CHAPTER 13 – HYDROLOGY AND HYDROGEOLOGY

GULF ALUMINA LTD – SKARDON RIVER BAUXITE PROJECT
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1</td>
<td>Introduction</td>
<td>13-1</td>
</tr>
<tr>
<td>13.2</td>
<td>Environmental Objectives and Performance Outcomes</td>
<td>13-1</td>
</tr>
<tr>
<td>13.2.1</td>
<td>Environmental Objectives</td>
<td>13-1</td>
</tr>
<tr>
<td>13.2.2</td>
<td>Performance Outcomes</td>
<td>13-1</td>
</tr>
<tr>
<td>13.3</td>
<td>Legislative and Policy Context</td>
<td>13-2</td>
</tr>
<tr>
<td>13.4</td>
<td>Hydrological Context</td>
<td>13-2</td>
</tr>
<tr>
<td>13.4.1</td>
<td>Rainfall</td>
<td>13-2</td>
</tr>
<tr>
<td>13.4.2</td>
<td>Intensity-Frequency-Duration Relationship</td>
<td>13-2</td>
</tr>
<tr>
<td>13.4.3</td>
<td>Evaporation</td>
<td>13-3</td>
</tr>
<tr>
<td>13.4.4</td>
<td>Flow Regimes</td>
<td>13-3</td>
</tr>
<tr>
<td>13.4.5</td>
<td>Runoff</td>
<td>13-5</td>
</tr>
<tr>
<td>13.5</td>
<td>Hydrogeological Context</td>
<td>13-6</td>
</tr>
<tr>
<td>13.5.1</td>
<td>Carpentaria Basin</td>
<td>13-6</td>
</tr>
<tr>
<td>13.5.2</td>
<td>Superficial Cover</td>
<td>13-7</td>
</tr>
<tr>
<td>13.5.3</td>
<td>Underlying Geological Sequence</td>
<td>13-7</td>
</tr>
<tr>
<td>13.5.3.1</td>
<td>Helby Beds and Garaway Beds, and the Gilbert River Formation</td>
<td>13-7</td>
</tr>
<tr>
<td>13.5.3.2</td>
<td>Rolling Downs Formation</td>
<td>13-8</td>
</tr>
<tr>
<td>13.5.3.3</td>
<td>Bulimba Formation (Wyaaba Beds)</td>
<td>13-8</td>
</tr>
<tr>
<td>13.5.3.4</td>
<td>Alluvium, Valley Cut and Fill Deposits</td>
<td>13-8</td>
</tr>
<tr>
<td>13.5.3.5</td>
<td>Surficial Beach Sand Deposits</td>
<td>13-8</td>
</tr>
<tr>
<td>13.5.4</td>
<td>Shallow Aquifers</td>
<td>13-9</td>
</tr>
<tr>
<td>13.5.5</td>
<td>Groundwater Dependent Ecosystems</td>
<td>13-13</td>
</tr>
<tr>
<td>13.5.6</td>
<td>Hydrology of Wetlands</td>
<td>13-13</td>
</tr>
<tr>
<td>13.6</td>
<td>Groundwater Modelling and Potential Impacts</td>
<td>13-13</td>
</tr>
<tr>
<td>13.6.1</td>
<td>Conceptual Model</td>
<td>13-14</td>
</tr>
<tr>
<td>13.6.2</td>
<td>Model Selection</td>
<td>13-14</td>
</tr>
<tr>
<td>13.6.3</td>
<td>Recharge</td>
<td>13-15</td>
</tr>
<tr>
<td>13.6.4</td>
<td>Other Parameters</td>
<td>13-15</td>
</tr>
<tr>
<td>13.6.5</td>
<td>Model Calibration and Groundwater Contours</td>
<td>13-15</td>
</tr>
<tr>
<td>13.6.6</td>
<td>Model Limitations and Continuing Improvement</td>
<td>13-17</td>
</tr>
<tr>
<td>13.6.7</td>
<td>Model Trials</td>
<td>13-17</td>
</tr>
<tr>
<td>13.6.8</td>
<td>Impacts of Shallow Aquifer Use for Water Supply</td>
<td>13-18</td>
</tr>
<tr>
<td>13.6.9</td>
<td>Impacts of Mining</td>
<td>13-20</td>
</tr>
<tr>
<td>13.6.9.1</td>
<td>Namaleta Creek</td>
<td>13-20</td>
</tr>
<tr>
<td>13.6.9.2</td>
<td>Lunette Swamp</td>
<td>13-23</td>
</tr>
<tr>
<td>13.6.9.3</td>
<td>Bigfoot Swamp</td>
<td>13-24</td>
</tr>
<tr>
<td>13.6.9.4</td>
<td>Skardon River Supratidal Wetland</td>
<td>13-26</td>
</tr>
<tr>
<td>13.6.9.5</td>
<td>Post Mining</td>
<td>13-27</td>
</tr>
<tr>
<td>13.7</td>
<td>Surface Water Modelling and Potential Impacts</td>
<td>13-28</td>
</tr>
<tr>
<td>13.7.1</td>
<td>Runoff Prediction</td>
<td>13-28</td>
</tr>
<tr>
<td>13.7.2</td>
<td>Impacts to Runoff</td>
<td>13-29</td>
</tr>
<tr>
<td>13.7.3</td>
<td>Namaleta Creek – Estuarine Wetlands</td>
<td>13-30</td>
</tr>
<tr>
<td>13.7.4</td>
<td>Wetland Catchments</td>
<td>13-31</td>
</tr>
<tr>
<td>13.7.5</td>
<td>Conceptual Hydrological Model for Wetlands</td>
<td>13-33</td>
</tr>
<tr>
<td>13.7.6</td>
<td>Wetland Model</td>
<td>13-33</td>
</tr>
<tr>
<td>13.7.7</td>
<td>Modelled Impacts to Wetlands</td>
<td>13-34</td>
</tr>
<tr>
<td>13.7.8</td>
<td>Post Mining Hydrology</td>
<td>13-38</td>
</tr>
<tr>
<td>13.7.9</td>
<td>Area of Catchments Impacted</td>
<td>13-39</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>13-23</td>
<td>Lunette Swamp Catchment</td>
<td>13-32</td>
</tr>
<tr>
<td>13-24</td>
<td>Schematic - Swamp Flow Processes</td>
<td>13-33</td>
</tr>
<tr>
<td>13-26</td>
<td>Modelled Water Levels for Bigfoot Swamp – Natural and Mined</td>
<td>13-35</td>
</tr>
<tr>
<td>13-27</td>
<td>Modelled Water Levels for Bigfoot Swamp – Natural and Rehabilitated</td>
<td>13-36</td>
</tr>
<tr>
<td>13-28</td>
<td>Modelled Water Levels for Lunette Swamp – Natural and Mined</td>
<td>13-37</td>
</tr>
<tr>
<td>13-29</td>
<td>Modelled Water Levels for Lunette Swamp – Natural and Rehabilitated</td>
<td>13-38</td>
</tr>
</tbody>
</table>
13. HYDROLOGY AND HYDROGEOLOGY

13.1 Introduction

This chapter describes the hydrology and hydrogeology within and surrounding the Project area, models and describes potential impacts to surface water and groundwater hydrology, proposes measures to mitigate impacts and provides a risk assessment for residual impacts to surface water and groundwater hydrology.

Information in this chapter is primarily based on the information provided in Appendix 4.

Chapter 12 describes the surface water and groundwater environment (e.g. catchments and water quality) of the Project area, potential impacts and mitigation measures.

Chapter 14 describes flood modelling and potential impacts from flooding of watercourses on the Project.

Chapter 16 describes potential impacts on aquatic ecology from changes to surface water and groundwater hydrology.

Appendix 15 describes the Surface Water and Groundwater Monitoring Plan.

13.2 Environmental Objectives and Performance Outcomes

The environmental objectives and performance outcomes below are based on Schedule 5, Table 2 of the Environmental Protection Regulations 2008 (EP Regulation). The mitigation and management measures presented in this chapter are designed to achieve these environmental objectives and performance outcomes. The environmental management plan (EM Plan) presented in Appendix 13 provides a consolidated description of these mitigation and management measures.

13.2.1 Environmental Objectives

- The activity will be operated in a way that protects environmental values of waters.
- The activity will be operated in a way that protects the environmental values of wetlands.
- The activity will be operated in a way that protects the environmental values of groundwater and any associated surface ecological systems.
- The choice of the site, at which the activity is to be carried out, minimises serious environmental harm on areas of high conservation value and special significance and sensitive land uses at adjacent places.

13.2.2 Performance Outcomes

- Any changes in the hydrology of wetlands or watercourses as a result of mining activities will be prevented or minimised.
- Any discharge to water or a watercourse or wetland will be managed so that there will be no adverse effects due to the altering of existing flow regimes for water or a watercourse or wetland.
- The activity will be managed so that adverse effects on environmental values are prevented or minimised.
- The activity will be managed in a way that prevents or minimises adverse effects on wetlands.
- The activity will be managed to prevent or minimise adverse effects on groundwater or any associated surface ecological systems.
Areas of high conservation value and special significance likely to be affected by the proposal are identified and evaluated and any adverse effects on the areas are minimised, including any edge effects on the areas.

Critical design requirements will prevent emissions having an irreversible or widespread impact on adjacent areas.

13.3 Legislative and Policy Context

The legislative and policy context for water supply from groundwater is described in Chapter 6. The legislative and policy context for determining environmental values and water quality objectives for the Project is described in Chapter 12.

13.4 Hydrological Context

13.4.1 Rainfall

Rainfall recorded at locations near the Project area is described in Chapter 9. For the purpose of generating rainfall data for use in hydrological modelling gridded Scientific Information for Land Owners (SILO) data was used. SILO datasets are constructed from observational records provided by the Bureau of Meteorology (BoM). SILO processes the raw data, which may contain missing values, to derive spatially and temporally complete datasets. The SILO record used for the Project includes both monthly and daily data for the period 1 January 1972 to 31 December 2014 from a site located in the centre of the Project area.

A comparison of SILO data and nearby rainfall gauge records at Weipa and Skardon River (data limited to 2006 to 2014 provides good correlation between all three sites (refer Figure 13-1). The SILO record has used in the hydrological analyses.

![Comparison of SILO Data and Rainfall Gauge Records](image)

**Figure 13-1** Comparison of SILO Data and Rainfall Gauge Records

13.4.2 Intensity-Frequency-Duration Relationship

The intensity-frequency-duration (IFD) relationship for a location in the centre of the Project area was derived from the BoM. The IFD relationships are estimated by BoM using a database comprising rainfall...
data from the Bureau’s rain gauge network and data from rainfall recording networks operated by other organisations across Australia. GIS-based methods are used for gridding rainfall datasets that have been analysed using standard hydrological statistical techniques to produce the IFD relationships.

The IFD is used in subsequent sections for peak flow estimation and in Chapter 14 for determining design flows for flood study analyses.

The IFD table is shown in Appendix 4. In general the relationship shows that the associated storm depths rise sharply up to a 3 hour storm, thereafter the rate of increase in depth against storm duration is slower. The IFD relationship is consistent with tropical climates where events even with a relatively low annual exceedance probability (AEP), are typified by significant storm depths.

13.4.3 Evaporation

SILO data has been used to estimate evaporation in the Project area. Although both records display similar seasonal behaviour, the SILO data is shown to be marginally higher than the Weipa Aero BoM station data throughout the year.

13.4.4 Flow Regimes

There are no long term flow records available for assessment of the flow regime of either of these rivers. The nearest stream flow record available is for the Doug’s Place Station (Gauge No. 926002A) on the Dulhunty River (1970 - 2011), about 43 km to the east of the Project area. Although it is distant from the Project area, the flow record does demonstrate the responsive nature of baseflow and the pronounced wet season that is typical of catchments in Cape York. Appendix 4 shows this gauging station plotted along with rainfall from the Heathlands National Park (gauge no. 027050) which is approximately 18.9 km distant, at the top of the same catchment. The flow recession appears to continue until September or October of each year.

Local catchments in the Project area are shown in Figure 13-2. Both Skardon River and Namaleta Creek are perennial towards the lower catchment reaches downstream. Skardon River is perennial over the reaches of the southern tributary that lies to the east of Project area, down to the estuary. In the case of Namaleta Creek, it is perennial immediately downstream of the existing crossing at the kaolin mine. The degree to which the tributaries to these rivers are ephemeral depends on the underlying geology. This is evident further to the north in the catchments that host Lunette Swamp (Catchment 4) (also referred to as Lunette Bog) and Bigfoot Swamp (Catchment 3) where the underlying lateritic facies are recharged by rainfall during the wet season. The lateritic facies absorb and store water which is released slowly through the year, supporting the wetland areas and stream flow downstream well into the dry months. With declining groundwater levels through the dry season, streamflow decreases, with many of the local watercourses being perennial.

In the lower reaches of Namaleta Creek, flow is confined to the main river channels through these swamps, and is supported through the dry season by strong baseflow and riverbank groundwater seepage in the vicinity of the swamps from the vegetation growth along the riparian corridor.
13.4.5 Runoff

Catchment runoff in response to the wet season occurs from late December, as soon as local shallow aquifer and soil water stores are saturated. Surface runoff is relatively low with much of the surface flow occurring as a result of interflow (i.e. water that travels through the unsaturated zone without reaching the water table before discharging to a surface water body or stream) and baseflow (i.e. the sustained flow in a stream that comes from groundwater discharge or seepage).

Runoff yield estimation was carried out for the principal subcatchments (refer to Figure 13-2) across the area using a conventional runoff model, the Australian Water Balance Model (AWBM), which is described in Appendix 4. The model was calibrated using the gauged stream flow described in Section 13.4.4, with the calibration results shown in Figure 13-3. While the short peak flows for certain years at the gauging station are not represented accurately, the AWBM simulations do provide reasonable agreement for lower flows, and particularly for the seasonal flow recession behaviour.

![AWBM Model Calibration](image)

A summary of the principal catchments in Project area contributing to runoff, catchment areas, and area and percentage of mining, excluding the Port infrastructure area, within each catchment is provided in Table 13-1. These include subcatchments of Namaleta Creek and also the western tributaries of Skardon River to the south of the Port area. The catchments were delineated using LIDAR data obtained by Gulf. For purposes of analysis, Namaleta Creek has been subdivided into more than one catchment to allow flow prediction to be carried out at the haul road crossings. This enabled an assessment of peak flow to be estimated for the crossing location to inform design and flood modelling.

Monthly cumulative yields and average flows were determined for each of the catchments. For the runoff analysis, AWBM was incorporated into the GoldSim modelling package to estimate catchment runoff for Project area conditions using the long term SILO rainfall and evaporation data sets. The output was used to predict maximum, average and minimum runoff for the delineated catchments as provided in Appendix 4. An example of the seasonal flow behaviour for catchment 1 is shown in Figure 13-4. This is an example, using catchment 1, to demonstrate the seasonal nature of flow behaviour in all catchments prior to Project disturbance. A comparison of flow behaviour pre-mining, during mining and during rehabilitation in impacted catchments is provided in Section 13.7.2.
### Table 13-1  Catchment Information

<table>
<thead>
<tr>
<th>Catchment ID#</th>
<th>Contributory Catchment(s)</th>
<th>Catchment area (km²)</th>
<th>Disturbed areas (km²)</th>
<th>% of catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>17.52</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>16.01</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>22.50</td>
<td>1.48</td>
<td>6.6%</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>52.56</td>
<td>4.48</td>
<td>8.5%</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>37.29</td>
<td>1.18</td>
<td>3.2%</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>42.71</td>
<td>4.34</td>
<td>10.2%</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>171.55</td>
<td>2.22</td>
<td>1.3%</td>
</tr>
<tr>
<td>8</td>
<td>1, 2 &amp; 4</td>
<td>86.10</td>
<td>4.48</td>
<td>5.2%</td>
</tr>
<tr>
<td>9</td>
<td>5 &amp; 6</td>
<td>80.00</td>
<td>5.52</td>
<td>6.9%</td>
</tr>
</tbody>
</table>

*# Refer to Figure 13-2 for catchment locations.*

### Figure 13-4  Seasonal Flow Behaviour (Catchment 1)

#### 13.5  Hydrogeological Context

##### 13.5.1  Carpentaria Basin

The groundwater resources in the area lie within the Carpentaria Basin which spans much of the western side of the Cape York Peninsula. The Basin is bounded in the east by the Coen inlier, and open to the west
where it extends out under the Gulf of Carpentaria. The geology displays reasonable lithological and formational continuity, although there is also some variation across the region.

Groundwater supply across Cape York is derived from both shallow aquifers and from deeper great artesian basin (GAB) sources. These supplies are generally of high quality and the local aquifers if well-managed, have been demonstrated to sustain reliable borefields. There have been few deep bores drilled into the Mesozoic Sandstones within the Carpentaria Basin, largely due to the costs associated with construction to the depths required which can exceed 850 m before reasonable artesian supplies can be accessed. As a consequence, most knowledge of the deep subartesian and artesian resources has come from exploration drilling at Aurukun, Kowanyama and Weipa. In the case of Weipa, artesian bores have been used in supply since the 1970s. The closest bores drilled that intersect the Mesozoic Sandstones were test wells constructed by Comalco during oil and gas exploration, the Pennefather and Rum Bottle bores drilled in 1991, and located south of Mapoon near the Wenlock River.

13.5.2 Superficial Cover
The superficial cover has a significant influence on the partitioning of incident rainfall into runoff, interflow, baseflow and aquifer recharge. There are two principal land categories in the areas to be mined that are relevant to groundwater movement: the bauxite plateau with bauxite and lateritic subsoil and the low lying clayey soil areas comprising kaolin that are flooded seasonally. The soil cover to the bauxite plateau is well drained red kandosol which has thin loamy topsoil underlain by a pisolithic bauxite (up to 6 m in places), which is underlain by ironstone. Areas overlain by bauxite display elevated aquifer recharge, which can result in a rapid response in groundwater levels following rainfall. By contrast the low lying clayey areas have a lower characteristic recharge, and result in higher runoff.

13.5.3 Underlying Geological Sequence
The stratigraphy of the Project area is shown in Table 13-2. The underlying sequence that is host to the primary aquifers within the Project area from oldest to youngest is:

- Helby Beds and Garraway Beds, and the Gilbert River Formation
- Rolling Downs Formation
- Bulimba Formation (Wyaaba Beds)
- Alluvium, Valley Cut and Fill Deposits
- Surficial Beach Sand Deposits

13.5.3.1 Helby Beds and Garraway Beds, and the Gilbert River Formation
This is the dominant host formation to artesian aquifers to the south at Weipa and Aurukun and which is expected to be present in the Skardon River area. These Mesozoic sandstones are interbedded with siltstone and conglomerate units and are host to aquifers in the Great Artesian Basin. They outcrop to the east and north-east of Skardon River in vicinity of the Great Dividing Range where they are recharged, and dip gently to the west. Yields from the artesian bores within the sandstones range up to 80 L/s at Andoom borefield at Weipa with the aquifer units at 700 – 1000 m below ground level. Generally water is fresh in unconfined outcrop areas and can deteriorate to brackish conditions down dip at deep confined depths. The aquifer hydraulic properties of the Gilbert River Sandstone Formation have been shown to be favourable for supporting a reliable supply (South of Embley EIS, 2012). The Gilbert River Sandstone and the Helby Beds are expected to be in the Skardon River area, but this has not been confirmed yet through field investigation. Douglas Partners (1995) suggest that the estimated depth of the Mesozoic sandstones would be between 500 and 600 m in the Skardon River area.
13.5.3.2 Rolling Downs Formation

The Rolling Downs Formation is mainly composed of marine argillaceous sediments comprising fine grained clastics, mudstones and some hydraulically unconnected sandstone lenses, possibly Mesozoic age. In the Skardon River area the upper part of the unit is laterised and has a strongly kaolinitic pallid zone. It is regarded as an aquitard or confining layer to the underlying artesian aquifer. It is possible that it extends to depths in excess of 250 m in the Skardon River area; in the vicinity of the Weipa borefields it can be in excess of 800 m below ground level (bgl). Douglas Partners (1995) report that a 129 m bore drilled near the Skardon River landing intersected the Rolling Downs Group at 17 m and this continued over the entire depth of the bore. Groundwater supplies from the Rolling Downs Formation tend to be low (less than 0.5 L/s) and the water quality brackish to saline.

13.5.3.3 Bulimba Formation (Wyaaba Beds)

The Bulimba Formation (Wyaaba Beds) comprises a variability of lithologies reflecting a several different depositional environments. The lithology ranges from claystone (often kaolinitic) to coarse grained unconsolidated sands, or cemented cobble conglomerate. Bauxite laterite develops at the top of the Bulimba Formation. Locally there are sandy, permeable deposits of ancient stream channels. The northern extremity of these units lies to the north of Skardon River. Shallow aquifers in the Bulimba Formation consist mostly of coarse grained sand beds. Aquifer recharge is direct through rainfall and is relatively fast. Elsewhere in Cape York, this unit has been found to be a significant source to meet demands of communities, stations and operation usage for the mines at Weipa. It is not possible to typify yields from bores constructed in the Bulimba Formation, they are highly variable. At Mapoon bores penetrating Bulimba sandstone at depths down to 30 m produce yields of about 2 to 5 L/s, whereas at Weipa, some of the shallow aquifer bores deliver yields in excess of 20 L/s. In general, water quality from bores within the Bulimba Formation is generally fresh.

13.5.3.4 Alluvium, Valley Cut and Fill Deposits

Alluvium, valley cut and fill deposits occur within drainage valleys and estuarine areas. The valleys containing these deposits are incised within the Bulimba or Rolling Downs Group units and comprise clayey and sandy alluvium channel deposits. The valley deposits are possibly Pleistocene in age and contain shallow thin sand aquifers. The Namaleta and Lunette sand aquifers are considered to be meandering palaeochannels within these valley systems and have been investigated for water supply purposes for the kaolin mine in the 1990’s. A shallow unconfined aquifer system has been identified within the clayey gravel and sand aquifer adjacent to the Port area. The alluvium can be highly kaolinitic as a result of deposition of source material from the pallid zone of Rolling Downs Group or Bulimba Formation. Yields from pumping investigations have indicated a sustainable range of 0.5 to 3 L/s from the sand aquifers. The water quality is fresh with laboratory tests showing total dissolved solids (TDS) level of below 105 mg/L.

13.5.3.5 Surficial Beach Sand Deposits

Surficial beach sand deposits occur along beach ridge sands of the Mapoon Plain, an irregular, narrow coastal lowland plain typified by cheniers (beach ridges), and are generally of limited areal extent and thickness, resting on marine muds and clays. They are directly recharged by rainfall infiltration and are likely to drain rapidly in dry season. These are possibly of Pleistocene and Quaternary age. Yields from these thin aquifers are expected to be limited, and any local bores would be vulnerable to the risk of saline intrusion from the sea.
### Table 13-2  Stratigraphy of the Project Area

<table>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Unit</th>
<th>Thickness (m)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cainozoic</td>
<td>Quaternary</td>
<td>Pliocene to Holocene Deposits</td>
<td>5-15</td>
<td>Quartzose sand, beach ridges, silty clay, coastal alluvium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pliocene</td>
<td>5-10</td>
<td>Ferruginous laterite, Aluminous laterite, bauxite, ferricrete</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Bulimba Formation</td>
<td>25</td>
<td></td>
<td>Quartzose sandy clay</td>
</tr>
<tr>
<td>Mesozoic</td>
<td>Cretaceous</td>
<td>Unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rolling Downs Group</td>
<td>250+</td>
<td>Mudstone, shale, siltstone</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Gilbert River</td>
<td>Sandstone(?)</td>
<td>300+</td>
<td>Quartzose sandstone, interbedded micaceous carbonaceous siltstone, coarse grained sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Helby Beds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Garraway Beds (?)</td>
<td>&lt;150</td>
<td>Coarse to fine clay-rich micaceous sandstone</td>
</tr>
<tr>
<td></td>
<td>Permian</td>
<td>Unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palaeozoic</td>
<td></td>
<td>Cape Grenville Volcanics</td>
<td>150+</td>
<td>Volcanic breccia, coarse tuff, overlain by acid-welded tuff</td>
</tr>
</tbody>
</table>

#### 13.5.4 Shallow Aquifers

The shallow aquifer (Cainozoic) is significant to the Project as a potential water supply. The water table in the Skardon River area is a subdued reflection of the local topography with deeper levels on the bauxite plateau and shallower levels in the low lying drainage areas. The bauxite deposit is located on the Weipa Plateau at 10 - 20 m AHD, and is partly dissected by drainage channels and consists of deeply weathered profile of bauxite, ferricrete and clay capping the Bulimba Formation.

Historic groundwater level data in the bauxite plateau displays a significant seasonal fluctuation which varies between 2 metres below ground level (mbgl) during the wet season, to more than 10 mbgl towards the end of the dry season. The groundwater levels in the low lying areas near wetlands and drainage channels are shallow and lie typically at depths of 3 mbgl or less.

Conceptual hydrogeological cross-sections for the superficial formations that host the shallow aquifer system are shown in Figure 13-5, Figure 13-6 (including Bigfoot Swamp) and Figure 13-7 (including Namaleta Creek and Lunette Swamp).

Studies were undertaken for the kaolin mine in the 1990s by Rockwater Pty Ltd (1994), Golder Associates Pty Ltd (1998) and Douglas and Partners Pty Ltd (1995) that are particularly relevant to developing understandings of the shallow aquifers. The studies focussed on assessing the availability of shallow groundwater supplies for the kaolin mine and are further described in Appendix 4. These studies identified sand aquifers in a palaeochannel along Namaleta Creek and near Lunette Swamp, and potential aquifers near the Port.

The Namaleta shallow aquifer system is a thin shallow palaeochannel sand aquifer in valley fill deposits and associated with the Namaleta Creek. The Lunette shallow aquifer system is a similar aquifer system to the Namaleta Creek sand aquifer, hosted within valley fill deposits that extend towards Lunette Swamp.
and further along drainage lines towards the coast. The Port area aquifer is composed of clayey gravel and sands. The Project area is made complex by the depositional history which has resulted in local alluvial aquifer systems that are associated with palaeochannels.

*Figure 13-5  Cross Sections*
Figure 13-6 Cross Section 1 – Bigfoot Swamp
Figure 13-7  Cross Section 2 – Namaleta Creek and Lunette Swamp
13.5.5 Groundwater Dependent Ecosystems

The wetlands within and surrounding the Project area (refer Chapter 12) include several groundwater dependent ecosystems located along drainage lines which comprise valley fill alluvial deposits with underlying shallow aquifer systems. All freshwater wetlands are likely to be recharged by surface water during the wet season and maintained during the dry season by seasonally perched groundwater recharge. All wetlands described in Chapter 12 are considered to be shallow aquifer groundwater dependent ecosystems.

The Gilbert River Sandstone that hosts the GAB further to the south at Weipa and the Helby Beds (both part of the Mesozoic Formation) are expected to be in the Skardon River area – but this has not been confirmed yet through field investigation. A review of seismic data and borelogs for the area indicated that the Rolling Downs Group extends to between 530 and 600 m below ground level and is underlain by about 100 m of Mesozoic Sandstone (Douglas and Partners, 1995). Furthermore they report that a 129 m bore drilled near the Port area intersected the Rolling Downs Group (which confines the GAB) at 17 m and this continued over the entire depth of the bore. Hence it is believed that any groundwater dependent ecosystems in the area are not linked to the GAB.

The Western Cape York Groundwater Study (DSITIA, 2014) used spatial analysis to predict the likelihood of GAB GDEs in Cape York. As stated in the report, the locations and rates of hydrological connections between potential GDEs and the GAB were found to be poorly understood in the region. The report predicts that Namaleta Creek and Bigfoot Swamp area ‘likely’ to be a wetland GAB GDEs and that there are a mix of ‘likely’ and ‘highly likely’ potential GAB springs to the west of the Project area (along the coastal dune margin). However, based on the best current understanding of the hydrogeology of the area and a lack of any evidence of artesian groundwater flow associated with the GAB, these mapped GAB GDE wetlands and springs are most likely to be in hydraulic continuity with local shallow aquifers and not the GAB.

13.5.6 Hydrology of Wetlands

The palustrine wetlands across the Project area are associated with depressions and water course drainage lines. In addition to retaining water they are also a repository of soils and sediments that will retain nutrients to support local biodiversity. The detailed nature of partitioning of the various components of the hydrological cycle – rainfall, runoff, recharge and baseflow, as they affect wetlands, is understood at a conceptual level for the area. However, it is recognised that these wetlands are dependent on surface water and groundwater interaction which can be impacted by mining in the associated catchments.

Based on site knowledge, Lunette Swamp and Bigfoot Swamp wetlands dry out during the dry season, except for small ponds at the lower end of Bigfoot Swamp, which can also dry out in some years. Lunette Swamp dries out fairly rapidly, by July 2015 there was no water in Lunette Swamp.

The riverine and estuarine wetlands reaches of Namaleta Creek adjacent to the Project and further downstream are affected by the behaviour of runoff and baseflows entering the creek. Any changes to the hydrological regime upstream will have the potential to impact on saline excursion on high tides which can affect the estuarine wetlands.

13.6 Groundwater Modelling and Potential Impacts

A groundwater model was developed based on an understanding of the hydrogeological context and available data. The model considers the potential impacts of mining and water usage on local hydrogeology and its interaction with surface water bodies. The groundwater model is described in Appendix 4 and summarised below.
13.6.1 Conceptual Model

For purposes of developing a numerical shallow aquifer groundwater model, information was obtained from the available groundwater database, field inspection, geological mapping, relevant geological information, and documentation reporting on hydrogeological and geological investigations carried out for the Project and for the previous kaolin mining operation.

The bauxite plateau which runs along the ridge between the old kaolin mine and the Port Infrastructure Area is typified by superficial pisolitic gravels that overlie a sandy clay layer (mottled red and brown with sub-angular quartz).

The aquifer depths towards the ridge line are relatively shallow, and transmissivities are expected to decline sharply with depth in the area. The aquifer systems in the area that have been developed are associated with palaeochannels and include the Namaleta Creek and Lunette Swamp systems (Figure 13-8 from model presented by Golder (1998)). In these systems, saturated flow occurs in coarse sand layers that are approximately 3 m in depth that are confined to the palaeochannels.

There is limited information about the shallow aquifer system away from the Namaleta and Lunette channel fill systems. Bore holes located on the bauxite plateau to the north and east of the camp, display a typical profile for lateritic conditions. The plateau is characterised by superficial pisolitic gravels that overlie a sandy clay layer, between 8 and 12 m deep. The aquifer depths towards the ridge line are relatively shallow, and transmissivities in the area are expected to decline sharply with saturated depth.

![Figure 13-8 Hydrogeological Interpretation (after Golders (1998))](image)

13.6.2 Model Selection

The United Stated Geological Survey (USGS) Modflow model selected for developing the numerical groundwater model. Modflow is capable of simulating both steady-state and transient conditions, and provides output that includes groundwater head distributions, seepage flows and water balances in a range of different formats. The model geometry and boundary conditions are described in Appendix 4.
13.6.3 Recharge

Recharge estimation has been carried out with reference to research work in Western Australia and in Queensland in bauxite mining areas. In general, clearing of such areas for any development, results in rising groundwater level and increased streamflow volume and discharge.

Recharge estimates were applied as a percentage of rainfall. Reasonable recharge estimates, which are regarded as representative of the area, were made with reference to Volker and Crees (1993). The general conclusion of their work was that there are no major long term changes to recharge once vegetation has been re-established in mined areas.

In similar conditions to the Project area at Weipa, the authors carried out field trials to estimate aquifer recharge under a range of different land use conditions. An important outcome of the work was the relationship that exists between annual rainfall and the percentage of recharge for the different land use conditions tested. The initial estimates of recharge for the Project groundwater model were based on the Volker and Crees (1993) relationship which gives the following annual recharge rates for the Project area for the average annual rainfall based on the SILO data of 1697 mm:

- unmined natural - 290 mm (17%)
- unmined cleared - 845 mm (50%)
- mined cleared - 720 mm (42%)
- mined rehabilitated - 435 mm (26%).

13.6.4 Other Parameters

The initial transmissivity and storativity values applied in the model were adopted from previous studies and the parameters distributions were then refined in a series of calibration trials. Transmissivities, storativities, hydraulic conductivity, aquifer depths, production yield and rainfall recharge were all estimated based on previous hydrogeological studies.

13.6.5 Model Calibration and Groundwater Contours

Model calibration was carried out against bore level data for steady conditions and transient conditions from data monitored at 7 bores (G2, G3, G4, G5, C1, C2, C3 as shown on Figure 13-9) between November 2013 and March 2015 (refer to Chapter 12 for monitoring data). Calibration results are presented in Appendix 4. The calibration results shows reasonable correlation with bore levels, however further data will assist in improving recharge estimation and variation of hydraulic conductivity profile with aquifer depth. These parameters have a significant effect on the recession of the groundwater hydrographs during the dry season.

Groundwater contours, for the steady state model output, for March 2014 are shown in Figure 13-9.
Figure 13-9

Gulf Alumina Limited

Modelled Groundwater Contours

Legend
- Mining Lease Boundaries
- Port of Skardon River
- Watercourses

Groundwater Monitoring Bores Used for Model Calibration

Groundwater Contours (m RL)
- Major Contour
- Minor Contour

Coordinate System: GDA 1994 MGA Zone 54
Map Scale: 1:80,000
Revision: R1
Date: 15/03/2016
Author: malcolm.nunn

Modelled Groundwater Contours

No warranty is given in relation to the data (including accuracy, reliability, completeness or suitability) and accept no liability (including without limitation, liability in negligence) for any loss, damage or costs (including non-monetary costs) relating to any use of or reliance upon the data. Data must not be used for direct marketing or be used in breach of privacy laws. Tenures © Geos Mining (2015). State Boundaries and Towns © Geoscience Australia (2006). Seek geographic data services. ©2013 Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.
13.6.6 Model Limitations and Continuing Improvement

The complexity resulting from palaeochannels is difficult to reflect in the model, and this is not well-understood beyond the investigation coverage which has been limited to date to the Namaleta Creek and Lunette Swamp areas. Recharge is difficult to predict in the tropics, although it has been possible to apply knowledge of similar conditions elsewhere in the prediction using the work of Volker and Crees (1993). Information on the distribution of permeability over depth (profile) across the area is limited.

River-aquifer interaction is a key feature of local behaviour. There is limited knowledge of the behaviour of creeks to the north and east of the Project area - particularly of the seasonal behaviour, and the extent and variation of perennial conditions along reaches of local creeks.

Despite these limitations, the model does provide a basis for assessing the potential impact of the Project on groundwater. Additional information will be collected as part of the ongoing monitoring programme (refer Chapter 12).

The groundwater model will be subject to continuing improvement in response to further information derived from field studies such as exploration drilling, and also from data sets extended through ongoing monitoring of groundwater levels and rainfall. Additional modelling will be undertaken prior to mining to inform the prediction of impacts and evaluate the monitoring program. The following actions will be undertaken to improve the model:

- A shallow aquifer survey targeted at assessing the groundwater potential for water supply will be undertaken. This work will utilise information from the proposed water supply bores (refer to Chapter 6, Section 6.5.3) and the existing and proposed groundwater bore monitoring network (refer to Chapter 12, Section 12.10.5). The work will also provide relevant information on the local hydrogeology, the aquifer yield and, potentially on the aquifer limits.
- Pumping tests will be undertaken. At present the aquifer properties have been applied in modelling from published values for similar local conditions to those in the Project area. Pumping tests will determine the hydraulic properties of the shallow aquifer in order to improve model reliability. These will be targeted to represent different zones of the shallow aquifer (bauxite plateau, river floodplain, etc.) and the existing and proposed groundwater bores.
- Additional data from piezometers at existing and proposed monitoring bores around wetland areas will be undertaken. Data from bores near wetlands can be combined with surface water monitoring in the wetlands, including wetland depth. The resulting data sets will provide further important knowledge of the interaction between groundwater and surface water.
- Recalibration of the model will be carried out against changes in land use. The groundwater model will be revised in response to the additional data sets such as rainfall and groundwater levels, but for this to be effective, the model will be updated for any local land use changes which impact on recharge and surface water runoff.

13.6.7 Model Trials

The model was used in simulation trials to review potential impacts to aquifers and local wetlands that might result from:

- shallow aquifer groundwater usage (refer Chapter 6) for meeting Project water demand
- mining activities that will disturb areas of the aquifer with the potential to affect recharge mechanisms, the aquifer host formation, and seepage and drainage behaviour.
Each trial was completed for steady-state conditions in which the mine plan (Refer Chapter 5) was represented in the model. Mining pits, cleared areas, undisturbed areas and rehabilitated areas were all simulated in the model:

- Recharge was altered to simulate changes between disturbed, cleared mined or rehabilitated areas.
- Seepage inflow to the open pits was assumed to be removed from the aquifer, either by pumping or evaporation.
- The shallow aquifer boreholes proposed for water supply were modelled at the locations shown in Chapter 6, Figure 6-9 using the discharge rates proposed in Chapter 6.

The mining pits were represented in the model in line with the proposed mine plan, and the model was run for representative conditions occurring in the early stages of each wet season (nominally at the start of April each year). During mining, modelling adopts the conservative assumption that all of the groundwater water seeping into the pits and runoff entering pits will be removed from the pit either through surface evaporation, evapotranspiration or through pumping for local use such dust suppression. This assumption is conservative as it results in greater groundwater drawdown during the actual mining phase. However, it is possible that in actual mining circumstances, residual water in pits will also become induced recharge into the surrounding aquifer as local groundwater levels decline over the dry season.

In areas where mining will have ceased and where rehabilitation can be assumed to have been established, recharge was factored to the appropriate figures described in Section 13.6.3. In the simulations, mined areas were also assumed to have been backfilled.

The changes expected to the groundwater regime result from complex interactions of rainfall recharge (which can be elevated or reduced at different stages of mining), and from the loss of the aquifer host formation due to the removal of topsoil, subsoil and the mined ore.

Modelling output is presented as groundwater drawdown contours, i.e. contours showing the specific impacts of the change to the aquifer against the initial or baseline conditions. The drawdown across the aquifer is calculated as the head difference, equal to the initial head minus the head for the year in question. The resulting drawdowns – as head difference in metres - are then contoured. Note these drawdown contours can be negative or positive, so that a positive drawdown represents a decline in groundwater levels, and negative drawdowns accompany elevated levels relative to initial conditions. Hence, positive contours indicate the drawdown conditions that can be expected from activities such as pumping for supply or pit dewatering. Negative influence drawdown values will result from increases to recharge which occur following clearing and mining.

**13.6.8 Impacts of Shallow Aquifer Use for Water Supply**

Modelling was carried out to assess the impact of groundwater usage alone – i.e. comparisons were made between current conditions, and conditions in which the proposed water supply borefield was operational (but without mining) in order to isolate individual impact of the proposed borefield development.

The water supply bores to the north of the Project area shown in Figure 13-10 are predicted to have little or no effect on surrounding surface water bodies. The southern water supply bores shown in Figure 13-11 could have an effect on the reach of Namaleta Creek adjacent to existing kaolin mine where levels are shown to be drawn down to between 0.1 and 0.2 m.
Figure 13-10  Drawdown - Shallow Aquifer Borefield Only (North)
13.6.9 Impacts of Mining

The groundwater model was used to simulate conditions of wetland systems (refer Chapter 12), including Namaleta Creek, Lunette Swamp, Bigfoot Swamp, and the supratidal wetland along the Skardon River South Arm. Modelling predicts that groundwater conditions in areas further away from the Project area than these wetlands (i.e. wetland complexes to the west and north) are unlikely to be affected.

For each trial all of the water supply bores described in Section 13.6.8 were considered to be operating fully until closure and the impact on groundwater from water supply is therefore included in the model simulations.

Groundwater conditions were simulated for wetlands in the years where pits will be operating locally under the mine plan (refer to Chapter 5). The years found to present the greatest potential impact for each of the wetlands are:

- **Namaleta Creek**: 2018 (Year 2 of mining), 2020 (Year 4 of mining), 2024 (Year 8 of mining)
- **Lunette Swamp**: 2020 and 2025 (Years 4 and 9 of mining)
- **Bigfoot Swamp**: 2022 and 2026 (Years 6 and 10 of mining)
- **Bigfoot Swamp and Skardon River South Arm supratidal wetland**: 2022 (Year 6 of mining)

13.6.9.1 Namaleta Creek

The years in which mining takes place to the immediate north and south of the river and which are significant to conditions in the Creek are 2018, 2020 and 2024. Modelled drawdown contours for these years are shown in Figure 13-12, Figure 13-13 and Figure 13-14 respectively.
During 2018 and up to 2020 (Figure 13-12 and Figure 13-13), mining of the pits and water supply from the Namaleta borefield, is predicted to result in potential drawdowns of 0.4 m at reaches of the Creek immediately adjacent to the former kaolin mine. A reduction in local baseflow has the potential to change normal tidal behaviour that could result in increased seasonal saline excursion upstream. Monitoring will be in place to detect saline water incursion (refer to monitoring plan described in Chapter 12 and Appendix 15) and inform operational decisions such as borefield pumping.

It is probable that the concentrated pattern of modelled water supply bores in the Namaleta borefield could be a significant factor affecting drawdown in this area. Therefore the exact location of future supply bores in the area will be chosen to avoid impacting baseflow and inducing potential intrusion of saline water. It should also be recognised that saline water intrusion into bores used by Gulf Alumina for mine site water supply (predominantly dust suppression) will detrimentally impact the ability to use water for supply purposes. Hence, as well as minimising the potential for environmental impacts, Gulf Alumina will seek to avoid saline water intrusion in bores for operational reasons.

Figure 13-12  Namaleta Creek: 2018 Drawdown (Year 2)
Following backfilling and the early stages of rehabilitation of mined areas by 2024 (Year 8), Figure 13-14 shows that it is expected that some recovery will take place with potential elevation of local levels along the northern bank of Namaleta Creek resulting from increased recharge to the rehabilitated pits. However, it is also evident that there is likely to be some drawdown from pits to the south while these pits are being mined. Following rehabilitation, local levels around pits to the south of Namaleta Creek will also be elevated through increased recharge.
13.6.9.2 Lunette Swamp

The years in which the Lunette Swamp is likely to be most impacted result from mining of the pits located immediately to the west (Year 4) and east (Year 9), as shown in Figure 13-15 and Figure 13-16 respectively.

During the years preceding Year 4 (2020) mining will take place to the west and south of Lunette Swamp, and there will be backfilling and rehabilitation under way. The result is that some surcharging of recharge will occur that will advance towards the south western fringe of the wetland. Mining will also occur to the north and east, but there will be no rehabilitation activity yet in that area, so there is likely to be a general reduction of levels which is evident in the positive drawdown contours.

In Year 9, mining of the pits immediately to the east also results in a decline in levels, which extend to the wetland area reducing groundwater heads by 0.1 m on its southern margin. It is planned that mining of the local pit will occur within a single dry season, so it is expected that decline in levels will reverse after a short time as there will be areas in rehabilitation both to the east and west of Lunette Swamp.

*Figure 13-15  Lunette Swamp: 2020 Drawdown (Year 4)*
13.6.9.3 Bigfoot Swamp

Modelling predicted that the largest drawdowns and surcharges affecting Bigfoot Swamp would occur during Year 6 and Year 10 as shown in Figure 13-17 and Figure 13-18 respectively.

In Year 6, mining to the east, and the borefield water supply towards the Port area (where three bores are proposed) combines to result in a cone of drawdown that approaches the north eastern side of Bigfoot Swamp. To the south east, the rehabilitation and backfilling of the pits mined in 2020 and 2021, could potentially raise levels towards Bigfoot Swamp, with a predicted increase in local groundwater head of 0.1 m.

The hydrogeology of Bigfoot Swamp is not known in detail, but it is considered that some perching occurs, particularly in the updip direction towards the south and east. It is possible that inflows enter Bigfoot Swamp from the south and east in the form of both baseflow and runoff. Any elevation in local groundwater level in this area will thus have the potential to introduce slight increases to the volume and surface area of the swamp.

By Year 10, local pits under rehabilitation, resulting in increased recharge, dominate with the model predicting elevated levels up to 0.3 m.
Figure 13-17  Bigfoot Swamp: 2022 Drawdown (Year 6)
13.6.9.4 Skardon River Supratidal Wetland

The greatest impacts to groundwater behaviour in the supratidal wetland along Skardon River South arm are predicted to occur during 2022 (Figure 13-19) as a consequence of mining on the bauxite plateau. The plateau is located at the top of the subcatchments that drain to the Skardon River. This would result in a partial and temporary loss of the host aquifer formation which supports groundwater flow in the area during the mining period, before backfilling occurs. The potential decline in groundwater head is predicted to be between 0.2 and 0.3 m along the wetland. This is expected to have a temporary impact on baseflow to the area during the mining period.

Figure 13-18  Bigfoot Swamp: 2026 Drawdown (Year 10)
Figure 13-19  Bigfoot Swamp/Skardon River: 2022 Drawdown (Year 6)

13.6.9.5  Post Mining

Figure 13-20 shows the predicted conditions for the entire Project area in the first year following mine closure where rehabilitation will still be under way. This shows that:

- at Namaleta Creek the predicted changes to recharge will result in elevated head which could range between 0.1 and 0.3 m
- elevated groundwater levels of up to 0.1 m will remain at Lunette Swamp
- elevated groundwater levels of approximately 0.2 m will remain at Bigfoot Swamp

This demonstrates the dominance of increased recharge during the rehabilitation phase in comparison to the mining phase resulting in elevated groundwater levels.
As noted in Appendix 4, groundwater levels and associated flow behaviour in the areas under rehabilitation have been observed to stabilise after a decade, once rehabilitation is mature.

13.7 Surface Water Modelling and Potential Impacts

13.7.1 Runoff Prediction

The AWBM rainfall runoff prediction model (Section 13.1.1) was used to simulate flows in each of the local catchments directly affected by mining (catchments 3, 4, 5, 6 and 7) as shown in Figure 13-2.
Catchment runoff will be affected by clearing, mining and rehabilitation which affects overland flow, aquifer recharge and groundwater storage. In order to characterise the behaviour of runoff resulting from changes to land use at different stages of the Project, representative changes were made to the baseflow index and baseflow recession constants in the AWBM model that simulate conditions associated with changes that can be expected to vegetation cover. These estimates affect the proportioning of components of the water balance and were made on the basis of the recharge predictions of Volker and Crees (1993) described in Section 13.6.3.

Runoff was predicted for the different stages of the Project as follows:

- unmined natural conditions, in which recharge is approximately 17% of rainfall (“Natural”)
- cleared conditions taken as the worst case to represent both mining and cleared situations, where 50% of rainfall is assumed to recharge the aquifer (“Mined”)
- mined rehabilitated conditions when recharge behaviour begins to return to pre-mining conditions at 26% of rainfall (“Rehabilitated”).

13.7.2 Impacts to Runoff

The assessment predicts that in all cases there is a decrease in wet season runoff, and a general increase in flow of up to 20% over the dry period from April to November. The catchments affected most are catchments 4 and 6 where the mining footprints are proportionally higher. These are shown in the plots in Figure 13-21 that summarises the temporary effects to seasonal runoff variation that result from altered recharge behaviour following changes to land use over the life of the Project.

![Figure 13-21 Runoff Variation (Catchments 4 and 6)](image)

There is elevated recharge to the aquifer and a reduction of surface runoff over the wet season. The higher recharge rates increase aquifer storage during the wet season, and when combined with reduced evaporative losses, lead to higher dry season runoff rate particularly in the early years following clearing
and mining. Although the percentage changes are greater for the dry season, this percentage change applies to a much lower volume of runoff in the dry season in comparison to the wet season.

An example of monthly averaged rainfall and percentage change in runoff for catchment 4 is presented in Table 13-3. This demonstrates that runoff is much greater during the wet season months and that mining results in a decrease in runoff during the wet months of approximately 2% to 3% as water is collected in the pits and recharged or evaporated. Once an area is subject to rehabilitation, wet season runoff decreases by less than 1% in comparison to pre-mining (natural) conditions. Examples for other catchments are provided in Appendix A of Appendix 4 and demonstrate similar runoff changes in the wet season and dry season for pre-mining (natural), mined and rehabilitated catchments.

### Table 13-3 Catchment 4 Runoff Prediction

<table>
<thead>
<tr>
<th>Month</th>
<th>Natural (m³/s)</th>
<th>Mined (m³/s)</th>
<th>Rehabilitated (m³/s)</th>
<th>Percentage of Natural Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>3.98</td>
<td>3.88</td>
<td>3.96</td>
<td>100.0% 97.4% 99.3%</td>
</tr>
<tr>
<td>Feb</td>
<td>5.85</td>
<td>5.72</td>
<td>5.82</td>
<td>100.0% 97.8% 99.4%</td>
</tr>
<tr>
<td>Mar</td>
<td>5.61</td>
<td>5.53</td>
<td>5.59</td>
<td>100.0% 98.6% 99.6%</td>
</tr>
<tr>
<td>Apr</td>
<td>2.24</td>
<td>2.28</td>
<td>2.25</td>
<td>100.0% 102.1% 100.6%</td>
</tr>
<tr>
<td>May</td>
<td>0.72</td>
<td>0.79</td>
<td>0.74</td>
<td>100.0% 110.6% 102.9%</td>
</tr>
<tr>
<td>Jun</td>
<td>0.35</td>
<td>0.41</td>
<td>0.36</td>
<td>100.0% 118.5% 105.0%</td>
</tr>
<tr>
<td>Jul</td>
<td>0.24</td>
<td>0.29</td>
<td>0.25</td>
<td>100.0% 119.7% 105.4%</td>
</tr>
<tr>
<td>Aug</td>
<td>0.18</td>
<td>0.21</td>
<td>0.19</td>
<td>100.0% 119.8% 105.4%</td>
</tr>
<tr>
<td>Sep</td>
<td>0.13</td>
<td>0.16</td>
<td>0.14</td>
<td>100.0% 119.8% 105.4%</td>
</tr>
<tr>
<td>Oct</td>
<td>0.11</td>
<td>0.13</td>
<td>0.11</td>
<td>100.0% 116.9% 104.6%</td>
</tr>
<tr>
<td>Nov</td>
<td>0.17</td>
<td>0.18</td>
<td>0.17</td>
<td>100.0% 106.5% 101.8%</td>
</tr>
<tr>
<td>Dec</td>
<td>1.00</td>
<td>0.99</td>
<td>1.00</td>
<td>100.0% 98.1% 99.5%</td>
</tr>
</tbody>
</table>

### 13.7.3 Namaleta Creek – Estuarine Wetlands

The downstream reaches of Namaleta Creek are host to estuarine wetlands that have the potential to be affected by mining activity through reductions in runoff and streamflow in Namaleta Creek which could have the potential to move the normal tidal excursion limit further upstream.

Impacts to the flow regime are expected to be limited. The catchments that would be most affected along the Namaleta Creek are catchments 5 and 6. The altered runoff in each catchment under mined and rehabilitated conditions are expressed as percentages relative to the pre-existing conditions and are shown in Table 13-4.

The changes to flow regime in each catchment show potential for increased flows to occur (relative to natural levels) during the dry season, with a smaller relative change as a reduction occurring during wet season months. However it is noted that although there is a smaller relative change in the wet season, the actual runoff is much greater during the wet season months. This would tend to move the tidal limit downstream during the wet season, and would allow a marginal movement upstream during the dry season, during the period that mining and rehabilitation was active in these catchments. The effects are likely to be temporary and limited in effect.
### Table 13-4 Percentage of Natural Runoff

<table>
<thead>
<tr>
<th>Month</th>
<th>Natural</th>
<th>Catchment 5</th>
<th></th>
<th>Catchment 6</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mine</td>
<td>Rehabilitated</td>
<td>Mine</td>
<td>Rehabilitated</td>
</tr>
<tr>
<td>Jan</td>
<td>100.0%</td>
<td>99.2%</td>
<td>99.8%</td>
<td>97.5%</td>
<td>99.3%</td>
</tr>
<tr>
<td>Feb</td>
<td>100.0%</td>
<td>99.4%</td>
<td>99.8%</td>
<td>97.9%</td>
<td>99.4%</td>
</tr>
<tr>
<td>Mar</td>
<td>100.0%</td>
<td>99.6%</td>
<td>99.9%</td>
<td>98.6%</td>
<td>99.6%</td>
</tr>
<tr>
<td>Apr</td>
<td>100.0%</td>
<td>100.6%</td>
<td>100.2%</td>
<td>102.0%</td>
<td>100.5%</td>
</tr>
<tr>
<td>May</td>
<td>100.0%</td>
<td>103.1%</td>
<td>100.8%</td>
<td>110.2%</td>
<td>102.8%</td>
</tr>
<tr>
<td>Jun</td>
<td>100.0%</td>
<td>105.4%</td>
<td>101.5%</td>
<td>117.7%</td>
<td>104.8%</td>
</tr>
<tr>
<td>Jul</td>
<td>100.0%</td>
<td>105.7%</td>
<td>101.6%</td>
<td>118.9%</td>
<td>105.2%</td>
</tr>
<tr>
<td>Aug</td>
<td>100.0%</td>
<td>105.8%</td>
<td>101.6%</td>
<td>119.0%</td>
<td>105.2%</td>
</tr>
<tr>
<td>Sep</td>
<td>100.0%</td>
<td>105.8%</td>
<td>101.6%</td>
<td>119.0%</td>
<td>105.2%</td>
</tr>
<tr>
<td>Oct</td>
<td>100.0%</td>
<td>104.9%</td>
<td>101.3%</td>
<td>116.2%</td>
<td>104.4%</td>
</tr>
<tr>
<td>Nov</td>
<td>100.0%</td>
<td>101.9%</td>
<td>100.5%</td>
<td>106.2%</td>
<td>101.7%</td>
</tr>
<tr>
<td>Dec</td>
<td>100.0%</td>
<td>99.4%</td>
<td>99.9%</td>
<td>98.2%</td>
<td>99.5%</td>
</tr>
</tbody>
</table>

### 13.7.4 Wetland Catchments

A review was completed for the Bigfoot Swamp and Lunette Swamp, which are sustained by catchments that drain the bauxite plateau across the proposed mining areas.

The catchment extent of each of these wetlands, along with the mine pit areas and flow directions are shown in Figure 13-22 and Figure 13-23 respectively.
Figure 13-22  Bigfoot Swamp Catchment

Figure 13-23  Lunette Swamp Catchment
13.7.5 Conceptual Hydrological Model for Wetlands

A conceptual model of the hydrology of the wetlands is shown in the schematic diagram in Figure 13-24, which assumes reasonable hydraulic continuity between the underlying aquifer and the surface water. It is not known if both systems are the same, however, it is expected that in each case there is some level of groundwater-surface water interaction that supports the wetland into the dry season after the local water table level has risen over the months from December to March.

![Figure 13-24 Schematic - Swamp Flow Processes]

13.7.6 Wetland Model

A reservoir model was developed of the above conceptual wetland system in GoldSim incorporating the AWBM model. The model includes all the factors shown in Figure 13-24 – runoff, baseflow, seepage, rainfall, evaporation and surface outflow. Model assumptions and input parameters are described in Appendix 4.

The model was calibrated for Bigfoot Swamp over the period August 2014 to March 2015, for which there were synchronous rainfall, evaporation and field data recorded as daily swamp water levels. The calibration of water levels for Bigfoot Swamp is shown in Figure 13-25, demonstrating that the model has a reasonable correlation with the recorded water levels.

The model indicates strongly that Bigfoot swamp is affected by the behaviour of both the groundwater seepage and surface runoff. It was found in calibration trials that it was not possible to replicate the behaviour which included a recession from August to December 2014 without allowing for a significant degree of seepage interchange to occur between the wetland and the surrounding aquifer through the bed of the swamp. It was also found that runoff behaviour is potentially highly responsive to the onset of the wet season rainfall; this is evident in the sharp rise in water levels shown in Figure 13-25, occurring in mid-December 2014.
13.7.7 Modelled Impacts to Wetlands

The model was used to predict water levels in wetlands for ‘natural’, ‘mined’ and ‘rehabilitated’ periods over a wet and dry season period (nominally August 2014 to March 2015).

Modelled results for Bigfoot Swamp and Lunette Swamp are presented in:

- **Figure 13-26** for Bigfoot Swamp showing water levels for natural (i.e. pre-disturbance) and mined conditions
- **Figure 13-27** for Bigfoot Swamp showing water levels for natural and rehabilitated conditions
- **Figure 13-28** for Lunette Swamp showing water levels for natural and mined conditions
- **Figure 13-29** for Lunette Swamp showing water levels for natural and rehabilitated conditions

These figures show that there is minimal impact to wetland levels during mined and rehabilitation conditions in comparison to the natural or pre-disturbance condition. The figures show that the wetland levels for ‘natural’ and ‘rehabilitated’ conditions are almost identical, demonstrating the following rehabilitation, modelling predicts there is insignificant impact on these wetland levels.

Lunette Swamp has a relatively small volume before it is overtopped, and hence the trials indicate that the flows over the wet season simulated were sufficient to keep it full through to March. However, the parameters applied in the trials were calibrated for Bigfoot Swamp, and so it should be recognised that the hydrology and hydrogeology around both wetlands could be different. The high rainfall early in the wet season in January 2015 results in a sharp flow increase resulting in high swamp elevations for all cases of recharge associated with potential changes to local land use.

Very minor drawdowns in level are evident as a result of the reduction in overland runoff for mined and rehabilitated conditions during the wet season months from January to March, with the maxima as 3.5 cm (Bigfoot Swamp) and 4.2 cm (Lunette Swamp).

During the wet season, flow reductions are evident between natural conditions and the mined and rehabilitated situations where the peak flows into the wetland areas can fall by up to 0.12 m$^3$/s (Bigfoot Swamp) and by 0.01 m$^3$/s (Lunette Swamp). However, it is clear from the water level hydrographs that
this change makes little difference to the levels (and hence to surface area). The increased flow under natural conditions will normally flow through the swamps and continue further down the catchment (surface outflow).

Under the cleared and mined conditions, baseflows would increase and contribute eventually to runoff further down the catchment. However, the release of baseflow from groundwater storage would result in lower runoff rates but that endure for longer periods further downstream while the upper catchment areas are temporarily cleared.

Figure 13-26  Modelled Water Levels for Bigfoot Swamp – Natural and Mined
Note that the water levels for ‘natural’ and ‘rehabilitated’ conditions are almost identical.

Figure 13-27  Modelled Water Levels for Bigfoot Swamp – Natural and Rehabilitated
Figure 13-28  Modelled Water Levels for Lunette Swamp – Natural and Mined
Note that the water levels and inflows to the swamp for ‘natural’ and ‘rehabilitated’ conditions are almost identical.

**Figure 13-29  Modelled Water Levels for Lunette Swamp – Natural and Rehabilitated**

### 13.7.8 Post Mining Hydrology

The restoration of the hydrological regime to the conditions or similar conditions that prevailed before mining depends on factors that relate particularly to landforming and revegetation. Landforming has the potential to improve drainage in areas where the landscape has depressions formed by loss of ore to prevent flooding during the wet season.

As part of closure planning Gulf will continue to acquire hydrological data through ongoing monitoring and regular hydrological assessment that will assist to inform site rehabilitation programmes.

The modelling indicates that changes to catchment flow behaviour are limited and likely to be local in nature. Downstream of the mine areas, the potential changes which could persist over the rehabilitation...
period following mining include a reduction of peak wet season flows, and a marginal elevation of dry season baseflow.

**13.7.9 Area of Catchments Impacted**

Table 13-5 shows the area of mining within each local catchment (Figure 13-2), including the Port infrastructure area. Table 13-5 marginally overestimates the area of mining within each catchment as it is based on original mine plan drawings which have subsequently been reduced in size. The water table in the Skardon River area is a subdued reflection of the local topography. The groundwater contours presented in Figure 13-9 have similar flow direction to the local surface water catchments and therefore mining will have a similar impact on the area and percentage of local groundwater flows.

A small area in the central extent of Pit 3 which is located within catchment 3 is likely to flow in a northerly direction towards Bigfoot Swamp and Skardon River (refer Figure 13-22). The actual mining area within catchment 3 is also relatively small, representing approximately 6.35% (142 ha) of the catchment.

As shown in Figure 13-23 flows from Pits 10 and a small part of Pit 11 are likely to flow towards Lunette Swamp.

It is expected that the majority of flows received by the supratidal wetlands are derived from the west of Skardon River (Pits 1, 2 and 3). These mining areas are not considered extensive (1.24% or 212 ha) in the context of catchment 7.

Pits 4, 5, 8, 9, 10, 11, 13, the north-west section of Pit 12 and the southern extent of Pit 3 are located in Catchment 4 and flows towards the wetland complexes to the north and west of the Project area.

Flows from Pits 14, 15 and southern extent of 12 are shown to flow towards Namaleta Creek, however these areas only represent approximately 10% (418 ha) of catchment 6.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Total Area (ha)</th>
<th>Area of Mining Within Catchment (Ha)</th>
<th>Percentage Area of Mining Within Catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1752.42</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>2</td>
<td>1601.17</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>3</td>
<td>2250.01</td>
<td>142.90</td>
<td>6.35%</td>
</tr>
<tr>
<td>4</td>
<td>5256.28</td>
<td>537.04</td>
<td>10.22%</td>
</tr>
<tr>
<td>5</td>
<td>3728.54</td>
<td>111.05</td>
<td>2.98%</td>
</tr>
<tr>
<td>6</td>
<td>4271.49</td>
<td>418.22</td>
<td>9.79%</td>
</tr>
<tr>
<td>7</td>
<td>17154.79</td>
<td>211.89</td>
<td>1.24%</td>
</tr>
</tbody>
</table>

**13.8 Potential Impacts**

The potential impacts to surface water hydrology are a result of changes to runoff and baseflow stemming from mining.

The potential impacts on groundwater hydrology are:

- changes to the hydrology and hydrogeology of shallow aquifers due to use of shallow aquifer water for mine water supply
- changes in the hydrogeological regime (colluvial and sandstone basement aquifers) resulting from clearing and mining activities
As described in Section 13.5.5, the GAB aquifer will not be impacted by the proposed shallow aquifer groundwater usage in the area.

The potential interaction of flood water with bauxite mining operations and former kaolin mine water management infrastructure is described in Chapter 14. Potential changes to flood behaviour as a result of the Namaleta Creel crossing area described in Chapter 14.

13.8.1 Changes to Runoff

Mining will result in altered drainage patterns due to excavation and earthworks following backfilling of pits, compaction from mining activity and rehabilitation of altered landforms. The post mining, rehabilitated landforms may contain depressions in some of the former pits from the volume of bauxite removed. It is not possible to predict these reliably, but depending on the drainage of these depressions this may lead to localised decreases in runoff as water is pooled and evaporates, or recharges shallow groundwater aquifers. This could also result in localised increases to runoff from compacted areas.

Similarly during mining, there may be localised changes to surface water runoff and baseflow through capture of runoff in pits which evaporates or releases to shallow groundwater, thereby decreasing overland flow. Any compaction of areas outside of the pits may also result in increased runoff.

Modelling of altered surface water and groundwater flows in response to changes in the catchments affected by mining as provided in Section 13.7, demonstrates that small net increases can be expected to dry season flows as a consequence of increased recharge. Although the net changes are relatively small when expressed in units of volume (m$^3$/s), they can represent as much as 20% increase to the relatively low dry season flows.

There is also likely to be a reduction of wet season peak runoff - particularly in areas where a significant component of the upstream catchment has been recently mined - because of the effect of clearing and mining in promoting recharge of the groundwater store.

Modelling of the hydrology of Bigfoot Swamp and Lunette Swamp was undertaken by considering runoff, baseflow, seepage, rainfall, evaporation and surface outflow (refer Section 13.7.7). The model was used to predict water levels in wetlands for ‘natural’, ‘mined’ and ‘rehabilitated’ periods over a wet and dry season period. Very minor drawdowns in level are evident as a result of the reduction in overland runoff for mined and rehabilitated conditions during the wet season months from January to March, with the maxima as 3.5 cm (Bigfoot Swamp) and 4.2 cm (Lunette Swamp).

During the wet season, flow reductions are evident between natural conditions and the mined and rehabilitated situations where the peak flows into the wetland areas can fall by up to 0.12 m$^3$/s (Bigfoot Swamp) and by 0.01 m$^3$/s (Lunette Swamp). However, it is clear from the water level hydrographs that this change makes little difference to the levels (and hence to surface area). The increased flow under natural conditions will normally flow through the swamps and continue further down the catchment (surface outflow).

As demonstrated in Section 13.7.9, the direct impact of mining on each of the local catchments is relatively small, with natural flow behaviour retained for the majority of the catchment. Therefore, despite the potential for mining to temporarily alter runoff and baseflow characteristics at the top of these catchments, this impact will be moderated by the continuing, natural flows downstream.

13.8.2 Changes to Groundwater Hydrology

Groundwater modelling (Section 13.6) demonstrates that there are a number of complex interactions of Project impacts on groundwater hydrology that may result in either increases or decreases to groundwater levels, as follows:
- Use of water from shallow aquifers for mine supply results in local drawdown, with modelled drawdown presented in Section 13.6.8.
- Groundwater seepage into pits may occur at times, requiring dewatering and hence drawing down groundwater levels.
- Mining and clearing have the potential to capture runoff in pits, elevating recharge to shallow aquifers.
- Following mining, during rehabilitation, mined areas have the potential capture runoff in pits and recharge shallow aquifers.
- Mined areas that have been backfilled and where rehabilitation is underway are still likely to have recharge rates that are above natural rates (a return to pre-mining conditions may take up to 10 years).
- Increased runoff from areas where the surface is compacted from mining activities may result in localised increases to runoff and decreased recharge of shallow aquifers.

A decline in groundwater levels has the potential to alter baseflows to the identified waters (creeks and swamps) downstream and down gradient of the Project. Use of shallow groundwater has the potential to shorten the period following the wet season in which shallow groundwater results in baseflows.

Modelling presented in Section 13.6.8, predicts that the water supply bores to the north of the Project area will have little or no effect on surrounding surface water bodies. The southern water supply bores could have an effect on the reach of Namaleta Creek adjacent to existing kaolin mine where levels are shown to be drawn down to between 0.1 and 0.2 m.

Modelled impacts from mining on groundwater levels at Namaleta Creek, Lunette Swamp, Bigfoot Swamp and Skardon River are presented in Section 13.6.9. Modelling demonstrates the following potential changes in groundwater levels during mining operations:

- between 0.4 m drawdown and 0.2 m elevation along Namaleta Creek
- between 0.1 m drawdown and 0.1 m elevation at Lunette Swamp
- between 0.1 m drawdown and 0.3 m elevation at Bigfoot Swamp
- between 0.2 m and 0.3 m drawdown along Skardon River South Arm supratidal wetland
- no modelled changes in groundwater levels at the wetland complexes to the west.

As mining progresses it is predicted to result in short term, local drawdown in groundwater levels near mining areas, however once rehabilitation has commenced it is expected that recovery (elevation) in groundwater levels will occur. As both active mining areas and progressive rehabilitation areas will exist in close proximity simultaneously, the modelled impacts on groundwater levels vary between drawdown and increased elevation. Following mining and progressive rehabilitation, it is expected that groundwater will be elevated at Namaleta Creek, Lunette Swamp, Bigfoot Swamp and Skardon River by between 0.1 m and 0.3 m. This demonstrates the dominance of increased recharge during the rehabilitation phase in comparison to the mining phase, resulting in elevated groundwater levels.

### 13.9 Mitigation and Management Measures

#### 13.9.1 Progressive Rehabilitation of Mined Areas

Following mining, ongoing progressive rehabilitation of the pit areas (refer Chapter 7) will result in runoff and baseflow characteristics more closely resembling the pre-mining runoff and baseflow characteristics of the area. As noted in Appendix 4, groundwater levels and associated flow behaviour in the areas under rehabilitation have been observed to stabilise after a decade, once rehabilitation is mature. Progressive
rehabilitation of mined areas will be important to promote the re-establishment of recharge to groundwater system to restore pre-mining seasonal behaviour.

The timeframes involved in recovery of groundwater levels (i.e. increasing levels where there has been a drawdown) can be gauged by reviewing the groundwater model outputs provided in Section 13.6.9.

Section 13.6.9.1 compares groundwater levels in the Namaleta Creek area in Years 2, 4 and 8 of mining:

- In Year 2 of mining drawdown is experienced
- By Year 4 of mining in rehabilitation areas, groundwater contours are elevated, indicating less than 2 years for recovery of groundwater levels in these areas.
- By Year 8 of mining, groundwater contours elevated in all areas north and south of Namaleta Creek where rehabilitation has been undertaken. This indicates less than 4 years for recovery of groundwater levels in these areas.
- The post mining landform (Section 13.6.9.5) shows that in the first year following mining all groundwater levels are elevated. This indicates less than 3 years for recovery of groundwater levels in all areas surrounding Namaleta Creek.

A comparison of groundwater levels near Bigfoot Swamp (Section 13.6.9.3) shows recovery of all groundwater between Years 6 and Years 10 (i.e. less than 4 years for recovery).

A comparison of groundwater levels in the Skardon River / Bigfoot Swamp area between Year 6 and post mining indicates all groundwater levels have recovered post mining (i.e. less than 5 years for recovery).

These are modelled predictions of changes in groundwater levels. The Groundwater and Surface Water Monitoring Plan (Appendix 15) and Section 12.10 describe the monitoring proposed to assess impacts on groundwater levels.

13.9.2 Shallow Aquifer Water Supply Management

As described in Chapter 6, there is potential to reduce or remove the need for shallow aquifer water supply through demand management such as recycling of water, use of dust suppressants and use of water stored in sediment ponds. These measures have the potential to reduce the number of bores in shallow aquifers required for water supply and hence reduce drawdown on groundwater levels.

13.9.3 Saline Water Intrusion

There is potential that use of groundwater from the Namaleta borefield and mining near Namaleta Creek may result in temporary reduction and reversal in groundwater gradient towards the coastal margin. This has the potential to lead to sea water intrusion in the aquifer. To limit or prevent this risk, the bore field will be designed to minimise this risk and it will be a priority whenever possible to use production bores away from Namaleta Creek. An early warning groundwater monitoring plan (Appendix 15 and Chapter 12) will be implemented at zones expected to be at risk, including monitoring of bores G3, G4, G12, G13 and G14. In addition the exact location of future supply bores in the area will be chosen to avoid impacting baseflow and inducing potential intrusion of saline water. Chapter 12 and Appendix 15 describe the salinity water quality monitoring plan to detect change in salinity of bores in the Namaleta aquifer.

13.9.4 Namaleta Creek Crossing

The design of Namaleta Creek crossing is described in Chapter 6. The upgraded crossing will result in the hydrology of the area more closely resembling its pre-disturbance condition, in comparison to the existing crossing. The potential impacts on flood behaviour of the Namaleta Creek crossing are described in Chapter 14, which demonstrates that the haul road crossing will not be overtopped by a 1:100 year flood.
13.9.5 Wetland Water Levels

Based on the modelling of wetland water levels provided in Section 13.7.6, the Project will have an insignificant impact on these wetland levels. Never-the-less, in order to determine the accuracy of modelling predictions, monitoring of wetland water levels and surrounding aquifer water levels will be undertaken (refer to Section 13.9.6). Should monitoring demonstrate changes in the hydrology of wetlands as a result of mining, with the potential for significant impacts on the ecology of the wetland, the following mitigation measures will be adopted:

- Local groundwater usage for mine water supply will be reduced in areas where groundwater supply is one of the factors impacting on wetland levels.
- Mining activities may be reduced in areas with potential for impact until such time as wetland hydrology is restored.
- Buffer zones around wetlands (refer to Chapter 15) may be increased if it is found that the proposed buffer zones provide insufficient protection.
- Early rehabilitation of mined areas that potentially impact wetland levels will be promoted.

13.9.6 Monitoring Plan

The Surface Water and Groundwater Monitoring Plan, including proposed receiving environment monitoring program is described in Appendix 15 and Chapter 12. The proposed monitoring program of flora and fauna associated with wetlands and watercourses is described in Chapter 16 and Appendix 16.

Ongoing monitoring of surface water and groundwater during operations will inform the understanding of the complex rainfall, runoff and groundwater seepage interactions. Water levels and flows in receiving water will be monitored to understand trends, detect adverse changes to trends and develop remedial strategies where required. This is likely to involve the use landform design to alter drainage conditions as part of closure design.

Ongoing groundwater monitoring and modelling will be undertaken to improve understandings of the local hydrogeological regime and to support identification and prediction of potential impacts of mining and groundwater use in supply. Groundwater and climate monitoring is important for detecting trends such as declining water levels, that will assist in improvement of water management across the Project area. The groundwater and hydrological models will be progressively updated as additional monitoring data becomes available and detailed mine planning is undertaken. During mining the groundwater and hydrological models will be calibrated against monitoring results observed in the field.

During operations, ongoing monitoring will support modelling to determine improved estimates of recharge and to understand the timescales involved for rehabilitating mined areas so that the hydrological regime can approach pre-mining conditions and stabilise.

Ongoing monitoring and modelling of the hydrological and ecological impacts of the Project on wetland and watercourse ecosystems will be used to inform mine planning decisions such as the sequence of mining, effective of rehabilitation strategies and constraints to proposed mining zones.

13.9.7 Management Measures in Response to Monitoring

The methodology for determining whether the Project has resulted in a change in groundwater levels is described in Appendix 15 and involves comparing groundwater level logger data against modelled percentile ranges in baseline groundwater level.

Where, over a period of 3 or more months, monitored water levels within groundwater exceed the 90th percentile or fall below the 10th percentile of the modelled groundwater levels, Gulf Alumina will:

- Compare water levels in compliance bores with water levels in reference bores over the period
Where trends in water levels in compliance bores are similar to those of reference bores then no action will be taken.

Where trends in water levels in compliance bores are different to those of reference bores, then Gulf will Alumina will complete an investigation into the potential for environmental harm and provide a written report to the administering authority in the next annual return outlining:

- details of the investigations carried out
- actions taken to prevent environmental harm.

Investigations into the potential cause of the variance considering:

- rainfall
- trends in water level relative to trends in rainfall
- quantum of change relative to quantum of natural change within bores
- proximity of mining activities to bores
- proximity of bores used for aquifer pumping for mine water supply
- changes in wetland water levels.
- mining activities by other proponents in the area, in particular Metro Mining’s proposed mining activities near Bigfoot Swamp.
- results of vegetation and aquatic ecology monitoring

Where Project activities result in a short term change (e.g. over a period of 12 months) in bore water levels that is considered to be resulting in an impact to groundwater dependent ecosystems, Gulf Alumina will:

- cease pumping water from aquifers with hydrological connection to the groundwater dependent ecosystems
- alter the location of mining away from the affected groundwater dependent ecosystems and commence rehabilitation of the nearer mining area
- reduce mining activities in areas with potential for impact until such time as groundwater dependent ecosystems hydrology is restored.
- increase buffer zones around groundwater dependent ecosystems if it is found that the proposed buffer zones provide insufficient protection.

Should activities be demonstrated to have a long term impact on groundwater water levels and associated, dependent vegetation and aquatic ecology (as measured in accordance with the Vegetation and Aquatic Ecology Monitoring Program in Appendix 16) despite the implementation of management measures, then offsets will be proposed for significant residual impacts. Long term impacts will be measured over the operational life of the mine comparing vegetation and aquatic ecology dependent on groundwater pre mining to post mining.

### 13.10 Risk Assessment

A risk assessment assessing the likelihood and significance of impacts to surface water and groundwater hydrology from the Project is provided in Table 13-6. The risk assessment considers mitigated risk; that is, the impact from the Project with the implementation of management measures. The risks to surface water and groundwater hydrology are low to medium.

**Table 13-6  Risk Assessment and Management Measures for Impacts to Hydrology**
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water hydrology</td>
<td>Mining of bauxite significantly alters hydrology of wetlands and watercourses. Refer Section 13.7 and Section 13.8.</td>
<td>Refer Section 13.9</td>
<td>Unlikely</td>
<td>Moderate</td>
<td>Medium</td>
</tr>
<tr>
<td>Groundwater hydrology</td>
<td>Use of shallow aquifer bores for water supply results in significant drawdown of groundwater. Refer Section 13.6 and Section 13.8.</td>
<td>Refer Section 13.9</td>
<td>Unlikely</td>
<td>Minor</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Mining of bauxite significantly alters groundwater hydrology of wetlands and watercourses. Refer Section 13.6 and Section 13.8.</td>
<td>Refer Section 13.9</td>
<td>Unlikely</td>
<td>Moderate</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Changes to groundwater hydrology result in salt water intrusion. Refer Section 13.6 and Section 13.8.</td>
<td>Refer Section 13.9</td>
<td>Possible</td>
<td>Minor</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Changes to groundwater hydrology result in GAB aquifer drawdown. Refer Section 13.5.</td>
<td>n/a</td>
<td>Rare</td>
<td>Minor</td>
<td>Low</td>
</tr>
</tbody>
</table>

13.11 Cumulative Impacts

Chapter 12 describes the projects considered as potentially having a cumulative impact with the Skardon River Bauxite Project. The only project considered to have a cumulative impact on surface water and groundwater hydrology with the Skardon River Bauxite Project is Metro Mining Ltd’s Bauxite Hills project, which is described in Chapter 12.

Metro Mining submitted an EPBC Act Referral for the Bauxite Hills project in August 2015 (EPBC Act Referral 2015/7538). This Referral contains the latest publically available environmental impact assessment for the Bauxite Hills project. Gulf Alumina recognises that Metro Mining submitted a Referral variation in November 2015 to increase the annual volume of bauxite mined and reduce the overall duration of the Project, although the total volume of bauxite mined will remain similar. However, there is no publically available information on environmental impacts of the revised mine plan. Therefore, Gulf Alumina has used the information contained in the EPBC Act Referral to assess cumulative impacts.

The conceptual hydrogeology of both project areas is the same for the Skardon River Bauxite Project and Bauxite Hills Project, including stratigraphy, aquifers and groundwater contours. The groundwater model presented in Metro’s Referral uses similar concepts and inputs as the groundwater model presented for the Project.

The Referral document shows changes in groundwater levels, as a result of the Bauxite Hills project, of:
Predicted maximum increase in groundwater level of 0.2 m at Bigfoot Swamp.

- No decrease in groundwater levels at Bigfoot Swamp.
- No change in groundwater levels at Lunette Swamp, Namaleta Creek or the estuarine section of the Skardon River.

As the Bauxite Hills Project does not predict an impact on Lunette Swamp, Namaleta Creek or the Skardon River, there can be no cumulative impacts with the Skardon River Bauxite Project at these environmental features.

The Skardon River Bauxite Project EIS assesses impacts on Lunette Swamp, Namaleta Creek and the Skardon River.

The Referral states, in relation to Bigfoot Swamp, that:

- The net groundwater discharge volume to Bigfoot Swamp in a given year is predicted to increase by up to 18% when mining takes place in the surrounding area (Figure 6-32).
- The post-mining discharge volume is predicted to decrease by 3% because the peak water table to the south and, to a lesser extent north, of the swamp is constrained by the lowered ground surface, resulting in a small reduction in the hydraulic gradient towards the swamp during the wet season compared to the ‘base case’ (Figure 6-32).
- The volume of groundwater discharged to Bigfoot Swamp is predicted to increase by up to 12% and 27% in a given mining year for additional 20% and 60% recharge, respectively.
- In reality, portions of groundwater discharged to Bigfoot Swamp during mining may be lost as runoff and subsequently enter surface water courses. Water in the mine pits surrounding the swamp will also pool to some elevation above the pit floor and the predicted reduction in discharge rate is therefore considered the most conservative scenario.

The groundwater model for the Skardon River Bauxite Project (refer above) predicts that:

- The largest drawdowns and surcharges affecting Bigfoot Swamp would occur during Year 6 and Year 10.
- In Year 6 Project activities could potentially raise levels towards Bigfoot Swamp, with a predicted increase in local groundwater head of 0.1 m.
- By Year 10, local pits under rehabilitation, resulting in increased recharge, dominate with the model predicting elevated levels up to 0.3 m.
- Post mining there will be elevated groundwater levels of approximately 0.2 m will remain at Bigfoot Swamp.

Both models predict similar changes in groundwater levels at Bigfoot Swamp, with an increase in elevation of approximately 0.2 m, as a result of the respective mining activities of each project.

However, as demonstrated above, water levels in Bigfoot Swamp are a function of groundwater recharge, seepage, rainfall, runoff and evaporation. A model was created for the Skardon River Bauxite Project, considering all these factors, to predict changes in Bigfoot Swamp water level as a result of Project activities. The model predicts that there will be very minor drawdowns in water level as a result of the reduction in overland runoff for mined and rehabilitated conditions during the wet season months from January to March, with the maxima as 3.5 cm at Bigfoot Swamp.

The Referral does not contain any similar modelling to predict changes in Bigfoot Swamp water levels as a result of the Bauxite Hills Project.
Information provided in Chapter 12 on water levels in Bigfoot Swamp demonstrates that natural variability in water level over the wet season and dry season is approximately 3 m. This is well in excess of the:

- modelled impact to water level (3.5 cm) for the Skardon River Bauxite Project
- modelled increase in groundwater levels (one of the factors influencing Bigfoot Swamp water level) by 0.2 m in both project’s models as a result of each project’s separate mine plan.

Information in Chapter 12 on bore water levels demonstrates that the bores closest to Bigfoot Swamp (C2 and G10) fluctuate by 6 m and 7 m respectively over the wet season and dry season. Natural variation is therefore well in excess of predicted change in groundwater levels in both project’s models (increase of 0.2 m).

It is not possible to quantify the change in groundwater levels or wetland levels precisely based on the information provided in the Referral and for the Project. A single groundwater model would not necessarily result in drawdowns (or increases in elevation) of groundwater that are the sum of the two models. However, it is reasonable to assume that the maximum impact – which would rely on both mine plans resulting in mining occurring locally near Bigfoot Swamp at the same time for each project – would be limited to a 0.4 m increase to groundwater levels. These increases in groundwater level are minor in the context of natural variation in both groundwater levels and Bigfoot Swamp water levels. This increase in recharge may be offset by decreased runoff resulting in very minor changes in Bigfoot Swamp water level.

The Surface Water and Groundwater Monitoring Plan (Appendix 15) provides:

- a comprehensive suite of water level monitoring in swamps and bores, including timing, location and reporting of monitoring
- criteria to assess whether change in water levels is a result of Project activities
- management measures should monitoring indicate a change in water levels as a result of Project activities resulting in impacts to wetland ecology.

Based on the information in the Referral, Metro Mining will also implement a similar swamp water level and groundwater bore monitoring plan. Monitoring information will be shared between Gulf and Metro.

The Vegetation and Aquatic Ecology Monitoring Plan (Appendix 16) describes monitoring of vegetation and aquatic ecology at Bigfoot Swamp (and all other wetland and watercourse features) and will complement the water monitoring program. The Vegetation and Aquatic Ecology Monitoring Plan describes:

- the proposed wet season and dry season monitoring of wetland eco-system health (including Bigfoot Swamp) prior to mining.
- criteria to assess the health and integrity of Bigfoot Swamp (and all other wetland ecosystems)
- establishment of reference sites and / or baseline data against which change in Bigfoot Swamp (and all other wetland ecosystems) can be measured
- management measures should monitoring indicate a change in vegetation or aquatic ecology monitoring criteria as a result of Project activities.

It is expected that Metro Mining will also implement a similar vegetation and aquatic ecology monitoring program in Bigfoot Swamp, with information shared between Metro and Gulf.

Gulf will cooperate with Metro on implementation of management measures should these be required.
If management measures are required to mitigate impacts detected through monitoring, and those management measures do not achieve the desired mitigation, then offsets will be proposed for any residual impacts.

13.12 Conclusion

The hydrological and hydrogeological contexts of the Project area have been described. Rainfall, intensity-frequency-duration relationships, evaporation, flow Regimes and runoff have been estimated and modelled for the Project area, demonstrating the relationship between wet season rainfall and hydrological response.

The groundwater resources in the area lie within the Carpentaria Basin. The stratigraphy of the Project area from oldest to youngest is Helby Beds / Garraway Beds / Gilbert River Formation, Rolling Downs Formation, Bulimba Formation, alluvium / valley cut and fill deposits, and surficial beach sand deposits. The shallow aquifer is significant to the Project as a potential water supply. The water table in the Skardon River area is a subdued reflection of the local topography with deeper levels on the bauxite plateau and shallower levels in the low lying drainage areas. The bauxite deposit is located on the Weipa Plateau at 10 - 20 m AHD, and is partly dissected by drainage channels and consists of deeply weathered profile of bauxite, ferricrete and clay capping the Bulimba Formation. The Project area is made complex by the depositional history which has resulted in local alluvial aquifer systems that are associated with palaeochannels, including along Namaleta Creek and the Lunette Swamp area.

The Rolling Downs Group extends to between 530 and 600 m below ground level and confines the GAB. Hence it is believed that any groundwater dependent ecosystems in the Project area are not linked to the GAB.

The potential impacts to surface water hydrology are a result of changes to runoff and baseflow stemming from mining. The potential impacts on groundwater hydrology are result of use of shallow aquifer water for mine water supply and changes in the hydrogeological regime resulting from clearing and mining activities.

Modelling of altered surface water and groundwater flows in response to changes in the catchments affected by mining demonstrates that small net increases can be expected to dry season flows as a consequence of increased recharge. There is also likely to be a reduction of wet season peak runoff - particularly in areas where a significant component of the upstream catchment has been recently mined - because of the effect of clearing and mining in promoting recharge of the groundwater store.

Modelling of the hydrology of Bigfoot Swamp and Lunette Swamp was undertaken by considering runoff, baseflow, seepage, rainfall, evaporation and surface outflow. The model was used to predict water levels in wetlands for ‘natural’, ‘mined’ and ‘rehabilitated’ periods over a wet and dry season period. Very minor drawdowns in level are evident as a result of the reduction in overland runoff for mined and rehabilitated conditions during the wet season months from January to March, with the maxima as 3.5 cm (Bigfoot Swamp) and 4.2 cm (Lunette Swamp).

The direct impact of mining on each of the local catchments is relatively small (1% to 10%), with natural flow behaviour retained for the majority of the catchment. Therefore, despite the potential for mining to temporarily alter runoff and baseflow characteristics at the top of these catchments, this impact will be moderated by the continuing, natural flows downstream.

Groundwater modelling demonstrates that there are a number of complex interactions of Project impacts on groundwater hydrology that may result in either increases or decreases to groundwater levels.

Modelling predicts that the water supply bores to the north of the Project area will have little or no effect on surrounding surface water bodies. The southern water supply bores could have an effect on the reach
of Namaleta Creek adjacent to existing kaolin mine where levels are shown to be drawn down to between 0.1 and 0.2 m.

Modelled impacts from mining on groundwater levels at Namaleta Creek, Lunette Swamp, Bigfoot Swamp and Skardon River demonstrates the following potential changes in groundwater levels during mining operations:

- between 0.4 m drawdown and 0.2 m elevation along Namaleta Creek
- between 0.1 m drawdown and 0.1 m elevation at Lunette Swamp
- between 0.1 m drawdown and 0.3 m elevation at Bigfoot Swamp
- between 0.2 m and 0.3 m drawdown along Skardon River South Arm supratidal wetland
- no modelled changes in groundwater levels at the wetland complexes to the west.

As mining progresses it is predicted to result in short term, local drawdown in groundwater levels near mining areas, however once rehabilitation has commenced it is expected that recovery (elevation) in groundwater levels will occur. As both active mining areas and progressive rehabilitation areas will exist in close proximity simultaneously, the modelled impacts on groundwater levels vary between drawdown and increased elevation. Following mining and progressive rehabilitation, it is expected that groundwater will be elevated at Namaleta Creek, Lunette Swamp, Bigfoot Swamp and Skardon River by between 0.1 m and 0.3 m. This demonstrates the dominance of increased recharge during the rehabilitation phase in comparison to the mining phase, resulting in elevated groundwater levels.

Groundwater levels and associated flow behaviour in the areas under rehabilitation have been observed to stabilise after a decade, once rehabilitation is mature. Progressive and final rehabilitation of mined areas will be important to promote the re-establishment of recharge to groundwater system to restore pre-mining seasonal behaviour.

Ongoing groundwater monitoring and modelling will be undertaken to improve understandings of the local hydrogeological regime and to support identification and prediction of potential impacts of mining and groundwater use in supply. Management measures are proposed should monitoring indicate that the Project is impacting groundwater levels.

With the implementation of proposed mitigation measures, environmental objectives and performance outcomes are expected to be achieved and the risks to surface water and groundwater hydrology are low to medium.