HANSON AUSTRALIA PTY LTD

CALGA SAND QUARRY

CLOSURE AND POST-CLOSURE GROUNDWATER MANAGEMENT PLAN

DUNDON CONSULTING PTY LTD

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1 CALGA SAND QUARRY

1.1 Background

The quarry is owned and operated by Hanson Australia Pty Ltd (Hanson) a national construction material company that assumed ownership of the quarry on 30 January 2016.

Sand extraction from the Calga Sand Quarry is approved under Development Consent DA 94-4-2004 ("the Consent"), as modified in June 2017 (MOD 3). The original Consent was granted by the Minister for Planning on 28th October 2005.

Condition 19 of Schedule 3 of the Modified Consent requires that Hanson prepare a Quarry Closure Groundwater Management Plan, as follows:

Quarry Closure Groundwater Management Plan

19. Prior to the commencement of quarrying in Stage 3/6 or 5 years prior to the cessation of quarrying (whichever is the sooner), the Applicant must commission a suitably qualified hydrogeologist, whose appointment has been approved by the Secretary, to assess the potential long term impacts of the final void on groundwater resources, and to develop a quarry closure and post-closure groundwater management plan. The plan must:

a) be prepared in consultation with the DPI-Water, the CCC, and landowners within the predicted drawdown impact zone identified in the Amendment Report; and

b) include strategies, in accordance with the Groundwater Contingency Strategy, to ensure the long-term security of water supply to any landowner whose groundwater bores exceed, or are likely to exceed in the future, the groundwater impact assessment criteria, to the satisfaction of the Secretary.

Groundwater monitoring at the Calga Sand Quarry (the "quarry") is undertaken in accordance with Condition 11 of Schedule 3 of the Consent. Condition 11 required that a Water Management Plan be prepared, which shall include, inter alia, a Groundwater Monitoring Program ("GWMP"). The Site Water Management Plan (SWMP), incorporating the Groundwater Monitoring Program, was completed in February 2006 (R W Corkery, 2006), and accepted by the Director-General on 13 March 2006. A revision of the SWMP (draft dated May 2018) is currently being considered for approval by the Secretary.

Condition 15 of the Consent detailed the specific items to be included in the GWMP, which has been periodically reviewed to ensure that it continues to meet the objectives embodied in Condition 15. The groundwater monitoring for the Quarry is undertaken by an independent contractor, Carbon Based Environmental ("CBE"). A monthly report is prepared by CBE detailing the results of monitoring undertaken in that month, and these reports are uploaded to the Hanson website. The monitoring and reporting are thus undertaken independently of the operators of the Calga Quarry.

Condition 17 of Schedule 3 of the Consent requires an annual independent audit of the groundwater impacts of the development to be prepared to determine compliance with the groundwater impact assessment criteria detailed in the SWMP, to the satisfaction of the Secretary.

For the purposes of this report, the property within which the quarry operations are located (Lot 2, DP229889) is referred to as the Quarry Site (**Figure 1**).

1.2 Quarry Status at the end of 2018

By the end of 2017, sand extraction had been completed in Stages 3/1, 3/2, 3/3 and part of 3/4, and tailings deposition had been completed in the long-term Stage 3/2 tailings storage up to an elevation of 200RL. Active sand extraction was taking place from the northern part of Stage 3/4, and tailings was being deposited into a new tailings storage area in Stages 3/3 and the SE part of Stage 3/4, up to a level of 195RL.

During 2018, sand extraction was completed from Stage 3/4, with the base level progressing from RL184 down to the final bottom elevation of RL179. Sand extraction commenced from Stage 3/5, with tailings deposition into the Stage 3/3 – 3/4 tailings storage area. This continued into 2019, and at April 2019, extraction in Stage 3/5 had advanced to RL188.

Extraction of friable sandstone commenced from Stage 3/6 on around 8 April 2011, and continued. intermittently from Stage 3/6 until 15 October 2011, down to an elevation of RL198. This extraction from Stage 3/6 was undertaken prematurely, prior to the completion of this Closure Plan as required under Consent Condition 19. Extraction was suspended on 15 October 2011, when the then operator of the quarry became aware of this non-compliance, and the Minister was notified in accordance with the notification requirements of the Consent. No further extraction has taken place from Stage 3/6 since that time, and the base of extraction in Stage 3/6 remained at RL198.

The quarry status as at April 2019 is depicted on **Figure 2**. This shows extraction taking place from Stage 3/5 at RL188, and tailings deposition to Stages 3/3 – 3/4, with the water level at RL186 in Stage 3/3 and RL179 in Stage 3/4. Extraction has still not recommenced from Stage 3/6, in which the floor level is still at RL198, where it was when extraction was suspended in October 2011. Stages 3/1, 3/2 and 3/3 have been partially backfilled with tailings, to RL186.

2 GROUNDWATER MONITORING

2.1 The Monitoring Network

The monitoring network in 2018 comprised 24 groundwater bores, three of which are located within the quarry site, and the rest are located on neighbouring properties. The bores on neighbouring properties include 7 water supply bores, and 14 monitoring bores installed by the quarry owners. Three bores that were installed as part of the investigations for the formerly proposed southern extension will be removed from the monitoring network from 2019.

It has been recommended that one of the southernmost bores MW7 be retained as a remote control bore to assist with impact assessment.

Three additional water supply bores located within 500m of the Quarry (CP1, CP2 and CP14) have been identified on neighbouring properties; however, the landowners have not given approval for these bores to be monitored.

The locations of all monitoring bores and the private water supply bores on neighbouring properties are shown on **Figure 1**, and are listed with bore construction details in **Table 1**.

Private water supply bores on neighbouring properties are named with a “CP” prefix. Hanson’s monitoring bore names have a “CQ” or “MW” prefix.

Bores either destroyed or lost in previous years have been omitted from **Table 1**, and readers should refer to previous annual groundwater audit reports for construction details.

The CQ series of bores were installed to monitor for possible impacts on the neighbouring bores from the quarry operations. Monitoring commenced from CQ1 to CQ4 in 2001. Further bores were installed later (CQ5 to CQ9 in 2004, and CQ10 to CQ13 in 2005) at strategic locations to ensure that there was at least one monitoring bore between the quarry and each neighbouring water supply bore. The bores were constructed with screens set at the same elevation as the production interval in the neighbouring bore. Where that zone is significantly deeper or shallower than the proposed maximum depth of excavation in the quarry, an additional monitoring bore was installed at each strategic location with screens at the same depth as the proposed base of the quarry. Thus there are pairs of shallow and deep monitoring bores at several of the monitoring sites.

The MW series of monitoring bores was installed across the area occupied by the previously proposed southern extension of the quarry site, to the south of the existing quarry (**Figure 1**).

The bores are monitored for both water level and water quality. Groundwater quality monitoring is undertaken bi-monthly in accordance with the SWMP. Groundwater levels are also monitored bi-monthly. From 2019, in accordance with the revised SWMP, water quality and water level monitoring will be undertaken quarterly.

Hanson has a licensed water supply bore adjacent to its amenities block (Licence No WA100255) for washroom water supply. Annual production is approximately 260 kL. This bore is not part of the monitoring network.

Table 1: Monitoring Bores and Water Supply Bores

Bore	Land-holder (Old bore name)	Registered Bore No	Licence Number	Location (MGA)		Ground Level (mAHD)	Stick-up (m)	Bore Depth	Groundwater Production Interval		Screen Interval		Water Level (4 December 2018)	
				Easting	Northing				(mBGL)	(mAHD)	(mBGL)	(mAHD)	(m below TOC)	(mAHD)
Neighbours' Water Supply Bores														
CP1	Power (PB1)	GW101409	20WA100239	333592.3	6301899.8	193.51	0.02	60.9	NR					
CP2	Power (PB2)	GW100548	20WA204164	333662.0	6301950.9	190.75	0.12	40.0	11–13	178–180	11-13 17-19 23-26	177.8-179.8 171.8-173.8 164.8-167.8		
CP4		GW066908	20WA100239	334118.0	6301917.3	218.00	0.27	44.0	13.9–14.1 27.3–27.7	204 191	Open hole		9.74	208.5
CP5	Kashouli	GW067408	20WA100223	334083.3	6301972.1	215.92	0.40	76.0	10.1–10.2 20.4–20.5 38.3–38.6 61.2–61.3	206 195 177 155	Open hole		10.10	206.2
CP6		GW101316		334120.7	6302011.4	217.27	0.75	92.0	16.5–16.8 62.7–63.0 76.2–76.5	201 154 141	Open hole		12.02	206.0
CP7		GW037925		333964.3	6302049.2	210.54	0.36	76.2	4.8–39.5	171-206	Open hole		3.73	207.2
CP8	Rozmanec	GW066907	10BL143533	334549.9	6301715.0	223.33	0.25	42.7	20.6–20.7 44.3–44.6	203 179	Open hole		22.74	200.8
CP13	White	NK	NK	334183.9	6302039.1	218.38	0.38	>50	??	??	??		18.34*	200.4
CP14	King	GW202106	NK	334405	6301855	~220	NK	126	NK					
CP15	Glenworth Valley	GW104887	NK	333597	6302041	~203	NK	40	NK				2.54*	~200
Hanson Monitoring Bores – Calga Quarry and Surrounds														
CQ3	*Hanson*	GW104245		333718.4	6301299.8	180.437	0.57	21.8			18.3–21.3	159.2–162.2	10.87	170.2

Bore	Land-holder (Old bore name)	Registered Bore No	Licence Number	Location (MGA)		Ground Level (mAHD)	Stick-up (m)	Bore Depth	Groundwater Production Interval		Screen Interval		Water Level (4 December 2018)	
				Easting	Northing				(mBGL)	(mAHD)	(mBGL)	(mAHD)	(m below TOC)	(mAHD)
CQ4	Hanson	GW104246		334147.85	6301797.3	214.821	0.68	20.0			16.4–19.4	195.4– 198.4	11.76	203.8
CQ5	Power (G31)	NK	NK	334003.3	6301838.4	212.697	0.83	23.7	-	-	20.7-23.7	189.0-192.0	8.65	204.9
CQ7	Power (G33)	NK	NK	333949.5	6301683.3	204.303	0.85	29.7	17.4 18.9 20.1	186.9 185.4 184.2	20.7–26.7	177.6–183.6	6.54	198.6
CQ8	Power (G34)	NK	NK	333786.4	6301778.8	200.904	0.86	26.6	19.6	181.3	17.7–23.7	177.2–183.2	7.52	194.2
CQ10	Hanson	GW202214	20BL170313	334520.7	6301453.3	223.13	0.85	57	28-31	195-192	51–57	166–172	26.90	197.1
CQ11S		GW202191		334170.5	6301822.7	216.34	0.78	38	22.4-26.5	194-190	32–38	178–184	12.56	204.6
CQ11D	Power	GW202192	20BL170191	334162.6	6301820.7	216.30	0.78	65	16-24 25.3-42.4	200-192 191-174	59–65	151–157	13.52	203.6
CQ12		GW202193		333794.2	6301802.3	202.61	0.02	15			9–15	188–194	5.85	196.8
CQ13	Kashouli	GW202215	20BL170190	334128.1	6301923.3	218.30	0.82	65	18-21 44-44.5	200-197 174	59–65	153–159	15.26	203.9
MW7		GW201798		*334506*	*6300226*	209.92	0.87	30.0			24-30	180–186	15.87	194.9
MW8**		GW201799		*334011*	*6300298*	191.03	0.88	30.0			21-30	161–170	8.41	183.5
MW9		GW201800		*334543*	*6301387*	223.56	0.88	27.0			24-30	194–200	24.61	199.8
MW10	Hanson	GW201801	20BL165571	*333716*	*6300992*	163.14	0.87	30.0			24-30	133–139	10.99	153.0
MW13		GW201802		*334236*	*6300819*	178.42	0.89	45.0			39-45	133–139	7.73	170.7
MW16**		GW201803		*334027*	*6300943*	173.67	0.89	27.0			21-27	147–153	8.26	165.4
MW17**		GW201804		*334029*	*6300588*	171.52	0.91	27.0			21-27	145–151	10.07	162.3

Bore	Land-holder (Old bore name)	Registered Bore No	Licence Number	Location (MGA)		Ground Level (mAHD)	Stick-up (m)	Bore Depth	Groundwater Production Interval		Screen Interval		Water Level (4 December 2018)	
				Easting	Northing				(mBGL)	(mAHD)	(mBGL)	(mAHD)	(m below TOC)	(mAHD)
Hanson Licensed Water Supply Bore														
Quarry Water Supply	Hanson		20WA100255	333926.8	6301405.7	194.35		120.0	34-36 65-66 89-90	158-160 128-129 104-105	34-37 66-69	157-160 125-128	24.015*	170.3

Bores CP3, CP9, CP10, CQ1, CQ2, CQ6 and CQ9 have been damaged or lost, and are not included in the table.

Red Water supply bores not monitored due to lack of landholder approval.

* Most recent available water level

** Southern bores no longer monitored.

NK Not Known

334506 Coordinates or elevations shown in blue are approximate, not yet confirmed by survey.

2.2 Monitoring Frequency

In accordance with the approved SWMP, monitoring of groundwater levels and groundwater quality is undertaken as follows:

- Water Levels
  - Hanson's monitoring bores (quarterly manual measurements, as well as automatic dataloggers recording at a nominal 6-hourly interval on selected key monitoring bores);
  - Privately-owned bores (quarterly manual measurements).
- Water Quality
  - On-site determination of electrical conductivity (EC) and pH every two months;
  - Comprehensive laboratory analysis (including major ions and dissolved metals) every six months.

Automatic dataloggers have been installed in 13 key Hanson monitoring bores. In addition to the automated monitoring with the dataloggers, water levels have also been measured manually in these bores every second month, both as a backup and to allow regular calibration of the dataloggers. Bores not equipped with dataloggers are monitored manually for water levels. The monitoring results are compiled into monthly reports by CBE and uploaded to the Hanson website.

In the revised SWMP, the manual water level monitoring and sampling for EC and pH are to be done quarterly.

2.3 Groundwater Impact Assessment Criteria

The groundwater impact assessment criteria are detailed in Section 7.4 of the approved SWMP. The criteria relating to groundwater levels and groundwater quality are:

Groundwater Levels

- If at any annual independent audit review, there is a declining trend in groundwater levels which is not attributable to climatic conditions or other factors not related to sand extraction, and if the groundwater level decline at monitoring bores CQ10 or CQ11 deemed due to sand extraction impact exceeds 1.0m, then the adjoining landowners will be approached to arrange re-testing of their existing production bore(s). The test results will be compared to pre-extraction tests, and if it is determined that any bore has suffered a reduction in the pumping yield of greater than 10% then action will be taken as described in Schedule 3, Condition 10 of DA 94-4-2004; and
- If at any other time, a landowner's bore within 500m of the quarry suffers a reported loss of yield greater than 10% due to declining groundwater levels, the loss of yield would be notified to both the Secretary and the affected landowner(s). The Company would also commission an independent hydrogeologist to conduct an investigation regarding the loss of yield. The investigation would include a review of all monitoring data, and if necessary a re-testing of the bore to allow comparison of performance with previous tests. If the investigation reveals that the loss of yield is attributable to the sand extraction activities, then arrangements would be made with the landholder to restore the supply by one of the means described in Schedule 3, Condition 10 of DA 94-4-2004.

Groundwater Quality

- If any private bore within 500m of the quarry experiences a salinity increase (20% increase in EC or TDS), response actions would be implemented as detailed in the Plan.

Amended impact assessment criteria have been proposed in the revised SWMP which is currently being reviewed by the Secretary. A draft Groundwater Contingency Strategy (Martens and Associates, 2017) is also being reviewed by the Secretary.

The amended impact assessment criteria are:

Groundwater Levels

If at any annual independent audit review, it is assessed that a drawdown in excess of 1m has occurred as a result of quarrying activity at any off-site monitoring bore, the drawdowns will be investigated to determine if any neighbouring private bore has suffered an adverse impact on bore yield. This may include consideration of drawdowns and drawdown trends, and if necessary re-testing of the private bore as detailed above.

Groundwater Quality

Groundwater quality will continue to be assessed against the ANZECC (2000) guideline values for freshwater ecosystem protection, where available, and the 95th percentile of records recorded between 2012 to 2017.

If any private bore within 500m of the quarry experiences a salinity increase (20% increase in EC or TDS based on the last five years of data), the following response actions would be implemented:

- Re-sample the bore to verify the quality.
- If the salinity increase is confirmed, immediately notify the Secretary and affected landholder and refer the data to an independent hydrogeologist for investigation.
- If the investigation confirms the sand extraction activities as the likely cause, then arrangements would be made with the landholder to restore the supply by one of the means described above.

2.4 Impact Assessment Methodology

Groundwater levels and groundwater quality both demonstrate significant natural background variation, spatially and temporally. Groundwater levels vary in response to intermittent rainfall recharge and continuous natural discharge. Variations in groundwater levels and recharge cause natural fluctuations in groundwater quality.

This means that both groundwater levels and groundwater quality are dynamic properties, and for each bore there is no single groundwater level or set of specific groundwater quality parameter values that if exceeded can be taken to be indicative of quarry impact. Rather, the assessment of impacts has to be based on changes that are greater or less than the natural variations. The assessment is therefore largely based on comparison of trends, both with other bores and with rainfall trends.

The groundwater level data are compared firstly with the Rainfall Cumulative Deviation curve, and secondly with the groundwater level data from distant monitoring bores CP7 to the north and MW7 to the south of the quarry.

The Rainfall Cumulative Deviation (RCD) used at Calga is derived from the BOM data for Mangrove Mountain[1], which has a much longer rainfall record than the quarry itself and is therefore a more

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[1] The Peats Ridge BOM site (11 km from Calga) was previously used for comparing site rainfall and groundwater trends, as it was the closest BOM site to the quarry. However, this site was closed at the end of 2012. The data from the next closest BOM site with an extended rainfall record Gosford North (12 km away) was then used to derive the rainfall cumulative deviation from average curve. However, although the Gosford North site remains open, there are no rainfall data on the BoM site for this station since October 2015. Therefore, the Mangrove Mountain site (15 km away) has been used in this report.

Although Mangrove Mountain is slightly further from the quarry than the Peats Ridge Station, they have similar topographic locations. The rainfall cumulative deviation curves for the two sites are very similar for the period of reliable basis for comparison with average rainfall trends. The RCD is the cumulative deviation of actual monthly total rainfalls from long-term monthly average rainfalls. Monthly rainfalls above the average represent a positive deviation, and monthly rainfalls below average represent a negative deviation. As it is a cumulative curve, periods of above average rainfall result in an upward-trending curve, while periods of below average rainfall result in a downward-trending curve. Comparing the water level hydrographs to the RCD curve facilitates the interpretation of water level changes that are climate-related, and enables them to be distinguished from non-climate related changes.

The distant monitoring bores CP7 (to the north) and MW7 (to the south) are used as control bores for comparison purposes, as they are the most distant from the quarry to the north and south respectively, and are considered to be located beyond the limit of potential drawdown influence from the quarry operations.

Groundwater quality data is also compared with the RCD curve, as monitoring has shown that the groundwater quality is to some extent related to the rainfall recharge pattern. By comparing the water quality trends with the RCD trends, water quality changes that are due to climatic influences can be distinguished from changes that may be related to the quarry operations.

By comparing the trends on both water level and water quality with the RCD curve and the control bores, fluctuations in water level or quality which are climate related can be eliminated, and attention can be focussed on changes that may be due to the quarry operations, or other factors.

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overlapping record, so it is considered acceptable to use Mangrove Mountain as the reference station now that Peats Ridge has been closed and Gosford North appears to be unavailable.

3 RAINFALL AND EVAPORATION

Daily rainfall and evaporation are recorded by an automatic weather station located within the quarry site, and reported in the monthly monitoring reports compiled by CBE. The site rainfall record extends from April 2006 to the present.

Rainfall data have also been extracted from nearby Bureau of Meteorology (BoM) rainfall stations (Peats Ridge and Mangrove Mountain). Average monthly rainfalls from these stations are compared with the Calga Quarry averages in **Table 2**. Peats Ridge was the closest BoM station to Calga, but ceased operation in 2012. Mangrove Mountain Station is the next closest station (15km from Calga), and has a long-term record covering the period 1994 to present.

Table 2: Average Rainfall and Evaporation – Calga Quarry and Nearby BOM Stations

	Average Monthly Rainfall (mm)			Average Monthly Evaporation (mm)		
	Calga Quarry*	Peats Ridge 061351	Mangrove Mountain 061375	Calga Quarry*	Peats Ridge 061351	Mangrove Mountain 061375
Available Data	**2006-2019**	**1981-2012**	**1994-2019**	**2006-2019**	**1981-2012**	**1994-2019**
January	90.3	113.3	103.0	129.4	142.6	NA
February	124.1	154.3	145.5	92.6	114.8	NA
March	139.6	135.9	137.2	87.9	105.4	NA
April	114.8	123	83.2	62.8	78	NA
May	60.4	89.7	80.6	45.2	58.9	NA
June	125.8	99.5	114.8	42.9	48	NA
July	42.1	62.7	41.7	59.4	52.7	NA
August	57.1	74	55.4	86.4	77.5	NA
September	59.7	69.1	62.5	108.5	102	NA
October	65.7	85.3	76.1	122.9	127.1	NA
November	90.0	100.7	96.0	116.2	132	NA
December	92.9	92.4	89.6	124.8	148.8	NA
Totals	**1062.5***	**1199.9**	**1085.6**	**979.0***	**1187.8**	**NA**

* Averages are approximate, due to occasional gaps in the record.

Monthly rainfall and evaporation totals for 2006 to 2019 from the quarry are presented in **Table 3** and **Table 4** respectively.

Historical monthly rainfall and evaporation data for the Calga Sand Quarry are plotted on **Figure 3**. Included on **Figure 3** is the RCD curve for Mangrove Mountain for the period 2005 to present. This is based on recorded total monthly rainfalls at Mangrove Mountain compared with long-term monthly average rainfall totals at that station. The difference between measured and average is calculated for each month, and accumulated progressively over the period to generate the cumulative deviation from average.

It can be seen from **Figure 3** that the RCD curve has been on a generally rising trend since the commencement of mining under the current consent (October 2005). However, within that period, there have been shorter periods of falling trend, most notably May 2009 to May 2011, November 2014 to July 2015, and April 2017 to September 2018.

Nevertheless, between October 2005 and April 2019, overall the RCD curve shows a net rise of more than 1500 mm, which equates to a rainfall excess of more than 1500 mm over this period compared to average rainfall.

Reference to the Mangrove Mountain BoM data, the average total evaporation and rainfall ore of similar magnitude, although through the year there are some months where rainfall exceeds evaporation, and others where evaporation exceeds rainfall, on average. Nevertheless, over the long-term, the two are in reasonable balance.

Table 3: Monthly Rainfall 2006-2019 – Calga Quarry

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
January		63.2	148.4	86.6	62.5	60	153.2	29.8	29.6	193.4	246.4	20.6	17.6*	62
February		166.2	179.2	225	143.4	53.6	227.8	280.6	106.6	60.7	27	2.2*	55.2*	86.2
March		75.4	103.4	71.4	127.8	134.4	164.4	150	145.6	66.7	72.4	412.2	85.6	205.8
April	14.6	147.6	185.2	146.2	54.6	206.5	154.4	116.2	53.4	377	35	48	41.8	27
May	15.6	40.4	11	148.2	122.4	146.6	22.6	82.2	30.8	119	18.6	17.6	10.8	6
June	42.8	405.4	153.8	68.4	111	106.8	140	120.2	90.4	79.9	160.2	95.8	61	94.6
July	64.2	21.8	65.6	30.6	47.4	161.2	22.8	8.8	23.1	36.7	54.6	3.4	7.2*	35.4
August	39.4	142	40.6	3.6	32.8	75	11.2	12.2	202.5	34.2	82	9.6	*	
September	165	39.6	143.6	9.2	36.4	104.6	29.6	16.8	70	58.7	50.8	4.8*	47.2	
October	12	18	77.6	156.2	94.6	92.6	16.6	48	57.3	49.7	30.4	50.4	150.2	
November	41.6	156	15.2	40.2	180.2	193	58.2	154.6	48.4	129.6	39	36.2*	77.2	
December	*	223.6	51.4	50	117.6	151.8	89.8	14.4	139.5	145.8	47.6	12.6*	70.8	
Totals	**395.2***	**1499.2**	**1175**	**1035.6**	**1130.7**	**1486.1**	**1090.6**	**1033.8**	**997.2**	**1351.4**	**864**	**713.4***	**624.6***	**517***

* Incomplete – some dates with no rainfall data.

Table 4: Monthly Evaporation 2006-2019 – Calga Quarry

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
January		166.1	115.6	171.9	107.2*	132.2	114.3	136.4	136.5	113.5	*	*	100.7*	*
February		106.2	83	101.2	105.4	105.4	82.6	86.2	87.4	73.3	*	*	94.9*	*
March		111.9	101.4	113.3	79	78	68.3	83.2	69.8	66.7	*	*	107.5	*
April	123.4	73.7	63.5	*	55.8	33.7	45.3	57.2	39.3	39.3	*	*	96.8	62.3
May	81.6	78.4	34.6	60.9	37.5	36.5	37.3	48.4	*	1.9*	*	*	79.8	74.4
June	53.6	46.2	47.9	50.2	111	33.7	27.4	34.5	9.6*	12.3*	*	35.8	52.9	39.7
July	67.2	79.1	73.8	73.3	36.5	49.2	31.9	48.9	62.5	59.6	*	73.8	57.5-	73.4
August	87.4	99.9	96.4	134	65.3	*	68.4	96.5	46.5	73.6	*	95.9	*	
September	135.1	116.4	120.5	155.1	104.3	90.1	95.2	113.5	79	90.5	*	93.6*	*	
October	143.2	152	111.1	121.1	97.1	*	113.3	165.1	102.8	118.1	*	104.9	*	
November	160.6	113.4	70.6*	144.5	112.3	117.9	97.2	*	114.3	120.9	*	110.4*	*	
December	*	116.3	159.5	133.9	138.6	91.1	127.9	168.5	113.7	*	*	73.8*	*	
Totals	**852.1***	**1259.6**	**1077.9**	**1259.4***	**1050**	**767.8***	**909.1**	**1038.4***	**861.4**	**769.7***	*****	**588.2**	**590.1***	**249.8***

* Incomplete – some dates with no evaporation data.

4 GROUNDWATER STATUS AT END 2018

4.1 Groundwater Levels

Groundwater levels at July 2019 in each of the monitoring bores are plotted on the site plan **Figure 4**.

Interpretation of the groundwater level hydrographs from the monitored bores, as reported in the 2018 Annual Groundwater Audit Report (Dundon Consulting, 2019), has allowed the following conclusions to be made:

- The quarry operations continue to have only a limited regional impact on the groundwater system.
- Two areas of off-site impact on groundwater levels have occurred – to the immediate north of the quarry; and to the east/southeast of the quarry.
- The two areas of groundwater level impact outside the Quarry Site are small. The impacted area to the north of the quarry is interpreted to extend less than 100m from the Site boundary. The impacted area to the east of the quarry is interpreted to extend to at least 165m, but is unlikely to extend more than 300m from the Site.
- Northern impact area:
    - The maximum drawdown attributable to the quarry operations was observed at monitoring bore CQ4, which is located just 20m outside the northern edge of the quarry, and within the Quarry Site. At the end of 2018, the net residual drawdown at CQ4 was interpreted to be 3.0m.
    - The maximum drawdowns observed outside the Quarry Site to the north were 1.6m at CQ11S and 1.4m at CQ11D, which are located approximately 60m from the quarry edge.
    - Smaller drawdowns may have occurred at greater distance, but would be too small to distinguish from the climate-related seasonal fluctuations, which over the period of monitoring have ranged up to more than 5m.
- Eastern/southeastern impact area:
    - The maximum drawdowns attributable to the quarry operations to the east/southeast of the quarry were observed at monitoring bores CQ10 and MW9, located 10m and 40m from the eastern crest of the quarry pit wall, and both within the quarry site. Maximum observed drawdowns to the end of 2018 were 3.2m and 2.4m respectively.
    - A smaller drawdown impact considered likely to have been attributable to the quarry operations has been observed at private bore CP8, located 165m east of the quarry, with the maximum probable impact to the end of 2018 interpreted to be 2.1m.
    - Smaller drawdowns may have occurred at greater distance from the quarry, but there are no more distant monitoring bores beyond CP8.
    - The magnitude of drawdown effect around the south-eastern corner of the quarry is smaller than the normal seasonal fluctuation in groundwater levels in those bores due to recharge and natural discharge.
- Apart from these two localised impacts, no other off-site bore shows any impact attributable to the quarry activity.
- The water level data trends continue to show a close correlation with the trends on the RCD Curve, indicating that rainfall recharge and natural discharge are the primary influences on groundwater levels.

4.2 Groundwater Quality

Groundwater salinity (electrical conductivity EC as µS/cm) at each monitoring bore at April 2019 is shown plotted on **Figure 5**.

The groundwater has low salinity, with measured electrical conductivities generally less than 200 µS/cm, and frequently less than 100 µS/cm. The lowest salinities are observed in the monitoring bores to the south of the quarry (where the land is mainly forested), and the highest in the bores to the north of the quarry (where the land is largely cleared). This may be a consequence of the more active land use practices to the north of the quarry.

The groundwater has a slightly acidic pH, generally between 4 and 6 (**Figure 6**).

Some changes in both EC and pH have been observed over the period of monitoring, the most notable being a gradual reduction in salinity in the bores to the north of the quarry, from typically between 200 and 300 µS/cm EC in 2006-2009 to generally between 100 and 200 µS/cm EC in 2016-2019 (**Figure 7**).

Elevated nitrate has been a feature of the groundwater, but only in areas to the north and east of the quarry site. The nitrates are believed to be derived from fertiliser use, and possibly also from intensive chicken farming in the past. There has been a noticeable decline in the nitrates in groundwater samples from bores to the north of the quarry over time (**Figure 8**), most likely due to a reduction in fertiliser use, or possibly the cessation of chicken farming.

No off-site water quality impacts attributable to the quarry operations have been observed. All changes in groundwater quality over time outside of the quarry site are believed to be related to changing land use practices on the private properties to the north of the quarry.

5 FUTURE EXTRACTION PROPOSALS

The quarry status as at April 2019 is depicted on **Figure 2**. The elevations shown in Stages 3/4, 3/5 and 3/6 (RL179, RP188 and RL198 respectively) refer to the lowest level of extraction reached in those three cells. The elevations shown in Stages 3/1, 3/2 and 3/3 refer to the top of backfilled tailings/rejects as at April 2019.

Future operations will involve the completion of extraction from Stage 3/5, and the resumption of extraction from Stage 3/6, with both stages being taken down to final bottom elevation of RL179.

Tailings deposition will continue to the Stage 3/3 – Stage 3/4 storage area.

Former extraction and tailings deposition areas will continue to be progressively rehabilitated.

The current monitoring program will continue until completion of extraction from the quarry, and post-closure, in accordance with Consent Condition 19 (Quarry Closure Groundwater Management Plan), Condition 40 (Quarry Exit Strategy), and as detailed in this Closure Plan.

6 GROUNDWATER MODELLING

Groundwater modelling was undertaken in 2018 specifically to predict groundwater impacts from the quarry operations through to the completion of sand/sandstone extraction, and thereafter for the post-closure period until equilibrium is re-established.

The sand quarrying operation is approved subject to a 2017 Modified Development Consent (Minister for Planning, 2017). The Modified Consent references groundwater modelling conducted in support of the initial project application, in reports appended to the 2004 EIS (Corkery, 2004) and amended application (Corkery, 2005). The formal project approval was signed on 28 October 2005. The modelling which formed the basis for the project approval was undertaken by C M Jewell and Associates (2004a and 2004b). However, over the years since the project was approved, several new modelling exercises were undertaken, which effectively supersede the 2004 Jewell modelling.

In the following sections, each phase of modelling is described briefly, to demonstrate the improvements with each new modelling phase, to assist in understanding why it is necessary to rely on more recent modelling to assess the potential impacts of the completion of extraction and the post-closure recovery period.

6.1 2004 EIS Modelling

The initial groundwater modelling for the Calga Sand Project was undertaken by C M Jewell and Associates as part of the studies for the 2004 Consent. The 2004 Development Application (DA94-4-2004) was for an extension (Stages 3 and 4) to the prior quarry. Stage 3 was contained within the existing property boundary, while Stage 4 involved an extension to the north-west.

Initially, simple analytical models were used "to provide context and a reality check on the subsequent numerical modelling". A finite element numerical modelling approach was then adopted, "using a combination of two models – a two dimensional, sectional (2D-S) finite element model and an axisymmetric finite element model" (Jewell, 2004a).

The results of the Jewell modelling formed the basis for the 2004 project approval. However, this modelling is considered to be of little value to the post-closure impact assessment, because it was done for an extraction plan that included quarry expansion to the northwest of the current quarry, within land that is now the Power property (referred to in the Application as Stage 4). Hence, the model focussed on impacts mainly to the north and northwest, beyond a proposed quarry boundary that would have been up to 350m northwest of the current quarry boundary. [The quarry extent proposed in the 2004 EIS is shown approximately on **Figure 1**.]

As this northwest quarry extension was not approved, the model predictions significantly overstate the impacts from the quarry as it has been developed. The Jewell report also did not discuss potential impacts to the east and south.

6.2 2005 Amendment Modelling

After submission of the 2004 EIS, the proponent proposed a revised development limited to the area of the current quarry, ie the Stage 3 area only, as depicted on **Figure 1** and **Figure 2**. The revised impacts for this were reported in Corkery (2005).

For the amendment, C M Jewell and Associates carried out 3-dimensional modelling of the quarry. This was reported in Jewell (2004b), and was included as Annexure 1 of Corkery (2005).

Jewell used the Seep3D finite element modelling code, and was run initially in steady state mode to replicate pre-extraction conditions, and starting heads for a subsequent transient simulation.

The transient simulation was run for a 28 year quarry life, however it assumed that full extraction from the quarry occurred instantaneously at the commencement of Year 1 of the model simulation. This is unrealistic, as it does not allow the prediction of progressive water level impacts as the quarry is progressed both laterally and to depth in each Stage. Instantaneous full extraction would significantly overstate impacts, and Jewell described it as a worst case scenario.

The Jewell (2004b) report presented drawdown distribution around the quarry at the end of 28 years (ie the end of the modelled extraction period); as well as a steady state prediction to represent the long-term post-extraction equilibrium conditions. These predictions formed the basis of the 2005 Development Approval.

The results of the 2005 Amendment modelling are not considered to be relevant to the present study, as the Jewell model has been superseded by a superior model developed by HydroSimulations (formerly known as Heritage Computing).

6.3 2009 Southern Extension Modelling – Golder Associates

An Environmental Assessment (EA) was prepared by R W Corkery and Associates for a proposed southern extension into the property immediately south of the existing quarry – Major Project Application 06-0278 (Corkery, 2009). The southern extension involved two areas to the south of the approved quarry, referred to as Stage 4[2] (between the quarry and an unnamed west-flowing tributary of Cabbage Creek) and Stage 5 (south of that tributary).

In support of this EA, a groundwater impact assessment report was prepared by GeoTerra (2009) which was included in Volume 1 of a Specialist Consultant Studies Compendium appended to the main EA document. Predicted impacts from the proposed quarry extension were assessed with the aid of groundwater modelling, which was undertaken for GeoTerra by Golder Associates. The Golder modelling report (Golder, 2009) was appended to GeoTerra's report as Appendix A.

The groundwater modelling undertaken by Golder used the Feflow code. Felfow is an industry standard 3-dimensional finite element model, which enjoyed relatively wide use at that time. The modelling approach followed by Golder is documented in their report (Golder, 2009), but in summary was as described below.

Initially, the model was run in steady state to calibrate the model against the observed groundwater conditions that prevailed at that time (ie pre-development conditions, based on bore water levels that were considered to be unaffected by quarrying).

Subsequent to calibration, four further steady state model runs were undertaken, to represent progressive stages of proposed quarry development, viz:

- Run 1 – Assumed full extraction of existing quarry (Stage 2) and Stage 3, with all parts of the quarry floor at 189 mAHD.
- Run 2 – Assumed full extraction of Stage 4, using the heads generated from Run 1 as starting condition, with all parts of the Stage 4 quarry floor at 141 mAHD.
- Run 3 – Assumed full extraction of Stage 5, using the heads generated from Run 2 as the starting condition, and with all parts of the Stage 5 quarry floor at 146 mAHD. This run was to represent groundwater conditions at the completion of quarrying.
- Run 4 – Post-closure conditions, based on assuming no further water removal from Stages 2, 3 and 4 (ie allowing water level recovery into those stages), and a final void in Stage 4 (represented by increasing the hydraulic conductivity of the mined out Stage 5 to 1000 times higher than pre-extraction conductivity).

No transient modelling was undertaken.

The results of this modelling were considered to be insufficient for approval, for the following main reasons:

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[2] Not the same as the Stage 4 included in the original 2004 EIS.

- No transient modelling was undertaken. Therefore the model was not able to predict progressive impacts, and may not have predicted the maximum impacts.
- Extraction was assumed to have occurred instantaneously at the start of each model simulation run, rather than progressively as would occur in practice. Therefore, the model did not allow staged impacts to occur in accordance with a progressive extraction schedule.
- Each Stage was assumed to have a uniform floor elevation across the entire area of that Stage. This was not a realistic representation of the actual extraction proposed, where a floor generally grading to lower elevations in the downslope parts of the quarry was likely.

A revised Preferred Project Report (PPR) was submitted in 2012 (Corkery, 2012), which included the above groundwater assessment by GeoTerra (2009) and groundwater modelling by Golder Associates (2009). Following an independent review by Kalf and Associates (2013), the groundwater impacts were re-assessed using a new groundwater model set up by Heritage Computing. This modelling was presented in Heritage Computing (2013).

6.4 2013 Heritage Computing Modelling

The groundwater model set up by Heritage Computing in 2013 has been used for all subsequent groundwater impact assessments. Initially the model was used to assess the impacts of the proposed southern extension (Stage 4 and Stage 5), reported in Heritage Computing (2013). It was then used for a revised proposal for a southern extension involving only Stage 4. This modelling was reported internally and has not been included in any published document.

Finally, the model has been used again to assess the remaining operations to closure, and post-closure recovery of the approved quarry operations, ie with only Stage 2 (completed) and Stage 3 (nearing completion). That modelling has not been reported, but the results are outlined below in **Section 6.6**.

As only the original 2013 modelling has been included in a published report, the basic details of the model structure as reported by Heritage Computing (2013) are summarised here. These details also apply to the 2018 closure and post-closure modelling, the results of which are discussed in detail in **Section 6.6**.

6.4.1 Model Structure – Heritage Model

The model as described in Heritage Computing (2013) is summarised as follows:

Compliance with Guidelines

- Modelling was conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012), with reference also to the earlier 2001 MDBC Groundwater Flow Modelling Guideline (MDBC, 2001).

Software

- Modelling was undertaken using the Groundwater Vistas (Version 6.22) software interface (Environmental Simulations Inc, 2011) in conjunction with MODFLOW-SURFACT (Version 4) distributed commercially by Hydrogeologic, Inc. MODFLOW-SURFACT is an advanced version of the MODFLOW code developed by the USGS (McDonald and Harbaugh, 1988), which is the industry standard for groundwater modelling.
- The Heritage model is based on a conceptual model depicted schematically in **Figure 9** (reproduction of Figure 7 from Heritage Computing (2013)). The dominant recharge processes in the aquifer system are infiltration from rainfall and runoff, while the dominant natural discharge processes are evapotranspiration, seepage face flow, spring outflow and baseflow to the local creeks (Heritage Computing, 2013). During extraction of the friable sandstone, groundwater would also discharge to the quarry, and there may be some reduction in creek baseflow.

- The main groundwater system occurring within and around the Project Site is the Hawkesbury Sandstone, a relatively flat-lying medium- to coarse-grained sandstone up to 250 m thick. 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.

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

Model Extent

- The groundwater model area was large enough to allow investigation of cumulative extraction effects 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 10** (reproductions of Figures 8 and 9 from Heritage Computing (2013). The area of coverage is 40 km east-west by 30 km north-south, a total of 1200 km^2.

Model Geometry

- The model comprises 10 model layers, each comprising 106 rows and 116 columns. Quarrying occurs only in the two uppermost layers, and the lower layers were included to allow good resolution of streams and baseflows across a wide range of topographic elevations.
- The Hawkesbury Sandstone is represented by model layers 1 to 7 while the Narrabeen Group occupies model layers 8 to 10. 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 model layers are depicted in cross-sections in **Figure 11** (a reproduction of Figure 10 from Heritage (2013)).
- The top two layers (1 and 2) comprise the friable sandstone (soft and medium) that is being 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.
- 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.

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 12**, which is a reproduction of Figure 11 from Heritage (2013)). The Hawkesbury River, its tributaries, Brisbane Water and the ocean 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 13**). The RIV package was defined in the model with stream stage equal to the streambed and to only allow 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 water table 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 m^2/d, with median 2,000 m^2/d. The hydraulic conductivity of the streambed varies from 0.05 to 1 m/d for stream widths from 2 to 100 m.

- "Drain" cells using the MODFLOW DRN package are used to represent sand 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/d to eliminate any resistance to flow.
- Rainfall recharge has been imposed as a percentage of actual rainfall for the transient calibration, while for the two prediction simulations the long-term average rainfall has been used, with specific percentages assigned across eight zones associated with the three major lithologies:
  - Alluvium,
  - Hawkesbury Sandstone, and
  - Narrabeen Group,

  as shown in **Figure 14**, which is a reproduction of Figure 13 from Heritage (2913).
- The recharge rates determined during the regional Kulnura model calibration (Alkhatib and Merrick, 2006) were used as initial estimates in the Calga model. They range from 5% to 25%.
- Evapotranspiration has been applied uniformly using MODFLOW's linear function, with a maximum rate of about 60 mm/a and an extinction depth of 3 m. These are the parameters that had been used in the regional Kulnura model (Alkhatib and Merrick, 2006).

6.4.2 2013 Simulations

Heritage Computing (2013) described four separate simulations that were run:

A. *Steady State calibration model*

   Initial calibration of hydraulic conductivities to match the regional groundwater levels and hydraulic gradients, using data unaffected by extraction.

B. *Transient calibration model*

   Calibration of groundwater system properties against bore water level responses to dynamic monthly rainfall recharge, for all available bores.

C. *Transient prediction run – sand extraction phase*

   Simulation of the annual progression of sand/sandstone extraction and backfilling with waste and tailings, 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 concurrently;

   to allow for both specific Calga impacts and cumulative impacts with other nearby quarries.

D. *Transient prediction run – post-extraction recovery.*

Simulation of progression to equilibrium groundwater levels post-closure for the final landform and pit voids.

The two transient prediction simulation models (Model C) used the TMP facility in MODFLOW-SURFACT to allow conductivity and storage properties to be updated each stress period, to simulate the progressive extraction and backfilling activities.

The transient calibration Model B ran from January 2007 to December 2012 in monthly steps, simulating extraction during that period from Stages 3/1, 3/2 and shallow part of 3/6. The transient prediction Model C ran for 25 years from 2013 to 2037 in annual steps for progressive extraction and backfilling of the remaining extraction cells in Stage 3 (2013 to 2019), Stage 4 (2013 to 2034) and Stage 5 (2030 to 2037). Transient Model D ran for a 200 year period from 2037 to 2237.

The results of the 2013 modelling are not appropriate for assessing long-term post-closure impacts and progressive recovery of water levels, as that modelling assumed the extraction of southern extension Stages 4 and 5, as well as Stage 3. Stages 4 and 5 were ultimately not approved, and no re-run of the model was undertaken for only Stage 3 at that time.

6.5 2014 Modelling

In 2014, during the approval process, the model was run for Stages 3 and 4 only, but the results were not reported. This was the same model used in the 2013 modelling, but without Stage 5 (2030 to 2037). A sensitivity analysis was also carried out. Relevant parts of the 2014 modelling results were summarised in Merrick (2014).

6.6 2018 Modelling

As the modelling in 2013 and 2014 did not address impacts for only Stage 3, HydroSimulations (current trading name of Heritage Computing) was engaged in May 2018 to re-run the 2013 Heritage model to provide up-to-date predictions of impact from the quarry towards its projected closure and post-closure. A summarised description of the model structure is presented in **Section 6.4.1**, and a more detailed description can be found in Heritage (2013).

The results of the 2018 modelling have been provided to Dundon Consulting for incorporation into this Closure Plan. HydroSimulations did not prepare a standalone report on the 2018 modelling.

The 2018 modelling comprised two model runs, viz:

1. **Calibration:** A six-year transient calibration run, from January 2013 to December 2018, matching the model-predicted water levels to observed levels at each bore in the monitoring network.

2. **Prediction:** A 208-year transient run, firstly from January 2013 to December 2020 (completion of extraction from Stage 3/5 and Stage 3/6), and then from January 2021 to December 2220 (200 years recovery post-closure).

Both transient runs (calibration and prediction) were run for two scenarios, one with the approved Stage 3 sand extraction, and one with no quarrying. The difference between the two scenarios has been used to determine the impacts of the quarry operation only, independent of any climatic (rainfall) effects.

6.6.1 Transient Calibration

The transient calibration was conducted for the time period January 2013 to December 2018, with six annual stress periods, and time step output at 100, 200, 300 and 365 days in each stress period. Initial hydraulic property values and initial heads were those generated in the 2013 transient calibration modelling, described in detail in Heritage Computing (2013).

Even though a transient calibration had already been carried out for the model, this new transient calibration was necessary because the earlier calibration conducted in 2013 for the period 2006 to

2013 used surface elevations at a number of bores to the north and north-west of the quarry which were not surveyed, but were estimated from surface contours. These bores were surveyed in 2014, and the correct surface elevations have been used to derive more accurate actual groundwater levels than were used in the 2013 model calibration[3].

The quarry conditions adopted for the commencement of the 2018 transient calibration run are those depicted on **Figure 15** for 2013. Progressive development of the quarry for the full calibration period in the model is based on the changing quarry status as depicted in **Figures 15**, **16** and **17**.

Actual annual rainfall totals from the Mangrove Mountain BoM station 061375 (15.6 km from Calga Sand Quarry) were used in the calibration run.

Observed water levels in all Hanson monitoring bores and neighbouring water supply bores which are routinely monitored by Hanson, were used as calibration points for the model calibration. The model also included transient calibration against all DPI-Water observation bores located inside the model domain (ie GW075012-1, GW075012-2, GW075013-1, GW075013-2, GW075013-3, GW075038-1, GW075038-2, GW080165, GW080166, GW080167 and GW080168), as well as the Hanson bores.

Minor adjustments were made to some hydraulic parameters to achieve a satisfactory calibration, which resulted in calibration statistics of 4.0 %RMS and 2.6 mRMS. This calibration conforms with the Australian modelling guideline (Barnett, et al, 2012).

Calibration hydrographs for each bore (ie comparative plots of observed vs model-predicted water levels for the period January 2013 to December 2018) are shown in **Appendix A**.

The calibration hydrographs show good correlation in most instances, however there are some that show good calibration in shape but some divergence in absolute levels. These divergences may be due to a number of factors or a combination of them, including:

- The finite size of each model cell which range from 50m x 50m near the quarry to 500m x 500m at the model boundaries. The actual water level can vary by several metres across the width of a model cell, whereas the model will predict a single water level that applies to every point within that cell. Two bores located within a single model cell may report different water levels, but both will be calibrated against the same single predicted value for that cell. Further, a bore located close to the edge of a model cell will be calibrated against the predicted value for that cell.
- The heterogeneous nature of the aquifer system and the simplifications inherent in the model layer setup. The Hawkesbury Sandstone contains many permeable fractured zones, and it has been subdivided into a small number of model layers, each of which may equate to a thickness of strata that contains a number of separate fracture zones, some very thin, each with its own water level.

  There is some imprecision in the assigning of a bore to a particular model layer. [Based on layer thickness, both CQ11S (38m deep) and CQ11D (65m deep) are assigned to Layer 2 in the model. The deeper CQ11D consistently reports a water level 1-2m lower than CQ11S, but the model predicts the same water level for both, as they are in the same model layer. Similarly for CQ8 (27m deep) and CQ12 (15m deep) – both were assigned to Model Layer 2, but have water levels consistently more than 3m different. In both cases, the shallower bore may have calibrated better if it were assigned to Layer 1 instead of Layer 2.]

[3] The 2013 model calibration was based on water levels that at some bores were derived from approximate surface elevations estimated from surface contours, rather than a field survey. The affected bores were re-surveyed in 2014, and it was found that some of the estimated surface elevations were in error, generally by less than 2.5m, but in one case by 11.1 m (CQ10) and in another case by 5.5 m (CP8). Hence it was considered necessary to re-calibrate the model with water levels based on the 2014 survey data.

And secondly, the model will predict a single water level for the entire model layer in that cell, even though there may in reality be several different water levels due to the presence of multiple discrete fracture zones. A bore that is screened across part of a model layer may report one of the distinct water levels from a particular fracture zone or a composite of several such zones, and may therefore be a few metres higher or lower than the model predicted water level for that model cell.

Further, the simulation of rainfall was also simplified such that average rainfalls were assumed across each time step (ie time steps in each year of 100, 100, 100 and 165 days respectively). Thus, the prediction hydrographs are much smoother than the observed hydrographs, which respond to actual daily rainfalls.

Hence, some error in the absolute water level predictions does not mean a poor calibration. It is more important that the predicted water level fluctuations are generally parallel with those observed, which shows a consistency of response to the stresses, either rainfall recharge stresses or quarry dewatering stresses.

Bore CQ3 (**Figure A1**) shows a divergence of approximately 5m between modelled and actual water level, but a consistent fluctuation over time. Bores CQ12 (**Figure A4**) and MW8 (**Figure A9**) show a similar divergence of 3m and 4m respectively, but with trends that are consistent between the modelled and actual water levels.

Bores CQ4 (**Figure A2**), CQ5 (**Figure A3**) and CQ7 (**Figure A3**) all show greater predicted drawdowns in 2017 and 2018 than observed. This has arisen because the model has been conservatively designed to simulate impacts in advance of actual impacts, by assuming that the drains are activated at the final extracted depth for a particular stress period from day one of that stress period. Further, in the model it was assumed that Stage 3/5 would be fully extracted down to RL179 by the end of 2017, and Stage 3/6 would be fully extracted down to RL179 by the end of 2018. In reality, in mid-2019, Stage 3/5 has only progressed to RL188, and Stage 3/6 remains at RL198.

Bores east of the quarry CQ10, MW9 and CP8 (**Figure A7**) show reasonable overall calibration, but all three actual water level hydrographs show increased drawdown in 2017-18 which is not matched by the modelled water levels. The model assumed that extraction from Stage 3/3 would have finished at the end of 2016, and from 2017 the water level in Stage 3/3 would have been elevated instantaneously by the deposition of tailings. However, extraction from Stage 3/4 was in progress at the time, and it is believed that the combination of underestimating the effects of this, and over-estimating the effect of tailings deposition into Stage 3/3, led to a prediction of higher water levels locally during 2017 and 2018.

Other bores north of the quarry Bores CQ11S and CQ11D (**Figure A2**), CQ9 (**Figure A3**), CQ6 and CQ8 (**Figure A4**) and CQ13 (**Figure A5**) all show good calibration. Bores south of the quarry, MW10, MW13 and MW16 (**Figure A8**), MW7, MW8 and MW17 (**Figure A9**) show good calibration, although there is a difference of about 5m in absolute water level values at MW8.

Private bores north of the quarry CP3 and CP4 (**Figure A5**), and CP5, CP6 and CP7 (**Figure A6**) all show good overall calibration between actual and predicted water levels. However, the observed water levels at the private bores show much more fluctuation than the Hanson monitoring bores in that area. This is a consequence of the private bores being periodically used for water supply pumping, causing the water levels to fluctuate in response to the pumped extraction. Without knowledge of when each private bore was pumped, and the pumping volumes involved, it was not possible to simulate the effects of private bore pumping in the model, so this has been ignored in the transient calibration modelling. This is a conservative approach for the purpose of predicting potential impacts from the quarry.

6.6.2 Transient Prediction Modelling for Period to Closure and Post-Closure

The post-project prediction model was run as an extension of the transient calibration run, and was run for a total simulation period of 208 years, ie from January 2013 to April 2220. This simulation covers the remaining sand/sandstone extraction, followed by a 200 year recovery period post completion of extraction. It was assumed that extraction would be completed by the end of 2019. In reality, actual extraction is up to 2 years behind the modelled schedule.

The stresses assumed in the model up to the end of 2018 were the same as for the transient calibration model. This had both extraction and rainfall varying between stress periods according to actual rainfall and actual extraction/backfilling. Thereafter to the end of extraction, the only time-varying stress in the prediction model is extraction, with rainfall applied at constant long-term average rates, and creeks simulated as non-recharging rivers. This allows clear definition of extraction effects which are not confused by climatic contributions. For the post-extraction recovery, constant long-term average rainfall was assumed, ie no time-varying stresses.

The modelling predicted quarry inflow rates, water levels and stream baseflows, for the remaining extraction period and thereafter to the end of the recovery period in 2220. These results are discussed in **Section 7**.

7 MODEL PREDICTIONS

7.1 Inflows

Groundwater inflows to the quarry predicted for the calibration period, followed by the completion of extraction and the post-extraction period are shown on **Figure 18**.

The quarry inflows were predicted to have generally declined from the peak inflow of 52 kL/d in the first quarter of 2014 to 20 kL/d at the end of 2016, coinciding with completion of extraction from Stages 3/3 and 3/4. An increase through 2017 and 2018 was predicted, coinciding with the resumption of extraction from Stage 3/5 to a new peak rate of 40 kL/d in the first quarter of 2018. Thereafter, inflow rates were predicted to decline rapidly through 2018 and 2019 to zero once extraction was assumed to cease at the end of 2019.

As the actual extraction schedule has lagged behind that assumed, inflows will likely continue beyond the end of 2019, but at a rate consistent with those predicted by the modelling for 2018 and 2019, ie declining from about 30 kL/d to 10 kL/d or less.

There are minimal signs of actual seepage observed within the quarry. What inflow does occur is visible as minor zones of wetness in places around the pit faces, or is masked by internal runoff from rainfall within the pit area that accumulates in low points within the quarry.

No pit inflow is predicted to occur once sand/sandstone extraction ceases, when the water table will naturally start to recover into the unconsolidated material on the pit floor and in waste stockpiles.

7.2 Groundwater Levels

The groundwater levels predicted by the model are presented in **Appendix B** as hydrographs and in **Figures 19** to **22** as contour plots at periodic dates.

Hydrographs are presented in **Appendix B** for all Hanson monitoring bores and the private water supply bores. Even though the simulation extended to 2220, the plots in **Appendix B** extend only to 2053, as all hydrographs have reached equilibrium well before this date. The plots show the full record of actual water levels as well for comparison. The water level record extends from 2001 for the first four bores CQ1 to CQ4, and from 2006 for most of the others.

The prediction hydrographs display a steady water level with none of the seasonal fluctuation that is observed on the superimposed hydrographs of actual monitored water levels. The prediction modelling has assumed a constant average rainfall, which evens out the natural fluctuation in response to rainfall. The prediction model simulation assumed changes to the extraction locations and depths up to the end of extraction, but thereafter no time-varying stresses area assumed.

The drawdown contours in **Figures 19** to **22** show the spatial distribution of drawdown or residual drawdown at four dates:

- End of 2017 (**Figure 19**)
- End of 2019 (**Figure 20**)
- End of 2025 (**Figure 21**)
- End of 2040 (**Figure 22**).

These contour plots have been derived from the difference between the “with Stage 3” and the “without Stage 3” simulations.

As water levels in all monitoring bores are predicted to have reached equilibrium by 2030 or earlier, the contour plots after 2040 are identical. **Figure 22** shows that there will be a permanent residual drawdown remaining after the completion of quarrying. The residual drawdown is less than 2.0m in all areas apart from a very small area immediately east of bore CQ10, and a slightly larger region extending up to 145m south of the quarry site, but within the property formerly proposed for a southern extension of the quarry. In these two areas, residual drawdown is predicted to be more than 2.0m but less than 5.0m.

To the east, north and northwest of the quarry, where all of the private bores are located, residual drawdowns at 2040 and thereafter are predicted to be between 0.1m and 1.0m. There is a small region west of Stages 3/6 and 3/2 (**Figure 22**) where permanent residual drawdowns are predicted to be greater than 1.0m, but less than 2.0m. There are no private water supply bores located within this zone.

7.2.1 West and Southwest of Quarry (Downgradient)

Monitoring bores CQ3 and MW10 are located within this zone. There are no private bores downgradient of the quarry.

Bore CQ3 prediction hydrograph (**Figure B1**) shows negligible long-term upward or downward trend, and both the actual and predicted water levels fluctuate over a range of less than 1.0m. The long-term water level is predicted to fluctuate within the same range of fluctuation as applied at the start of monitoring (2001).

The groundwater level at the CQ3 site at the start of monitoring (2001) reflects two things:

- Residual impact from quarrying before 2001, as CQ3 is located adjacent to the initial quarry area (Stage 1); and
- Proximity to the downstream water storage Dam 7.

During the Stage 3 extraction program under the Consent, all extraction and backfilling has been carried out at some distance upgradient from CQ3. As a result, CQ3 is not highly responsive to the quarrying (due to remoteness) and the moderating effect of the continuous presence of water in Storage Dam 7 (**Figure 1**) at a water level of RL172. This moderating effect of the water in Dam 7 is predicted to continue after completion of extraction.

There is predicted to be a small residual drawdown at bore MW10, of between 0.1m and 1.0m. However, this magnitude of residual drawdown is not perceptible on the hydrograph (**Figure B1**), and is only detectible on the contour plot (**Figure 22**).

The monitoring indicates that impacts from quarrying under the Consent at the downgradient area have been negligible to date. The post-closure model prediction is for this to continue.

7.2.2 North of Quarry

This region contains private bores CP4, CP5, CP6, CP7, CP13, CP14 and CP15 and former bore CP3. The Hanson monitoring bores in this region are CQ4, CQ5, CQ7, CQ8, CQ11S, CQ11D, CQ12 and CQ13, and former bores CQ6 and CQ9.

The prediction hydrographs for bores CQ4, CQ5, CQ6, CQ7, CQ8, CQ9, CQ11S and D, CQ12 and CQ13 (**Figures B2** to **B5**) all show water levels continuing to decline until the completion of extraction, before starting to recover. The remaining extraction activity will be taking place solely in Stages 3/5 and3/6, the closest part of the quarry to this group of bores, and the ongoing water level decline will be in response to the progressive deepening of the quarry in these final two Stages of the project.

The prediction hydrographs for the private bores (**Figures B5** and **B6**) likewise show further drawdown will occur during the extraction of Stages 3/5 and 3/6, but they too will all recover rapidly once extraction has been completed. The largest drawdown impact is predicted to occur at the location of the former bore CP3[4] (**Figure B5**). The residual drawdown at that site is predicted to be

[4] CP3 has been removed from use and the site ploughed over.

more than 0.1m but less than 1.0m (**Figure 22** and **Figure B5**). Smaller residual drawdown are predicted at the other private bores, within the same range (ie 0.1m to 1.0m).

Water levels are predicted to reach equilibrium by 2030 or earlier in all bores.

7.2.3 East of Quarry

Bores east of the quarry include private water supply bore CP8, and monitoring bores CQ10 and MW9.

The CQ10 and MW9 hydrographs (actual water levels on **Figure B7**) show that water levels fell to the end of 2015, rose in 2016, then fell again until mid-2018, before starting to recover again from mid-2018 into 2019. The prediction hydrographs calibrate very well against this, but are offset by about 12 months, as the model assumed that extraction ceased in 2014 from Stage 3/3, whereas it ceased one year later at the end of 2015. This pattern is more muted at CP8, as it is further away from the quarry. However it too shows the start of recovery occurred at the end of 2018 (**Figure B7**).

All three bores are predicted to undergo significant water level recovery, reaching equilibrium before 2035. The equilibrium water level is predicted to be 2m to 5m higher than current water levels (**Figure B7**). The long-term residual drawdown is predicted to be around 0.1m at CP8 and MW9 and around 2m at CQ10 (**Figure 22**).

7.2.4 South of Quarry

Two groups of monitoring bores are located south of the quarry – bores MW13 and MW16 between the quarry and the unnamed tributary of Cabbage Tree Creek referred to as Reach 3 in the baseflow impact predictions (see **Section 7.3** below), and bores MW17, MW7 and MW8 beyond (south of) this tributary (see **Figure 22** for bore locations). There are no private water supply bores within 500m to the south of the quarry.

The actual water level hydrographs of both MW13 and MW16 (**Figure B8**) show negligible response to quarrying and minimal response to rainfall recharge events. Likewise, the predicted impacts for the remaining sand/sandstone extraction are minimal. The small predicted decline at MW16 between 2013 and 2017 is due to below average rainfall during that period, rather than a predicted quarry impact. Hydrographs for bores MW7, MW8 and MW17, all located south of the Reach 3 creek system, show no impact from quarrying (**Figure B9**).

Drawdown recovery post-extraction is predicted to be incomplete immediately south of the quarry, and a permanent residual drawdown of between 0.1m and more than 2.0m is predicted for a region extending up to 400m from the boundary of the quarry property (**Figure 22**). This zone of permanent residual drawdown is mostly contained within the property formerly proposed for a southern extension to the quarry, however the zone of residual drawdown extends to the west (75m into Glenworth Valley property) and to the east (100m across the eastern property boundary to the eastern side of Peats Ridge Road). The residual drawdown in these two zones is predicted to be between 0.1m and 1.0m, and will not be detectible against the natural water table fluctuations.

7.2.5 Summary of Water Level Impacts

Post-extraction drawdown impacts at each of the private water supply bores within 500m of the quarry are summarised in **Table 5** below.

These predictions are based on a combination of observed impacts to date, and the recovery prediction modelling results (hydrographs and contour plots). The maximum drawdown impact at the private bores is predicted to occur at or close to the completion of extraction. There may be a small lag for more distant bores, and the maximum drawdown at CP8 has probably already occurred, since extraction from Stage 3/4, the nearest part of the quarry to CP8, has already ceased.

Table 5: Predicted Maximum Drawdowns and Long-Term Residual Drawdowns

Private Bore	Property	Approximate Distance from Quarry Site (m)	Maximum predicted drawdown (m)	Long-Term Residual Drawdown (m)
CP1	Power	500	~0.2	<0.1
CP2	Power	450	~0.3	<0.1
CP3 (gone)	Power	15	7.4	0.8
CP4	Kashouli	110	3.6	0.7
CP5	Kashouli	175	1.5	0.5
CP6	Kashouli	200	2.0	0.4
CP7	Kashouli	290	1.1	0.4
CP8	Rozmanec	150	0.9	<0.1
CP13	White	220	~1.0	0.3
CP14	King	85	~1.8	0.6
CP15	Glenworth Valley	460	~0.2	<0.1

7.3 Baseflow Impacts

Baseflows have been determined from the groundwater model for a the surface streams around the Calga Quarry. These streams were subdivided into a number of specific reaches to enable individual catchments to be assessed separately. The reaches adopted for the simulations are shown on **Figure 13** as they are represented in the model. They are the same reaches that have been used in all HydroSimulations modelling since 2013. Reaches close to the quarry are shown on the topographic map on **Figure 23**.

The impacts of the completion of sand/sandstone extraction have been determined by calculating the difference between baseflows with the "with Stage 3" and "without Stage 3" model runs. The impacts up to completion of extraction and residual impacts post-extraction are plotted on **Figure 24**, and summarised in **Table 6** below.

Table 6: Predicted Baseflow Impacts – Completion of Extraction and Post-Closure

Reach	Maximum Baseflow Reduction		Date of Maximum Impact	Long-Term Equilibrium Baseflow Reduction	
	kL/d	%		kL/d	%
Reach 3 (Creeks A, B and C – Cabbage Creek Tributary south of Quarry)	3.74	0.054	2019	2.56	0.037
Reach 501 (Mooney Mooney Creek Tributaries)	2.25	0.049	2021	0.60	0.013
Reach 5 (Cabbage Tree Creek)	1.80	0.593	2021	0.87	0.290
Reach 2 (Popran Creek Upper)	0.36	0.005	2019	0.14	0.002
Reach 500 (Mooney Creek Upper)	0.33	0.006	2020	0.13	0.002
Reach 1 (Popran Creek)	0.16	0.007	2020	0.07	0.003
Total	**8.43**	**0.042**	**2019**	**4.36**	**0.022**

Baseflow impacts are largest in Reaches 3 (Creeks A, B and C – tributary of Cabbage Tree Creek), 5 (Cabbage Tree Creek) and 501 (Mooney Mooney Creek Tributaries) – see **Figures 13** and **23**. However, impacts in all catchments are small in absolute terms, and are predicted to reach a combined maximum reduction in baseflow of 8.4 kL/d, which is a 0.04% reduction in the total baseflow of the six catchments listed in **Table 6**. Other reaches defined on **Figure 13** reported negligible change in baseflow or streambed leakage.

In percentage terms, the largest impact is predicted for Reach 5 (Cabbage Tree Creek), which is predicted to reduce by up to 0.59%, with the impact peaking in 2021 (ie 2 years after the simulated completion of extraction – 2019). In any event, the percentage reduction is well below 1% of the total baseflow in Cabbage Tree Creek.

Post-closure, baseflows are predicted to recover, but not completely. Equilibrium baseflows are predicted to develop by 2050 or earlier, and will continue into the long-term as a permanent reduction in total baseflow of 4.4 kL/d, which is 0.02% of the total baseflow in the affected catchments. The largest residual impact is predicted to be in the tributary catchment immediately south of the quarry (Reach 3 – Creeks A, B and C). In this catchment, long-term baseflow reduction is predicted to be 2.56 kL/d, or 0.04% of the normal baseflow. The long-term impact in the Cabbage Tree Creek catchment (Reach 5) is predicted to be the largest in percentage terms at 0.29% or 0.87 kL/d.

In summary, the total baseflow reduction due to the quarry operations is predicted to peak at 8.4 kL/d (3.1 ML/a) during the final year of extraction, and then to steadily recover post-closure to a long-term equilibrium reduction of 4.4 kL/d (1.6 ML/a). In percentage terms, the peak baseflow impact is predicted to be 0.04% of normal average baseflows, and the permanent long-term impact would be a reduction of 0.02%.

It should be noted that the HydroSimulation 2018 modelling has addressed only the impacts on baseflows from the start of the simulation (2013). The detailed catchment assessment of baseflow impacts was not undertaken during any of the earlier model calibrations (up to 2014), and the above impacts need to be added to any existing impacts prior to 2013. However, as the baseflow impacts are a direct consequence of lowered groundwater levels, the maximum baseflow impacts would occur at the time of greatest groundwater level impact, which is during the extraction to final depth in Stages 3/6 and 3/5. Hence the impacts predicted by the 2018 modelling are considered to be a reliable indication of the likely maximum baseflow impacts of the quarry operations, and long-term equilibrium baseflows.

8 MONITORING AND MANAGEMENT

The current monitoring program and annual audits will continue in accordance with the approved SWMP until the completion of sand/sandstone extraction. Monitoring will continue for a period of at least two years after completion of extraction, to ensure that the post-extraction recovery occurs generally in accordance with the model predictions as described above in **Section 7**.

Particular attention should be paid to water levels in the bores to the north, northeast and northwest of the quarry, as extraction is progressed to final depth in Stage 3/6.

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