Eliwana Rail Water Supply

Groundwater Impact Assessment

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### Eliwana Rail Water Supply: Groundwater Impact Assessment

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</table>
# TABLE OF CONTENTS

1. **INTRODUCTION** ......................................................................................... 7

2. **PREVIOUS AND RELATED STUDIES** ................................................... 8
   
   2.1 Western Hub Water Supply Assessment .............................................. 8
   
   2.2 Solomon Rail (Hamersley Line) Rail Construction .............................. 8
   
   2.3 Mainline Rail Construction .................................................................. 8
   
   2.4 Southern Fortescue Borefield ................................................................. 8

3. **PROJECT SETTING** ................................................................................. 9
   
   3.1 Location .................................................................................................. 9
   
   3.2 Climate .................................................................................................... 9
   
   3.3 Hydrology ............................................................................................... 10
   
   3.4 Geology and Hydrogeology ................................................................. 11
      
       3.4.1 Fortescue Group .............................................................................. 12
       
       3.4.2 Hamersley Group .......................................................................... 13
       
       3.4.3 Valley Fills and Pisolites ................................................................. 14
   
   3.5 Hydrogeology ........................................................................................ 14
      
       3.5.1 Unconsolidated Sedimentary and Palaeochannel Aquifers .......... 15
       
       3.5.2 Chemically-Deposited Aquifers (Calcrete and Pisolites) ............. 16
       
       3.5.3 Fractured Rock Aquifers ............................................................... 16
   
   3.6 Groundwater Levels ............................................................................ 17
      
       3.6.1 Wittenoom and Palaeochannel aquifer (Southern Fortescue Borefield) 17
       
       3.6.2 Sheila Valley CID ........................................................................... 17
       
       3.6.3 Fractured Rock Aquifer (Marra Mamba, Bunjinah and Jeerinah Formation) .................................................................................................................. 17
       
       3.6.4 Wittenoom Formation (Eliwana and Flying Fish Prospects) .......... 18
   
   3.7 Regional Water Quality ................................................................. 18
   
   3.8 Environmental Considerations ....................................................... 18
   
   3.9 Cultural Considerations ........................................................................ 19
   
   3.10 Groundwater Users ........................................................................... 20
      
       3.10.1 Mining ......................................................................................... 20
       
       3.10.2 Pastoral .......................................................................................... 20
List of Tables

Table 1: Climate Averages for BoM Stations in the Vicinity of the Eliwana Rail Line ................................................................. 10
Table 2: Eliwana Catchment Areas ................................................................................................................................. 11
Table 3: Main Stratigraphic Units with the Eliwana Rail Project Area ...................................................... 12
Table 4: Summary of Aquifer Types and Prospectivity (Modified after: Johnson and Wright, 2001) .................................................. 14
Table 5: Vegetation Communities Considered as PGDE or GDE......................................................... 19
Table 6: Summary of Aquifer Properties used in Analytical Modelling .................................................. 26
Table 7: Summary of Analytical Modelling Results ................................................................................ 27
LIST OF FIGURES

Figure 1: Eliwana Rail Location Plan ................................................................. 34
Figure 2: Location of 2017 Groundwater Exploration Drilling .......................... 35
Figure 3: Regional Surface Catchments .......................................................... 36
Figure 4: Regional Surface Geology along the Eliwana Rail Alignment ............ 37
Figure 5: Summary of Groundwater levels along the Eliwana Rail Alignment ... 38
Figure 6: Environmental Considerations along the Eliwana Rail Alignment ...... 39
Figure 7: Environmental Considerations in GIAA 1 ........................................ 40
Figure 8: Environmental Considerations in GIAA 2 ........................................ 41
Figure 9: Environmental Considerations in GIAA 3 ......................................... 42
Figure 10: Environmental Considerations in GIAA 4 ....................................... 43
Figure 11: Environmental Considerations in GIAA 5 ....................................... 44
Figure 12: Environmental Considerations in GIAA 6 ...................................... 45
Figure 13: Location of Existing Third Party Bores ........................................... 46
Figure 14: Rail Water Supply Demand Profile .................................................. 47
Figure 15: Map of Eliwana Rail Water Supply Strategy .................................... 48

LIST OF APPENDICES

Appendix 1: 2017 Groundwater Exploration Borelogs
Appendix 2: Analytical Assessment Results
1. INTRODUCTION

Fortescue Metals Group Ltd (Fortescue) is proposing to develop the Eliwana Mine Project (the Project) in the Pilbara region of Western Australia. The Project is located approximately 90 km west-north-west of Tom Price (Figure 1).

A 120km railway line will be constructed to link the Project to existing rail infrastructure currently associated with Fortescue’s Solomon Hub. Construction of the railway line will require water supplied for dust suppression and material compaction. Fortescue proposes to abstract the required volume of water from groundwater resources at regular intervals along the railway line.

This report collates available information on groundwater resources along the planned rail alignment and presents an impact assessment for the proposed groundwater abstraction.
2. PREVIOUS AND RELATED STUDIES

2.1 Western Hub Water Supply Assessment

A water supply assessment was undertaken for the Eliwana Rail (previously termed Western Hub rail) in order to provide a high level understanding of groundwater resources and likely bore targets along the rail alignment. Available geological, geophysical and other datasets were reviewed to inform the study.

Approximately 180 water supply exploration targets were identified mainly being of low to medium prospectivity in the West and higher prospectivity in the East. A dozen of the low prospectivity zones were subject to reconnaissance exploration drilling and slug testing in mid-2017 to inform early planning of water source strategy. The location of these drillholes are shown in Figure 2; Borelogs are included in Appendix 1.

2.2 Solomon Rail (Hamersley Line) Construction

Water supply for the construction of the Solomon rail was developed in 2011-2012, with a total of 40 bores being completed. The rail construction bores supplied approximately 3.4 GL of groundwater during the construction period. A number of the bores were completed in challenging geological terrain, analogous to that expected along the Eliwana Rail alignment.

2.3 Mainline Rail Construction

The Mainline rail was constructed in 2007 as part of the initial mine, rail and port development. The construction utilised approximately 60 bores at 20 water supply sources. These bores supplied approximately 4 GL during the construction period. An extension to this line was completed in 2009 linking the Christmas Creek mine to the port, and duplication of the line has taken place in some locations to increase capacity of the rail.

2.4 Southern Fortescue Borefield

The Southern Fortescue Borefield was installed in late 2013 to provide additional water for the Solomon mine site. The borefield commenced abstraction in November 2013.

The borefield currently abstracts from a palaeovalley fill aquifer and weathered bedrock (Wittenoom Dolomite Formation) setting near the Solomon airstrip, in a valley setting south of the Solomon mining area. The borefield was has been developed to abstract up to 12 GL/a to meet future water supply requirements.
3. PROJECT SETTING

This section characterises key features of the project physiology, including the hydrology and hydrological regimes.

3.1 Location

The proposed Eliwana rail is located in the Pilbara region of Western Australia, in the Central Hamersley Range, approximately 50 kilometres (km) to the north of Tom Price. The route will link the Eliwana mine to the Solomon rail alignment by a 140 km railway.

3.2 Climate

The Pilbara has an arid tropical climate characterised by high temperatures and low to variable rainfall, high diurnal temperature variations and high evaporation rates (BoM, 2011). Summer months extend from October to April, with average daily temperatures exceeding 30°C and average daily maxima exceeding 35°C from October to March. The winter months extend from May to September, with temperatures ranging from approximately 7°C to 23°C.

Rainfall in the Pilbara is generally low and variable with annual rainfall declining from 300–350 millimetres (mm) in the north-east to less than 250mm in the south and west, and generally associated with cyclonic events between mid-December and April. There are significant rainfall events during tropical storms which enhance aquifer recharge and also result in localised flooding in inland areas (URS, 2010).

The closest public meteorological stations to the Eliwana rail alignment are Wittenoom, approximately 32 km from the eastern end of the alignment and Tom Price, approximately 49 km south of the Southern Fortescue area. Climate data averages for these stations obtained from the Bureau of Meteorology (BoM, 2017) are summarised in Table 1.
Table 1: Climate Averages for BoM Stations in the Vicinity of the Eliwana Rail Line

<table>
<thead>
<tr>
<th>Months</th>
<th>Wittenoom Station (005026)</th>
<th>Tom Price Station (005072)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Max Temp (°C) - 1951 to 2017</td>
<td>Mean Min Temp (°C) - 1951 to 2017</td>
</tr>
<tr>
<td>January</td>
<td>39.5</td>
<td>26</td>
</tr>
<tr>
<td>February</td>
<td>37.8</td>
<td>25.3</td>
</tr>
<tr>
<td>March</td>
<td>36.7</td>
<td>24.3</td>
</tr>
<tr>
<td>April</td>
<td>33.2</td>
<td>21.2</td>
</tr>
<tr>
<td>May</td>
<td>27.8</td>
<td>16.2</td>
</tr>
<tr>
<td>June</td>
<td>24.5</td>
<td>12.8</td>
</tr>
<tr>
<td>July</td>
<td>24.2</td>
<td>11.5</td>
</tr>
<tr>
<td>August</td>
<td>26.9</td>
<td>13.2</td>
</tr>
<tr>
<td>September</td>
<td>31.2</td>
<td>16.8</td>
</tr>
<tr>
<td>October</td>
<td>35.5</td>
<td>20.9</td>
</tr>
<tr>
<td>November</td>
<td>38.1</td>
<td>23.6</td>
</tr>
<tr>
<td>December</td>
<td>39.7</td>
<td>25.5</td>
</tr>
<tr>
<td>Annual</td>
<td>32.9</td>
<td>19.8</td>
</tr>
</tbody>
</table>

3.3 Hydrology

The Eliwana rail project spans the Lower Fortescue River and Ashburton River basins, with the majority of rail infrastructure located within the Ashburton basin (as shown in Figure 3). Within these basins, the rail traverses the Weelumurra Creek sub-catchments of the Lower Fortescue River and the Duck Creek sub-catchment of the Ashburton River. The catchment areas of these basins and associated above sub-catchments are summarised in Table 2.

Pilbara creeks are typically ephemeral, and with the exception of pools and groundwater fed springs, are dry for the majority of the year. Significant streamflow usually occurs when antecedent moisture content of the soils is high, which is caused by significant rainfall in the days or weeks preceding a storm event. There are typically two different types of climatic events which cause flood responses in the Pilbara, namely: Cyclonic activity/Tropical Low Pressure Systems and localised diurnal thunderstorms.

Cyclonic activity can result in severe and widespread flooding generally on a river catchment scale. This type of flooding typically produces large peak flows and may result in damage to infrastructure due to magnitude of flows and total volume of water. However, not all cyclones will result in severe flooding.
Isolated thunderstorms have the potential to create fast and localised flooding, referred to as flash flooding. These events are much harder to predict as they can occur in the upper reaches of catchments. These events generally have a lower potential for widespread damage as the extent and magnitude of flooding is much smaller than cyclonic events.

### Table 2: Eliwana Catchment Areas

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (sq. km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Fortescue River Basin</td>
<td>18,607</td>
</tr>
<tr>
<td>Weelumurra Creek (at confluence with Fortescue River)</td>
<td>2,290</td>
</tr>
<tr>
<td>Weelumurra Creek (at downstream end of Weelumurra Plain)</td>
<td>1,220</td>
</tr>
<tr>
<td>Ashburton River Basin</td>
<td>78,777</td>
</tr>
<tr>
<td>Duck Creek (at confluence with Ashburton)</td>
<td>6,800</td>
</tr>
<tr>
<td>Duck Creek (at Confluence with Boolgeeda Creek)</td>
<td>3,691</td>
</tr>
<tr>
<td>Boolgeeda Creek</td>
<td>1,658</td>
</tr>
<tr>
<td>Caves Creek</td>
<td>1,938</td>
</tr>
<tr>
<td>Barnett Creek</td>
<td>520</td>
</tr>
<tr>
<td>Wackilina Creek</td>
<td>210</td>
</tr>
</tbody>
</table>

### 3.4 Geology and Hydrogeology

Groundwater availability is dependent upon an adequate understanding of the various geological depositional environments associated with each of the existing geological units, the geomorphology associated with recent deposition, and the underlying structures (lineaments, type of faulting etc.) controlling flow within each of the potential aquifer systems. This section provides a brief summary of the geological units within and in the vicinity of the Eliwana rail corridor before focusing on the potential aquifer formations.

The geology of the Eliwana rail corridor is detailed in the Australia 1:250,000 Geological Map Series - Mount Bruce and Wyloo sheets. The basement geology is dominated by the Archaean and Proterozoic rocks of the Pilbara Craton. The Project area is dominated by rocks of the Fortescue and Hamersley Groups.

The main stratigraphic units in the Project area are presented in Table 3, with surface geology illustrated in Figure 4.
Table 3: Main Stratigraphic Units with the Eliwana Rail Project Area

<table>
<thead>
<tr>
<th>Group</th>
<th>Formation</th>
<th>Member</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary and Tertiary</td>
<td>Alluvium</td>
<td></td>
<td>Clay, silt, sands and gravel.</td>
</tr>
<tr>
<td></td>
<td>Lacustrine Deposits</td>
<td></td>
<td>Stiff clay and silt</td>
</tr>
<tr>
<td></td>
<td>Colluvium and Alluvium</td>
<td></td>
<td>Clay, partly ferruginised silt, sand and gravel</td>
</tr>
<tr>
<td></td>
<td>Robe Pisolites – (CID)</td>
<td></td>
<td>Pisolitic Limonite developed along river channels.</td>
</tr>
<tr>
<td>Hamersley Group</td>
<td>Brockman Iron Formation</td>
<td>Bee Gorge Member</td>
<td>BIF, chert and petle</td>
</tr>
<tr>
<td></td>
<td>Mount McRae Shale</td>
<td>Paraburdo Member</td>
<td>Pelite, chert and BIF</td>
</tr>
<tr>
<td></td>
<td>Wittenoom Dolomite</td>
<td></td>
<td>Thin to medium bodied metadolomite</td>
</tr>
<tr>
<td></td>
<td>Marra Mamba Iron Formation</td>
<td>Mount Newman</td>
<td>BIF with thin shale intervals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Member</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MacLeod Member</td>
<td>Shales, chert and BIF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nammuldi Member</td>
<td>Chert and iron-formation</td>
</tr>
<tr>
<td>Fortescue Group</td>
<td>Jeerinah Formation</td>
<td></td>
<td>Pelites, chert, shale</td>
</tr>
<tr>
<td></td>
<td>Mount Jope Volcanics</td>
<td></td>
<td>Pillow basalts with pyroclasts</td>
</tr>
<tr>
<td></td>
<td>Bunjinah Formation</td>
<td>Bunjinah Member</td>
<td>Pillowed and massive metabasalt, metabasaltic breccia, metamorphosed volcanic sandstone,</td>
</tr>
<tr>
<td>Pilbara Craton</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4.1 Fortescue Group

The Fortescue Group forms the lowermost of the three sub divisions of the Mount Bruce Supergroup. It is 150 to 250 m-thick and comprises predominantly pelites, cherts and thin bedded sandstones intruded by dolerite sills.

It is an Archaean volcano-sedimentary sequence of marginal marine deposits that is subdivided into four formations of which Jeerinah Formation and Mount Jope basalts including the Bunjinah Pillow Lava Member outcrop within the Project area.

The Mount Jope Volcanics comprise basaltic lava, pillow lava, pillow breccia, fine- to coarse-grained pyroclastics, and minor fine-grained sedimentary rocks (Seymour et al, 1988). There are three members of the Formation, of which the Bunjinah Pillow Lava Member outcrops through the western end of the corridor.

The Jeerinah Formation is the youngest formation within the Fortescue Group. It conformably overlies the Mount Jope Volcanics in the Wyloo Dome area and forms a large outcrop in the
Jeerinah Anticline. It consists of thin-bedded mudstone, chert, BIF, and basalt, intruded by numerous dolerite sills. The sills may comprise up to 60% of the formation's maximum thickness. The Jeerinah Formation is interpreted as a marine sequence and transitional upwards into the Marra Mamba Iron Formation of the Hamersley Group. The contact with the Marra Mamba is generally conformable (Honvitz, 1978). Within the Eliwana rail corridor and vicinity, the Jeerinah Formation outcrops from approximately the central part of the rail alignment to the west transitioning from the Fortescue Group to the Hamersley Group.

3.4.2 Hamersley Group

The Hamersley Group lies conformably over the Fortescue Group and consists of metamorphosed Archaean–Proterozoic sedimentary rocks, such as banded iron formation (BIF), interbedded with chert, shale, dolomite and some volcanoclastic rock, and dolerite dyke intrusions.

Marra Mamba Iron Formation is the basal unit and consists of inter-bedded iron-stained chert and shale. Outcrops occur within the Project area to the centre of the rail alignment. The Formation consists mainly of BIF with intervals of shale and chert, and is subdivided into three members. The oldest, the Nammuldi Member, comprises chert and BIF and is approximately 100 m thick. The MacLeod Member (45 m thick) comprises shale, chert and BIF, and the youngest member, the Mount Newman Member is a 60 m thick predominantly BIF unit with some thin shale intervals.

The Wittenoom Formation is 200 to 750 m thick, and consists mainly of dolomites and shale and comprises three members: West Angela, Paraburdoo Member and Bee Gorge. The Wittenoom Formation is dominated by dolomites with (dolomitic) argillite, the Paraburdoo Member has the presence of chert and the base of the West Angela Member is marked by a 20 m thick sequence of interbedded chert, BIF, and shale. The third member unit is the 75 and 230 m thick Bee Gorge Member, dominated by argillite with subordinate carbonate, chert, volcanoclastic and BIF (Thorne et al, 1977). The karstic dolomites of the Paraburdoo Member underlie the majority of the Southern Fortescue valley in the eastern part of the rail alignment.

Mount McRae Shale is dominated by shale, with subordinate dolomitic shales and BIF. Dolerite dykes cross-cut the formations, trending typically east northeast and west-northwest. The 70 m thick Mount McRae Shale is interbedded with chert bands and can be significantly silicified.

The Brockman Iron Formation conformably overlies the Mount Sylvia Formation and the Mount McRae Shale. This formation consists of four members with alternating BIF and chert and shale lithologies, creating an overall thickness of approximately 550 m. The oldest member of the Brockman Iron Formation is the Dales Gorge Member, a 150 m-thick unit comprising BIF with argillite bands. This is overlain by the Whaleback Shale, which has two BIF bands near its base and consists of 75 m of alternating chert and shale. This is in turn overlain by the Joffre Member, another BIF with minor shale, which can be up to 280 m thick. The youngest unit is the Yandicoogina Shale; a 40 m-thick, interbedded chert and shale sequence.
3.4.3 Valley Fills and Pisolites

The Southern Fortescue region to the east of the Eliwana rail corridor is dominated by recent and palaeodrainage valley fill deposits which can be greater than 100 m thick in places. There are east west trending alluvial palaeodrainage sediments to the west of the rail line that are typically deposited on the Wittenoom Formation during the Cainozoic. The stratigraphy of the Cainozoic sediments typically comprises Eocene palaeochannel sand and gravel at the basal, CID and silcrete, overlain by thick Pliocene lacustrine clay and more recent Quaternary detritals. The presence of the lacustrine clay is a key marker for palaeovalley facies across the state (Magee 2009). This clay is finely laminated, plastic, stiff to very stiff and represents the onset of a drying climate in the regional geological history. Significantly, the clay is typically present across the entire palaeovalley and is generally thickest in the deepest part of the palaeovalley.

Low to high ranging alluvial fans and colluvial and detrital sediments are also seen in the east and central parts of the alignment where pockets of calcrete and silcrete are also encountered.

3.5 Hydrogeology

Hydrogeologically, the aquifers in the Central Pilbara have been divided into three main types (Johnson and Wright 2001) based on their potential. These are:

- Unconsolidated sedimentary aquifers;
- Chemically deposited calcrete; and
- Fractured rock aquifers,

Each of these units are located along the length of the Eliwana rail alignment. Johnson and Wright (2001) have divided the prospectivity of the aquifers as shown in Table 4; this summary has been amended based upon known hydrogeological properties derived from regional Fortescue investigations.

<table>
<thead>
<tr>
<th>Aquifer Type</th>
<th>Aquifer</th>
<th>Geological Unit</th>
<th>Saturated Thickness (m)</th>
<th>Bore Yield (L/s)</th>
<th>Aquifer Potential</th>
<th>Anticipated Water Quality TDS (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconsolidated sedimentary</td>
<td>Valley fill</td>
<td>Alluvium</td>
<td>15</td>
<td>&lt;10</td>
<td>Major</td>
<td>200 – 1,000</td>
</tr>
<tr>
<td>aquifer</td>
<td></td>
<td>Colluvium</td>
<td>30</td>
<td>&lt;10</td>
<td>Major</td>
<td></td>
</tr>
<tr>
<td>Palaeochannel</td>
<td>Basal Sand</td>
<td>15</td>
<td>5 - 20</td>
<td>Major</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemically deposited</td>
<td>Calcrete</td>
<td>Calcrete</td>
<td>15</td>
<td>5 - 20</td>
<td>Major</td>
<td>200 – 1,500</td>
</tr>
<tr>
<td>aquifer</td>
<td>Pisolitic</td>
<td>Vuggy CID /</td>
<td>10</td>
<td>10 – 20</td>
<td>Major</td>
<td></td>
</tr>
<tr>
<td>Fractured-rock aquifer</td>
<td>BIF</td>
<td>Brockman Iron</td>
<td>20</td>
<td>5 – 10</td>
<td>Local (Major where mineralised)</td>
<td>400 – 3,500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquifer Type</td>
<td>Aquifer</td>
<td>Geological Unit</td>
<td>Saturated Thickness (m)</td>
<td>Bore Yield (L/s)</td>
<td>Aquifer Potential</td>
<td>Anticipated Water Quality TDS (mg/L)</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
<td>-------------------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Marra Mamba Iron Formation</td>
<td></td>
<td>20</td>
<td>5 – 20</td>
<td>Local (Major where mineralised)</td>
<td></td>
</tr>
<tr>
<td>Fractured / weathered Dolomite</td>
<td>Wittenoom Formation</td>
<td></td>
<td>25 – 50</td>
<td>5 – 40</td>
<td>Major where fractured</td>
<td></td>
</tr>
<tr>
<td>Fractured metasediments</td>
<td>Jeerinah Formation</td>
<td></td>
<td>20</td>
<td>2 – 5</td>
<td>Minor</td>
<td></td>
</tr>
<tr>
<td>Fractured basalt</td>
<td>Bunjinah Formation</td>
<td></td>
<td>20</td>
<td>2 - 5</td>
<td>Minor</td>
<td></td>
</tr>
</tbody>
</table>

The main aquifer units along the Eliwana rail line comprise the following hydro-stratigraphic units.

### 3.5.1 Unconsolidated Sedimentary and Palaeochannel Aquifers

Alluvial aquifers occur across the study area with groundwater generally contained in unconfined conditions within Quaternary sediments associated with present day creek lines, broad river valley of the Southern Fortescue River. The alluvial deposits are expected to be highly variable and heterogeneous due to their mode of deposition, ranging from silty clays through to gravels. The deposits are reported to have a thickness generally ranging between 10 to 40 m, with thicknesses of up to 60 m reported at Solomon (FMG, 2015) or greater (up to 150m reported in the larger Fortescue Valley (Sinclair Knight Merz, 1977)). The colluvial deposits may comprise cobble sized detritals within a clay matrix. Groundwater is within the primary porosity of the sediments and generally in hydraulic continuity with underlying fractured rock systems.

Recharge to the unconfined aquifer is through direct surface run off and infiltration from rainfall. Recharge will be high along the scree deposits where there is a change in relief or in the broad river valleys. Groundwater flow direction is mainly downgradient along surface flow gradient. Bore yields will be highly variable and will depend on the heterogeneity within the unit.

The palaeochannel aquifers are located in the deepest sections of the palaeovalley which runs beneath the Southern Fortescue River and west towards Caves Creek. They form a series of interconnected, confined strip aquifers located between 80 and 120 m bgl. The deposits can be between 10 and 20 m thick and are present below the confining lacustrine clay unit and is often in hydraulic connection to deep silcrete, CID aquifers and bedrock. The Southern Fortescue borefield comprises a number of production bores that yield up to 20 L/s from the confined aquifer system, often drilled into CID and Wittenoom Formation dolomite which are considered to form one aquifer unit (FMG, 2016).
Short term groundwater abstraction from the confined aquifer unit is considered to be from confined aquifer storage. Recharge to the palaeochannel occurs via leakage from the sediments above and below the palaeochannel aquifer, with likely pathways via the edges of the palaeovalley (Magee, 2009).

### 3.5.2 Chemically-Deposited Aquifers (Calcrete and Pisolites)

Calcrete and pisolitic aquifers are limited in the eastern and central parts of the alignment within the Tertiary palaeochannel sediments although minor occurrences of calcretes along drainage channels are seen to the west of the corridor. These aquifers are formed by secondary chemical reactions and deposition within Tertiary palaeodrainages (Johnson and Wright, 2001), river channels and along major drainage lines. Both aquifers are characterised by secondary porosity and also may have the potential for high bore yields. Recharge is expected to be mainly through leakage from creek bed sediments. Bore yields of 0.5 to 3 l/s are commonly recorded.

Pisolitic aquifers or Robe pisolite within the study area (Thorne et al, 1996) are Channel Iron Deposit (CID) aquifers commonly used in the Pilbara for groundwater supplies. This unit outcrops at places in the central part of the Eliwana rail alignment and forms local aquifers below current day and palaeodrainages. Pisolitic aquifers can be vuggy and porous with medium to high yields.

These aquifers are recharged primarily by leakage through the overlying alluvium within creek beds. During high rainfall and episodic cyclonic flood events water levels in the shallow alluvium in creek beds and broader palaeovalleys will fill up and recharge these units resulting in direct infiltration and increased storage.

### 3.5.3 Fractured Rock Aquifers

The fractured rock aquifers along the rail alignment are dominated by a number of rock types. Banded Iron Formation aquifers of the Marra Mamba and Brockman Iron Formation occur mainly along the central part of the alignment although outcrops of Brockman Formation are limited and sporadic within the corridor.

The dolomitic aquifer within the Archean Paraburdoo Member of the Wittenoom Formation is the highest yielding and most significant aquifer along the Eliwana rail alignment and within the Flying Fish area to the south of the western end of the alignment. Karstic features and dissolution cavities within this aquifer indicates high but variable bore yields. The Dolomite from the Wittenoom Formation is highly variable and ranges from a highly transmissive and high yielding aquifer in karstic areas through to fresh, undeformed bedrock with very limited groundwater potential (Johnson and Wright, 2001). The existing Southern Fortescue borefield abstracts groundwater from this aquifer.
The fractured rock units of the Fortescue Group to the west of the rail alignment comprising Jeerinah Formation, Mount Jope Volcanics, and Bunjinah Formation, are expected to be low yielding except in areas where there is a greater degree of weathering in the upper profile and or recharge from the numerous minor creeks controlled by fractures that dissect these rock types.

Groundwater recharge to fractured rock aquifers is rainfall dependent and will occur where fractured, jointed and weathered zones are exposed to rainfall. Recharge may also be enhanced where fractures zones are intersected by drainage lines such as creeks and rivers, along existing smaller and larger catchments. In fractured rock environments groundwater is largely held in fractures, shear zones and weathered horizons.

### 3.6 Groundwater Levels

Groundwater levels along the rail alignment vary depending on topography, drainage features, underlying geology and structure. In general, shallowest levels occur in valleys and near to major drainage features, whilst structural features (such as dykes) can also influence water levels in bedrock aquifers.

#### 3.6.1 Wittenoom and Palaeochannel aquifer (Southern Fortescue Borefield)

Standing water levels in the Southern Fortescue borefield, supplying water to Solomon Mine, vary between 590 and 595 m AHD. Depth to groundwater increases from 7 m bgl in the low lying areas to 45 m bgl up the hillslope of the Hamersley Range. There is a hydraulic gradient of 0.2 m/km from east to west.

Near to Hamersley Station, Sylvia Bore has a recorded groundwater level of 575 m AHD, which corresponds to a depth of 17 m bgl.

The range of water levels have been annotated on Figure 5, along with points where water level data is available.

#### 3.6.2 Sheila Valley CID

Water levels in the proposed potable supply bore, CPP16, were measured as 583 m AHD (15.2 m bgl) in December 2017.

#### 3.6.3 Fractured Rock Aquifer (Marra Mamba, Bunjinah and Jeerinah Formation)

There is very sparse data regarding water levels in these units along the rail alignment. Water levels measured directly in bores completed in mid-2017 for water exploration purposes (Section 2.1) have been annotated on Figure 5. No regional groundwater gradient has been
established within this aquifer, although the broad pattern of data is for groundwater levels to be decreasing to the west, which is coincident with the direction of surface drainage.

More detailed studies in the Flying Fish and Eliwana prospect areas (Section 3.6.4) indicate compartmentalisation due to dykes, faults and low permeability strata. The Bunjinah and Jeerinah Formations may also be subject to the same compartmentalisation, with the fractured rock aquifer compartmentalised by geological structures (e.g. dykes) and surrounding, low permeability, unfractured rock.

3.6.4 Wittenoom Formation (Eliwana and Flying Fish Prospects)

Groundwater levels of the Wittenoom Formation within the Eliwana and Flying Fish prospects have been described in detail by Golder (2017). Compartmentalisation of the Wittenoom formation by cross cutting dykes and bounding, lower permeability shale strata has resulted in discrete sub catchments with flat hydraulic gradients.

As indicated in Figure 5, water levels in the Flying Fish area vary between compartments; 553 mAHD and 544 mAHD in areas with bore data as shown. Depths to groundwater range due to topography but are as shallow as 8 m bgl in low lying areas. Water levels in the Eliwana compartments shown are approximately 474 m AHD and 459 m AHD, with depths to groundwater between 5 and 50 m bgl.

3.7 Regional Water Quality

Groundwater quality of the regional aquifers is considered to range from fresh to brackish, with fresher water being located closer to the recharge zones. A summary of known water quality from available bore data is below:

- The Wittenoom and Palaeochannel aquifer of the Southern Fortescue Borefield has water quality between 200 and 1000 mg/L;
- Initial exploratory drilling in the Bunjinah Basalt and Jeerinah Formation on the western end of the alignment suggests water quality ranges from 500 to 3500 mg/L
- Wittenoom Formation dolomite from the Flying Fish prospect area is between 1200 and 1700 mg/L;
- Wittenoom Formation dolomite from the Eliwana prospect area’s fractured rock aquifers are less than 1200 mg/L.

There are no major regional sources of saline or hypersaline water.

3.8 Environmental Considerations

Environmental considerations include groundwater dependent ecosystems (GDEs) and natural springs and pools.
GDEs may include vegetation that rely, or partially rely on groundwater typically within 10 m of ground level (Astron, 2016). Fortescue considers that *E. camaldulensis* and *M. argentea* are indicative of a GDE, while *E. victrix* is an indicator of a potential GDE. Publically available vegetation mapping and Fortescue’s in-house databases have identified the communities listed in Table 5 as groundwater dependent or potentially groundwater dependent; these are presented in Figure 6.

<table>
<thead>
<tr>
<th>Groundwater Depend Vegetation Unit</th>
<th>Potentially Groundwater Dependent Vegetation Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcAcEUaTe</td>
<td>AcBte</td>
</tr>
<tr>
<td>EcApyTErCYa</td>
<td>EvAcCcERlt</td>
</tr>
<tr>
<td>EvAcVIDICf</td>
<td>EvAcMgERlt</td>
</tr>
<tr>
<td></td>
<td>EvATuApyTErTHt</td>
</tr>
<tr>
<td></td>
<td>EvExAcTht</td>
</tr>
<tr>
<td></td>
<td>EvVfApyCYPvTHt</td>
</tr>
</tbody>
</table>

Intermittent pools will form along the upper reaches of Duck Creek and Caves Creek following periods of intense storm activity and flooding, whilst semi-permanent to permanent pools will persist throughout the year. The extent of the pools will change depending on the climatic conditions; expanding during wetter seasons and contracting during periods of drought. Figure 6 and associated insets (Figure 7 - 12) illustrate the surface water features within the proposed groundwater impact assessment areas (refer to Section 5.4), identified from aerial imagery captured in August 2004 and August 2013, and compares their extent during this time.

Characterisation of these pool features has been undertaken in the groundwater impact assessment areas, based on the aerial imagery, geological setting, vegetation assemblages and nearby groundwater levels. The majority of the pool features appear to persist, as indicated by the overlapping temporal polygons, and the presence of GDE assemblages indicate some groundwater interaction for these pools. The geological setting and groundwater level information further imply that, for pools in the west of the RDE, groundwater interaction is likely to be localised, reliant on bedrock controls and recharge from proximal fracture systems. Of these pools, the only one that occurs in a named government database is Donkey Pool. Donkey Pool is located in the vicinity of chainage 108 km on one of the upper reaches of an unnamed tributary of Duck Creek; this pool is 2.7 km north of the rail alignment. Section 5.5 further discusses the impact assessment of this pool.

Pools identified in the central portion of the RDE, within Wacklina and Caves Creek, are in an area with groundwater levels approximately 15 – 30 m below surface. These pools have been characterised as either remnant surface flow or surface water dependent.

### 3.9 Cultural Considerations

There are minimal potential cultural considerations in relation to groundwater abstraction along the rail alignment, with the exception of Hamersley Station (see Section 3.10.2) and
Nharraminju Wuntu (Donkey Hole). Nharraminju Wuntu, shown in Figure 13, has been identified during surveys as a site of ethnographic significance, which is in part contributed to by the presence of surface water at the site.

3.10 Groundwater Users

Other groundwater users may include other mining operations' water supplies, pastoral station bores and any other third party users (ie shire road maintenance bores). The bores located within close proximity to proposed rail alignment bores will need to be assessed for drawdown impacts so that the existing supplies are not impacted.

3.10.1 Mining

Mining operations and linear infrastructure in close vicinity to the rail alignment are associated with Rio Tinto's Pilbara Iron Ore (RTIO) operations. These include Silvergrass and Brockman 2 (Nammuldi) mines; the Hamersley Rail alignment and rail access road (in the vicinity of the proposed rail crossing at chainage 43 km) and the Silvergrass haul road crossing (at chainage 84 km). These operations have existing bores identified in Figure 13.

Groundwater is used in these operations for potable and non-potable water supplies and dewatering of mine voids.

A search of the Department of Water's (DoW) online Water Register shows that Silvergrass and Brockman 2 operations are licensed to abstract approximately 11 GL/a until 2025 (GWL107413 and GWL164398) from the Pilbara Fractured Rock Aquifer. These licenses were issued in 2016 and therefore have a total capacity of approximately 95 GL.

3.10.2 Pastoral

There are six pastoral bores located within 1 km of the rail alignment. Hamersley station homestead is located within 700 m of the rail alignment; in this area five bores are present. The sixth bore is an unnamed bore at chainage 48 km, which is considered to be an equipped pastoral bore. Details of these bores on the Department of Water’s WIN Database suggest that all bores are shallow targeting the alluvium, colluvium and detritals of the surficial aquifer. The locations of existing pastoral wells are presented in Figure 13.

3.10.3 Other

The rail alignment crosses the upper reaches of the Millstream Drinking Water Catchment Source Protection zone between approximate chainages 35 km and 50 km. This catchment is covered by a Drinking Water Source Protection Plan (DWSPP) (DoW, 2010) that determines the area as a Priority 2 (P2) Reserve. The DWSPP stipulates that railways and roads have a low hazard potential for pollution, related to Hydrocarbon and other chemical spills from accidents.
4. PROJECT DESCRIPTION

4.1 Rail Alignment

The Eliwana Railway alignment commences near to the Solomon Mine, at the terminus of the Fredericks rail spur, traveling westward along the flanks of the Hamersley Ranges prior to crossing the RTIO’s Hamersley Railway. After crossing the railway, the alignment transects Caves Creek and continues westward, adjacent to RTIO’s Nammuldi Agricultural Project and crosses over RTIO’s Silvergrass transport corridor in a southwest direction. The alignment continues towards Eliwana Iron Ore Mine, terminated in a rail loop.

The project includes a power and communications corridor, and a rail maintenance track, both of which have designed to be located adjacent to the rail alignment with the occasional diversion as. Water infrastructure will also be located in these corridors, with bores drilled within available land tenure held by Fortescue.

4.2 Water Demand

Earthworks and cut and fill volumes have been developed for the proposed rail alignment based on the construction requirements. The water demands are highest in areas of greater cut and fill volumes, typically in areas of rapid topographic change or where crossings are required for third party infrastructure.

The water demand estimate considers 200 litres per cubic metre (m$^3$) of placed fill is required for adequate soil compaction, whilst road dust suppression is estimated to require approximately 1,500 m$^3$ per day per km. Water demands have been assessed based on 5 km chainage increments along the rail alignment. On average this equates to a demand of approximately 30 L/s operating over a ten hour shift per 5 km. Over the entire rail alignment and taking into account some variability in relation to estimates in earthworks this equates approximately 3 GL (Figure 14). Construction may occur over multiple staggered construction work fronts.

4.3 Water Supply Strategy

The alignment has been divided into five strategy zones (Figure 15) determined by the availability of existing water supplies and the prospectivity of the local aquifers. Feasibility options are being assessed for providing construction water at 5 km or 10 km intervals along the alignment. The water sources will be in the form of a containment structure (turkey’s test, tank or similar) supplied by the nearest available bore or borefield.

A. Chainage 15,000 to 43,000 (28 km) – Solomon Mining area and Southern Fortescue borefield. Water will be sourced mainly from existing water supplies and managed
under the relevant operating strategies and licences. Construction requires up to 0.7 GL over approximately eight months.

B. Chainage 43,000 to 53,000 (10 km) – New water supply bores targeting the Wittenoom Formation and overlying palaeochannel sediments of west of the RTIO rail crossing. Construction requires up to 0.3 GL over approximately four months.

C. 53,000 to 120,000 (67 km) Water supplies will be sourced from a combination of new water supply bores targeting the fractured rock aquifers of the Mara Mamba and Fortescue Group (Basalt and metasediments) and existing Wittenoom Formation dolomite bores from Flying Fish (D’). Construction requires up to 1.5 GL over approximately nine months split across two working fronts either side of the RTIO Silvergrass Mine conveyor crossing.

D. Chainage 120,000 – 144,000 (24 km) – Supplies will be piped from the Wittenoom aquifer located in the Eliwana Mining area (D”). Construction requires up to 0.4 GL over approximately five months.

E. Camp Water Supplies - Two camps are proposed to service the construction of the railway and associated infrastructure. One north of chainage 50 km and another between chainage 90,000 and chainage 115,000. An existing water supply is available within the Sheila Valley area for the eastern camp sourced from a CID aquifer, whilst the western camp will rely on the nearest proposed borefield target sourced from C. Camp water supplies are expected to require less than 100,000 kL/a (0.05 GL/a) per camp for the duration of construction.
5. IMPACT ASSESSMENT

Potential hydrogeological impacts associated with the Project described in Section 4 include groundwater level drawdown and groundwater quality deterioration.

Water level drawdown occurs in response to abstraction from a bore or well, the response may be temporary or long term in nature. Temporary effects are characterised by short term abstraction and potentially an active recharge regime, where water levels drawdown whilst under pumping conditions but recover to baseline conditions when turned off. Longer term effects are characterised by a reduction of storage where water levels do not recover to baseline conditions.

The degree of drawdown may be exacerbated or mitigated by a number of factors. Clusters of closely spaced production bores may have overlapping drawdown cones (interference effects). This may increase drawdown and consideration of production bores spacing is therefore required when determining drawdown impacts. These impacts are particularly important when individual bore yields will not meet demand and multiple bores are required to be in operation together within the same aquifer.

The target aquifer may be limited in extent (bounded) and once drawdown extends to encounter the edge of the aquifer the rate of drawdown may increase. This response is typically encountered when abstraction occurs from calcrite and fractured rock aquifers and in particular where compartmentalisation of aquifers occurs through structural features or dolerite intrusions.

The degree of drawdown may be reduced where an active recharge regime or recharge boundary is present, for example, in the vicinity to a regular flowing creek system or permanent pool. However, these instances may have increased environmental risks that may limit the available drawdown. Structural features may also link target aquifers and be a conduit to a recharge boundary.

Water quality deterioration may occur from groundwater abstraction through ingress of poorer water quality into a fresh water aquifer. This may occur where a saline interface is known to occur within a creek or coastal aquifer system or in instances where a freshwater lens is being exploited.

The degree of drawdown and water quality impacts on identified receptors should also take into account the current stress on the aquifer. Aquifer stress may be caused by periods of low rainfall or drought or existing impacts by third parties (mining operations, pastoral wells, other users). Impact assessment should take into account the current stress on an aquifer system including cumulative impacts.
5.1 Water Supply Assumptions

A number of water supplies can be identified from existing bores within the Southern Fortescue Borefield (A), Flying Fish Mine area (D’) and Eliwana Mine area (D’”). Exploration drilling and testing of new targets is required to accurately determine impacts between chainages 43 km and 120 km (B, C and D). For the purposes of this impact assessment analytical modelling will be used to estimate impacts of the proposed abstraction. Due to the short term nature of the abstraction, use of conservative parameters and consideration of the associated pumping responses of each of the target aquifers, the analytical assessment of impacts is considered appropriate.

The supply of groundwater from the Southern Fortescue Borefield (A) will be managed under an existing groundwater operating strategy.

5.2 Analytical Modelling

Analytical modelling has been completed using Theis equations for radial groundwater flow (Theis, 1935) to determine a preliminary estimate of water level drawdown based on the current understanding of aquifer properties and abstraction volumes.

\[ s = \frac{Q}{4\pi T} W(u) \]

Where, \( T \) is the aquifer transmissivity, \( Q \) is the steady pumping rate, \( s \) is the drawdown, and \( W(u) \) is the well function. Values of \( u \) are calculated as:

\[ u = \left( \frac{r^2 S}{4Tt} \right) \]

Where \( t \) is time, \( r \) is the radius and \( S \) is storativity (assumed to be specific yield in unconfined aquifer conditions). No recharge has been considered in these calculations which also assume the aquifer is homogenous, isotropic, of uniform thickness and of seemingly infinite areal extent. The assumptions listed and the types of aquifers targeted for rail water supply mean that the outputs from the equations are approximate in nature. It is assumed all bores are operating constantly for 365 days with no recharge.

For fractured rock aquifers of the Mara Mamba, Jeerinah and Bunjina Formations, unconfined conditions are expected and specific yield (Sy) has been substituted for storage (S).

The CID/ palaeochannel sand and Wittenoom dolomite aquifer is considered to be confined in nature and has been treated as the same aquifer. Water level responses will likely be piezometric in nature and the degree of water table drawdown with the overlying surficial aquifer is linked to rate of vertical leakage through the confining clay layer.
The Wittenoom dolomite aquifer is considered to be unconfined in the area of Flying Fish from testing completed as part of the mine water supply assessment, aquifer properties have been derived from this testing (Golder 2016).

Where fractured rock aquifers dominate water supply targets additional assumptions on linear drawdown and boundary conditions have been assumed.

The aquifer properties used in the analytical modelling calculations are presented in Table 6.

**Table 6: Summary of Aquifer Properties used in Analytical Modelling**

<table>
<thead>
<tr>
<th>Aquifer Unit</th>
<th>Anticipated Bore Depth (m)</th>
<th>Aquifer Thickness (m)</th>
<th>K (m/d)</th>
<th>T (m²/d)</th>
<th>Unconfined Storage - Sy (-)</th>
<th>Confined Storage - S (-)</th>
<th>Source</th>
<th>Anticipated Bore Yield (L/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palaeochannel Sand and CID</td>
<td>120</td>
<td>10</td>
<td>15</td>
<td>650</td>
<td>N/A</td>
<td>1E-04</td>
<td>Southern Fortescue Borefield Conceptual Model</td>
<td>15</td>
</tr>
<tr>
<td>Weathered / fractured Wittenoom Formation beneath palaeovalley</td>
<td></td>
<td>50</td>
<td>10</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flying Fish Wittenoom Fm</td>
<td>100</td>
<td>50</td>
<td>30</td>
<td>1500</td>
<td>0.01</td>
<td>N/A</td>
<td>Flying Fish Water Supply</td>
<td>40</td>
</tr>
<tr>
<td>Marra Mamba Formation</td>
<td>60</td>
<td>20</td>
<td>1</td>
<td>20</td>
<td>0.03</td>
<td>N/A</td>
<td>Assumed qualitative values</td>
<td>8</td>
</tr>
<tr>
<td>Fractured Basalt and Metasedimentary Bores of the Fortescue Gp</td>
<td>80</td>
<td>20</td>
<td>0.6</td>
<td>14</td>
<td>0.03</td>
<td>N/A</td>
<td>Hydraulic conductivity derived from slug testing of initial exploration bores</td>
<td>4</td>
</tr>
</tbody>
</table>
5.3 Groundwater Drawdown

A summary of the analytical results is presented in Table 7 and the full results are presented in Appendix 2.

Table 7: Summary of Analytical Modelling Results

<table>
<thead>
<tr>
<th>Aquifer Unit</th>
<th>Static Water Level (mbgl)</th>
<th>Maximum drawdown at the bore (m)</th>
<th>Radius of 1m drawdown (m)</th>
<th>Average Predicted Yield (L/s)</th>
<th>Minimum Number of Bores Required per Water source</th>
<th>Anticipated distance between Bores (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weathered / fractured Wittenoom Formation</td>
<td>10 - 20</td>
<td>6</td>
<td>12,000 (confined drawdown)</td>
<td>15</td>
<td>2</td>
<td>1000</td>
</tr>
<tr>
<td>Palaeochannel Sand and CID</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mara Mamba Formation</td>
<td>15 - 30</td>
<td>40</td>
<td>600</td>
<td>6</td>
<td>5</td>
<td>600</td>
</tr>
<tr>
<td>Fractured Basalt and Metasedimentary Bores of the Fortescue Gp</td>
<td>10 – 40</td>
<td>40</td>
<td>600</td>
<td>4</td>
<td>8</td>
<td>600</td>
</tr>
<tr>
<td>Flying Fish Wittenoom Dolomite</td>
<td>15</td>
<td>7</td>
<td>&lt;2000</td>
<td>20</td>
<td>2</td>
<td>550*</td>
</tr>
</tbody>
</table>

*two bores (FFPB0001 and FFPB0002) were installed and test pumped as part of the Flying Fish water supply assessment (Golder, 2016)

5.3.1.1 Combined Wittenoom Dolomite and Palaeochannel Sand

The outputs of the analytical modelling indicate that abstraction from one water source within the palaeochannel sand and Wittenoom dolomite aquifer produces a broad flat confined cone of depression within the aquifer that has a piezometric drawdown of approximately 6 m at the bore site. The cone of depression in the aquifer is calculated to extend up to 12 km on a confined basis only, without consideration of leakage or boundary conditions.

This assessment is a considerable over-estimate of the likely impact to the aquifer as it assumes continuous pumping and no recharge. Furthermore, it is expected there will be limited water table drawdown due to the low vertical conductivity through the stiff lacustrine clays which forms a confining layer across the palaeovalley.

It is anticipated that the piezometric drawdown will recover to pre pumping water levels once abstraction ceases. This may take between a few days to three months to occur.
5.3.1.2 Marra Mamba Formation

Drawdown in the Marra Mamba is estimated to be up to 45 m at the production bore sites. The cone of depression is anticipated to extend up to approximately 600 m from any one water source with bores spaced at 600 m apart.

The fractured nature of the Mara Mamba aquifers may contribute to greater than anticipated drawdown on a bore by bore basis which may limit bore yields and increase drawdown locally.

It is likely that storage will be depleted from fractured rock aquifers and therefore for water levels to fully recover a recharge event is most likely required. Fractured rock aquifers close to outcrop and creek lines will likely more readily recharge than those away from these features.

5.3.1.3 Fractured Basalt and Metasediments

Drawdown associated with abstraction from the fractured basalt and metasedimentary aquifers is estimated to be up to 45 m at the production bore sites. The cone of depression is anticipated to extend up to approximately 600 m from any one water source with up to eight bores spaced at 600 m apart.

The preliminary targets identified for water supply exploration follow the regional structural trend in this area of the project. Dolerite dykes and extensional deformation trends in a northwest south-easterly direction, drawdown will likely propagate in this direction along linear features.

In a similar concept to the Marra Mamba aquifers, it is likely that groundwater storage will be depleted from abstraction of fractured rock aquifers. Therefore, for water levels to fully recover a recharge event is most likely required. Fractured rock aquifers close to outcrop and creek lines will likely more readily recharge than those away from these features.

5.3.1.4 Flying Fish Wittenoom Dolomite

Analytical modelling utilising known aquifer parameters derived from the Flying Fish water supply test pumping suggests that maximum drawdown at the bores would be approximately 7 m. The cone of depression is expected to extend up to 2 km from each bore sites.

Test pumping of the water supply bores (FFPB0001 and FFPB0002) suggest the aquifer is highly compartmentalised with no drawdown being observed away from the production bore site over three days of test pumping.

5.4 Groundwater Impact Assessment Areas

The location of water supply bores will be constrained within land tenure available to Fortescue and to prospective areas identified in desktop assessments. Groundwater Impact Assessment Areas (GIAA) have been developed which buffer the tenure upon which bores are planned to be drilled by a value at least equivalent to the radius of 1 m drawdown presented in Table 7.
most cases the areas have been enlarged to encompass nearby features or to add additional conservatism to the assessment. The exception is the Combined Wittenoom Dolomite and Palaeochannel Sand aquifer target where no drawdown in the surficial aquifer is expected. Here a nominal buffer has been adopted to complete the assessment.

5.5 Impact to Groundwater Dependent Ecosystems and Surface Water Features

A number of stretches of GDE and potential GDE zones are mapped in creek lines and tributaries of GIAA 2, 4, 5 and 6, as illustrated in Figures 7 - 12. Due to the nature of the fractured rock geology between chainage 53 and 120 km, a number of production bores may be constructed within the vicinity of these mapped potential GDE areas, targeting lineaments that cross recharge zones. As indicated in Section 5.3.1.3, the depletion of storage from short term abstraction will be replenished by annual recharge events. Intermittent rainfall may also relieve stress to the vegetation during the period of abstraction.

Similarly, intermittent and semi-permanent pools characterised within the GIAA will possibly experience short term impacts due to abstraction, although the low permeability of the fractured basalt and metasedimentary aquifers indicates drawdown will not extent more than 600 m from any one bore location. Once construction is complete, and during operations where any groundwater use is minimal and of short duration, surface water features are expected to return to their natural state. This assessment includes the only named pool, Donkey Pool, which lies on the outer extent of GIAA 4.

Pools 22 – 24 and 31, characterised along Wacklina Creek within GIAA 1, will not be impacted by groundwater abstraction as groundwater levels are between 15 – 30 m below ground in this area. The pools have been characterised as surface water dependent.

5.6 Impact to Cultural Sites

Nharraminju Wuntu (Donkey Hole) is over a kilometre to the east from the nearest potential water source location and coincides with identified pools 2 - 6. Analysis indicates drawdown from bores in the Fortescue Group basalt will not extend beyond 600 m any bore within the GIAA 2, unless preferential fracture flow extends in the direction of the site. More importantly, any impact to groundwater levels or pool levels will be of less than 6 months’ duration and is expected to recover with the first recharge event.

5.7 Impact to Pastoral Stations and Third Party Bores

Four pastoral bores and one Hamersley Rail bore are within the vicinity of Hamersley Station, located within 1000 m from the corridor in the vicinity of chainage 43 km (Hamersley rail crossing).
These bores are all installed within the shallow detrital aquifer of the Southern Fortescue Palaeovalley. The bores are considered disconnected from the deep confined Wittenoom and Palaeochannel aquifer, which is the target for water supplies in this area, by the confining clay layer. Pumping from the deep confined aquifer is not expected to have measurable impacts over the life of the project on the unconfined detrital aquifer system.

Other notable users of groundwater in the vicinity of the rail corridor include RTIO’s Brockman 2 (Nammuldi) and Silvergrass mines. Brockman 2 is located approximately 5 km to the south of chainage 80 to 90 km. Whilst, Silvergrass is located approximately 6 km to the north of chainage 90 km. The major rail water supply water demand areas are over 25 km away from the RTIO Operations and are considered too far away to be impacted by rail water supply demand.

5.8 Millstream Water Reserve

The only abstraction planned within the Millstream Water Reserve is that required to supply a construction camp (Rail Camp 50). Minimal volumes of groundwater will be required to supply the camp, with abstraction in the order of 5 L/s expected to occur for several hours a day. Full recovery of groundwater levels is expected in between periods of pumping and periods of rest. Therefore, no impact to the Millstream Water Reserve is expected.

5.9 Water Quality

Water quality impacts are not anticipated from the more productive regional aquifers of the Wittenoom and Palaeochannel Aquifers. However, local marginal aquifers may deteriorate in locations where groundwater recharge zones have been targeted by exploration drilling and abstraction activities. In these locations water quality may reduce by 10s to 100s of mg/L TDS, but not expected to significantly degrade over 2000 mg/L. Changes in water quality at these locations are considered to be short term until recharge next occurs following the end of abstraction. Longer term water quality impacts are expected to be negligible.
6. CONCLUSIONS

The Eliwana Rail construction water supply requires approximately 30 L/s per 5 – 10 km of rail construction. It is considered that a total water demand for the project is approximately 3 GL. The rail is anticipated to be constructed over a 20 month period with water demands peaking in areas where large earthworks volumes and 3rd party linear infrastructure crossings are required.

The water supply demand will be sourced by a combination of existing water supply bores in the Southern Fortescue Borefield, Flying Fish Mine area and the Eliwana Mine area; and new water supplies in areas where water cannot be piped from existing water sources.

Analytical modelling has been completed using assumed aquifer properties and proposed water supply targets as a basis of quantifying potential groundwater impacts.

Hamersley Station is located within 1 km of the rail alignment and operates a number of pastoral bores within 1 km of the rail alignment. It is anticipated that water supplies will be sourced from the deep Wittenoom and Palaeochannel aquifer in this area which is considered to be hydraulically disconnected from or poorly connected to the shallow surficial aquifer that the pastoral bores abstract from. Therefore, considering the short term nature of the proposed abstraction there will likely be minimal impacts to any surficial aquifer water levels in this vicinity.

Environmental and cultural features have been identified within Groundwater Impact Assessment Areas, which coincide with areas where development of groundwater bores will take place. Potential groundwater impacts to Donkey Pool, Donkey Hole, potentially groundwater dependent vegetation zones, unnamed surface water features and the Millstream Water Reserve have been assessed. Analytical modelling of abstraction suggests that drawdown and minor impacts to water quality may occur in discrete zones associated with structures within the Pilbara Fractured Rock Aquifer. However, due to the nature of the project these will be of limited duration and these impacts are anticipated to recover following the next recharge event (wet season), minimising any prolonged impacts to GDEs and surface water features within the Groundwater Impact Assessment Areas. The limited nature of abstraction within the Millstream Water Reserve is such that no impact to groundwater levels or quality will occur.
REFERENCES


FIGURES
Figure 2
Groundwater Exploration Drilling
2017
Bores with Level data

FMG Locations; FMG, Flying Fish

PER Rail Alignment

Eliwana Rail Camp Area

FMG Rail Alignments

Rio Tinto Rail

Pilbara Region 250k Geology

Fortescue Group Dolerite

Mt McRae/Sylvia Fm

Bunjinah Fm

Jeerinah Fm

Marra Mamba Fm

Wittenoom Fm

boolgeeda Fm

Woongarra Rhyolite

Brockman Fm

Turee Creek Fm

Weeli Wollo Fm

Cainozoic

All water level are in m AHD

Figure 5

Groundwater Level Summary

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<tr>
<th></th>
<th>474</th>
<th>459</th>
<th>464</th>
<th>468</th>
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<th>505</th>
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<th>508</th>
<th>534</th>
<th>542</th>
<th>575</th>
<th>590-595</th>
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<tr>
<td>Soil</td>
<td>Dry</td>
<td>Dry</td>
<td>Dry</td>
<td>Dry</td>
<td>Dry</td>
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<td>Dry</td>
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<td>Dry</td>
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Requested by: M Carroll

Drawn by: M Carroll

Revised by: mcarroll

Approved by:

Scale: 1:457,909

Coordinate System: GDA 1994 MGA Zone 50

Document Name: Water Levels

FMG accepts no liability and gives no representation or warranty, express or implied, as to the information provided, including its accuracy, completeness, merchantability or fitness for purpose.

Date: 1/06/2018

Size: A4L

Revision: 1

Confidentiality: 1

Bores with Level data

FMG Locations; FMG, Flying Fish

PER Rail Alignment

Eliwana Rail Camp Area

FMG Rail Alignments

Rio Tinto Rail
Figure 6
Environmental Considerations and Groundwater Impact Assessment Areas

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Figure 7

Environmental Considerations in Groundwater Impact Assessment Area 1

Requested By: M Carroll
Drawn By: M Carroll
Revised By: mcarroll
Approved By:
Scale: 1:120,114
Coordinate System: GDA 1994 MGA Zone 50
Document Name: Potential GDV - GIAA1

PDWSA
PER Rail Alignment
Rio Tinto Rail
Watercourse
Potentially Groundwater Dependent Assemblage
Groundwater Dependent Assemblage
Vegetation Mapping Extents

Fortescue Metals Group Ltd
The New Iron Ore
Figure 8

Environmental Considerations in Groundwater Impact Assessment Area 2
Figure 9
Environmental Considerations in Groundwater Impact Assessment Area 3

PDWSA
PER Rail Alignment
Rio Tinto Rail
Watercourse
Potentially Groundwater Dependent Assemblage
Groundwater Dependent Assemblage
Vegetation Mapping Extents
Figure 10
Environmental Considerations in Groundwater Impact Assessment Area 3

PDWSA
PER Rail Alignment
Rio Tinto Rail
Watercourse
Potentially Groundwater Dependent Assemblage
Groundwater Dependent Assemblage
Vegetation Mapping Extents

Pool 16
Pool 17
Pool 18
Pool 19
Pool 20
Pool 21
Potential Existing GW Users and Social/Cultural Considerations

- Jerkunha / Ngajaranha (Balbina Bore)
- Township of Soloman
- Kartaynha
- Sheila Valley

Pilbara Region 250k Geology
- Fortescue Group Dolerite
- Maddina Fm
- Bunjinah Fm
- Jeerinah Fm
- Marra Mamba Fm
- Wittenoom Fm
- Mt McRae/Sylvia Fm
- Brockman Fm
- Weeli Wooll Fm
- Boolgeeda Fm
- Woongarra Rhyolite
- Turee Creek Fm
- Cainozoic

FMG locations
- Eliwana Rail Camp Area
- Fortescue Production Bore
- Flinders Mines Ltd
- RTIO
- "No Current Owner"
- Rio Tinto Rail
- FMG Rail Alignments
- Rio Tinto Mines

Figure 13

FMG accepts no liability and gives no representation or warranty, express or implied, as to the information provided including its accuracy, completeness, merchantability or fitness for purpose.
Figure 14: Rail Water Supply Demand Profile
Appendix 1: 2017 Groundwater Exploration Borelogs
Westerm Hub Rail Feasibility Assessment

WHR_WS15MB01

**Final Bore Details**

- **Drilled Depth (mbgl):** 68
- **Cased Depth (mbgl):** 67.8
- **Casing Stick Up (magl):** 0.29
- **Development Yield (l/s):** 1
- **Water Level (mbgl) & Date:** 34.6 / 8/05/2017
- **Quality - pH & EC (µS/cm):** 8.25 / 1108

**Bore Construction**

- **_DEPTH**
  - 0 - 38m: 10" Dual Rotary
  - 3.2 - 6.4 mm Graded Gravel Pack
  - 50mm Blank PVC
  - 38 - 68m: 9" Air Hammer
  - 3.2 - 6.4 mm Graded Gravel Pack
  - 50mm Slotted PVC
  - 50mm PVC end cap

**Stratigraphy**

- **Tertiary Alluvium**
  - Calcrete & Clay: white (N9) to very light grey (N8), silty, kaolinitic clay, minor ironstone, quartz, moderately rounded, poorly cemented.
  - Saprolite: pale yellowish orange (10YR 8.6), highly weathered, clayey, minor angular quartz, rock chips, fractured fabric, fine even grained.
  - Saprock: pale brown (5YR 6/2), highly weathered bedrock, fine even grained, minor rock fabric with fractures, generally soft with minor hard well cemented bands.
  - Basalt: dark greenish grey (5GY 4/1), fractured Basalt, fine even grained, yellow staining on fracture planes, moderately fractured.
  - Basalt - Fractured: dark greenish grey (5GY 4/1), moderately fractured, yellow staining on fracture planes, moderately hard, fine even grained.
  - Basalt - Fractured: dark greenish grey (5GY 4/1), moderate to well fractured, yellow staining on fracture planes, minor quartz veins.
  - Basalt - Fresh: dusky blue (5PB 3/2), non-fractured, hard, fresh, fine even grained.

**Lithology**

- **Unknown**
  - Saprolite: light brown (5YR 6/4), as above, silty.
  - Saprock: pale brown (5YR 5/2), highly weathered bedrock, fine even grained, minor rock fabric with fractures, generally soft with minor hard well cemented bands.

**Description**

- **Comments:** Calcrete overlying fractured Basalt

Page 1 of 1
### Western Hub Rail Feasibility Assessment

**PROJECT NAME:** Western Hub Rail Feasibility Assessment  
**LOCATION:** WS16MB01  
**DRILLING CO:** Easternwell  
**DRILLING METHOD:** Dual Rotary  
**LOGGED BY:** MR-S  

### Drilling Details

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<th>Drilled Depth (mbgl)</th>
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</thead>
<tbody>
<tr>
<td>Cased Depth (mbgl)</td>
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</tr>
<tr>
<td>Casing Stick Up (magl)</td>
<td>0.355</td>
</tr>
<tr>
<td>Development Yield (l/s)</td>
<td>1</td>
</tr>
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</table>

### Water Level & Date

- Water Level (mbgl): 27.28
- Date: 13/05/2017

### Quality - pH & EC (µS/cm)

- pH: 8.25
- EC (µS/cm): 4400

### Bore Construction

<table>
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<th>Stratigraphy</th>
<th>Lithology</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Gravelly Clay: Light brown-reddish plastic clays (driller injecting water)</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>with subrounded Fe-rich chip rocks and some calcite.</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Saprolite: Light brown-reddish plastic clays with 1% small medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>grained equigranular brown and green mafic chips - Highly weathered basalt.</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Saprolite: Same with trace of QV - Highly weathered basalt.</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Saprolite: Some increase in the amount of rock chips, but overall plastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>clays with f gr. Massive textured mafic -Highly weathered basalt.</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Saprock: Dark green, fine-med grained, massive equigranular textured</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>weathered basalt.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basalt - Fresh: Very slightly weathered and fractured basalt.</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Basalt - Fractured: Fresh dark grey-green, fine-med grained, massive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>equigranular. Chips generally small (hard rock) with some big ones; only</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>minor face staining.</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Basalt - Fractured: WET, low yield; with trace of QV at 62-64m.</td>
</tr>
<tr>
<td>0 - 32m</td>
<td><strong>Unknown</strong></td>
<td><strong>Unknown</strong></td>
<td>Basalt - Fractured: Fresh, fractured basalt with QV from 64m (it could be</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>contamination from above). Yeilds increasing steadily. EOH</td>
</tr>
</tbody>
</table>

### Comments:

0 - 32m: 10" DR; 32 - 81m open hole. Weathered and fresh, fractured basalt
### Project Details
- **Project Name:** Western Hub Rail Feasibility Assessment
- **Location:** WS17MB01
- **Drilling Co.:** Easternwell
- **Drilling Method:** Dual Rotary / Open hole
- **Logged By:** LS
- **Date Begun:** 9/06/2017
- **Date Completed:** 12/06/2017

### Final Bore Details

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<tr>
<th>Description</th>
<th>Drilled Depth (mbgl)</th>
<th>Cased Depth (mbgl)</th>
<th>Casing Stick Up (m)</th>
<th>Development Yield (l/s)</th>
<th>Water Level (mbgl) &amp; Date</th>
<th>Quality - pH &amp; EC (µS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilled Depth (mbgl)</td>
<td>112</td>
<td>112.05</td>
<td>0.46</td>
<td>0.05</td>
<td>36.96 21/06/2017</td>
<td>8.64 1122</td>
</tr>
</tbody>
</table>

### Bore Construction
- **Concrete Plinth**
- **Lockable Cap**
- **0 - 4m: 7" Dual Rotary**
- **Grout including 5% Bentonite Seal**
- **3.2 - 6.4 mm Graded Gravel Pack or Backfill**
- **80mm Blank PVC**
- **4 - 112m: 5.75" Air Hammer**
- **Bentonite Seal**
- **3.2 - 6.4 mm Graded Gravel Pack**
- **80mm Slotted PVC**
- **80mm PVC Cap**

### Stratigraphy and Lithology

#### Dolerite Dyke Intrusion
- Dolerite: Dark grey to light grey Silty matrix. Altered, weathered, Dolerite, mostly fine <2mm. Hard drilling.
- Dolerite: Light grey Silty matrix. A-SR, medium hardness becoming hard to depth, medium grained, Dolerite, mostly fine becoming powdery from 24m. Bigger chips @ 24-28m; 36-40m with clay infills; 64-68m. Trace of Quartz from 68-72m. Water strike @ 24m. Small fracture

#### Shale: Transition zone.
- Shale: A-SA, black Shale, mostly hard with some soft platy shales. Hard carboneous Chert. Including 5% of Pyritic shales. Trace of Quartz. Matrix becoming clayey and dry @110. No increase in flow.

### Comments
- 0 - 4m: 10" DR; 10 - 112m open hole. Fresh Dolerite sill to 98m. Fresh Jerrinah Formation to EOH. Trace flow throughout the hole.
## Western Hub Rail Feasibility Assessment

**PROJECT NAME:** Western Hub Rail Feasibility Assessment  
**LOCATION:** WS17MB02  
**DRILLING CO:** Easternwell  
**DRILLING METHOD:** Dual Rotary / Open hole  
**LOGGED BY:** LS  
**DATE BEGUN:** 6/06/2017  
**DATE COMPLETED:** 8/06/2017

### FINAL BORE DETAILS

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<th>STRATIGRAPHY</th>
<th>LITHOLOGY</th>
<th>DESCRIPTION</th>
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<tr>
<td>0-4m</td>
<td>7&quot; Dual Rotary Grout including 5% Bentonite Bentonite Seal</td>
<td>Concrete Plinth Lockable Cap</td>
<td>0 - 4m: 7&quot; Dual Rotary Grout including 5% Bentonite Bentonite Seal</td>
</tr>
<tr>
<td>3.2 - 6.4 mm Graded Gravel Pack or Backfill 80mm Blank PVC</td>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
<td></td>
</tr>
<tr>
<td>4 - 82m: 5.75&quot; Air Hammer</td>
<td>80mm Slotted PVC</td>
<td>80mm PVC Cap</td>
<td></td>
</tr>
<tr>
<td>Bentonite seal</td>
<td>Bentonite seal</td>
<td>Bentonite seal</td>
<td></td>
</tr>
<tr>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
<td></td>
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<tr>
<td>80mm Blank PVC</td>
<td>80mm Blank PVC</td>
<td>80mm Blank PVC</td>
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<tr>
<td>4 - 82m: 5.75&quot; Air Hammer</td>
<td>4 - 82m: 5.75&quot; Air Hammer</td>
<td>4 - 82m: 5.75&quot; Air Hammer</td>
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<tr>
<td>Bentonite seal</td>
<td>Bentonite seal</td>
<td>Bentonite seal</td>
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<tr>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
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<tr>
<td>80mm Slotted PVC</td>
<td>80mm Slotted PVC</td>
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<tr>
<td>80mm PVC Cap</td>
<td>80mm PVC Cap</td>
<td>80mm PVC Cap</td>
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**EASTING (m):** 527402.31  
**NORTHING (m):** 7526467.95  
**ELEVATION (mAHD):** 523.62  
**DRILLING DIAMETER(S) (mm):** 178  
**COLLAR STICKUP (m):** 0.475

### WESTERN HUB BORE LOG

**BORE NUMBER:** WHR_WS18MB01  
**DATE BEGUN:** 6/06/2017  
**DATE COMPLETED:** 8/06/2017

**Drilled Depth (mbgl):** 88  
**Cased Depth (mbgl):** 81.99  
**Casing Stick Up (magl):** 0.388  
**Development Yield (l/s):** 2  
**Water Level (mbgl) & Date:** 16.372 11/06/2017  
**Quality - pH & EC (µS/cm):** 7.6 2640

**Comments:** Jeerinah Formation including dolerite intrusion, weathered horizon at the top. Bore located along a creek. Reasonnable final flow rate (2L/s).
**PROJECT NAME:** Western Hub Rail Feasibility Assessment  
**LOCATION:** WHR_WS19MB01  
**DRILLING CO:** Easternwell  
**DRILLING METHOD:** Dual Rotary / Open hole  
**LOGGED BY:** JB  
**DATE BEGUN:** 2/06/2017  
**DATE COMPLETED:** 6/06/2017

### FINAL BORE DETAILS

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<tr>
<td>Drilled Depth (mbgl):</td>
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<tr>
<td>Cased Depth (mbgl):</td>
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<td>Development Yield (l/s):</td>
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<td>11/06/2017</td>
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<td>Quality - pH &amp; EC (µS/cm):</td>
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<td>5249</td>
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### BORE CONSTRUCTION

- **Concrete Plinth**  
- **Lockable Cap**  
- **0 - 4m: 7” Dual Rotary**  
- **Grout including 5% Bentonite**  
- **Bentonite Seal**

- **3.2 - 6.4 mm Graded Gravel Pack or Backfill**  
- **80mm Blank PVC**

- **4 - 88m: 5.75” Air Hammer**  
- **Bentonite seal**

- **3.2 - 6.4 mm Graded Gravel Pack**  
- **80mm Slotted PVC**  
- **80mm PVC Cap**

### STRATIGRAPHY

- **Tertiary Detrital**  
  - Clay & Gravel: Brown silty Clay with gravel and sand.
  - Clay & Sand: Brownish grey Clay and Sand. Very weak dolerite fragments likely make up clay. Sand is basalt and quartz.

- **Dolerite Dyke Intrusion**  
  - Dolerite and Basalt: Alternating intervals of Dolerite and Basalt, predominantly Dolerite (Sill?). Stiff dolerite.

- **Bunjinah Formation**  
  - Basalt - Fresh: Fresh Basalt with minor quartz veining. Broken zone at 64 m, with fractures infilled with white clay. No increase in yield. Increase in quartz between 76 - 88m.

### Comments:

0-4m 7” DR, 4-88m open hole. Weathered and fresh basalt. No apparent flow into bore following initial removal of head during airlift.
### Fortescue Metals Group Ltd
Level 2, 87 Adelaide Terrace
East Perth, WA 6004
PH: 08 62188888  FAX: 08 62188880

#### PROJECT NAME:
Western Hub Rail Feasibility Assessment

#### LOCATION:
WS20MB01

#### DRILLING CO:
Easternwell

#### DRILLING METHOD:
Dual Rotary / Open hole

#### LOGGED BY:
JB

#### EASTING (m):
517668.99

#### NORTHING (m):
7525438.79

#### ELEVATION (mAHD):
513.62

#### DRILLING DIAMETER(S) (mm):
178

#### COLLAR STICKUP (m):
0.43

#### DATE BEGUN:
31/05/2017  
#### DATE COMPLETED:
2/05/2017

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### FINAL BORE DETAILS

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</tr>
<tr>
<td>Quality - pH &amp; EC (µS/cm)</td>
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### BORE CONSTRUCTION

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<th>Lithology</th>
<th>Description</th>
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<tbody>
<tr>
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<td>Tertiary</td>
<td>Detrital</td>
<td>Clay &amp; Gravel: Brown Alluvial silty Clay with gravel and sand. Sub rounded BIF gravel.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay &amp; Sand: Light brown Clay with some sand.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay &amp; Sand: Leached white Clay with some sand. Non calcareous</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gravelly Clay: Gravelly Clay with some sand. Clay is white/brown/grey. Some course intervals (more sand, less clay) at 32m, 36m, 4m and 48m. Sand and gravel is rounded to subrounded, BIF, Quartz and Dolerite. Dolerite is very fine grained and weak.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gravelly Sand with Clay: White/Grey sand and gravel with some clay. Predominantly quartz clasts. Some lumps of rounded grey dolerite fragments. Basalt fragments near end of interval with quartz veining and fixed to dolerite.</td>
</tr>
<tr>
<td>95</td>
<td>Bunjinah</td>
<td>Formation</td>
<td>Basalt - Fresh: Fresh Basalt. Some evidence of minor weathering/fracturing (staining). Driller observed a broken zone at 92 m, but no evidence in air lift yield or in chips. Water yield became much more clear of fines.</td>
</tr>
</tbody>
</table>

---

### Comments:
0-76m 7" DR, 76-94m Open hole. Alluvials over fresh basalt.
**PROJECT NAME:** Western Hub Rail Feasibility Assessment  
**LOCATION:** WS21MB01  
**DRILLING CO:** Easternwell  
**DRILLING METHOD:** Dual Rotary / Open hole  
**LOGGED BY:** JB  
**DATE BEGUN:** 25/05/2017  
**DATE COMPLETED:** 30/05/2017

### FINAL BORE DETAILS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilled Depth (mbgl)</td>
<td>99</td>
</tr>
<tr>
<td>Cased Depth (mbgl)</td>
<td>73.9</td>
</tr>
<tr>
<td>Casing Stick Up (magl)</td>
<td>0.3</td>
</tr>
<tr>
<td>Development Yield (l/s)</td>
<td>&gt;3</td>
</tr>
<tr>
<td>Water Level (mbgl) &amp; Date</td>
<td>5.75</td>
</tr>
<tr>
<td>Quality - pH &amp; EC (µS/cm)</td>
<td>7.62</td>
</tr>
</tbody>
</table>

### BORE CONSTRUCTION

- **Concrete Plinth**
- **Lockable Cap**
- **Grout including 5% Bentonite**
- **Bentonite Seal**
- **0 - 10m: 7" Dual Rotary**
- **3.2 - 6.4 mm Graded Gravel Pack or Backfill**
- **80mm Blank PVC**
- **Bentonite seal**
- **10 - 99m: 5.75" Air Hammer**
- **3.2 - 6.4 mm Graded Gravel Pack**
- **80mm Slotted PVC**
- **80mm PVC Cap**

### STRATIGRAPHY

- **Tertiary Alluvium**
- **Basalt - Weathered**: Pale grey, minor clay weathered basalt. Iron staining on chips.
- **Basalt - Fractured**: Grey basalt with some secondary mineralisation and quartz. Large angular chips.
- **Basalt - Fractured**: Light grey, highly fractured basalt. Large chips with iron staining. Especially fractured at 62-68 m, with vuggy secondary mineralisation.
- **Basalt - Fractured**: Grey slightly fractured basalt. Looks fresh, with some quartz veining.
- **Basalt - Fractured**: Dark grey slightly fractured basalt. Looks fresh, with some quartz veining.

### LITHOLOGY

- **Calcrete & Clay**: Pale grey- off white Clay matrix, medium plasticity, 40%. SR, medium hardfness, Calcrete chips (fizz test), <5mm. SR-SA, highly weathered Saprolite. Minor black Shale or weathered Manganese chips.
- **Calcrete & Clay**: Same as above but larger chips.
- **Saprock**: Darker pale grey clay with calcrete and weathered basalt.
- **Basalt - Weathered**: Pale grey, minor clay weathered basalt. Iron staining on chips.
- **Basalt - Fractured**: Grey basalt with some secondary mineralisation and quartz. Large angular chips.
- **Basalt - Fractured**: Grey basalt with some clay. Finer chips than above.
- **Basalt - Fractured**: Light grey, highly fractured basalt. Large chips with iron staining. Especially fractured at 62-68 m, with vuggy secondary mineralisation.
- **Basalt - Fractured**: Grey slightly fractured basalt. Looks fresh, with some quartz veining.
- **Basalt - Fractured**: Dark grey slightly fractured basalt. Looks fresh, with some quartz veining.

### DESCRIPTION

- **Basalt - Weathered**: Pale grey, minor clay weathered basalt. Iron staining on chips.
- **Basalt - Fractured**: Grey basalt with some secondary mineralisation and quartz. Large angular chips.
- **Basalt - Fractured**: Light grey, highly fractured basalt. Large chips with iron staining. Especially fractured at 62-68 m, with vuggy secondary mineralisation.
- **Basalt - Fractured**: Grey slightly fractured basalt. Looks fresh, with some quartz veining.
- **Basalt - Fractured**: Dark grey slightly fractured basalt. Looks fresh, with some quartz veining.

### COMMENTS

0-70m 7" DR, 70-99m Open hole. Fresh basalt with a broken zone from 46 to 70 m.
WESTERN HUB BORE LOG

BOREHOLE NUMBER

WHR_WS22MB01

PROJECT NAME: Western Hub Rail Feasibility Assessment
LOCATION: WHR_WS22MB01
DRILLING CO: Easternwell
DRILLING METHOD: Dual Rotary / Open hole
LOGGED BY: ALR
DATE BEGUN: 21/05/2017
DATE COMPLETED: 24/05/2017

EASTING (m): 508118.39
NORTHING (m): 7520360.63
ELEVATION (mAHD): 520.09
DRILLING DIAMETER(S) (mm): 178
COLLAR STICKUP (m): 0.507

FINAL BORE DETAILS

Drilled Depth (mBGL): 88
Cased Depth (mBGL): 88.06
Casing Stick Up (magl): 0.443
Development Yield (l/s): 0.1
Water Level (mBGL) & Date: 13.75 25/05/2017
Quality - pH & EC (µS/cm): 8.07 1198

BORE CONSTRUCTION

- Concrete Plinth
- Lockable Cap
- Grout including 5% Bentonite
- Bentonite Seal
- 0 - 10m: 7" Dual Rotary
- 3.2 - 6.4 mm Graded Gravel Pack or Backfill
- 80mm Blank PVC
- 10 - 88m: 5.75" Air Hammer
- Bentonite seal
- 80mm Slotted PVC
- 3.2 - 6.4 mm Graded Gravel Pack
- 80mm Blank PVC
- 80mm PVC Cap

STRATIGRAPHY

Unknown
- Calcrete & Clay: Pale light brown, silty, clay with minor ironstone and calcrete, trace quartz, poorly cemented.
- Saprolite: Light greeny brown, highly weathered clay and possibly highly weathered saprolite. Trace quartz.
- Saprolite: Light greeny brown, massive clays, possibly highly weathered saprolite.
- Saprolite: Light greeny brown, with trace to minor small greeny grey SR-SA chips. Highley weathered possibly saprolite clays.
- Saprolite: Light grey green brown, highly weathered clays possibly saprolite, no rock chips.
- Basalt - Weathered: Light bluey grey, weathered basalts, small to medium sized SA chips, some minor clays.
- Basalt - Weathered: Light bluey grey, slightly weathered basalts, small and medium sized SA chips.
- Basalt - Fresh: Light grey, small and medium sized SA chips, hard basalt.
- Basalt - Fresh: Light grey, medium and some larger sized SA-AA chips, hard Basalt.

Bunjinah Formation
- Calcrete & Clay: Pale light brown, silty, clay with minor ironstone and calcrete, trace quartz, poorly cemented.
- Saprolite: Light greeny brown, highly weathered clay and possibly highly weathered saprolite. Trace quartz.
- Saprolite: Light greeny brown, massive clays, possibly highly weathered saprolite.
- Saprolite: Light greeny brown, with trace to minor small greeny grey SR-SA chips. Highley weathered possibly saprolite clays.

LITHOLOGY

- Unknown
- Calcrete & Clay
- Saprolite
- Basalt

YIELD (l/s)
EC (µS/cm)
pH

0.25
1017
7.74

Comments: 0-10m 7" DR, 10-88m Open hole. Highly weathered clays and fresh basalt
PROJECT NAME: Western Hub Rail Feasibility Assessment
LOCATION: WS23MB01
DRILLING CO: Easternwell
DRILLING METHOD: Dual Rotary / Open hole
LOGGED BY: ALR
EASTING (m): 504113.56
NORTHING (m): 7518184.48
ELEVATION (mAHD): 522.95
DRILLING DIAMETER(S) (mm): 178
COLLAR STICKUP (m): 0.517
DATE BEGUN: 18/05/2017
DATE COMPLETED: 20/05/2017

**BORE CONSTRUCTION**

**DEPTH**

- 0 - 4m: 7" Dual Rotary
- 0 - 4m: 7" Dual Rotary Grout including 5% Bentonite Bentonite Seal
- 3.2 - 6.4 mm Graded Gravel Pack or Backfill
- 80mm Blank PVC
- 4 - 82m: 5.75" Air Hammer
- Bentonite seal
- 3.2 - 6.4 mm Graded Gravel Pack
- 80mm Slotted PVC
- 80mm PVC Cap

**Bunjinah Formation**

- Basalt - Weathered: Light grey-green brown, slightly weathered basalt, small medium and larger SA-AA chips lightly coated in clay. Some brecciated chips
- Basalt - Fresh: Light grey, fresh basalt, small and some medium SA-AA chips.
- Basalt - Fresh: Darker grey, fresh basalt, small and some medium, SA-AA chips, some evidence of brecciated chips. Minor medium soft light brown saprolite chips.
- Basalt - Fresh: Light blue-grey, fresh massive fine even grained basalt, small with occasional medium sized SA-AA chips indicating hard rock. Minor quartz veining at 56-58m. Some trace quartz evident in other intervals

**STRATIGRAPHY**

- Lockable Cap
- Concrete Plinth
- 3.2 - 6.4 mm Graded Gravel Pack or Backfill
- 80mm Blank PVC
- 4 - 82m: 5.75" Air Hammer
- Bentonite seal
- 3.2 - 6.4 mm Graded Gravel Pack
- 80mm Slotted PVC
- 80mm PVC Cap

**LITHOLOGY**

- Lockable Cap
- Concrete Plinth
- 3.2 - 6.4 mm Graded Gravel Pack or Backfill
- 80mm Blank PVC
- 4 - 82m: 5.75" Air Hammer
- Bentonite seal
- 3.2 - 6.4 mm Graded Gravel Pack
- 80mm Slotted PVC
- 80mm PVC Cap

**DESCRIPTION**

- Basalt - Weathered: Light grey-green brown, slightly weathered basalt, small medium and larger SA-AA chips lightly coated in clay. Some brecciated chips
- Basalt - Fresh: Light grey, fresh basalt, small and some medium SA-AA chips.
- Basalt - Fresh: Darker grey, fresh basalt, small and some medium, SA-AA chips, some evidence of brecciated chips. Minor medium soft light brown saprolite chips.
- Basalt - Fresh: Light blue-grey, fresh massive fine even grained basalt, small with occasional medium sized SA-AA chips indicating hard rock. Minor quartz veining at 56-58m. Some trace quartz evident in other intervals

**QUALITY - pH & EC (µS/cm):**

- pH: 7.74
- EC (µS/cm): 740

**YIELD (l/s):**

- 0.05

**DEVELOPMENT YIELD (l/s):**

- N/A

**WATER LEVEL (mbgl) & DATE:**

- DRY: 22/05/2017

**COMMENTS:**

- 0-4m 7" DR, 4-82m open hole. Weathered and fresh basalt
## Western Hub Rail Feasibility Assessment

**PROJECT NAME:** Western Hub Rail Feasibility Assessment

**LOCATION:** WS24MB01

**DRILLING CO:** Easternwell

**DRILLING METHOD:** Dual Rotary / Open hole

**LOGGED BY:** JB

**DATE BEGUN:** 19/06/2017

**DATE COMPLETED:** 22/06/2017

### FINAL BORE DETAILS

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilled Depth (mbgl)</td>
<td>118</td>
</tr>
<tr>
<td>Cased Depth (mbgl)</td>
<td>117.94</td>
</tr>
<tr>
<td>Casing Stick Up (magl)</td>
<td>0.4</td>
</tr>
<tr>
<td>Development Yield (l/s)</td>
<td>N/A</td>
</tr>
<tr>
<td>Water Level (mbgl) &amp; Date</td>
<td>106.86 22/06/2017</td>
</tr>
<tr>
<td>Quality - pH &amp; EC (µS/cm)</td>
<td>N/A  No sample</td>
</tr>
</tbody>
</table>

### BORE CONSTRUCTION

- **Concrete Plinth**
- **Lockable Cap**
- **Grout including 5% Bentonite**
- **Bentonite Seal**
- 0 - 10m: 7" Dual Rotary

### STRATIGRAPHY

- **Tertiary Detrital**
  - Clay & Gravel: Pale brown, weathered BIF. Clayey with chert and ironstone.
  - Clay & Gravel: Pale brown, weathered BIF. Chert and ironstone with some clay.

- **Jeerinah Formation**
  - Basalt - Fresh: Hardcap. Blueish grey basalt with some quartz
  - BIF & Chert: Leached BIF. Friable fragments.

- **Bunjinah Formation**
  - Basalt - Fresh: Dark blueish grey Basalt with some quartz veining.

### LITHOLOGY

- **Clay & Gravel:** Pale brown, weathered BIF. Clayey with chert and ironstone.
- **Bentonite:**
- **Gravel:** Pack or Backfill
- **Bentonite Seal:**
- **3.2 - 6.4 mm Graded Gravel:**
- **Pack or Backfill:**
- **80mm Blank PVC:**
- **10 - 118m:** 5.75° Air Hammer
- **Bentonite Seal:**
- **3.2 - 6.4 mm Graded Gravel:**
- **Pack:**
- **80mm Slotted PVC:**
- **80mm PVC Cap:**

**EC (µS/cm):** 600

**pH:** 7.77

**Comments:** 0-10m 7" DR, 10-118m Open hole. Weathered and fresh Basalt. Extremely slow recovery after airfliting dried bore. Logger left to monitor recovery as level was rising at about 0.2 m per hour.
PROJECT NAME: Western Hub Rail Feasibility Assessment

LOCATION: WS25MB01

DRILLING CO: Easternwell

DRILLING METHOD: Dual Rotary / Open hole

LOGGED BY: ALR

EASTING (m): 493169.02

NORTHING (m): 7519111.82

ELEVATION (mAHD): 471.74

DRILLING DIAMETER(S) (mm): 178

COLLAR STICKUP (m): 0.508

DATE BEGUN: 17/06/2017  DATE COMPLETED: 19/06/2017

**FINAL BORE DETAILS**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilled Depth (mbgl)</td>
<td>82</td>
</tr>
<tr>
<td>Cased Depth (mbgl)</td>
<td>82</td>
</tr>
<tr>
<td>Casing Stick Up (magl)</td>
<td>0.457</td>
</tr>
<tr>
<td>Development Yield (l/s)</td>
<td>0.5</td>
</tr>
<tr>
<td>Water Level (mbgl) &amp; Date</td>
<td>9.27 19/06/2017</td>
</tr>
<tr>
<td>Quality - pH &amp; EC (µS/cm)</td>
<td>7.76 2215</td>
</tr>
</tbody>
</table>

**HYDROGEOLOGY**

- **Tertiary Alluvium**
  - Clay & Gravel: Light brown alluvials, silty clay with gravel SR to SA chips.
  - Basalt - Fresh: Light grey, medium sized, SA chips, hard competent fresh basalt.

- **Bunjinah Formation**
  - Basalt - Fresh: Grey, small and medium sized SA chips, medium to hard fresh basalt with significant pyrite with trace to minor quartz veining.

- **Jeerinah Formation**
  - Shale, Chert, Volcanics: Dark grey, small and medium SA platy chips. Medium to soft carboneous shale and chert with trace quartz veining in some intervals.

**COMMENTS:**

0-4m 7" DR, 4-82m open hole. Fresh basalt and Shale, chert volcanics.
WESTERN HUB BORE LOG

**PROJECT NAME:** Western Hub Rail Feasibility Assessment

**LOCATION:** WS25MB02

**DRILLING CO:** Easternwell

**DRILLING METHOD:** Dual Rotary / Open hole

**LOGGED BY:** ALR

**EASTING (m):** 492059.95

**NORTHING (m):** 7518304.02

**ELEVATION (mAHD):** 475.31

**DRILLING DIAMETER(S) (mm):** 178

**COLLAR STICKUP (m):** 0.497

**DATE BEGUN:** 15/06/2017

**DATE COMPLETED:** 17/06/2017

**BORE CONSTRUCTION**

- Concrete Plinth
- Lockable Cap
- 0 - 4m: 7" Dual Rotary
- Grout including 5% Bentonite
- Bentonite Seal
- 3.2 - 6.4 mm Graded Gravel
  - Pack or Backfill
  - 80mm Blank PVC
- 4 - 112m: 5.75" Air Hammer
- Bentonite seal
- 3.2 - 6.4 mm Graded Gravel
  - Pack or Backfill
  - 80mm Slotted PVC
- 80mm PVC Cap

**STRATIGRAPHY**

- **Tertiary Alluvium**
  - Clay & Gravel: Light brown alluvials, silty Clay with gravel SR to SA chips.
  - Basalt - Fresh: Light grey, small and medium sized SA chips, hard competent fresh basalt.

- **Bunjinah Formation**

- **Jeerinah Formation**
  - Shale, Chert, Volcanics: Dark grey, small SA chips. Hard carboneous shale and chert.

**LITHOLOGY**

- Tertiary
- Alluvium
- Bunjinah Formation
- Jeerinah Formation

**DETAILED BOREHOLE LOG**

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>STRATIGRAPHY</th>
<th>LITHOLOGY</th>
<th>DESCRIPTION</th>
<th>YIELD (l/s)</th>
<th>EC (µS/cm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Tertiary Alluvium</td>
<td>Clay &amp; Gravel: Light brown alluvials, silty Clay with gravel SR to SA chips.</td>
<td>Basalt - Fresh: Light grey, small and medium sized SA chips, hard competent fresh basalt.</td>
<td>7.81</td>
<td>3180</td>
<td>-</td>
</tr>
<tr>
<td>3.2</td>
<td>Bunjinah Formation</td>
<td>Shale, Chert, Volcanics: Darker grey, medium sized SA chips. Hard carboneous shale and chert</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4</td>
<td>Jeerinah Formation</td>
<td>Shale, Chert, Volcanics: Dark grey, small SA chips. Hard carboneous shale and chert</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.2</td>
<td>80mm PVC Cap</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FINAL BORE DETAILS**

- **Drilled Depth (mbgl):** 112
- **Cased Depth (mbgl):** 111.98
- **Casing Stick Up (magl):** 0.454
- **Development Yield (l/s):** 0.05
- **Water Level (mbgl) & Date:** 22.43 19/06/2017
- **Quality - pH & EC (µS/cm):** 7.81 3180

**COMMENTS:** 0-4m 7" DR, 4-112m open hole. Fresh basalt and Shale, chert volcanics.
**PROJECT NAME:** Western Hub Rail Feasibility Assessment  
**LOCATION:** WHR_WS25MB03  
**DRILLING CO:** Easternwell  
**DRILLING METHOD:** Dual Rotary / Open hole  
**LOGGED BY:** ALR  
**DATE BEGUN:** 13/06/2017  
**DATE COMPLETED:** 15/06/2017

<table>
<thead>
<tr>
<th>BORE CONSTRUCTION</th>
<th>DEPTH</th>
<th>STRATIGRAPHY</th>
<th>LITHOLOGY</th>
<th>DESCRIPTION</th>
<th>YIELD (l/s)</th>
<th>EC (µS/cm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Plinth</td>
<td>0</td>
<td>Bunjinah</td>
<td>Basalt - Weathered: Greeny brown weathered basalt with minor clays, SA small and medium sized chips, soft to medium hard. Driller indicates soft loose material</td>
<td>2</td>
<td>1366</td>
<td>7.49</td>
<td></td>
</tr>
<tr>
<td>Lockable Cap</td>
<td>5</td>
<td></td>
<td>Basalt - Weathered: Light pale brown, highly weathered basalt with significant clays, small and medium sized SA chips, moderately soft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grout including 5% Bentonite Seal</td>
<td>10</td>
<td></td>
<td>Basalt - Weathered: Grey green, slightly weathered basalt, medium and large SA chips, medium hardness. Driller indicates fracture at 15m with first water strike</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 16m: 7” Dual Rotary</td>
<td>15</td>
<td></td>
<td>Basalt - Fresh: Light grey, fresh basalt, medium and large SA chips, medium hardness. Driller indicates small fracture at 21m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentonite Seal</td>
<td>20</td>
<td>Jeerinah</td>
<td>Basalt - Fresh: Light grey fresh basalt, small and medium sized SA chips. Hard chips. Driller indicates small fracture at 29m</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3.2 - 6.4 mm Graded Gravel Pack or Backfill</td>
<td>25</td>
<td></td>
<td>Shale, Chert, Volcanics: Darker grey, small and medium sized SA chips, medium to hard with the driller reporting softer and some ground. Hard carbonateous shale and chert. Small fracture zone at 72m. Very broken ground at 82-84m with some quartz veining in these samples</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Pack or Backfill</td>
<td>30</td>
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</tr>
<tr>
<td>80mm Blank PVC</td>
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</tr>
<tr>
<td>16 - 94m: 5.75” Air Hammer</td>
<td>40</td>
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<td>Bentonite seal</td>
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<td>80mm Slotted PVC</td>
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<tr>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
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<tr>
<td>80mm PVC Cap</td>
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<td>80mm Slotted PVC</td>
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<tr>
<td>3.2 - 6.4 mm Graded Gravel Pack</td>
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</tr>
</tbody>
</table>

**FINAL BORE DETAILS**

- Drilled Depth (mbgl): 94
- Cased Depth (mbgl): 88.917
- Casing Stick Up (magl): 0.443
- Development Yield (l/s): 4.5
- Water Level (mbgl) & Date: 17.55 17/06/2017
- Quality - pH & EC (µS/cm): 7.42 1389

**EASTING (m):** 7517878.95  
**NORTHING (m):** 490506.69  
**ELEVATION (m):** 483.01  
**DRILLING DIAMETER(S) (mm):** 178  
**COLLAR STICKUP (m):** 0.507

Comments: 0-16m 7" DR, 16-94m open hole. Weathered and fresh basalt. Shale, chert volcanics.
Appendix 2: Analytical Assessment Results
### Wittenoom and Channel Sands

- **Flow Rate** $Q$: 1296 m$^3$/day 15 L/s
- **No. Bores**: 2
- **Bore Spacing**: 1000 m
- **Hydraulic Conductivity** $K$: 11 m/d
- **Aquifer thickness** $b$: 60 m
- **Transmissivity** $T$: 650 m$^2$/day
- **Storativity** $S$: 1.00E-04

### Flow Rate and Rate

- **Flow Rate** $Q$: 
  - 1296 m$^3$/day
  - 15 L/s

### Distance-drawdown

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<th>Distance (m)</th>
<th>Interference Effects</th>
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### Time-drawdown

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### Constant Drawdown

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Theis Equation - Forward Modelling Well Performance

after Theis, C.V (1935)

Wittenoon
Flow Rate Q 1728 m3/day 20 L/s
Hydraulic Conductivity K 10 m/d
Aquifer thickness b 50.00 m
Transmissivity T 500 m2/day
Storativity S 5.00E-02

Distance-drawdown

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Time-Drawdown

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Constant Drawdown

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Graphs of distance-drawdown and time-drawdown relations.

Graphs of constant drawdown with time.
**Theis Equation - Forward Modelling Well Performance**

*after Theis, C.V (1935)*

<table>
<thead>
<tr>
<th>Marra Mamba</th>
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<tbody>
<tr>
<td>Flow Rate Q</td>
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<tr>
<td>Hydraulic Conductivity K</td>
</tr>
<tr>
<td>Aquifer thickness b</td>
</tr>
<tr>
<td>Transmissivity T</td>
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<tr>
<td>Storativity S</td>
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</table>

### Distance-drawdown Interference

<table>
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<tr>
<th>Distance (m)</th>
<th>u (365 days)</th>
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### Time-drawdown PWL (60% efficient)

<table>
<thead>
<tr>
<th>Time (Days)</th>
<th>u (8” production bore)</th>
<th>Drawdown Drawdown</th>
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### Constant Drawdown S 40 m

<table>
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<th>u (40 m)</th>
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Graphs showing distance-drawdown, time-drawdown, and constant drawdown.
Fractured Basalt
Flow Rate \( Q \) 345.6 m³/day 4 L/s No. Bores 7.5
Hydraulic Conductivity \( K \) 0.6 m/d
Aquifer thickness \( b \) 20.00 m
Transmissivity \( T \) 12 m²/day
Storativity \( S \) 3.00E-02

### Distance-drawdown Interference

<table>
<thead>
<tr>
<th>Distance ( u )</th>
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### Time-Drawdown

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### Constant Drawdown

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