Enclosure 1:
Revised Groundwater Assessment

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HERITAGE COMPUTING REPORT

CALGA SAND QUARRY SOUTHERN EXTENSION
GROUNDWATER MODELLING

FOR

ROCLA MATERIALS PTY LTD

By

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Heritage Computing Pty Ltd

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A1 INTRODUCTION

Heritage Computing Pty Ltd (HCPL) has been engaged by R.W. Corkery & Co. Pty Limited (Corkery) on behalf of Rocla Materials Pty Limited (Rocla) to undertake additional groundwater modelling as a supplement to the Preferred Project Report (PPR) issued in November 2012 for the proposed Calga Sand Quarry Southern Extension Project (the Project). The modelling supplements earlier modelling undertaken by Golder Associates (2009) and the predicted groundwater-related impacts supplement the groundwater assessment for the Project conducted by GeoTerra Pty Ltd (2009).

The Project Site is located approximately 11 kilometres (km) west of Gosford in New South Wales (NSW), on the Somersby Plateau on the western side of Peats Ridge Road about 1 km north-west of the Calga Interchange of the F3 motorway (**Figure 1**). Rocla proposes to extend its existing sand extraction and processing operations on Lot 2, DP 229889 at Calga (Calga Sand Quarry) to the south onto Lots 1 and 2, DP 805358 (Southern Extension) (**Figure 2**).

A1.1 SCOPE OF WORK

Kalf and Associates Pty Ltd (2013) completed in March 2013 a review of the groundwater assessment in the Environmental Assessment of 2009 for the Department of Planning and Infrastructure. This review concluded:

> *"The modelling work available at present for the existing and proposed extensions to the Calga Quarry is considered to be incomplete and therefore inadequate to fully assess the cumulative drawdown impact for the existing and proposed Stage 4 and 5 mine extensions."*

The major issues raised in the review which led to this conclusion are:

1. Modelling was limited to steady state for calibration, prediction, and recovery;
2. No transient calibration of readily available groundwater hydrographs was attempted;
3. No simulation of progressive extraction;
4. No justification for the rainfall recharge rates in two zones;
5. No cause-and-effect analysis of groundwater hydrographs using the rainfall residual mass technique to isolate climatic and extraction responses;
6. No drawdown map was provided for the effect of the existing extraction operation;
7. Additional graphics would have been useful - e.g. north-south and east-west cross sections of potentiometric heads or pressure heads before extraction, at end of extraction, and after recovery; and
8. Unrealistic recharge rates for the sensitivity case.

The Kalf review concluded that the "hydrogeological description is reasonable". This means that the bulk of the GeoTerra (2009) report is satisfactory, but the modelling component should be supplemented.

Also, Issue 5 above has been addressed fully by the report compiled by Dundon Consulting Pty Ltd on 26 March 2013: "*Calga Sand Quarry - 2012 Annual Independent Groundwater Audit*".

Given the limited scope defined by Kalf (2013), this report is a standalone document that focuses on enhanced modelling without replication of the hydrogeological matters and the data analysis in the GeoTerra (2009) and Dundon (2013) reports. However, a summary of those reports follows.

A1.2 GEOTERRA (2009) REPORT

The GeoTerra (2009) report notes that the Project Site is located within Zone 7 of the Lower Mangrove and Popran Creeks Groundwater Source, and is managed under the Water Sharing Plan for the Kulnura Mangrove Mountain Groundwater Sources (the Plan). The Plan commenced on 1 July 2004 and was amended in August 2011. It is due for extension or replacement in July 2014, at which time it is likely to be merged with the Alstonville Plateau Water Sharing Plan and the Dorrigo Basalt Groundwater Source into the North Coast Fractured and Porous Rock Groundwater Sharing Plan. The Plan includes rules for protecting the environment, extractions, managing licence holders' water accounts and water trading.

Since completion of the groundwater assessment, the NSW Aquifer Interference Policy was issued in September 2012. Hence, no comment on minimal harm considerations appeared in the GeoTerra (2009) report.

The main findings of the GeoTerra groundwater assessment were:

- Two first order creeks, present in the upper part of the Project Site, named Creek A and Creek B, coalesce to form Creek C which flows into Cabbage Tree Creek (**Figure 3**). Cabbage Tree Creek flows into Popran Creek with ultimate discharge to the Hawkesbury River about 14 km downstream.
- A number of pools along the creeks appear to be fed by baseflow seepage.
- Hawkesbury Sandstone is the primary groundwater source in the vicinity of Calga. The groundwater system consists essentially of alternating sheet sandstone and massive sandstone facies. Sheet sandstone layers act as semi-confined aquifers at depth or as unconfined aquifers at elevation or adjacent to cliff faces, while the massive sandstone layers act as aquitards.
- There are 45 licensed bores within a 3 km radius of the Project Site. Bore depths range from 28 m to 120 m below ground level.
- The Water Sharing Plan does not identify any high priority groundwater dependent ecosystems (GDEs) on the Project Site.
- Three GDEs are mapped as occurring in the lower reaches of Cabbage Tree Creek (600 m due west of the south-western boundary of the Project Site) and are likely to be reliant on water flowing through Cabbage Tree Creek:

  - MU1 Coastal Wet Gully Forest;
  - MU37 Swamp Mahogany – Paperbark Swamp Forest; and
  - MU40 Swamp Oak – Rushland Forest.
- Small patches of Gahnia-Banksia Swamp (E103) on the Project Site are likely to be perched obligate GDEs (totally dependent on groundwater).
- Sandstone Hanging Swamps (E54) along Creek B are likely to be perched obligate GDEs (totally dependent on groundwater).
- Sandstone Ranges Gully Rainforest (E2) in the drainage line of Creek C is a facultative GDE that is likely to be partially dependent on groundwater discharge at dry times.
- Steady state modelling suggests a drawdown cone extending more to the east than the west, confined by Cabbage Tree Creek to the west, Kelly Creek to the south and Mooney Mooney Creek to the east.
- Less than 1 m drawdown is anticipated in private bores CP1 to CP7; and up to 5 m drawdown could occur at CP8 and GW102729 following extraction of Stage 4 and Stage 5.
- Steady state modelling suggests pit inflows in the order of 30 ML/a for approved Stage 3 extraction, 140 ML/a at the end of Stage 4, and 160 ML/a at the end of Stage 5.
- Steady state modelling suggests baseflow to Cabbage Tree Creek of about 7 L/s (0.6 ML/day) and about 4.5 L/s (0.4 ML/day) to Creeks A, B and C, with maximum reductions during extraction of about 7% (0.04 ML/day) at Cabbage Tree Creek and about 15% (0.06 ML/day) at Creeks A, B and C.
- GDEs associated with Cabbage Tree Creek (MU1, MU37, MU40) are unlikely to be significantly affected by sand extraction, as flow in the creek would have only a minor reduction.
- A small area (0.4 ha) of obligate GDE E103 would be removed during Stage 4 extraction.
- Obligate GDE E54 along Creek B could be affected by predicted watertable drawdowns of about 10 m.
- Facultative GDE E2 along Creek C could be affected by predicted watertable drawdowns of 1-10 m.

A1.3 DUNDON (2013) REPORT

The 2012 Annual Independent Groundwater Audit conducted by Dundon Consulting Pty Ltd (2013) includes a description of the groundwater monitoring network, an overview of climate data, presentation of groundwater hydrographs and water quality time series, and cause-and-effect analysis of groundwater level variations.

The Groundwater Monitoring Program is detailed within the Site Water Management Plan, completed in February 2006 and accepted by the Director-General in March 2006. Monitoring is done by Carbon Based Environmental, who prepare a monthly report for uploading on the Calga Quarry website.

The 25 bores in the monitoring network are measured for water level and water quality. The locations of the monitoring bores are shown on **Figure 4**. The network consists of the following bores:

- Neighbours' Water Supply Bores - CP1 to CP8.
- Existing Quarry and Surrounds - CQ1 to CQ13.
- Proposed Southern Extension - MW7 to MW10, MW13, MW16.

Site CQ11 is screened at two depths:

- CG11S - from 32 to 38 m depth (182-188 mAHD).
- CG11D - from 59 to 65 m depth (155-161 mAHD).

The main findings of the groundwater audit were:

- Groundwater levels and groundwater quality have considerable variation.
- The observed variations are due almost entirely to natural conditions.
- The long-term average rainfall at the Peats Ridge climate station is 1257 mm.
- The rainfall residual mass curve for 2006-2012 shows that wetter conditions prevailed from mid-2007 to early-2008 and mid-2011 to early-2012, with drier conditions during all of 2009 and 2010, and also during the second half of 2012.
- There is a strong correlation between the residual mass curve and the groundwater hydrographs.
- No extraction effect is evident prior to 2011.
- Three bores to the north of the quarry (adjacent to cell 3/6) show evidence of an extraction effect from early-2011 to mid-2012 (**Figure 5**):
    - CQ4 - 3.5 m drawdown;
    - CQ11S - 1.6 m drawdown;
    - CQ11D - 1.5 m drawdown;
    - CP3 - 0.7 m drawdown.
- The observed extraction-induced drawdown was limited to a distance of no more than 100 m from the quarry site boundary.
- Recovery of about 1 to 1.5 m occurred at the three affected sites in the second half of 2012 following completion of cell 3/6 extraction in October 2011.
- No bores to the south of the quarry site show an extraction effect.
- No private production bores show an extraction effect (other than CP3).
- No adverse water quality impacts are apparent at any monitoring bore.

A2 GROUNDWATER SIMULATION MODEL

A2.1 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines announced in June 2012, sponsored by the National Water Commission (Barnett *et al.*, 2012). These guidelines build on the 2001 MDBC Groundwater Flow Modelling Guideline (MDBC, 2001), with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The 2012 guide has replaced the model complexity classification in the 2001 guide by a "model confidence level". The Calga model may be classified as Class 2 (effectively “medium confidence”), which is an appropriate level for this context. Under the 2001 modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. The guide (MDBC, 2001) describes this model type as follows:

> *Impact Assessment Model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.*

Numerical modelling has been undertaken using the Groundwater Vistas (Version 6.22) software interface (Environmental Simulations Inc [ESI], 2011) in conjunction with MODFLOW-SURFACT (Version 4) distributed commercially by Hydrogeologic, Inc. (Virginia, USA). MODFLOW-SURFACT is an advanced version of the popular MODFLOW code developed by the United States Geological Survey (McDonald and Harbaugh, 1988). MODFLOW is the most widely used code for groundwater modelling and is considered an industry standard.

MODFLOW-SURFACT is a three-dimensional modelling code that is able to simulate variably saturated flow and can handle desaturation and resaturation of multiple aquifers without the “dry cell” problems of Standard-MODFLOW. This is pertinent to the dewatering of layers adjacent to open pit mines. Standard-MODFLOW can handle this to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by “dry cells”.

The model complexity/confidence level is adequate for simulation of contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the Project.

A2.2 PRIOR MODELLING

For the Environmental Assessment, a numerical groundwater model was developed using FEFLOW software by Golder Associates (2009). The model extent of about 7 km (east-west) by about 10 km (north-south) was defined primarily by boundaries along Popran Creek and Mooney Mooney Creek. Two model layers were assigned to represent weathered and fresh sandstone respectively, with a uniform thickness of 20 m for the upper layer. The assigned horizontal hydraulic conductivities were approximately 0.1 m/day for layer 1 and 0.01 m/day for layer 2, with vertical hydraulic conductivities taken to be an order of magnitude lower.

Calibration was limited to steady state matching against water levels at 18 of the bores in the monitoring network, with good calibration performance statistics of 1.4 %RMS[1] and 2.7 mRMS. Rainfall recharge was calibrated as 15% of mean annual rainfall regionally with pockets of 6% and 30% close to the Project Site. The model did not include evapotranspiration. Prediction of extraction impacts was undertaken with a series of steady state simulations at the ends of Stage 3, Stage 4 and Stage 5, and post-closure equilibrium conditions. Transient simulations for progressive quarrying were not undertaken.

An earlier MODFLOW-SURFACT regional groundwater model was developed by Alkhatib and Merrick (2006) for the entire Kulnura - Mangrove Mountain area. The model extent was about 40 km (east-west) by about 59 km (north-south). The model grid was divided into 118 rows and 80 columns with a uniform cell size of 500 m by 500 m. A total of 30 model layers was applied to extend the stratigraphy down to sea level and to give good resolution of cliff seepage and stream baseflow across a wide range of elevations. The layers comprised alternating sheet sandstone and massive sandstone facies of the Hawkesbury Sandstone formation, with the Narrabeen Group as the basal layer. Alluvial and dune sediments were included near the coast. Calibration was performed initially for steady state conditions for both groundwater levels and baseflow estimates for seven streams. Transient calibration was conducted against groundwater levels and vertical head differences at 20 government observation bores from January 1985 to October 2003 with a monthly stress period. Groundwater discharge was found to be apportioned as 39 % to cliff seepage faces, 19 % as evapotranspiration, 29 % as baseflow to creeks and 12 % outflow to Hawkesbury River, Tuggerah Lake and Tasman Sea, and 1.6% as groundwater extraction from private bores.

A2.3 CONCEPTUAL MODEL

The regional conceptual model developed by Alkhatib and Merrick (2006) is illustrated in **Figure 6**. The dominant recharge processes would be the infiltration from rainfall and irrigation while bore abstraction, evapotranspiration, seepage face flow, spring outflow and baseflow would be the dominant discharge processes in the aquifer system.

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[1] Root Mean Square

Consistent with the relevant Water Sharing Plan, the main groundwater system occurring within the Project Site and surrounds is the Hawkesbury Sandstone, a relatively flat-lying medium- to coarse-grained sandstone up to 250 m thick. The sheet sandstone strata are more productive than the massive sandstone strata. The groundwater system has both primary porosity (matrix pores) and secondary porosity (fractures). Beneath the Hawkesbury Sandstone are less permeable sediments of the Narrabeen Group consisting of alternating sequences of sandstones and siltstones.

Where Hawkesbury Sandstone outcrops, it has weathered to a friable cover of 20-30 m thickness. This zone would have enhanced permeability relative to the fresher rock underneath.

A local conceptual model is illustrated in **Figure 7** before extraction and during extraction, approximately at northing 6301000. The dominant recharge process would be the infiltration from rainfall and runoff. The dominant natural discharge processes would be evapotranspiration, seepage face flow and baseflow to the local creeks. During extraction of the friable sandstone, groundwater would also discharge to open cut pits. Some reduction in creek baseflow would be expected during extraction.

Groundwater levels are sustained by rainfall infiltration but are controlled by topography, geology and surface water levels in local drainages. Local groundwater would tend to mound beneath hills, with ultimate discharge to distant drainages (via subsurface throughflow). The watertable is generally 10-30 m below ground level but near drainage lines and cliff faces it could be less than 5 m at which depth loss by evapotranspiration through sandstone outcrops and vegetation is likely to occur. .

During extraction, the potentiometric heads[2] in the Hawkesbury Sandstone groundwater system would be reduced in the vicinity of the quarry, but the watertable would tend to rise beneath the spoil infills as extraction progresses.

Layering within the Hawkesbury Sandstone would interrupt the dominant downwards groundwater flow and encourage lateral flow towards gullies and cliff faces.

A2.4 MODEL EXTENT

The extent of the regional numerical groundwater model has been selected to allow investigation of cumulative extraction effects (if necessary) from other sand quarries in the region, and the regional controls exerted by the Hawkesbury River and the ocean. The model domain and the regional topography are shown in **Figure 8**. The modelled area extends between MGA eastings 319000 and 359000 and MGA northings 6283500 and 6313500. The area of coverage is 40 km east-west by 30 km north-south, a total of 1200 km^2.

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[2] The potentiometric head is the level to which water would rise in a bore that is drilled into an aquifer that is confined or under pressure. The watertable is the potentiometric surface for an unconfined aquifer.

A2.5 MODEL GEOMETRY

The model domain has been discretised into 122,960 cells arranged into 10 layers comprising 106 rows and 116 columns. While the quarrying occurs only in the two top layers, the extra layers permit good resolution of streams and baseflows across a wide range of elevations, as indicated in **Figure 7**. The dimensions of the model cells vary from 50 m at the quarry to 500 m towards the model edges (**Figure 9**). A maximum aspect ratio[3] of 1.5 has been maintained in generating the variable grid.

The model layers are divided into two main parts: Hawkesbury Sandstone and Narrabeen Group (Figure 7). The Hawkesbury Sandstone is represented by model layers 1 to 7 while the Narrabeen Group occupies model layers 8 to 10 with a total thickness of about 120 m. In the coastal area, layer 8 is the Gosford Formation and layer 9 holds alluvium and coastal sands, with thickness ranging from a few metres to more than 30 m.

The top two layers (1 and 2) comprise the friable sandstone (soft and medium) that is to be quarried, with typical thickness from 20 to 30 m. Hard sandstone commences in layer 3. More permeable Hawkesbury Sandstone strata are defined in layers 3, 5 and 7. Less permeable strata (massive sandstone or shale/siltstone/clay) occupy layers 4 and 6.

Layer 1 has been given a uniform thickness of 10 m. The thickness of layer 2 is generally 10 m regionally but varies from 10 to 20 m across the Project Site to conform with the thickness of friable sandstone determined during exploration drilling. The floor elevations of layers 1 and 2 are defined by subtracting the layer thickness from ground surface. At the Project Site, horizontal layer surfaces are applied below an elevation of 120 mAHD. Representative model cross-sections are displayed in **Figure 10** for easting 334200 (model column 45) and northing 6300900 (model row 50) through the Project Site in each direction.

Where Hawkesbury sandstone layers pinch out or are eroded, the layers must continue laterally in a MODFLOW model and therefore have a notional thickness but are given properties associated with the underlying lithology.

The hydraulic properties initially were those found by calibration of the regional Kulnura model (Alkhatib and Merrick, 2006), but were refined during model calibration of Calga datasets.

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[3] Aspect ratio is the ratio of the widths of adjoining model cells. A small ratio is required for faithful representation of lateral hydraulic gradients.

A2.6 MODEL STRESSES AND BOUNDARY CONDITIONS

Model cells to the south of Hawkesbury River are deactivated in the model, as are cells beyond the western catchment boundary. Cells overlying the major waterbodies are also deactivated (**Figure 11**). The Hawkesbury River, its tributaries, Brisbane Water and the sea are represented as constant heads in the basal layer (layer 10) with average elevation 0.0 mAHD.

The northerly reaches of the main tributaries, and low-order perennial and ephemeral streams, are established as "river" cells in model layers 8 and 9 using the MODFLOW RIV package, with occasional representation in layers 1 to 7 (**Figure 11**). The RIV package was defined in the model with stream stage equal to the streambed and to allow only water to move in one direction from the groundwater system into the stream. This has been done for minor streams so that these cells will accept baseflow if the watertable rises above the bed elevation of the stream, but they will never provide a source of water for the groundwater system. The conductances vary from 4 to 80,000 square metres per day (m^2/day), with median 2,000 m^2/day. The hydraulic conductivity of the stream bed varies from 0.05 to 1 m/day for stream widths from 2 to 100 m.

Creeks represented by river cells are allocated distinct reach numbers (**Figure 12a**) to permit separate accounting of baseflows during model simulations. The most important reaches for this assessment are Reach 3 (Creeks A, B and C) and Reach 5 (Cabbage Tree Creek) (**Figure 12b**).

"Drain" cells using the MODFLOW DRN package are used also to represent extraction in layers 1 and 2. Invert levels are set at the base of the friable sandstone. The drain conductance value is set at 1,000 m^2/day to eliminate any resistance to flow.

Rainfall recharge has been imposed as a percentage of actual rainfall (for transient calibration) or long-term average rainfall (for prediction simulations) across eight zones associated with the three major lithologies (**Figure 13**):

1. Alluvium;
2. Hawkesbury Sandstone; and
3. Narrabeen Group;

The recharge rates determined during the regional Kulnura model calibration (Alkhatib and Merrick, 2006) were used as initial estimates in the Project model. They range from 5% to 25%.

Evapotranspiration has been applied uniformly using MODFLOW's linear function, with a maximum rate of about 60 millimetres per annum (mm/a) and an extinction depth of 3 m. The same parameters were applied in the regional Kulnura model (Alkhatib and Merrick, 2006).

A2.7 MODEL SIMULATIONS

Four distinct operational models were developed, as follows:

A. *Steady state model*

   Initial calibration of hydraulic conductivities in order to replicate the regional hydraulic gradients, using data unaffected by extraction.

B. *Transient calibration model*

   Thorough calibration of groundwater system properties against hydrographic responses for dynamic monthly rainfall recharge, for Project and other private monitoring bores and NOW observation bores.

C. *Transient prediction simulation (for single mine and cumulative effects)*

   Simulation of the annual progression of open cut extraction, allowing for time-varying material properties (TMP) for mine waste rock (hydraulic conductivity and specific yield), with prediction of potential impacts of Project development on the groundwater regime (particularly stream-aquifer interaction and groundwater dependent ecosystems) and prediction of mine inflow rates. Two versions of the model were developed:

   1) Calga Sand Quarry Project operating alone; and
   2) Calga Sand Quarry Project and other quarries operating at the same time.

D. *Transient recovery simulation*

   Simulation of equilibrium groundwater levels for the final landform and pit voids.

The transient prediction simulation models (Model C) using the TMP facility in MODFLOW-SURFACT allow hydraulic and storage subsurface properties to be updated each stress period, whenever and wherever necessary, in transient groundwater flow simulations.[4]

Table 1 and **Table 2** summarise the stress period setup for Models B, C and D and the sequencing of open cut operations, backfilling, and duration of final voids. The transient calibration model (Model B) ran from January 2007 to December 2012 in monthly steps, simulating extraction stages 3/1, 3/2 and 3/6 (**Table 1**). The prediction model (Model C) ran for 25 years from 2013 to 2037 in annual steps for extraction stages 3/3a to 5/3 (**Table 2**). A recovery simulation was conducted for 200 years, with four final voids (**Table 2**).

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[4] The alternative approach in common practice uses a set of sequential time-slices and numerous stop-start linked simulations. TMP is a routine in MODFLOW-SURFACT that allows changes in hydraulic properties as simulation progresses at particular time steps - in this case for simulating waste rock backfilling.

Table 1. Stress Period Definition and Sequencing of Extraction Activities for the Calibration Period

	Stress Period	Period Length (days)	Start	End	Stage 3
Calibration	SP1	31	1/01/2007	31/01/2007	3/1
	SP2	28	1/02/2007	28/02/2007	3/1
	SP3	31	1/03/2007	31/03/2007	3/1
	SP4	30	1/04/2007	30/04/2007	3/1
	SP5	31	1/05/2007	31/05/2007	3/1
	SP6	30	1/06/2007	30/06/2007	3/1
	SP7	31	1/07/2007	31/07/2007	3/1
	SP8	31	1/08/2007	31/08/2007	3/1
	SP9	30	1/09/2007	30/09/2007	3/1
	SP10	31	1/10/2007	31/10/2007	3/1
	SP11	30	1/11/2007	30/11/2007	3/1
	SP12	31	1/12/2007	31/12/2007	3/1
	SP13	31	1/01/2008	31/01/2008	3/1
	SP14	29	1/02/2008	29/02/2008	3/1
	SP15	31	1/03/2008	31/03/2008	3/1
	SP16	30	1/04/2008	30/04/2008	3/1
	SP17	31	1/05/2008	31/05/2008	3/1
	SP18	30	1/06/2008	30/06/2008	3/1
	SP19	31	1/07/2008	31/07/2008	3/1
	SP20	31	1/08/2008	31/08/2008	3/2
	SP21	30	1/09/2008	30/09/2008	3/2
	SP22	31	1/10/2008	31/10/2008	3/2
	SP23	30	1/11/2008	30/11/2008	3/2
	SP24	31	1/12/2008	31/12/2008	3/2
	SP25	31	1/01/2009	31/01/2009	3/2
	SP26	28	1/02/2009	28/02/2009	3/2
	SP27	31	1/03/2009	31/03/2009	3/2
	SP28	30	1/04/2009	30/04/2009	3/2
	SP29	31	1/05/2009	31/05/2009	3/2
	SP30	30	1/06/2009	30/06/2009	3/2
	SP31	31	1/07/2009	31/07/2009	3/2
	SP32	31	1/08/2009	31/08/2009	3/2
	SP33	30	1/09/2009	30/09/2009	3/2
	SP34	31	1/10/2009	31/10/2009	3/2
	SP35	30	1/11/2009	30/11/2009	3/2
	SP36	31	1/12/2009	31/12/2009	3/2
Calibration	SP37	31	1/01/2010	31/01/2010	3/2
	SP38	28	1/02/2010	28/02/2010	3/2
	SP39	31	1/03/2010	31/03/2010	3/2
	SP40	30	1/04/2010	30/04/2010	3/2
	SP41	31	1/05/2010	31/05/2010	3/2
	SP42	30	1/06/2010	30/06/2010	3/2
	SP43	31	1/07/2010	31/07/2010	3/2
	SP44	31	1/08/2010	31/08/2010	3/2
	SP45	30	1/09/2010	30/09/2010	3/2
	SP46	31	1/10/2010	31/10/2010	3/2
	SP47	30	1/11/2010	30/11/2010	3/2
	SP48	31	1/12/2010	31/12/2010	3/2
	SP49	31	1/01/2011	31/01/2011	3/2
	SP50	28	1/02/2011	28/02/2011	3/2
	SP51	31	1/03/2011	31/03/2011	3/2
	SP52	30	1/04/2011	30/04/2011	3/2 & 3/6
	SP53	31	1/05/2011	31/05/2011	3/2 & 3/6
	SP54	30	1/06/2011	30/06/2011	3/2 & 3/6
	SP55	31	1/07/2011	31/07/2011	3/2 & 3/6
	SP56	31	1/08/2011	31/08/2011	3/2 & 3/6
	SP57	30	1/09/2011	30/09/2011	3/2 & 3/6
	SP58	31	1/10/2011	31/10/2011	3/2 & 3/6
	SP59	30	1/11/2011	30/11/2011	3/2
	SP60	31	1/12/2011	31/12/2011	3/2
	SP61	31	1/01/2012	31/01/2012	3/2
	SP62	29	1/02/2012	29/02/2012	3/2
	SP63	31	1/03/2012	31/03/2012	3/2
	SP64	30	1/04/2012	30/04/2012	3/2
	SP65	31	1/05/2012	31/05/2012	3/2
	SP66	30	1/06/2012	30/06/2012	3/2
	SP67	31	1/07/2012	31/07/2012	3/2
	SP68	31	1/08/2012	31/08/2012	3/2
	SP69	30	1/09/2012	30/09/2012	3/2
	SP70	31	1/10/2012	31/10/2012	3/2
	SP71	30	1/11/2012	30/11/2012	3/2
	SP72	31	1/12/2012	31/12/2012	3/2
		2192 days			

Table 2. Stress Period Definition and Sequencing of Extraction Activities for the Prediction Period

	Stress Period	Period Length (days)	Year	Start	End	Stage 3	Stage 4	Stage 5
Prediction	SP1	365	Year 1	1-Jan-13	31-Dec-13	3/3a	Quarter of 4/1	
	SP2	365	Year 2	1-Jan-14	31-Dec-14	3/3a, 3/4	Quarter of 4/1	
	SP3	365	Year 3	1-Jan-15	31-Dec-15	3/4	4/1, 4/2	
	SP4	366	Year 4	1-Jan-16	31-Dec-16	3/4, 3/5	4/2, 4/3	
	SP5	365	Year 5	1-Jan-17	31-Dec-17	3/5	4/2, 4/3	
	SP6	365	Year 6	1-Jan-18	31-Dec-18	3/5, 3/6, 3/3b	4/2, 4/3, 4/4	
	SP7	365	Year 7	1-Jan-19	31-Dec-19	3/6, 3/3b	4/2, 4/3, 4/4	
	SP8	366	Year 8	1-Jan-20	31-Dec-20		4/5	
	SP9	365	Year 9	1-Jan-21	31-Dec-21		4/5	
	SP10	365	Year 10	1-Jan-22	31-Dec-22		4/5	
	SP11	365	Year 11	1-Jan-23	31-Dec-23		4/5	
	SP12	366	Year 12	1-Jan-24	31-Dec-24		4/6	
	SP13	365	Year 13	1-Jan-25	31-Dec-25		4/6	
	SP14	365	Year 14	1-Jan-26	31-Dec-26		4/6	
	SP15	365	Year 15	1-Jan-27	31-Dec-27		4/6	
	SP16	366	Year 16	1-Jan-28	31-Dec-28		4/7	
	SP17	365	Year 17	1-Jan-29	31-Dec-29		4/7	
	SP18	365	Year 18	1-Jan-30	31-Dec-30		4/7	5/1
	SP19	365	Year 19	1-Jan-31	31-Dec-31		4/7	5/1
	SP20	366	Year 20	1-Jan-32	31-Dec-32		4/8	5/1
	SP21	365	Year 21	1-Jan-33	31-Dec-33		4/8	5/2
	SP22	365	Year 22	1-Jan-34	31-Dec-34		4/8	5/2
	SP23	365	Year 23	1-Jan-35	31-Dec-35			5/3
	SP24	366	Year 24	1-Jan-36	31-Dec-36			5/3
	SP25	365	Year 25	1-Jan-37	31-Dec-37			5/3
RECOVERY						DAMS 7a/b	DAMS 21/22	DAM 20
					mAHD	**180**	**168**	**168**

A2.8 STEADY STATE CALIBRATION

A long term steady state calibration was conducted with Model A by reproducing pre-extraction water levels representative of the Project Site. The objective of Model Variant A was to produce long term average water levels to be used as initial conditions in the transient model calibration run (i.e. Model Variant B).

Since the extraction at stage 3/1 started in March 2006 and the monitoring bore hydrographs at the Project Site showed that there is no extraction effect on groundwater levels until the first quarter of 2011 (Dundon, 2013), measured water levels at January 2007 were selected as representative stable data as this period of time had average climate conditions according to the rainfall residual mass plot (Dundon, 2013). Initial hydraulic property values were guided by field measurements and the transient calibration of the regional Kulnura model (Alkhatib and Merrick, 2006).

Suitable stable head measurements were available at 36 sites consisting of 19 Calga Sand Quarry bores, six private production bores, and 11 Office of Water (NOW) observation bores (**Figure 14**). The simulated watertable contours are shown in **Figure 15**.

The head targets were divided into four groups based on location and ownership (**Table 3**).

Table 3. Steady State Calibration Head Target Sites

Site	Bore Name	Group	No. of Monitoring Bores
Calga North Bores	CQ series	1	13
Calga South Bores	MW series	2	6
Neighbours' Water Supply Bores	CP series	3	6
NOW Bores	GW series	4	11
Total			**36**

The steady state calibration results in **Table 4** show that the residual varies from -5.5 m to +12.4 m, with median +3.0 m.

Table 4. Calibration Performance at 36 Monitoring Bores

Page 1 of 2

Monitoring Bore	Group	Layer	Measured Water Level (m AHD)	Simulated Water Level (m AHD)	Residual (m)
CQ1	1	3	201.2	191.9	9.3
CQ10	1	4	188.0	183.9	4.2
CQ11D	1	1	207.4	206.9	0.5
CQ11S	1	1	208.8	206.7	2.2
CQ12	1	2	193.8	192.7	1.1
CQ13	1	2	205.1	203.0	2.1
CQ3	1	2	170.3	172.5	-2.2
CQ4	1	2	206.2	201.7	4.5
CQ5	1	2	204.9	200.8	4.0
CQ6	1	3	191.7	188.4	3.2
CQ7	1	2	198.2	194.1	4.1
CQ8	1	2	190.9	192.0	-1.1
CQ9	1	3	180.6	175.3	5.4
MW10	2	3	148.3	146.5	1.8

Table 4. Calibration **Performance at 36 Monitoring Bores (Cont'd)**

Page 2 of 2

Monitoring Bore	Group	Layer	Measured Water Level (m AHD)	Simulated Water Level (m AHD)	Residual (m)
MW13	2	2	169.8	169.4	0.4
MW16	2	3	164.6	158.7	5.9
MW7	2	3	192.5	188.3	4.2
MW8	2	2	181.3	177.1	4.3
MW9	2	3	201.5	192.8	8.6
CP3	3	2	205.4	202.2	3.2
CP4	3	2	204.9	202.9	2.0
CP5	3	1	207.1	207.5	-0.4
CP6	3	2	201.8	202.6	-0.8
CP7	3	2	197.1	202.6	-5.5
CP8	3	3	205.9	196.1	9.8
GW075012_1	4	1	242.4	239.3	3.1
GW075012_2	4	4	221.8	214.6	7.2
GW075013_1	4	2	273.5	276.4	-2.9
GW075013_2	4	3	266.0	267.9	-2.0
GW075013_3	4	4	256.7	258.2	-1.5
GW075038_1	4	1	257.5	248.3	9.2
GW075038_2	4	2	243.6	244.1	-0.4
GW080165	4	5	166.0	163.2	2.8
GW080166	4	4	175.5	167.7	7.8
GW080167	4	4	182.6	170.2	12.4
GW080168	4	2	186.1	185.0	1.1

A scattergram of simulated versus measured heads in **Figure 16** demonstrates good agreement across the whole range of measurements.

The overall performance of the steady state calibration is quantified by a number of statistics in **Table 5**. The key statistic is 4.0 %RMS, which is well below the groundwater modelling guideline value of 5-10% (MDBC, 2001; Barnett *et al.*, 2012) for acceptable model calibration.

Table 5. Steady State Calibration Performance

Calibration Statistics	Value
Number of Data (n)	36
Root Mean Square (RMS) (m)	5.0
Scaled Root Mean Square (SRMS) (%)	4.0
Average residual (m)	3.0
Absolute average residual (m)	3.9

A2.9 TRANSIENT CALIBRATION

The transient calibration was conducted on Model B for the time period January 2007 to December 2012 for 72 monthly stress periods. The starting date is shortly after the commencement of extraction stage 3/1 at the Calga Sand Quarry in March 2006. Initial hydraulic property values in the Project model were guided by steady state calibration results.

The transient calibration has enabled better estimation of storage properties required for transient prediction (Model C). Initial heads were based on the heads generated by the long term steady state model (Model A) as shown in **Figure 15**.

The monitoring bores associated with the Calga Sand Quarry, neighbouring private water supply bores and NOW bores have allowed the transient calibration to replicate the hydrographs in each area and thereby enhance the reliability of impact assessment. The Project model has included transient calibration against all NOW observation bores located inside the model domain (i.e. GW075012-1, GW075012-2, GW075013-1, GW075013-2, GW075013-3, GW075038-1, GW075038-2, GW080165, GW080166, GW080167 and GW080168) (**Figure 14**).

Table 6 lists the number of monitoring sites and the number of head targets which were used to calibrate the transient model. In all, 2333 target heads were established for 36 sites. Calibration was conducted manually. A separate verification process was not conducted as the full length of mine monitoring records was required for calibration of hydrographs exhibiting extraction effects.

Table 6. Transient Calibration Head Target Sites

Site	Bore Name	Group	No. of Monitoring Bores	No. of Transient Points
Calga North Bores	CQ series	1	13	942
Calga South Bores	MW series	2	6	420
Neighbours Water Supply Bores	CP series	3	6	369
NOW Bores	GW series	4	11	602
Total			**36**	**2333**

A2.9.1 Calibrated Model Properties

Table 7 summarises the hydraulic and storage properties for the stratigraphic section at the end of transient calibration. The adopted property distributions are displayed in **Attachment AA**.

The adopted values for rainfall recharge expressed as percentages of rainfall are (**Figure 13**):

- Alluvium [Zone 1]: 8%
- Alluvium [Zone2]: 25%
- Hawkesbury Sandstone [Zone 3]: 8%
- Hawkesbury Sandstone [Zone 4]: 5%
- Hawkesbury Sandstone (high land area) [Zone 5]: 14%
- Narrabeen Group (Gosford Formation) [Zone 6]: 8%
- Narrabeen Group (Gosford Formation) [Zone 7]: 5%
- Narrabeen Group [Zone 8]: 5%

Table 7. Calibrated Horizontal and Vertical Hydraulic Conductivities, Storage Coefficient and Specific Yield

Layer		**Lithology**	**Kx (m/d)**	**Kz (m/d)**	**S**	**Sy**
1	🟩	Soft Sandstone	0.05	0.001	0.0003	0.03
2	🟫	Medium Sandstone	0.02	0.001	0.0003	0.03
3	🟥	Hard Sandstone	0.005	0.0001	0.00005	0.005
4	▨	Massive Sandstone / Shale	0.0005	0.00005	0.00001	0.001
5	🟥	Hard Sandstone	0.005	0.0005	0.00005	0.005
6	▨	Massive Sandstone / Shale	0.0005	0.00005	0.00001	0.001
7	🟥	Hard Sandstone	0.005	0.0005	0.00003	0.003
8	🟦	Narrabeen Group (Gosford Formation)	0.05	0.001	0.000025	0.0025
	▨	Siltstone / Shale	0.005	0.0001	0.000025	0.0025
9	🟨	Alluvium	10	0.1	0.0005	0.05
	⬜	Narrabeen Group (Gosford Formation)	0.05	0.001	0.000025	0.0025
	🟩	Narrabeen Group exposed creek walls	0.1	0.01	0.0001	0.01
	▨	Siltstone / Shale	0.005	0.0001	0.000025	0.0025
10	⬛	Basement	0.005	0.0005	0.00001	0.001

Kx – horizontal hydraulic conductivity, Kz – vertical hydraulic conductivity, S – Storage Coefficient, Sy – specific yield

A2.9.2 Transient Calibration Performance

A scattergram of simulated versus measured heads in **Figure 17** demonstrates good agreement across the whole range of measurements. There is no bias towards overestimation or underestimation.

The overall performance of the transient calibration is quantified by a number of statistics in **Table 8**. The key statistic is 2.2 %RMS, which is well below the groundwater modelling guideline value of 5-10% (MDBC, 2001; Barnett *et al.*, 2012) for acceptable model calibration.

Table 8. Transient Calibration Performance

Calibration Statistics	Value
Number of Data (n)	2333
Root Mean Square (RMS) (m)	2.8
Scaled Root Mean Square (SRMS) (%)	2.2
Average residual (m)	0.5
Absolute average residual (m)	2.1

The ability of the model to replicate observed groundwater hydrographs is illustrated in full in **Attachment AB**.

For illustration, **Figure 18** and **Figure 19** show comparisons of simulated and observed hydrographs at representative sites within the four groups of monitoring bores. The trends, due to climate variation, are reproduced faithfully. In some cases the initial levels are a little low, but after the model "warms up" the trends match well. The match at bore CQ4 (**Figure 18a**) is particularly good. This is the monitoring site that has recorded the largest extraction-induced drawdown effect to date (see **Figure 5** contour map). Some observed bore hydrographs, for example CP3, show clear pumping effects believed to be due to pumping from the bore itself (**Figure 19a**). As the model does not include private pumping due to the difficulty in estimating timing and pumping rates, the aim is to track the upper envelope of such hydrographs.

Most simulated hydrographs show some systematic offset from the observed hydrographs, as quantified by the overall 2.8 mRMS performance measure (**Table 8**). The offset could be reduced (if necessary) by a heterogeneous hydraulic conductivity distribution (or other hydraulic parameters) instead of uniform values applied to large lithological zones.

The spatial distribution of simulated drawdown at December 2012 (end of calibration period) is shown in **Figure 20**. The effect of extraction to date is focused in the northern part of the Project Site with only minor excursions offsite. The drawdown extent is a little broader than what has been observed (**Figure 5**) but the simulated drawdown contours are sensitive to which cells are actively being extracted in the model at that time, and to the assumed floor levels of the pit.

A2.9.3 Transient Water Balance

The transient water balance across the entire model area is summarised in **Table 9** for the full calibration period (January 2007 to December 2012). The average inflow (recharge) to the groundwater system was approximately 167 ML/day, comprising rainfall recharge as the only significant source of inflow.

Stream baseflow accounts for the majority of the groundwater discharge, at 59%. Next in order of importance is evapotranspiration (22%). Seepage face discharge at cliffs is about 16%. The boundary outflow to water bodies at sea level is about 3%. The computed inflow to Calga Sand Quarry stages 3/1, 3/2 and 3/6 (0.03 ML/day) is insignificant in comparison with the total groundwater discharge over the model area and the aggregate rainfall recharge.

Over the calibration period (January 2007 to December 2012), recharge exceeded discharge by about 6 ML/day.

Table 9. Simulated Average Water Balance during the Transient Calibration Period

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	167.0	-
Evapotranspiration	-	34.6
Rivers/Creeks (Rivers)	0.00	95.2
Seepage Faces	-	26.4
Mines (Drains)	-	0.03
Boundary Flow (Constant Head)	0.01	4.5
TOTAL	**167.0**	**160.8**
Storage	**6.2 Gain**	
Discrepancy (%)	**-0.10**	

A3 SCENARIO ANALYSIS

As described in Section A2.7, two model versions were considered for predictive scenario analysis:

1) with the Project alone (referred to herein as the Project-only scenario) and using the TMP features (time varying properties); and
2) with the Project and other quarries operating at the same time.

A3.1 EXTRACTION SCHEDULE

Using the hydraulic and storage properties found during transient calibration and a pit activation period of one year, the model was run in transient mode from January 2013 (after the end of the calibration Period) to December 2037 in annual steps. The Project is taken to commence stage 3/3a in the model in January 2013 (stress period 1) with all stage 3 working to be finished by December 2019 (stress period 7). The stage 4/1 extraction was also activated from stress period 1 to stress period 22 (end 2034) and the stage 5 extraction was activated from stress period 18 to stress period 25 (end 2037) (**Table 2**).

The only time-varying stress in the prediction model is extraction. Rainfall was applied at constant long-term average rates, and creeks were simulated as non-recharging rivers. This allows clear definition of extraction effects which are not confused by climatic contributions.

The progression of extraction in the model was applied consistent with the general arrangement snapshots for the Project presented in the PPR report (Corkery, 2012; Figures 2.7 and 2.8), and the pit was assumed to extend to the floor of model layer 2 (base of friable sandstone). Figures 2.7 and 2.8 also define the silt deposition sequence which was taken into account in the model by progressive changes to hydraulic conductivity and specific yield.

A3.2 WATER BALANCE

Simulated water balances for the entire model extent have been averaged over the 25 years of the proposed Project life (stress periods 1 to 25) and are examined in **Table 10**.

For the Project-only scenario, recharge by rainfall infiltration provides the total average inflow into the groundwater system apart from very minor boundary inflow. The river/creek baseflow accounts for about 58% of groundwater discharge from the model area. The other significant discharge mechanisms are evapotranspiration (24%) and seepage face discharge to the cliffs (15%). The boundary outflow to water bodies at sea level is about 3%. The average inflow to the sand quarry during the its life is insignificant in comparison to the total groundwater discharge over the model area.

Table 10 gives the simulated average components over the entire model extent for the Project-only scenario with TMP. The Calga Sand Quarry is expected to have an average inflow of about 65 kL/day.

Table 10. Average Simulated Water Balance for the Prediction Model during the Project Life

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	159.1	-
Evapotranspiration	-	37.1
Rivers/Creeks	0.00	91.7
Seepage Faces	-	24.3
Mines (Drains)	-	0.07
Boundary Flow (Constant Head)	0.02	4.54
TOTAL	**159.1**	**157.7**
Storage	**1.4 Gain**	

A3.3 PREDICTED PIT INFLOW

The time-varying pit inflows predicted by the model are illustrated in **Figure 21** for the Project-only scenario. The combined Project inflow is expected to vary between 15 and 310 kL/day during the mine life. The inflows to stages 3, 4 and 5 are expected to peak around 35, 300 and 70 kL/day respectively. As much of the groundwater seepage would be evaporated at seepage faces, very little water is expected to pool in the floor of the active extraction area.

A3.4 PREDICTED BASEFLOW CHANGES

The streams / creeks near the Project Site have been divided into multiple reaches (segments) in order to assess whether any baseflow reduction might occur due to the extraction activity of the Project. **Figure 12** shows the location map for nine reaches, seven of which were simulated as rivers and two of which were simulated as constant heads (reach 99 is Mangrove Creek and reach 499 is Mooney Mooney Creek).

Table 11 summarises the average and maximum simulated stream baseflow reduction in kL/day units and as a percentage of the total baseflow at commencement of the Project (in model year 1). The results show that the maximum relative baseflow reduction would be expected to be about 50% (98 kL/d) in reach 3 which combines Creek A, Creek B and Creek C that cross the Project Site, and about 40% on average.

The predicted baseflow reduction in all other creeks was not significant with a maximum reduction of 0.15% in the Cabbage Tree Creek which is located just to the west of the Project.

Table 11. Simulated Baseflow Reduction for the Prediction Model during the Project Life

Reach	Average Baseflow Reduction		Maximum Baseflow Reduction	
	kL/d	%	kL/d	%
Drain Reach 1 (Popran Creek)	0.14	0.01	0.18	0.01
Drain Reach 2 (Popran Creek upper)	0.24	0.00	0.35	0.01
Drain Reach 3 (Creeks A, B, C)	73.3	38.8	97.6	51.6
Drain Reach 5 (Cabbage Tree Creek)	0.98	0.09	1.60	0.15
Drain Reach 99 (Mangrove Creek upper)	0.00	0.00	0.21	0.00
Drain Reach 500 (Mooney Mooney Creek upper)	0.43	0.01	0.57	0.01
Drain Reach 501 (Mooney Mooney tributaries)	0.55	0.01	0.85	0.02
Constant Head Reach 99 (Mangrove Creek)	0.00	0.00	0.00	0.00
Constant Head Reach 499 (Mooney Mooney Creek)	0.01	0.00	0.01	0.00

Figure 22 shows the simulated baseflows for each defined reach. Note that Reach 3 (Creeks A, B and C) is the only one that shows any temporal variation, in tune with the proximity of active extraction. This reach shows baseflow variations between about 0.1 and 0.2 ML/day due to sand extraction.

A3.5 PREDICTED DRAWDOWNS

The predicted watertable drawdowns during extraction, at 5-year intervals, are shown in **Figures 23-27**. As the quarry proceeds from year to year, the maximum drawdown would move from one location to another. For example, the maximum drawdown after 5 years of extraction is predicted to be about 6 m at the boundary between stages 3 and 4. After 10 years of extraction, the maximum drawdown is predicted to be about 14 m at the middle of stage 4. After 15 years, the maximum drawdown is expected to reduce to 12 m in the northern quarter of stage 4. As extraction would proceed in year 20 to extract stage 4/8 and the start of extraction of stage 5/1, two cones of depression would be established with maximum drawdown about 14 m in stage 4 and 16 m in stage 5. At the end of extraction year 25, the only pit that would be active is stage 5/3. With the backfilling process, the maximum drawdown in stage 4 would decrease to about 12 m in stage 4 and would increase in stage 5 to about 18 m.

The maximum extent for 1 m drawdown is expected to be about 200 m south of the Project boundary at the end of year 25 due to the extraction of stage 5/3. The 1 m drawdown is also expected to extend about 200 m east of the Project Site boundary at the end of years 10, 15 and 20 due to the extraction of stage 4. From the northern boundary (just south of bore CQ7), the 1 m drawdown would extend about 125 m outside the Project Site boundary due to the extraction of stage 3. However, the 1 m drawdown is not likely to ever extend past the western Project boundary during the life of the Project.

A3.6 CUMULATIVE IMPACTS

The cumulative impact assessment considered two neighbouring quarries: *Central Coast Sands Quarry, Somersby* which is located about 6 km north-east of the Project and south-east of Mooney Mooney Dam; and *Boral's Hard Rock Peats Ridge Quarry* which is located about 8 km north of the Project Site. Without detailed knowledge of the extraction sequence or timing, the external quarries were simulated under worst-case conditions by activating the entire quarry footprint for the entire prediction period. This will inevitably overestimate the inflows to the neighbouring quarries.

Table 12 reports the cumulative effect on water balance components. Recharge is dominated by rainfall infiltration (100%) and provides essentially all the inflow into the groundwater system. The river/creek baseflow accounts for about 58% of groundwater discharge from the model area. The other significant discharge mechanisms are evapotranspiration (24%) and seepage face discharge to the cliffs (15%). The boundary outflow to water bodies at sea level is about 3%. The total average inflow to the Calga Sand quarry and the two other quarries on the Somersby Plateau over 25 years is about 0.34 ML/day (0.2%). This amount is insignificant in comparison to the total groundwater discharge over the model area.

Table 12. Average Simulated Water Balance for the Prediction Model during the Project Life for the Project and Two Quarries on the Somersby Plateau

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	159.1	-
Evapotranspiration	-	36.9
Rivers/Creeks (Rivers)	0.00	91.7
Seepage Faces	-	24.2
Mines (Drains)	-	0.34
Boundary Flow (Constant Head)	0.02	4.54
TOTAL	**159.1**	**157.7**
Storage	**1.4 Gain**	

As illustrated in **Figure 28**, the modelled 1 m drawdown contour after 25 years for each quarry remains very localised to the individual sites. There is no possibility of hydraulic interference between the quarries. The drawdown extent would be no more than about 250 m beyond the boundary of each Project Site.

A3.7 POST-EXTRACTION EQUILIBRIUM

A transient groundwater recovery simulation was conducted by taking into consideration the final landform with four final voids treated in the model as constant heads to represent Dams 7a/7b, 20, 21 and 22. The final landform and the water levels in these dams were defined in the model based on Figure 2.13 from the Preferred Project Report. The simulation was run for 200 years.

The post-extraction estimates of groundwater inflows and outflow are presented in **Table 13** in 5-year steps for 200 years. The equilibrium long-term groundwater inflow to the dams is expected to be about 0.5 kL/day for Dams 7a/7b, about 20 kL/day for Dam 20. However, Dam 21 (which is located just west of Creek A) and Dam 22 (which is located between Creek A and Creek B) are expected to discharge about 32 kL/day and 3 kL/day respectively into the groundwater system and ultimately into Creek C.

Figure 29 and **Figure 30** show simulated prediction and recovery hydrographs at representative sites within the four groups of monitoring bores. The prediction and recovery hydrographs at all 36 monitoring bores used in the steady state and transient calibration are displayed in **Attachment AC**. Recovery of groundwater levels at the monitoring sites would be very rapid. In most cases, recovery would have occurred by the time of Project completion. Most sites would recover completely to pre-development levels, but some sites would have a permanently lowered water level (to a maximum of 8 m difference at bore MW8).

Table 13. Post-Extraction Estimates of Groundwater Inflows and Outflow to/from Final Dams

Page 1 of 2

Time	**Dam 7a/7b (Stage 3)**	**Dam 20 (Stage 5)**	**Dam 21 (Stage 4)**	**Dam 22 (Stage 4)**
	WL @ 180 mAHD	WL @ 168 mAHD	WL @ 168 mAHD	WL @ 168 mAHD
(years)	Flux (kL/d)	Flux (kL/d)	Flux (kL/d)	Flux (kL/d)
5	-0.1	-11.7	32.6	2.9
10	-0.3	-19.3	32.5	2.8
15	-0.4	-19.6	32.5	2.8
20	-0.5	-19.6	32.5	2.8
25	-0.5	-19.6	32.5	2.8
30	-0.5	-19.6	32.5	2.8
35	-0.5	-19.6	32.5	2.8
40	-0.5	-19.6	32.5	2.8
45	-0.5	-19.6	32.5	2.8
50	-0.5	-19.6	32.5	2.8
55	-0.5	-19.6	32.5	2.8
60	-0.5	-19.6	32.5	2.8
65	-0.5	-19.6	32.5	2.8
70	-0.5	-19.6	32.5	2.8
75	-0.5	-19.6	32.5	2.8
80	-0.5	-19.6	32.5	2.8
85	-0.5	-19.6	32.5	2.8
90	-0.5	-19.6	32.5	2.8
95	-0.5	-19.6	32.5	2.8
100	-0.5	-19.6	32.5	2.8
105	-0.5	-19.6	32.5	2.8
110	-0.5	-19.6	32.5	2.8
115	-0.5	-19.6	32.5	2.8
120	-0.5	-19.6	32.5	2.8
125	-0.5	-19.6	32.5	2.8
130	-0.5	-19.6	32.5	2.8
135	-0.5	-19.6	32.5	2.8
140	-0.5	-19.6	32.5	2.8
145	-0.5	-19.6	32.5	2.8
150	-0.5	-19.6	32.5	2.8
155	-0.5	-19.6	32.5	2.8
160	-0.5	-19.6	32.5	2.8
165	-0.5	-19.6	32.5	2.8
170	-0.5	-19.6	32.5	2.8
175	-0.5	-19.6	32.5	2.8
180	-0.5	-19.6	32.5	2.8
185	-0.5	-19.6	32.5	2.8
190	-0.5	-19.6	32.5	2.8
195	-0.5	-19.6	32.5	2.8
200	-0.5	-19.6	32.5	2.8

A4 IMPACTS ON THE GROUNDWATER RESOURCE

A4.1 POTENTIAL IMPACTS ON GROUNDWATER

A4.1.1 Changes in Hydraulic Properties

There would be a change in hydraulic properties over the quarry footprint where process fines or silts are to infill the excavation down to the floor of the open cut. As silty infill[5] would have lower permeability and porosity than the natural material in this area, there would be associated changes in hydraulic gradients in accordance with Darcy's Law. As one decreases, the other must increase to maintain the same flow.

In **Figure 31**, the equilibrium groundwater levels after 200 years show the modified hydraulic gradient across the Project Site.

A4.1.2 Changes in Groundwater Flow and Quality

As extraction progresses, the extraction pits would act as groundwater sinks. This would cause a temporary change in groundwater flow direction, sometimes reversal of direction due to the depth of excavation, until extraction is completed and the groundwater system recovers to a new equilibrium (**Figure 31**).

The post-extraction groundwater level pattern in **Figure 31** and the quantitative net flow estimates in **Table 13** show that two of the four final voids would act as permanent groundwater sinks. Dams 21 and 22, however, would act as flow-through lakes with a net outflow to the groundwater system.

The final voids are to be located at the western corners of the stages 3, 4 and 5 (Dams 7a/7b, Dam 21 and Dam 20 respectively) and between Creek A and Creek B of the excavation stage 4 (Dam 22). The permanent water levels of the dams, generally 5 to 10 m below the natural land surface prior to extraction, would cause permanent changes to local groundwater levels.

Post-extraction, the groundwater flow direction would be expected to continue in the same south-westerly direction as occurred naturally before extraction commenced (**Figure 31**).

The quality of the inflow water to the dams and the outflow from Dam 21 and Dam 22 would be a mixture of the qualities of the waters derived from rainfall, runoff and shallow Hawkesbury Sandstone. The influence of fresh inputs is expected to offset a mild increase in salinity from evaporation. Dundon (2013) has reported typical groundwater electrical conductivity of 100-250 µS/cm at bores in the monitoring network.

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[5] Infill properties in the model: 0.001 m/day horizontal and vertical hydraulic conductivity; 1% specific yield; 1% rain recharge

The NSW Aquifer Interference Policy requires "*Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity*". No detrimental effect can occur adjacent to Dams 7a/7b or 20 as these dams behave as groundwater sinks and are not sources of water for the groundwater system. The outflows of about 0.03 ML/day from Dam 21 and 0.003 ML/day from Dam 22 are too small to cause a significant change in groundwater salinity and certainly no transition to a different beneficial use category.

A4.1.3 Pit Inflows

Up to the end of extraction, there would be a continuous loss of water from the groundwater system to the extraction void. The groundwater within the friable Hawkesbury Sandstone is the only groundwater source for pit inflows.

The predictive simulation in **Section A3.3** demonstrates that pit inflow is expected to vary between approximately 0.02 and 0.31 ML/day during the life of the Project. The year-by-year expected annual pit inflows are listed in **Table 14**. The annual volumes are expected to range from 9 to 74 ML with an average of 23 ML.

Table 14. Predicted Pit Inflows for the Project at the End of Each Year

Project Year	Calendar Year	Pit Inflow (ML/a)
1	2013	9
2	2014	15
3	2015	29
4	2016	22
5	2017	17
6	2018	42
7	2019	74
8	2020	25
9	2021	29
10	2022	34
11	2023	29
12	2024	23
13	2025	21
14	2026	21
15	2027	16
16	2028	19
17	2029	13
18	2030	33
19	2031	21
20	2032	28
21	2033	13
22	2034	16
23	2035	13
24	2036	11
25	2037	14

A4.1.4 Potential Impacts on Private Production Bores

As described in **Section A1.3**, the private water supply bores CP1 to CP8 are located about 65 to 520 m from the Project Site boundary (**Figure A-12**). **Table 15** indicates the predicted drawdowns for the eight privately-owned bores within the friable Hawkesbury Sandstone formation. Bore CP8 (i.e. Rozmanec water supply bore) which is located about 160 m to the east of the Project Site boundary is predicted to experience a maximum drawdown impact of about 0.5 m during the extraction of stage 3 (at the end of year 5) and then the predicted drawdown will be close to zero when stage 3 is backfilled and the extraction proceeds to stage 4 and stage 5. All other bores CP1 to CP7 would not be affected from the Calga Sand Quarry Project.

The NSW Aquifer Interference Policy requires "*A maximum of a 2 m decline cumulatively at any supply work*" for the watertable in a Porous and Fractured Rock Water Source that hosts a less productive groundwater source. No bore is expected to be affected under the terms of this policy.

As illustrated in **Figure 28**, the modelled 1 m cumulative drawdown effect on the watertable at the end of Project life (year 25) is predicted to be local for each quarry and to not extend more than 250 m beyond the boundary of each quarry. As a result, no privately-owned bores surrounding the Project Site are predicted to be measurably impacted during combined extraction operations or post-closure (i.e. any drawdown effect would be less than 1 m and is therefore considered to be acceptable) (**Table 15**). The Project would therefore not impact the agricultural use of the Hawkesbury Sandstone groundwater system for irrigation purposes.

Table 15. Bores within the Predicted Drawdown Impact Zone of the Project

Bore ID	Ownership	Description	pH*	EC* (µS/cm)	Depth to Water from Ground Level* (m)	Predicted Maximum Groundwater Drawdown (m)	Approximate Distance from Quarry (m)
CP1	Private	Gazzana Domestic Bore	-	-	-	<0.1	520
CP2	Private	Gazzana Domestic Bore	-	-	-	<0.1	475
CP3	Private	Gazzana Domestic Bore	4.7	151	8.98	<0.1	65
CP4	Private	Kashouli Production Bore	5.0	166	10.94	<0.1	200
CP5	Private	Kashouli Production Bore	4.2	247	7.23	<0.1	250
CP6	Private	Kashouli Production Bore	4.3	203	10.27	<0.1	150
CP7	Private	Kashouli Production Bore	4.6	221	2.92	<0.1	350
CP8	Private	Rozmanec Water Supply	4.1	145	19.84	0.5	160

* Measured on 2nd October 2012

A4.2 POTENTIAL IMPACTS ON SURFACE WATERBODIES

According to the drainage and topographic characteristics of the main creeks, the catchments of Mangrove Creek, Mooney Mooney Creek and Popran Creek drain much of the central and southern areas towards the Hawkesbury River.

The stream-groundwater interaction status of several creeks has been examined in detail in **Section A3.4**. The main local drainage systems associated with the Project are Creeks A, B and C and Cabbage Tree Creek.

The results show that the maximum baseflow reduction would be expected to be about 52% (0.1 ML/d) in Creek A, Creek B and Creek C that cross the Project Site. Evans and Peck (2008) estimate that a flow of 0.1 ML/day would correspond to a pre-development flow out of the Creek C catchment that has about 30% probability of exceedance.

The predicted baseflow reduction in all other creeks would not be significant with a maximum percentage reduction of 0.15% in Cabbage Tree Creek which is located just to the west of the Project Site. The Project would have negligible impact on baseflow for the main rivers and creeks such as Mooney Mooney Creek, Popran Creek and Mangrove Creek.

A4.2.1 Changes in Water Balance

With only the Project operating, recharge is dominated by rainfall infiltration (100%). The river/creek baseflow accounts for about 58% of groundwater discharge from the model area, about 1% less than the period 2007-2012. The other significant discharge mechanisms are evapotranspiration (24%) and seepage face discharge to the cliffs (15%), which are within 2% of pre-Project proportions. The boundary outflow to water bodies at sea level remains about 3%.

Average inflow to the quarry during the Project life is predicted to be about 0.05% of all groundwater discharge in the model area, and about 8% of the groundwater discharge through the local catchment (as defined in Figure 2.7 of Evans & Peck, 2008).

These figures suggest that the Project would have a minimal effect on the component water balance magnitudes and proportions.

A4.2.2 Effects on Groundwater Dependent Ecosystems

The NSW Aquifer Interference Policy requires "*Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40m from any ... high priority groundwater dependent ecosystem... listed in the schedule of the relevant water sharing plan*" in a Porous and Fractured Rock Water Source that hosts a less productive groundwater source.

As the Water Sharing Plan does not identify any high priority groundwater dependent ecosystems (GDEs) near the Project Site, this condition does not apply.

However, GeoTerra (2009) notes that there are three GDEs mapped in the lower reaches of Cabbage Tree Creek (600 m due west of the south-western boundary of the Project Site) that are likely to be reliant on water flowing through Cabbage Tree Creek:

- MU1 Coastal Wet Gully Forest;
- MU37 Swamp Mahogany – Paperbark Swamp Forest; and
- MU40 Swamp Oak – Rushland Forest.

As **Table 11** shows that the baseflow reduction in Cabbage Tree Creek is of the order of 0.001 ML/day and **Figure 28** shows that the drawdown extent would not reach Cabbage Tree Creek, there would be negligible extraction impact on these GDEs.

GeoTerra (2009) also recognises a number of GDEs on or adjacent to the Project Site.

- Small patches of Gahnia-Banksia Swamp (E103) on the Project Site are likely to be perched obligate GDEs (totally dependent on groundwater).
- Sandstone Hanging Swamps (E54) along Creek B are likely to be perched obligate GDEs (totally dependent on groundwater).
- Sandstone Ranges Gully Rainforest (E2) in the drainage line of Creek C is a facultative GDE that is likely to be partially dependent on groundwater discharge at dry times.

The vegetation cover map in **Figure 32** shows their distribution. Each GDE will receive some impact from sand extraction, although the effect at facultative GDE E2 along Creek C is likely to be minimal due to an expected drawdown of about 0.1 m and a reduction in baseflow of no more than 0.1 ML/day. The small area (0.4 ha) of obligate GDE E103 (northing 6301200) would be removed during stage 4 extraction.

The obligate GDE E54 along Creek B could be affected significantly. To investigate the size of the effect, two hypothetical "bores" have been placed in the model at locations shown in **Figure 33**. The simulated baseflow along Creek B (during extraction) and the simulated watertable levels at the two sites are shown in **Figure 34**. There is a strong correlation between the reduction in baseflow in Creek B and the decrease in the water level in the two E54 areas due to the impact from the Project. The baseflow is expected to reduce by about 0.03 ML/day, a small amount, but the watertable is expected to drop by at most 2 m at E54_1 and at most 5 m at E54_2 for up to 5 years. There is the possibility of a significant impact on this GDE, unless the GDE is sustained by a perched water table that is distinct from the regional watertable being simulated.

The groundwater assessment by GeoTerra (2009) has already foreshadowed an impact on this GDE: "*In the case of the Sandstone Upland Swamp, this community is likely to have experienced, and adapted to fluctuating groundwater levels over time, limiting the potential impact on the species of this community." "It is also worthy of note that 1.3ha of this community would be conserved within a biodiversity offset area established on the neighbouring 'Glenworth Valley' property*."

A4.3 GROUNDWATER LICENSING

GeoTerra (2009) summarises the groundwater availability within Zone 7 of the Lower Mangrove and Popran Creeks Groundwater Source, managed under the Water Sharing Plan for the Kulnura Mangrove Mountain Groundwater Sources. A long-term average extraction limit of 2,334 ML/a is cited. As an embargo is in place on new Water Access Licences, Rocla is required to obtain any additional required entitlement on the open market. GeoTerra (2009) notes that Rocla had licences (in 2009) for 52 ML/a.

The predicted average annual groundwater volumes required to be licensed over the life of the Project and post-extraction are summarised in **Table 16**.

Table 16. Project Groundwater Licensing Summary

Water Sharing Plan	Management Zone/ Groundwater Source	Predicted Average Annual Inflow Volumes requiring Licensing [ML/annum]*	
		During Project	Post-Extraction
Kulnura Mangrove Mountain Groundwater Sources	Lower Mangrove and Popran Creeks	Av. 23 Max. 74	Max. 18

* Refer to **Table 14** for predicted groundwater inflows.

In addition, the individual baseflow reductions in **Table 11** combine to give an annual take from streams of 37 ML maximum and 35 ML on average, during the life of the Project.

A5 COMPARATIVE PREDICTIONS

Current modelling is more detailed than the modelling by Golder (2009), in that successful transient calibration has been demonstrated, progressive transient simulations have been done (allowing for backfilling), and the results have been expressed in terms appropriate for the Aquifer Interference Policy.

As the Golder (2009) modelling was limited to steady-state predictions, it would be expected that the Golder (2009) impact assessment would be overly conservative. A comparison of the two modelling approaches in **Table 17** shows that this expectation is borne out.

Table 17. Comparative Predictions using the Golder (2009) and the Current Model

Feature	Golder (2009) Finding	Heritage Computing (2013) Finding
Drawdown extent	1m drawdown cone would extend 0.7 km north, 1.5 km east, 1.2 km south, 0.7 km west	1m drawdown cone would extend 0.1 km north, 0.2 km east, 0.2 km south, 0.0 km west
Drawdown at private bores	Up to 5 m drawdown at CP8 and GW102729; <1m drawdown at bores CP1 to CP7	Up to 0.5 m drawdown at CP8; <0.1m drawdown at bores CP1 to CP7
Pit Inflows	30 ML/a for approved Stage 3 extraction, 140 ML/a at the end of Stage 4, and 160 ML/a at the end of Stage 5.	Average 23 ML/a; maximum 74 ML/a
Baseflow	Baseflow to Cabbage Tree Creek of about 7 L/s (0.6 ML/day) and about 4.5 L/s (0.4 ML/day) to Creeks A, B and C	Baseflow to Cabbage Tree Creek of about 1.0 ML/day and about 0.1 ML/day to Creeks A, B and C
Baseflow reduction	Maximum reductions during extraction of about 7% (0.04 ML/day) at Cabbage Tree Creek and about 15% (0.06 ML/day) at Creeks A, B and C	Maximum reductions during extraction of about 0.2% (0.002 ML/day) at Cabbage Tree Creek and about 50% (0.1 ML/day) at Creeks A, B and C
GDEs offsite	GDEs associated with Cabbage Tree Creek (MU1, MU37, MU40) are unlikely to be significantly affected by extraction	GDEs associated with Cabbage Tree Creek (MU1, MU37, MU40) are unlikely to be significantly affected by extraction
GDEs onsite	Obligate GDE E54 along Creek B could be affected by predicted watertable drawdowns of about 10 m.	Obligate GDE E54 along Creek B could be affected by predicted watertable drawdowns of about 5 m maximum.
GDEs onsite/offsite	Facultative GDE E2 along Creek C could be affected by predicted watertable drawdowns of 1-10 m.	Facultative GDE E2 along Creek C is unlikely to be affected by predicted watertable drawdowns of about 0.1 m and a reduction in baseflow of no more than 0.1 ML/day.

A6 MODEL LIMITATIONS

At this stage, the model has adopted laterally uniform properties in distinct lithologies within model layers and uniform rainfall recharge across four major zones. As more data are gathered, the spatial distributions of formation hydraulic properties can be modified and/or refined.

As friable sandstone permeability can be quite variable and would reduce with depth, pit inflows and groundwater drawdowns would adjust accordingly. In practice, pit floor elevations could be higher or lower than the uniform geometry adopted in the model. This would also have the effect of perturbing pit inflows and drawdown extent compared to predictions.

However, the steady-state predictions in the Golder (2009) model are expected to indicate worst-case conditions, while the current modelling is more applicable to likely conditions.

A7 REFERENCES

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ILLUSTRATIONS

Figures 1 to 34

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