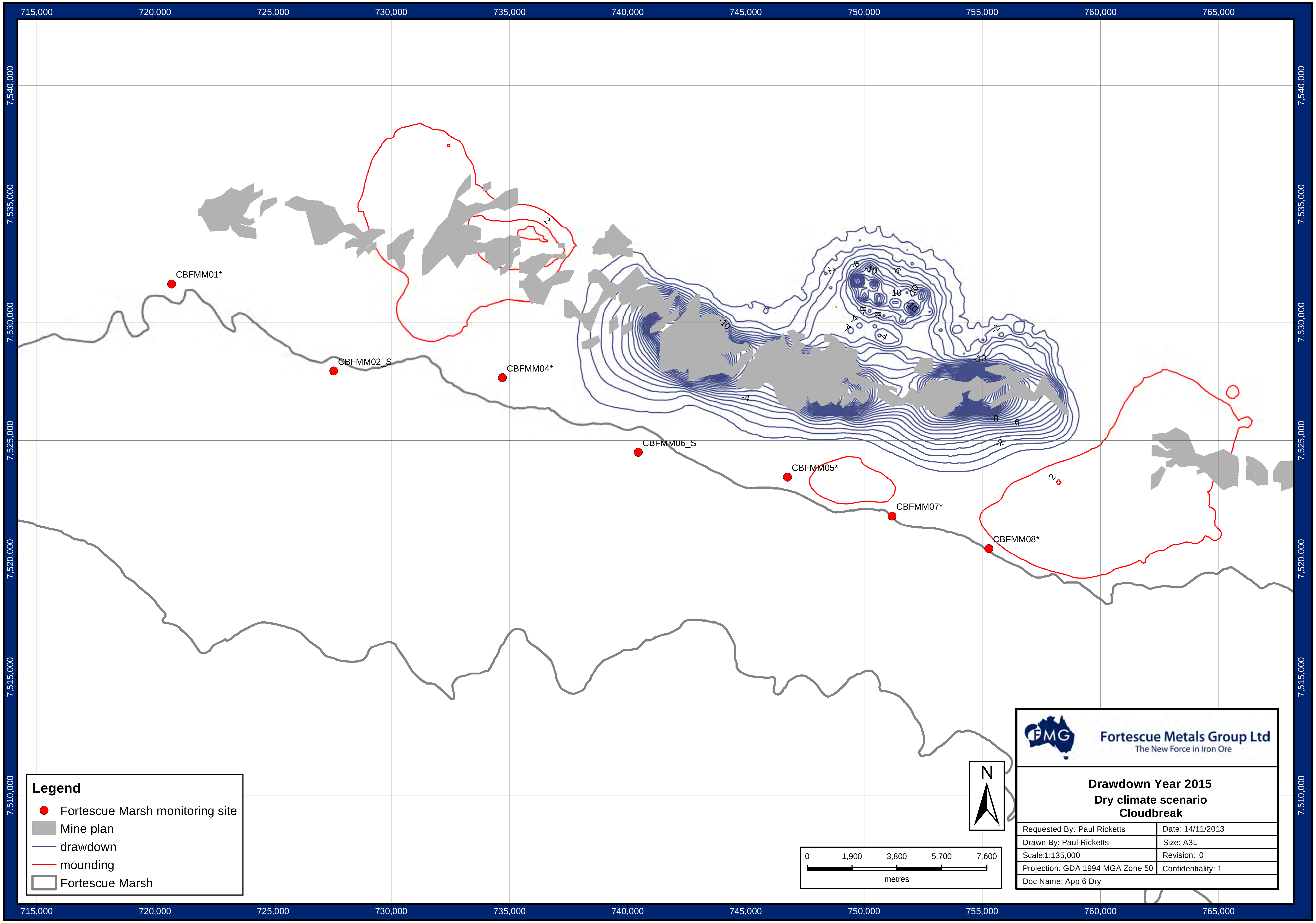
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
FMG
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2018
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry

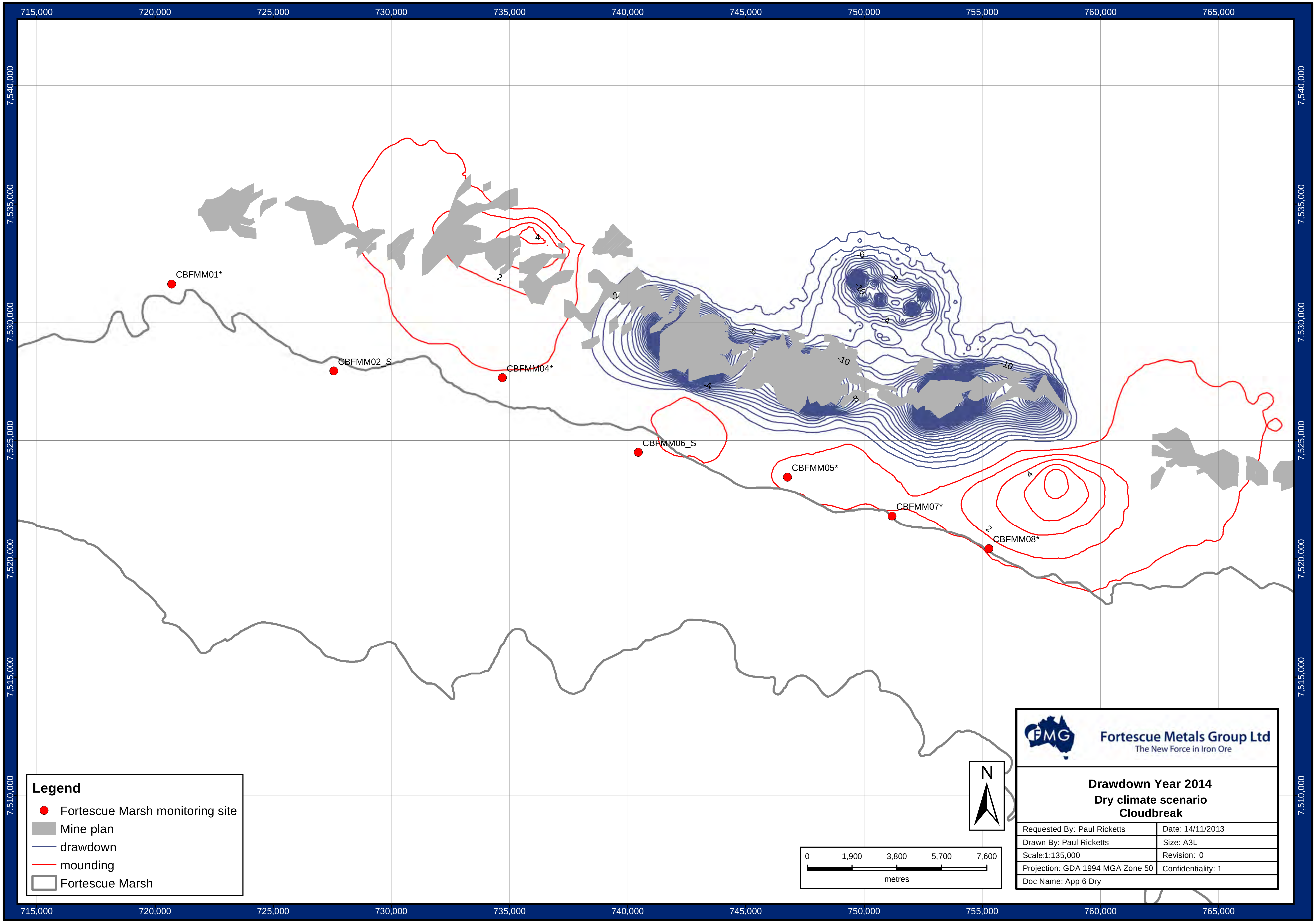


715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2017
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry

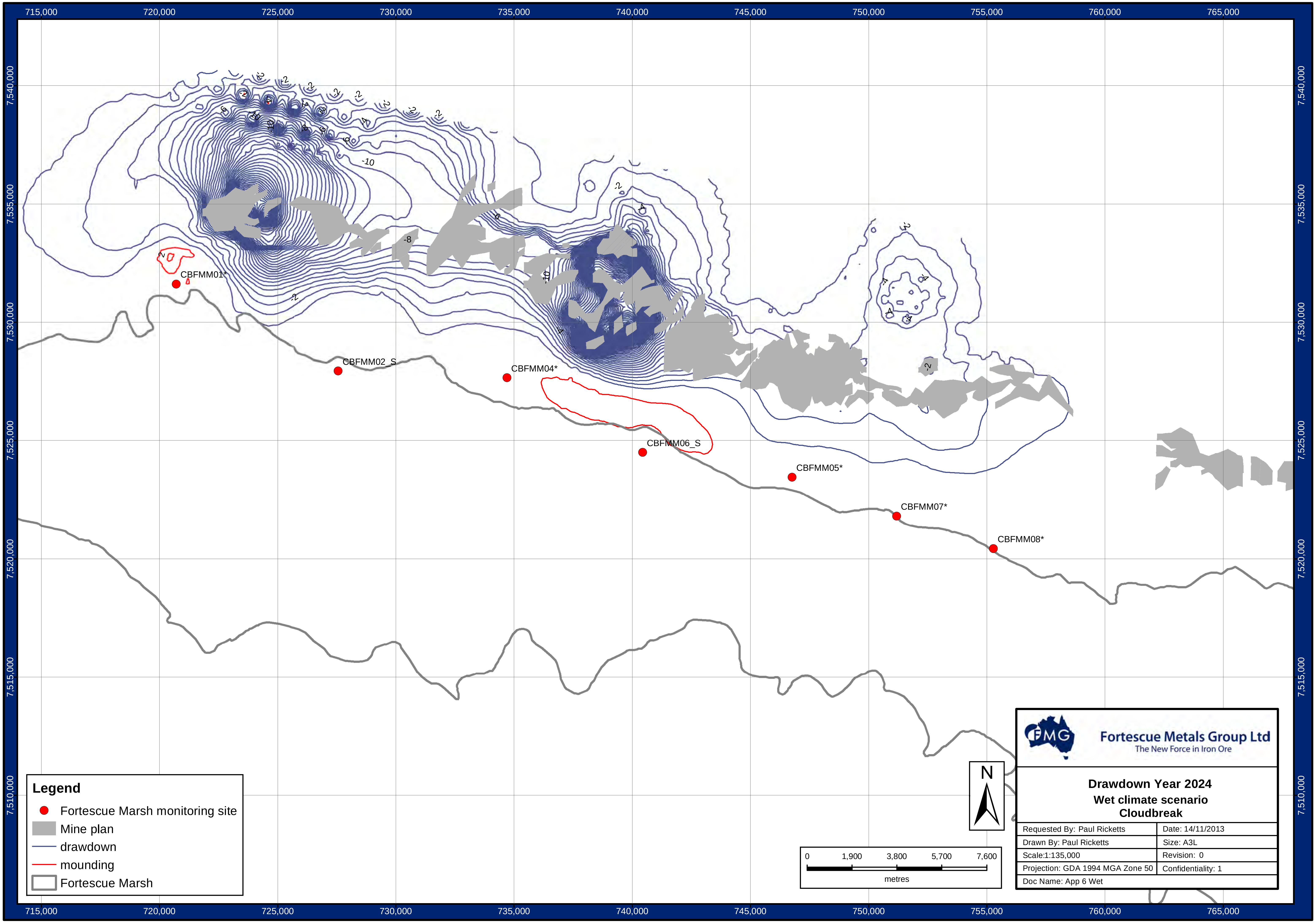


CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0 1,900 3,800 5,700 7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2016
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry

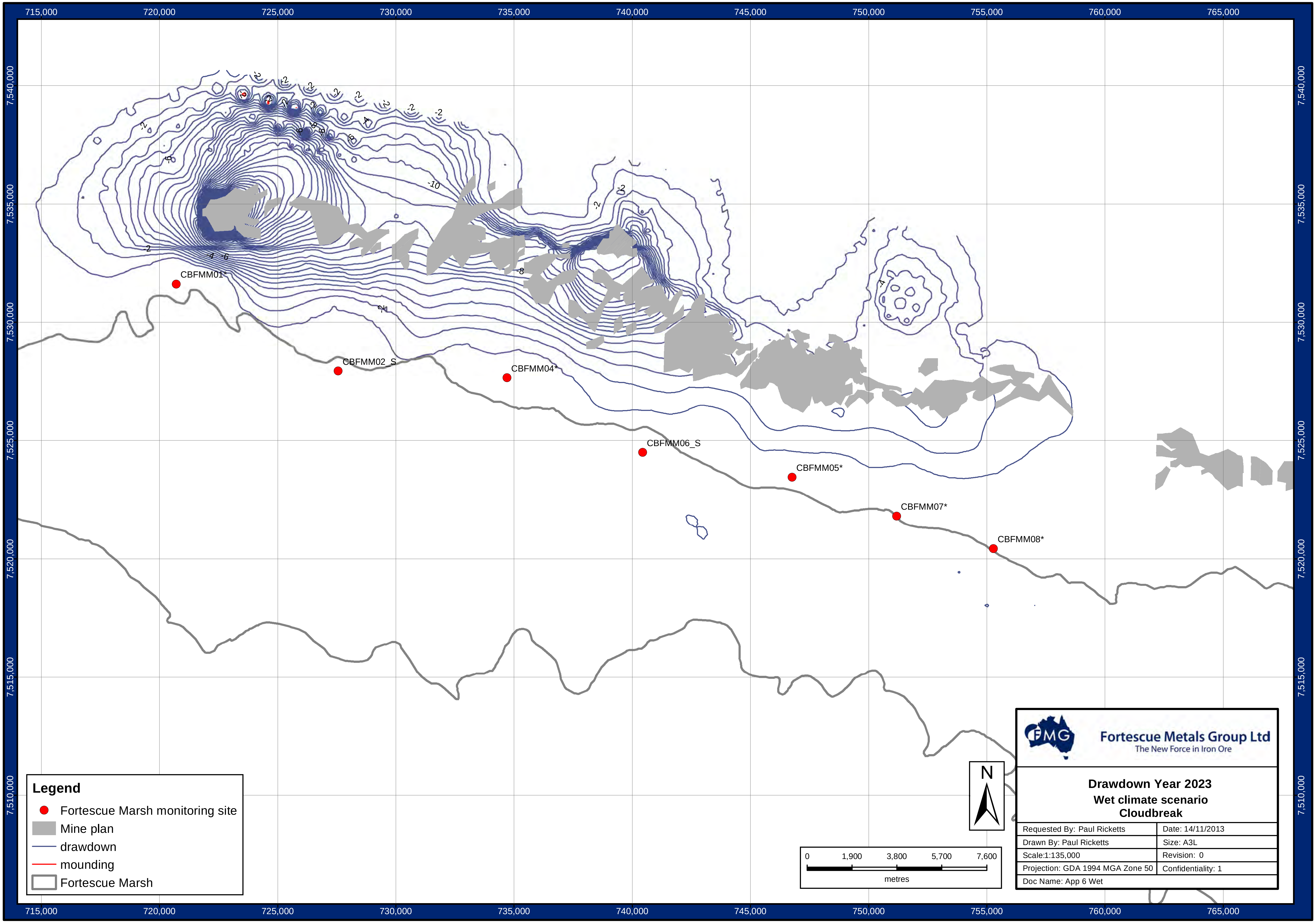

715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2015
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



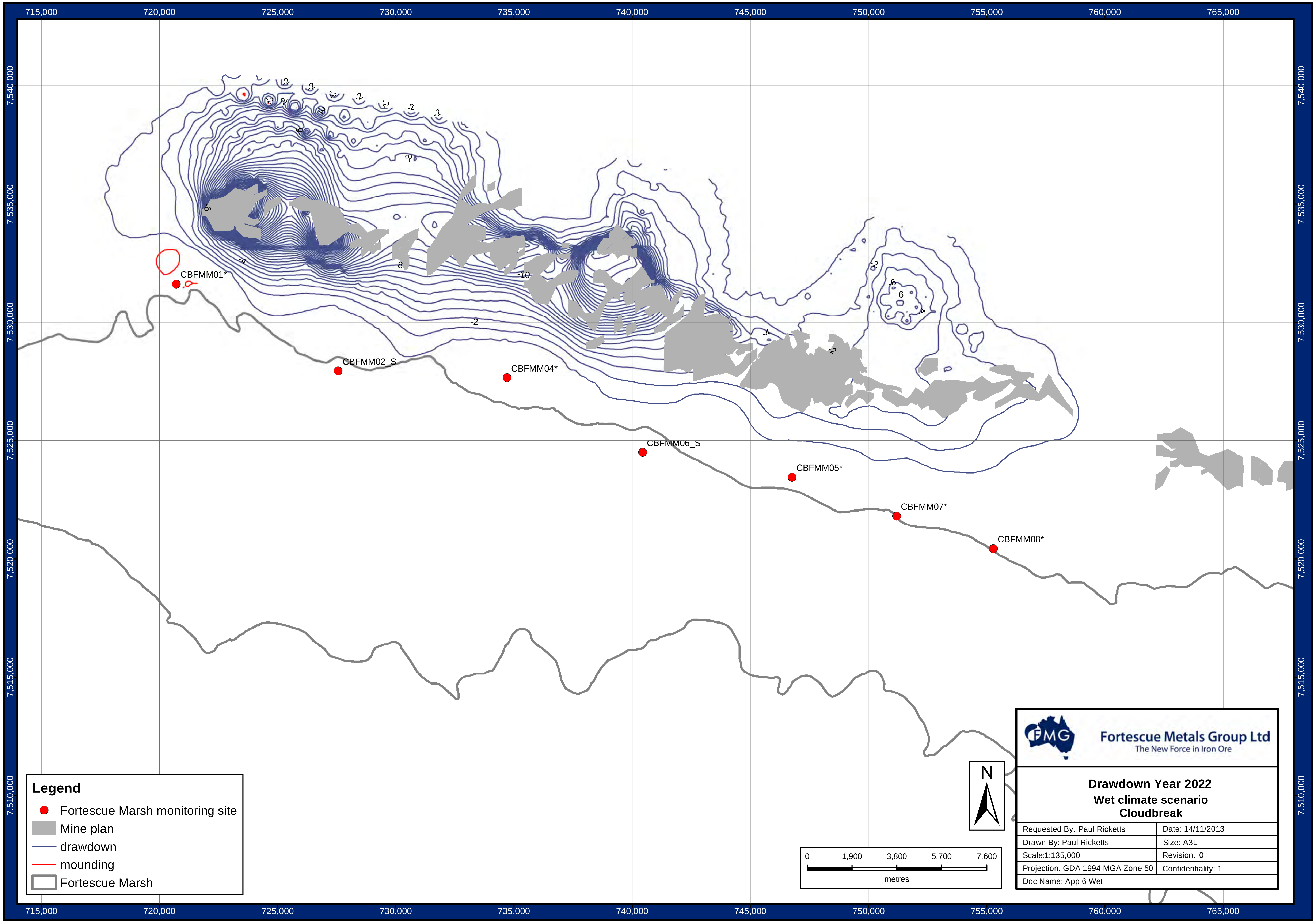
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2014
Dry climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Dry



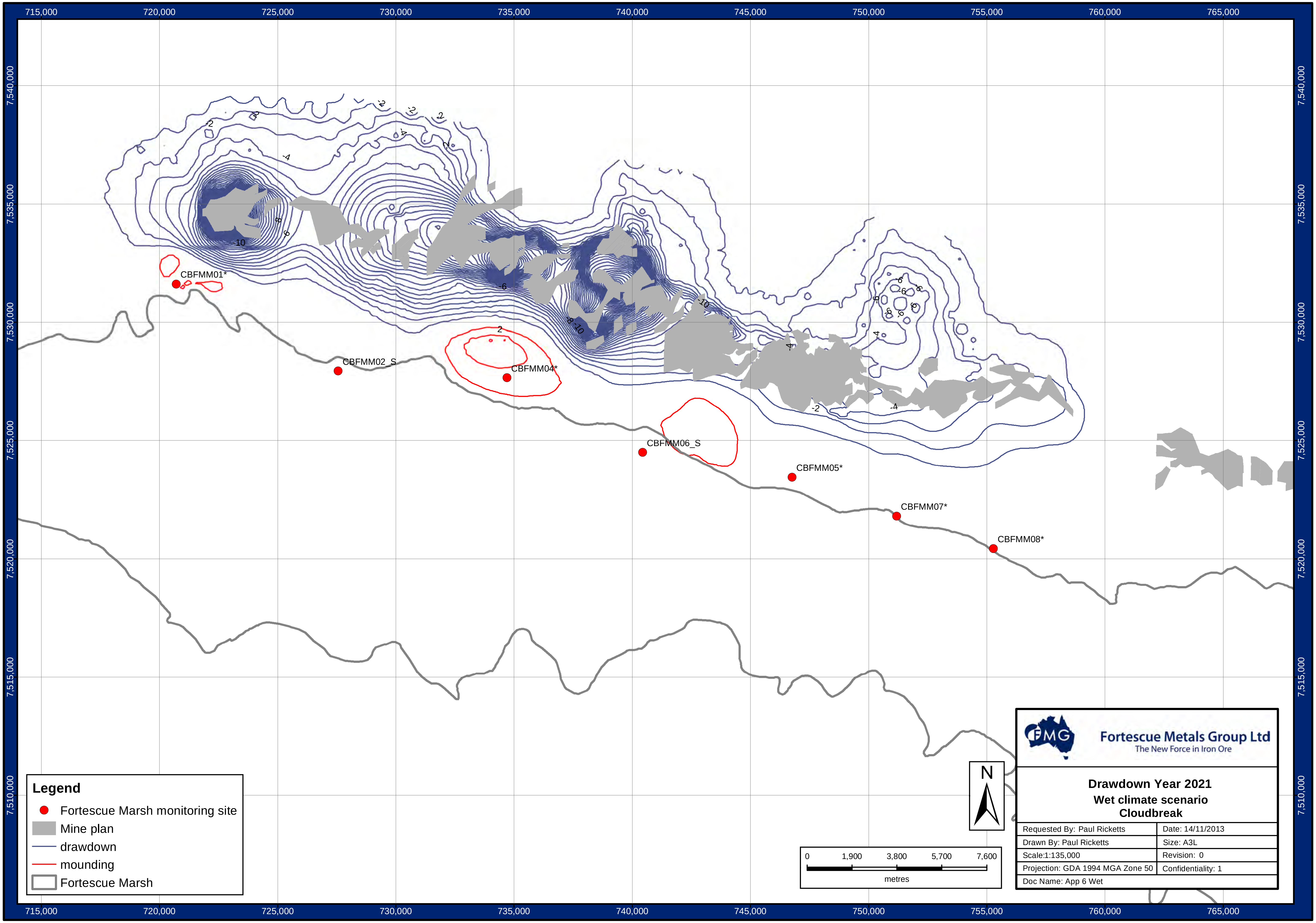
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
-10
-8
-6
-4
-2
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2024
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet

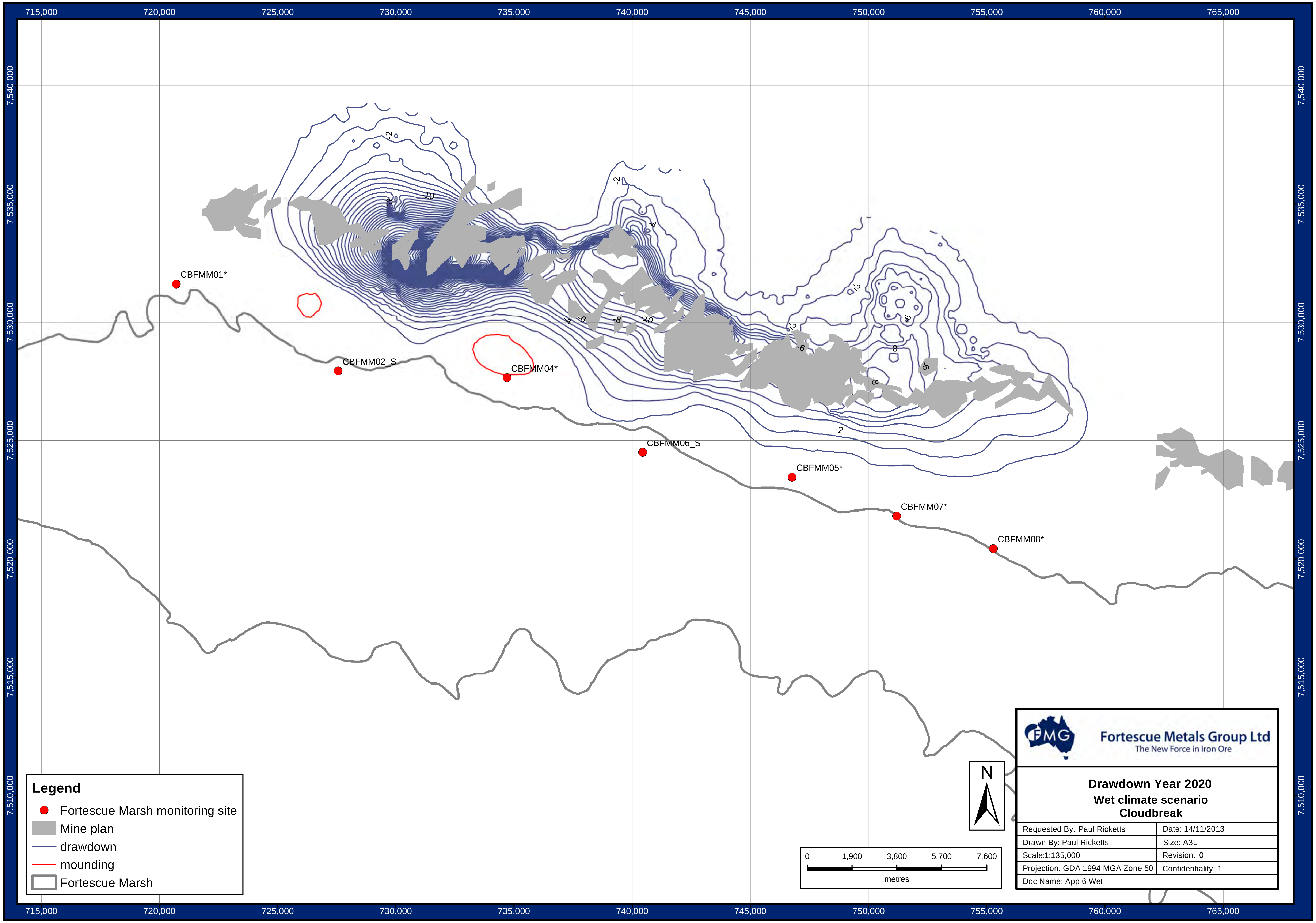


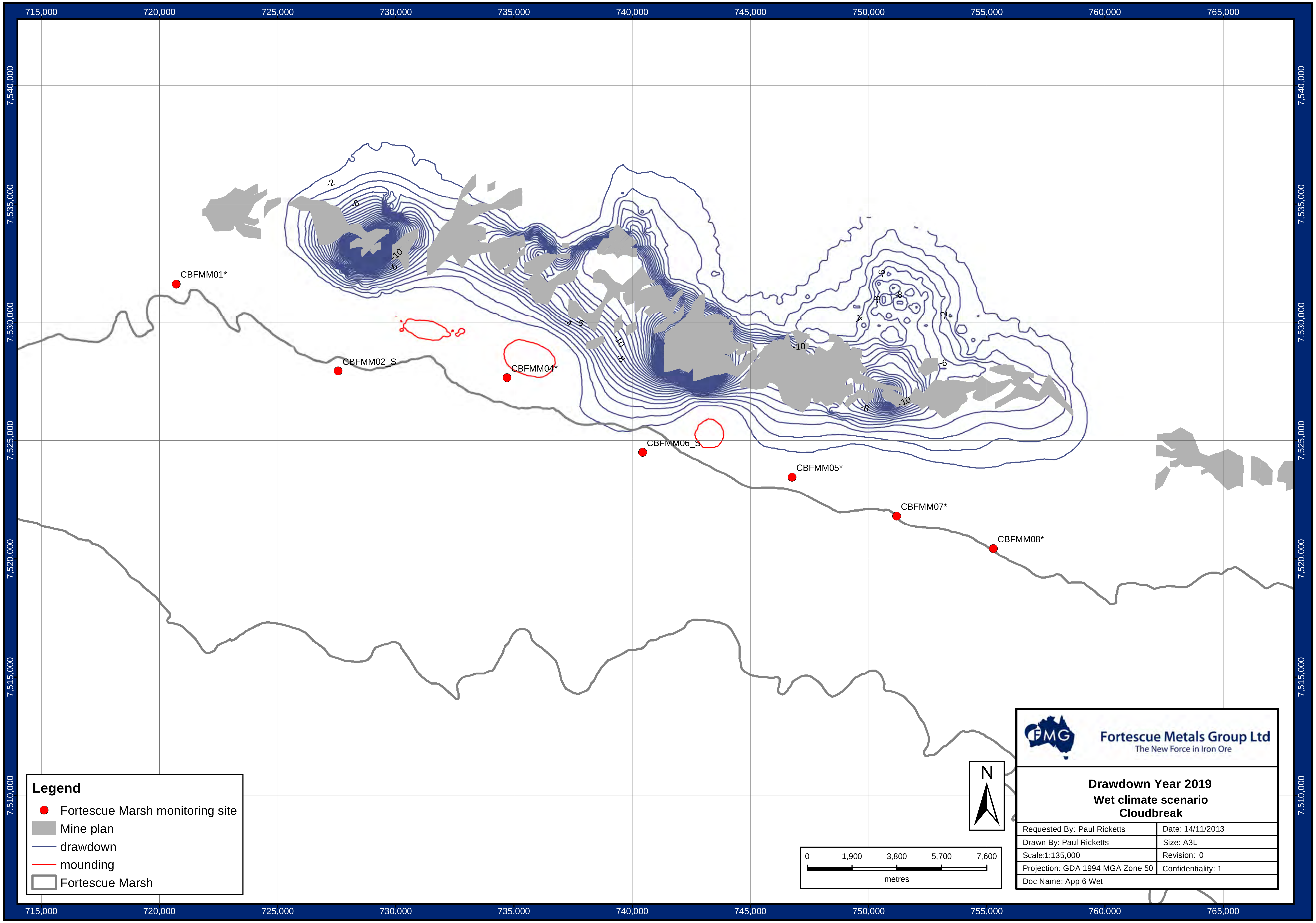
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
FMG
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2023
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet



715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
FMG
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2022
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet


715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
2
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2021
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet

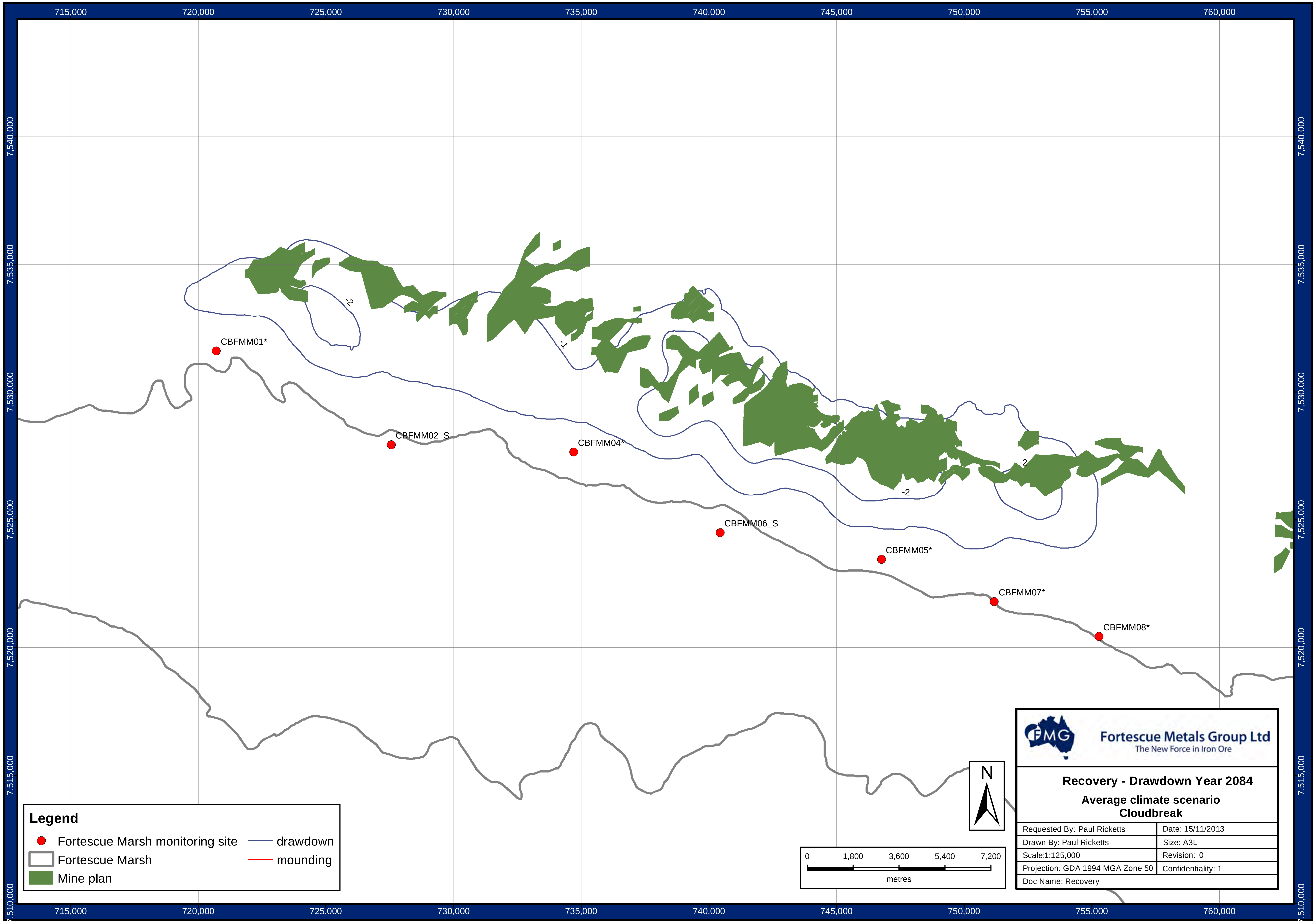

715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-4
-6
-8
-10
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
N
0
1,900
3,800
5,700
7,600
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2020
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet



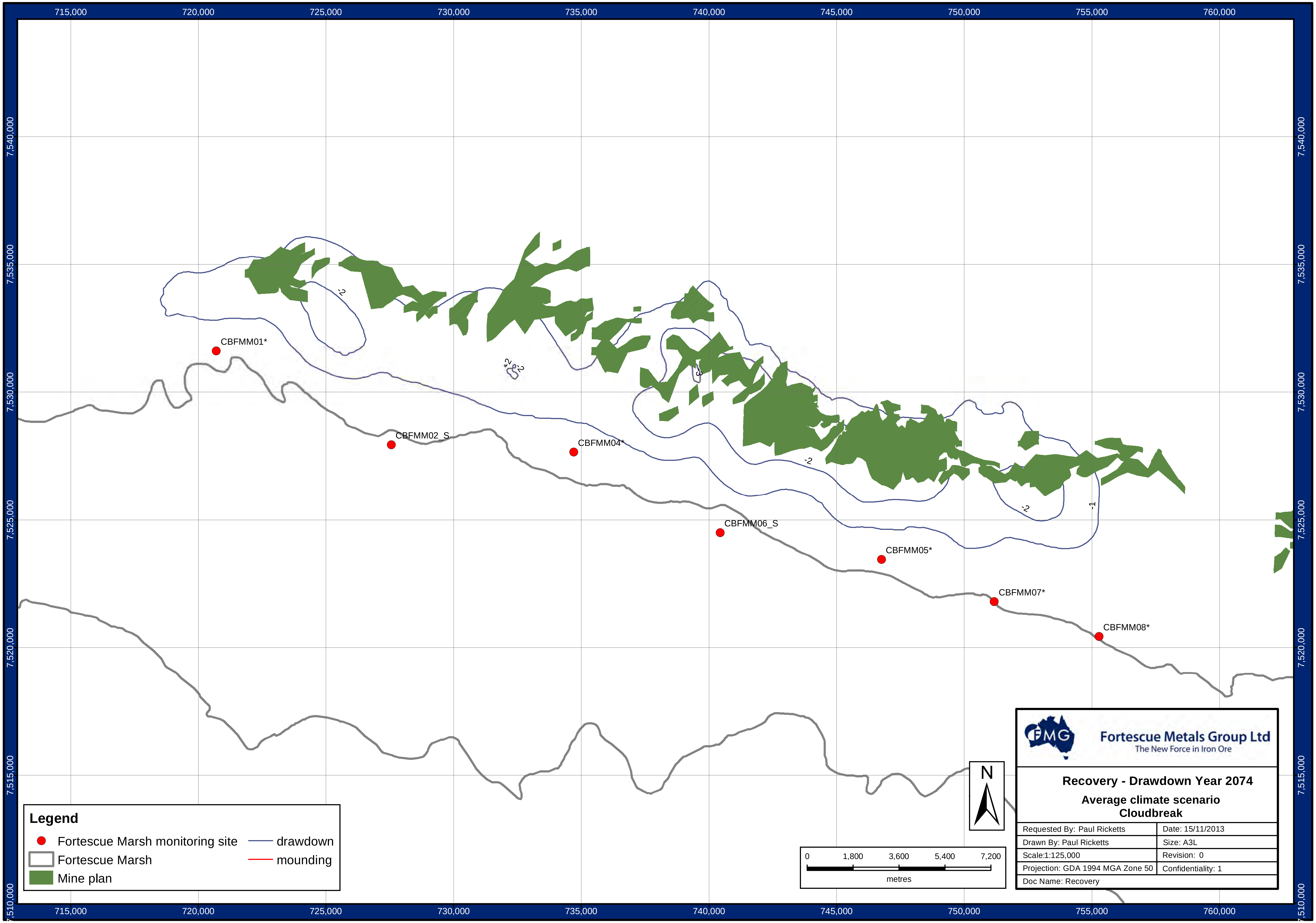
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
765,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Mine plan
drawdown
mounding
Fortescue Marsh
0
1,900
3,800
5,700
7,600
metres
N
Fortescue Metals Group Ltd
The New Force in Iron Ore
Drawdown Year 2019
Wet climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 14/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:135,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: App 6 Wet

# Appendix 7: Groundwater level recovery after mine closure

This page has been left blank intentionally



715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-1
-2
-2
Legend
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
drawdown
mounding
N
0
1,800
3,600
5,400
7,200
metres
FMG
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2084
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery

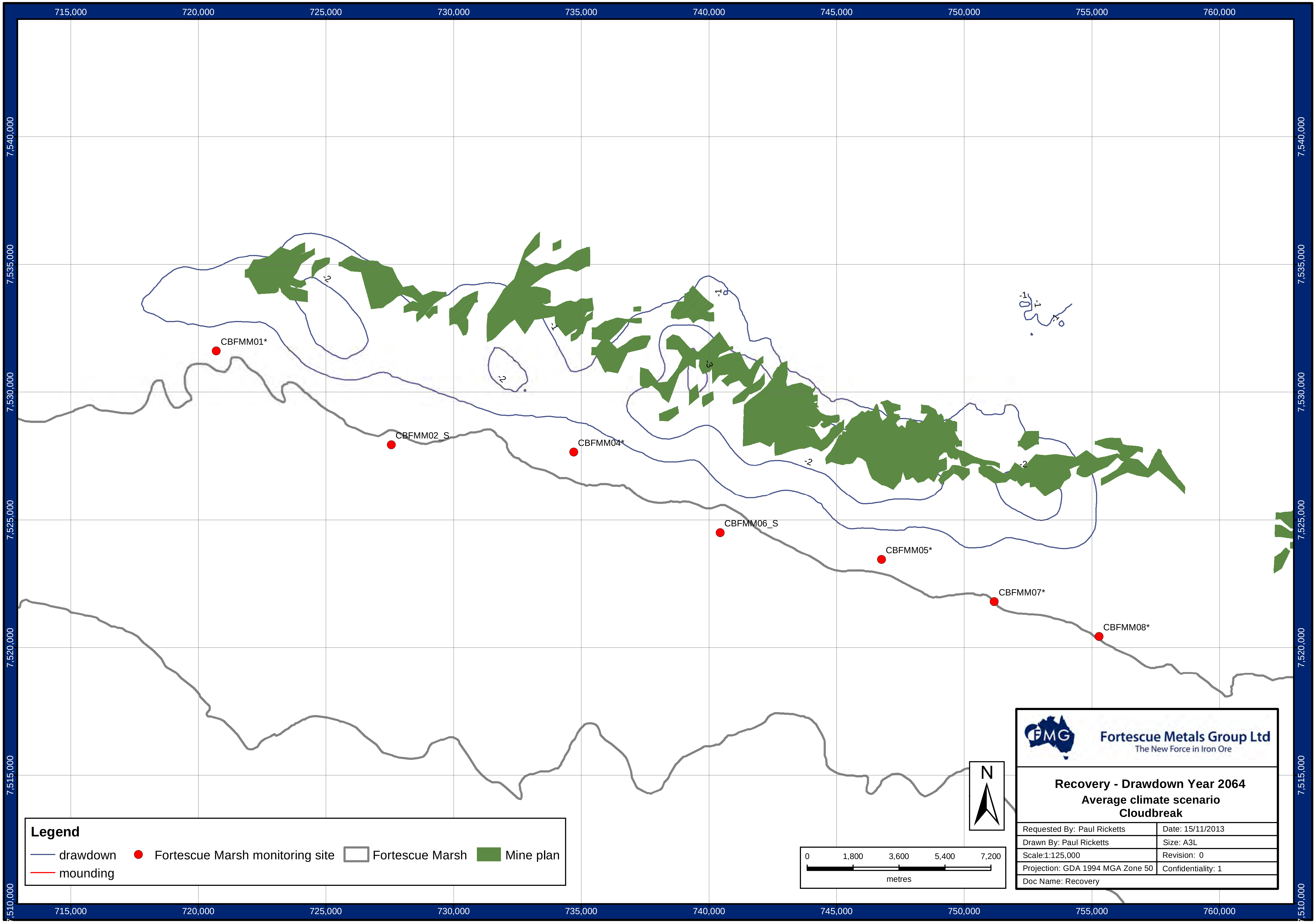



Fortescue Metals Group Ltd
The New Force in Iron Ore

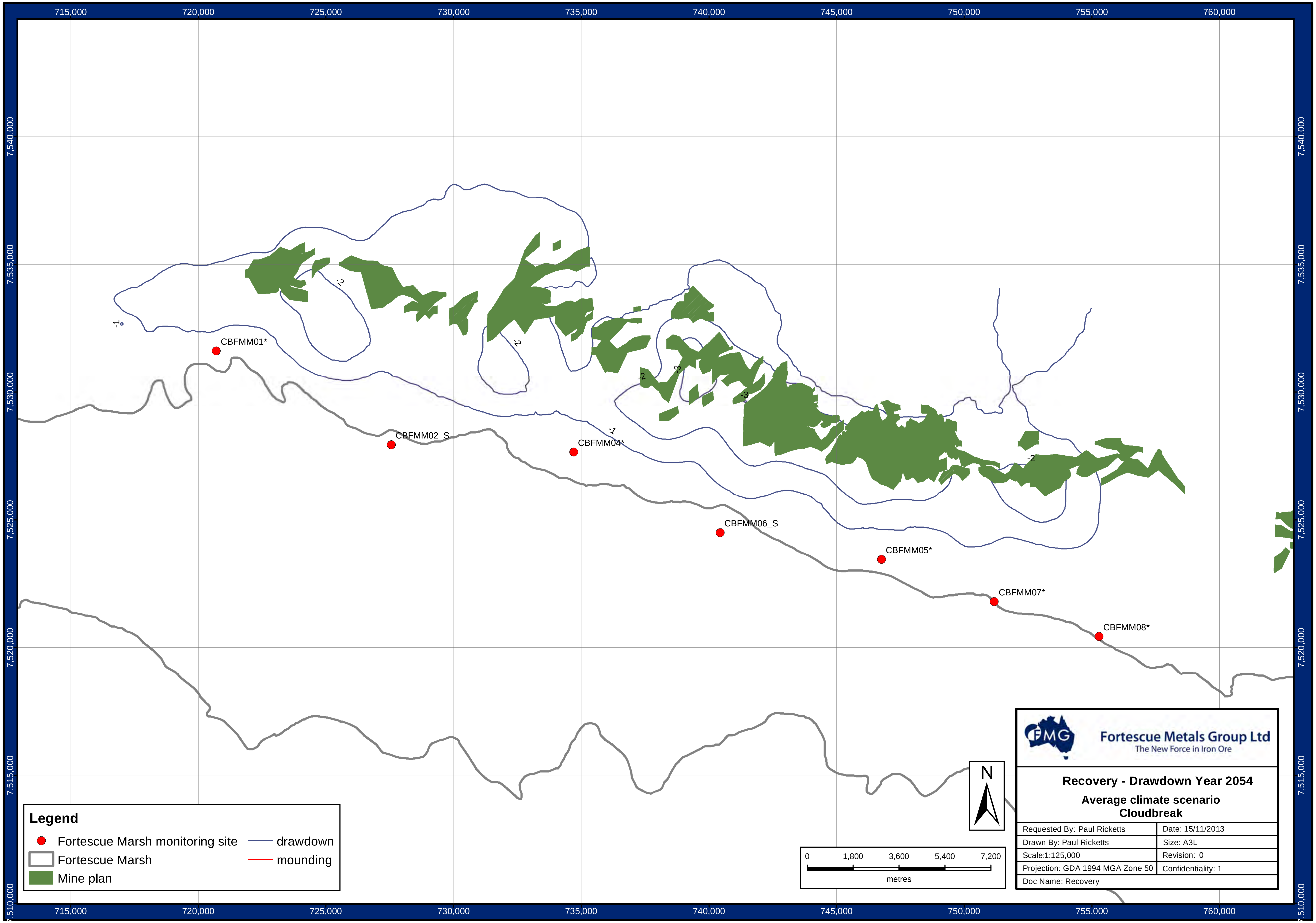
**Recovery - Drawdown Year 2074**

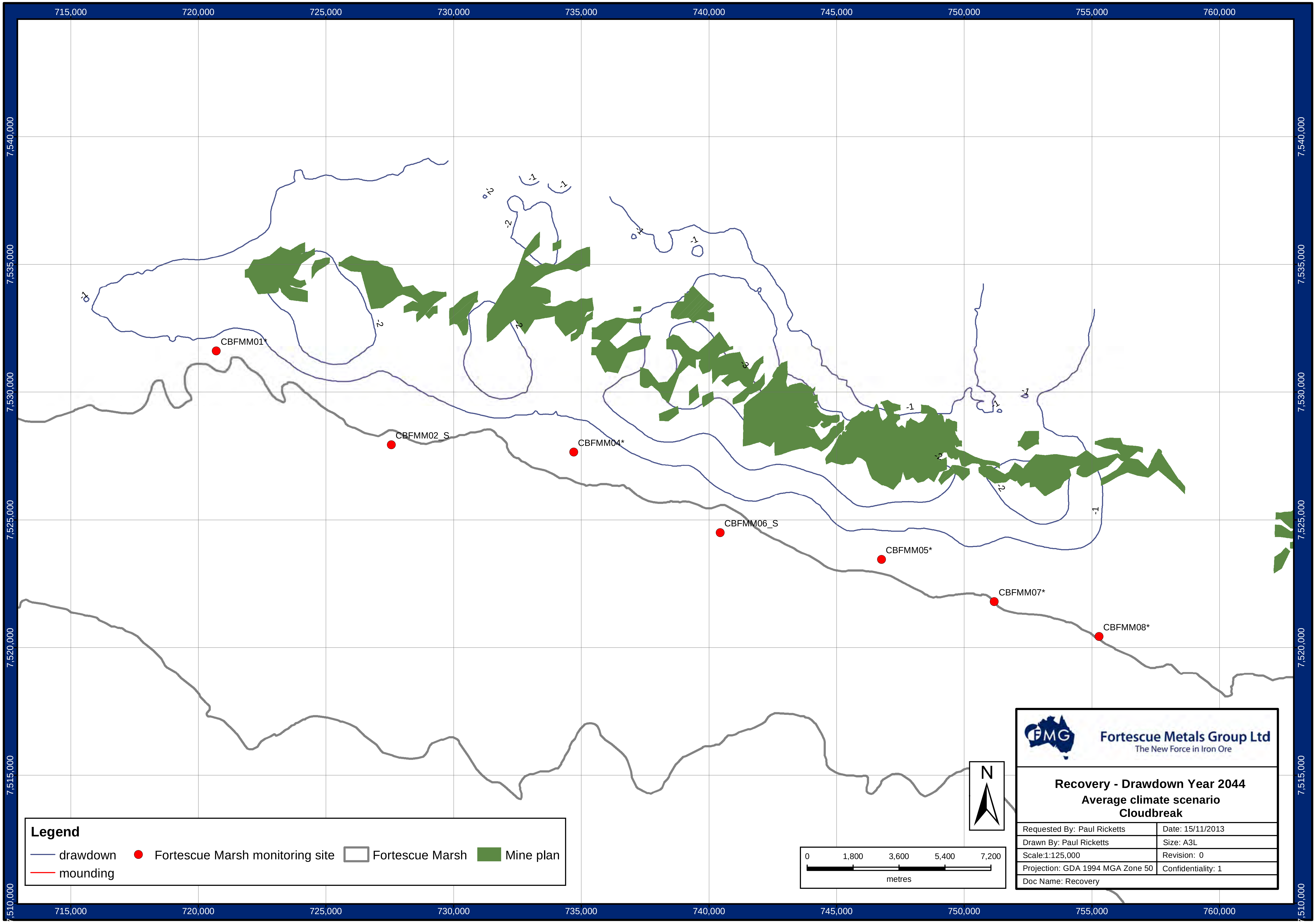
**Average climate scenario**
**Cloudbreak**

| | |
|---|---|
| Requested By: Paul Ricketts | Date: 15/11/2013 |
| Drawn By: Paul Ricketts | Size: A3L |
| Scale:1:125,000 | Revision: 0 |
| Projection: GDA 1994 MGA Zone 50 | Confidentiality: 1 |
| Doc Name: Recovery | |

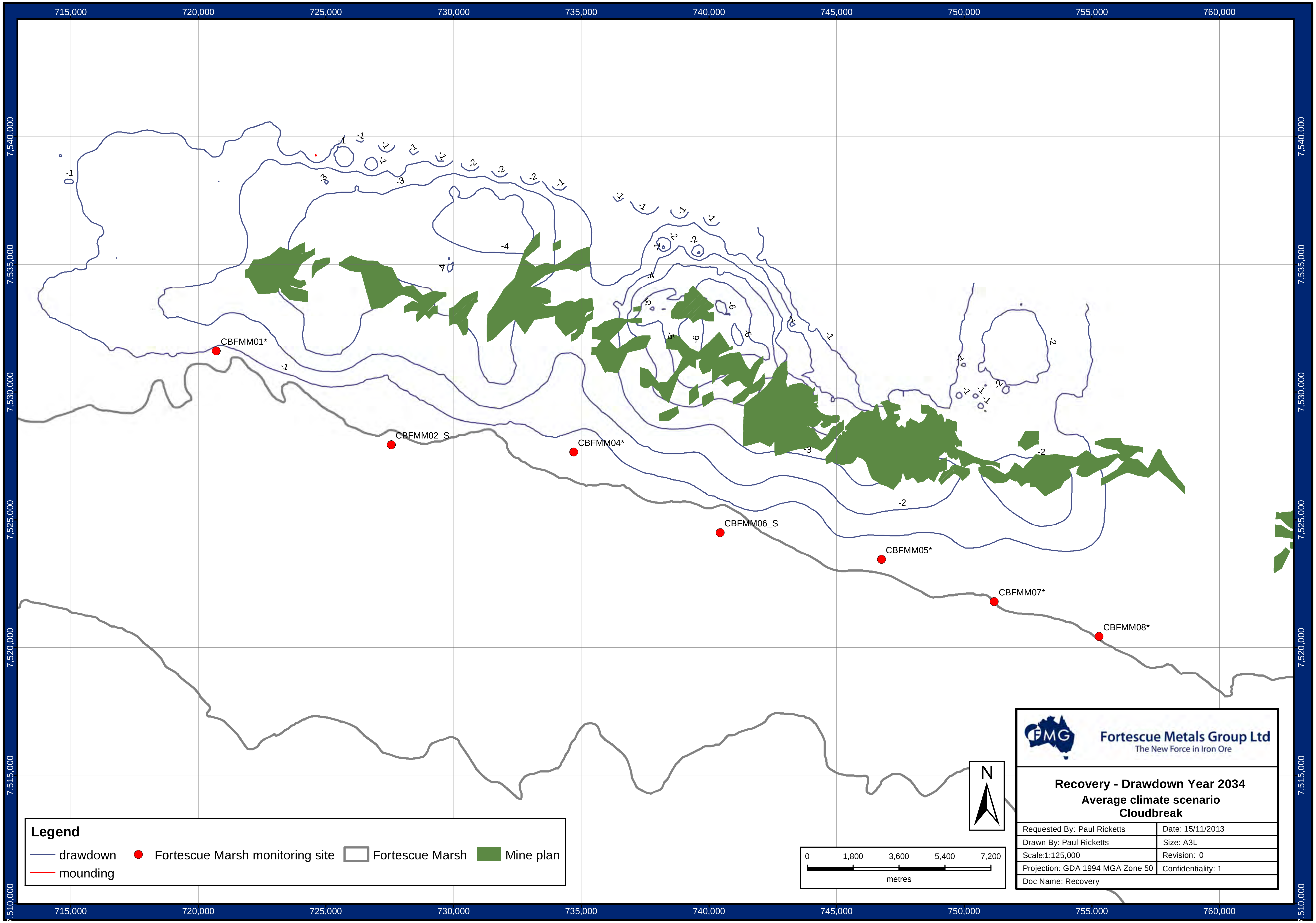


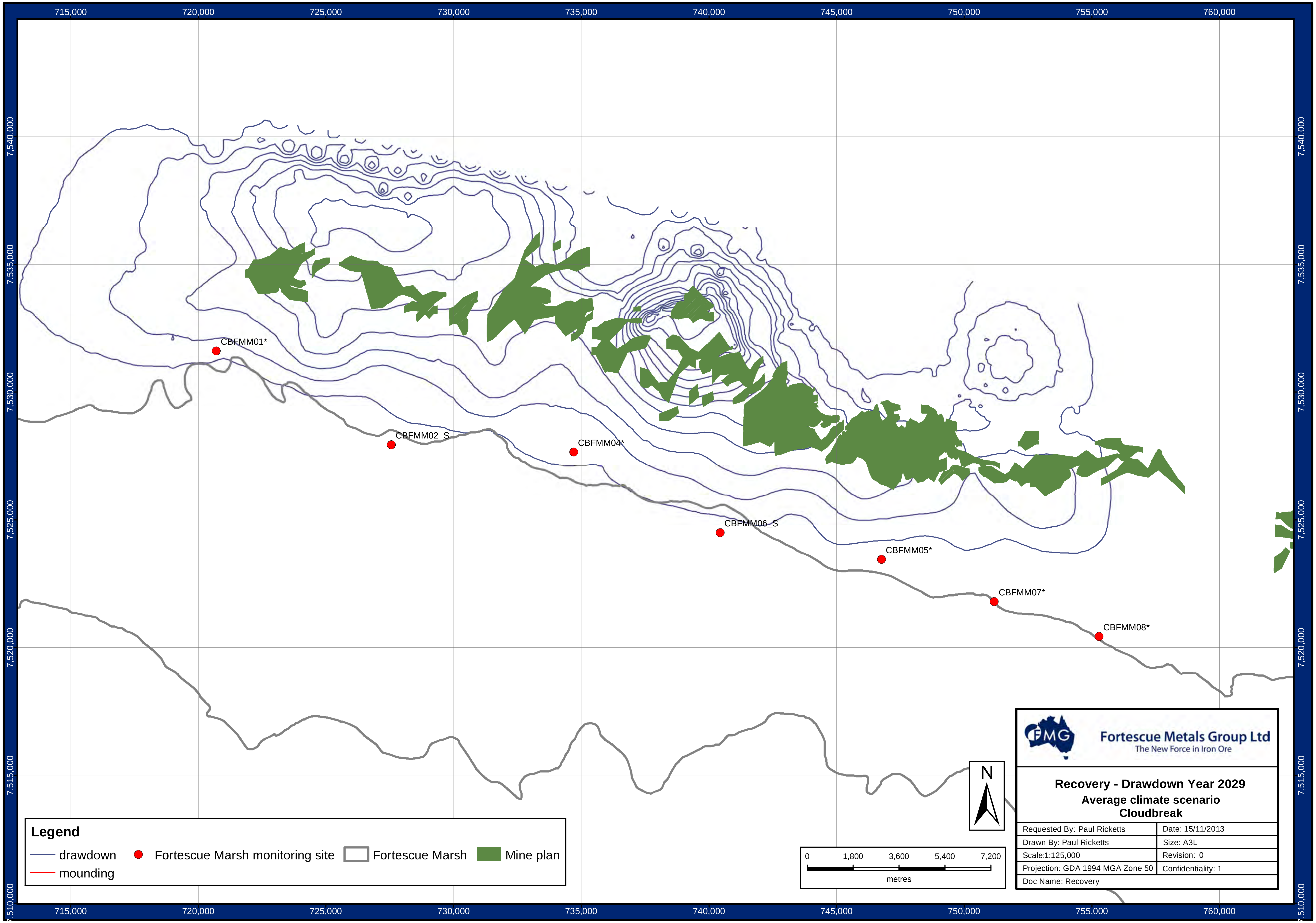
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-1
-3
Legend
drawdown
mounding
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
0
1,800
3,600
5,400
7,200
metres
N
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2064
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery


715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-1
-2
-3
Legend
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
drawdown
mounding
0
1,800
3,600
5,400
7,200
metres
N
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2054
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery

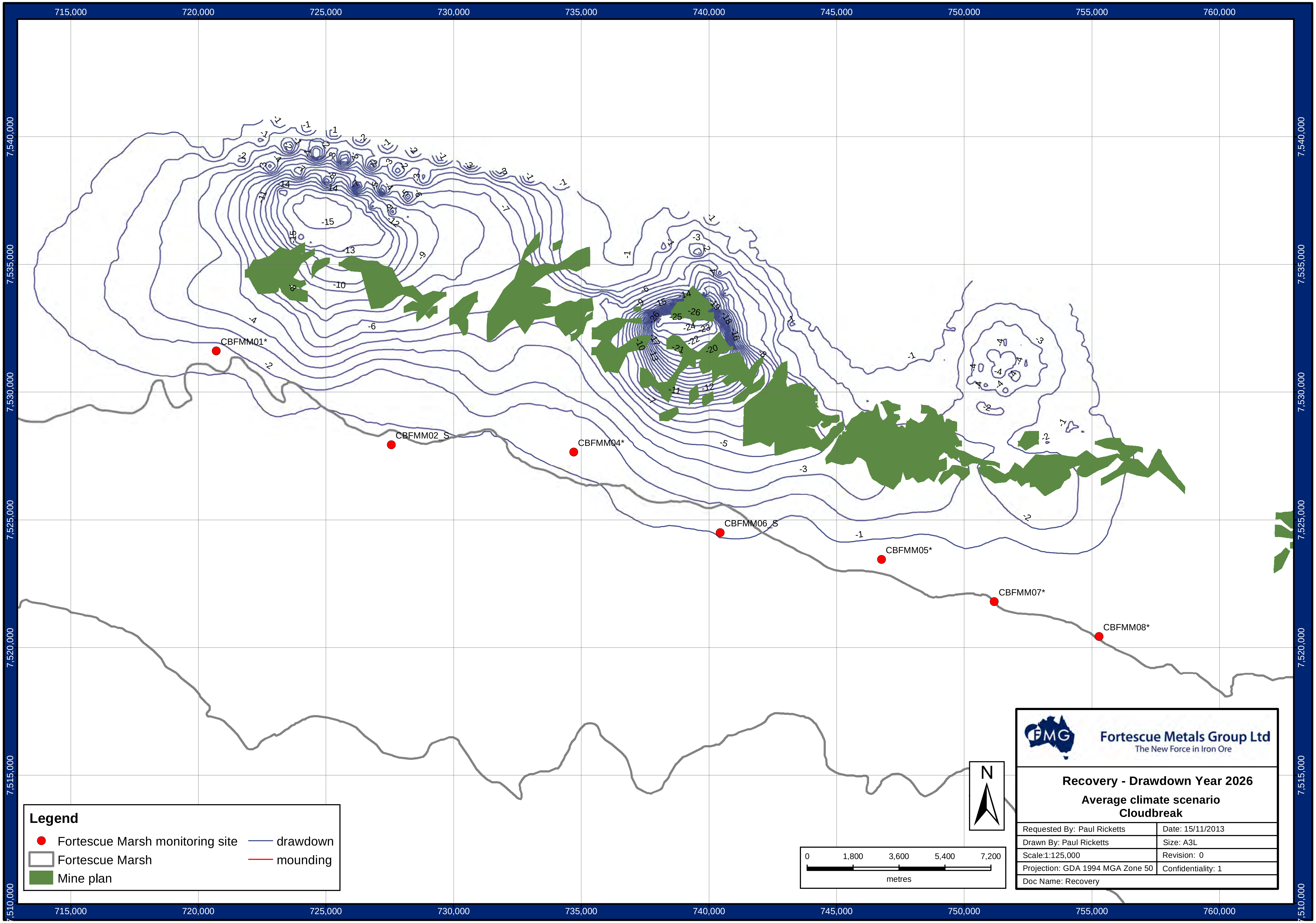


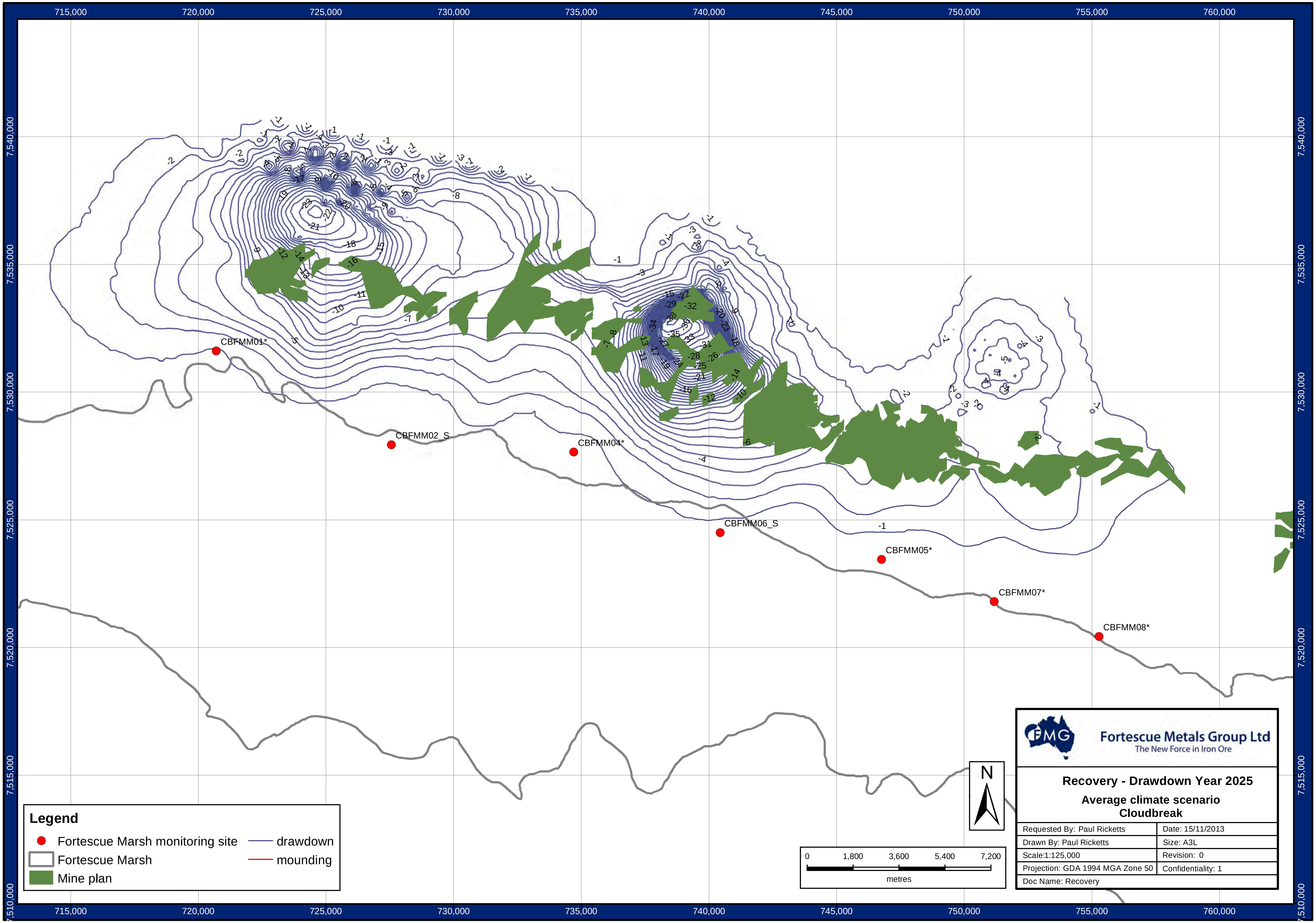
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-1
-2
N
Legend
drawdown
mounding
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
0
1,800
3,600
5,400
7,200
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2044
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery

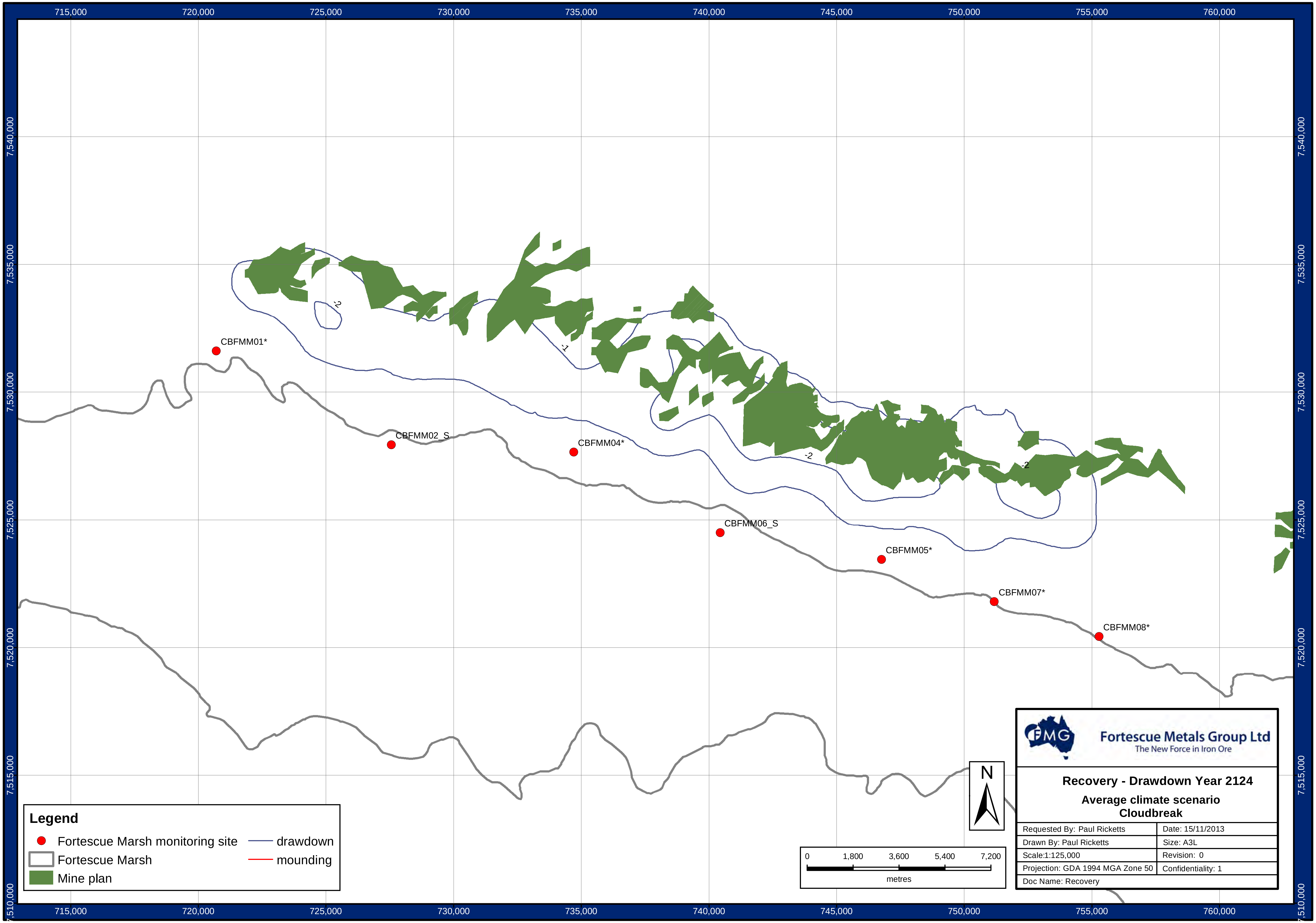

715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-1
-2
-3
-4
-5
-6
Legend
drawdown
mounding
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
0
1,800
3,600
5,400
7,200
metres
N
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2034
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery



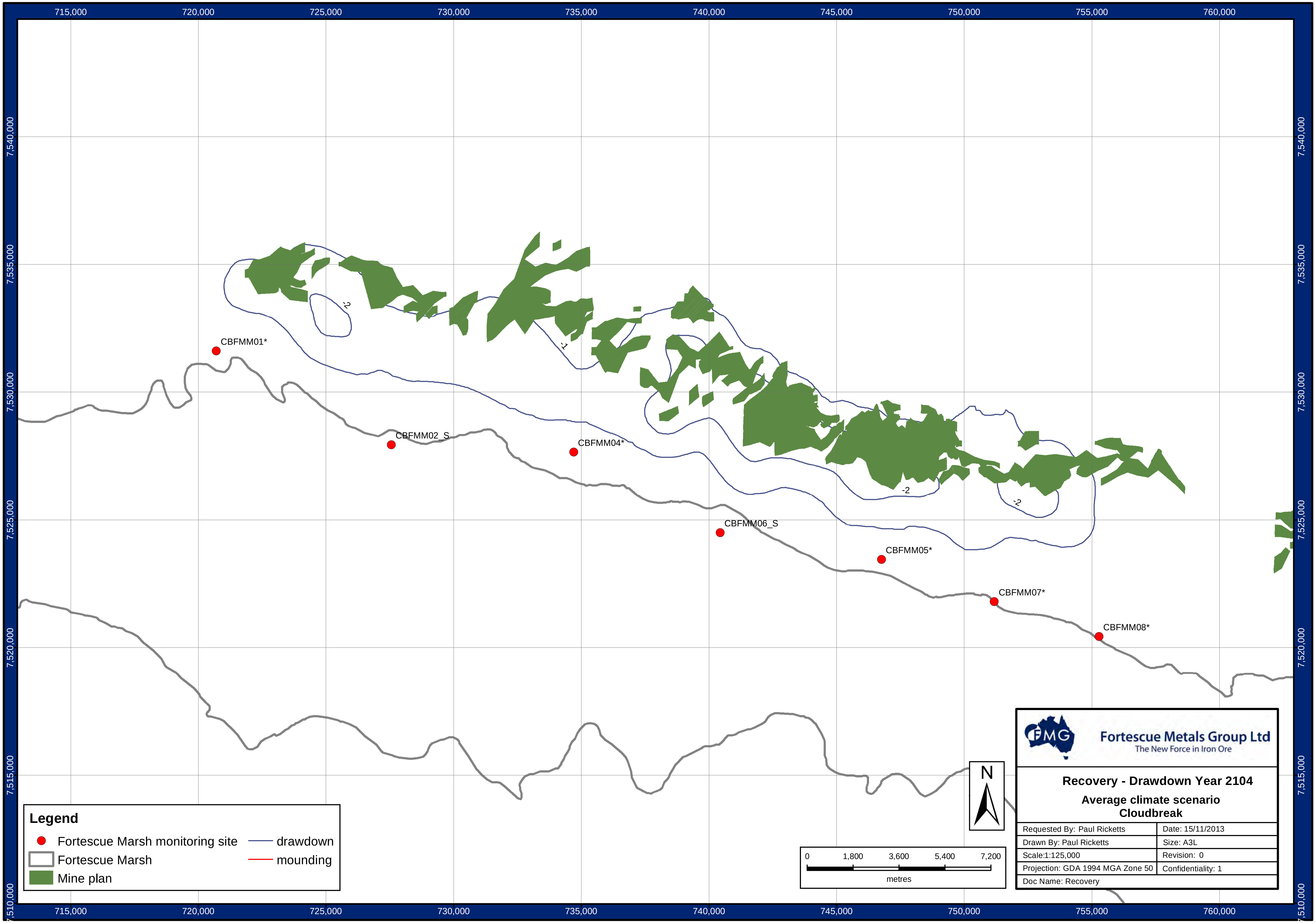
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
drawdown
mounding
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
0
1,800
3,600
5,400
7,200
metres
N
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2029
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery


715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
drawdown
mounding
N
0
1,800
3,600
5,400
7,200
metres
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2026
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery


Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2025
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery
Legend
Fortescue Marsh monitoring site
drawdown
Fortescue Marsh
mounding
Mine plan
N
0
1,800
3,600
5,400
7,200
metres
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000



715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
-2
-1
Legend
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
drawdown
mounding
0
1,800
3,600
5,400
7,200
metres
N
FMG
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2124
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery



715,000
720,000
725,000
730,000
735,000
740,000
745,000
750,000
755,000
760,000
7,540,000
7,535,000
7,530,000
7,525,000
7,520,000
7,515,000
7,510,000
-2
-1
-2
-2
CBFMM01*
CBFMM02_S
CBFMM04*
CBFMM06_S
CBFMM05*
CBFMM07*
CBFMM08*
Legend
Fortescue Marsh monitoring site
Fortescue Marsh
Mine plan
drawdown
mounding
0
1,800
3,600
5,400
7,200
metres
N
Fortescue Metals Group Ltd
The New Force in Iron Ore
Recovery - Drawdown Year 2104
Average climate scenario
Cloudbreak
Requested By: Paul Ricketts
Date: 15/11/2013
Drawn By: Paul Ricketts
Size: A3L
Scale:1:125,000
Revision: 0
Projection: GDA 1994 MGA Zone 50
Confidentiality: 1
Doc Name: Recovery

# Appendix 8: Effect of hydraulic property of backfilling materials on model predictions

This page has been left blank intentionally

## *Effect of the Hydraulic Properties of Pit Backfilling Materials*

Based on FMG's mine closure plan, all mined pits will be backfilled with waste materials. The hydraulic properties of the backfilling materials are usually different from those of the original overburden and the ore. Although not actually measured, the hydraulic conductivity of the backfilling materials is likely larger than the conductivity of the original overburden, but smaller than that of the original ore. Since backfilling materials cannot be packed as dense as the original overburden, its specific yield should be larger than that of the original overburden.

Assuming that the conductivity of backfilling materials is 10 m/day (between overburden (2.5 m/day and ore (70 m) conductivities) and specific yield is 0.052 (30% larger than overburden), a simulation was setup. The results from this simulation are compared to those from the simulation that didn't consider the change of hydraulic properties after mining and the difference in dewatering volumes is presented in Figure H.1. The difference in dewatering volumes between these two simulations is less than 2.5 GL/a, except in year 2020 (3.9 GL/a). The average difference in annual dewatering volumes is only bout 4%, which is small compared to prediction uncertainties associated with other factors, such as spatial variations in hydraulic conductivity. Similarly, the difference in the spatial distribution of groundwater drawdown/mounding between the two simulations are marginal (not shown here).

In summary, neglecting the change in hydraulic parameters after mining in our model setup would not significantly change our model predictions. Therefore, all numerical simulations were conducted without considering the temporal change in hydraulic properties before and after mining.

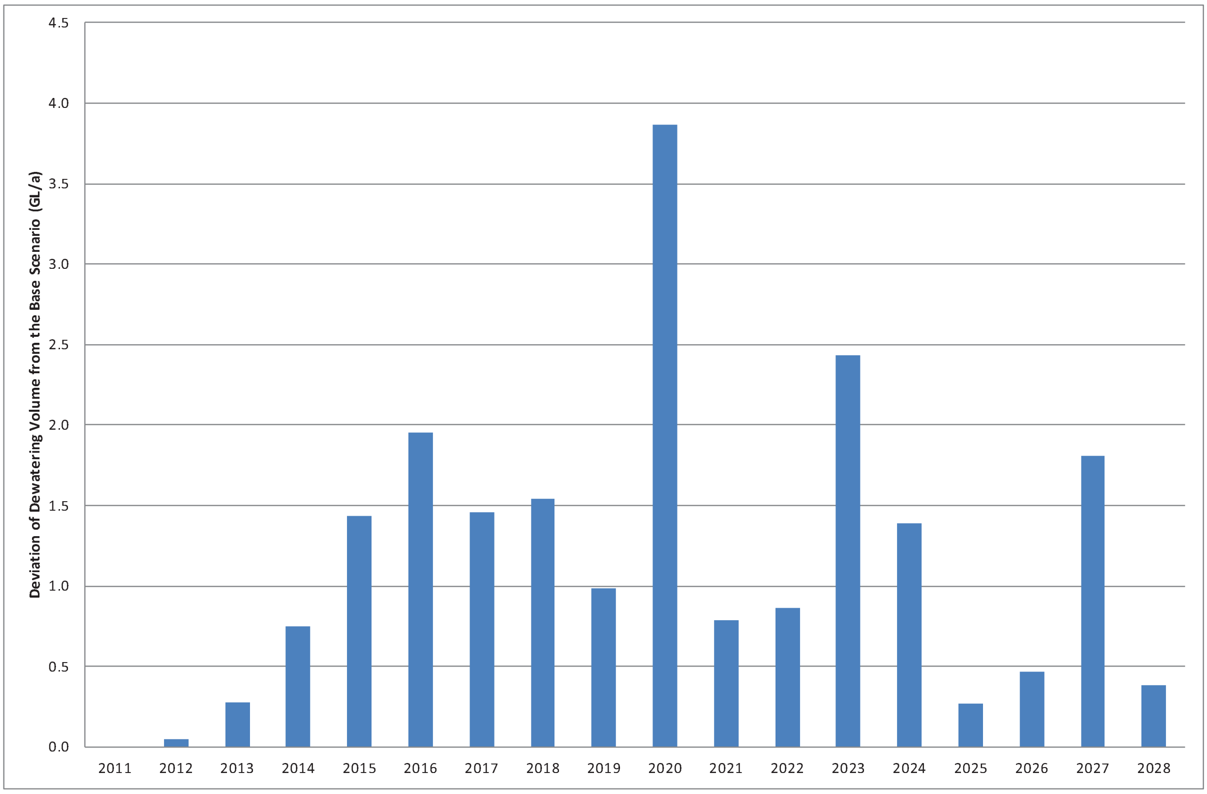



**Figure H.1: Dewatering volume differences between the Base Scenario simulation and the simulation considering the changes in hydraulic properties after pits being backfilled.**