### VOLUME 20: WATER ASSESSMENT

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<th>Prepared by:</th>
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<tr>
<td><img src="image1.png" alt="World Titanium Resources Logo" /></td>
<td><img src="image2.png" alt="Aquaterre Logo" /></td>
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</tbody>
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January 2013
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1. INTRODUCTION

This document is prepared by AQUATERRE following a request from TOLIARA SANDS PROJECT (TSP), to assess the proposed water abstraction for the dry mining project of the Ranobe mineral deposit. This is a desk-top review of existing reports focusing mainly on water abstraction (water discharges and seepage from the mine operations were not included in this review).

The initial water studies were prepared by Hydromad & SRK based upon an earlier description of the project and initial estimates for water requirements. Early assessments were based on the initial project concept i.e. dredge mining under the previous operation. Since then, the design of the project has changed to dry mining and thereby reduced potential water requirements.

AQUATERRE reviewed SRK and Hydromad documents as well as the new simplified project description and associated water requirements. Pertinent information from these documents were extracted/summarised, and assessed to determine if current information has been able to prove if there is sufficient subterranean water for the new project operation. The purpose of this review was also to identify any gaps in the information provided in the SRK and Hydromad reports. At this stage, there are no foreseen plans to collect additional data or perform further modelling and data analysis.
2. PROJECT DESCRIPTION AND MAIN CHANGES

This section gives a brief review of the project focusing on water aspects and changes, which were assessed for the current project based upon the water resources previously assessed by Hydromad in 2004; SRK in 2007; and Rison in 2008.

2.1 Initial Project: Dredge Mining

Figure 2-1 shows the project location and the main features of the area (Rison 2008).

The proposed mine is located at about 20 km inland from the coast and 5 km to the south of the Manombo River course at the base of an Eocene limestone escarpment.

The initial project included the following (Rison 2008):

- Removing of Vegetation
- Stripping of topsoil
- Dredge mining which results in the creation of an open area filled with water
- Tailings behind the open void, as mining advances
- Rehabilitation once the tails stacking is completed

Water would have been required to fill the dredging ponds and to compensate for the losses through seepage from these ponds. After the initial fill, the amount of required water would be directly proportional to the anticipated water losses from the ponds. Rison outlined that these losses were uncertain, as they considered that the modelling hypothesis in SRK’s assessment were not considered appropriate. Based upon similar projects with comparable conditions, losses from dredge ponds could range from 50 000 to 80 000 m$^3$/day, according to Rison.

2.2 Current Project: Dry Mining

Following these initial water assessments, the project design changed significantly, as dry mining was adopted instead of dredge mining. As a consequence, the water needs was decreased from around 4500 m$^3$/h to around 560 m$^3$/h, which could be produced by 3 wells, based upon a potential production of 180 m$^3$/h per well, as estimated by SRK.
Figure 2-1: Project Location
3. REVIEW OF PREVIOUS WORK AND IMPLICATIONS FOR SCALE OF CURRENT PROJECT

3.1 Water Resources Assessment

The water resources were assessed by Hydromad and SRK studies between 2004 and 2007. The assessment was made based upon climatic historical data, hydrologic historical data, geological information and background hydrogeological knowledge, as well as data derived from a network of production and observation wells.

3.1.1 Rainfall and Evaporation

The main parameters for the assessment are precipitation and evapotranspiration which both influence the water balance and water availability.

Annual precipitations were derived from historical data in the area, as there was no weather station or rain gauge at the site. Figure 3-3 shows isohyets at regional level (Hydromad, 2007): Average rainfall decreases from 800 mm at the extreme north-east corner of the limestone plateau to between 400 and 500 mm on the coastline.

The majority of the limestone plateau in the area of Ranobe receives between 450 and 700 mm of rain. The period of records which were used to draw these isohyets is not indicated; however Fleuve et Riviere de Madagascar (ORSTOM), which is given as the reference for these isohyets is dated 1993.

Available rainfall data at the regional weather stations are given in Table 3-1.

Table 3-1: Available rainfall data at regional weather stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Distance and direction from Ranobe Mineral Deposit</th>
<th>Average rainfall</th>
<th>Period of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toliara</td>
<td>40 km south</td>
<td>375</td>
<td>1901-2004</td>
</tr>
<tr>
<td>Manombo</td>
<td>20 km north-west</td>
<td>462</td>
<td>1949-1990</td>
</tr>
<tr>
<td>Befandriana</td>
<td>100 km north</td>
<td>834</td>
<td>1937-1975</td>
</tr>
<tr>
<td>Mahaboboka</td>
<td>80 km east</td>
<td>529</td>
<td>1960-1963</td>
</tr>
<tr>
<td>Ankazoabo</td>
<td>100 km north-east</td>
<td>709</td>
<td>1911-1976</td>
</tr>
</tbody>
</table>

Annual rainfall is characterised by a high variability: in Toliara, annual records range between 135 and 970 mm during the period 1950 to 2000, with an average just below 400 mm.

The rainfall distribution throughout the year was not presented; however, the rainfall pattern shows a dry season from June to September and a wet season from October to May. This distribution is also important to take into consideration.

Severe droughts have been experienced in the past, as well as cyclonic events where the majority of the annual rainfall occurs with very high intensities.

Annual evaporation was also derived from historical data, which is generally not very well known. Annual pan evaporation is estimated to be 1950 mm for the Manombo catchment (SRK, 2007), while Piche evaporation is 1250 mm in Toliara, and 1563 mm in Morondava (Hydromad, 2004). Potential evapotranspiration, which can be calculated from the pan evaporation, is estimated to be 344 mm/year (SRK, 2007).
3.1.2 Groundwater resources

Aquifers

The mine concession and proposed well field is located in the foothills of a karst plateau. The major aquifers are as follows (See Figure 3.2):

- Unconsolidated alluvium along the floodplain of the Manombo River and coastline, with primary inter-granular porosity.
- Upper Eocene Limestone formation, with both primary inter-granular porosity and secondary permeability associated with fractures, faults and karstication.
- Lower Eocene Limestone Plateau, with both primary inter-granular porosity and secondary permeability associated with fractures, faults and karstication.

Most of the population rely upon groundwater, given the scarcity and seasonality of surface water. At present, local people use mainly the alluvium aquifer, which is the most accessible but also the most vulnerable to contamination and overuse. However, as the mine develops and standards of living evolve in the area, this may change and the limestone aquifer may be used.

Finally, it was recommended to prefer the karstic aquifer, because it is considered more reliable in terms of water quality, levels and quantity and is not used by local inhabitant at present.
Recharge

Recharge is an important parameter to assess wells’ sustainable yields.

Direct recharge from the rainfall was estimated by SRK based upon the initial tritium concentration in rainfall (2.5 TU) and a Mean Annual Precipitation (MAP) of 800 mm over the recharge area. According to this assessment, recharge ranged between 8 and 20 % of the MAP for the Eocene limestone aquifer. Meanwhile, the recharge was estimated to be less than 2 % of the MAP for the unconsolidated sand aquifer.

Based upon the comparison with similar aquifers in South Africa, Rison also proposed rates between 3 and 32 % (most likely value around 12 %) of the MAP for the lower Eocene limestone aquifer. Rison also considered a lower MAP of 650 mm, instead of 800 mm for this aquifer, which appears more accurate. The direct recharge from rainfall to the upper Eocene limestone underneath the unconsolidated sand would be controlled by the recharge to this unconsolidated material. This recharge has been estimated to be 5 to 6 % of the MAP.

According to Rison, additional recharge to the Eocene aquifer would occur east of the Toliara fault, from streams and rivers and would vary depending upon seasonal surface flows (which are highly variable) and variations of permeability along the river beds. Recharge from the Manombo River is likely to be relatively high in the upper reaches of the river. Irrigation channels in the project area would also contribute to the groundwater recharge, depending upon the permeability of the channel beds.

According to SRK, isotope data suggest that at the base of the limestone escarpment, groundwater dates from fairly recent recharging from within the plateau within a short travel time indicating potential sustainable exploitation of this resource. According to Rison, the high variability of water chemistry suggests that there could be at least two sources of water throughout the system; however available macro-chemistry and isotope data did not allow differentiation of these sources (e.g. surface and groundwater) and the interactions between boreholes. For the shallow unconsolidated sand aquifer, Rison observes that water chemistry is influenced by the vertical migration of groundwater, suggesting a localised recharge; however, water levels seem to be influenced by a regional lateral flow from the underlying Eocene limestone aquifer.

As outlined by Rison, it is important to note that recharge will primarily occur between October and April, due to the seasonality of rainfall. However, both SRK and Rison water assessment resources appear to have been done at an annual level and not at monthly levels.
Figure 3-2: Regional geology
Water levels and groundwater flows

Water levels were measured at 18 locations, within the unconsolidated sand aquifer and the Eocene limestone aquifer west of the Toliara fault, as follows:

- 2 production wells drilled for the project
- 4 observation wells drilled for the project
- 7 monitoring wells drilled for the project
- 5 community wells

Water levels are deep (40 to 60 m below ground level) at the foot of the limestone escarpment and become shallower towards the coast (1 to 5 m below groundwater within the Recent Dunes aquifer).

The gradient indicates water flows from east to the coastline, although the groundwater surface is relatively flat from the foothills of the escarpment. The hydraulic gradient is presumably much steeper from the eastern plateau and eastwards to the Toliara fault; however there is no data for the water levels within the limestone plateau.

Within the proximities of the limestone escarpment, water levels show a time lag of about 2 months after the rain with persistent increases suggesting regional influences. At Ranobe, the water levels respond to the rain within a similar time lag, while the persistence of elevated levels also suggests a regional influence. Meanwhile, the rapid response to rainfall within the coastal Recent Dunes aquifer shows no obvious long term recharge associated with the Eocene limestone regional flow.

Groundwater reserves, sustainable yields from wells and water supply

Deep limestone aquifer

As mentioned previously, the limestone aquifer has been shown by SRK as the preferred groundwater resource.

According to SRK, total groundwater reserves could be derived from the area of the contributing aquifer (about 325 000 000 m$^2$), the mean aquifer thickness (approximately 50m) and storativity$^1$ (approximately 0.001), which accounted for 16 250 000 m$^3$. It includes both the static groundwater table (quantity remains unchanged, e.g. fossil water reserves) and the renewable resource (originating from groundwater recharge).

The renewable resource represents the maximum amount of water that can be extracted from the groundwater in a sustainable mode. It is derived from the recharge rate per annum (as previously discussed) and the area of the contributing aquifer related to the wells. According to SRK, this renewable resource could range between 0.3 m$^3$/s and 2.8 m$^3$/s.

The lower limit was calculated upon a recharge rate derived from a numerical model. The calibrated recharge was: 4% of MAP for the limestone plateau; 1.5% between plateau and coastline; and 3% from the Manombo River to Manombo. The MAP was set at 500mm, which can be considered as a conservative scenario. The upper limit was calculated upon the higher recharge rate of 20% derived from the isotope method. This figure can be considered as an optimistic scenario.

$^1$ Storativity (S) - [-] the volume of water released per unit area of aquifer for a unit decline in head. In a confined aquifer, S is essentially the specific storage (Ss) times aquifer thickness; in an unconfined aquifer, S is essentially equal to the specific yield or the effective porosity. Value without unit
In addition, one production well was tested during 96 hours, at the rate of 54 l/s (194 m$^3$/hr), with minimal influence to the surrounding water levels. Numerical models were also used to calculate sustainable yields, with the result of 110 and 55 l/s (396 and 198 m$^3$/h) respectively for TPW1 and TPW2. Although the cumulative effect of 3 wells was not assessed, it suggests that 180 m$^3$/hr would represent a sustainable yield for each well.

Finally, a numerical flow model was used to simulate the abstraction of groundwater from 3 well fields located in the limestone aquifer on the eastern side of the project concession. The cumulative abstraction rate from 30 wells was 1.5 m$^3$/s. A maximum decline of 8 m over 40 years was observed around the simulated well fields (See Figure 3.3). The drawdown decreased rapidly to only 1m, west of the simulated well fields, and was not evident at the locations of the Ranobe spring and settlement. However, the drawdown within the limestone plateau remains above 3m as far as the most eastern model boundaries being 15km east of the simulated well fields. The impact of a 5 year drought was also predicted as the worse case scenario. Groundwater levels decreased by as much as 4m outside of the mine lease (See Figure 3.4) and had an impact upon a wider area including Ranobe Spring, a coastal wetland, and the proximities of the Manombo River.

Rison used a different model with different sets of parameters to simulate the mining activities, including water abstraction and losses from the tailings and dredging ponds. This confirmed that the higher drawdown was confined to the proximities of the proposed production wells, and as high as 80m. Meanwhile, drawdown on the coast was estimated to be 3m. Water recycling reduced the drawdown to 45 m and 1 m, respectively near the well fields and the coast.

*Shallow alluvium aquifer*

SRK simulated the abstraction of groundwater from two well fields located in the alluvium (See Figure 3.5). The predicted drawdown after 40 years ranged from 9 m near the well field, to 2 m along the Manombo River (See Figure 3.5). The results indicates the potential depletion of the aquifer, taking into account that the alluvial aquifer has a thickness of about 20 m, and the saturated thickness is generally about 10 m below ground level. The results also showed a significant lowering of simulated heads along the entire length of the Manombo River, due to abstraction from the alluvial aquifer.
Figure 3.3: Predicted drawdown at time = 40 years (water abstraction of 1.5 m$^3$/s in Eocene limestone aquifer)

Figure 3.4: Predicted drawdown for a 5 year drought (water abstraction of 1.5 m$^3$/s within Eocene limestone aquifer)
3.2 Impact assessment

Impacts of water abstraction upon surface water and groundwater were assessed by SRK and Rison. The assessment took into consideration a number of mitigation and monitoring measures as follows:

- Exploit the limestone aquifer and not the alluvial aquifer;
- Manage consumption in the mining operations by means of optimising the recovery of water on an ongoing basis;
- Manage abstraction from the well fields in such a way that impacts on the water table are minimised;
- Install downgradient monitoring wells from the well fields to monitor water levels;
- Update the numerical model with recorded data from these wells to optimise water management;
- Supply alternative water resources to affected communities if declining water levels are confirmed;
- Pump water to the spring if declining water levels are confirmed;
- Survey the area for sinkhole, keep infrastructure minimum around the well fields and rehabilitate sinkholes when they occur; and
- If salt intrusion occurs due to the mine abstraction, limit the amount of abstraction from the limestone aquifer and find an alternative source of water for the mine.

Abstraction from the alluvium aquifer was considered to have a significant impact on the surrounding communities and was not foreseen as an acceptable option by SRK and Rison.
3.2.1 Impacts of water abstraction to groundwater levels

As mentioned previously, water abstraction was simulated by SRK for 30 wells producing a total of 1.5 m$^3$/s during 40 years. The simulation had shown a drawdown of 8m within the proximities of wells (See Figure 3.3), and rapidly decreased to below 1 m, north and west of the mine concession towards Manombo River, Ranobe spring and settlement, and the coastal wetlands. Meanwhile, the drawdown remains relatively high east of the mine and upon the limestone plateau.

The impact of a 5 year drought was also predicted as the worse case scenario by SRK, when groundwater levels decreased by as much as 4m outside the mine concession (See Figure 3.4). This scenario also had an impact upon a wider area including Ranobe Spring, coastal wetlands, and the proximities of the Manombo River.

Based upon a simulation over 30 years, Rison confirmed that the higher drawdown was confined to the proximities of the proposed production wells; however, this could be as high as 80 m which is 10 times more than SRK predictions. Meanwhile, the drawdown at the coast was estimated to be 3m, which is also much higher than predicted by SRK. In addition, Rison notes that groundwater levels almost return to pre-mining conditions, 5 years after the end of mining, which indicates that impacts to water levels would be reversible within a reasonable time period. Rison also indicated that water management (recycling) would reduce the drawdown from 80 and 3 m to 45 and 1 m, respectively, near the well fields and on the coast.

3.2.2 Development of sinkholes linked with water abstraction

Abstraction from the karst limestone can result in the formation of sinkholes, as cavities are dewatered. This could result in potentially unstable ground conditions. According to SRK, within the plain, the sand cover above the karst limestone is thick (>30 m) so it is anticipated that this layer should buffer the impact of sinkhole formation, therefore the risk is considered to be moderate. However, on the plateau, east of the Toliara fault, there is no sand to buffer the impact of sinkhole formation; therefore the risk could be higher. Following mine rehabilitation, Rison suggests impacts of low significance.

3.2.3 Salt water intrusion linked to water abstraction

Abstraction from coastal aquifers can result in the advance of the saltwater/freshwater interfaces resulting in localised losses of coastal aquifers. Both SRK and Rison suggest that this impact is unlikely to occur, but suggest if it should appear, it would be highly significant.

3.2.4 Decrease in water availability for natural vegetation associated with water abstraction

The lowering of the water table could impact on the capillary capacity of the vadose zone decreasing water availability for natural vegetation. However, given the nature of xerophytic vegetation, the depth of the water table and the fact that the soils are generally dry in the area, this impact is considered as unlikely or of low significance. However, the risk is higher within the coastal wetlands (see Section 4.7).

3.2.5 Decrease of groundwater discharge into surface water

The potential drawdown of groundwater could cause a decrease in groundwater discharge to surface water at the Manombo River, springs, and coastal wetlands.

According to SRK, the recharge model indicates that the pressure head difference in the limestone plateau is driving the re-surgence along the coastline at the sea/fresh water interface and within the sinkhole at Ranobe village. A drop in the head may lower the water table at the zones of resurgence resulting in a loss of the aquatic habitat and water supply associated with these zones.
The flow model indicates a localised drop in the head of only 5m within the limestone plateau after abstraction of 1.5m³/s for 40 years. Given the head difference between the plateau and the coastal plain of more than 200m, this impact is considered to have very low significance.

As outlined by Rison, interrelations between the Manombo River and groundwater depend upon the Manombo River bed characteristics which may vary along the river, as well and flow rates, which vary throughout the year. Losses from the Manombo River to groundwater are expected to occur during high flows. During the dry season, most of the flow is base-flow in the alluvial aquifer. Even a slight drawdown of groundwater could have an impact upon the Manombo base-flow.

According to Rison, coastal wetlands/lakes in the Ranobe area are generally slightly above groundwater level with intermittent connexions, where there is a delicate balance between the wetlands/lakes feeding the groundwater and vice versa. This fragile balance could be affected by a drawdown of water levels, where the ecology of these surface water bodies could be affected, or worse, they could dry up.

As mentioned in Section 4.1, the water table drawdown on the coastal areas and nearby the Manombo River was predicted to range between 0 and 1m, after 30 or 40 years of water abstraction at the rate of 1.5 m³/s. However, for a 5 year drought, the drawdown could increase to up to 3m. In addition, as outlined by Rison, even a slight drawdown would have an impact on the fragile balance between groundwater and surface water. As a consequence, Rison expects significant impacts on surface water, including the Manombo River base-flow, springs and wetlands/lakes.

### 3.2.6 Impact of water abstraction upon local users

As outlined by Rison, surrounding rural settlements are concentrated along the coastline and the Manombo River and associated Andoharano irrigation canal. An exception is the village of Ranobe as well as the area immediately inland of Ambolomalaika Village, both of which are located adjacent to surface depressions that collect surface water. Access to water is clearly a influential factor upon the distribution of the local population. Water for agriculture is derived directly from the irrigation canal, while drinking water is predominantly derived from shallow hand dug wells (generally less than 10m in depth).

All users are located north and west of the mine lease, where the predicted groundwater drawdown is minimal. Meanwhile, there are no users east of the mine concession, where the predicted groundwater drawdown is higher (See Section 4.1). Impacts on users were considered by SRK as low following mitigation measures. However, Rison suggests an impact of average significance for surface water users, as surface water occurrence depends upon a fragile balance between groundwater and surface water. Users would therefore be sensitive to even a slight decrease in groundwater levels (less than 1m). In addition, it has to be noted that during a drought period, impacts would be higher according to SRK’s simulation. Finally, if there is an impact, the provision of alternative sources of water to local users may not be a sustainable mitigation measure, as people will be dependant upon the mining project or other providers of water, which may also require high technological costs.

As outlined by Rison, several hotels are located on the coast and utilise deep wells for water abstraction. These establishments would be sensitive to salt intrusion linked to water abstraction for the mine. As mentioned in Section 4.3, the impact of the proposed water abstraction was deemed to be unlikely, but should it occur, it would be highly significant.
4. IMPLICATIONS FOR CURRENT PROJECT SCALE

The amount of water abstraction is significantly reduced as previous assessments were prepared for a total of 1.5 m$^3$/s. The current scale project would now require 0.156 m$^3$/s. It is not possible at this stage (based upon a desk-top review of existing reports) to quantify the drawdown generated by this reduced abstraction, as this would require remobilising the simulation model with the new proposed water abstraction.

Subsequently, it is not possible to quantify impacts on groundwater, surface water (Manombo river, coastal wetlands, springs/streams), aquatic habitats and other uses, although these would be significantly lower than requirements from the initial project. Although some of the impacts may remain significant, specifically during dry periods.

In addition, it has to be noted that it is not possible, at this stage, to predict the effect of losses from the tailings to groundwater, which would partially compensate for water abstractions. This would also require the remobilising of the simulation model incorporating the new mine design.

4.1 Water Resources

4.1.1 Deep Limestone Aquifer

The water requirement for the new project design is 560 m$^3$/hr (0.156 m$^3$/s) which is below the most conservative renewable resource estimates associated with the mean annual rainfall. Based upon this assessment, there is high confidence that water requirement could be globally satisfied without depleting the aquifer on average.

This yield is also 10 times below the simulated abstraction over 40 years, which had shown no evidence of drawdown outside of the mine lease area towards the Ranobe spring and settlement, according to SRK. However, it is not possible to predict what would be the drawdown from reduced flow, although is likely to be significantly lower. The drawdown during a 5 year drought would also be significantly lower.

It is important to note that there are some limitations and gaps in the information associated with this review, which are discussed later in this report.

4.1.2 Shallow alluvium aquifer

The simulation performed by SRK has shown that a 1.2 m$^3$/s abstraction rate from the alluvium would lead to the depletion of this resource and unacceptable impacts upon local communities. The abstraction for the current and new project is much lower (0.156 m3/s), which would lead to a significantly reduced drawdown of the water table, and the possibility that this water supply would be sustainable. However, this option is still questionable when compared to the deep aquifer for the following reasons:

- The alluvium aquifer is shallower and the production wells would have to be installed at a greater distance from the mine site (hence the need for longer pipelines with increased head losses and additional costs);
- Local people rely heavily on this alluvium aquifer and even a slight drawdown of water levels in this aquifer may lead to significant impacts upon local users;
- The production wells would also be located closer to local users (villages and rice fields), generating the maximal drawdown of water level in the immediate vicinity of current local exploitation.
4.2 Impacts of the current project

The impacts of current project are assessed upon the basis that water will be abstracted from the deeper limestone aquifer and apply the same mitigation measures as proposed for the former project (see Section 3.2). A full impact assessment supported by numerical simulation would be required for abstraction from the alluvium aquifer, which was not included in this current review of existing studies.

4.2.1 Impacts of water abstraction to groundwater levels

As mentioned in Section 3.2.1, impacts were simulated for a total abstraction of 1.5 m$^3$/s. The new project requirement is 0.156 m$^3$/s, which is almost 10 times less than the simulated abstraction. Therefore, the impact will be significantly reduced. However, it is necessary to re-run the simulation to predict the resulting drawdown, as the impact may still be significant during the dry periods.

4.2.2 Development of sinkholes associated with water abstraction

In previous studies, the risk was considered to be moderate on the plain area (but higher on the plateau area). Reducing the total abstraction by a factor of almost 10 would significantly reduce the drawdown upon water tables, as mentioned above; this would significantly reduce the risk of sinkholes.

4.2.3 Salt water intrusion associated with water abstraction

This impact was considered unlikely to occur with a 1.5 m$^3$/s abstraction. With the current project, the likelihood of this impact is even lower.

4.2.4 Decrease in water availability for natural vegetation associated with water abstraction

This impact was considered as unlikely to occur or of low significance with a 1.5 m$^3$/s abstraction. With the current project, it would be even more unlikely and of very low significance for xerophytic vegetation (see below for wetland habitats).

4.2.5 Decrease of groundwater discharge into surface waters and potential impacts upon wetland habitats

The potential impact of a 1.5 m$^3$/s abstraction was considered as significant upon surface waters, including the Manombo River base-flow, springs and wetlands/lakes. Although the proposed abstraction of 0.156 m$^3$/s would generate a much lower impact upon surface waters, it is not possible to quantify the impacts at this stage. This influence upon surface waters would subsequently affect the aquatic ecology, flora and fauna, as well as potential impacts upon local users.

4.2.6 Impact of water abstraction upon local users

Potential impacts were considered to have an average significance upon users (local populations), where even a slight drawdown of water levels could have significant affects. The impact will be significantly reduced with the current project, although there are potential significant impacts during the dry periods.
5. INFORMATION GAPS AND LIMITS ASSOCIATED WITH PREVIOUS STUDIES

As outlined by SRK, characterising karst aquifers is complex, due to problems of scale and the complex nature of karst systems. In addition, current numerical models have had difficulties to represent boundaries for this type of aquifer, and subsequently the simulation of groundwater flows at both local and regional levels.

As outlined by Rison, the assessments were based upon limited existing data at the time of the studies, while monitoring of weather, groundwater and surface water have been recently initiated or on-going at the site.

As outlined in Rison, the sources of data used to characterise the lower Eocene limestone aquifer east of the Toliara fault are uncertain as no observation/production wells were drilled in this aquifer. This is a major gap in the studies, as it constitutes most of the recharge area for the project zone. This implies that major characteristics of the aquifer are uncertain, such as groundwater gradients between the limestone plateau and the coastal plain, groundwater recharge, transmissivity, hydraulic conductivity and storage, which are important parameters to determine sustainable yields for water abstraction.

As outlined by SRK, the exact location of the Toliara Fault could not be determined from the geophysics and no pump tests was conducted along this fault. Therefore, this fault has not been included in the model, which appears to be a major gap in the assessment, given the importance of faults in groundwater hydraulics.

Both SRK and Rison outlined that the direct recharge rate is uncertain, specifically for the Eocene limestone aquifer, and could be within a significant range of values (3 to 32 %). In addition, both assessments are contradictory in terms of methodologies used and results obtained. Rison also suggests that there are potential recharges from the Manombo River and irrigation canals which depend upon seasonal variations and unknown river/canal bed characteristics. Subsequently the renewable resources e.g. sustainable extractable yield from the aquifer, are also uncertain.

Rison outlined the need to better understand the hydrological regime of Manombo River, in order to improve assessments of recharge from the river to groundwater during high flows.

Both SRK and Rison outline the need for more isotope and macro-chemistry data (for rainfall and groundwater) to differentiate the different origins of water and confirm the preliminary recharge estimates.

SRK used a 800 mm mean annual rainfall to calculate the recharge to the limestone aquifer, which seems overestimated based upon the isohyets presented in the study (the recharge area lies between 450 and 800 mm isohyets, where 800 mm occurs at only the extreme north-eastern outreaches of the plateau).

SRK outlines that for technical reasons, pump tests where performed at a maximum rate of 54 l/s. This rate could not sufficiently stress the aquifer, which means that results do not reflect the boundaries conditions and the maximum abstraction capacity. Due to this fact, the calculated transmissivity and hydraulic conductivity be less conservative values.

Pump tests were performed for one single well producing a maximum yield of 54 l/s. It has not been performed for 3 wells producing a cumulative yield of 560 m3/h (156 l/s). These test will be required to obtain the permit for water abstraction from the national water authority (ANDEA).

From the SRK report, analysis of the drawdown in the observation wells indicates that there was a rise in water level during the pumping tests. According to Rison, this renders any interpretation of the aquifer parameters, as ambiguous.
There are uncertainties regarding groundwater recharge, specifically for the Eocene limestone aquifer. Subsequently, availability of renewable resources and sustainable yields for water supplies at the mine site are equally uncertain.

Rison stated that SRK’s groundwater model was incomplete and criticised the recharge area and the boundaries which were used in SRK’s model. In addition, the SRK study was based on local recharge; while Rison suggested that there is more regional influence.

Rison and SRK used the MODFLOW model with different sets of parameters and assumptions, leading to contradictory results regarding the drawdown of water levels associated with mine activities and subsequent social and environmental impacts. Data on geohydrology were limited, which explains why various and different assumptions have been made. More detailed data is required to refine the model and create a more accurate set of parameters for the area.

In addition, although it is not clearly stated, SRK analysed separately the effect of water abstraction from groundwater and the effect of water losses from dredge ponds to the groundwater. It seems that Rison simulated both effects within the same simulation, where the losses from tailings and dredge ponds may partially compensate for the water abstraction. However, this is not clearly stated in Rison report. Losses from the new project would be significantly different and therefore require simulation.

Climate change is not taken into consideration. Although it is difficult to predict changes in rainfall patterns, regional climate change models suggest a significant decrease of annual rainfall could be expected in dry areas. In addition, more unpredictable rainfall patterns and intense storms (potentially leading to higher runoff, lower infiltration and thus lower groundwater recharge) are possible. These changes would significantly affect water resources.

Abstraction by local communities and hotels were not accounted for in the numerical flow model, assessment of water resources and sustainable yields as there was no data available. This is a major gap, as there may be significant impacts from existing activities as well as cumulative impacts with the proposed mine activities. If it is not ascertained now, it may be difficult at a later stage to identify mutual responsibilities. In addition, as outlined by Rison, the limestone aquifer has not traditionally been exploited due to the depth to groundwater and the cost of drilling equipment; however, this may change should mining proceed and income levels change within the surrounding communities. This potential increase of water abstraction was not considered in the model.

The entire assessment is based upon average annual data. Rison outlines the importance of taking into consideration that most of the groundwater recharge occurs between December and March. However, no assessment was done on a monthly basis, especially during the driest months of the year and/or when the lower groundwater levels occur.

SRK outlines the need for accurate measurement of evaporation, as the existing studies are based upon limited regional data, and evaporation is a major parameter for groundwater recharge.

The worse case scenario is given for a 5 year drought. However, the worst case scenario should have a very low probability to occur during the project implementation. It should therefore be based upon a dry return period above the total duration of the project, e.g. 40 years (project life), but preferably 50 or 100 years.
6. CONCLUSION AND RECOMMENDATIONS

These recommendations focus mainly upon the proposed water abstraction for the mine. Water seepage and discharges were not included in this review.

6.1 Water resources and environmental and social impacts

There is a high degree of confidence that water needs for the proposed dry mining could be supplied by sustainable abstractions from the Eocene limestone aquifer, where 3 wells would each produce approximately 180 m$^3$/h.

There is a certain degree of confidence that social and environmental impacts from these abstractions should be of low significance. However, it is not possible to accurately predict the magnitude of reduction of the impacts compared to existing impact assessments for dredge mining with higher water abstraction rates. Therefore, it would necessary to reinitiate the numerical simulation with new water abstraction rates.

There is a high degree of confidence that the water levels would recover to pre-mining conditions within 5 years following the termination of mining activities.

Due to the distance between the proposed wells and surface water bodies (coastal marshes and Manombe River), the impacts of groundwater abstraction on surface waters are likely to be low. However, a slight decrease in water levels may exhibit a significant difference due to the highly fragile equilibrium between groundwater and surface water for both local people and natural habitats. Therefore, the impact assessment of water requirements from the new mine design should be supported by updating the simulation model with the new water requirement for the mine (including any potential dewatering and any losses from the tailings to the groundwater), as well as recently collected data on site, which was not used or not available for previous studies.

The SRK suggestion to use the Eocene limestone aquifer came from dredging requiring significant water supplies. The alluvium aquifer option could be revisited as water requirements are now much lower. However, the sustainability of these resources should be demonstrated through simulation modelling. In addition, the location of this aquifer would mean that the wells would be farther from the mine but closer to local communities, which may not be the best option from technical and social perspectives.

In both cases (water abstraction from limestone or alluvium aquifer), the cumulative/compensative effects of water seep into the alluvium aquifer and/or surface water discharge should be assessed through numerical simulation for the current project.

The simulation should take into account current uses by local communities and commercial activities (hotels), as well as potential increases in the future.

The simulation should use a 50 or 100-year drought as the worse case scenario. The simulation should also be performed on a monthly basis, specifically for the drier months of the year, and take into account higher water demands for agriculture. In addition, climate change scenarios including significant lowering of rainfall patterns in the region should be simulated by the model.

Additional information is needed as gaps in the information where identified. This data would include the following:

- Quantify evaporation and rainfall with more accuracy for the entire recharge area, based upon local measurements.
- Quantify the recharge rate of the limestone aquifer with more accuracy, and verify the recharge area of this aquifer.
- Better characterise the lower Eocene aquifer characteristics east of the Toliara fault (limestone plateau), which will require additional drilling in this area.
• Additional data points (drilling) are also needed across the mine site and coastal area to improve the resolution across the entire study area.

• Better understand the interactions between groundwater and surface water, specifically for the Manombo river (and associated irrigation canals), springs and coastal marshes/lakes; this would require additional surface water data (flows and water levels; river bed characteristics).

• Quantify current water uses by local communities and hotels, as well as predict future uses (including induced effect linked to the mine development).

• Better understand the macro-chemistry and isotopes of rain water, surface water and groundwater in order to better understand groundwater recharge as well as surface and groundwater interactions.

Finally, if the proposed water abstraction has impacts on water table in the vicinity of the coastal wetlands, additional work should be conducted by ecologists to establish the significance of these impacts upon wetland ecology.

Additional data and analysis (numerical modelling) are required prior to implementation of the project’s design phase purposes.

6.2 **Borefield design**

As mentioned by SRK, a detailed geophysical survey would be necessary to select the optimal position of production wells.

Following drilling, pump tests will be necessary, under ANDEA’s supervision, in order to obtain the water abstraction authorisation. During these pump tests, water levels will have to be monitored at the production wells, surrounding observation/monitoring wells (drilled by the project), and local community/hotel and/or other private users’ wells to demonstrate that the proposed abstractions will not have any adverse effects upon these existing users.

6.3 **Preliminary recommendation for long term monitoring**

Long term monitoring is required to confirm the results of model, insure that the project does not have any unexpected impacts upon local users and the surrounding environment, and support corrective measures, where and if necessary. However, it is not designed to be a surrogate for lacunas in or lack of information/data for project design and used in the ESIA.

Current recommendations are preliminary as they need to be reviewed following when re-modelling has been completed and the impacts of the current project are quantified.

Long term monitoring (during and after project implementation) of the following:

• Weather monitoring (specifically rainfall and evapotranspiration);

• Piezometric levels at observation wells located near and downward from the mine area and well fields, and also near sensitive areas (villages, Manombo River, coastal wetlands);

• Water levels within the surface water bodies (Manombo River, coastal wetlands) as well as flows on the Manombo River;

• Local water supplies (hand-dug wells, private (hotel) wells, irrigation channels);

• Inspection of the surrounding of the well fields to insure that no sinkholes are developing;

• Water chemistry (salinity) at observation wells were there could be a potential risk of salt intrusion; and

• Ecological monitoring of coastal wetlands.

It will be important to include monitoring sites which are not affected by the mine and water abstraction processes, as comparative sites, to assess potential background changes which are not associated with the mine development.