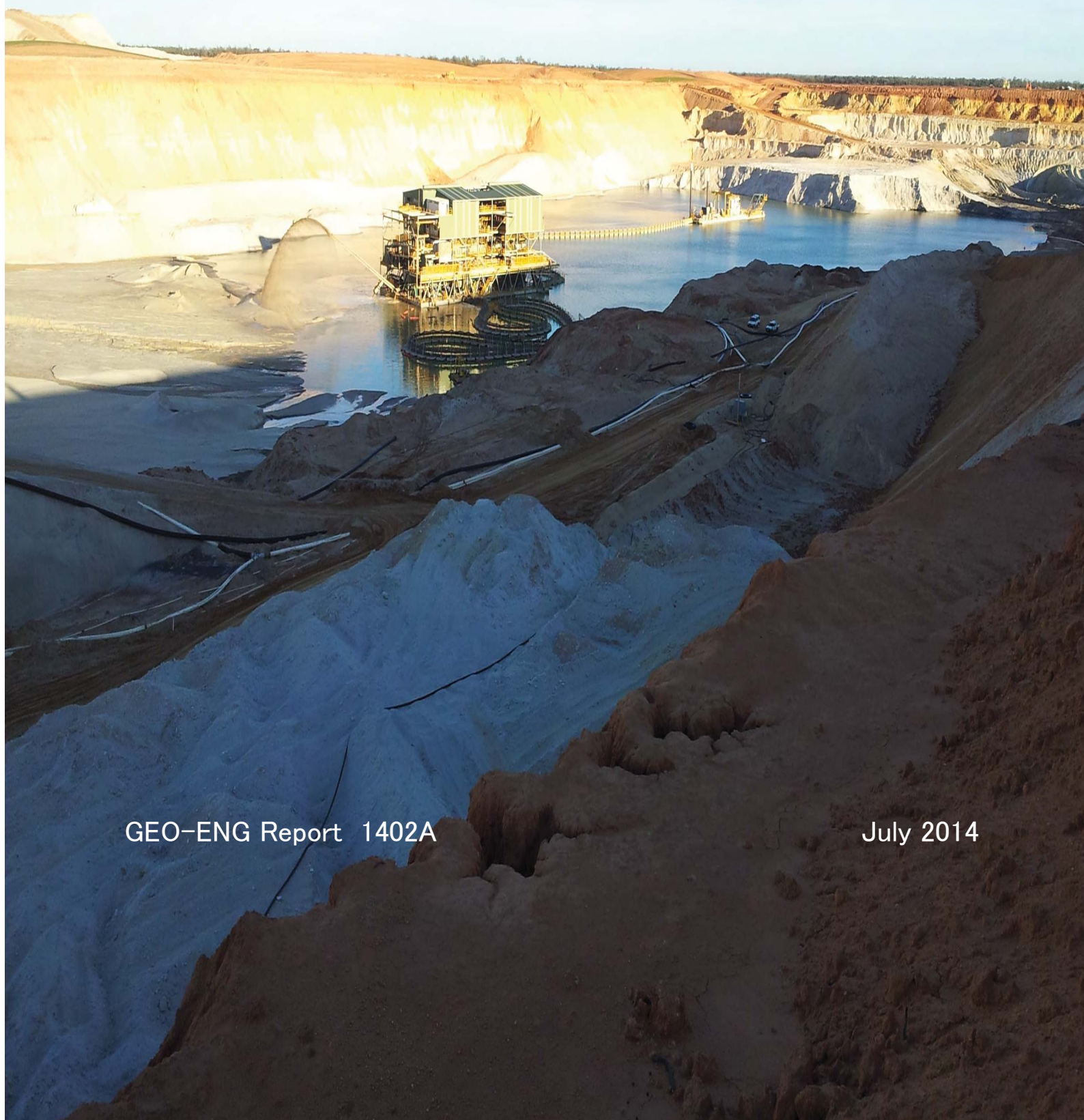




**Appendix A**  
**Hydrogeological Review**

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Cristal Mining Australia  
Snapper Mine Production Increase Modification  
Hydrogeological Review  
Pooncarie, NSW



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## 1 INTRODUCTION

Cristal Mining Australia Limited (Cristal Mining) operates the Snapper and Ginkgo Mines, which are located approximately 85 kilometres (km) northeast of Wentworth and approximately 170 km to the southeast of Broken Hill in western New South Wales (NSW) (Figures 1 and 2).

### 1.1 Snapper Mine

The Snapper Mine was approved under Part 3A of the NSW *Environmental Planning and Assessment Act, 1979* (EP&A Act) in 2007 (Project Approval 06\_0168) and commenced operations in late 2010. The Snapper Mine is currently approved to:

- undertake mining operations to 2026;
- extract up to 9.1 million tonnes per annum (Mtpa) of mineral sands ore, producing a maximum 621,000 tonnes per annum (tpa) of mineral concentrate for processing at Cristal Mining's Broken Hill Mineral Separation Plant (the MSP); and
- receive MSP process waste for designated stockpiling, prior to depositing on the sand residue beach and/or with overburden.

### 1.2 Ginkgo Mine

The Ginkgo Mine was approved under Part 4 of the EP&A Act in 2002 (Development Consent DA 251-09-01) and was commissioned in 2005. The Ginkgo Mine is currently approved to:

- undertake mining operations to 2023;
- extract up to 14 Mtpa of mineral sands ore, producing a maximum 576,000 tpa of mineral concentrate for processing at the MSP; and
- receive MSP process waste for designated stockpiling, prior to depositing on the sand residue beach and/or with overburden.

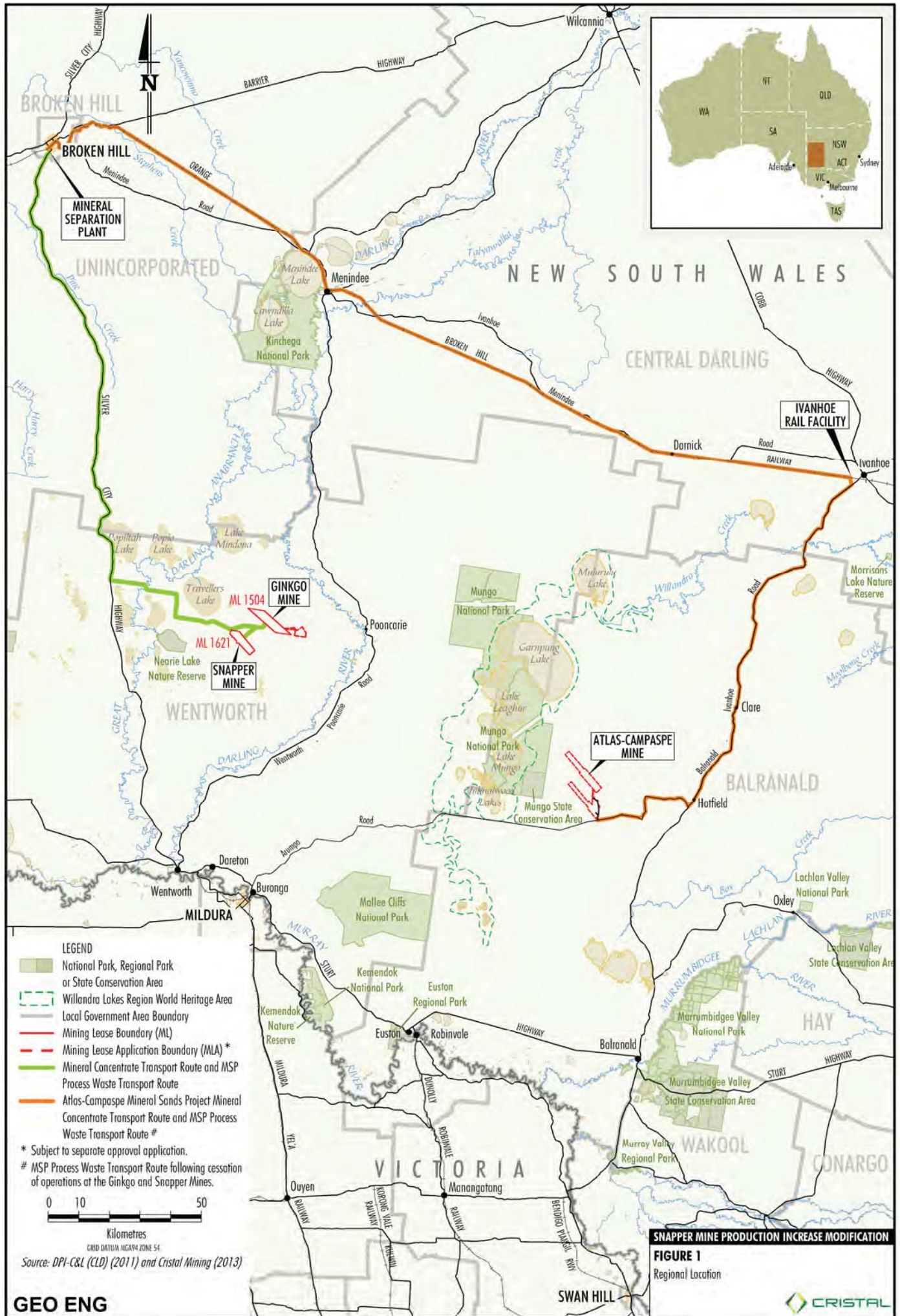
Cristal Mining lodged a separate application to modify the Ginkgo Mine Development Consent (DA 251-09-01) under section 75W of the EP&A Act in November 2012 (the November 2012 Modification). This separate application is relevant to the development of the satellite Crayfish Deposit and is unrelated to this Modification.

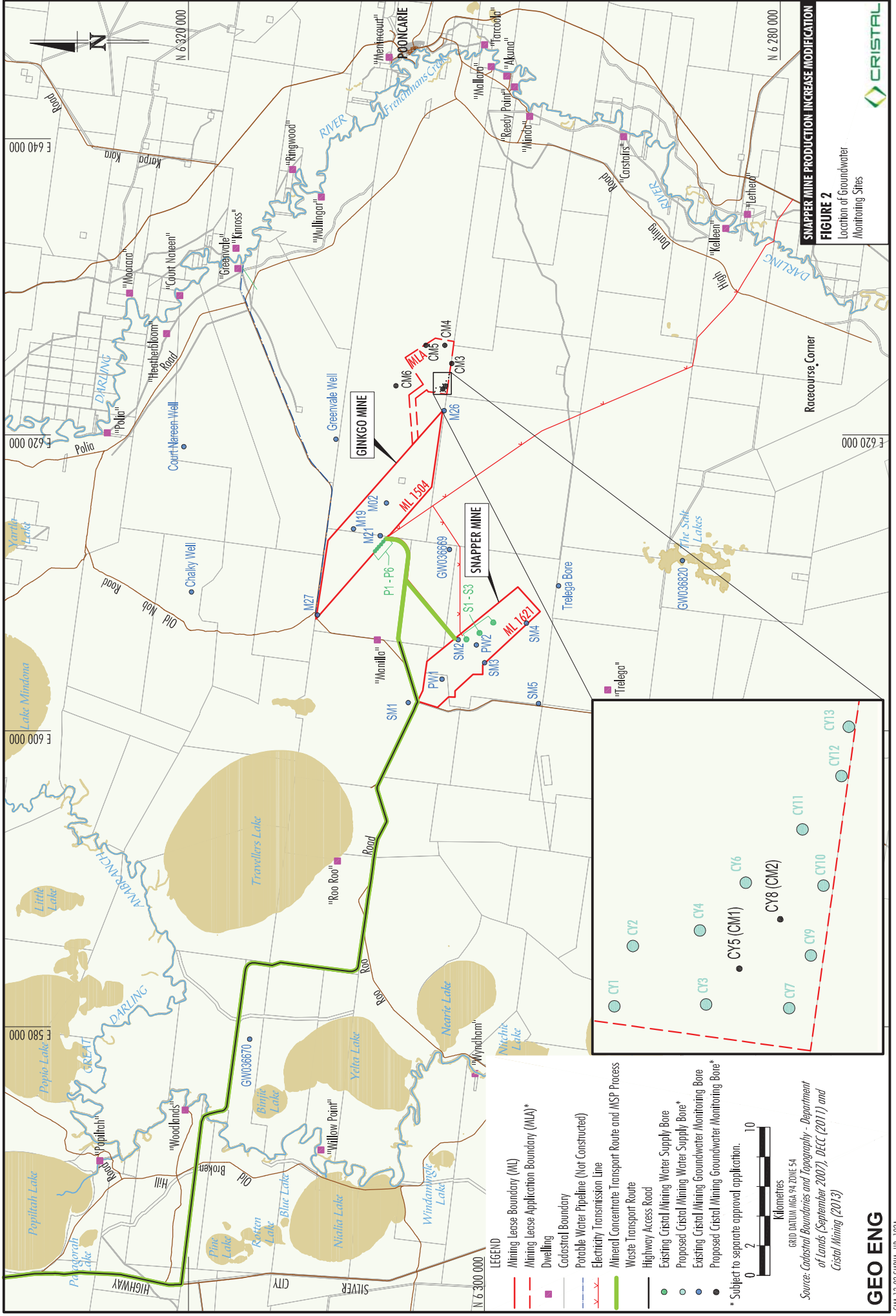
### 1.3 Snapper Mine Production Increase Modification

Cristal Mining is proposing modifications to the approved Snapper Mine (the Snapper Production Increase Modification [the Modification]). The Modification would include the following key components:

- variations to the Snapper Mine mining sequence (Mining Options 1 to 3);
- increase in the Snapper Mine maximum annual ore extraction rate;
- an option to use an overburden slurry pipeline system to transport overburden at the Snapper Mine; and
- increase in the combined mineral concentrate/heavy mineral concentrate (HMC) haulage rate.

This document is a Hydrogeological Review for the proposed Modification.





**FIGURE 2**  
 Location of Groundwater Monitoring Sites



- LEGEND**
- Mining Lease Boundary (ML)
  - - - Mining Lease Application Boundary (MLA)\*
  - Dwelling
  - Cadastral Boundary
  - Portable Water Pipeline (Not Constructed)
  - Electricity Transmission Line
  - Mineral Concentrate Transport Route and MSP Process
  - Waste Transport Route
  - Highway Access Road
  - Existing Cristal Mining Water Supply Bore
  - Proposed Cristal Mining Water Supply Bore\*
  - Existing Cristal Mining Groundwater Monitoring Bore
  - Proposed Cristal Mining Groundwater Monitoring Bore\*

\* Subject to separate approval application.



GRID DATUM: MGA 94 ZONE 54  
 Source: *Cadastral Boundaries and Topography - Department of Lands (September 2007), DECC (2011) and Cristal Mining (2013)*

## 2 SNAPPER AND GINKGO MINES MODIFICATION

In response to lower than planned mineral concentrate production at the Snapper Mine (due to lower than expected ore grades in the northern section of the Snapper deposit), Cristal Mining has conducted a review of the existing/approved mining operations to identify options to maintain the approved maximum mineral concentrate production rate (i.e. 621,000 tpa). The mining operations review recommended the following modifications to the existing/approved mining operations:

- variations to the Snapper Mine mining sequence (Mining Options 1 to 3);
- increase in the Snapper Mine maximum annual ore extraction rate from 9.1 Mtpa to 14 Mtpa; and
- an option to use an overburden slurry pipeline system to transport overburden at the Snapper Mine;

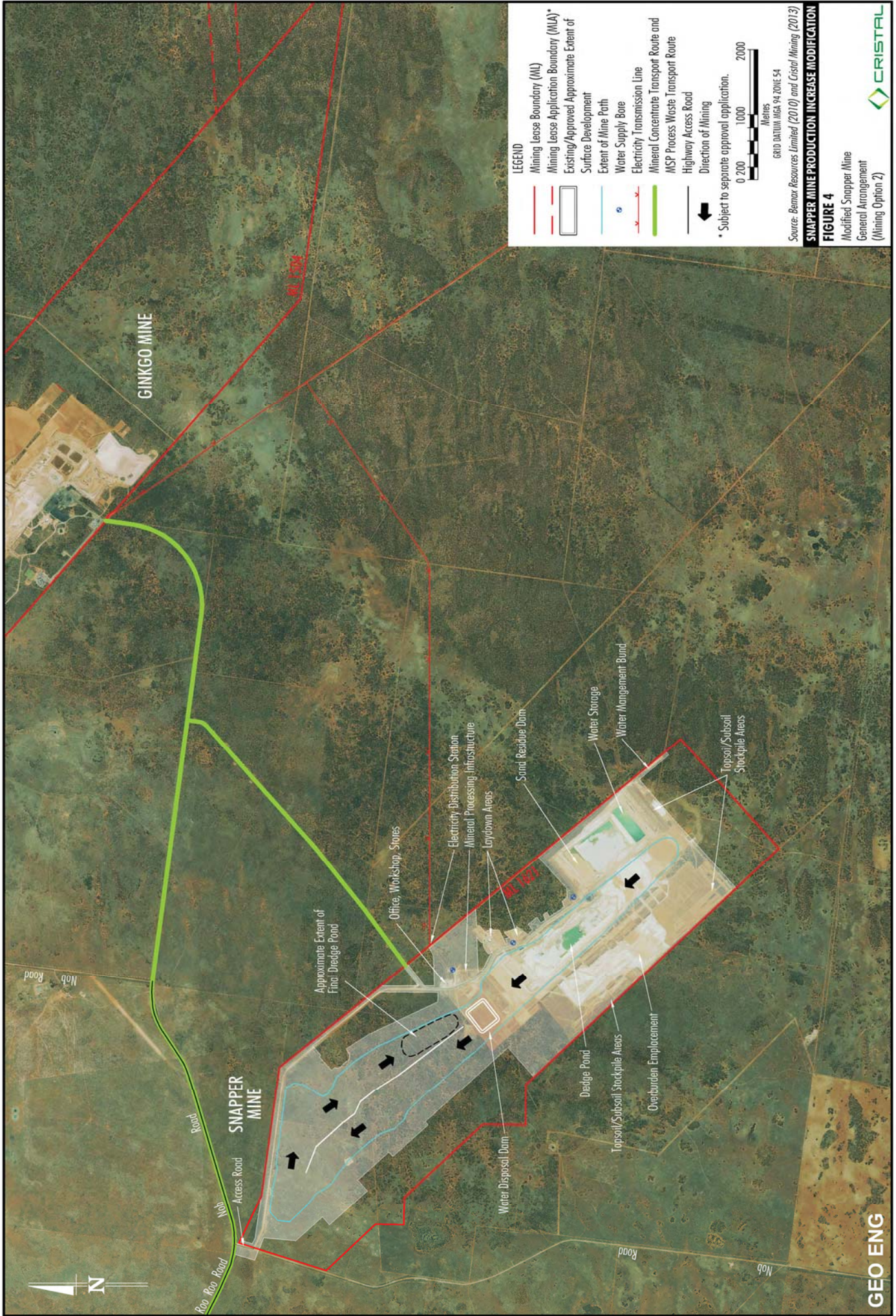
The existing/approved mining operations involve an initial single-pass mining followed by double-pass mining (in an anti-clockwise direction) using conventional dredge mining methods supplemented with dry mining. The Modification would include either of the following mining options:

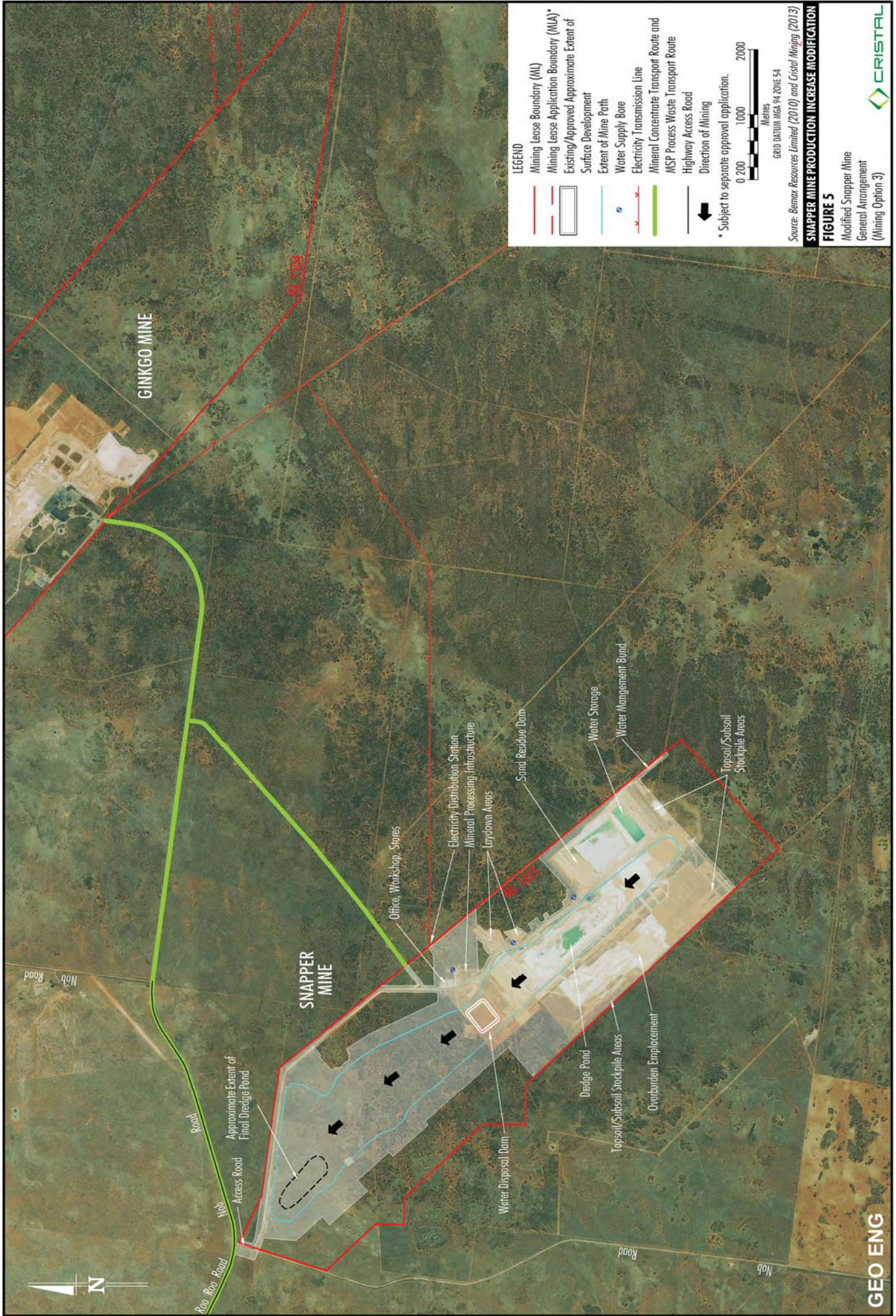
- **Mining Option 1** – initial single-pass mining followed by double-pass mining (in an anti-clockwise direction) (Figure 3) using conventional dredge mining methods supplemented with dry mining (i.e. as per the currently approved) at an increased ore production rate of up to approximately 14 Mtpa.
- **Mining Option 2** – initial single-pass mining followed by double-pass mining (in a clockwise direction) (Figure 4) using conventional dredge mining methods supplemented with dry mining at an increased ore production rate of up to approximately 14 Mtpa.
- **Mining Option 3** – single-pass mining (Figure 5) using conventional dredge mining methods supplemented with an additional small dredge and dry mining at an increased ore production rate of up to approximately 14 Mtpa.

The Modification would also include an increase in the combined mineral concentrate/HMC haulage rate from 735,000 tpa to 975,000 tpa. This change associated with the Modification would not impact groundwater resources at the Snapper Mine and is therefore not considered further in this Hydrogeological Review.

A detailed description of the Modification is provided in Section 3 of the Environmental Assessment.







**SNAPPER MINE PRODUCTION INCREASE MODIFICATION**  
**FIGURE 5**  
 Modified Snapper Mine  
 General Arrangement  
 (Mining Option 3)

### 3 HYDROGEOLOGICAL ENVIRONMENT

#### 3.1 Topography and Drainage

The Snapper and Ginkgo Mines are located within the lower Darling River Basin of the lower Murray River system in NSW (Figure 1). The major drainage feature is the Darling River, which intersects the Murray River at Wentworth. Paralleling the Darling River is the Great Darling Anabranch which only flows under flood conditions. Numerous ephemeral lakes are associated with the Great Darling Anabranch, which occasionally hold water. Further north, the Menindee Lakes are used for water storage and irrigation supply.

Regionally the topography is relatively flat, with local undulation due to sand dune ridges, which have been stabilised by vegetation. There are no significant drainage channels to the Darling River or the Anabranch from the Snapper and Ginkgo Mine sites. Rainfall run-off may temporarily collect in local topographic lows before infiltrating to the underlying aquifer or evaporating.

#### 3.2 Surface Water Features

Regional and local hydrological features of relevance to the proposed Modification are described below:

- **Darling River** – The Darling River (Figure 1) is surrounded by a fresh to brackish groundwater lens (alluvial lens).<sup>1,2</sup> The Darling River provides some local fresh water recharge to the alluvial system. Interaction to the underlying deeper groundwater system is considered to be localised and episodic.<sup>1,2</sup>
- **Menindee Lakes** – The Menindee Lakes (Figure 1) are natural lakes with man-made weirs to raise their level for water storage. The lakes provide local fresh water recharge to the local shallow aquifers.<sup>1,2</sup>
- **Great Darling Anabranch** – The Great Darling Anabranch (Figure 1 and Figure 2) normally consists of a series of pools and occasionally floods. Similar to the Darling River, the Great Darling Anabranch is surrounded by a fresh to brackish groundwater lens (alluvial lens).<sup>1</sup> It is expected that periods of high flow in the Great Darling Anabranch would result in some limited contribution to the underlying deeper groundwater systems; however, due to the intermittent nature of these events and the lack of significant connection between surface and deeper systems, this contribution is likely to be lower than that from the Darling River.<sup>1</sup>

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1 Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land and Water. *Salinity Impact Assessment. Appendix K of Darling Anabranch Environmental Impact Assessment for Stock and Domestic Pipeline and Reinstatement of Environmental Flows*, 2004.

2 Geoscience Australia. *Broken Hill Managed Aquifer Recharge (BHMAR) Project, Report 5, Summary Report*, GeoCat #73823, 2012.

- **Great Darling Anabranch Lakes** – The lakes adjacent to the Great Darling Anabranch (Figure 1 and Figure 2) are gentle deflation basins that are normally dry, however some of the lakes do receive water when the Great Darling Anabranch has flow released from the Menindee Lakes.<sup>3</sup> Occasional wet surface conditions in the lakes would provide small intermittent recharge to the deeper underlying saline groundwater.<sup>1</sup>
- **The Salt Lakes** – Water loss from the Loxton-Parilla aquifer occurs via evaporation at locations where the surface elevation is near to the groundwater table level. Deposition of salt left behind from the saline water results in "salt pans". The Salt Lakes, 8 km southeast of the Snapper Mine (Figure 2) is one such location. Others locations are found at distances of 50 to 100 km to the south-west and west of the Snapper Mine.<sup>4</sup>
- **Localised Freshwater Lenses** – Isolated freshwater lenses also occur below localised topographic depressions in the region. This generally occurs in topographically enclosed basins where rainfall runoff is concentrated and recharges shallow groundwater. Rainfall recharge in these areas form a localised freshwater lens over the denser more saline groundwater. An example of this is located at Chalky Well (Figure 2) to the north-east of the Snapper and Ginkgo Mines.
- **Lake Victoria** – Lake Victoria is a shallow freshwater lake adjacent to the Murray River, approximately 100 km to the south-west of Snapper and Ginkgo Mines. It is managed as off-river storage by government agencies, with an embankment around its extent to increase storage capacity.<sup>5</sup> Groundwater seeps from the base of the lake into the shallow aquifer and towards the Murray River. Given the lakes' distance from the mine sites, there is not expected to be any groundwater effect from the mining operation at this location.
- **Murray River** – At its closest point, the Murray River is approximately 80 km south of the Snapper and Ginkgo Mines (Figure 1). In this section of the river, the water levels are controlled by a series of locks resulting in a range of effects including groundwater inflow and outflow from the river, depending on the local gradient.<sup>6</sup> Saline groundwater flow from the Loxton-Parilla, and other shallow aquifers, enters the river along much of its length increasing the salinity load which eventually reaches South Australia. The effect of groundwater changes at the Snapper and Ginkgo Mines would be negligible over this distance.

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3 Earthtech, *Darling Anabranch Environmental Impact Statement for Stock and Domestic Pipeline and Reinstatement of Environmental Flows*. Department of Infrastructure, Planning and Natural Resources, NSW.

4 Murray Basin Hydrogeological Map Series 1:250,000 Map Sheets, AnaBranch, Menindee, Ana Branch, Mildura, BMR and AGSO, 1992–1994

5 Murray Darling Basin Commission. *Lake Victoria*, [www2.mdbc.gov.au/rmw/river\\_murray\\_system/lake\\_victoria.html](http://www2.mdbc.gov.au/rmw/river_murray_system/lake_victoria.html).

6 Brodie, R.S., *The Lower Darling Regional Steady State Groundwater Flow Model*, Australian Geological Survey Organization, Canberra, 1998/19.

### 3.3 Regional and Local Hydrogeology

A number of large scale ridges and basins (likely fault bounded blocks) form the pre-Tertiary basement profile, over which the relatively flat lying Tertiary and Quaternary sediments of the Murray Basin have formed.<sup>7</sup>

Specific groundwater information is provided by the Murray Basin Hydrogeological Map Series,<sup>8</sup> which indicate the general geometry of various aquifers and aquitards, based on sparse distribution of drillholes.

The Snapper, Ginkgo and Crayfish Deposits lie in the shallow, saline aquifer of the Loxton-Parilla Sands beneath the shallow Quaternary Woorinen and Shepparton Formation Layers. High permeability 'surf-zones' are commonly found in the off-shore direction from the beach deposition of the mineral strands, and the ore zone itself has a higher permeability than the average for the Loxton-Parilla Formation.

Saline aquifers within the underlying Renmark Group have been mapped to include sand beds of the Upper, Middle and Lower Olney Formation and the basal Warina Sand.<sup>7</sup> At the mine sites the Upper Olney Formation is indicated to be a thin zone of fine sand directly beneath and connected to the Loxton-Parilla Sands.<sup>9</sup>

The Middle Olney Formation is not well defined in the local area but is more significant to the north where it connects with both the Upper and Lower Olney Formations.<sup>7</sup> The Lower Olney Formation and Warina Sand are located at about RL -170 m to RL -260 m beneath the mine sites overlying pre-Tertiary bedrock.<sup>10</sup> The Geera Clay Aquitard is approximately 130 m thick in the local area and separates the saline Upper and Lower Olney Formation units.<sup>9</sup> Further south the Geera Clay is partially replaced by clays of the Bookpurnong Beds, Winnambool Formation and Ettrick Formation which encase the permeable Murray Group Limestone Aquifer.

The groundwater flow in all aquifers is from recharge areas in the north and east to discharge areas in the south-west towards the Murray River and Lake Victoria. The groundwater gradient is very flat with a local gradient of about 1V:10,000H. Groundwater pressures in each aquifer are similar, with a small downward gradient in the recharge areas (north) and a larger upward gradient in the discharge zone (south).

### 3.4 Groundwater Dependent Ecosystems

There are currently no high priority groundwater dependent ecosystems identified in the Western Murray Porous Rock Water Source defined in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* under the *Water Management Act, 2000* within which the Snapper and Ginkgo Mines are located.

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7 Brown, C.M. and Stephenson, A.E., *Geology of the Murray Basin, Southeastern Australia*. Bureau of Mineral Resources, Australia. Bulletin 235, 1991.

8 Australian Geological Survey Organisation, *MurrayBasin Hydrogeological Map Series, 1993*.

9 Bemax Resources, Exploration Drilling Database – Pooncarie Region.

10 GEO-ENG, *Deep Bore DPB-02 Commissioning*, Snapper Mine Site, 7005(N2), 2009.

NSW State Groundwater Dependent Ecosystems Policy<sup>11</sup> recognises the four Australian groundwater dependent ecosystem types<sup>12</sup> that can be found in NSW, namely:

- terrestrial vegetation;
- baseflows in streams;
- aquifer and cave ecosystems; and
- wetlands.

It is unlikely that there would be groundwater dependent ecosystems at the Snapper and Ginkgo Mine sites as the groundwater table is located approximately 30 m below the surface and there is no evidence of any perched water tables.

There is no groundwater dependent vegetation known to occur within the Snapper Mine or surrounds.<sup>13</sup> There are no permanent surface water features at the Snapper and Ginkgo Mine sites (i.e. no groundwater window lakes fed by the deep underlying saline groundwater aquifer) and therefore no groundwater dependent baseflows in streams and wetlands.

Groundwater and surface water elevation data indicates that the Lower Darling River exists under losing conditions most of the time (level higher than the groundwater table), and thus is not dependent on groundwater.<sup>14,15</sup>

The Salt Lakes are located approximately 8 km to the southeast of the Snapper Mine. The water table is approximately 2 m from the surface at this location and the local ecosystem is affected by the evaporation of the saline water from the aquifer.

### 3.5 Groundwater Quality

Groundwater monitoring results from the Snapper and Ginkgo Mines and the Murray Basin Hydrogeological Map Series<sup>7</sup> indicate salinities in excess of 35,000 milligrams per litre (mg/L) for the shallow Pliocene Loxton-Parilla Sands aquifer and 14,000 mg/L to 35,000 mg/L for the deep Tertiary Lower Olney Formation/Warina Sand aquifer.

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11 Department of Land and Water Conservation, *NSW State Groundwater Dependent Ecosystems Policy*, 2002.

12 Hatton, T. And Evans, R., *Dependence of Ecosystems on Groundwater and Its Significance to Australia*. LWRC Occasional Paper No. 12/98.

13 FloraSearch and Resource Strategies, *Snapper Mineral Sands Project Flora Assessment*, February 2007.

14 NSW Office of Water, *Western Murray Porous Rock and Lower Darling Alluvium Groundwater Sources*, *Groundwater Status Report 2011*. Published January 2013.

15 Golder Associates, *Hydrogeological Feasibility Study for the Ginkgo Mineral Sands Project in the Murray Basin*, July 2001, Report # 01612006.

### 3.6 Groundwater Users

Previous investigations have identified that groundwater use in the local area is limited to three private wells (Chalky Well, Court Nareen Well and Greenvale Well – Figure 2) which access fresh water lenses above the saline water table. The private bore at Trelega (Figure 2) is not used due to high salinity levels. The lack of active bores in the region is understandable given the poor quality of the groundwater.

### 3.7 Licensing

The Snapper and Ginkgo Mines are located within the Western Murray Porous Rock Water Source as defined in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* under the *Water Management Act, 2000*.

Relevant to the Modification, the Western Murray Porous Rock Water Source includes groundwater contained in all shallow unconsolidated geological layers (Shepparton Formation to Renmark Group Units).

The long term annual extraction limit stipulated in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* for the Western Murray Porous Rock Water Source is 530,486 million litres (ML)/annum.<sup>14</sup> As of January 2013, water allocation includes 26,747 ML/annum for basic landholder rights, 21,780 ML/annum for Access licence use (primarily Cristal Mining's allocation as indicated below) and 14,582 ML/annum for Special purpose access (salinity and water table management).<sup>14</sup>

Cristal Mining currently holds a combined total of 21,442 share components (units or ML) in the Western Murray Porous Rock Water Source for the Snapper and Ginkgo Mines, authorised by the following water access licences (WALs):

- WAL 27918 (60AL582836) – 14,000 shares;
- WAL 27915 (60AL582832) – 7,402 shares; and
- WAL 27912 (60AL582834) – 40 shares.

As the groundwater is saline, there is no significant demand for water from this source in the region, and the aquifers are indicated to be under allocated.

#### 4 EXISTING HYDROGEOLOGICAL ASSESSMENTS

A hydrogeological assessment and numerical groundwater model was prepared by Golder Associates in 2001 for the Ginkgo Mine.<sup>16</sup> The assessment and model were subsequently revised by Golder Associates in 2007 to incorporate the effects of the Snapper Mine.<sup>17,18,19</sup> A further hydrogeological assessment was carried out in 2010 to assess the potential hydrogeological impacts associated with the proposed change to the lower aquifer water supply (rather than the approved Loxton Parilla Sands aquifer [upper aquifer] water supply) for Snapper Mine, which reduced the hydrogeological impact of the mining.<sup>20</sup>

An assessment of the potential hydrogeological impacts associated with the proposed development of the Crayfish Deposit at the Ginkgo Mine was completed in late 2012,<sup>21</sup> and subsequently modified in mid-2013 (the 2013 Hydrogeological Assessment).<sup>22</sup> The previously developed groundwater model was modified to incorporate the effects of the proposed mining the Crayfish Deposit at the Ginkgo Mine along with the approved Snapper Mine.

The 2013 Hydrogeological Assessment details the cumulative hydrogeological impacts associated with the approved Snapper and Ginkgo Mines. A summary of the key findings of the 2013 Hydrogeological Assessment is provided in Table 1.

**Table 1**  
**Summary of Key Findings of the Ginkgo Mine Crayfish Deposit 2013**  
**Hydrogeological Assessment**

Assessment Component	Finding
Regional Drawdown	<ul style="list-style-type: none"> <li>• 1 m drawdown in the Lower Renmark Formation (lower aquifer) at approximately 5 km.</li> <li>• 1 m drawdown in the Loxton-Parilla Sands (upper aquifer) at approximately 4 km.</li> </ul>
Hydrological Features	<ul style="list-style-type: none"> <li>• No significant change in water levels beneath local hydrological features (Darling River, Darling Anabranh and associated lakes, The Salt Lakes, Lake Victoria and the Murray River).</li> </ul>
Groundwater Users	<ul style="list-style-type: none"> <li>• Maximum predicted drawdown at private bore is not considered significant (0.18 m).</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>• There is not expected to be any measurable effect on groundwater quality.</li> <li>• Any small change in salt concentrations due to increased evaporation is expected to be insignificant.</li> </ul>

16 Golder Associates, *Hydrogeological Feasibility Study for the Ginkgo Mineral Sands Project in the Murray Basin*, July 2001, Report # 01612006.

17 Golder Associates, *Snapper Mineral Sands Project Environmental Assessment Report, Appendix A—Hydrogeological Assessment*, March 2007, Report # 06613504/016.

18 Golder Associates, *Hydrogeological Study for Snapper Deposit Pooncarie, NSW*, December 2007, Report # 06613504/017.

19 Golder Associates, *Re-Run of Regional Groundwater Model, Snapper Mineral Sands Project.*, 19 September 2008. Project # 087616009001.

20 GEO-ENG, *BEMAX Resources Limited, Section 75W Modification, Snapper & Ginkgo Mines – Hydrogeological Assessment*, Pooncarie, NSW, 2010.

21 GEO-ENG, *Cristal Mining Australia, Ginkgo Mine Modification, Crayfish Deposit – Hydrogeological Assessment*, Pooncarie, NSW, October 2012.

22 GEO-ENG, *Cristal Mining Australia, Ginkgo Mine Modification Modified Request Project Crayfish Deposit – Hydrogeological Assessment*, Pooncarie, NSW, September 2013.

## 5 EXISTING AND MODIFIED GROUNDWATER INTERACTIONS

### 5.1 Existing Snapper Mine Mining Operations

Dredge mining at the Snapper Mine requires the development and maintenance of a dredge pond. The level of the dredge pond varies above or below the natural groundwater table level according to the relative position of the orebody in relation to the natural groundwater table level.

The dredge consists of a rotating bucket wheel that cuts the ore and then deposits it at the dredge suction pipe inlet. The ore slurry is then pumped to the primary gravity concentration unit for primary gravity concentration.

Sand residues generated at the primary gravity concentration unit were initially placed in an off-path sand residue dam but are now placed in the mining void behind the dredge pond (which creates a groundwater mound and returns water to the upper aquifer).

Make-up water for the Snapper Mine is provided by water supply bores located at the Snapper Mine at up to 270 litres per second (L/s). The water supply bores extract water from the Lower Olney Formation/ Warina Sand (the lower aquifer), which is isolated from the shallow aquifer.

The existing/approved water management system at the Snapper Mine is primarily a recirculating system, where greater than 90% of the water used to pump ore from the mining face is infiltrated back into the dredge pond/shallow groundwater aquifer from the deposited sand residues. The remainder is lost via evaporation, residual moisture in the HMC/mineral concentrate taken off-site, dust-suppression, and office, camp and workshop use.

As the sand residues are placed near to the mining void behind the dredge pond, there is a significant groundwater flow from the sand residues back to the dredge pond. The level of the dredge pond relative to natural water table and the maximum level and position of the deposited sand residues relative to the back of the dredge pond will affect the gradient and thus the amount of water recirculated. For example, spreading the sand residue to a height of 10 m over a distance of 80 m behind the dredge pond, compared to a 10 m height over 40 m will approximately halve the amount of groundwater water returning to the dredge pond.

### 5.2 Modification – Mining Operations

The Modification would include either of three potential mining options (Section 2).

Cristal Mining's mine planning indicates that the dredge pond levels and the deposited sand residue elevations would remain similar to the existing/approved Snapper Mine operations (i.e. as assessed in the 2013 Hydrological Assessment) for all three potential mining options.

### 5.2.1 *Mining Option 1*

Mining Option 1 would involve the currently approved mining operations (i.e. initial single-pass mining followed by double-pass mining [in an anti-clockwise direction] using conventional dredge mining methods supplemented with dry mining) at an increased ore production rate of up to approximately 14 Mtpa.

Potential changes to the approved hydrogeological impacts would be associated with the increased ore production rate. Increasing the ore production rate would result in a more rapid advance of the dredge pond. As the placement of sand residue behind the dredge pond is planned to be over the same area and to the same height as the current operation, the primary hydrogeological change will be a reduced groundwater gradient between the deposited sand residue and the back of the dredge pond because the pond moves away from the sand disposal area at a faster rate. This will result in less groundwater returning to the pond, and conversely more water held in the groundwater mound behind the active mining area.

With less water returning to the pond, additional water would need to be made-up by increased pumping from the water supply bores, resulting in the transfer of more water from the lower aquifer to the upper aquifer compared to the existing mining operations. Although there would be an increase in extraction from the water supply bores, the extraction rate is expected to remain below the currently approved extraction rate (i.e. 270 L/s), as current (2013) extraction averaged only approximately 130 L/s.

Looking at both aquifers together, the net effect (compared to the current hydrogeological impacts) would be a similar total reduction in water volume (mainly due to water lost to evaporation). In the upper aquifer there will be more water (compared to the current hydrogeological impacts) and thus the upper aquifer impacts would be reduced. In the lower aquifer there will be an increase in water extraction increasing the extent of drawdown by a small amount (compared to the current hydrogeological impacts). The expected small change in the lower aquifer would be negligible at any receiving environment.

### 5.2.2 *Mining Option 2*

Mining Option 2 would involve an initial single-pass mining followed by double-pass mining (in a clockwise direction) using conventional dredge mining methods supplemented with dry mining at an increased ore production rate of up to approximately 14 Mtpa.

Changing the direction of mining would not have any net change in water usage or loss, with local variation in the drawdown contours not having any significance beyond the immediate mining area. Thus the only significant changes to the approved hydrogeological impacts would be associated with the increased ore production rate as described for Mining Option 1 (Section 5.2.1).

### 5.2.3 *Mining Option 3*

Conventional dredge mining methods supplemented with an additional small dredge and dry mining methods to mine a single-pass at an increased ore production rate of up to approximately 14 Mtpa would be adopted for Mining Option 3.

As a single-pass mining operation would be adopted, the mine path would be wider than the approved double-pass mine path and therefore the dredge pond would advance at a similar rate to the approved mining operation despite the increased ore production rate. As the dredge pond would advance at a similar rate to the currently approved mining operation, the percentage of groundwater return from the sand residue placed behind the dredge pond would remain at a similar rate to the approved mining operations. The rate of extraction from the bores would increase due to the increased pond size (i.e. evaporation). Although there would be an increase in extraction from the water supply bores, the extraction rate is expected to remain below the currently approved extraction rate (i.e. 270 L/s), as current (2013) extraction averaged only approximately 130 L/s. The groundwater mounding in the upper aquifer and the groundwater drawdown in the lower aquifer would develop quicker, but the long-term net effect would be about the same as the approved hydrogeological impacts.

### 5.2.4 *Overburden Slurry Pipeline System*

The Modification (all mining options) would include the option to reintroduce a limited overburden slurry pipeline system at the Snapper Mine. The overburden slurry pipeline system (if adopted) would be used in combination with the existing/approved truck and shovel methods.

If the overburden slurry pipeline system is reintroduced at the Snapper Mine, the placement of slurried overburden in the mining void behind the dredge pond would create additional mounding as the entrained water returns to the upper aquifer.

The 2010 hydrogeological assessment<sup>20</sup> modelled a full-time overburden slurry pipeline system. The conclusions from this assessment can therefore be used to estimate the additional mounding that would occur in the upper aquifer as a result of the overburden slurry pipeline system. The extent of the 1 m mounding contour in the upper aquifer extends approximately 1.5 km further than the extent of mounding predicted in the 2013 hydrogeological assessment<sup>22</sup> (i.e. the currently approved impact). The extent of mounding in the upper aquifer (1 m contour) would therefore be expected to increase by approximately 1.5 km if the overburden slurry pipeline system is reintroduced.

The reintroduction of an overburden slurry pipeline system would require increased extraction from the water supply bores. Although there would be an increase in extraction from the water supply bores, the extraction rate is expected to remain below the currently approved extraction rate (i.e. 270 L/s), as current (2013) extraction averaged only approximately 130 L/s. The groundwater drawdown in the lower aquifer would develop quicker, but the long-term net effect would be the same as the approved hydrogeological impacts.

### 5.2.5 Summary

A summary of the potential changes to the hydrogeological impacts associated with each of the mining options is provided in Table 2.

**Table 2**  
**Summary of Predicted Groundwater Effects for Proposed Mining Options**

Mining Option	Upper Aquifer	Lower Aquifer
1	<ul style="list-style-type: none"> <li>• Additional water transferred to the upper aquifer from the lower aquifer.</li> <li>• Decreased extent of cumulative groundwater drawdown effects.</li> </ul>	<ul style="list-style-type: none"> <li>• Additional water transferred from the lower aquifer to the upper aquifer.</li> <li>• Increased extent of groundwater drawdown effects.</li> </ul>
2	<ul style="list-style-type: none"> <li>• Additional water transferred to the upper aquifer from the lower aquifer.</li> <li>• Decreased extent of cumulative groundwater drawdown effects.</li> <li>• Minor temporary and local variations to the groundwater effects due to the change in mine path direction.</li> </ul>	<ul style="list-style-type: none"> <li>• Additional water transferred from the lower aquifer to the upper aquifer.</li> <li>• Increased extent of groundwater drawdown effects.</li> </ul>
3	<ul style="list-style-type: none"> <li>• Additional water transferred to the upper aquifer from the lower aquifer.</li> <li>• Decreased extent of cumulative drawdown effects.</li> </ul>	<ul style="list-style-type: none"> <li>• Additional water transferred from the lower aquifer to the upper aquifer.</li> <li>• Increased extent of groundwater drawdown effects.</li> </ul>
Overburden Slurry Pipeline System (for all mining options)	<ul style="list-style-type: none"> <li>• Further additional water transferred to the upper aquifer from the lower aquifer.</li> <li>• Decreased extent of cumulative drawdown effects.</li> </ul>	<ul style="list-style-type: none"> <li>• Further additional water transferred from the lower aquifer to the upper aquifer.</li> <li>• Increased extent of groundwater drawdown effects.</li> </ul>

Based on the relatively minor nature of the proposed changes to the Snapper Mine mining operations and the predicted groundwater effects associated with the modification (Table 1), groundwater modelling is not considered to be required for the Modification.

### 5.3 Modification – Water Disposal Dam

A water disposal dam is approved to be constructed within the mine path. The dam walls will be clay-lined to minimise lateral seepage while the base of the dam will not be clay-lined. The base will overlay the permeable overburden and sand residues to allow vertical seepage to the groundwater table.

The Modification would not change the requirement for or the location of the water disposal dam. The Modification would therefore not change groundwater interactions associated with the water disposal dam.

### 5.4 Modification – Final Depression

At the cessation of mining, a final depression is approved to remain at the Snapper Mine. The final depression will be partially backfilled with overburden material pushed down from the depression batters and replaced overburden.

The final depression will be backfilled such that its floor would be at approximately 2 to 4 m above the final groundwater table. Capillary rise in sand is typically less than 1 m.<sup>23</sup> Thus direct evaporation from the aquifer should be prevented.

Incident rainfall and local surface water runoff following rainfall events will temporarily pond in the depression prior to evaporating or infiltrating into the lower aquifer. The rate of infiltration will be higher than normal, but over the scale of the aquifer, this will be insignificant.

The approved location of the final depression would remain approximately unchanged for the Modification if Mining Option 1 is selected (Figure 3).

The locations of the final depression associated with the final dredge pond for Mining Options 2 and 3 would change as mining would cease at different locations:

- Mining Option 2 – immediately to the north-east of the approved final depression location (Figure 4).
- Mining Option 3 – at the northern extent of the mine path (Figure 5).

The location of the final depression associated with the water disposal dam would remain unchanged for all mining options (Figure 5 to 7).

Mining Option 1 would therefore not change groundwater interactions associated with the final depressions.

As the final depression associated with the final dredge pond would be rehabilitated using the same methodology as described above for all mining options, the groundwater interactions would be the same except for the location. The Modification (Mining Options 2 and 3) would therefore only result in insignificant local changes to the groundwater drawdown effects associated with the final depression compared to the currently approved Snapper Mine.

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<sup>23</sup> Venkatramaiah, *Geotechnical Engineering*, New Age International, 2006, New Delhi.

## 6 HYDROGEOLOGICAL IMPACT ASSESSMENT

### 6.1 Regional Drawdown

The Modification would result in minor changes to the approved regional groundwater drawdown effects in the upper and lower aquifers. These minor changes are discussed below for both of the aquifers.

#### 6.1.1 Lower Aquifer

The Modification (Mining Options 1 and 2) would result in a minor increase in the approved extent of drawdown effects in the lower aquifer. The change in groundwater drawdown effect in the lower aquifer is expected to be negligible beyond 5 km from the Snapper Mine.

If Mining Option 3 is selected, there is expected to be short-term variations to the groundwater drawdown, while the long-term effect would be the same as the approved extent of drawdown effects on the lower aquifer.

#### 6.1.2 Upper Aquifer

The Modification (Mining Options 1 and 2) would result in a minor decrease in the approved extent of drawdown effects in the upper aquifer. The reduction in drawdown effect in the upper aquifer is expected to negligible beyond 5 km from the Snapper Mine.

For Mining Option 3 the extent of the groundwater mound in the upper aquifer around Snapper Mine (which would offset groundwater drawdowns associated with water supply bores at the Ginkgo Mine [including the Crayfish Deposit]) would develop quicker, but over the long-term would be similar to the approved hydrogeological impact.

### 6.2 Hydrological Features

Based on expected groundwater drawdown effects (Section 6.1) and experience to date at the Snapper and Ginkgo Mines, the change in water levels beneath local surface water features (Darling River, Darling Anabranh and associated lakes, The Salt Lakes, Lake Victoria and the Murray River), would be very small and would not have any measureable effect on these features (i.e. no change to the approved impacts).

### 6.3 Groundwater Quality

The Modification is expected to result in negligible impacts on groundwater quality.

The water drawn from the lower aquifer is less saline than water in the upper aquifer. Thus the transfer of water from the lower aquifer to the upper aquifer (via the water supply borefield) results in a reduction in the salinity levels of the upper aquifer (i.e. dilution effect).

The Modification (Mining Options 1 and 2) would result in increased transfer of water from the lower aquifer to the upper aquifer and therefore the salinity of the upper aquifer would continue to reduce. No change to the lower aquifer water quality is expected.

Any changes to the approved water quality impacts in the upper aquifer are expected to be negligible for the Mining Option 3 as there would be no increased total transfer of water between the lower aquifer and upper aquifer. No change to the lower aquifer water quality is expected.

#### 6.4 Groundwater Users

Previous investigations have identified that groundwater use in the local area is limited to three private wells (Chalky Well, Court Nareen Well and Greenvale Well – Figure 2) which access fresh water lenses above the saline water table. The private bore at Trelega (Figure 2) is not used due to high salinity levels. The lack of active bores in the region is understandable given the poor quality of the groundwater.

Based on expected groundwater drawdown effects (Section 6.1) and experience to date at the Snapper and Ginkgo Mines, the potential impact at the nearest private bore, Greenvale Well, approximately 16 km to the north-east of Snapper Mine would also be negligible (i.e. no change to the approved impact).

#### 6.5 Final Depression

The approved location of the final depression would remain unchanged for the Modification if Mining Options 1 and 2 are selected. The Modification (Mining Options 1 and 2) would therefore not change groundwater interactions associated with the final depression.

For the Modification (Mining Option 3), the final depression would be located at the northern extent of the mine path (Figure 5) as this is where mining would cease. As the final depression would be rehabilitated using the same methodology as described in Section 5.4, the groundwater interactions would be the same except for the location. The Modification (Mining Option 3) would therefore only result in insignificant local changes to the approved groundwater drawdown effects associated with the final depression.

#### 6.6 Assessment against the Aquifer Interference Policy Minimal Impact Considerations

The *Aquifer Interference Policy* (the AIP) (NSW Government, 2012) establishes minimal impact considerations for highly productive and less productive groundwater. NSW Office of Water mapping indicates that there is no highly productive groundwater in the vicinity of the Snapper Mine. It follows that porous rock aquifers in the vicinity of the Snapper Mine are less productive.

Table 3 provides an assessment of the Modification against the minimal impact considerations in the AIP and include consideration of cumulative impacts where appropriate.

**Table 3**  
**Less Productive Porous Rock Aquifer – Minimal Impact Considerations**

Level 1 Minimal Impact Consideration	Assessment
<p><u>Water Table</u></p> <p>Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 m from any:</p> <p>(a) High priority groundwater dependent ecosystem; or</p> <p>(b) High priority culturally significant site; Listed in the schedule of the relevant water sharing plan.</p> <p>OR</p> <p>A maximum of a 2 m water table decline cumulatively at any water supply work.</p>	<p><b>Within Level 1</b></p> <ul style="list-style-type: none"> <li>• The <i>Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011</i> does not list any “high priority groundwater dependent ecosystem” in the vicinity of the Snapper Mine.</li> <li>• The Modification would not result in a cumulative drawdown or more than 2 m at any privately owned water supply work (Section 6.4).</li> </ul>
<p><u>Water Pressure</u></p> <p>A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.</p>	<p><b>Within Level 1</b></p> <ul style="list-style-type: none"> <li>• The Modification would not result in cumulative drawdown or more than 2 m at any privately owned water supply work (Section 6.4).</li> </ul>
<p><u>Water Quality</u></p> <p>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.</p>	<p><b>Within Level 1</b></p> <ul style="list-style-type: none"> <li>• The Modification is expected to result in negligible impacts on groundwater quality (Section 6.3). On this basis, the Modification would not lower the beneficial use category of the groundwater source.</li> </ul>

## **7 MONITORING, MANAGEMENT AND MITIGATION MEASURES**

The existing Borefield Impact Management Plan, which includes regular groundwater level and quality measurements, at and around the Snapper and Ginkgo Mine sites, is considered to be appropriate, and no changes are required for the Modification.

Groundwater mitigation processes, if required, have been previously developed and would not require any changes due to the Modification.

## 8 GROUNDWATER LICENSING

Table 4 summarises water licence information and the maximum requirements for Cristal's Mining approved and proposed operations in the Murray Darling Basin. Based on the existing and proposed mining operations, the existing volumetric licence allocations held by Cristal Mining are considered to be adequate. As the Snapper Mine, Ginkgo Mine and the Atlas-Campaspe Project are located within the same groundwater source (i.e. Western Murray Porous Rock Water Source) the appropriate licence allocations would be traded in accordance with the rules of the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*.

**Table 4**  
**Estimated Groundwater Licensing Requirements**

Year	Predicted Maximum Requirements [Western Murray Porous Rock Water Source <sup>1</sup> ] ML/yr				Current Licences
	Snapper Mine (including Modification) <sup>2</sup>	Ginkgo Mine (including proposed Crayfish Deposit) <sup>3</sup>	Atlas-Campaspe Project <sup>4</sup>	Total	
2014	8,515	1,700	-	10,215	21,442
2015	8,515	10,060	-	18,575	
2016	8,515	10,060	-	18,575	
2017	8,515	10,060	536	19,111	
2018	8,515	1,700	3,343	13,558	
2019	8,515	1,700	3,564	13,779	
2020	8,515	1,700	5,582	15,797	
2021	8,515	1,700	599	10,814	
2022	8,515	1,700	2,050	12,265	
2023	8,515	1,700	4,699	14,914	
2024	8,515	-	5,771	14,286	
2025	8,515	-	6,244	14,759	
2026	-	-	6,528	6,528	
2027	-	-	6,086	6,086	
2028	-	-	6,150	6,150	
2029	-	-	6,244	6,244	
2030	-	-	4,289	4,289	
2031	-	-	4,983	4,983	
2032	-	-	5,519	5,519	
2033	-	-	5,613	5,613	
2034	-	-	5,140	5,140	
2035	-	-	5,424	5,424	

<sup>1</sup> As defined in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* under the NSW *Water Management Act, 2000*.

<sup>2</sup> Conservatively assumes that the Snapper Mine would operate at its approved maximum extraction rate (i.e. 270 L/s) for the remainder of the Snapper Mine life.

<sup>3</sup> Based on water demand requirements outlined in *Cristal Mining Australia, Ginkgo Mine Modification Modified Request Project Crayfish Deposit – Hydrogeological Assessment*, Pooncarie, NSW (GEO-ENG, 2013).

<sup>4</sup> Based on water demand requirements outlined in *Atlas-Campaspe Mineral Sands Project – Hydrogeological and Water Supply Assessment* (GEO-ENG, 2013).

## 9 CONCLUSION

The Modification is not expected to result in any significant change to the cumulative groundwater impacts associated with the Snapper and Ginkgo (including the proposed Crayfish Deposit) Mines (Table 1).

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GEO-ENG