# Report

## Wonnerup and Wonnerup South Projects
## Addendum for Concurrent Mining Plans

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Prepared for

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# Executive Summary


## Background

The Wonnerup and Wonnerup South project areas are located on Lot 100 and M70/785, on the Swan Coastal Plain approximately 18 km southwest of Capel and dissected by the Sabina River and Sues Road. The current mining proposal incorporates concurrent excavations to the east (Wonnerup) and west (Wonnerup South) and east of Sues Road.

Earlier proposals for mining, framed during 2008 and 2012, were changed. The earliest (URS, April, 2008) assessments of the potential on the local groundwater environment were based on mining plans for Wonnerup South project area. Recent (URS, September 2012) assessments were based on mining plans for the Wonnerup project area.

## Mining and Water Table Setting

Mining is proposed to occur concurrently within the Wonnerup and Wonnerup South project areas from May 2013 to end-June 2017, a period of about 51 months. Typically, the proposed mining excavations would have depths of 2 to 6 m; the deepest excavations would be up to 12 m. Bottom elevations of the proposed excavations range from -2.5 to 11.0 m AHD. The local groundwater level records indicate the water table occurs at shallow depths below the ground surface, with elevations from 5.8 to 14.7 m AHD. Seasonal fluctuations range from 1.2 to 2.0 m, with local occurrence of waterlogging of the ground surface.

## Predictive Modelling

The MODFLOW model used for the predictive simulations was compatible with the URS (April 2008) model; the boundary conditions, parameterisation and water balance of the calibrated model were unaltered. The mining plans, pit development schedules and drain specifications used to simulate pit dewatering were changed. Sequential monthly mining block developments were simulated with the MODFLOW drainage package, with drain elevations specified based on average design pit floor elevations. Individual drains were activated only during the mining period for the specified mining block and enabled the simulation of groundwater abstraction to lower the water table to the typical pit floor elevation. After mining the wet sand tailing operations was simulated to recharge the water table. An average recharge rate of 3,450 mm/annum was simulated during the tailing operation based on results of tailings slurry infiltration tests conducted at the Ludlow Deposit.

The current model form and parameterisation associated with the drains and drawdown predictions was expected to provide reasonable worst-case scenarios. There were differences in the specified drain elevations and sequencing compared to the earlier (URS, 2008) predictions. Consequently, it was expected that the predicted groundwater abstraction volumes and drawdown footprints may slightly vary from those presented by URS (2008).

Predicted abstraction rates typically occurred in the range of 250 to 2,300 kL/day, with aggregate abstraction ranging from 0.1 to 0.4 GL/annum. In comparative terms, the predicted aggregate annual abstraction volumes are broadly compatible with those earlier (URS, April 2008); the earlier predictions typically ranged from 0.22 to 0.57 GL/annum.

The concurrent mining of the Wonnerup and Wonnerup South project areas results in predicted cumulative drawdown footprint that temporarily extends beneath the Sabina River. The magnitude of the cumulative drawdown ranges from 0.1 to 0.3 m and occurs over a 150 m reach of the Sabina River. The predicted duration of the cumulative drawdown footprint is one to three months.

Findings from the predictive model indicate:

- Drawdown beneath the Sabina River:
  - Piezometer WNMB07 drawdown of 0.1 to 0.2 m.
  - Piezometer WNMB08 drawdown of 0.1 m.
  - Piezometer WNMB14 drawdown of 0.3 m.
  - Piezometer WNMB15 drawdown of less than 0.1 m.
  - Piezometer WNMB16 drawdown of 0.1 to 0.2 m.
- Drawdown beneath the Abba River:
  - Piezometer WNMB01 drawdown of less than 0.1 m.

The simulated drawdown influences on the Sabina River and the Abba River would seem to be minor, both limited in magnitude and of short-term duration. At present, however, it is difficult to gauge if the model over-estimates or under-estimates the predicted drawdown footprint and transient magnitudes of drawdown. It would be prudent, therefore, to use the local monitoring bores to assess the actual transient drawdown impacts and inform change management strategies. If the observed drawdown propagates beneath the local reaches of the Sabina and Abba rivers, then local replenishment of the water table may be warranted. Local infiltration cells would enable replenishment of the water table in sensitive settings and also limit the propagation of the drawdown distribution.

A snapshot six months after the cessation of mining predominantly reflects water table recovery within this time.

# Background

## 1.1 Project Area Settings

The Wonnerup and Wonnerup South project areas are located approximately 18 km southwest of Capel on the Swan Coastal Plain. Both project areas straddle strand line mineral sands deposits that span a strike length of about 4,000 m. The Sabina River and Sues Road dissect the project areas, the Abba River is situated on the northeast fringe of the Wonnerup Project area and Bussell Highway is located close by to the north. The project area settings are shown on Figure 1-1.

Surface expressions of the superficial formations comprise aeolian sands of the Bassendean Sand dunes and sandy silt deposits of the Guildford Formation. The local landforms are of very low relief. Man-made drains transect perimeter areas of the Sabina River and are subject to seasonal inundation. Local reaches of the Sabina River and Abba River are perennial, providing indications of shallow water table settings. The project areas are predominantly cleared excepting remnant stands of vegetation along the watercourses, on remnant dunes and north of the Bussell Highway.

## 1.2 Earlier Project Area Hydrogeology Reports

In April 2008, URS completed a groundwater model of the Wonnerup Project area to support change assessments associated with the local groundwater environment and regulatory approvals for mine development. Findings of this modelling are captured under the April 2008 report "*Groundwater Environmental Impact Assessment – Wonnerup Deposit; reference 42906378/629-F8202.2*".

An accompaniment to this report is a Draft Operating Strategy (Cable Sands (W.A) Pty Ltd; December 2011, CD427; *Operating Strategy for Groundwater Dewatering, Wonnerup Mineral Sands Mine*). The Operating Strategy outlines groundwater monitoring and management strategies to define the actual impacts of mining at the Wonnerup Project on the groundwater environment and procedures to identify and mitigate potential risks to local environmentally sensitive areas.

Recently in September 2012, URS provided deliverables that illustrated predicted groundwater abstraction and local drawdown footprints associated with a current mining plan for the Wonnerup Project. These deliverables were provided under the cover "*Wonnerup Project – Addendum for Re-Modelling of Mining Plans*; *reference 42908187/Modelling Addendum/B Final*".

## 1.3 Wonnerup and Wonnerup South Mining Plans

Since the URS (September 2012) report was prepared, the mining plans for the Wonnerup Project have been refined. The refined mining plans involve concurrent development of the Wonnerup and Wonnerup South project areas.

The proximity of the two discretised project areas to one another during concurrent mining operations was anticipated to manifest in a broader cumulative drawdown footprint linked to groundwater abstraction from the Superficial Aquifer for pit dewatering.

## 1.4 Addendum for Concurrent Mining Plans

This document forms an addendum to the earlier URS (April 2008 and September 2012) reports. The addendum addresses the concurrent mining plans for the Wonnerup and Wonnerup South project areas, providing the findings of associated groundwater flow modelling and change assessments related to the baseline environment. The addendum is intended to be a supporting document after reference to URS (April 2008) and Cable Sands (W.A.) Pty Ltd (December 2011).

# 1 Background

Specifically, this addendum incorporates:

- Recent groundwater level monitoring data for the project area monitoring bores.
- Comparative plots of actual and simulated pre-mining water table elevations.
- The incorporation of concurrent mining plans for Wonnerup and Wonnerup South project areas within the groundwater flow model.
- Simulation of transient monthly groundwater abstractions associated with the mining developments that extend below the water table.
- Presentation of the findings of the predictive modelling, including hydrographs for selected project area monitoring bores and a number of virtual monitoring bores.
- Assessment of the predicted drawdown footprint in context to potential groundwater dependent ecosystems on the Sabina and Abba rivers.

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# Wonnerup Project Mining Plans

The proposed mining associated with the Wonnerup and Wonnerup South project areas is constrained to strands that occur on Lot 100 and M70/785, to the east and west of Sues Road, respectively. The proposed mining plans, with discretisation of mining blocks and monthly development schedules are shown on Figure 2-1. Mining is proposed to occur from May 2013 to end of June 2017, a period of about 51 months.

The mineral sands are hosted within the Bassendean Sand and Guildford Formation of the superficial formations. Typically the mining excavations would be comparatively shallow, with depths commonly from 2 to 6 m; the deepest excavations would be up to 10 and 12 m within the northeast strands. Bottom elevations of the proposed excavations (Figure 2-2) range from -2.5 to 11.0 m AHD.

# Recent Groundwater Levels

A number of monitoring bores (WPMB01 to WPMB23, inclusive) populate the Wonnerup and Wonnerup South project areas to characterise the pre-mining water table elevations within the Superficial Aquifer. A summary of the monitoring bore locations, screen intervals and water table elevations is presented in Table 3-1 and locations are shown on Figure 3-1. The monitoring bores were installed in several campaigns. Those (WPMB18 to WPMB23, inclusive) at Wonnerup South were installed during the first-half 2013, with initial monitoring in June 0213.

The monitoring bores at Wonnerup provided initial monthly water level records during first-quarter 2007. Subsequently, monthly water level data were typically recorded from July 2009 to June 2013; monthly monitoring is ongoing.  Figure 3-2 to Figure 3-5, inclusive, illustrate the measured monitoring bore hydrographs for WPMB01 through WPMB09 and for WPMB14, WPMB15 and WPMB16.

The piezometer data indicate water table occurs at shallow depths below the ground surface, with elevations from 4.5 to 16.9 m AHD. Flow is towards the northwest and Wonnerup Inlet. The project area settings are also characterised, in part, by seasonal inundation, with associated water table rise to the ground surface, waterlogging and rejected recharge. Cyclical fluctuations in the water table elevations tend to range from seasonal lows around April each year to seasonal highs in August; the observed fluctuations range from 1.2 to 2.0 m.

# 3 Recent Groundwater Levels

**Table 3-1 Piezometer Construction Summary**

| Monitoring Bore | Coordinates (GDA94) | | Elevation (m AHD) | | Screen Interval (m) | Water Table Measurements | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | February 2007 | | February 2012 | February 2013 | June 2013 |
| | Northing | Easting | Ground | Collar | | (m b toc) | (m AHD) | (m AHD) | (m AHD) | |
| WPMB01 | 6275271 | 355181 | 10.16 | 11.06 | 3.3- 6.3 | 2.77 | 8.29 | 8.27 | 8.34 | 9.09 |
| WPMB02 | 6274593 | 355429 | 13.48 | 14.22 | 1.0 - 4.0 | 2.40 | 11.83 | 11.90 | 11.96 | 12.84 |
| WPMB03 | 6273654 | 355223 | 17.49 | 18.12 | 1.7 - 4.7 | 3.45 | 14.68 | 15.12 | 15.03 | 15.52 |
| WPMB04 | 6274662 | 354894 | 15.46 | 16.19 | 4.0 - 7.0 | 3.86 | 12.33 | 12.02 | 11.97 | 12.17 |
| WPMB05 | 6274489 | 354197 | 11.07 | 11.96 | 3.9 - 6.9 | 2.77 | 9.20 | 9.17 | 9.46 | 10.26 |
| WPMB06 | 6274959 | 354107 | 7.50 | 8.23 | 3.6 - 6.6 | 2.68 | 5.55 | 5.18 | 5.16 | 5.70 |
| WPMB07 | 6273707 | 353855 | 9.74 | 10.74 | 3.7 - 6.7 | 1.63 | 9.12 | 9.07 | 9.16 | 9.75 |
| WPMB08 | 6273609 | 353554 | 9.43 | 10.15 | 1.3 - 7.3 | 2.53 | 7.63 | 7.60 | 7.68 | 8.81 |
| WPMB09 | 6273432 | 352594 | 8.15 | 8.93 | 1.4 - 3.4 | 2.40 | 6.54 | 6.85 | 6.81 | 8.08 |
| WNMB10 | 6273433 | 355228 | 16.89 | 17.45 | 1.5 – 4.3 | no data | no data | 13.61 | 14.76 | 15.36 |
| WNMB11 | 6275667 | 354634 | 7.35 | 7.92 | 1.5 – 4.3 | no data | no data | 4.86 | 5.03 | 5.75 |
| WNMB12 | 6275186 | 353872 | 6.82 | 7.40 | 1.5 – 4.3 | no data | no data | 4.56 | 4.76 | 4.94 |
| WNMB13 | 6274252 | 353643 | 9.32 | 9.89 | 1.5 – 4.3 | no data | no data | 7.34 | 7.53 | 8.34 |
| WNMB14 | 6273903 | 353652 | 9.53 | 10.16 | 1.5 – 4.5 | no data | no data | 7.46 | 7.92 | 8.97 |
| WNMB15 | 6273849 | 353578 | 8.86 | 9.51 | 2.5 – 5.5 | no data | no data | 6.00 | 6.27 | 7.16 |
| WNMB16 | 6273601 | 353763 | 9.95 | 10.19 | 0.5 – 1.5 | no data | no data | 8.09 | 8.06 | 9.00 |
| WNMB18 | 6274384 | 352724 | 6.55 | 7.24 | 3.0 – 6.6 | no data | no data | no data | no data | 4.94 |
| WNMB19 | 6273884 | 353175 | 8.80 | 9.53 | 1.0 – 2.8 | no data | no data | no data | no data | 7.34 |
| WNMB20 | 6272157 | 353048 | 17.37 | 17.96 | 1.0 – 4.0 | no data | no data | no data | no data | 16.85 |
| WNMB21 | 6273208 | 352247 | 9.24 | 9.90 | 1.6 - 4.6 | no data | no data | no data | no data | 8.71 |
| WNMB22 | 6273853 | 352515 | 7.58 | 8.27 | 1.2 – 4.2 | no data | no data | no data | no data | 4.84 |
| WNMB23 | 6274064 | 352125 | 6.57 | 7.27 | 4.0 – 7.0 | no data | no data | no data | no data | 4.59 |

**Notes:** m b toc - refers to metres below top of casing collar.

# Simulation of Wonnerup and Wonnerup South Mining Plans

The earlier groundwater model (URS, September 2012) was recovered to support this addendum. The boundary conditions, parameterisation and water balance of the calibrated model were unaltered. Mining schedules and drain specifications used to simulate pit dewatering were changed to provide compatibility to the current concurrent development plans for the Wonnerup and Wonnerup South project areas. The changes relate to the specified drain elevations and sequencing of pit dewatering and subsequent tailings operations.

## 4.1 Observed and Simulated Water Table Elevations

In practical terms the Wonnerup and Wonnerup South project areas occur in a heterogeneous environment which was represented in the developed model in comparatively homogeneous terms. As such, the developed model was comparatively broad-brush. This approach was both reasonable and practical given the available data, the shallow depths of excavations and short-term nature of the proposed mining developments.

Model calibration was based on a snapshot of seasonal low data. The model transient calibration has been compared to the measured piezometer hydrographs on Figure 3-1 to Figure 3-4, inclusive. These figures indicate the calibration provides a number of higher-than and lower-than comparisons to measured data but overall a reasonable fit; the simulated water table elevations at WPMB01, WPMB02, WPMB03, WPMB05, WPMB08, WPMB09, WPMB14, WPMB16, WPMB18, WPMB19, WPMB20, WPMB21 and WPMB23 fitting within the observed range.

In terms of over-all fit, the calibration indicates the model tends to over-estimate the seasonal-low water table elevations; there is only WPMB04 where the observed water table elevation is higher than that simulated. The amplitude of seasonal fluctuations is, however, evidently underestimated by the model. Typically the simulated fluctuations range from 0.5 to 1.0 m compared to observed fluctuations from 1.2 to 2.0 m. The differences probably indicate that the recharge rates applied to the model are conservatively low and/or the unconfined aquifer storage characteristics are too high. The simulated recharge characteristics would tend to cause the predictive model to over-estimate potential drawdown impacts due to groundwater abstractions from the Superficial Aquifer.

In context, the characteristics of the developed and calibrated model would tend to present reasonable worst-case scenarios in terms of predicted drawdown during the seasonal-low periods. A likely outcome in this respect is that the proposed pits may intercept larger groundwater volumes during winter than have been predicted; the drawdown footprint during winter may also be over-estimated to again reflect reasonable worst-case scenarios.

Over-all, the model and report have been used to define drawdown of 0.1 m increments. This probably over-reaches the likely model accuracy.

## 4.2 Simulated Changes Due to Mineral Sand Mining

### 4.2.1 Model Form for the Mining Operations

The proposed mining plans for the Wonnerup and Wonnerup South project areas were incorporated within the groundwater flow model within a monthly framework. Sequential mining block developments were simulated with the MODFLOW drainage package for pit dewatering and recharge fluxes to represent tailings operations.

# 4 Simulation of Wonnerup and Wonnerup South Mining Plans

The simulated drain elevations were specified based on the average design pit floor elevations. All of the drains in individual mining blocks were assigned the same elevation. Individual drains were activated during the mining period for the specified mining block, and then subsequently deactivated after mining. This approach enabled broad simulation of the groundwater abstraction potentially associated with the individual mining blocks, with local lowering of the water table to 0.5 m beneath the pit floor. A drain conductance of 781 $m^2$/day was assigned dependent on the drain cell dimensions to allow groundwater to flow into the mine blocks with relative ease. The predictive model outcomes were not expected to be sensitive to the drain conductance.

After mining, the wet sand tailing operations were simulated with an average recharge rate of 3,450 mm/annum applied to the discrete mining blocks. This recharge rate was based on results of tailings slurry infiltration tests conducted at the Ludlow Deposit (URS, December 2002).

Further to these aspects, the predictive model incorporated the Process Water Dam within the eastern third of Mining Block 11, Wonnerup project area (Figure 2.1). It was assumed the Process Water Dam occupied the mined void and associated recharge was characterised by a fixed-head boundary condition that locally sustained the pre-mining water table elevation. The southwest tip of Mining Block 11 was similarly recharged to mitigate the local propagation of drawdown. Recharge to both of these source areas commenced in May 2013 and was sustained for the period of mining.

### 4.2.2 Predictive Model Outcomes

The predictive model was used to quantify the potential pit dewatering abstraction rates and volumes and transient changes to the groundwater environment due to the groundwater abstractions and subsequent tailing operation recharge. These aspects are discussed below.

The change assessments have been based on comparative transient assessments between a baseline model and the model that incorporates the proposed mining plans.

#### *4.2.2.1 Groundwater Abstraction During mining*

Forecast abstraction rates and cumulative volumes are shown in Table 4-1 and on Figure 4-1. Total aggregate abstractions are typically in the range 0.1 to 0.4 GL/annum. For a number of the monthly time-steps there is no predicted abstraction. In these periods, the average pit floor elevations occur above the baseline water table or discrete mine blocks have been passively dewatering by abstractions from nearby mine blocks.

In comparative terms, the predicted aggregate annual abstraction volumes are broadly compatible with those earlier (URS, April 2008); both the range of monthly average abstractions rates (about 250 to 2,300 kL/day) and the annual aggregate abstraction volumes are similar. The earlier predictions typically ranged from 200 to 2,300 kL/day and 0.22 to 0.57 GL/annum.

# 4 Simulation of Wonnerup and Wonnerup South Mining Plans

**Table 4-1 Predicted Groundwater Abstraction Rates and Volumes**

| Period | Average Abstraction Rate (kL/day) | | Annual Aggregate Abstraction (GL) |
|---|---|---|---|
| | Wonnerup | Wonnerup South | |
| May-13 | 53 | nil | 0.10 |
| Jun-13 | 810 | nil | |
| Jul-13 | 38 | nil | |
| Aug-13 | nil | nil | |
| Sep-13 | 674 | nil | |
| Oct-13 | 393 | nil | |
| Nov-13 | 853 | nil | |
| Dec-13 | 655 | nil | |
| Jan-14 | 865 | nil | 0.36 |
| Feb-14 | 292 | nil | |
| Mar-14 | 1,206 | nil | |
| Apr-14 | 2,275 | nil | |
| May-14 | 1,171 | nil | |
| Jun-14 | 1,105 | nil | |
| Jul-14 | 1,006 | nil | |
| Aug-14 | 1,334 | nil | |
| Sep-14 | 1,063 | nil | |
| Oct-14 | nil | nil | |
| Nov-14 | 616 | nil | |
| Dec-14 | 1,171 | nil | |
| Jan-15 | 497 | nil | 0.42 |
| Feb-15 | 402 | nil | |
| Mar-15 | 688 | nil | |
| Apr-15 | 217 | nil | |
| May-15 | 294 | nil | |
| Jun-15 | 594 | nil | |
| Jul-15 to Sept-15 | nil | nil | |
| Oct-15 | nil | 67 | |
| Nov-15 | nil | 381 | |
| Dec-15 | nil | 318 | |
| Jan-16 | nil | 252 | 0.16 |
| Feb-16 | nil | 522 | |
| Mar-16 | nil | 497 | |
| Apr-16 | nil | 623 | |
| May-16 | nil | 630 | |
| Jun-16 | nil | 413 | |
| Jul-16 | nil | 539 | |
| Aug-16 | nil | 405 | |
| Sep-16 | nil | 117 | |
| Oct-16 | nil | 501 | |
| Nov-16 | 218 | nil | |
| Dec-16 | 550 | nil | |
| Jan-17 | 853 | nil | 0.12 |
| Feb-17 | 555 | nil | |
| Mar-17 | 606 | nil | |
| Apr-17 | 742 | nil | |
| May-17 | 560 | nil | |
| Jun-17 | 615 | nil | |

## 4 Simulation of Wonnerup and Wonnerup South Mining Plans

#### 4.2.2.2 Drawdown of the Water Table

The predictive groundwater flow modelling indicates that groundwater abstraction associated with mining below the water table will cause local drawdown within the Superficial Aquifer. The predicted transient changes to the water table setting, from May 2013 to June 2017 are shown in discrete annual plan-view snapshots on Figure 4-2 through Figure 4-5, inclusive. To provide additional spatial context, north-to-south and west-to-east cross-sections show the predicted drawdown distributions during January 2017 on Figure 4-6 and Figure 4-7, respectively.

The concurrent mining of the Wonnerup and Wonnerup South project areas results in predicted cumulative drawdown of the water table beneath local reaches of the Sabina River. The predicted magnitude of the cumulative drawdown is temporary, ranges from about 0.1 to 0.3 m and occurs over a 150 m reach of the Sabina River. The predicted duration of the cumulative drawdown footprint is limited to comparatively short-terms of one to three months.

The predicted maximum extents of the 0.1 m and 0.5 m drawdown contours are shown on Figure 4-8. Within the Wonnerup project area, the predicted 0.1 m drawdown footprint extends up to 500 m from the pit crests, particularly to the north and northeast. Within the Wonnerup South project area, the 0.1 m drawdown footprint typically propagates less than 200 m from the pit crests. Drawdown of magnitude 0.5 m is tightly constrained to the near vicinity of the excavations, typically propagating less than 100 m beyond the pit perimeters, except to the north where it propagates about 300 m.

#### 4.2.2.1 Drawdown Beneath Local Reaches of the Sabina and Abba Rivers

The predictive model has been used to assess the occurrence of drawdown beneath the Sabina and Abba rivers. Findings from the predictive model indicate:

- Drawdown beneath the Sabina River:
  - Piezometer WNMB07 drawdown of 0.1 to 0.2 m.
  - Piezometer WNMB08 drawdown of 0.1 m.
  - Piezometer WNMB14 drawdown of 0.3 m.
  - Piezometer WNMB15 drawdown of less than 0.1 m.
  - Piezometer WNMB16 drawdown of 0.1 to 0.2 m.
- Drawdown beneath the Abba River:
  - Piezometer WNMB01 drawdown of less than 0.1 m.

#### 4.2.2.2 Drawdown Sensitivity and Uncertainty

The predictive assessments of drawdown at the water table are expected to be influenced by a number of assumptions that characterise the model form and hydraulic behaviours. The model is not calibrated to observations of local pumping stressors and is based on average bottom pit elevations. It also hosts a seasonal water balance that underestimated rainfall recharge and does not incorporate potential environmental water that may be available in the local watercourses of the Sabina and Abba rivers. .

At present it is difficult to gauge if the model over-estimates or under-estimates the predicted drawdown footprint and transient magnitudes of drawdown. It would be prudent to use the local monitoring bores to assess the actual transient drawdown impacts and inform change management strategies.

## 4 Simulation of Wonnerup and Wonnerup South Mining Plans

The simulated drawdown influences impose on the Sabina River and to a less extent on the Abba River. The simulated influences would seem to be minor, both limited in magnitude and of short-term duration. Nevertheless, if the simulated drawdown is matched by or exceeded by monitoring bore observations then local replenishment of the water table may be warranted. Local infiltration cells would enable replenishment of the water table in sensitive settings and also limit the propagation of the drawdown distribution.

#### *4.2.2.3 Water Table Recovery*

The predictive model continues to run after mining, enabling completion of tailings operations and to track the characteristics of the water table recovery. A plan-view snapshot of the residual drawdown six months after the cessation of mining is shown on Figure 4-9. At this time, there is no predicted residual drawdown. The predictions show:

- Mounding of the water table by 0.1 to 0.2 m in the vicinity of the Mining Blocks 44 to 49 (Wonnerup).
- Mounding of the water table by 0.1 to 0.3 m in the vicinity of the Mining Block 28 (Wonnerup South).

Mining blocks 44 to 49 (Wonnerup) were simulated to be mining in the first-half 2017. Mining block 28 (Wonnerup South) was simulated to be mining in 2015 (Figure 2-1).

# 5 Conclusions

The derived conclusions only reflect the purposes of this addendum. The conclusions include:

- The recent piezometer records for WPMB01 through WPMB23, inclusive, reflect water table elevations in the range from 4.5 to 16.9 m AHD, with typical seasonal fluctuations of 1.2 to 2.0 m.
- Comparisons of the observed and calibrated model simulated water table elevations at monitoring bore sites indicated a reasonable match. Most of the simulated water table elevations were within the observed range.
- The model provides a magnitude of seasonal fluctuations from 0.5 to 1.0 m, thus is indicated to be characterised by conservatively low rates of recharge. As such, the model may tend to over-estimate potential drawdown impacts due to groundwater abstractions.
- The current model form and parameterisation was expected to provide reasonable worst-case scenarios given the model under-estimates recharge. The assignment of drain elevations that reflect the average bottom elevations of individual mining blocks would tend to provide reasonable predictions of abstraction to provide dry mining conditions.
- Predicted abstractions rates typically occurred in the range of 250 to 2,300 kL/day, with aggregate abstraction volumes ranging from 0.1 to 0.4 GL/annum.
- The concurrent mining of the Wonnerup and Wonnerup South project areas results in predicted cumulative drawdown footprint that temporarily extends beneath the Sabina River. The magnitude of the cumulative drawdown ranges from 0.1 to 0.3 m and occurs over a 150 m reach of the Sabina River. The predicted duration of the cumulative drawdown footprint is one to three months. Findings from the predictive model indicate:
  - Drawdown beneath the Sabina River:
    - Piezometer WNMB07 drawdown of 0.1 to 0.2 m.
    - Piezometer WNMB08 drawdown of 0.1 m.
    - Piezometer WNMB14 drawdown of 0.3 m.
    - Piezometer WNMB15 drawdown of less than 0.1 m.
    - Piezometer WNMB16 drawdown of 0.1 to 0.2 m.
  - Drawdown beneath the Abba River:
    - Piezometer WNMB01 drawdown of less than 0.1 m.
- The simulated drawdown influences on the Sabina River and the Abba River would seem to be minor, both limited in magnitude and of short-term duration. Nevertheless, if the simulated drawdown is matched by or exceeded by monitoring bore observations then local replenishment of the water table may be warranted. Local infiltration cells would enable replenishment of the water table in sensitive settings and also limit the propagation of the drawdown distribution.
- Within the Wonnerup project area, the predicted 0.1 m drawdown footprint extends up to 500 m from the pit crests, particularly to the north and northeast.
- Within the Wonnerup South project area, the 0.1 m drawdown footprint typically propagates less than 200 m from the pit crests.
- Drawdown of magnitude 0.5 m is tightly constrained to the near vicinity of the Wonnerup and Wonnerup South excavations, typically propagating less than 100 m beyond the pit perimeters, except to the north where it propagates about 300 m.
- A snapshot six months after the cessation of mining indicated that there was no residual drawdown footprint.

# 6 Recommendations

Licensed groundwater abstraction of 0.6 GL/annum has been sought from the Department of Water to support the groundwater management that will be necessary during mining below the water table. The sought allocation limit is marginally higher than the predicted maximum annual abstraction, providing the Wonnerup Project a practical contingency, and should not be exceeded.

Refine the Operating Strategy for Groundwater Dewatering, Wonnerup Mineral Sands Mine (Cable Sands (W.A) Pty Ltd, December 2011) to incorporate trigger values for drawdown beneath the Sabina and Abba rivers. Further, the Operating Strategy would include a set of actions to be implemented, perhaps in a staged approach, if a trigger is breached. On action would be to provide artificial recharge to the local aquifer to offset the observed drawdown impacts and associated environmental risk.

# References

Cable Sands (W.A) Pty Ltd, December 2011; CD427; Operating Strategy for Groundwater Dewatering, Wonnerup Mineral Sands Mine.

URS, December 2002; Ludlow Deposit – Impacts of Changed Water Balances Due to Mining; Reference 16155-010-562/498-F5384.2; prepared for Cable Sands (WA) Pty Ltd.

URS, April 2008; Groundwater Environmental Impact Assessment – Wonnerup Deposit; Reference 42906387/629-F8202.2.DOC; prepared for Bemax Resources Limited.

URS, September 2012; Wonnerup Project – Addendum for Re-Modelling of Mining Plans; Reference 42908187/Modelling Addendum/B Final; prepared for Bemax Resources Limited.

# Limitations

## Geotechnical & Hydro Geological Report

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Cristal Mining Australia Limited and only those third parties who have been authorised in writing by URS to rely on the report.

It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the contract dated 31 August 2012.

The methodology adopted and sources of information used by URS are outlined in this the Report.

Where this report indicates that information has been provided to URS by third parties, URS has made no independent verification of this information unless required as part of the agreed scope of work. URS assumes no liability for any inaccuracies in or omissions to that information.

This Report was prepared between 15$^{th}$ June and 5$^{th}$ July 2013. The information in this report is considered to be accurate at the date of issue and is in accordance with conditions at the site at the dates sampled. Opinions and recommendations presented herein apply to the site existing at the time of our investigation and cannot necessarily apply to site changes of which URS is not aware and has not had the opportunity to evaluate. This document and the information contained herein should only be regarded as validly representing the site conditions at the time of the investigation unless otherwise explicitly stated in a preceding section of this report. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

This report contains information obtained by inspection, sampling, testing or other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. The borehole logs indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the uniformity of conditions and on the frequency and method of sampling as constrained by the project budget limitations. The behaviour of groundwater and some aspects of contaminants in soil and groundwater are complex. Our conclusions are based upon the analytical data presented in this report and our experience. Future advances in regard to the understanding of chemicals and their behaviour, and changes in regulations affecting their management, could impact on our conclusions and recommendations regarding their potential presence on this site.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, URS must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time. Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

# 8 Limitations

Except as required by law, no third party may use or rely on this Report unless otherwise agreed by URS in writing. Where such agreement is provided, URS will provide a letter of reliance to the agreed third party in the form required by URS.

To the extent permitted by law, URS expressly disclaims and excludes liability for any loss, damage, cost or expenses suffered by any third party relating to or resulting from the use of, or reliance on, any information contained in this Report. URS does not admit that any action, liability or claim may exist or be available to any third party.

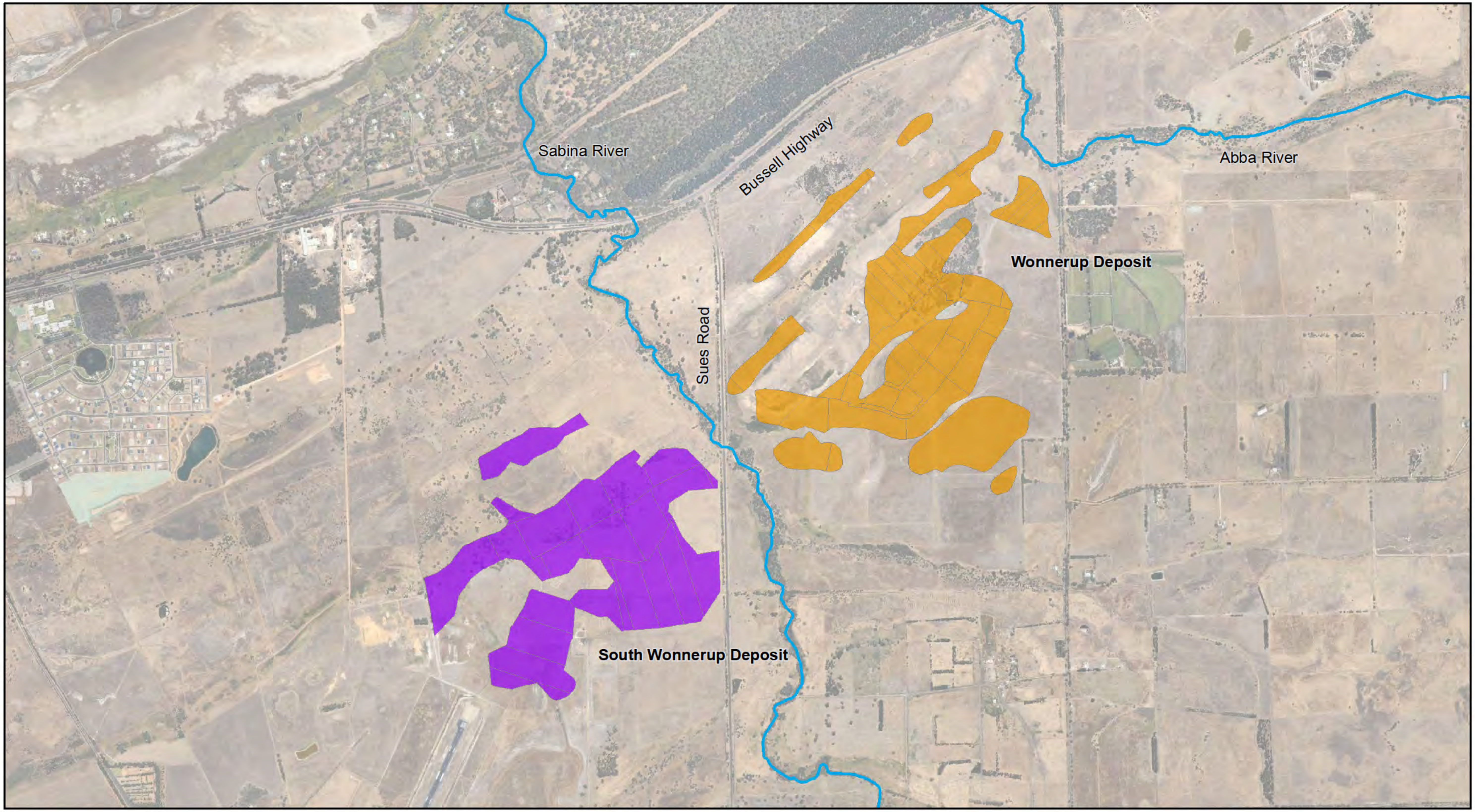
URS does not represent that this Report is suitable for use by any third party.

Except as specifically stated in this section, URS does not authorise the use of this Report by any third party.

It is the responsibility of third parties to independently make inquiries or seek advice in relation to their particular requirements and proposed use of the relevant property.

Any estimates of potential costs which have been provided are presented as estimates only as at the date of the Report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

# Figures




N
W E
S
1:20,000
0 100 200 300 400 m
Projection: MGA94 Zone 50

Legend

Pit Outline

- South Wonnerup
- Wonnerup
- Watercourse

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

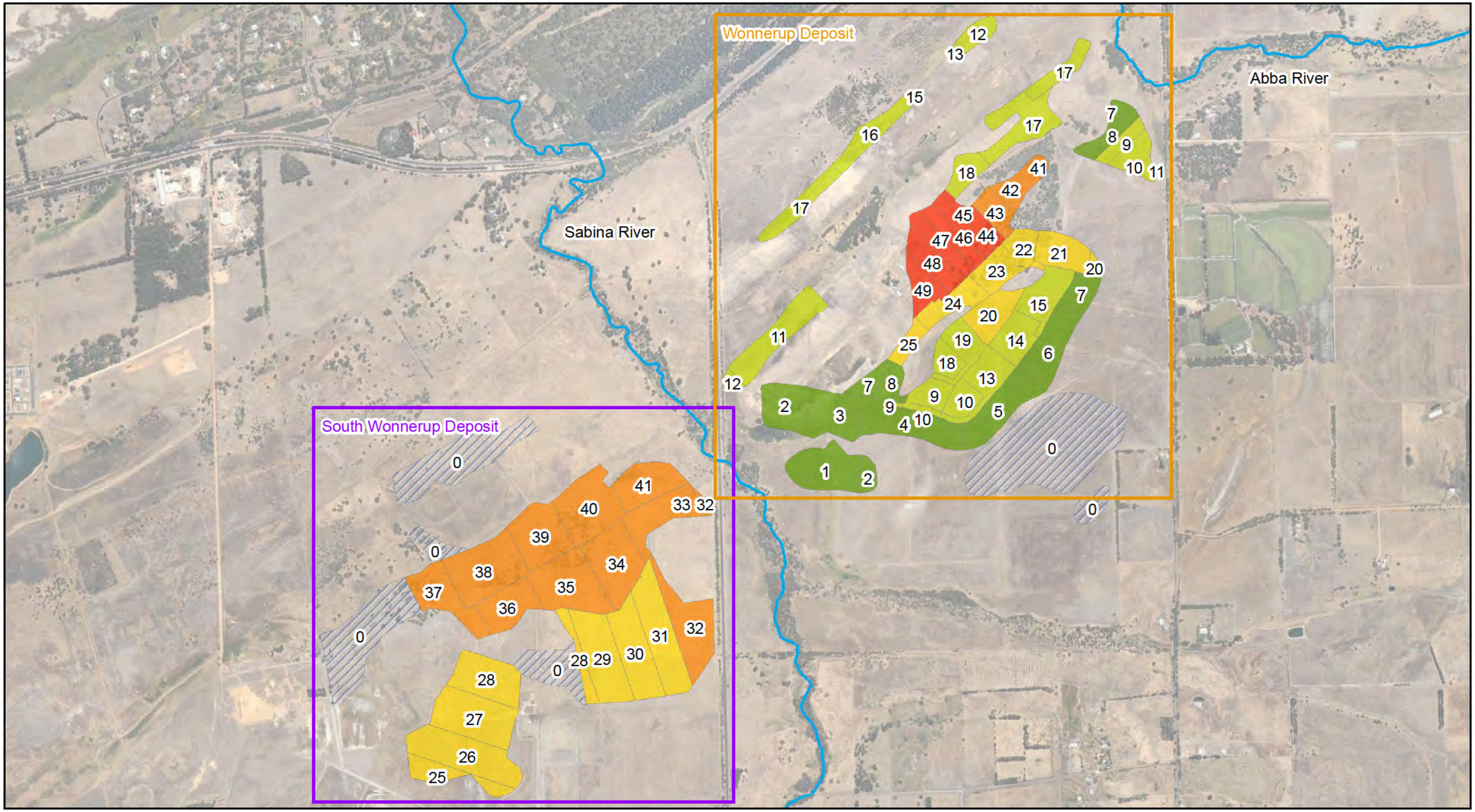
**LOCATION PLAN**

URS

File No: 42908187-GW-016.mxd | Drawn: GM | Approved: IB | Date: 07-JUL-13

Figure: 1.1

Rev. A | A3




This drawing is subject to COPYRIGHT. \\PER-FS\jobs\Jobs\42908187\5 Works\GIS\MXD\42908187-GW-007.mxd

N
W E
S
1:15,032
0 100 200 300 400 m
Projection: MGA94 Zone 50

Legend

**Mining Sequence**

- Mining above water table
- 2013
- 2014
- 2015
- 2016
- 2017
- Watercourse

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

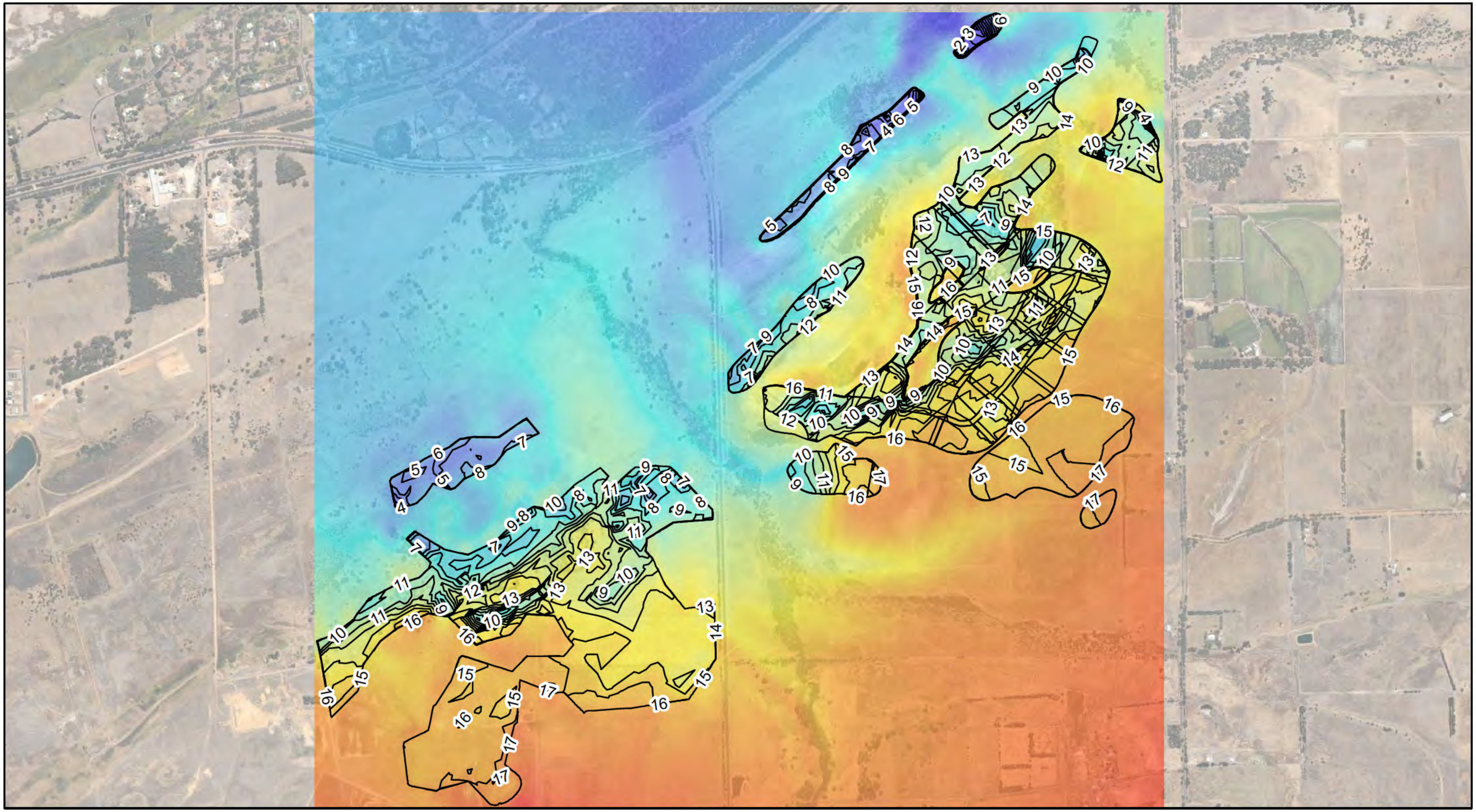
**WONNERUP AND WONNERUP SOUTH MINING PLANS**

URS

File No: 42908187-GW-007.mxd | Drawn: GM | Approved: IB | Date: 07-JUL-13

Figure: 2.1

Rev. A | A3



N
W E
S
1:14,774
0 100 200 300 400 m
Projection: MGA94 Zone 50

## Legend

- Pit Outline
- Pit Floor Elevation (m AHD)
- High : 18.7 m AHD
- Low : -2.16 m AHD

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

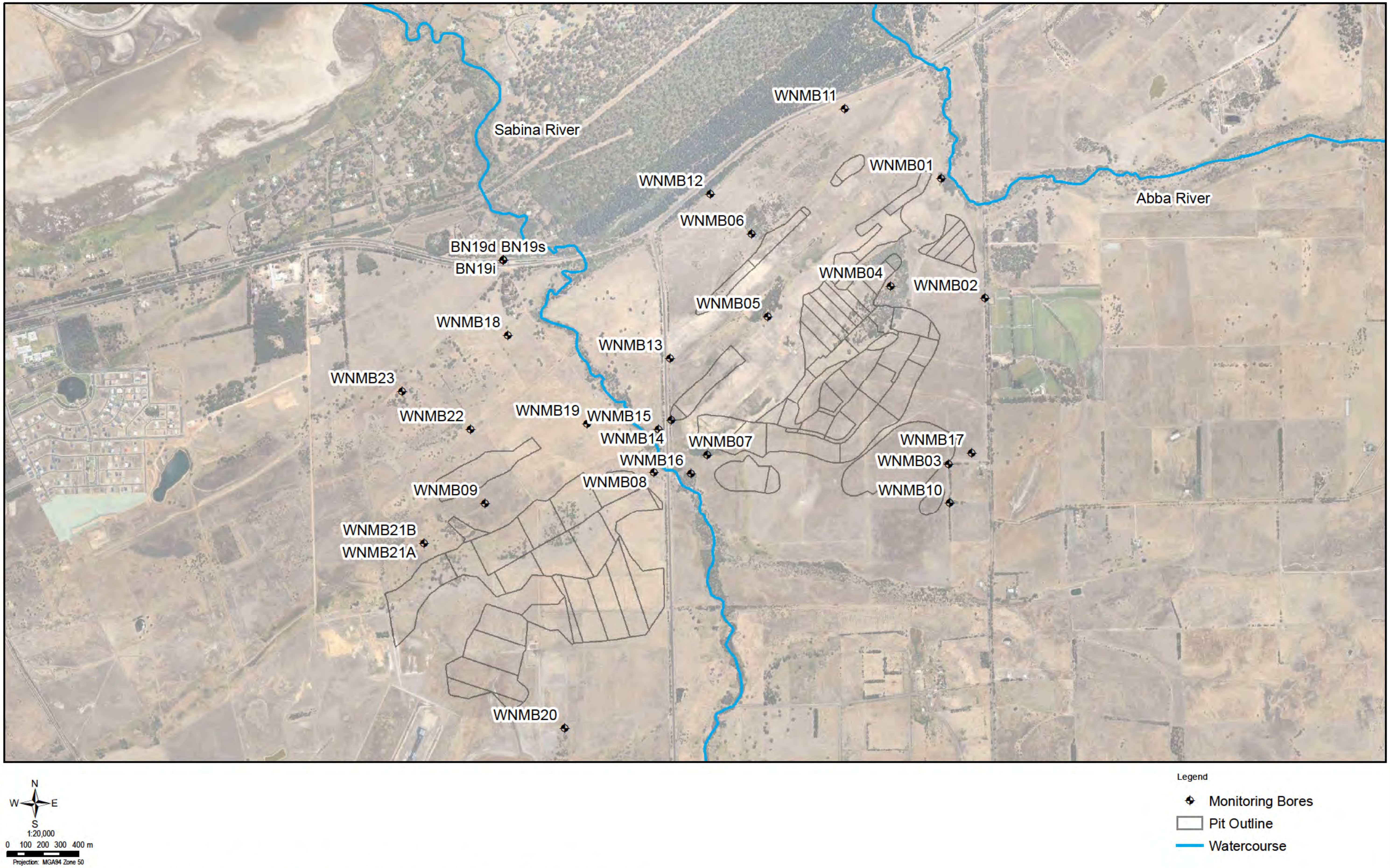
**PIT FLOOR ELEVATIONS**

URS

File No: 42908187-GW-008.mxd | Drawn: GM | Approved: IB | Date: 07-JUL-13

Figure: 2.2

Rev. A | A3




Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

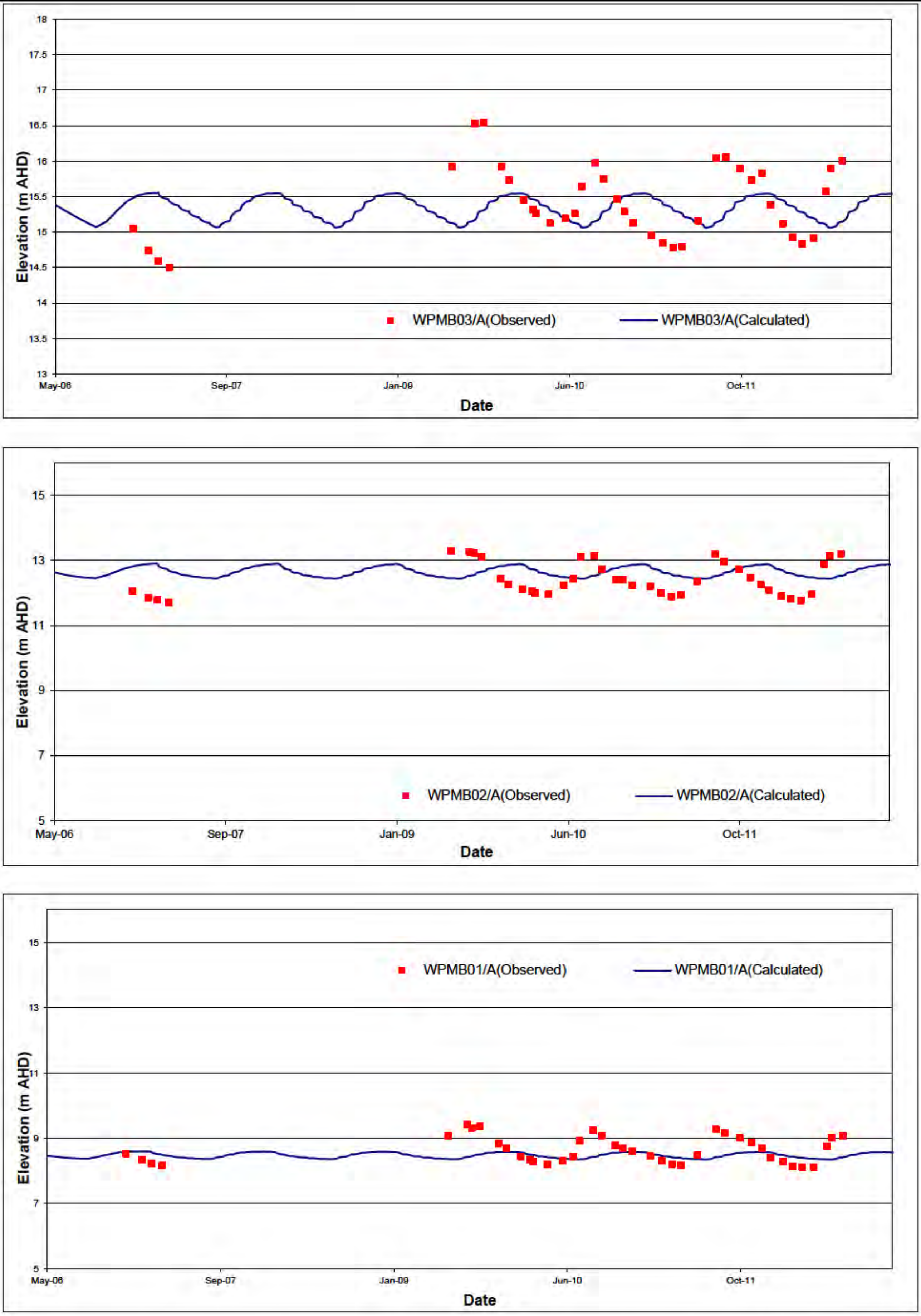
**LOCATIONS OF MONITORING BORES**

URS

File No: 42908187-GW-015.mxd | Drawn: GM | Approved: IB | Date: 07-JUL-13

Figure: 3.1

Rev. A | A3




Source: URS





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CRISTAL MINING AUSTRALIA LIMITED

Wonnerup and Wonnerup South Projects – Addendum for Concurrent Mining Plans

**CALIBRATION HYDROGRAPHS WPMB01, WPMB02 AND WPMB03**

URS

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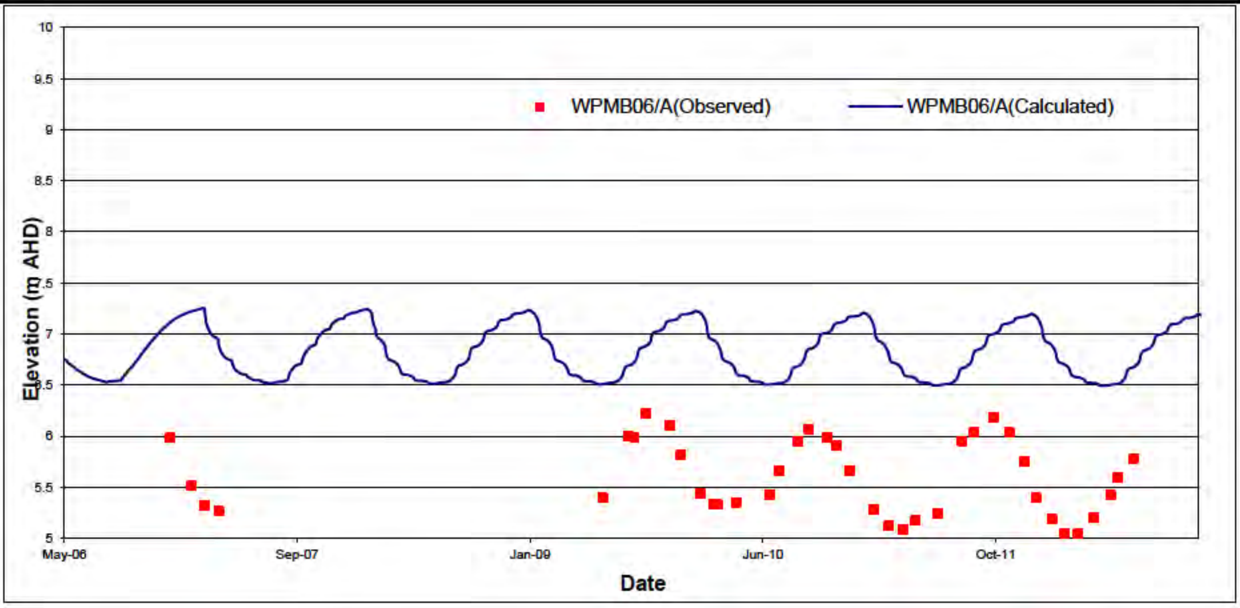
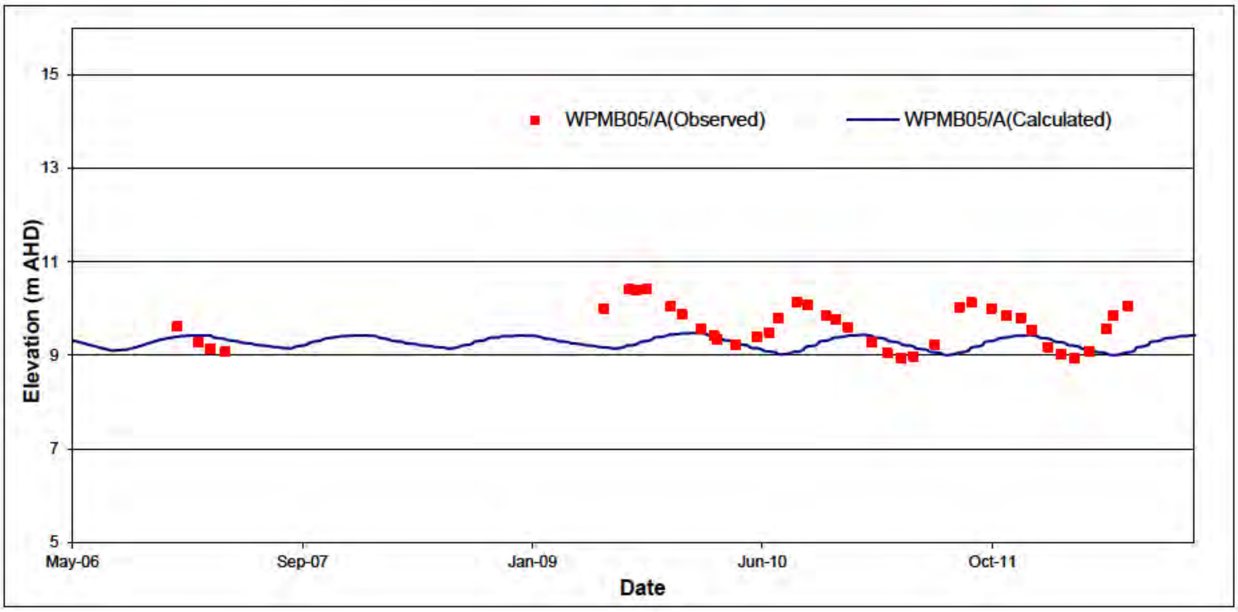
File No: \Calibration Figures_H | Drawn: GM | Approved: IB | Date: 05-07-2013

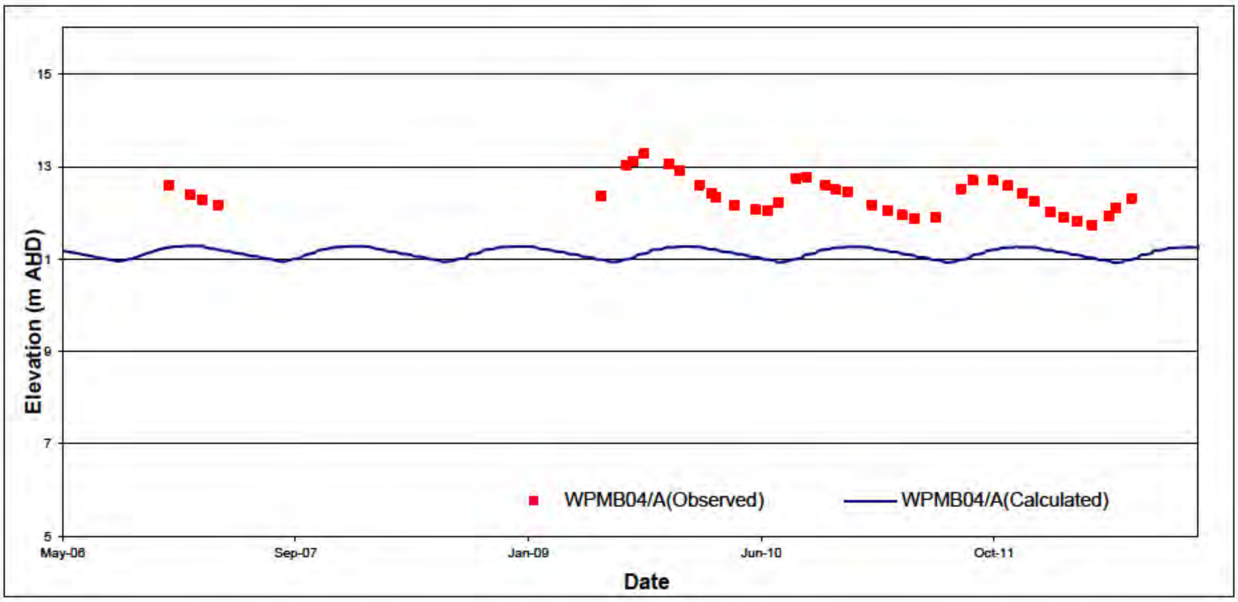
Figure: 3-2

Rev. A

A4




Source: URS



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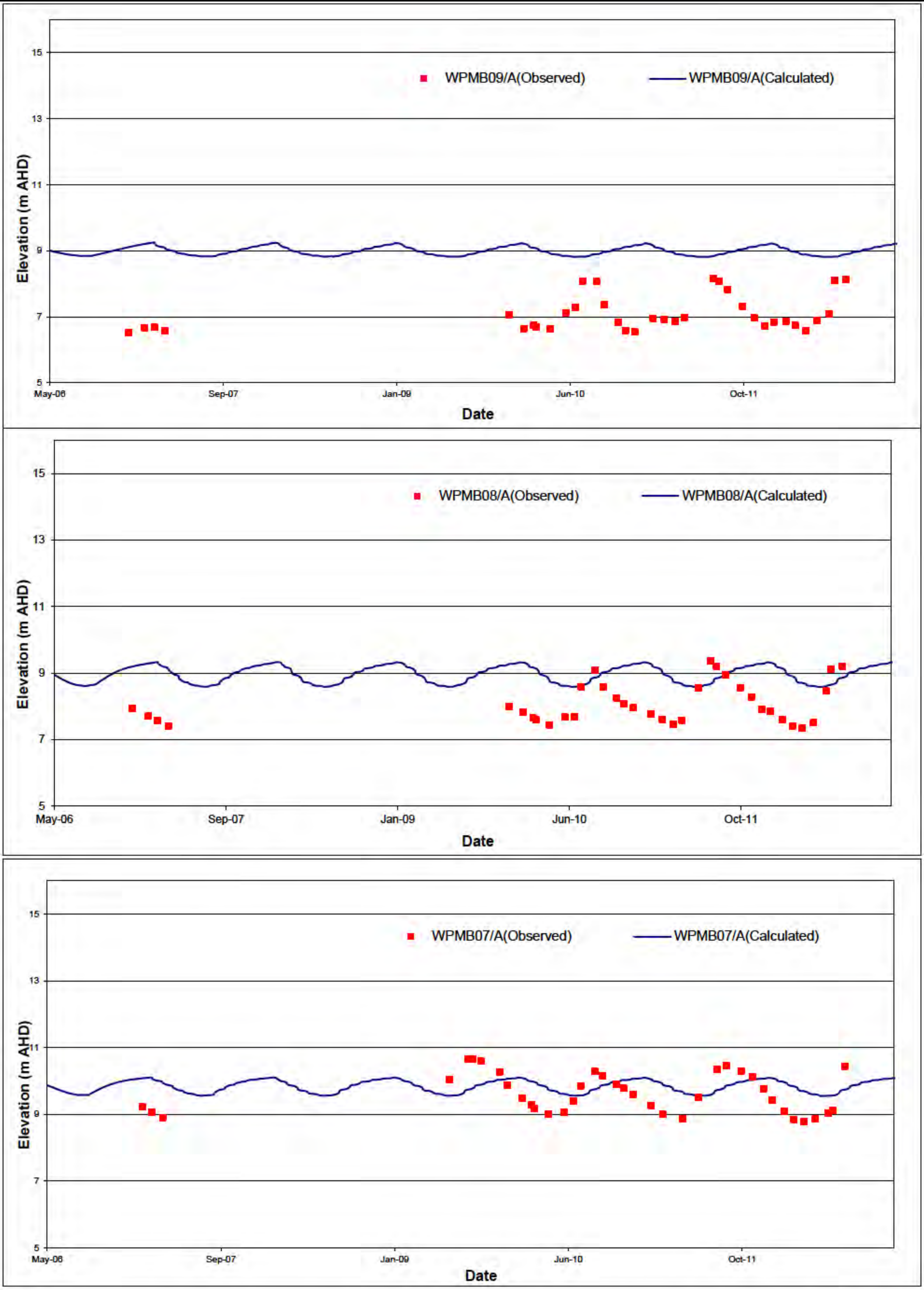
Wonnerup and Wonnerup South Projects – Addendum for Concurrent Mining Plans

**CALIBRATION HYDROGRAPHS WPMB04, WPMB05 AND WPMB06**

URS | **CRISTAL MINING AUSTRALIA LIMITED** | Figure: **3-3**

File No: \Calibration Figures_H | Drawn: GM | Approved: IB | Date: 05-07-2013 | Rev. **A** | A4




Source: URS



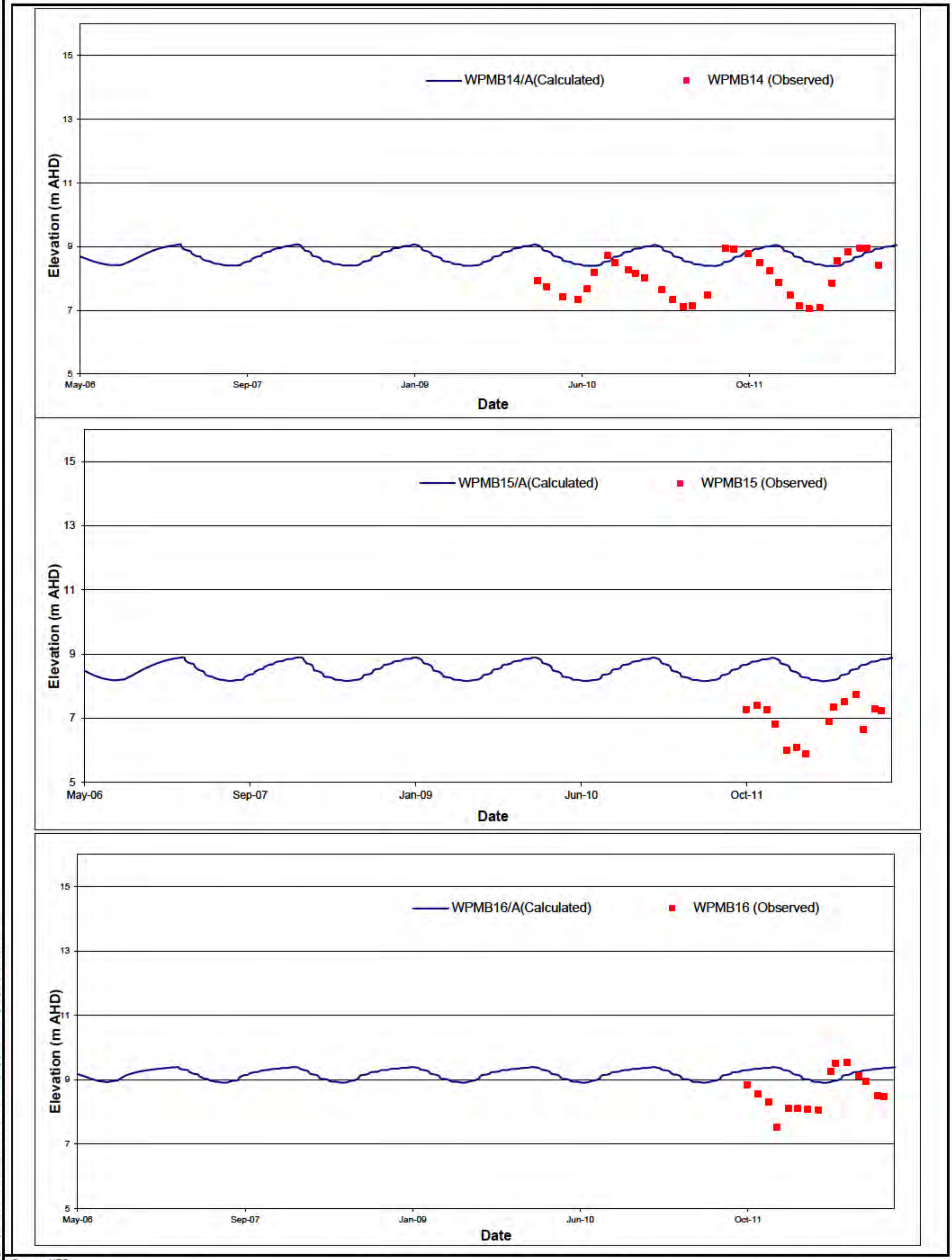
CRISTAL MINING AUSTRALIA LIMITED

Wonnerup and Wonnerup South Projects – Addendum for Concurrent Mining Plans

**CALIBRATION HYDROGRAPHS WPMB07, WPMB08 AND WPMB09**

URS | CRISTAL MINING AUSTRALIA LIMITED | Figure: 3-4

File No: \Calibration Figures_H | Drawn: GM | Approved: IB | Date: 05-07-2013 | Rev. A | A4




Source: URS



CRISTAL MINING AUSTRALIA LIMITED

Wonnerup and Wonnerup South Projects – Addendum for Concurrent Mining Plans

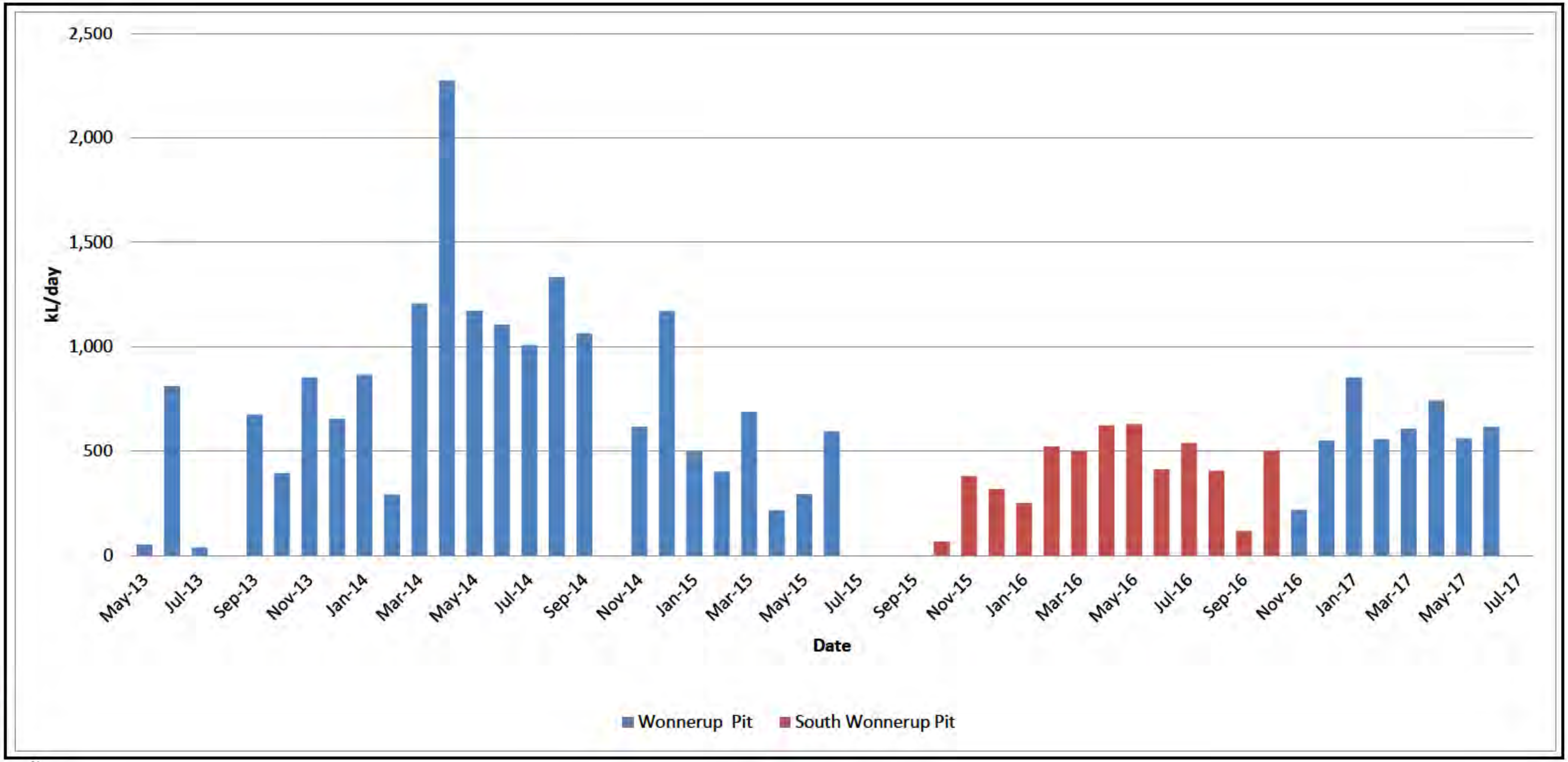
**CALIBRATION HYDROGRAPHS WPMB14, WPMB15 AND WPMB16**

URS

**CRISTAL MINING AUSTRALIA LIMITED**

Figure: 3-5

File No: \Calibration Figures_H | Drawn: GM | Approved: IB | Date: 05-07-2013 | Rev: A | A4




Source: URS



**CRISTAL MINING AUSTRALIA LIMITED**

Wonnerup and Wonnerup South Projects – Addendum for Concurrent Mining Plans

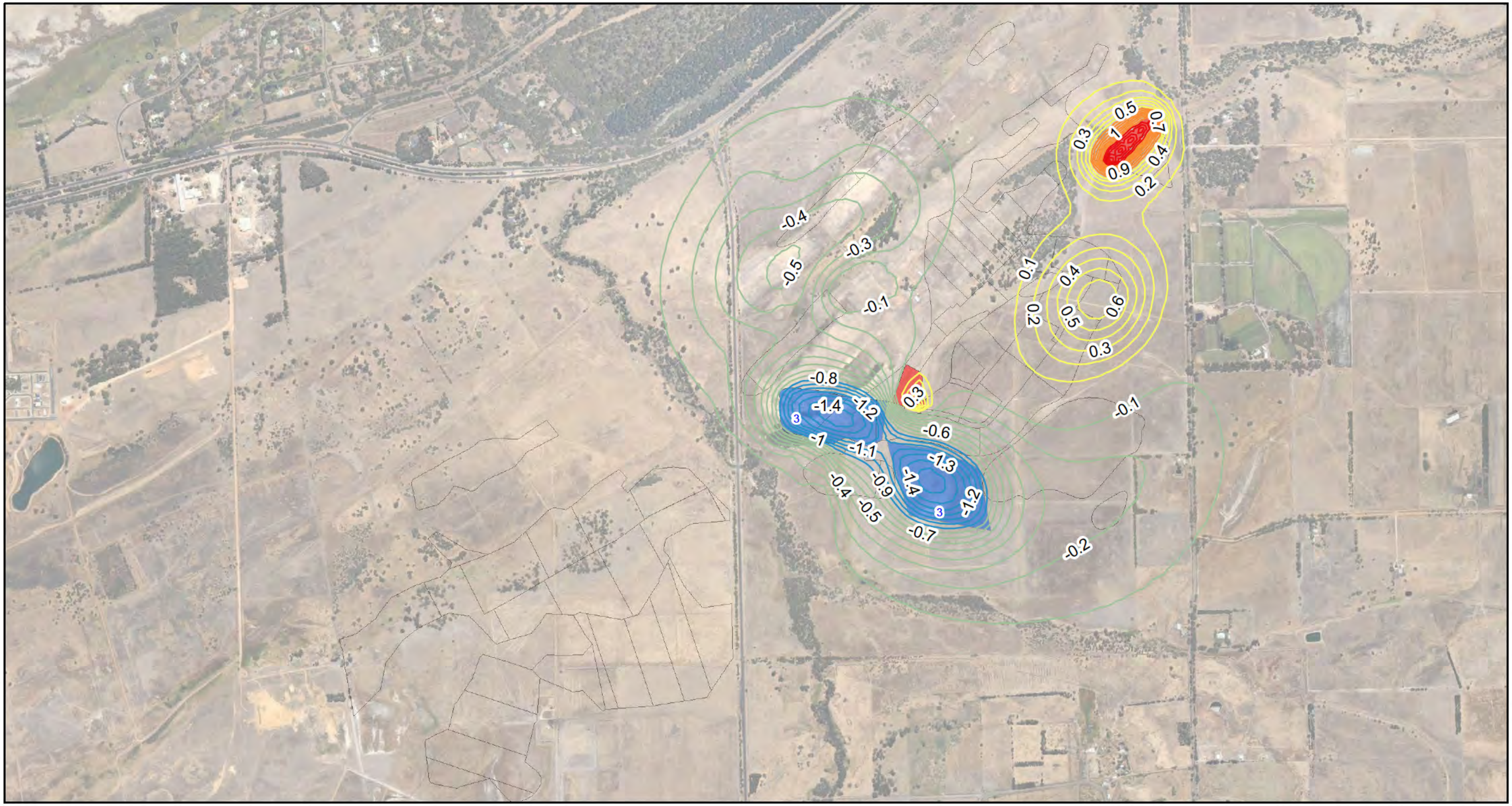
**Predicted Monthly Abstraction**

URS

File No: WB_C.xlsx | Drawn: GM | Approved: IB | Date: 05/07/2013

Figure: 4.1

Rev: A | A4




N
W E
S
1:15,375
0 100 200 300 400 m
Projection: MGA94 Zone 50

Legend

**Drawdown Contours (m)**

- -1.5 - -0.9
- -0.8 - -0.1
- 0.0 - 0.6
- 0.7 - 1.3
- 1.4 - 1.9
- Pit Outline
- Active Pit Dewatering
- Active Tailing

Positive value means drawdown
Negative value means mounding

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

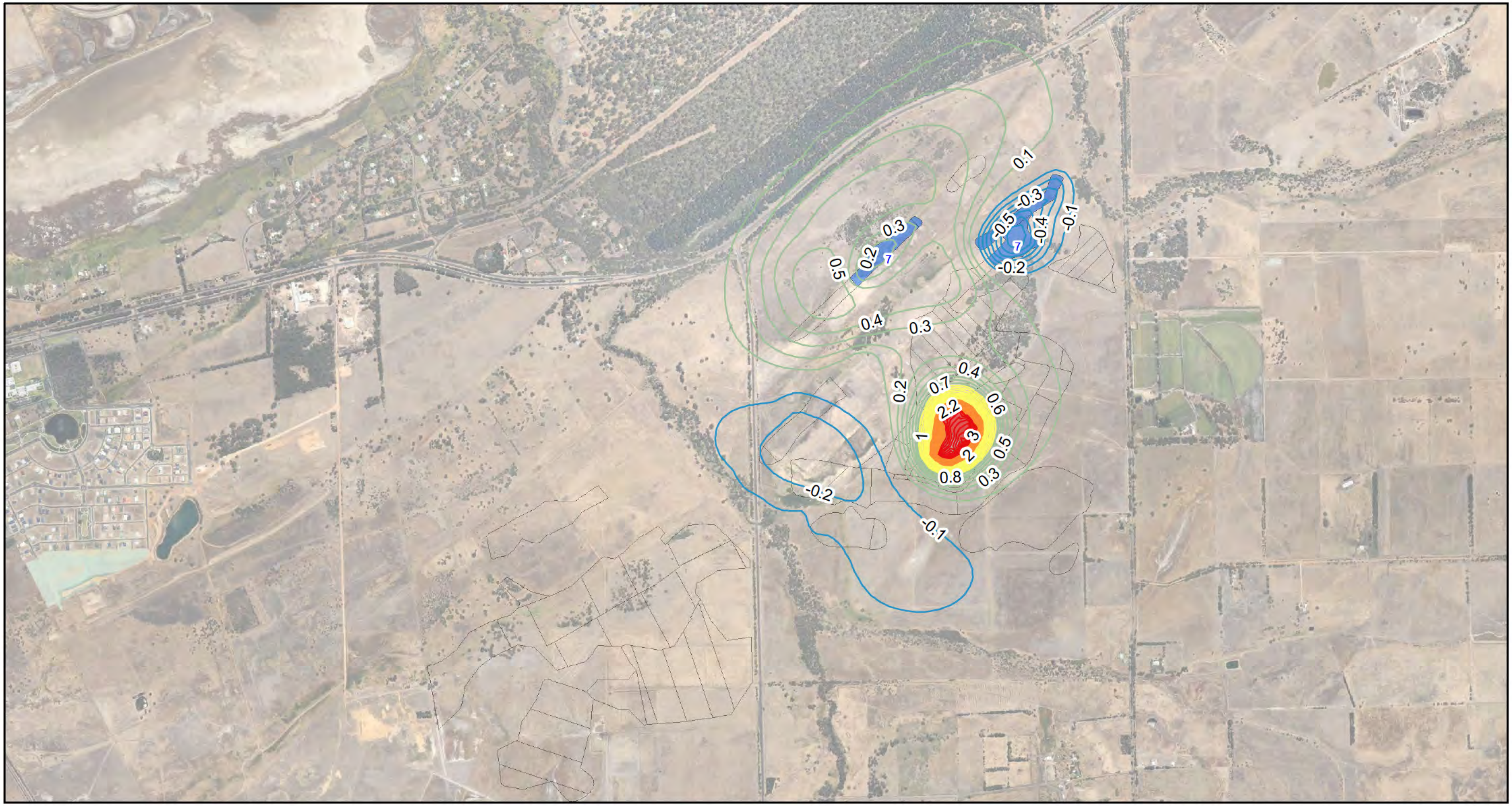
## PREDICTED DRAWDOWN – PLAN VIEW SNAPSHOT JANUARY 2014

URS

File No: 42908187-GW-001.mxd Drawn: GM Approved: IB Date: 07-JUL-13

Figure: 4.2

Rev. A A3




Legend

Pit Outline
Active Pit Dewatering
Active Tailing

Positive value means drawdown
Negative value means mounding

**Drawdown Contours (m)**

- -0.7 - -0.1
- 0.0 - 0.8
- 0.9 - 1.7
- 1.8 - 2.7
- 2.8 - 3.5

N W E S
1:18,588
0 100 200 300 400 m
Projection: MGA94 Zone 50

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

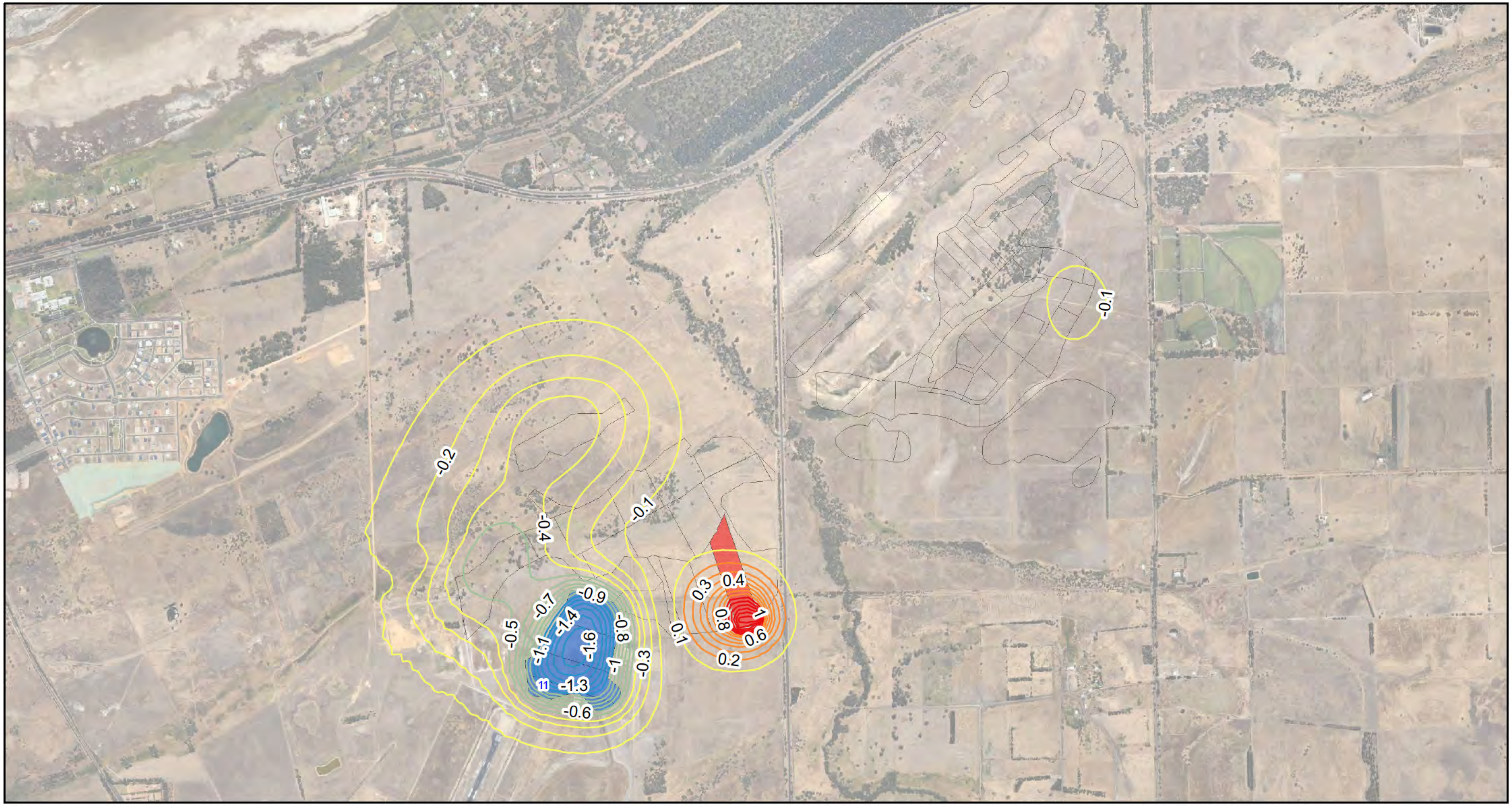
**PREDICTED DRAWDOWN – PLAN VIEW SNAPSHOT JANUARY 2015**

URS

File No: 42908187-GW-002.mxd Drawn: GM Approved: IB Date: 07-JUL-13

Figure: 4.3

Rev. A A3




N
W E
S
1:18,769
0 100 200 300 400 m
Projection: MGA94 Zone 50

Legend

| | |
|---|---|
| Pit Outline | |
| Active Pit Dewatering | |
| Active Tailing | |

**Drawdown Contours (m)**

- -1.6 - -1.1
- -1.0 - -0.5
- -0.4 - 0.1
- 0.2 - 0.8
- 0.9 - 1.4

Positive value means drawdown
Negative value means mounding

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

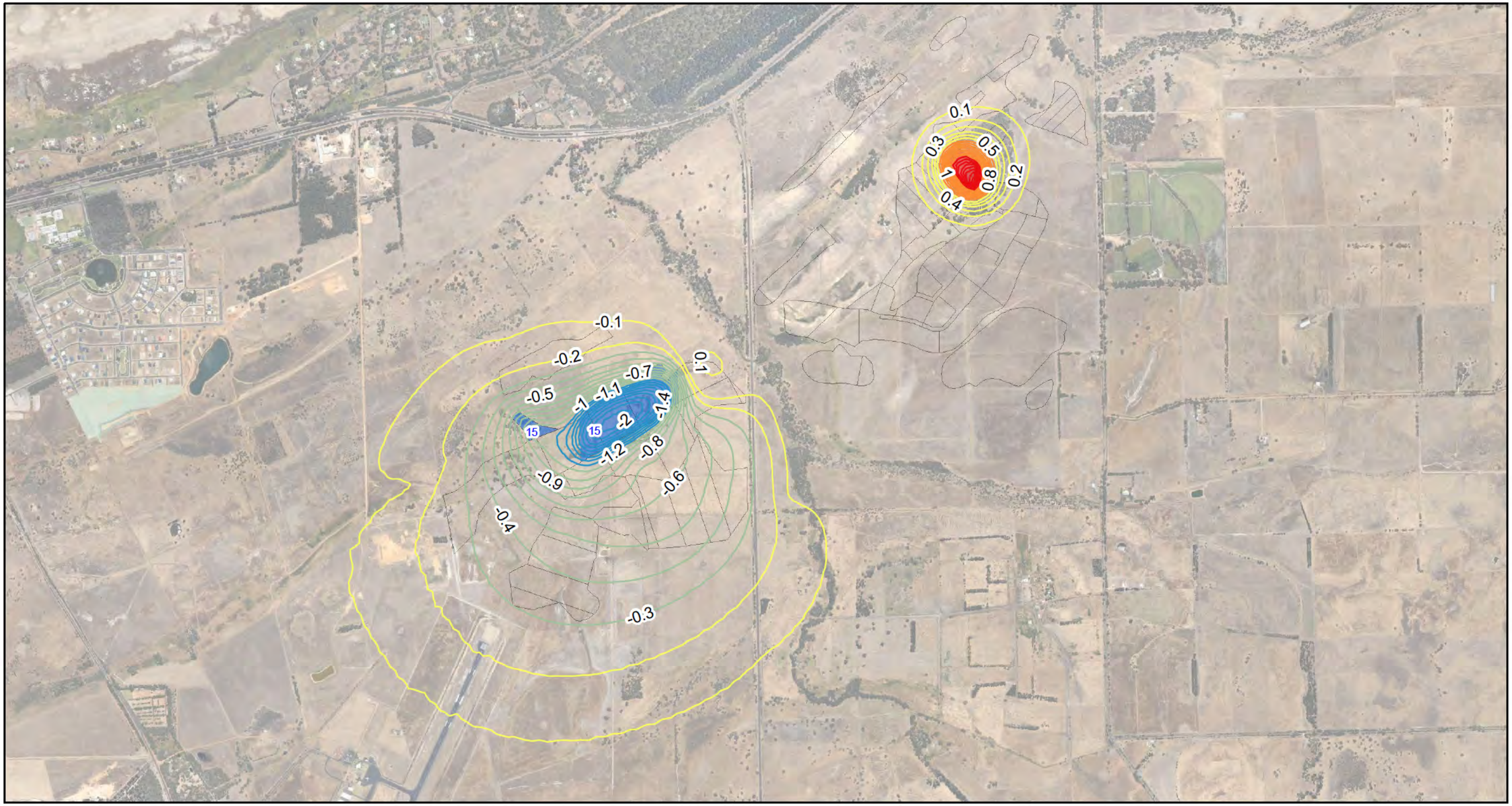
**PREDICTED DRAWDOWN – PLAN VIEW SNAPSHOT JANUARY 2016**

URS

File No: 42908187-GW-003.mxd Drawn: GM Approved: IB Date: 07-JUL-13

Figure: 4.4

Rev. A A3




Legend

| | |
|---|---|
| Pit Outline | |
| Active Pit Dewatering | |
| Active Tailing | |

**Drawdown Contours (m)**

- -2.0 - -1.2
- -1.1 - -0.3
- -0.2 - 0.6
- 0.7 - 1.5
- 1.6 - 2.4

Positive value means drawdown
Negative value means mounding

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



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WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

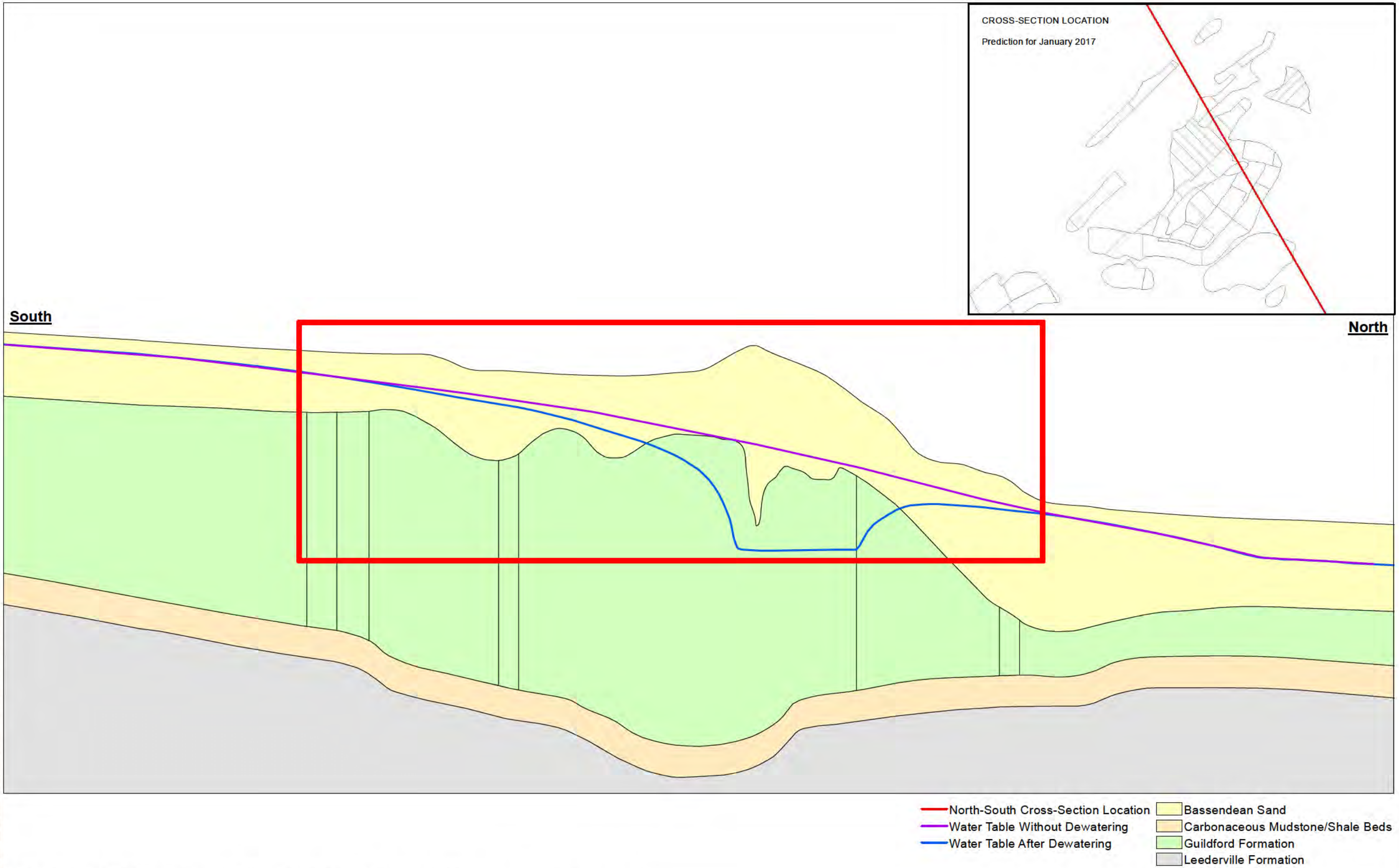
**PREDICTED DRAWDOWN – PLAN VIEW SNAPSHOT JANUARY 2017**

URS

File No: 42908187-GW-004.mxd | Drawn: GM | Approved: IB | Date: 07-JUL-13

Figure: 4.5

Rev. A | A3




Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



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WONNERUP PROJECT - ADDENDUM FOR RE-MODELLING OF MINING PLANS

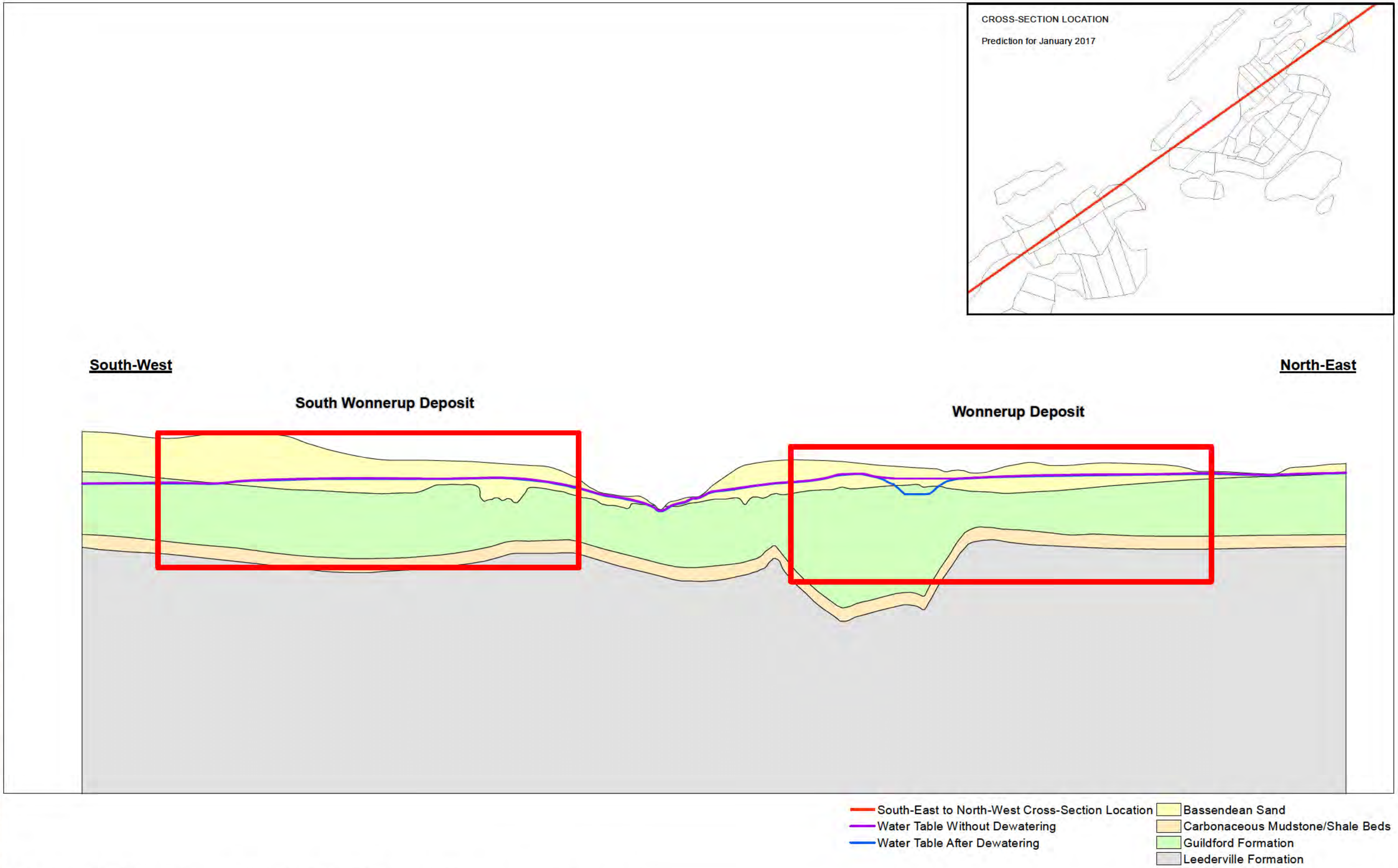
**PREDICTED DRAWDOWN - NORTH-SOUTH CROSS-SECTION SNAPSHOT JANUARY 2017**

URS

File No: 42908187-GW-005.mxd | Drawn: RNM | Approved: GM | Date: 07-JUL-13

Figure: 4.6

Rev. A | A3




Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

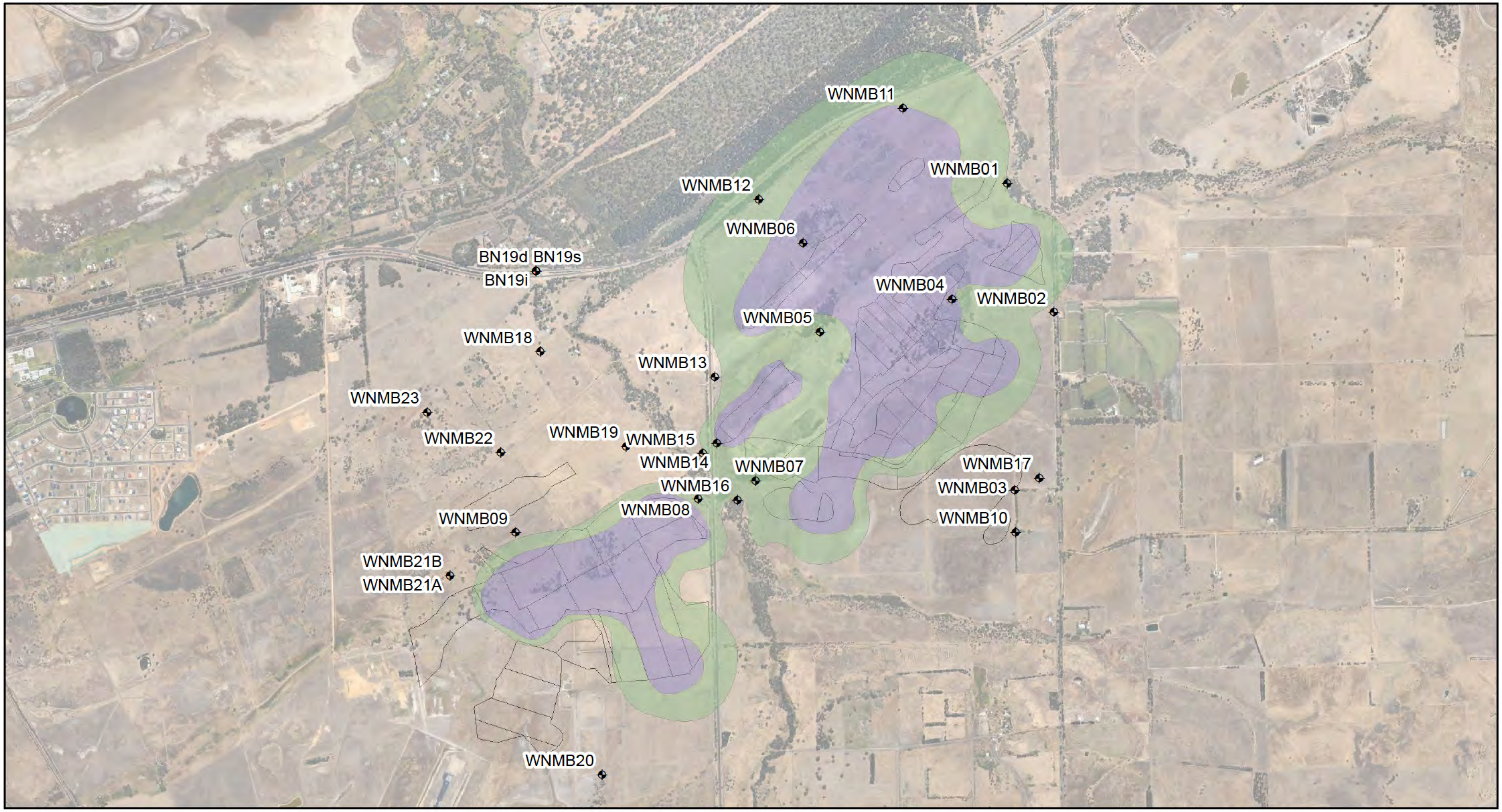
WONNERUP PROJECT - ADDENDUM FOR RE-MODELLING OF MINING PLANS

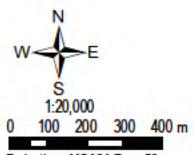
**PREDICTED DRAWDOWN - SOUTH-WEST/NORTH-EAST CROSS-SECTION SNAPSHOT JANUARY 2017**

URS

File No: 42908187-GW-017.mxd | Drawn: RNM | Approved: GM | Date: 07-JUL-13

Figure: 4.7 | Rev. A | A3




Projection: MGA94 Zone 50

**Legend**

- Pit Outline
- Monitoring Bores

**Predicted Drawdown Footprints**

- Predicted 0.1 m Footprint
- Predicted 0.5 m Footprint

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012



CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

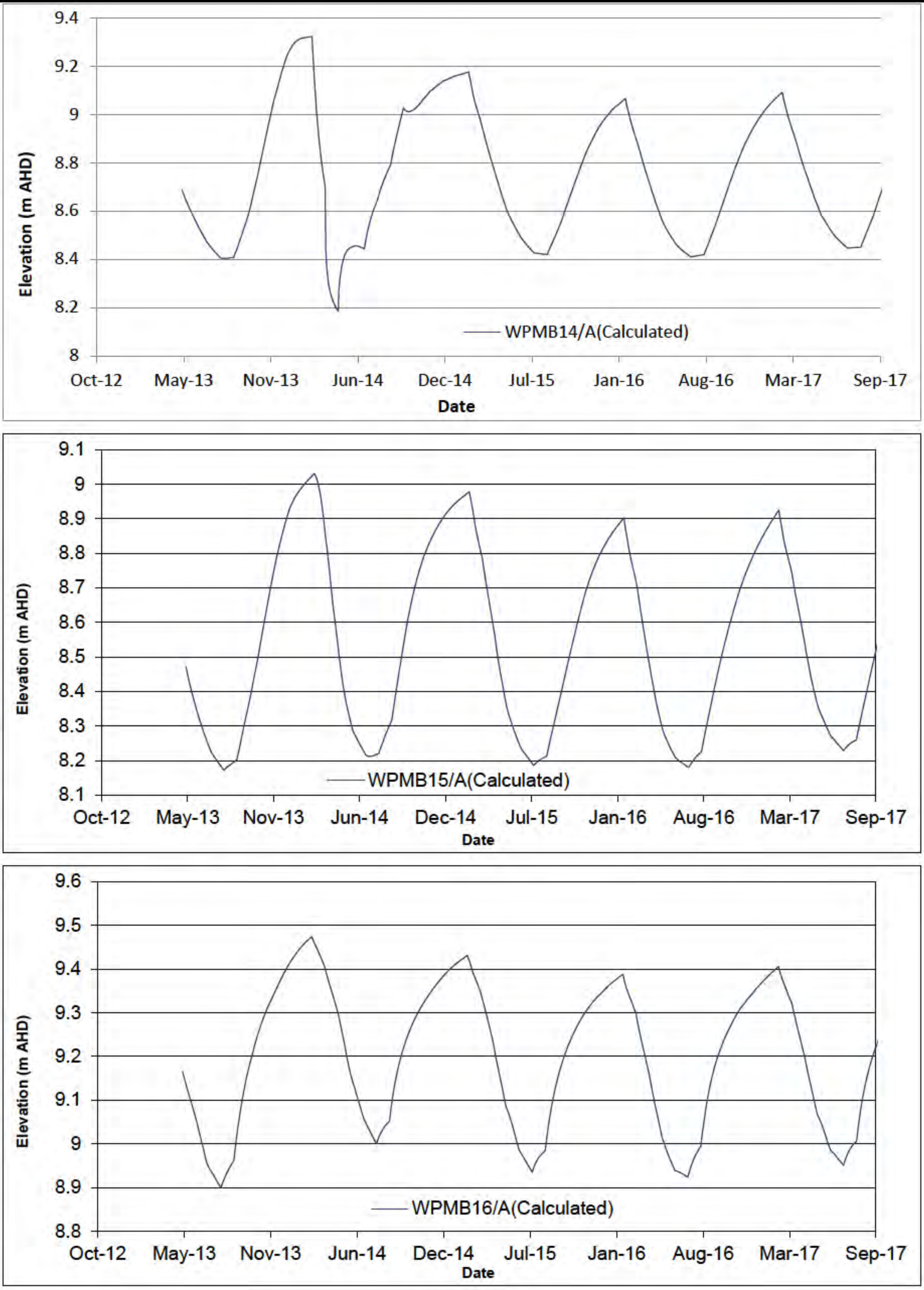
**PREDICTED MAXIMUM DRAWDOWN DISTRIBUTION**

URS

File No: 42908187-GW-013.mxd | Drawn: GM | Approved: IB | Date: 07-JUL-13

Figure: 4.8

Rev. A | A3




Source: URS



CRISTAL MINING AUSTRALIA LIMITED

Wonnerup and Wonnerup South Projects – Addendum for Concurrent Mining Plans

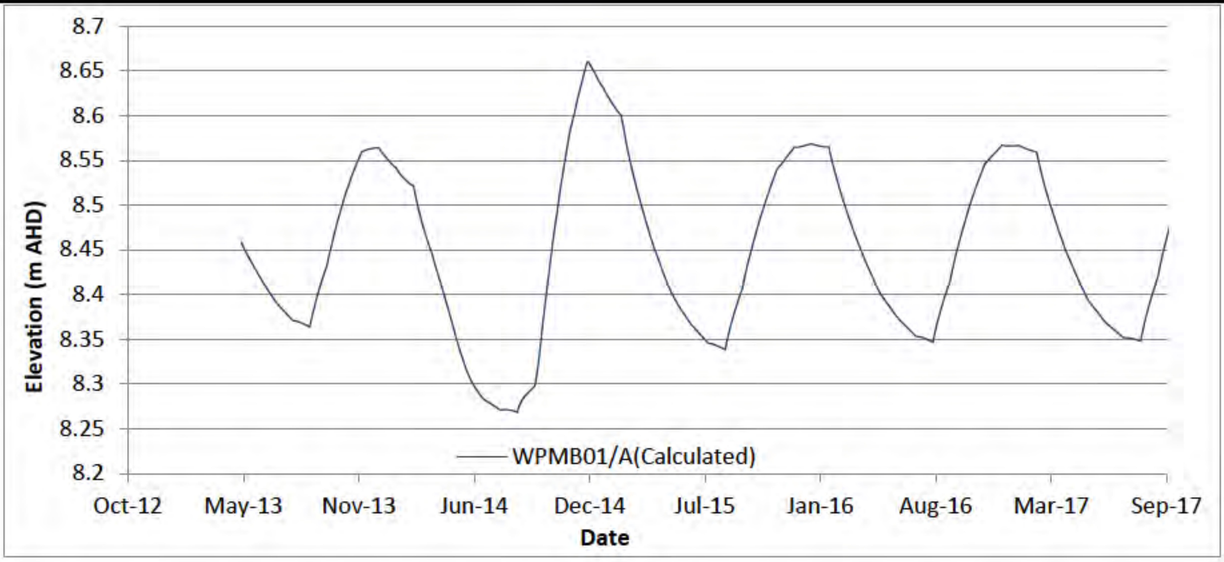
**PREDICTIVE HYDROGRAPHS WPMB14, WPMB15 AND WPMB16**

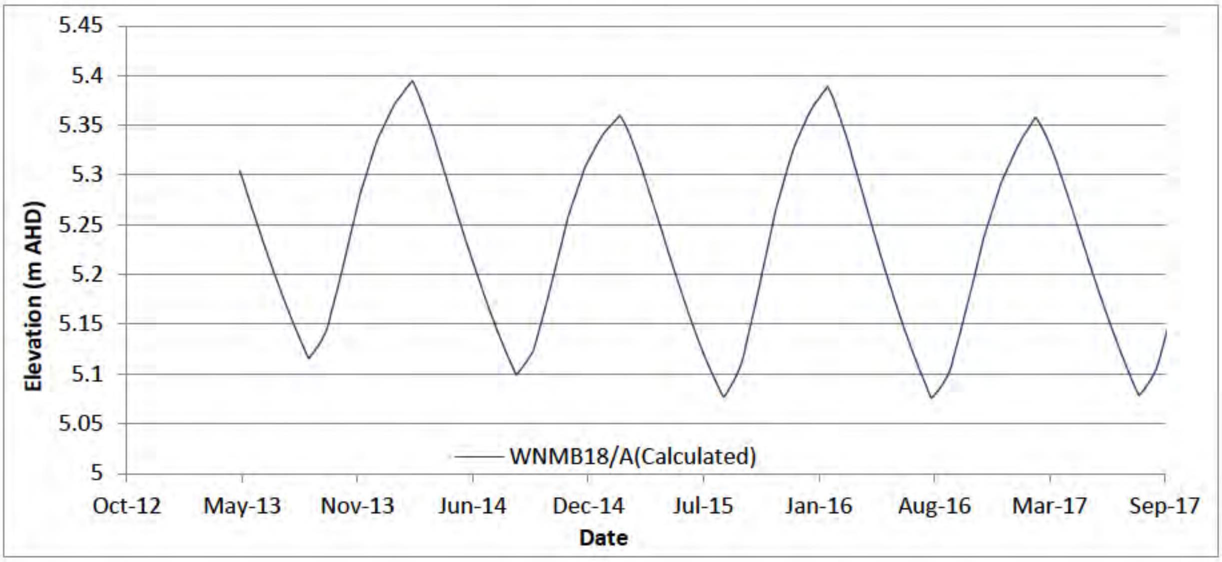
URS

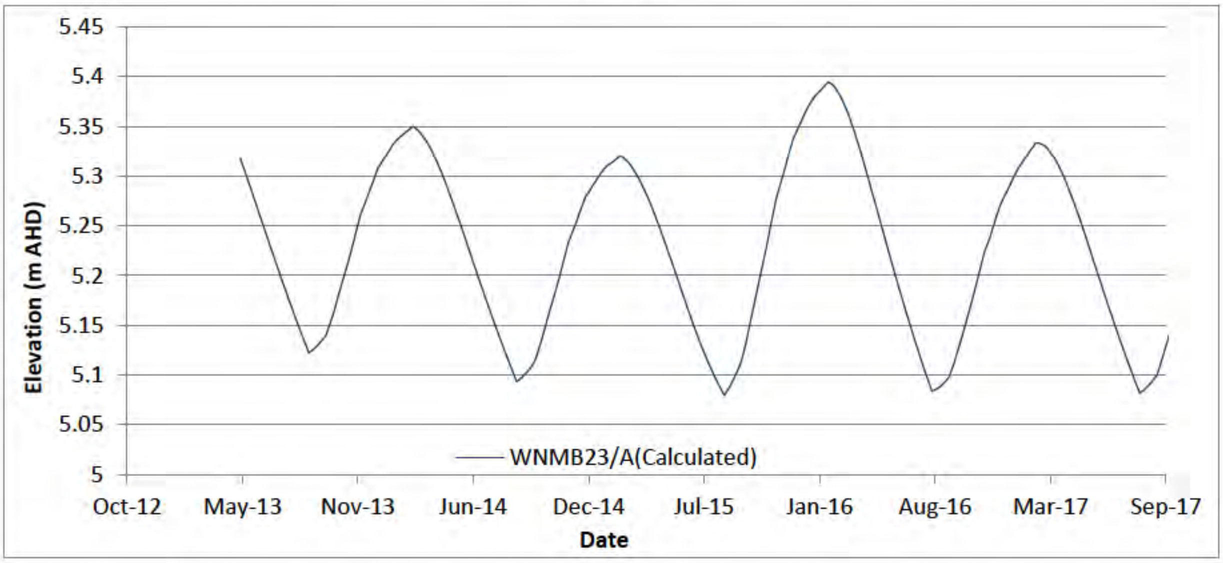
CRISTAL MINING AUSTRALIA LIMITED

File No: \Calibration Figures_H | Drawn: GM | Approved: B | Date: 05-07-2013

Figure: 4-9 | Rev. A | A4




Source: URS



CRISTAL MINING AUSTRALIA LIMITED

Wonnerup and Wonnerup South Projects – Addendum for Concurrent Mining Plans

**PREDICTIVE HYDROGRAPHS WPMB01, WNMB18 AND WNMB23**

URS

**CRISTAL MINING AUSTRALIA LIMITED**

Figure: 4-10

File No: \Calibration Figures_H | Drawn: GM | Approved: B | Date: 05-07-2013 | Rev. A | A4


Legend

Pit Outline

**Drawdown Contours (m)**

- -0.3
- -0.2
- -0.1

Positive value means drawdown
Negative value means mounding

N
W E
S
1:18,408
0 100 200 300 400 m
Projection: MGA94 Zone 50

Source: Based on information provided by and with the permission of the Western Australian Land Information Authority trading as Landgate (2010)., Landgate Imagery February 2012





CRISTAL MINING AUSTRALIA LIMITED

WONNERUP AND WONNERUP SOUTH PROJECTS – ADDENDUM FOR CONCURRENT MINING PLANS

**PREDICTED RESIDUAL DRAWDOWN SIX MONTHS AFTER MINING**

URS

File No: 42908187-GW-014.mxd | Drawn: GM | Approved: IB | Date: 07-JUL-13

Figure: 4.11 | Rev. A | A3

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