1.1. Surface and Groundwater Resources

1.1.1. Introduction

The west coast of South Africa is an arid area. Mean annual precipitation is less than 100mm, the majority of which falls in the winter months May to July / August, and potential annual evaporation from open water surfaces is of the order of 2 000mm. The temperature regime is, however, moderate, with a mean maximum summer temperature of less than 30°C, and an average of around 18°C in July.

The Kamiesberg project is situated in Water Management (WMA) Area 14 – Lower Orange and straddles the catchment divide between quaternary catchments F50G and F40H (DWAF 2004). The natural mean annual runoff of all the coastal catchments in the WMA, which stretch some 285km from Strandfontein in the south to Alexander Bay at the mouth of the Orange River in the north, is estimated to be 24 million cubic metres (Mm³). All rivers in the area are ephemeral / episodic, and flow only sporadically in response to high rainfall events, mostly on their upper catchments, remote from the coast, where annual rainfall can exceed 100mm. As a result available reliable yield from surface water sources in all the coastal catchments is estimated to be zero, while reliable yield from groundwater from the catchments is estimated to be a total of 3 Mm³/a. Approximately 6 Mm³/a of water is transferred into the area from the Orange River to meet the urban / domestic requirements in the Springbok area.(DWAF 2004).

Much of the data and information in this section is synthesised from four reports prepared by Schlumberger Water Services (SWS) for Zirco, as follows:

- A hydrogeological scoping assessment of the Kamiesberg project area (SWS 2012), the results of which were used to establish a hydrogeological baseline for the site prior to the commencement of mining activities, and to make recommendations for project implementation to ensure water resource protection.

- A full hydrological and hydrogeological prefeasibility study (PFS) for the Kamiesberg project area (SWS 2013), which provides a pre-feasibility assessment of the surface water, groundwater and hydro-geochemistry issues related to mining, and provides an assessment of the potential impacts to these systems, based on the current preliminary mine plan for the Kamiesberg project. The PFS comprised the following studies:
  - A hydrological study to determine the flood risks to infrastructure intended to be built close to the ephemeral rivers in the mining area.
  - A hydrogeological study, including drilling new boreholes, to better characterise the site lithology, aquifer units and groundwater regime.
  - Numerical modelling of the site to assess the potential risks associated with the use of

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1 Since the First Edition of the NWRS was published the number of WMAs has been reduced from 19 to 9 to reduce the number of management institutions that need to be created. The entire Orange River catchment is now WMA 6.

2 The data in the First Edition of the NWRS has not been up-dated in the 2nd Edition, which was published in 2013.
seawater in mineral processing, especially storing tailings and backfilling with material saturated with seawater, and the associated impacts on water resources in the area.

- A hydro-geochemical study to characterise the physico-chemical quality of the water resources on site, including the presence of radioactive isotopes, and to assess the potential for the use of seawater to leach elements from the mineral sands.

- Additional hydrogeological studies, including further numerical modelling, for the project area (SWS 2014), to further refine the hydrogeological assessment of the site and to identify potential risks and impacts related to specific facilities and operations on the site, and to support future water resource, environmental and mine planning decisions.

- Additional field surveys, empirical observations, water quality analyses and numerical model simulations to investigate the potential impact of project implementation on the hydrochemistry and ecology of the Groenrivier estuary (SWS 2015).

Other sources of data and information are referenced in the text, and a list of references is provided.

1.1.2. Surface water

Two rivers, the Groenrivier and the Bitterrivier, border the mining area to the south and north respectively (Figure 1.1). Neither river transects the mining areas, but a small tributary of the Bitter – the Outeepriver - flows through the north-eastern corner of the Leeuvlei mining area.

The lower reaches of both rivers flow through the Namaqua National Park, the boundaries of which are shown in green on Figure 1.1.

Figure1.1: Rivers in the project area

The Groen and the Bitter, as is the case with other rivers in Namaqualand, comprise relatively small river channels (in places, more than one channel) meandering in wide, shallow, alluvium-filled valleys that have been incised over time into the granite bedrock (Heydorn & Grindley, 1981a).
The episodic nature of the flow in the rivers is confirmed by records from a hydrological gauging station (F5H001) on the Swartdoring River, a tributary of the Groenrivier, at Bruinjieshoogte. The station, which is the only gauge on the Groenrivier system, has a 92% complete verified daily flow record from April 1967 to March 2014. The area of the catchment upstream of the gauging station is 2 349km², about 43% of the total catchment area – 4 500km² – at the estuary. A brief analysis of the 531 months for which peak flow data is recorded indicates that there was no flow in the river for 445 months (84%). Peak flow rates exceeded 1m³/sec in 28 months, 10m³/sec in 13 months, and 20m³/sec in 5 months. The two maximum recorded flow rates during the 57 years of the gauging station’s operation were 46m³/sec (June 1967) and 45m³/sec (August 1974). During these events it is probable that the peak flow rates in the downstream reaches of the system, closer to the mining areas, were greater than those at the gauging station, because of the greater catchment area. It is, however, meteorologically improbable that the peak flow rates increased by the ratio of the catchment areas: that is, they were unlikely to have exceeded 100m³/sec.

The ephemeral nature of the rivers in the project area means that surface water resources are not used to any significant extent in the area, either for domestic use or stockwatering. Neither river flows sufficiently reliably to be considered as a possible source of water for mining operations.

**Flooding**

Although there is no visible flow in the rivers for most of the time they do experience flooding events from time to time. It is important to be aware of the probable extent of out-of-channel inundation arising from such events, in order to ensure that floods do not damage mining infrastructure near to the rivers, and equally to ensure that the rivers are not affected by mining infrastructure.

In the absence of published flood flow data for the river systems the flooding regimes were estimated using the DWAF publication TR137 – Regional Maximum Flood Peaks in Southern Africa (DWAF 1988), as recommended in the Best Practice Guidelines for Water Resource Protection in the South African Mining Industry (DWAF 2006). The process followed to estimate the extent of flooding resulting from high-flow events with long return periods was as follows:

(i) Estimate the catchment areas at points on each river where flooding may impact on mining activities.

(ii) Identify the regional category of the catchment using the categorisation in TR 137.

(iii) Estimate the peak flow magnitude (Q), in cubic metres per second (m³/sec), of the Regional Maximum Flood (RMF) using the relationships presented in TR 137.

(iv) Estimate the peak flow magnitude for floods with return periods of 50, 100 and 200 years using the relationship between such floods and the RMF in TR137.

**Note:** TR137 presents relationships between the RMF and floods of other return periods for South Africa and also for Namibia. The flood magnitudes for Namibia are higher than for South Africa, and it was considered prudent to use the higher, more conservative (Namibian) estimates, given the uncertainties in the data used to derive them.

The results of the flood peak magnitude estimates are shown in Table 1.1.

### Table 1.1: Estimated peak flood magnitudes at selected points in the project site

<table>
<thead>
<tr>
<th>River</th>
<th>Location</th>
<th>Catchment Area (km²)</th>
<th>QRMF (m³/s)</th>
<th>South African relationship</th>
<th>Namibian relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q50 (m³/s)</td>
<td>Q100 (m³/s)</td>
<td>Q200 (m³/s)</td>
</tr>
<tr>
<td>Groen</td>
<td>A</td>
<td>3 327</td>
<td>1 108.5</td>
<td>395.8</td>
<td>517.7</td>
</tr>
<tr>
<td>Bitter</td>
<td>B</td>
<td>484</td>
<td>310.6</td>
<td>91.5</td>
<td>125.9</td>
</tr>
<tr>
<td>Outeep</td>
<td>C</td>
<td>91</td>
<td>165.2</td>
<td>41.2</td>
<td>59.2</td>
</tr>
</tbody>
</table>

Locations:
A – Groenrivier, south-west corner of Roode Heuvel block.
B – Bitterrivier, north-west corner of Leeuvlei block.
C – Outeeprivier, Boundary of Leeuvlei block upstream of confluence with Bitterrivier.
Source: Adapted from SWS 2013, Table 3.2

(v) Define the physical dimensions of the river channels, including the overbank areas, and the channel gradient, using readily available terrain data, and describe the reaches of the rivers using a number of representative channel cross-sections (transects).

Note: Where the Groenrivier borders the Roode Heuvel block and where the Outeeprivier transects the Leeuvlei block, bespoke Light Detection and Ranging (LIDAR) data was available, which enabled reasonably high definition (0.5m contour intervals), of the river channels. Where the Leeuvlei block extends to the Bitterrivier at its north-eastern extremity, very limited high-definition terrain data was available, and the definition of the river channel was therefore limited and less precise than for the other rivers.

(vi) Estimate the flood profiles in terms of water depths and widths of inundation for each return period using the Conveyance Estimation System (CES) (EA 2004), developed by HR Wallingford LTD for the UK Environment Agency. Flood profiles and widths of inundation were estimated for the following river reaches:
- Groenrivier: ±6km upstream from the SW corner of Roode Heuvel block.
- Bitterrivier: ±500m where the Leeuvlei block abuts the river.
- Outeeprivier: ±5km upstream from the Outeeprivier / Bitterrivier confluence.

Given the uncertainties in the data used to determine the flood profiles the results must be regarded as preliminary. The analysis does, however, indicate that the extent of flooding during the 100- and 200-year floods is not expected to exceed the limits of the well-defined riverbed / floodplain areas of any of the rivers, even for the higher peak magnitudes derived by using the Namibian relationships between RMF and other return periods. The analysis indicates, for instance, that it is highly improbable that District Road DR 2938, which runs alongside the Groenrivier for much of its length between the N7 and the mine site, and which will be used as the transport route to and from the mine, will be inundated by large floods.

Accordingly it can reasonably be concluded that the risk to mine infrastructure from flooding will be restricted to that built within the riverbed / floodplain areas. This includes the upgraded District Road (DR 2939) crossing of the Groenrivier, and the pipeline crossing the Groenrivier to deliver process water (seawater) to the mine.

Estuaries
The estuaries of the Groenrivier and the Bitterrivier lie to the south and the north of the proposed mining area respectively. Both estuaries are within the boundaries of the Namaqua National Park. Recent scientific / technical data and information on the estuaries is very limited, and the most comprehensive compilation of information remains Part II of the CSIR's 1981 Estuaries of the Cape series of reports, Synopses of Available Information on Individual Systems, 1981, edited by Heydorn & Grindley.

Groenrivier estuary
In 1981 Heydorn & Grindley reported that “The state of knowledge of the [estuary of the] Groen [River] is poor. The area, being remote, has received little attention in the past and the bulk of information in this report originates from the Estuarine and Coastal Research Unit (ECRU) survey.” (Heydorn & Grindley 1981a).

The areal extent of the estuary was reported in Heydorn & Grindley (1981a) to be around 28ha, and at the time of the survey, in October 1980, the approximate area of open water in the lagoon was 13ha. Prior to the survey the previous significant surface flow was recorded at the Swartdoring gauging station in February 1976.
Among the conclusions of the report were:

- Although the Groen flows infrequently, probably once in about five years, surface water is always present in the estuary, even during dry periods.
- The occurrence of perennial water in the estuary makes it an important wetland habitat on the Namaqualand coast, particularly in respect of the diversity and abundance of aquatic bird life, since river mouths on the coastline between the Groen and Orange are often dry. **Note**: The importance of the estuary for bird life is also noted by the Working for Wetlands Kamiesberg Wetland Project (see next section), and is the primary reason for the proposed rehabilitation of certain aspects of the wetland. The list of birds expected to be found in the estuary is reproduced from a 1991 publication by the CSIR’s AEF Heydorn.
- The water body in the estuary appears to be partially maintained during dry periods by springs situated on the flood plain in the upper reaches of the estuary (that is, about 2.5km upstream from the river mouth).
- The volume of inflow from the springs upstream of the head of the estuary is insufficient to compensate for the evaporative losses from the water surface, resulting in a gradual reduction of the water level in the lagoon and a progressive increase in salinity. This is especially so in the downstream reaches of the lagoon, where extreme hypersalinity was reported to occur. Such extreme saline conditions appeared to be moderated in the upper reaches of the estuary by the diluting effect of the springwater, which emphasised the importance of the wetland source of the system.
- Elevated salinity in the lower reaches of the closed estuary after extended periods of zero surface flow places a severe constraint on the ecological viability of the estuary, as very little aquatic life is able to survive in such extreme saline conditions.

The report includes details of salinity measurements taken on four separate occasions: January 1979 (Grindley); October 1980 (ECRU survey); February 1981 (Heydorn & Heinecken) and March 1981 (Stauth). On all occasions the mouth of the estuary was reported to be closed. The results are tabulated in Table 1.2, and indicate that the water in the estuary is always highly saline, but on occasion there is a decreasing salinity gradient from the mouth of the estuary to the head.

**Table 1.2: TDS levels recorded in the Groenrivier estuary 1979 to 1981**

<table>
<thead>
<tr>
<th>Date</th>
<th>Mouth</th>
<th>Mouth +100m</th>
<th>Mouth +200m</th>
<th>Mouth +300m</th>
<th>Mouth +700m</th>
<th>Mouth +1000m</th>
<th>Mouth +1 100m</th>
<th>Middle reaches</th>
<th>Head of Lagoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 1979</td>
<td>118 000</td>
<td>95 000</td>
<td>91 000</td>
<td>44 000</td>
<td>29 000</td>
<td>18 000</td>
<td>12 000 (location not specified)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>October 1980</td>
<td>70 000</td>
<td>65 000</td>
<td>47 000</td>
<td>7-8 000</td>
<td>10 000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February 1981</td>
<td>117 000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>115 000 (location not specified)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March 1981</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>125 000 (location not specified)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TDS in mg/litre in all cases

*Source: Data from Heydorn & Grindley 1981a*

In addition:

- In October 1980 the salinity of the flow from the spring feeding the southern channel was recorded as between 6 000 and 8 000 mg/l (which is approximately equal to the TDS recorded in the south channel of the lagoon).
- In February 1981 the salinity of the flow from the springs feeding the south and north channels were recorded as 6 000 mg/l and 47 000 mg/l respectively.

The period over which the salinity measurements were taken in the estuary, and for a number of years prior to them, were exceptionally dry. Although there had been a major flood (maximum flow rate 45 m3/sec) in August 1974, the only other flow events recorded at hydrological gauging station F5H001 before the last salinity measurement in March 1981 was for nine days in October 1974.
(maximum flow rate 28 litres/sec), and then for five days in August 1980 (maximum flow rate of 219 litres/sec). It is probable, although by no means certain, that the very high salinity levels measured in the estuary resulted from an almost complete lack of surface or sub-surface inflow from the river, and probably reduced inflow from groundwater sources.

The relevance of the results to the present study must be viewed with some circumspection, since they were recorded more than 30 years ago. Nevertheless, comparison of these results with the water quality analyses carried out by Schlumberger Water Services for the Kamiesberg project (SWS 2012, SWS 2013) (see Tables 1.5 and 1.6, read with Figure 1.2) indicates that TDS levels on the north side of the river are considerably higher (on average 40%) than those on the south side (see Table 1.3), as reported in Heydorn & Grindley (1981a). The February 1981 result for the spring feeding the northern channel – 47 000 mg/l – does, however, seem questionable, and may have been taken in the lagoon itself.

Table 1.3: Salinity measurements in boreholes in the vicinity of the Groenrivier

<table>
<thead>
<tr>
<th>Borehole Ref</th>
<th>Total Dissolved Salts (mg/l)</th>
<th>Borehole Ref</th>
<th>Total Dissolved Salts (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZIRCH02</td>
<td>8 420</td>
<td>ZIR09</td>
<td>4 220</td>
</tr>
<tr>
<td>ZIR10</td>
<td>7 130</td>
<td>ZIR20</td>
<td>6 100</td>
</tr>
<tr>
<td>ZIR11</td>
<td>7 020</td>
<td>ZIR13</td>
<td>7 540</td>
</tr>
<tr>
<td>ZIRCH01</td>
<td>6 610</td>
<td>ZIR14</td>
<td>5 970</td>
</tr>
<tr>
<td>ZIRCH03</td>
<td>9 470</td>
<td>ZIR18</td>
<td>3 800</td>
</tr>
<tr>
<td>ZIR19 *</td>
<td>8 760</td>
<td>ZIR17 *</td>
<td>7 330</td>
</tr>
</tbody>
</table>

* Boreholes ZIR19 (north side) and ZIR17 (south side) are 2.2 km and 2.7 km upstream of the head of the estuary respectively.

Source: Data from SWS 2012, SWS 2013

Plate 1.1: The downstream end of Groenrivier estuary, looking upstream

Note the unpaved road (DR2938), which runs alongside the estuary and river for much of its length, in the upper right of the frame.
More recent studies by Schlumberger Water Services (SWS 2015) have provided a more detailed characterisation of the estuary and its relationship to other surface and groundwater resources in the area. The studies showed that the spring identified by CSIR (Heydorn & Grindley, 1981a), which is located at the lower limit of a natural wetland in the river channel, approximately 1 km upstream of the head of the estuarine lagoon (see Plate 4.2), can reasonably be supposed to be the only source of perennial discharge into the lagoon. In February 2014 the flow rate from the spring was estimated to be 1 litre per second.

The episodic nature of surface flow in the river channel has already been noted, but the possibility of subsurface flow was investigated by SWS by conducting a survey of the Groen River bed to identify any springs, seeps, sumps or any other features which may indicate that sub-surface flow occurs along the channel. Seven locations - referred to as 'sumps' – were identified over a distance of about 17km along the channel in which standing water was identifiable, or at which some evidence of the recent presence of water was inferred. Electrical conductivity levels in these sumps were higher by up to a factor of two than those recorded in water sampled from boreholes in the immediate vicinity of the river, indicating significant evapo-concentration in the sumps. It was concluded from these observations that subsurface flow along the channel bed is negligible, and also that there is negligible discharge, as base flow or interflow, of groundwater to into the river bed.

Additional sumps, both about 1m deep were hand excavated upstream and downstream of two low-level crossings of the river, one approximately 31 km upstream of the proposed mining site and one about 3 km downstream. The excavations were observed over a period of days to determine any differential accumulation of water in the sumps. No change in the water levels was observed in either sump, and it was concluded that subsurface flow between the sumps was likely to be negligible.

Electrical conductivity measurements were taken in the river channel and lagoon from the spring to the seaward end of the lagoon (Figure 1.2). Immediately downstream of the spring the water was relatively fresh (EC between 10 and 12 mS/cm), thereafter increasing to between 20 and 40 mS/cm within 100m of the spring. Apart from two isolated occurrences of EC measurements (exceeding 100 mS/cm) the EC in the channel remained relatively stable within this range, increased to around 150-170 mS/cm over a distance of about 100m, then remained constant in this range to the sandbar at the downstream end of the lagoon. The data is interpreted as reflecting a system in which relatively fresh spring water is subject to evapo-concentration by around a factor of 5 during transit through the uppermost 500 m of the estuarine feeder canal. Downstream of this channel reach there is a clearly defined mixing zone in which hyper-saline lagoon waters and fresher recharge waters interact, and further downstream there is little evidence of aquatic life in the lagoon. In the lowermost reaches of the system the waters exhibited a distinct sulphidic odour, signifying a high ambient rate of SO$_4$ reduction.

Water samples for use in multi-element characterisation analysis were collected at four sites between the spring and the ocean: at the seaward end of the lagoon, in the mid reaches and at the upper end adjacent to the spring. The discharge from the spring was also sampled. The analysis indicates that the water chemistry of the system evolves in a downstream direction from the spring to the ocean, and this progression closely reflects the observed increase in EC from around 8 000 mg/l at the spring to around 200 000 mg/l at the seaward end of the lagoon. All waters throughout the system are routinely of NaCl type, with secondary CaSO$_4$ and KCl components of the balance become increasingly prominent in the most acutely evapo-concentrated waters of the lower lagoon.
Figure 1.2: Electrical conductivity survey of the Groenrivier and its estuary
Source: SWS 15, Figure 3.1
A thermodynamic geochemical model was used to simulate the progressive evapo-concentration and concurrent geochemical fractionation, which was observed from field measurements and laboratory analyses of water samples, of water matching the characteristics of the water discharged from the spring. The simulated concentrations of most major ions following the evapo-concentration of spring water were found to be are extremely closely comparable to those sampled and measured analytically at the seaward end of the Lagoon. This was particularly so for Na, Cl, K and Mg ions, and provides strong evidence that the spring provides the principal perennial inflow to the lagoon.

The investigations support the conclusion that there is negligible perennial flow in the river system, either at the surface or in the shallow substrate or channel fill, and that the lagoon is sustained by discharge from the spring at the head of the estuary, which is fed by a shallow groundwater system in the riparian zone.

The possibility that groundwater beneath the proposed mine site could contribute to the discharge from the spring was investigated by the use of hydrochemical ‘fingerprinting’, which is a comparison of high-resolution hydrochemical data for three boreholes in the mining area and equivalent data for the spring discharge. Data for all waters was compared statistically, and using conventional hydrochemical ‘typing’ plots. The results of the comparisons were:

- The TDS level of the estuarine spring water (approximately 8 000 mg/l) is markedly higher than all the groundwaters of the mining area (a range of between 3 300 and 7 300 mg/l)
- While all waters are NaCl dominated, a clear distinction exists with regard to the remaining major ion balance of the groundwater suite on site and spring water. This is particularly pronounced with respect to the contributions of Ca+Mg and SO$_4$ to the ion balance. In all instances, levels of Ca and Mg in the Kamiesberg groundwaters range up to approximately 150 and 200 mg/l respectively, while in the spring water the concentrations of these cations are 594 and 423 mg/l respectively. In the case of SO$_4$, enrichment by a factor of 2 to 3 is evident in the spring water relative to the groundwater suite.
- Relative enrichment of Sr is evident in the spring at a magnitude analogous to that described above for SO$_4$.
- Groundwater samples of the Kamiesberg district are routinely high in F. Despite the conservative nature of F in solution, there is no evidence of fluoride enrichment in the spring water. This provides strong evidence of a lack of direct hydraulic inter-connection.

Key distinctions between the groundwater data and that of the spring strongly support the
conclusion that a direct hydrogeological connection between them is highly unlikely.

The results of 3-dimensional groundwater flow and solute transport modelling, performed for a 100-year period beginning at mine start-up, indicate that saline seepage from the pit backfill and the tailings storage facility will enter the groundwater system at around Year 20, more or less at the anticipated end of mining operations (year 20). A plume of saline seepage will then migrate southward, passing beneath the bed of the Groenrivier River by around Year 80. Under current conditions of groundwater elevation in the riparian zone of the Groenrivier modelling indicates that the saline plume, with a TDS of around 20 000 mg/l, would pass about 1-2m beneath the channel bed, without affecting the current elevation of ground water, and will therefore not induce river flow, and will therefore not cause high salinity water to be conveyed to the estuary.

Although there is no identifiable hydrological mechanism for the discharge of surface water or groundwater from the mining areas into the Groenrivier estuary, the vulnerability of the estuarine system to any post-mining saline seepage must be viewed in the context of the naturally hypersaline nature of the system and the attendant limitation to biological activity. Modelling of the impact of estuarine lagoon chemistry which would arise from the hypothetical replacement of existing spring inflow with post-mining Kamiesberg groundwater suggests that any adjustment would be inconsequential, because:

- The estuarine system is fed by a spring with a baseline TDS within the brackish range (>10 000 mg/l TDS).
- The lower estuarine lagoon is characteristically hypersaline (TDS of around 200 000 mg/l) with indications of active sulphate reduction, anoxia and methanogenesis.
- Post-mining groundwater TDS levels to the south of the mining area will peak at approximately 24 000 mg/l. Any minor flux of such water to the estuarine system, either via river conveyance or groundwater discharge, both of which are confirmed to be of low plausibility, would therefore be unlikely to significantly influence the baseline conditions of the estuarine system.
- In addition, the time period for the potential passage of contaminated water across the 10 km distance separating the mining area and the estuary will exceed hundreds of years, and will also be subject to long-term dilution effects over this distance (SWS, 2015). Consequently any potential increase in salinity at the head of the estuary is unlikely, but in the event of any flux of such water, salinity will increase in the upper estuary, but probably not beyond threshold levels of estuarine organisms that could potentially occur there

- **Bitterrivier estuary**

The estuary of the Bitterrivier, when it exists due to surface water inflow or seawater penetration, is much smaller than that of the Groen, being about 5ha, and extending only about 400m upriver from the beach. There is no published flow-related information for the river, and the periods during which the estuary is wet are likely to be short and widely separated in time.

Heydorn & Grindley (1981b) concluded:

“The [estuary of the] Bitter [River] is probably of limited value as an estuary in the true sense, due to the episodic nature of its flow. However, being as yet relatively undisturbed by man’s activities (at the time of the CSIR survey the area was part of the De Beers Consolidated Mines prospecting area, and public access was restricted), this scenic section of the coast has high aesthetic value and is part of the last remaining stretch of the Namaqualand coastline as yet unaffected by mining operations.”

**Wetlands**

The Working for Wetlands Kamiesberg Wetland Project has prepared rehabilitation plans for nine individual wetland systems - Kleingaas, Groenrivier, Kleikop, Schaaprivier, Langvlei, Natpad, Windpoort, Xharas and Kraaifontein – in the Northern Cape Province in the general area of the Kamiesberg mining project (Working for Wetlands 2014).
All but one of the wetland systems identified for attention in the project - the Groenrivier wetland - are situated in four quaternary catchments - F30A, F30C, F50A and F50E - near the towns of Kamieskroon and Leliefontein, inland from the mine site. Of these four catchments the nearest catchment boundary - that of F50E - is 27km inland from the mining area. None of the wetlands in these four quaternaries will be affected in any way by mining or related activities.

- **Groenrivier wetland**

The Groenrivier wetland, however, is situated in quaternary catchment F50G, at the mouth of the Groenrivier some 10.5km south-west of the south-western corner of the Roode Heuvel block (see Figure 1.1 above). The wetland is situated in the Namaqua National Park, and its extent approximates to that of the Groenrivier estuary, discussed previously.

The rationale for the rehabilitation work proposed for the wetland system is “The (proposed bird) hide site is at a very scenic location visited by a diversity of wetland-dependent birds. It is located within the Namaqualand National Park and there is good public access. In addition, through the use of appropriate signage, there are good opportunities for raising public awareness of the importance of wetlands in the overall catchment.” (Working for Wetlands 2014). The rehabilitation work is rated 4th in order of priority out of a total of nine wetlands in the project as a whole.

The mouth of the Groenrivier is relatively easy to access for camping, bird watching, hiking and 4x4 tracks. As a result the wetland has been subjected to a number of impacts associated with the formation of a number of informal access routes for watching birds, as well as short hiking trails, all of which have increased the impact of erosion and sedimentation by providing preferential flow routes for surface water draining. The primary objective of the rehabilitation is to provide formalised enhanced public access for watching birds and appreciate the scenic beauty of the Groenrivier estuary without impacting negatively on the estuary. This can be achieved by means of a bird hide and boardwalk access to the hide, and the construction of an additional boardwalk at the seaward end of the wetland to enhance access whilst avoiding trampling of saltmarsh.

Although the wetland / estuary is some distance from the mine site, it will be important to ensure that the mining project does result in direct or indirect impacts on the wetland, nor prejudice the success of the rehabilitation project.

### 1.1.3. Groundwater

#### Hydrocensus

A hydrocensus covering the project area was conducted by SWS during September 2012. The hydrocensus was subsequently extended in 2013 to include the area between the project site and the Atlantic Ocean to the west. A total of 23 sites were investigated, 19 boreholes, two pits (sumps) excavated in the bed of the Groenrivier, and two sites in the ocean. Data from the hydrocensus is shown in Table 1.4, and the locations of the sites on Figure 1.3.

<table>
<thead>
<tr>
<th>Location &amp; Sample ID</th>
<th>Coordinates (South)</th>
<th>Site type</th>
<th>Use</th>
<th>Collar height (m)</th>
<th>Water level (mbc)</th>
<th>Water level (mbgl)</th>
<th>Water level (mamsl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocensus 2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>ZIR01</td>
<td>-30.7452 17.64536</td>
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<td>Livestock; Domestic</td>
<td>0.41</td>
<td>Unable to measure</td>
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</tr>
</tbody>
</table>
Drilling has indicated a relatively straightforward arrangement of aquifers and hydrostratigraphic units on the site, comprising an unconsolidated primary aquifer overlying a fractured secondary aquifer: The upper aquifer consists of surface aeonian sands, and basal grits and conglomerates, generally unconsolidated and relatively permeable, with a relatively high slimes content - clays constitute 21% of the overall volume, with local values up to 35%. Beneath the upper weathered profile the bedrock consists of predominantly fractured gneisses and granites, which are high grade metamorphic rocks of the Namaqua-Natal Mobile Belt and which are generally massive and highly deformed. Drilling also indicated the presence of a thick layer of weathered bedrock material with elevated proportions of kaolinite clay between the upper aeonian sands aquifer and the lower fractured bedrock aquifer. This relatively impermeable layer probably may act as an aquitard, which restricts water flow between the two aquifers and, importantly, influences the volume and rate of seepage from backfilling operations to the water table.

Geologically there are no distinct structural or lithological boundaries within the site, and as a result it is assumed that the Bitterrivier to the north and the Groenrivier to the south act as boundaries to flow in these directions. High ground to the east acts as a watershed for surface water, and is assumed to coincide with the boundary between groundwater units, while the Atlantic Ocean to the

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**Hydrogeological structure**

Drilling has indicated a relatively straightforward arrangement of aquifers and hydrostratigraphic units on the site, comprising an unconsolidated primary aquifer overlying a fractured secondary aquifer: The upper aquifer consists of surface aeonian sands, and basal grits and conglomerates, generally unconsolidated and relatively permeable, with a relatively high slimes content - clays constitute 21% of the overall volume, with local values up to 35%. Beneath the upper weathered profile the bedrock consists of predominantly fractured gneisses and granites, which are high grade metamorphic rocks of the Namaqua-Natal Mobile Belt and which are generally massive and highly deformed. Drilling also indicated the presence of a thick layer of weathered bedrock material with elevated proportions of kaolinite clay between the upper aeonian sands aquifer and the lower fractured bedrock aquifer. This relatively impermeable layer probably may act as an aquitard, which restricts water flow between the two aquifers and, importantly, influences the volume and rate of seepage from backfilling operations to the water table.

Geologically there are no distinct structural or lithological boundaries within the site, and as a result it is assumed that the Bitterrivier to the north and the Groenrivier to the south act as boundaries to flow in these directions. High ground to the east acts as a watershed for surface water, and is assumed to coincide with the boundary between groundwater units, while the Atlantic Ocean to the
west acts as a natural boundary. Given the distance of the site from the coastline, and the surface elevation of the bedrock and groundwater levels, there is no risk of seawater intrusion as a result of groundwater abstraction.

Groundwater levels on site vary from 1.6m below surface in the Groenrivier bed to the south of the site, and 80.5m below surface up gradient topographically towards the centre of the Roode Heuvel block. On a regional scale groundwater flow is from east to west towards the Atlantic Ocean, but on a more local scale groundwater flows from the centre of the site towards the rivers.

**Borehole yields**

Boreholes ZIRCH01, 02 and 03 and the associated observation boreholes, ZIROB01, 02 and 03, were drilled in the Groenrivier. Boreholes 01 (5m) and 02 (11m) were shallow characterisation boreholes drilled through the alluvial sediment in the river bed until bedrock was reached in order to characterise groundwater flow in the river bed sediments, whilst 03 (120m) was drilled into the underlying basement lithologies to characterise the deeper, fractured aquifer. The three observation boreholes were drilled in the river in close proximity to the shallow characterisation boreholes.

ZIRCH04, 05 and 06 were deep boreholes (all 120m deep) drilled to the north of the Groenrivier in order to identify and characterise any possible groundwater flow in the unconsolidated sands, as well as fractured flow in the underlying bedrock lithologies.

Pump tests were conducted on boreholes ZIRCH01, ZIRCH03 and ZIRCH04, since the remaining boreholes did not yield sufficient water (seepage only) to sustain a pump test. Of these three boreholes the blow yield\(^4\) of ZIRCH03 – 10.9 l/sec - was higher than expected for the region, and a constant discharge test was carried out at a maximum pump discharge rate of 10 l/sec for 39 hours. During this test the drawdown of the groundwater level stabilised after 7 hours at approximately 30% (23.38m) of the available drawdown of 77.2m, and remained relatively static for the remainder of the test. On cessation of pumping, the borehole recovered to within 95% of the maximum drawdown within 2 hours.

The stabilisation of drawdown at relatively shallow levels is indicative of high transmissivity\(^5\) in the major fracture zones encountered during drilling. The rapid recovery of the groundwater level after pumping stopped, which is considered uncharacteristic of the region, indicates relatively high levels of storage commonly associated with a major fault/fracture zone with significant lateral extent. The rapid recovery also indicates that the test did not fully “stress” the aquifer which implies that the sustainable yield of the borehole may be higher than first expected. Accordingly it is anticipated that borehole ZIRCH03 is able to sustain a yield of approximately 10 l/sec. The geometry of the river and the results of a resistivity survey of the Roode Heuvel block (which included four transects across the Groenrivier valley) indicate that it is likely that there may be an additional two areas in the Groenrivier valley from which similar yields may be expected from boreholes. It is therefore possible that a total of approximately 30 l/sec of groundwater (approximately 950 000 m\(^3\)/a) could be available for abstraction.

However, the long term sustainability of this rate of abstraction will need to be confirmed through the application of a longer constant discharge test at a higher discharge rate. It will be important to determine the potential impacts on local farmers who rely on groundwater abstracted from the same fault/fracture system that are exploited by ZIRCH03. This could be determined by testing ZIRCH03 at an abstraction rate likely to achieve at least 60% of the total available drawdown for at least 7 days continuously, and drilling and aquifer testing of at least two additional characterisation boreholes with associated monitoring wells.

\(^4\) Blow yield: The volume of water per unit of time blown from the borehole during drilling – an indication of the rate at which groundwater can be abstracted from a borehole.

\(^5\) Transmissivity: A measure of the rate at which groundwater flows laterally through the subsurface material.
Groundwater quality

- **Potability**

Water samples were taken from the hydrocensus boreholes, characterisation boreholes, dug sumps and the Atlantic Ocean during the hydrocensus in 2012 and extended hydrocensus in 2013 (see Table 1.4 above). Samples were analysed for dissolved and total concentrations of major and trace elements, cations and anions. The results are summarised in Tables 1.5 and 1.6, and are compared to the SANS241: 2006 Standards for Drinking Water.

The tables show that the groundwater samples from all sources are brackish, with elevated levels of Total Dissolved Solids, sodium, chloride, magnesium and zinc. Samples from ZIR01, 02, 06, 07, 17 and 19 also have elevated fluoride levels. The quality of the water from all of the boreholes exceeds the SANS Class II drinking water limits, and is not suitable for human consumption.
The analysis also indicated that, although water quality exceeds the ideal recommended values for livestock watering, as set out in South African Water Quality Guidelines for: Agricultural Use: Livestock Watering (DWAF 1996), it is still within acceptable values that are not likely to cause permanent damage (Table 1.7). It is, however, evident that any significant increase in TDS levels, which currently range between about 4 000 and 8 000 mg/l, such that they exceed the threshold of 13 000 mg/l, may render the water unfit for consumption by livestock.

**Geochemistry and mineralogy**

Additional testwork was carried out to determine the potential impacts of the Kamiesberg project on the groundwater resources of the area.

**Radionuclides**

The ore body contains monazite, a phosphate mineral containing rare earth metals, which contains the radioactive element thorium. Three groundwater samples were analysed to determine the concentrations of isotopes of uranium (\(^{234}\text{U}, ^{235}\text{U}\) and \(^{238}\text{U}\)), radium (\(^{226}\text{Ra}\)) and thorium (\(^{228}\text{Th}, ^{230}\text{Th}\) and \(^{232}\text{Th}\)). The results of the radiochemical analysis of groundwater were compared to the WHO (2011) guideline limits, and all samples were well within the limits. Nevertheless, it will be necessary to implement appropriate occupational health and safety measures when handling monazite.

**Leaching of chemicals from the ore**

Because of the lack of an appropriate supply of fresh water on the site Zirco intends to use seawater in the process of separating heavy minerals from the parent material. Synthetic Precipitation Leach Protocol (SPLP) and kinetic Humid Cell (HC leach tests were conducted to determine if there could be any interaction between the minerals and the seawater, resulting in the leaching of chemicals into the groundwater, and degrading the resource.

The principal conclusion that may be drawn from the geochemical and mineralogical testwork performed on a range of size-fractions of Kamiesberg tailings material is that the material is relatively inert in terms of solute mobilisation potential in response to both fresh water and seawater lixivants. The main control on the geochemistry of water which may seep from the tailings during consolidation and long-term storage is likely to be the composition of the seawater feed used for processing. Modifications to the chemistry of this water as a result of interaction with the tailings are likely to be restricted to minor increments to iron (Fe) and aluminium (Al) concentrations, plus some level of exchange between sodium (Na) and major cations such as calcium (Ca) and magnesium (Mg) in the clay fraction of the tailings.

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6 Lixiviant: A liquid medium used in hydrometallurgy to selectively extract the desired metal from the ore or mineral. It assists in rapid and complete leaching, and the metal can be recovered from it in a concentrated form after leaching.
Table 1.5: Hydrocensus 2012 - Water quality results compared with SANS 241:2006 standards for drinking water

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Total Dissolved Solids (mg/l)</th>
<th>Nitrate as N (mg/l)</th>
<th>Chlorides as Cl (mg/l)</th>
<th>Total Alkalinity as CaCO3 (mg/l)</th>
<th>Sulphates as SO4 (mg/l)</th>
<th>Calcium as Ca (mg/l)</th>
<th>Magnesium as Mg (mg/l)</th>
<th>Iron as Fe (mg/l)</th>
<th>Manganese as Mn (mg/l)</th>
<th>Conductivity at 25°C (mS/cm)</th>
<th>pH Value at 25°C</th>
<th>Aluminium as Al (mg/l)</th>
<th>Ammonium Nitrogen as N (mg/l)</th>
<th>Fluoride as F (mg/l)</th>
<th>Cadmium as Cd (mg/l)</th>
<th>Copper as Cu (mg/l)</th>
<th>Lead as Pb (µg/l)</th>
<th>Zinc as Zn (µg/l)</th>
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<tr>
<td>Class I</td>
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</tr>
</tbody>
</table>

Values highlighted thus fall into SANS 241:2006 Class II – Maximum allowable limit for stated duration.
Values highlighted thus exceed SANS 241:2006 maximum allowable limits for human consumption.
Values highlighted thus (ZIR12) are from a seawater sample and are not compared to drinking water standards.

Source: SWS 2012, Table 3.2
Table 1.6: Hydrocensus and Groundwater Characterisation 2013- Water quality results compared with SANS 241:2006 standards for drinking water

<table>
<thead>
<tr>
<th>Sample ID (Recomme</th>
<th>Total Dissolved</th>
<th>Chloride as Cl</th>
<th>Total Alkalinity as CaCO3</th>
<th>Magnesium as Mg</th>
<th>Potassium as K</th>
<th>Iron as Fe</th>
<th>Conductivity at 25°C in</th>
<th>Aluminium as Al</th>
<th>Fluoride as F</th>
<th>Manganese as Mn</th>
<th>Copper as Cu</th>
<th>Lead as Pb</th>
<th>Zinc as Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>(Max. Allowable)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
<td>(µS/cm)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
<td>(mg/L)</td>
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<td>261.0</td>
<td>47.1</td>
<td>2.41</td>
<td>1190.0</td>
<td>9.42</td>
<td>&lt;29</td>
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<td>ZIR14</td>
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<tr>
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<td>3740.0</td>
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<td>646.0</td>
<td>241.0</td>
<td>226.0</td>
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<td>4220.0</td>
<td>270.0</td>
<td>704.0</td>
<td>399.0</td>
<td>254.0</td>
<td>2040.0</td>
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<td>1100.0</td>
<td>812</td>
</tr>
<tr>
<td>ZIR20</td>
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<td>1610.0</td>
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<td>&lt;0.19</td>
<td>0.02</td>
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<td>800</td>
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<td>ZIR21</td>
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<td>7.76</td>
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</tbody>
</table>

* Orange highlighted values fall into Class 2: Maximum allowable limit
* Red highlighted values exceed SANS 241: 2006 Drinking Water Standards
* ZIR12 (Blue highlighted values) is a seawater sample and thus not relevant for comparison to SANS241:2006. Values are shown for baseline comparison purposes
* *NS – No standard
* *NA – Not analysed

Source: SWS 2013, Tables 5.1 and 5.2
Table 1.7: Comparison of all hydrocensus and characterisation borehole results to the SAWQG for livestock watering

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Total Dissolved Solids (mg/l)</th>
<th>Chlorides as Cl (mg/l)</th>
<th>Magnesium as Mg (mg/l)</th>
<th>Sodium as Na (mg/l)</th>
<th>Fluoride as F (mg/l)</th>
<th>Cadmium as Cd (mg/l)</th>
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</thead>
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<tr>
<td>No adverse effects</td>
<td>0-3000</td>
<td>0-4000</td>
<td>0-5000</td>
<td>0-2000</td>
<td>0-4</td>
<td>0-0.01</td>
</tr>
<tr>
<td>Limited temporary adverse effects</td>
<td>3000-13000</td>
<td>4000-5000</td>
<td>5000-10000</td>
<td>2000-4000</td>
<td>4-12</td>
<td>0.01-0.02</td>
</tr>
<tr>
<td>Permanent Adverse effects</td>
<td>&gt;13000</td>
<td>&gt;6000</td>
<td>&gt;1000</td>
<td>&gt;4000</td>
<td>&gt;12</td>
<td>&gt;0.02</td>
</tr>
<tr>
<td>GAT1</td>
<td>1250</td>
<td>640</td>
<td>28</td>
<td>352</td>
<td>0.595</td>
<td>&lt;0.001</td>
</tr>
<tr>
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<td>1770</td>
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<td>916</td>
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</tr>
<tr>
<td>ZIR02</td>
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<td>3330</td>
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<td>1840</td>
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</tr>
<tr>
<td>ZIR03</td>
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<td>ZIR06</td>
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<tr>
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<td>175</td>
<td>1450</td>
<td>1.31</td>
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</tr>
<tr>
<td>ZIR17</td>
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<td>0.0007</td>
</tr>
<tr>
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<td>183</td>
<td>1530</td>
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</tr>
<tr>
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<td>1610</td>
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<tr>
<td>ZIRCH03</td>
<td>9470</td>
<td>4560</td>
<td>157</td>
<td>2720</td>
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<tr>
<td>ZIRCH05</td>
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<td>174</td>
<td>2140</td>
<td>1.04</td>
<td>0.0002</td>
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</tbody>
</table>

Source: SWS 2013, Table 5.3

Seepage modelling

Processing the mineral sands will yield two classes of tailings in the form of seawater saturated slurries:

- A coarser fraction from 45μm-2mm, referred to as “sands” and
- Fines less than 45μm, referred to as “slimes”.

The sand, and a proportion of the slimes, will be placed into the mined out voids either separately as sand, or together in areas which have been identified as suitable for co-disposal by Zirco in their Tailings Management Strategy. A Tailings Storage Facility (TSF) will be constructed to store the remaining slimes. Both the backfilled pits and the TSF overlie unsaturated aeonian sands where the water table is in broad terms between 20m and 60m below ground level. The majority of the backfill will contain a significant volume of saline seawater. The mining areas, areas of no backfill, backfill with sand and backfill with sand and slimes, and the location of the TSF, are shown in Figure 1.4.
Figure 1.4: 2D modelling section locations, mining areas, co-disposal zones and TSF location

Source: SWS 2014, Figure 4.9

Uncoloured areas in the mine path are backfilled with sand only.
Sections 1, 2 & 3 are those used in the 2-D seepage model.
As discussed previously the groundwater in the area is moderately saline, and is used by local farmers for livestock watering and some non-potable domestic purposes. Seepage of seawater from the backfill to this resource may have an adverse impact on groundwater quality and usefulness to the local inhabitants. The objectives of the seepage modelling were therefore to:

- Characterise the potential for seepage from both the backfilled mine voids and the TSF.
- Assess the likelihood that the groundwater regime may be impacted.
- Provide seepage estimates in a variety of geological settings for input to the regional 3-D contaminant transport groundwater model.

The 3-D model was set up with 120 “stress” periods, each a year in length and each with ten time steps, during which seawater saturated backfill was deposited in the mining voids and on the TSF in accordance with the Tailings Management Strategy. The model represents the 20 years of mining in the Roode Heuvel block, followed by 100 years post closure. At the same time flow paths from the mining area where modelled to estimate the flow paths and travel times of the contaminant plume from each backfilled area.

A number of simplifications and generalisations were made to the model where data was not available:

- With the exception of the fracture along the bed of the Groenrivier (inferred from the results of drilling and pump tests) was included in the model setup, since insufficient information exists to include the bedrock fracture network that is believed to exist in the bedrock. The higher hydraulic conductivity of these structures compared with the unfractured bedrock is thought to play an important role in determining groundwater flow directions and travel times.
- Density effects of saline water, which will cause the sea water to move downwards at a faster rate, where not modelled.
- Evaporation losses (from, for instance, ponding in area of the TSF), were not modelled since the evaporation rate at Kamiesberg is not currently well defined.

Because of these simplifications the results of the modelling should not be considered to be definitive, but can be used to give a conservative estimate of the potential groundwater flow directions, TDS concentrations and the impacts that the saline backfill may have on the nearby aquifer.

**Summary of results and interpretation**

The model results show that saline water added during tailings deposition is likely to migrate out of the mining concession area over time. The plume is predicted to travel westwards in the direction of the coast and south towards the Groenrivier. One hundred years after the cessation of mining the front of the saline plume is predicted to have travelled approximately 750 metres down gradient from the concession area. Figure 1.5 shows the predicted impact that mining will have on TDS concentrations in the hydrocensus boreholes:

- ZIR03, ZIR14, ZIR15 and ZIR16 are not impacted by mining over the 100 year period and TDS concentrations remain at the assumed background level of 6000 mg/l.
- The boreholes predicted to be affected all lie in southern half of the mining area.
- Boreholes ZIR01 and ZIR02 are within the concession area and the model results show that groundwater TDS concentrations are likely to increase to up to 25 000 mg/l at these locations.
- Concentrations at ZIR02 are higher than ZIR01 because ZIR02 is located in a co-disposal backfill area. Co-disposal backfill produces more seepage than sand backfill. In both boreholes there is predicted to be a sharp increase in TDS which begins close to the time of deposition for nearby paddocks.
- At 100 years post closure concentrations are stabilising but have not yet started to fall significantly.
- ZIR20 is also situated along the Groenrivier but is further to the east. Here TDS concentrations reach around 12 000 mg/l, but are still rising at 100 years post closure.
- Borehole ZIR04 shows the effect that the progression of the plume westwards can have on groundwater TDS concentrations. After backfill deposition concentrations gradually increase to
a peak of around 17 300 mg/l. Once the plume has migrated westwards concentrations decrease as lower TDS groundwater from upstream of the mine starts to dilute the groundwater in this area. At this point concentrations decline to around 10 000 mg/l.

- Borehole ZIR08 shows the impact that the TSF is likely to have on nearby groundwater, and is the only location at which TDS is predicted to increase during the 20-year mining period. ZIR08 is situated on the southern edge of the TSF. TDS concentrations increase to a maximum of 11 000 mg/l as the seepage from the TSF migrates southwards. By around 110 years post mining the TDS concentration is beginning to reduce as the majority of groundwater originating from the TSF has already passed by the borehole.

**Mitigation measures**

The modelled base case scenario assumes that no water is removed through capture in sumps, and that all saline water deposited with the backfill seeps into the ground and eventually finds its way into groundwater. Seepage rates and associated impacts could be reduced by capturing some of the water in the backfill in sumps in the paddocks, and pumping it out to be re-used during mineral processing. Two 3-D models were run to simulate the potential impacts on groundwater resulting from a 50% reduction in seepage to groundwater and a 25% reduction in seepage, in order to predict the mitigation effects that a sump capture scheme may provide.

The results show that TDS concentrations decrease as the rate of seepage to groundwater decreases. Average TDS concentrations for layer three in the base case model 100 years post closure are around 25 000 mg/l in parts of the concession area impacted by co-disposal backfill, whereas when the seepage to groundwater is reduced by 50% the average TDS concentration in co-disposal areas in layer three of the model drops to around 20 000 mg/l.

The results are shown graphically in Figure 1.6. The flow direction of the contaminant plume remains the same, meaning that the same pattern of TDS increase and decrease is seen for each of the hydrocensus boreholes, the main difference being the magnitude of the change. On average, at each of the impacted hydrocensus boreholes, a 50% reduction in seepage results in a 5 000 mg/l decrease in TDS concentration compared to the base case model. There does not appear to be a linear relationship between reduction in groundwater seepage and drop in TDS concentration, since the reduction in concentration resulting from a 25% reduction in seepage rate is often a little less than half the difference predicted when modelling a reduction of 50%.

Although reducing seepage to groundwater does impact TDS concentration, the model predicts that much of the resulting plume will still be above the South African Water Quality Guidelines (SAWQG) standard for TDS concentrations permissible for livestock watering. TDS concentrations above 13 000 mg/l are considered to cause permanent adverse effects to livestock; therefore the reduction in TDS concentration predicted by mitigating seepage to groundwater is not sufficient to bring much of the plume area below this standard. Figure 1.7 shows the predicted areal extent of the TDS plume based on the SAWQ 13 000 mg/l TDS standard. It shows that reducing the rate of seepage to groundwater does reduce the extent of the area of impact, but the change is not sufficient to prevent hydrocensus boreholes being adversely impacted by the saline backfill.

**Conclusions and recommendations**

- The modelling study suggests that, within the 120-year modelling period, saline backfill water is likely to reach groundwater and could result in a plume of groundwater with TDS levels sufficiently high (exceeding 13 000 mg/l) to be unsuitable for livestock watering.
- The plume is predicted to impact existing boreholes within the Kamiesberg project area, including some boreholes adjacent to the Groenrivier along the southern boundary of the Roode Heuvel block. Although the plume is expected to migrate beyond the western edge of the project area in 120 years, it is not expected to impact the Namaqua National Park area, or reaches of the Groenrivier outside the project area.
- High conductivity structures, which will control the movement of contaminants, have not been specifically modelled due to a lack of data. Further investigations into the fracture network and bedrock properties at Kamiesberg are recommended for future studies in order to further refine the groundwater models.
It is also recommended that, when a full year of data becomes available from the weather station installed at Kamiesberg at the end of 2013, the data is analysed in order to improve groundwater recharge estimates, and also to allow evaporation losses to be considered in the modelling.
Figure 1.5: Variation of TDS concentrations at hydrocensus points downgradient of backfilling
Source: SWS 2014, Figure 5.10.
Figure 1.6: Impacts of mitigation measures on TDS concentrations at hydrocensus points downgradient of backfilling (graphical)
Source: SWS 2014, Figure 5.12.
Figure 1.7: Impacts of mitigation measures on TDS concentrations at hydrocensus points downgradient of backfilling (plan)
Left: Weathered bedrock. Right: Competent bedrock.
Source: SWS 2014, Figure 5.13.
1.2. Assessment of impacts

1.2.1. Impacts on groundwater

Impact 1: Impacts on groundwater of the tailings storage facility and backfill

Impacts relating to groundwater are assessed for the construction period, the anticipated 20-year operational life of the mine, and also for an approximately 100-year period following the cessation of mining, during which the effects of saline seepage from backfill and the tailings storage facility (TSF) are expected to become evident.

Cause and comment

Seawater will be used for mineral processing, and as a result tailings used to backfill mining voids will contain a significant volume of saline seawater. Seepage of seawater from backfill and from the tailings storage facility down to the groundwater table will cause elevated TDS levels in the already brackish groundwater, which may render it unfit for stockwatering, which is currently the predominant use for groundwater in the area.

- Construction impacts: No impacts are anticipated.
- Operational impacts: Groundwater modelling indicates that increases in TDS during the 20-year operational lifetime of the mine will occur only in the immediate vicinity of the TSF, and is unlikely to prejudice any activity outside the mining area even after mining ceases.
- Long-term post-closure Impacts: The results of groundwater modelling indicate that the potential plume of saline seepage from backfill and the TSF will continue to be mobile for many years after the cessation of mining, and that the TDS levels in some locations in the southern half of the Roode Heuvel block (an area of about 30km²) and for about 750m westward of its boundary, will rise to levels well above 13 000mg/l, which is considered unsuitable for animal consumption.

The severity of the impacts is assessed on the assumption that, after completion of mining, the land will be returned to agriculture, meaning that groundwater will be required for stockwatering as soon as the mined areas have been rehabilitated and revegetated. However, in this context it must be borne in mind that the vegetation specialist assessment recommends that, in order to address the prevailing effects of overgrazing, stock should not be reintroduced until the vegetation is properly established, and then re-introduced at reduced, more sustainable levels.

Given that the groundwater model predicts that salinities in much of the mining area will show increased levels, sufficient to preclude safe stockwatering, only between about 5 and 40 years after the end of mining, the necessity for and nature of mitigation measures will need to be reviewed as mining proceeds, and as mine closure approaches and negotiations begin for the return of the land to some form of post-mining activity.

Mitigation and management

- Recover seawater from tailings via sumps in paddocks and recycle as process water.
- Optimise the use of slimes mixed with coarser material (co-disposal) to reduce the rate of infiltration and seepage.
- Continuously monitor the salinity of the groundwater in and around the mining area to confirm or otherwise the results of modelling, and continuously update the model to take account of the monitoring results and data from the weather station.
- If necessary, concomitant with the chosen form of post-mining land use, provide alternative sources of water for stockwatering if salinity levels exceed levels appropriate for animal consumption. New boreholes may need to be established outside the mining area to the east and west, and also on the south side of the Groenrivier.

Significance statement

If the land is to be returned to stock grazing after mining the impact will be permanent, confined to the study area, very severe, and will probably occur: the overall significance will be High negative.
Successful mitigation will reduce the severity to moderate and the likelihood of occurrence to possible: the overall significance will be reduced to Moderate negative.

It is important to note that if the land is not to be used for stock grazing the impacts will be negligible.

| Impact 1: Impacts on groundwater of the tailings storage facility and backfill |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Impact                          | Effect          | Severity of Impact | Risk or Likelihood | Overall Significance |
| Long-term post-closure          |                 |                 |                  |                  |
| Without Mitigation              | Permanent       | Study area       | Very Severe      | Probable         | HIGH-           |
| With Mitigation                 | Permanent       | Study area       | Moderate         | Possible         | MODERATE-       |

Impact 2: Impacts on groundwater of groundwater abstraction

Cause and comment
Abstraction of groundwater for any mining-related use could lower the groundwater table and reduce yields from local boreholes wells that are used mainly for livestock watering.

- **Construction impacts**: Impacts on groundwater levels may occur when groundwater is abstracted for construction purposes.
- **Operational impacts**: Impacts on groundwater levels will almost certainly occur if groundwater is abstracted for use in mineral processing, even if groundwater is used only to supplement seawater.
- **Long-term post-closure Impacts**: After closure and decommissioning groundwater abstraction will cease and groundwater levels will gradually recover.

The current proposal is to abstract seawater for all operational purposes on the site, with a small proportion being desalinated for domestic purposes, and the remainder being used without treatment for mineral processing.

The severity of the impacts is therefore assessed on the assumption that it will probably be necessary to abstract groundwater from boreholes in the Groenrivier valley for construction purposes, and that it may be necessary to maintain these boreholes in working order during the operation of the mine to provide a backup supply of water in the event of electrical, mechanical or process failure of the seawater abstraction, delivery and treatment system. In this scenario it is likely that the borehole(s) will be worked at a delivery rate considerably less than the sustainable yield indicated by the pump tests.

Mitigation and management

- Restrict groundwater abstraction to the long-term sustainable yield of the well field to minimise lowering of groundwater table.
- If necessary provide an alternative source of water for stockwatering if abstractions for mining purposes prejudice the yield of existing wells and boreholes used by local population.
- Continuously monitor groundwater levels via observation wells.

Significance statement
Although the likelihood of the impact occurring will be reduced by implementing mitigation measures, the overall severity of the impact for construction and operation will be Low negative before and after mitigation.
Impact 2: Impacts on groundwater of groundwater abstraction

<table>
<thead>
<tr>
<th>Construction and Operation</th>
<th>Effect</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without Mitigation</strong></td>
<td>Long term</td>
<td>Local</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>With Mitigation</strong></td>
<td>Long term</td>
<td>Local</td>
<td>Slight</td>
</tr>
</tbody>
</table>

Impact 3: Impacts on groundwater of pollution by contaminants

**Note:** The impacts of waste, including hazardous materials and sanitary waste, on soil and water resources are addressed in the Waste Specialist report.

**Cause and comment**

Groundwater may be polluted by a range of substances that, if not stored, handled and managed properly, may find their way into the aquifer underlying the mine site and permanently contaminate the water. The main contaminants during construction and operation are hydrocarbons such as fuel, oil and other lubricants, paints and solvents, which must be stored, handled and managed to prevent spills and leakage, and measures put in place to rectify incidents immediately they occur. During construction other contaminants such as cement must be properly managed to prevent spillage onto exposed soil surfaces.

**Mitigation and management**

- All hydrocarbons of all types must be stored on impermeable surfaces with appropriately-sized containment bunds and grease traps. Traps must be regularly cleaned.
- All chemicals of all types must be stored on impermeable surfaces in secure and bunded designated storage areas.
- Cement must be stored on impermeable storage areas protected from the rain and mixed only in designated areas. Cement residue must be cleaned up immediately.
- Vehicle repairs, servicing, refuelling and washing must be done only in designated areas with impermeable surfaces with appropriately-sized containment bunds and grease traps.
- Where it is necessary to service, repair or refuel a vehicle or item of plant in the field drip trays must be used to catch drips, spills and leaks.
- Spill kits must be available at all locations where chemicals of hydrocarbons are stored, handled or used, and spills must be cleaned up immediately in accordance with an established protocol appropriate to the material in question.

**Significance statement**

Without mitigation the impacts during the construction phase will be of Moderate negative significance, which can be reduced to Low negative by diligent and sustained implementation of mitigation control measures.

The operational phase is of much longer duration, and the significance without mitigation is considered to be High negative. Nevertheless, the significance can be reduced to Low negative by diligent and sustained implementation of mitigation control measures.

Impact 6: Impacts on groundwater of pollution by contaminants

<table>
<thead>
<tr>
<th>Construction</th>
<th>Effect</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without Mitigation</strong></td>
<td>Short term</td>
<td>Study area</td>
<td>Severe</td>
</tr>
<tr>
<td><strong>With Mitigation</strong></td>
<td>Short term</td>
<td>Study area</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
1.2.2. Impacts on Surface Water

Assessment of the impacts of mining on the surface water resources of the area is restricted to assessing the potential impacts on the Groenrivier estuary which, because it is one of the few estuaries along this stretch of the west coast with an area of open water for much of the year, is regarded as an important area for wetland-dependant bird life.

Impact 4: Impacts on surface water of the tailings storage facility and backfill

Cause and comment

Groundwater modelling indicates that the saline plume from the TSF and backfilling will reach the northern side of the Groenrivier valley where it borders the southern extent of Roode Heuvel block about 10 to 20 years after mine closure, and that TDS levels in groundwater in the immediate vicinity of the river may increase to 15 000 - 20 000 mg/l. The saline plume is expected to pass beneath the bed of the river channel at around Year 80 (that is, about 60 years after mine closure). The model indicates that the plume will pass beneath the channel, and there will be no net change in groundwater level. The plume will not contribute to flow in the river channel and thence seawards to the estuary. The possibility of ground water levels rising sufficient for the saline plume to contribute to river flow, either as a result of mining or as a result of external influences such as climate change is considered to be extremely unlikely. Even if hydrological connectivity between the seepage plume and the river channel did occur the lower estuarine lagoon is characteristically hypersaline, with a TDS of around 200 000 mg/l, indications of active sulphate reduction, anoxia and methanogenesis, and no significant ecological functioning. Post-mining groundwater TDS levels to the south of the mining area, on the other hand, will peak at approximately 24 000 mg/l. and minor flux of such water to the estuarine system, either via river conveyance or groundwater discharge, both of which are confirmed to be improbable, would therefore be unlikely to significantly influence the baseline conditions of the estuarine system. In addition the spring at the head of the estuary lies some 8km downstream at the closest approach of the plume, and extensive mixing and dilution will occur.

- **Construction impacts:** No impacts are anticipated.
- **Operational impacts:** No water quality impacts on the Groenrivier related to backfilling or the TSF are anticipated.
- **Long-term post-closure Impacts:** The results of groundwater modelling indicate that the probability of the plume of highly-saline seepage from backfill and the TSF affecting the integrity of the estuary is sufficiently low to be considered negligible.

Mitigation and management

- Mitigation measures proposed for Impact 1 may result in a reduction of salinity levels of around 5 000 mg/l.
- Having established a pre-mining baseline of the salinity levels in the estuary (SWS 2015), the general biological state of the estuary should be established and monitored at regular intervals thereafter.

Significance statement

The low probability of the saline seepage from the TSF and backfill contributing to the flow regime of the river and entering the estuary, and the comparative salinities of the seepage (relatively lower) and the water of the lagoon (relatively higher) indicates that, even if the impact did occur, and although it would to all intents and purposes be permanent, it would be localised, with slight
severity, and with an overall significance of LOW negative. No mitigation measures are required, but measures recommended (Impact 1) to reduce the salinity of the seepage would also serve to further mitigate this already low impact.

<table>
<thead>
<tr>
<th>Impact</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
<th>Severity of Impact</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Mitigation</td>
<td>Permanent</td>
<td>Local</td>
<td>Slight</td>
<td>Unlikely</td>
<td>LOW-</td>
</tr>
<tr>
<td>With Mitigation</td>
<td>Permanent</td>
<td>Local</td>
<td>Slight</td>
<td>Unlikely</td>
<td>LOW-</td>
</tr>
</tbody>
</table>

Impact 5: Impact on surface water of groundwater abstraction from the Groenrivier valley

Cause and comment
SWS’s 2015 study indicates that there is negligible perennial flow in the Groenrivier system, either at the surface or in the shallow substrate or channel fill, and that the lagoon is sustained by discharge from the spring at the head of the estuary. The spring is fed by a shallow groundwater system in the riparian zone. The discharge from the spring was estimated to be 1 litre per second. The study also showed, by means of hydrochemical fingerprinting, that a direct hydrogeological connection between the general groundwater resources adjacent to the river and the spring is highly unlikely. The river and estuary will only be affected in the unlikely event of water being abstracted from the shallow groundwater system in the riparian zone that feeds the spring. Since the discharge from the spring has been observed to be very low (around 1 litre per second in February 2015) compared to the estimated yield of the deeper groundwater system (possibly up to 30 litres per second), there is no intention to abstract water from the riparian groundwater system.

Provided no water is abstracted from the groundwater system that feeds the spring no impacts on the river or estuary are anticipated during construction or operation, or in the long-term after mine closure.

Mitigation and management
- Ensure that water is not abstracted from the shallow groundwater system in the riparian zone

Impact 6: Impacts of river crossing infrastructure

Cause and comment
It will be necessary to upgrade (or possibly even to replace) the existing DR2938 road crossing over the Groenrivier to accommodate increased mine-related traffic. It will also be necessary to construct a pipeline across the river to convey mineral processing water from the seawater intake on the coast south of the mine site to the mine site.

- **Construction impacts:** The construction of the road crossing and pipeline will necessitate working in and immediately adjacent to the river channel, and may require excavation in or alterations to the river bed and riparian zones.
- **Operational impacts:** A road crossing already exists, and the upgraded / new crossing is not expected to cause additional impacts to the flow regime of river, or to the bed or banks, during mine operation. The seawater pipeline will be constructed across the river at a height sufficient to avoid damage by the occasional high flows in the river.
- **Closure and Long Term Impacts:** The access road will remain in place after mine closure and decommissioning, since the District Road provides access to local farms, the Namaqua National Park and Groenriviermond and estuary. It is probable that the seawater pipeline will be removed when mining ceases.
The existing road crossing is a drift, with no culverts. The structure prevents subsurface flow, when it occurs, which backs up and flows over the road slab\textsuperscript{7}. The road is impassable during the infrequent high-flow events. The upgraded / new crossing will not result in any impacts on the flow regime of the river that do not already occur. If the upgraded crossing is designed to include culverts it will not obstruct low flows up to the culvert capacity.

Mitigation and management

\textit{Road crossing}

- If it is necessary to construct a new crossing, not on the alignment of the existing drift, it should be sited to avoid extensive excavation in the banks, and to avoid sensitive areas in the channel or riparian areas.
- The conditions of the Water Use Licence (or General Authorisation) must be strictly adhered to

\textit{Pipe crossing}

- Site the crossing to avoid extensive excavation in the banks, and to avoid sensitive areas in the channel or riparian areas.
- As far as possible avoid the construction of structures below the level of the 100-year flood.
- Remove the crossing after closure and decommissioning of the mine.
- The conditions of the Water Use Licence must be strictly adhered to

Significance statement

Without proper care in siting and constructing the crossings the bed and banks of the river could be damaged, resulting in impacts of Moderate significance. Impacts can be reduced to Low significance by adhering to the conditions in the Water Use Licence / General Authorisation.

Operational impacts are expected to be of Low significance.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|}
\hline
\textbf{Impact} & \textbf{Effect} & \textbf{Temporal Scale} & \textbf{Spatial Scale} & \textbf{Severity of Impact} & \textbf{Risk or Likelihood} & \textbf{Overall Significance} \\
\hline
\textbf{Construction} & & & & & & \\
Without Mitigation & & Local & Moderate & Probable & MODERATE- \\
With Mitigation & & Local & Slight & Possible & LOW- \\
\hline
\textbf{Operation} & & & & & & \\
Without Mitigation & & Local & Slight & Possible & LOW- \\
With Mitigation & & Local & Slight & Unlikely & LOW- \\
\hline
\end{tabular}
\end{table}

References:


\textsuperscript{7} This is evident on the Google Earth images of the road crossing, which are dated 24th September 2013, two days after a flow rate of 1.7m\textsuperscript{3}/sec was recorded at the Swartdoring gauging station.
Forestry, Pretoria, June 2006.


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