Hanson Construction Materials Pty Ltd

Hydrogeological Assessment:

Hanson's Bass Point Quarry Project

ENVIRONMENTAL

WATER

WASTEWATER

GEOTECHNICAL

CIVIL

PROJECT MANAGEMENT

P0902486JR07V03
April 2013

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Document and Distribution Status

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Revision No.	Status	Release Date	Document Location					
			File Copy	MA Library	Hanson Pty Ltd	Kalf and Associates		
1	Draft	01.03.2013	1P, 1E	-	1P	1P		
2	Draft	25.03.2013	1P, 1E	-	1P	1P		
3	Final	09.04.2013	1P, 1E	-	1P	1P		

Distribution Types: F = Fax, H = hard copy, P = PDF document, E = Other electronic format. Digits indicate number of document copies.

All enquiries regarding this project are to be directed to the Project Manager.

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1 Executive Summary

1.1 Background

Martens and Associates ('Martens') prepared a Hydrogeological Assessment (P0902486JR01V02, June 2010) assessing proposed extension of Hanson's Bass Point Quarry (BPQ), Bass Point Quarry Road, Shellharbour, NSW (hereafter known as the "site"). The report formed part of an Environmental Assessment (EA) for an application for project approval under Part 3A of the *Environmental Planning and Assessment Act* (1979).

A review of the Hydrogeological Assessment by Mackie Environmental Research Pty Ltd (MER) (2012) on behalf of the NSW Department of Planning and Infrastructure (DoPI) recommended additional investigation of the site and further assessment of likely impacts.

Recommendations of MER (2012) were considered by Martens and Kalf and Associates (engaged by Hanson as a secondary independent expert) with a joint response to MER (P0902486JC10V01, dated September 2012) detailing supplementary investigation works which was then approved by DoPI and implemented.

This report details the findings of supplementary investigations and provides reassesses site hydrogeological conditions and the proposed development's impact accordingly. This report supersedes Martens' previous Hydrogeological Assessment (P0902486JR01V02, June 2010).

1.2 Proposed Development

Proposed site development is described in detail in the project EA and is summarised as the deepening and extension of the two existing quarry pits to -40 mAHD.

1.3 Key Issues

The key environmental issue at the site is the potential effect of the proposed development on the adjacent Killalea Lagoon. The potential impact of the development is assessed by quantifying likely dewatering rates for the extraction pits (lowered to – 40 mAHD), any resultant local groundwater drawdown and subsequent impacts on Killalea Lagoon's leakage to and from the groundwater system.

1.4 Assessment Methodology

Supplementary site investigations developed additional groundwater level monitoring data, hydraulic conductivity information (packer test data) and soil, silt and rock profile data (borehole and vibracore data). Vibracore investigations of the Killalea bed sediments allowed for characterisation of the bed sedimentology of Killalea Lagoon and, through collection of undisturbed bed samples, for the assessment of bed hydraulic conductivity which is critical in considering lagoon leakage to and from the groundwater system.

These data were used to refine the project conceptual model, the project numerical hydrogeological model and to assist in the calibration of that model. The model was calibrated and run as both a steady state and transient solution with subsequent predictive and combined sensitivity/uncertainty models used to assess the likely hydrogeological responses to the proposed development and post extraction recovery.

Lagoon leakage (to and from the groundwater system) results from the groundwater model were incorporated into a daily water balance model for the lagoon. This water balance model was then used to evaluate the likely impact of the proposed development on the water levels within Killalea Lagoon, this is considered to be a critical analytical approach to assess the impact of the development on the lagoon ecosystem.

1.5 Results and Discussion

Results of assessment are summarised as follows:

1. Killalea Lagoon's bed is generally comprised of an upper peat layer of the order of 1 to 3 m thick underlain by organic silts overlying clay. The bed sediments have very low harmonic mean hydraulic conductivity that impedes flow of groundwater into and out of the lagoon.

2. Local latite rock is massive and has negligible primary hydraulic conductivity with water bearing structures comprised of irregular fractures. The bulk of the latite is characterised by low hydraulic conductivity as evidenced by packer testing.

3. Modelled peak groundwater flow to the quarry pits determined by the base case transient predictive model is approximately 479 m3/d. Of this approximately 43% is direct flow from the ocean to the void.

4. Changes in the Killalea Lagoon's water balance due to surface and groundwater flow changes result in slight reductions in the lagoon water level through time. Median water level reduction is 19 mm and 5th percentile water level is reduced by 40 mm through the modelled period of 1990 - 2004.

5. Drawdown determined through the base case transient predictive model at the two licensed bores within the groundwater model's domain does not exceed 2 m.

Changes in the lagoon's water balance and subsequent lagoon water level are considered to be negligible. Modelled changes in water level are very small compared to the monitored lagoon water level variability of 900 mm. The assessed lagoon water level change induced by the quarrying is considered negligible and shall not significantly affect the lagoon's ecological values of function.

As drawdown at the two licensed bores within the groundwater model's domain does not exceed 2 m 'make good provisions' for these bores are not considered necessary in accordance with the NSW Aquifer Interference Policy (2012).

No mitigation measures are considered necessary for the project to address assessed hydrogeological changes or impacts on Killalea Lagoon. To mitigate against the long time period required for water levels within the extraction pits to recover to equilibrium levels an underbored connection to the ocean may be considered. This mitigation measure will reduce the time period for which site water licensing of groundwater take shall be required.

1.6 Conclusion

The impacts of the proposed quarry extension at Hanson's Bass Point Quarry are considered acceptable. The quarry shall not impact on the local hydrogeological system in such a way as to have significant detrimental effects for nearby groundwater users or ecological systems.

No mitigation measures are required to address hydrogeological impacts. An underbored connection between the void and the ocean may be used to reduce the time to fill the voids and thus reduce the need for ongoing groundwater licensing.

2 Introduction

2.1 Background

Martens and Associates ('Martens') prepared a Hydrogeological Assessment (P0902486JR01V02, June 2010) assessing proposed extension of Hanson's Bass Point Quarry (BPQ), Bass Point Quarry Road, Shellharbour, NSW (hereafter known as the "site"). The report formed part of an Environmental Assessment (EA) for an application for project approval under Part 3A of the *Environmental Planning and Assessment Act* (1979).

Review of the Hydrogeological Assessment was undertaken by Mackie Environmental Research Pty Ltd (MER) (2012) on behalf of the NSW Department of Planning and Infrastructure (DoPI) and review recommended additional investigation of the site and further assessment of likely impacts.

Additional investigations recommended by MER (2012) were considered by Martens and Kalf and Associates who were engaged by Hanson as a secondary independent expert. The joint response to MER (P0902486JC10V01, dated September 2012) outlined a program of supplementary investigation works and was approved by DoPI.

This report details the findings of supplementary site investigations and reassesses site hydrogeological conditions and the proposed development's impact accordingly. This report supersedes Martens' previous Hydrogeological Assessment (P0902486JR01V02, June 2010) which was based on less complete site data.

2.2 Objectives

Objectives of this assessment were formulated to address Director General Environmental Assessment Requirements (DGEARs) (15/09/2008) for the project and include the following:

1. Assess the existing groundwater regime.
2. Determine site groundwater system properties.
3. Identify existing groundwater users or environments which may be influenced by the proposed expansion of operations.
4. Develop a finite-difference groundwater flow model to assess likely groundwater ingress volumes, groundwater drawdown and any influence to Killalea Lagoon.

5. Provide mitigation measures (if necessary) to ensure the proposed-development results in either beneficial or neutral impact.

2.3 Site Location/Use

The site (Lot 22, DP1010797) is located at Bass Point Quarry Road, Shellharbour, NSW within the Shellharbour Local Government Area and is located approximately 8 km north north east of Kiama and 2 km south east of Shellharbour on Bass Point. The site is bordered by Bass Point Reserve to the east, Killalea State Park to the west (containing Killalea Lagoon), ocean to the south and north and Shell Cove residential subdivision and boat harbour precinct to the north west.

The predominant site use is hard rock quarrying. The portion of grass land to the north of Bass Point Quarry Road accommodates a small number of cattle. A pistol club and concrete batching plant are also operated on site. A survey of the existing site is provided in Attachment A (SK001).

2.4 Approved-Development

Previous development approvals have been issued for extraction to levels summarised below as shown in Figure 1:

- Extraction to 15 mAHD across whole site
- Extraction to 7.5 mAHD across zones 1 to 7
- Extraction to 0 mAHD across zones 1 to 6

2.5 Proposed Development

Proposed development at the site (Figure 2) comprises:

1. Decommissioning of the existing processing plant and construction of new processing plant.
2. Relocation of existing concrete plant, office, workshop and amenities.
3. Deepening of the western extraction area from the approved level of 0 mAHD to -40 mAHD.
4. Reconfiguration of bund approved by Shellharbour City Council under D947/2002.
5. Deepening of the eastern extraction area from the approved level of 0 mAHD to -40 mAHD.

2.6 Abbreviations

BH – borehole

GWL – groundwater level

K – Hydraulic conductivity

Kh, Kxy – Horizontal hydraulic conductivity

Kv, Kz – Vertical hydraulic conductivity

mBBL – m below bed level

mBGL – m below ground level

S_s – Specific storage

S_y – Specific yield

3 Hydrogeology

3.1 Bore Field and Works Overview

The site contains a total of 25 monitoring bores (Attachment A – SK001):

BHs 1, 2, 3, 4, 5 and 6

- Drilled by Coffey Geosciences in April and May, 2004 using down hole hammer.
- Maximum air lift test of 0.3 L/s at BH6.
- Drilled to depths ranging from 18.5 (BH3) to 39.4 m (BH6) through overburden, latite and agglomerate.
- Rising head tests completed at all bores.
- Packer tests completed at BH1, BH2 and BH4.
- Bore construction details are provided on borehole logs in Attachment C.

BHs 7, 8, MW01, MW02 and MW06

- Construction and testing details unknown.

BHs BT0701, BT0702, BT0703, BT0704, BT0705, BT0706

- Drilled by Aqua Drilling and Grouting using down hole hammer (drilling dates unknown but before April, 2007 based on rising head tests).
- Maximum air lift test of 21.4 L/s (BT0704) with air lift tests ranging from 0 to 0.4 L/s at remaining bores within this group.
- Drilled to depths ranging from 50 m (BT0702) to 90 m (BT0706) through latite at BT0702 and BT0703, latite with underlying sandstone at BT0701, BT0704, BT0705, and latite, breccia and sandstone at BT0706.
- Rising head tests completed at BT0702, BT0703, BT0704 and BT0706.
- Bore construction details are provided on borehole logs in Attachment C.

BHs BT1201, BT1202, BT1203 and BT1204

- Drilled in accordance with program of supplementary investigation works which was approved by DoPI. (P0902486JC10V01, September 2012). The purpose of these bores was to provide additional information to improve characterisation of the groundwater flow system in the area between the western edge of the quarry and Killalea Lagoon.
- Bores were completed as nests comprising pairs BT1202 and BT1203, and BT1201 and BT1204.
- Drilled by Terratest using a combination of down hole hammer and coring in October, 2012 through latite, agglomerate and sandstone as summarised in Table 1.
- Air lift tests ranging from 0.3 L/s (BT1201) to 1 L/s (BT1202).
- Packer testing completed at all bores within this group.
- Bore construction details are provided on borehole logs in Attachment C.

Table 1: Borehole summary.

	BT1201		BT1202		BT1203		BT1204	
Element	**mBGL**	**mAHD**	**mBGL**	**mAHD**	**mBGL**	**mAHD**	**mBGL**	**mAHD**
Ground Level (mAHD)		10.88		20.88		21.88		11.38
Latite (clay overburden above)	6 to 40.7	4.88 to -29.82	1 to 25	19.88 to -4.12	1 to 24	20.88 to -2.12	3 to 14.9	8.38 to - 3.52
Agglomerate			25 to 36	-4.12 to -15.12	24 to 34	-2.12 to -12.12		
Latite			36 to 54	-15.12 to - 33.12	34 to 36	-12.12 to - 14.12		
Sandstone	40.7 to 44.9	-29.82 to - 34.02	54 to 59	-33.12 to - 38.12				

Notes:
1. Ground levels to be confirmed.

BHs BT1205, BT1206, BT1207 and BT1208

- Drilled using down hole hammer in December, 2012 with all holes surrounding bore BT1203.
- Drilled by Hanson following Martens analysis of BT1201, BT1202, BT1203 and BT1204 groundwater levels which showed BT1203 groundwater levels to be distinctly different (higher) than other levels.
- Undertaken to understand groundwater level variability in this region.
- Bores were drilled to 21.5 mBGL, completed as unlogged open holes and were within say 3 - 8 m of BT1203 to the north, south, east and west.

3.2 Surrounding Groundwater Users

Querying of the NSW Natural Resource Atlas on 04/02/2013 revealed 2 licensed bores (GW101125 and GW060313) within an area of 5 km by 3 km approximately centred over the site (Figure 3). This area was utilised as it represents the groundwater model domain used for this investigation.

GW101125 is located in a separate watershed to the west of the site and Killalea Lagoon and is authorised for 'recreation'.

GW060313 is located approximately 1.4 km north west of the site and is authorised for 'recreation'.

Groundwater works summaries for the two above bores are provided in Attachment G.

3.3 Groundwater Dependent Ecosystems (GDEs)

No GDEs have been identified or commented upon in correspondence from NSW Office of Environment and Heritage (OEH) or in the RPS Harper Somers O'Sullivan (2010) Flora and Fauna Assessment. Killalea Lagoon is not reliant on groundwater and as the proposed development does not lead to significant reduction in lagoon water levels, the lagoon is not considered a GDE.

3.4 Geological Setting

Review of drill records and geological cross section detail provided by Hanson's geologist (Peter Browne) and recent additional investigations indicates the geology in the vicinity of the site comprises:

1. Clay overburden typically of the order of 1 to 5 m.
2. Upper coarse grained latite of the order of 25 m (western extraction pit) to 30 - 40 m thick (eastern extraction pit).
3. Agglomerate of the order of 4 - 9 m thick (western extraction pit) to 4 - 12 m thick (eastern extraction pit). The thickness of the agglomerate layer increases in the area between the two proposed extraction pits where crushing plant is to be located.
4. Lower fine grained latite of the order of 25 m thick (western extraction pit) to 18 - 22 m thick (eastern extraction pit).
5. Underlying very fine grained sandstone of unknown thickness. The top of this unit varies from approximately -34 to -37 mAHD (western extraction pit) to -42.6 to -36 mAHD (eastern extraction pit). The proposed base level of both proposed extraction pits is -40 mAHD.

A geological cross section and long section is provided in Attachment A (SK002).

3.5 Killalea Lagoon

3.5.1 Overview

Killalea Lagoon is situated approximately 80 m west of the site's western boundary, approximately 230 m to the west of the proposed Stage 3 western extraction pit and approximately 250 m to the north of the ocean. The lagoon is separated from the ocean by a barrier beach and vegetated foredunes. The lagoon is identified by *State Environmental Planning Policy No. 14 – Coastal Wetlands.*

3.5.2 Water Levels/Salinity

Based on a gauge which according to Hanson was installed to mAHD and water level monitoring undertaken by ALS laboratory, water levels within the lagoon (Table 2) vary from less than 0 mAHD to 0.9 mAHD. The lagoon is considered to overflow to the ocean once water levels exceed approximately 1 mAHD.

Lagoon water is typically moderately brackish but varies from fresh to very brackish (Table 2). The lagoon is only rarely temporarily inundated by seawater during storm conditions (Switzer *et.al*, 2005).

A plan showing site and lagoon location is provided in Attachment A (SK001).

Table 2: Killalea Lagoon water levels and water quality.

Date	Water level (mAHD)	pH	EC (µs/cm)	Salinity g/L	Temp (°C)	ORP (mV)
15/06/2012		7.7	438	<2.0	14.4	230
16/05/2012		7.1	360	0.2	12.6	137
16/04/2012		7.6	507	0.3	21.6	132
16/03/2012		7.2	515	0.3	23.5	133
29/02/2012		7.8	617	0.3	23.9	164
13/01/2012	0.75	7.5	708	0.4	20.2	105
16/09/2011		7.2	460	0.3	14.7	95
15/07/2011	0.9	6.7	457	0.3	8.6	142
16/06/2011		6.4	403	0.2	13.4	-71
13/05/2011	0.8	6.5	455	0.3	11.7	156
25/03/2011	0.1	7.5	1200	0.7	19.8	136
15/02/2011	0.2	7	1290	0.7	20.3	169
18/01/2011	0.3	8.4	1130	0.6	22.5	133
15/12/2010	0.4					
18/11/2010	Gauge Out of Water					
25/10/2010	<0.001	8.29	1254	0.78	15.45	103
28/09/2010	<0.01 (dry)	7.53	1295	0.78	16.41	126
27/08/2010	gauge out of water	7.39	1093	0.76	10.74	156
20/07/2010		8.61	1419	1.04	9.12	133
25/03/2010		7.86	2820	1.69	18.64	40
19/02/2010	0	7.63	1984	1.1	20.93	67
15/01/2010	0	8.11	2286	1.28	20.92	127
18/12/2009	0	8.2	1987	1.11	20.69	122
23/11/2009	0	7.9	1645	0.95	19.05	-12
12/06/2007	0.42		1155	0.577	12.2	
8/05/2007	0.37	6.76	1249	0.614	20.4	
2/04/2007		9.38	1657	0.852	30.6	

Date	Water level (mAHD)	pH	EC (µs/cm)	Salinity g/L	Temp (°C)	ORP (mV)
14/03/2007		6.23	1625	0.82	27.1	
8/02/2007		6.74	1928	0.903	24.8	
12/01/2007	0.18	6.34	1381	0.663	27.5	
13/12/2006	0.29	6.4	1214	0.598	20.6	
14/11/2006	0.46	6.15	905	0.48	23.8	
11/10/2006	0.575	6.31	912	0.439	20.4	
13/09/2006	0.775	6.25	812	0.401	18.2	
11/08/2006	0.481	6.16	894	0.445	15.6	

3.5.3 Bed Sediments

3.5.3.1 Overview

Nine vibracores were drilled through the bed of Killalea Lagoon from a floating barge to investigate lagoon bed sediments. This was undertaken so that bed sediment hydraulic conductivity (K) and thickness could be characterised and represented in the groundwater model.

Bed sediment K was assessed by laboratory through flexible wall permeameter testing of seven vibracore samples and remoulded permeability testing of one sample (KL02) in accordance with AS 1289.6.7.3. The flexible wall permeameter samples were transported to the laboratory within the aluminium tubes that were used for the vibracoring.

Vibracore locations are shown in Attachment A (SK001) with logs in Attachment C and laboratory results in Attachment D. Investigations included:

a) Holes VC01A and VC02 – drilled to only 2.15 m due to equipment limitations. These holes were not fully logged due to their shallow refusal prior to clays. Profiles at both holes comprised interbedded peat and silts.

b) Holes KL01 – KL07 - drilled by a subsequent contractor (GeoCoastal) to desired investigation depths as shown on vibracore logs.

3.5.3.2 Results

Vibracore findings are summarised below:

1. Lagoon water depth ranged from 0.8 to 1.32 m (mean 1.14 m).

2. Sediment in the southern area of the lagoon (KL05) (i.e. near to the barrier) comprised a surface layer of sand (0.5 m) underlain by peat from 0.5 to 2.5 m below bed level (mBBL). Medium grained sands and a thin layer of organic silt extended from 2.5 to 13.4 mBBL (termination depth). Investigations could not be progressed to further depths due to equipment limitations.

3. Sediment approximately 120 m north east of KL05 at KL06 displayed a similar profile with the exception of gravelly clay which was observed from 10.73 mBBL to the termination depth of 11.05 mBBL.

4. Sediments at remaining locations generally comprised an upper peat layer of the order of 1 to 3 m thick underlain by organic silts overlying clay. The depth to the clay varies but generally increases from the west (KL01 - 1.95 mBBL) to the centre of the lagoon (KL03 – 10.6 mBBL) then decreases towards eastern lagoon edge (KL02 – 7.4 mBBL).

5. Depth to clay decreases in the north of the lagoon as evidenced by its absence at KL07 which terminated at 2.4 m on weathered latite.

6. Results of laboratory lagoon bed K testing are summarised in Table 3 with laboratory reports in Attachment D.

7. Depth averaged vertical hydraulic conductivity (Kv) of the investigated Killalea Lagoon bed profile was calculated for KL01 to KL07 assuming series flow through layers of soil with varying K (i.e harmonic mean). For the purpose of calculations, representative K values (Table 4) were assumed for the different material types encountered. Kv was calculated based on the equation:

$$\frac{1}{Kv} = \frac{0.9}{Kmaterial} + \frac{0.1}{Kmaterial}$$

Where:

Kv is vertical hydraulic conductivity.

Kmaterial is the representative K for the given material type (Table 4).

0.9 and 0.1 are the percentage contributions (expressed as 0 to 1) of the relevant Kmaterial thickness relative to the total investigation thickness at each vibracore hole.

Results for KL01 to KL07 are summarised in Table 5.

Table 3: Summary of laboratory K testing for Killalea Lagoon sediments.

Location	Sampled Depth (mBBL) and Test Medium	K (m/s)	K (m/d)
VC01A	1.25 to 1.65 – peat	1.44×10^{-9}	0.0001
VC01A	1.8 to 2.05 – peat	4.36×10^{-10}	0.00004
KL01	2.2 to 2.6 – clay	2×10^{-9}	0.0002
KL02 [2]	8.55 to 9.25 – clay	6.6×10^{-10}	0.0001
KL03	11.7 to 12.1 – clay	1×10^{-9}	0.0001
KL04	9.2 to 9.6 – clay	2.5×10^{-9}	0.0002
KL06	10.65 to 11.05 – gravelly clay	1×10^{-10}	0.00001
KL07	2.1 to 2.4 (organic silt)	1.2×10^{-7}	0.01
Geometric mean		1.5×10^{-9}	0.0001
Median		1.2×10^{-9}	0.0001
Mean		1.6×10^{-8}	0.001

Notes:
1. mBBL = m below bed level.
2. Remoulded permeability test. All other tests flexible wall permeameter using undisturbed tube samples of material.

Table 4: Adopted representative values for integrated Killalea Lagoon Kv calculations.

Material	Adopted Representative K (m/s)	Adopted Representative K (m/d)	Comment
Peat	1.44×10^{-9}	0.0001	Equates to highest test result for material (VC01A 1.25 – 1.65 m)
Organic Silt	1.2×10^{-7}	0.01	Test result for material (KL07)
Sand	5.79×10^{-5}	5	Assumed based on medium grained sand
Clay	1.25×10^{-9}	0.0001	Average of clay test results

Table 5: Calculated integrated Kv of investigated Killalea Lagoon sediments assuming series flow.

Location	Calculated Lagoon Bed K_v (m/s)	Calculated Lagoon Bed K_v (m/d)
KL01	1.39×10^{-9}	0.0001
KL02	3.58×10^{-9}	0.0003
KL03	4.87×10^{-9}	0.0004
KL04	1.53×10^{-9}	0.0001
KL05	9.59×10^{-9}	0.0008
KL06	6.44×10^{-9}	0.0006
KL07	4.80×10^{-9}	0.0004
Geometric mean	3.78×10^{-9}	0.0003
Median	4.80×10^{-9}	0.0004
Mean	4.60×10^{-9}	0.0004

3.6 Hydraulic Conductivity (K)

Rising head tests (Table 6) have been conducted by a range of consultants at site bores. The current site assessment utilises data from recent packer testing to characterise groundwater system's K. This decision was made as data quality was known and packer tests are best suited to assessment of hydraulic conductivity in fractured rock.

Packer testing was completed in boreholes BT1201, BT1202, BT1203 and BT1204 to assess K variation with depth. Results of packer testing at boreholes BT1201 – BT1204 are summarised in Table 7 with results of

Coffey (July, 2003) packer testing at BH1, BH2 and BH4 summarised in Table 8 for comparison.

Results indicate that latite, agglomerate and sandstone was unfractured with negligible K at the majority of test sites and depths. Of the total 24 tests completed, 16 tests showed no flow. Of the total tested profile length, 68% showed no flow. In portions where interconnected fracturing is present the K of the latite and agglomerate is generally low with only isolated areas of fracturing and higher hydraulic conductivity.

Zones of relatively higher K were observed at:

- BT1202 (-18.12 to -26.62 mAHD) (0.79 m/d)
- BT1204 (5.63 – 1.38 mAHD) (0.13 m/d)
- Coffey's (2003) BH4 test (-12.1 to -18.6 mAHD) (0.1 m/d).

BT1202 is associated with a zone of fractured latite which was not generally observed in bores and is considered unrepresentative of the wider site. The absence of such a zone in BT1201overlying sandstone is noted. BT1204 K is most likely associated with weathering at the top of the rock profile and is unrepresentative of the main latite mass. BH4 is associated with a fractured latite zone, details of which are difficult to confirm from available documentation.

Depth averaged K at packer tested holes is provided in Table 9. The geometric mean and median depth averaged K is 0.01 m/d whilst the mean is 0.03 m/d. Depth averaged K at BT1202 (bore with highest packer tested K zone) is 0.11 m/d.

Review of bore logs and packer testing data indicates fractured zones are discontinuous with regards to distribution across site and depth to zone, there is no data to suggest the presence of a continuous highly fractured layer across the site.

Table 6: Summary of rising head tests.

Piezometer	Test Type/Consultant	Estimated K (m/d) [3]	Source
BT0702	Rising Head/Larkin	0.04	Larkin (April, 2007)
BT0703		0.04	
BT0704		1.2	
BT0706		0.0003	
BT0703	Rising Head/Martens	0.01	NA – completed for this report
BT0704		0.01	
BH1		0.06	
BH2		1.47	
BH1	Rising Head/Coffey	0.01	Coffey (July, 2003)
BH2		0.18	
BH3		0.01	
BH4		0.165	
BH5		0.01	
BH6		0.125	
BH1	Packer Test/Coffey	0.005	Coffey (July, 2003)
BH2		0.013	
BH4		0.1	
Geometric mean [2]		0.04	
Median [2]		0.04	
Mean [2]		0.19	

Notes: [1]. Where multiple tests were performed on a borehole, the average of test results has been reported.

Table 7: Martens packer test results summary.

Bore ID and Surface Level (mAHD)	Top (mBGL)	Bottom (mBGL)	Test Interval Length (m)	Predominant Test Interval Stratum	Lugeon	K (m/d)
BT1201 (10.88)	15	20	5	Latite	NA - no flow	0
	20	25	5	Latite	2.6	0.03
	25	30	5	Latite	NA - no flow	0
	30	35	5	Latite	0.3	0.003
	35	40	5	Latite	NA - no flow	0
	40	45	5	Sandstone	NA - no flow	0
BT1202 (20.88)	7	12	5	Latite	NA - no flow	0
	13	18	5	Latite	NA - no flow	0
	19	24	5	Latite	NA - no flow	0
	24	29	5	Agglomerate	NA - no flow	0
	29	34	5	Agglomerate	NA - no flow	0
	34	39	5	Agglomerate/ Latite	NA - no flow	0
	39	44	5	Latite	70.3	0.79
	43.5	48.5	5	Latite	43.0	0.48
	49	59	10	Latite/ Sandstone	NA - no flow	0
	54	59	5	Sandstone	NA - no flow	0
BT1203 (21.88)	6	11	5	Latite	NA - no flow	0
	11	16	5	Latite	NA - no flow	0
	16	21	5	Latite	NA - no flow	0
	21	26	5	Latite/ Agglomerate	NA - no flow	0
	26	31	5	Agglomerate	0.2	0.002
	31	36	5	Agglomerate/ Latite	0.8	0.009
BT1204 (11.38)	5.75	10	4.25	Latite	11.6	0.13
	8.5	14.9	6.4	Latite	1.9	0.02

Table 8: Coffey (July, 2003) packer test results summary.

Bore	Top (mBGL)	Bottom (mBGL)	Test Interval Length (m)	Predominant Test Interval Stratum	Lugeon	K (m/d)
BH1	14.5	21.0	6.5	Latite	NA - no flow	0
	20.5	27.0	6.5	Latite	0.7	0.006
	25.5	32.0	6.5	Latite	1.0	0.009
BH2	14.50	21.0	6.5	Latite	3.0	0.03
	20.5	27.0	6.5	Latite/ Agglomerate	NA - no flow	0
	25.5	32.0	6.5	Agglomerate/ Latite	1.5	0.01
BH4	20.1	26.6	6.5	Latite	12.0	0.1

Table 9: Summary of depth averaged K derived from packer testing.

Bore [1]	Depth Averaged K (m/s)	Depth Averaged K (m/d)
BT1201	4.6×10^{-8}	0.004
BT1202	1.3×10^{-6}	0.11
BT1203	2.3×10^{-8}	0.002
BT1204	5.8×10^{-7}	0.05
BH1	5.8×10^{-8}	0.005
BH2	1.2×10^{-7}	0.01
Geometric mean	1.3×10^{-7}	0.01
Median	8.7×10^{-8}	0.01
Mean	3.5×10^{-7}	0.03

Notes:
1. BH4 excluded - single packer zone tested and therefore depth averaged value can't be calculated.

3.7 Storage

Based on packer test results and Bair and Lahm's (2006) cited representative values and ranges for porosity and specific yield (S_y) of basalt and fractured igneous and metamorphic rocks, S_y of the latite/agglomerate is likely to be within the range of say 0.01 to 0.1. Given primary K is very low, it is anticipated that S_y is likely to be at the lower end of this range and near to 0.01. Sandstone's S_y is also likely to be in this range based on literature (Bair and Lahm, 2006).

Specific storage (S_s) was calculated using an equation (Jacob, 1940) which relates S_s to barometric efficiency (BE) and effective porosity. BE was calculated using the slope method described by Kinkela (2009) using 188 days of continuous logger data at 6 bores. With an assumed effective porosity of 0.01 the average S_s value from the 6 bores is 0.001 m^{-1}. This is a high S_s value in the context of literature values where Batu (1998) cited a S_s range for fissured/jointed rock of 6.89 x 10^{-5} to 3.28 x 10^{-6} m^{-1} (median value of 3.6 x 10^{-5} m^{-1}). Given the rock matrix is expected to be relatively rigid, S_s is not expected to be large like the value estimated based on BE and effective porosity and therefore is taken to be of the order of 3.6 x 10^{-5} m^{-1} for the latite, agglomerate and sandstone.

3.8 Groundwater Levels

3.8.1 BT1201 to BT1208 (Dipped Levels)

Groundwater levels (GWLs) within BT1201 – BT1204 as measured by Hanson are summarised in Table 10. Significant difference in GWLs between nested bores BT1202 (screened -16.62 to -38.12 mAHD) and BT1203 (screened 1.38 to -14.12 mAHD) is noted.

GWLs at 4 additional boreholes (BT1205 – BT1208) surrounding BT1203 (holes undertaken to improve understanding of GWLs in this region) are provided in Table 11.

The GWL data set for BT1202, BT1203 and BT1205 – BT1208 shows substantial variation considering the bores are located within an area of approximately 10 x 15 m. From highest to lowest bore surface elevation; GWLs are approximately 5 mAHD (BT1206), 18 mAHD (BT1203), 16 mAHD (BT1207 + BT1208), 1 mAHD (BT1202) and 12 mAHD (BT1205). This large degree of GWL scatter suggests that multiple compartmentalised water bearing zones exist in this area above a more continuous water table at approximately 1 mAHD.

Table 10: Groundwater level summary (bores BT1201 to BT1204).

	BT1201		BT1202		BT1203		BT1204	
Element	**mBGL**	**mAHD**	**mBGL**	**mAHD**	**mBGL**	**mAHD**	**mBGL**	**mAHD**
Ground Level (mAHD)		10.88		20.88		21.88		11.38
GWL – 30/10/2012	9.35	1.53	19.5	1.38	3.85	18.03	7.68	3.7
GWL – 07/11/2012	9.43	1.45	19.59	1.29	3.78	18.1	7.75	3.63
GWL – 20/11/2012	9.5	1.38	19.64	1.24	3.7	18.18	7.9	3.48
GWL – 30/11/2012	9.43	1.45	19.60	1.28	3.68	18.20	7.95	3.43

Notes:
1. Ground levels yet to be confirmed.
2. GWL derived based on Hanson data and an assumed monument height of 900 mm at each location.
3. GWL = groundwater level.

Table 11: Groundwater level summary (bores BT1205 to BT1208).

	BT1205		BT1206		BT1207		BT1208	
Element	**mBGL**	**mAHD**	**mBGL**	**mAHD**	**mBGL**	**mAHD**	**mBGL**	**mAHD**
Ground Level (mAHD)		19.88		22.88		21.38		21.38
GWL – 11/12/2012	8.2	11.68	18.3	4.58	5.3	16.08	5.1	16.28

Notes:
1. Ground levels yet to be confirmed.
2. GWL derived based on Hanson data.
3. GWL = groundwater level.

3.8.2 *All Bores (Dipped Levels),*

GWL observations presented in Martens (June, 2010, P0902486JR01V02) Hydrogeological Assessment are summarised in Table 12. The complete record of dipped observations is in Attachment E and includes dips from 2009 to 2012 which are not incorporated into the Table 12 GWL statistics.

Table 12: Summary of groundwater level monitoring previously undertaken at the subject site with bores grouped (Martens 2010 P0902486JR01V02).

Borehole	Surface Level (mAHD)	Open Interval of Bore (mAHD)	Monitored Material	GWL mAHD	GWL mBGL	Borehole Group
BH1	9.88	7.38 to -23.12	Latite with minor agglomerate (bottom 0.9 m of hole)	8.39 [1]	1.49 [1]	1
BH2	9.62	7.42 to -23.38	Latite and agglomerate	8.51 [1]	1.11 [1]	
BH7	10.09	No information	No information	8.57 [2]	1.52 [2]	
BH8	11.66	No information	No information	11.62 [2]	0.04 [2]	
BH3	6.99	-6.91 to -11.51	Latite	1.91 [1]	5.08 [1]	2
BH4	7.32	-14.48 to -20.38	Latite	1.56 [1]	5.76 [1]	
BH5	8.83	-5.17 to -12.67	Latite	1.85 [1]	6.98 [1]	
BT0701	26.94	-25.06 to -33.26	Sandstone	1.19 [3]	25.75 [3]	
BT0702	26.93	-5.6 to -31.6	Latite	1.22 [3]	25.71 [3]	
BT0706	44.34	41.84 to -29.66	Latite/agglomerate	0.92 [3]	43.42 [3]	
BT1201 [5]	10.88	-5.62 to -33.62	Latite/Sandstone	1.45 [4]	9.43 [4]	
BT1202 [5]	20.88	-16.12 to -38.12	Latite/Sandstone	1.3 [4]	19.58 [4]	
BT1204 [5]	11.38	1.98 to -3.52	Latite	3.56 [4]	7.82 [4]	
BT1206 [5]	22.88	22.88 to 1.38	Latite	4.58	18.30	
BH6	23.58	6.58 to -15.82	Latite/agglomerate	16.36 [1]	7.22 [1]	3
MW01	18.66	No information	No information	14.36 [3]	4.30 [3]	
MW02	21.31	No information	No information	15.22 [3]	6.09 [3]	
MW06	20.38	No information	No information	17.78 [3]	2.60 [3]	
BT0704	20.88	16.38 to -44.62	Latite	18.73 [3]	2.15 [3]	
BT0705	23.58	-48.42 to -54.42	Sandstone	14.97 [3]	8.61 [3]	
BT0703	14.13	-32.87 to -51.97	Latite	9.42 [3]	4.71 [3]	
BT1203 [5]	21.88	1.38 to -14.12	Agglomerate/Latite	18.13 [4]	3.75 [4]	
BT1205 [5]	19.88	19.88 to -1.62	Latite	11.68	8.20	
BT1207 [5]	21.38	21.38 to -0.12	Latite	16.08	5.30	
BT1208 [5]	21.38	21.38 to -0.12	Latite	16.28	5.10	

Notes: (following page)

[1.] Average observed groundwater level of data taken at approximate monthly intervals (total data set extent - 10.12.2003 – 12.06.2007). [2.] Average observed groundwater level of data taken at approximate monthly intervals (total data set extent – 11.08.2006 – 12.06.2007). [3.] Average observed groundwater level of data taken at approximate monthly intervals (total data set extent – 14.03.2007 – 12.06.2007). [4.] Geometric mean of 4 dips taken between 30.10.2012 and 30.11.2012. [5.] Bore surface level yet to be confirmed. [6.] GWL = groundwater level.

3.8.3 *Logger Data Record*

GWL data logger record exists from 13/02/2012 to 18/07/2012 at bores BH3, BH4, BH6, BT0703, BT0704 and BT0706, and from 25/11/2012 to 14/12/2012 at bores BT01201 to BT01204 at the time of reporting. Due to the short record length relative to the dip record, GWL data analysis has focused on utilising the dipped data.

3.8.4 *Cumulative Residual Rain Mass*

With the exception of plateaus/rises indicative of near average or above average rainfall throughout most of 2007 and from 2010 to July, 2012 (end of analysis period), cumulative monthly residual rain mass (Figure 4) shows a general broad scale trend of below average rainfall.

3.8.5 *Bore Hydrographs/Cumulative Residual Rain Mass*

Bore hydrographs with cumulative residual rain mass on the secondary axis are in Figure 5 through to Figure 10 for bores BH3, BH4, BH5, BT0701, BT0702 and BT0706. Hydrographs were derived from the dip data in Attachment E with mean monthly logger data values used in place of dip data where available (i.e January, 2012 to July, 2012). These bores were analysed as they are calibration bores used in the numerical groundwater model.

There is no evident correlation between GWLs in the bores and cumulative monthly residual rain mass suggesting that GWLs within the monitored bore intervals are weakly influenced by rainfalls trends, and that rainfall recharge to the latite groundwater system is likely to be low. This is also consistent with packer testing results and GWL analysis (Section 3.8.1) which suggest fracturing of the latite is discontinuous and the matrix K negligible.

BT0706 water level sudden decrease in early 2012 (Figure 10) is not observed in other bores and is likely to be related to logger error. This is evidenced by a dipped value for the bore of 1.65 mAHD on 13/01/2012 relative to the mean logger level for the same day of 0.25 mAHD. For model calibration purposes the mean monthly logger levels at BT0706 were increased by 1.4 m (the margin of difference).

3.8.6 *GWL Summary*

Review of GWL observations in Martens (June, 2010, P0902486JR01V02) and data from bores BT1201 to BT1208 allows for grouping (Table 12) of bores:

- Group 1 – Bores in quarry pit in vicinity of surface water dam. Bores were considered by Mackie Environmental Research (June, 2012) to have GWLs possibly representative of surface water influences. This view is supported by the updated site conceptual model.

- Group 2 – Bores with GWLs of the order of 0 to 5 mAHD. These bores generally surround the western and southern extents of the proposed western extraction pit and are considered to represent the locally significant water table located below a series of perched discontinuous water bearing zones.

- Group 3 – Bores with water levels of the order of 9 to 19 mAHD. Water levels in these bores are considered to reflect water a series of perched discontinuous water bearing zones.

Based on the above, the locally significant water table is considered likely to flow somewhat radially from a mound approximately centred over the headland. Assuming the mound is greatest at the centre of the headland (approximately 500 m inland from the ocean), and the mean hydraulic gradient from Group 2 bores to the ocean/Killalea Lagoon of approximately 1 to 2%, water table elevation at the mound is likely to be of the order of 5 to 10 mAHD. On the basis of Section 3.10 which observed that no significant groundwater inflow has been observed during quarrying to a current level of 1 mAHD, the mound is taken to be of the order of 5 mAHD rather than 10 mAHD.

Analysis (Section 3.8.1) has identified a series of perched discontinuous water bearing zones with limited vertical and horizontal connection above the locally significant water table at approximately 5 mAHD. Perched water bearing zones are not considered significant and are not considered in groundwater modelling of inflows.

3.9 Groundwater Quality

Groundwater quality data as presented Martens (June, 2010, P0902486JR01V02) is in Table 13. Results indicate the following:

- pH ranges from slightly alkaline to slightly acidic with an average of 6.97 (near neutral). BH1 and BH2 both had a geometric mean pH level of 8.2, the most alkaline value. This is expected given that these piezometers are relatively close to the coast and seawater typically has a pH of around 8.

- Electrical Conductivity (EC) ranges that are indicative of fresh to brackish water.

- The geometric mean of Total Nitrogen (TN) values is 0.46 mg/L. BH1 returned elevated TN values (geometric mean of 7.3 mg/L.

- The geometric mean of Total Phosphorus (TP) values is 0.11. BH1 returned elevated TP values. BH3 and BH5 also returned relatively high values. BH3 and BH5 are outside of the influence of quarrying and therefore suggest that elevated nutrient concentrations within the groundwater are a natural occurrence.

Further groundwater quality sampling and analysis has been undertaken by the laboratory ALS throughout 2010, 2011 and 2012. Laboratory reports are in Attachment F.

Table 13: Summary of groundwater quality monitoring results previously undertaken at Bass Point Quarry site.

Borehole	GWL mAHD	GWL mBGL	pH	EC (µS/cm)	Total Dissolved Solids (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
BH1	8.39 [3]	1.49 [3]	8.2 [1]	740 [1]	546 [2]	7.3 [2]	0.63 [2]
BH2	8.51 [3]	1.11 [3]	8.2 [1]	823 [1]	588 [2]	0.7 [2]	0.02 [2]
BH3	1.91 [3]	5.08 [3]	6.5 [1]	589 [1]	416 [2]	0.3 [2]	0.33 [2]
BH4	1.56 [3]	5.76 [3]	7.3 [1]	702 [1]	436 [2]	0.2 [2]	0.1 [2]
BH5	1.85 [3]	6.98 [3]	6.4 [1]	621 [1]	458 [2]	0.3 [2]	0.26 [2]
BH6	16.36 [3]	7.22 [3]	7.0 [1]	3263 [1]	3080 [2]	0.1 [2]	0.02 [2]
BH7	8.57 [4]	1.52 [4]					
BH8	11.62 [4]	0.04 [4]					
MW01	14.36 [5]	4.30 [5]	6.5 [6]	4086 [6]			
MW02	15.22 [5]	6.09 [5]	6.0 [6]	2870 [6]			
MW06	17.78 [5]	2.60 [5]					
BT0705	14.97 [5]	8.61 [5]	7.2 [6]	299 [6]			
BT0704	18.73 [5]	2.15 [5]	6.8 [6]	997 [6]			
BT0703	9.42 [5]	4.71 [5]	6.6 [6]	1852 [6]			
BT0706	0.92 [5]	43.42 [5]	6.6 [6]	1736 [6]			
BT0702	1.22 [5]	25.71 [5]	7.2 [6]	2824 [6]			
BT0701	1.19 [5]	25.75 [5]	7.1 [6]	1953 [6]			

Notes: [1.] Geometric mean of data taken at approximate monthly intervals (total data set extent - 10.12.2003 – 12.06.2007). [2.] Laboratory results from sampling completed 10.12.2003. [3.] Average observed groundwater level of data taken at approximate monthly intervals (total data set extent - 10.12.2003 – 12.06.2007). [4.] Average observed groundwater level of data taken at approximate monthly intervals (total data set extent – 11.08.2006 – 12.06.2007). [5.] Average observed groundwater level of data taken at approximate monthly intervals (total data set extent – 14.03.2007 – 12.06.2007). [6.] Geometric mean of data taken at approximate monthly intervals (total data set extent – 14.03.2007 – 12.06.2007).

3.10 Existing Dewatering

Based on a site survey dated November, 2012, the quarry's lowest drop cut typically ranges from about 1.4 m – 2.6 mAHD with sumps at approximately 1 mAHD. To date the operator has observed no significant groundwater inflow. However, it is possible that minor groundwater inflow may have occurred during cut progression and been removed in conjunction with surface water flow and evaporation and not been noted by Hanson workers.

3.11 Hydrogeological Conceptualisation

3.11.1 Geological Cross Section and Long Section

A geological cross section and long section is provided in Attachment A (SK002). The cross section extends through the quarry and Killalea Lagoon whilst the long section extends through Killalea Lagoon to the ocean.

3.11.2 Rock Layers and Jointing/Fracturing

Water bearing zones in the vicinity of the site comprise fractures and structures within the igneous latite/agglomerate. Latite jointing observed in the quarry pit is predominantly vertical (columnar) with some horizontal fracturing present. The nature of jointing and fracturing is consistent between the latite and agglomerate but variable across the site and both layers. Fracturing within the sandstone is typically horizontal at 0.5 to >1 m spacing.

3.11.3 Hydraulic Conductivity (K), Storage and Confinement

Latite/agglomerate K is dependent on fracturing/jointing/structures and varies with depth and location. The available data does not support the presence of a continuous fractured layer across the site but rather a series of discontinuous fractured water bearing zones each separated from zones above and below by very low K rock. For conceptualisation purposes, depth averaged K of the latite, agglomerate and sandstone is taken to be 0.01 m/d based on the depth averaged packer test results (Table 9).

Groundwater occurs under semi-confined to confined conditions in the rock strata.

S_y of the latite/agglomerate is anticipated to be near to 0.01 while S_s is taken to be 3.6×10^{-5} m^{-1}. S_y and S_s values for the sandstone are considered to be similar. Both S_y and S_s values were evaluated during transient groundwater model calibration.

3.11.4 Flow Directions and Water Table Elevation

The main site water table gradient in the groundwater system indicates that groundwater flow occurs away from a central water table rainfall recharge mound situated between the ocean and Killalea Lagoon (Figure 18). Water table mound elevation is considered to be approximately 5 mAHD as discussed in Section 3.8.6.

A series of isolated perched water tables with poor vertical and horizontal connection are above the main site water table. Perched water tables are not considered significant and are not considered in groundwater modelling of inflows.

3.11.5 Killalea Lagoon Leakage

Any Killalea Lagoon leakage, should it occur, to the underlying groundwater system would be potentially impeded by the lagoon bed's vertical K and bed thickness. Lagoon bed vertical K is taken to be 9.59×10^{-9} m/s (8.29×10^{-4} m/d) which corresponds with the highest estimated integrated vertical K.

3.11.6 Sources and Sinks

Recharge to the groundwater system is from rainfall. Runoff from quarry surfaces drain to dams in the floor of the void. These dams also collect seepage from quarry faces. Site dam leakage is an indirect source of rainfall recharge to the groundwater system. The system discharges to the ocean and to the atmosphere through evapotranspiration in areas where the water table is near to the surface (limited areas only within the quarry site).

Currently the quarry is not dewatering groundwater. However, minor seeps exist which are associated with rainfall infiltration in perched water bearing zones.

4 Numerical Groundwater Model

4.1 Objectives

Groundwater model objectives were to:

1. Estimate groundwater inflow rates to the quarry pits over the extraction period to -40 mAHD.
2. Estimate changes to groundwater levels during the extraction period and post quarrying period of water level recovery.
3. Estimate the magnitude of any Killalea Lagoon leakage over proposed extraction period and post quarrying period of water level recovery.
4. If required outline any mitigation option(s).

4.2 Software

MODFLOW SURFACT Version 4 was utilised within the Visual MODFLOW 2011.1 Pro graphical user interface. SURFACT was utilised due to readily simulate variably saturated conditions and avoid the 'dry cell' problem associated with standard MODFLOW.

4.3 Settings and Water Balance Error Criteria

MODFLOW SURFACT's Pseudo-soil function was utilised in both steady state and transient models. Closure criterion was kept equal to or below 0.01 m for all simulations.

Convertible layers were used for all layers/models.

A water balance error threshold of 1% was utilised which represents the typically adopted industry threshold value. If the error was above 1% either time step durations were reduced and/or closure criterion was increased to ensure the water balance error remained below 1%.

4.4 Model Extents

A total model domain area of 5 km by 3 km was utilised (Figure 11). Of this, approximately half comprised active model area with the remaining portion being inactive. The active model domain extents were assigned as pathline boundaries remote from the proposed excavations at topographic divides assumed to represent groundwater flow divides, and, at the ocean where a constant head of 0 mAHD was applied.

4.5 Layers

Model layering was established in accordance with the proposed layering documented in Martens and Kalf and Associates (P0902486JC10V01, September 2012) letter and comprised:

Layer 1 (top): surface terrain (Figure 11) – this layer assumes pre-quarrying topography and was defined using 1:25,000 topographic map contours, and site survey points. Terrain was estimated in areas where site operations had modified natural ground levels.

Layer 2 (top): 0 mAHD – this layer was assigned a uniform elevation of 0 mAHD.

Layer 3 (top): sandstone surface (Figure 12) – the pre quarry and approved development models' sandstone layer was assigned a variable elevation to represent the sandstone surface. Elevations from boreholes which intersected the sandstone were used to guide interpolation. The sandstone surface dips to the north east. In areas of no data the same dip angle and strike was assumed to interpolate sandstone layer elevations.

For all other simulations the elevation for the sandstone surface was assigned as outlined above with the exception of the proposed extraction pit areas. In these areas the sandstone was assigned an elevation of -40 mAHD to simulation of dewatering. This modification is appropriate given the layer properties are uniform.

Layer 3 (bottom): sandstone – the base of this layer was derived using a 40 m thickness (i.e reproduction of layer top surface but 40 m lower).

4.6 Boundary Conditions

4.6.1 Drain boundary

Drain boundaries were applied to represent the existing drop cut in the west pit. Drain levels and areas were increased from 2010 to 2012 on a yearly basis based on review of site surveys. Before 2010 the drain is inactive as quarrying extraction levels are above the pre-quarrying water table level. A drain conductance value of 100 m^2/d was utilised to achieve appropriate model simulation of pit drainage in consultation with Kalf and Associates.

4.6.2 *River Boundary*

The 'River package' in MODFLOW Surfact was used to simulate groundwater seepage interaction with Killalea Lagoon as it is equivalent to a large wide segment of river channel with a depth of surface water. A 'river' (lagoon) stage of 0.5 mAHD was assigned based on the mean monitored level of 0.47 mAHD for gauged values (i.e mean excludes values below gauge base).

Conductance for the lagoon bed layer was assigned based on a cell area of 625 m^2 multiplied by a vertical lagoon bed conductivity of 9.59 x 10^{-9} m/s divided by lagoon bed thickness. Since lagoon bed thickness varies and increases from north to south, conductance was assigned to decrease progressively in a linear manner from north to south. The method utilised involved estimating bed thickness in the far north of the lagoon and the far south using the hydrogeological long section (Attachment A – SK002). Conductance was varied lineally between the 2 points. No attempt was made to vary conductance east to west.

Adopted simplification of east to west conductance was considered acceptable based on preliminary model runs which compared a single uniform conductance value to varying conductance described above and found computed leakage rates were not sensitive to conductance.

Conductance at the most northern river boundary cells was assigned a value of 0.446 m^2/d (assumed bed thickness of 1.16 m). Conductance at the most southern river boundary cells was assigned a value of 0.029 m^2/d (assumed bed thickness of 18.04 m).

4.6.3 *Constant Head*

A constant head boundary of 0 mAHD was applied to all layers at the land/ocean interface.

4.6.4 *Seepage Face*

Surfact's seepage face boundary was applied at recharge zones with a ponding depth of 0 m.

4.7 Model Parameters

4.7.1 *Hydraulic Conductivity*

A uniform horizontal hydraulic conductivity value of 0.01 m/d (median and geomean of depth averaged packer testing - Table 9) was assigned for all layers with the exception of the sand barrier immediately south of Killalea Lagoon which was assigned 5 m/d for layers 1 and 2.

Uniform vertical hydraulic conductivity was assigned based on an assumed anisotropy of 0.1 (K_v = 0.001 m/d) for all layers other than the sand barrier which was assigned an anisotropy 1 (K_v = 5m/d).

Conductivity distribution is shown in Figure 15.

4.7.2 Recharge

Initial recharge values were determined during pre-quarrying steady state calibration.

4.8 Calibration

4.8.1 Steady State Pre-quarrying Simulation

Steady state recharge rates were adjusted in order to generate a groundwater mound of approximately 5 mAHD in the central area of the site. This adjustment was done whilst maintaining hydraulic conductivity values as given in Section 4.7.1.

Initially only 2 recharge zones were utilised which comprised the area of sand barrier sediments to the south of Killalea Lagoon, and, the remaining model area. However, preliminary runs with the Surfact seepage face boundary switched off resulted in head well above ground level in the west of the model. To address this, a third recharge zone was introduced (Zone 2) and assigned with a lower recharge rate.

Final calibrated recharge rates are shown in Figure 16 with total head for layer 1 in Figure 17 and the model's water balance in Table 14. A cross section through row 69 of the model is in Figure 18.

Table 14: Steady state pre-quarrying water balance.

Constant head (m^3/d)		Recharge (m^3/d)		Lagoon leakage [1] (m^3/d		Total (m^3/d)	
In	Out	In	Out [2]	In	Out	In	Out
0	84	99	5	0	10	99	99

Notes:
[1.] 'In' and 'out' volumes accord with MODFLOW convention and are from perspective of groundwater system, that is lagoon leakage 'out' indicates flow to the lagoon from the groundwater system. [2.] Represents volume of groundwater which breaches ground level and is then removed from model by seepage face boundary.

4.8.2 Transient Simulation

4.8.2.1 Calibration Period

Transient model calibration used the simulation period 2002 to 2012. The simulation period does not start prior to quarry operations as is typical as calibration data is available only from 2003 onwards, and, quarry extraction levels do not go beneath the modelled steady state pre-quarrying water table level (5 mAHD) until 2010.

4.8.2.2 Calibration Data

A total of 317 GWL observations were used from BH3, BH4, BH5, BT0701, BT0702, BT0706, BT1201, BT1202 and BT1204 for model calibration. This data generally comprises dipped level data. However, approximately 6 months of logger data for BH3, BH4 and BT0706 was available in 2012 and was used to derive mean monthly GWLs for this time period. The dipped GWL observations were entered into the model as observation levels at the time which they were observed. Monthly means derived from logger data were entered into the model to coincide with the middle of each month.

4.8.2.3 Calibration Data Frequency/Quality

The calibration data is not ideal for transient model calibration given the frequency and duration of GWL data collection. GWL data is available on a single date in 2003 for half of the calibration bores, no data is available for the others. In 2009 only two dates have data for all calibration bores. The data record for half the calibration bores (BH3, BH4 and BH5) generally comprises monthly dips spanned across the calibration period (excluding years of 2003 and 2009 mentioned previously). Data record at remaining calibration bores (BT0701, BT0702 and BT0706) spans only the recent half of the calibration period.

Notwithstanding the above, the calibration data comprises all that is available, is still useful and therefore transient calibration was conducted.

4.8.2.4 Calibration Method

K values and recharge rates from the steady state calibration were retained. Only S_s and S_y were adjusted during transient calibration.

Recharge was assigned on a monthly basis by applying the calibrated steady state percentage rates (Figure 16) to observed monthly rain at Albion Park BOM station from January 2002 to December 2012. This station is the closest to the site with no data gaps over the calibration period. This resulted in monthly stress periods for the calibration period.

Initial head for the simulation comprised the head from the steady state pre-quarrying model.

4.8.2.5 Calibration Results

The anticipated S_y and S_s values of 0.01 and 3.6 x 10^{-5} m^{-1} (Section 3.11.3) resulted in a general underprediction of head. To address this S_s was increased to 6.89 x 10^{-5} m^{-1} which accords with the upper end of the range outlined in Section 3.7. This resulted in head that was still slightly underpredicted. Given the fractured rock comprises a rigid rock structure, S_s was not increased any further and S_y was increased from 0.01 to 0.02. This resulted in a residual mean of -0.01 m, absolute residual mean of 0.55 m and NMRS of 16%.

This relationship between groundwater head and storage occurs due to the relationship between storage and the model's sinks. That is, increasing the storage parameters results in reduced drawdown from the model's sinks (such as constant head at ocean) and therefore higher groundwater head.

A scatter plot of observed and modelled head is provided in Figure 19 with observed/modelled hydrographs provided in Figure 20 through to Figure 28. In summary hydrographs indicate that the model is overpredicting head at BH3, BH4, BT1201, BT1202, underpredicting head at BT0701, BT0702 and BT1204, and, neither over or underpredicting head at BH5 and BT0706.

4.8.2.6 Interpretation of Calibration

The calibrated model does not replicate observed short term hydrograph variation. This may be attributable due to barometric and tidal influences which are not accounted for in the model, and because recharge is applied in the model on a monthly basis or because complex environmental processes/features are not accounted for in the model. The fact that the model is unable to replicate short term observed hydrograph trends is not critical to achieving model objectives as long term reduction to GWLs is considered the fundamental process to be modelled. Consequently, the model is considered suitable for assessing the quarry's overall drawdown and influence on Killalea Lagoon.

Ultimately, for future model verification purposes it is recommended that GWL data from observation bores surrounding the quarry pits and dewatering volumes be collected throughout the life of the project. This will allow verification of model results and provide data for recalibration should this be considered necessary.

4.9 Target Model Confidence-Level Classification

In accordance with Australian groundwater modelling guidelines (June, 2012), the model is considered to generally represent a 'Class 2' model confidence-level classification suitable for impact assessment.

A 'Class 2' classification is justified on the basis of the following:

- Geotechnical data coverage is reasonable in the vicinity of the proposed pits.
- Killalea Lagoon bed has been investigated.
- Mass balance error is less than 1%.
- Parameters are consistent with conceptualisation.

However, the following applies to the current model:

- Temporal head data coverage is limited to isolated dip measurements except for a short (~6 months) period of logger data for 2012.
- Observations of pit dewatering flows are not used in the calibration. This data was unavailable because the existing pit inflows have been very small, and subject to evaporation.

In spite of these limitations the model's target confidence level is considered suitable to determine both the regional drawdown influence and the leakage from Killalea Lagoon.

5 Predictive Simulations

5.1 Steady State Model

5.1.1 Approved Development

A steady state model to assess the current approved development was created using parameters determined from the calibrated pre-quarrying model.

The approved development was simulated by applying drains with levels according to the approved extraction levels (Figure 1).

The model's water balance is in Table 15.

Table 15: Steady state water balance for approved development.

Constant head (m^3/d)		Drain (m^3/d)		Recharge (m^3/d)		Lagoon leakage (m^3/d		Total (m^3/d)	
In	Out	In	Out	In	Out	In	Out	In	Out
0	61	0	27	99	4 [2]	0	7	99	99

Notes:
[1.] 'In' and 'out' volumes accord with MODFLOW convention and are from perspective of groundwater system, that is lagoon leakage 'out' indicates the groundwater system is discharging to the lagoon. [2.] Represents volume of groundwater which breaches ground level and is then removed from model by seepage face boundary.

5.1.2 Proposed Development

Steady state modelling of proposed quarrying included drain boundaries set to -40 mAHD over the footprint of both the eastern and western pits.

Total head for layer 1 is in Figure 29, a cross section through the row 69 of the model is in Figure 30 and drawdown is in Figure 31. The model's water balance is in Table 16.

Layer 1 drawdown at bore GW060313 is approximately 4 m with negligible drawdown considered likely at GW101125 based on the modelled result (Figure 31).

Table 16: Steady state water balance for model with both pits at -40 mAHD.

Constant head (m^3/d)		Drain (m^3/d)		Recharge (m^3/d)		Lagoon leakage (m^3/d		Total (m^3/d)	
In	Out	In	Out	In	Out	In	Out	In	Out
246	30	0	330	100	0	14	0	360	360

Notes:
1. 'In' and 'out' volumes accord with MODFLOW convention and are from perspective of groundwater system, that is lagoon leakage 'in' indicates flow to the groundwater system from the lagoon.

5.2 Transient Model

5.2.1 Simulation Period and Model Progression

The simulation period for the proposed development proceeds from year 0 to year 29 (i.e 30 year duration). After this period the model proceeds for a further 500 years for the purpose of water table/pit lake recovery modelling.

To achieve this simulation period, 3 separate transient models were run and results stitched together. Initial head for the first transient model comprised the head from the transient calibration model's last time step. Initial head for the second and third transient models comprised the initial head obtained from the last time step of the former transient model.

This procedure was adopted as the software does not enable hydraulic groundwater system properties to vary throughout a simulation, and this was required for the simulation of pit water level recovery following completion of extraction. The 3 transient models were required as opposed to 2 because pit lake recovery begins in the west pit at an earlier time than the east pit.

5.2.2 Stress Periods/Time Steps

Annual stress periods were utilised for years 0 to 40 (development simulation + first 10 years of pit lake recovery following quarry closure). From year 41 to 530 stress periods were assigned at 10 year intervals.

10 time steps and a time step multiplier of 1.2 were used for all stress periods.

5.2.3 Boundary Conditions/Parameters

Drain levels of the proposed pits were increased lineally (Figure 14) on a yearly basis in accordance with the project's staging of extraction levels.

The drain boundaries representing the extraction pits were switched off at the time of pit lake recovery modelling and hydraulic groundwater system properties altered in the area occupied by the east and west pits at the time of pit lake recovery. The water filled excavated pit voids were assigned relatively high hydraulic conductivity (100 m/d); S_y of 1; and S_s equivalent to the compressibility of water (5×10^{-6} m^{-1}) as a proxy to allow simulation of water level recovery.

A drain boundary was applied over the area of the extraction pits at a level of 7.8 mAHD during water level recovery simulation to represent the invert level of the quarry's existing discharge pipe which discharges to the ocean.

With the exception of periods of pit water level recovery, recharge rates were held constant (i.e did not change with time) and equivalent to the calibrated steady state recharge rates (Figure 16). This was done so that lagoon leakage and drain flow results could be evaluated independently of varying recharge and instead rather evaluated in the context of varying pit excavation levels. A simulation which incorporated the impact of time varying recharge rates was undertaken and is discussed in Section 6.

During pit water level recovery simulation, recharge rates were altered to simulate net surface water recharge to the pit voids. Recharge rates were altered over the west pit to be 398 mm/year and 183 mm/year over the east pit until the modelled water level in each of the respective pits exceeded 0 mAHD. After the water levels reach 0 mAHD a higher evaporative surface takes place due to proposed pit geometry. Consequently, after pit water levels exceed 0 mAHD recharge rates were lowered to be 111 mm/year and 142 mm/year over the west and east pits respectively. Recharge rates were derived from an annual water balance incorporating catchment area surrounding the pits, run off coefficient of 0.4 (based on rehabilitated quarry), pan evaporation of 0.77, mean annual rain from Windang BOM station and mean annual evaporation from NOWRA Treatment Works BOM station.

All other boundaries and parameters remained unchanged from the transient calibration model.

5.2.4 Results

Drain flow rates for both pits are in Figure 32 whilst cumulative drain flow over the life of the project is in Figure 33. In periods with both drains simultaneously active, drain flow rates were calculated by applying the relevant percentage contribution of each pit's rate as outputted in the zone budget and applying this to the cumulative drain volume. This method was undertaken to overcome software limitations in order to allow the higher drain flows in earlier time steps to be accounted for. Combined peak dewatering rate occurs at the end of year 20 (when the west pit reaches the maximum extraction level of -40 mAHD) with a value of 479 m^3/d.

Killalea Lagoon net leakage rates are in Figure 34 for the project life and the entire model period and indicate quarrying will result in a reversal of leakage. That is, proposed quarrying will cause a shift from groundwater discharging from the groundwater system to the lagoon, to discharge from the lagoon to the groundwater system. At the end of the first simulation year approximately 7 m^3/d of groundwater is discharging from the groundwater system to the lagoon. This volume decreases throughout the simulation until the end of year 30 (i.e end of quarrying and year of maximum change to net leakage) where approximately 12 m^3/d of groundwater is discharging from the lagoon to the groundwater system. This represents a maximum reduction in flow to the lagoon of 19 m^3/d. After year 30 the net leakage rate begins to recover slowly and equilibrates approximately 170 years after quarry closure with a volume of approximately 13 m^3/d of groundwater discharging from the groundwater system to the lagoon.

Water level recovery within both pits following quarry closure is plotted in Figure 35. Water level in the west pit recovers to approximately 0 mAHD approximately 75 years after quarry closure. Water level in the east pit recovers to approximately 0 mAHD approximately 125 years after quarry closure.

Equilibrium water level is achieved in the west pit approximately 160 years after quarry closure at approximately 7.8 mAHD. Equilibrium in the east pit's water level is achieved approximately 200 years after quarry closure at approximately 7.8 mAHD. The equilibrated water level of 7.8 mAHD occurs due to the quarry's existing discharge pipe.

At the end of year 20, Layer 1 drawdown at bore GW060313 is approximately 1 m. Maximum drawdown of approximately 2 m to Layer 1 head at bore GW060313 occurs 60 years after quarry closure.

Negligible drawdown is considered likely at GW101125 based on interpretation of the modelled results with respect to the bore's location within the inactive model domain.

A discussion of results and results summary follows sensitivity/uncertainty analysis (Section 6) is in Section 8.

5.3 Source of Groundwater Inflow to Quarry Pits

Based on the predictive steady state model's water balance for the proposed development (Table 16), and the constant head boundary 'in' flow of 246 m^3/d (0 m^3/d in pre-quarry model), the percentage contribution of groundwater sourced from seawater to the total dewatering rate of 330 m^3/d is approximately 75%.

With respect to the transient predictive model, the percentage contribution of groundwater sourced from seawater relative to the total groundwater flow rate into the extraction pits varies throughout the simulation. The percentage contribution varies from close to 0 at the start of the simulation to 43% at the end of year 20 and peaks at 72% at the end of year 30 (analysis was not conducted beyond year 30).

It is noted that for years 21 to 30 the west pit's drain boundary is inactive in the model and therefore does not contribute to the total 'dewatering' rate outputted by the model. Consequently, groundwater inflow to the west pit during this time was back calculated based on the pit's water level and added to the eastern pit's drain rate in order to ensure constant head 'in' flows were being compared to total groundwater inflows.

In light of the above it is concluded that groundwater sourced from seawater comprises a significant component of total inflow to the quarry pits.

6 Sensitivity/Uncertainty Analysis

6.1 Overview

Sensitivity/uncertainty analysis was undertaken through undertaking a variety of transient and steady state model runs containing different parameter sets. The primary sensitivity/uncertainty target assessed was lagoon leakage with drain flow rate a secondary target.

Transient runs analysed sensitivity/uncertainty associated with recharge and storage whilst steady state runs analysed sensitivity/uncertainty associated increased combinations of hydraulic conductivity and recharge, and increased lagoon conductance.

6.2 Transient Model Sensitivity/Uncertainty Simulations

6.2.1 Time Varying Recharge

The transient predictive model was run for assessment purposes with constant recharge as determined through model calibration. For sensitivity assessment purposes the model was rerun with recharge varied on an annual basis. Recharge application utilised the same method as the transient predictive model with the exception of the observed rainfall being annual as opposed to monthly. Annual rain values were sourced from Windang BOM station from 1963 (start of record) onwards.

Plots comparing dewatering rates and lagoon net leakage rates from the predictive and sensitivity model are provided in Figure 36 and Figure 37 for the first of the 3 transient models. Results indicate varying recharge has a negligible impact on modelled dewatering rates and lagoon net leakage rates.

At the end of year 20, Layer 1 drawdown at bore GW060313 is approximately 1 m with negligible drawdown considered likely at GW101125 based on the modelled result.

6.2.2 High Storage

The transient predictive model was run with high storage for the purpose of sensitivity/uncertainty analysis. This procedure was only completed for the first of the three transient models. This proved to be sufficient to provide insight into sensitivity given peak dewatering rates and peak lagoon leakage occur at the end of the first transient model's simulation period (i.e end of year 19).

S_y was increased from 0.02 to 0.1 and S_s was increased from 6.89 x 10^{-5} to 6.89 x 10^{-4} m^{-1}. Although S_y was increased to 0.1, this is highly unlikely to be the bulk value. No other changes were made to the model.

Applying the high storage parameters to the calibration model resulted in an increase to residual mean from -0.01 to 0.57 and therefore on balance these parameters cause over prediction of head.

Plots comparing dewatering rates and lagoon net leakage rates between the transient model with high storage and the base case transient model are in Figure 38 and Figure 39.

Peak dewatering rate at year 20 for both pits increases from 479 m^3/d to 1157 m^3/d due to the high storage.

Lagoon leakage rate at year 20 is approximately 2 m^3/d from the groundwater system to the lagoon in the high storage simulation. In the probable simulation model at year 20 the flow is approximately 8 m^3/d from the lagoon to the groundwater system.

At the end of year 20, Layer 1 drawdown at bore GW060313 is approximately 1 m with negligible drawdown considered likely at GW101125 based on the modelled result.

6.2.3 Low Storage

A low storage sensitivity run was performed using the same method as the high storage run documented in Section 6.2.2.

S_y was decreased from 0.02 to 0.002 and S_s was decreased from 6.89 x 10^{-5} to 6.89 x 10^{-6} m^{-1}.

Applying the low storage parameters to the calibration model resulted in a decrease to residual mean from -0.01 to -1.11 and therefore on balance these parameters cause under prediction of head.

Plots comparing dewatering rates and lagoon net leakage rates between the transient model with low storage and the base case transient model are in Figure 40 and Figure 41.

Peak dewatering rate at year 20 for both pits decreases from 479 m^3/d to 330 m^3/d due to the low storage.

Lagoon leakage rate at year 20 is approximately 13 m^3/d from the lagoon to the groundwater system in the low storage simulation. In the probable simulation model at year 20 the flow is approximately 8 m^3/d from the lagoon to the groundwater system.

At the end of year 20, Layer 1 drawdown at bore GW060313 is approximately 1 m with negligible drawdown considered likely at GW101125 based on the modelled result.

6.3 Steady State Model Sensitivity/Uncertainty Simulations

6.3.1 Sensitivity/Uncertainty Simulations

The following steady state model runs were completed for the purpose of sensitivity/uncertainty analysis:

<u>Run 1</u> – Kxyz and recharge increased one order of magnitude (except at sand barrier zone).

<u>Run 2</u> – Kxy increased to 0.03 (mean of depth integrated packer testing, see Table 9), Kz increased to 0.003 (anisotropy maintained), recharge rates increased by same margin as K values (i.e threefold increase). However, no changes were made at the sand barrier zone.

<u>Run 3</u> – lagoon conductance increased by an order of magnitude.

<u>Run 4</u> – lagoon conductance increased by 2 orders of magnitude.

All model runs were completed with both pits simulated at a level of -40 mAHD.

6.3.2 Results

Results are provided in Table 17 and summarised below:

- With respect to the base case model, increasing Kxyz and recharge one order of magnitude increased the drain rate approximately tenfold and increased the reduction to lagoon flow approximately sixfold. Layer 1 drawdown at bore GW060313 is approximately 5 m with negligible drawdown considered likely at GW101125 based on the modelled result (drawdown was similar to steady state base case drawdown shown in Figure 31).

- With respect to the base case model, increasing Kxyz and recharge threefold increased the drain rate and reduction to lagoon flow approximately threefold. Layer 1 drawdown at bore GW060313 is approximately 5 m with negligible drawdown considered likely at GW101125 based on the modelled result (drawdown was similar to steady state base case drawdown shown in Figure 31).

- With respect to the base case model, increasing the lagoon conductance by an order of magnitude increased the drain rate by approximately 0.3% and increased reduction to lagoon flow by approximately 4% (1 m3/d increase). Layer 1 drawdown at bore GW060313 is approximately 4 m with negligible drawdown considered likely at GW101125 based on the modelled result (drawdown was similar to steady state base case drawdown shown in Figure 31).

- With respect to the base case model, increasing the lagoon conductance by two orders of magnitude increased the drain rate by approximately 0.3% and increased reduction to lagoon flow by approximately 8% (2 m3/d increase). Layer 1 drawdown at bore GW060313 is approximately 4 m with negligible drawdown considered likely at GW101125 based on the modelled result (drawdown was similar to steady state base case drawdown shown in Figure 31).

Table 17: Steady state model sensitivity of drain rate and lagoon leakage to increased K and recharge, and, to increased lagoon bed conductance.

Sensitivity Run	Drain rate (m^3/d)	Pre quarry Lagoon leakage (m^3/d		Lagoon leakage with both pits at -40 mAHD (m^3/d		Reduction to lagoon flow due to leakage changes (m^3/d)
	Out	In	Out	In	Out	
Base case	330	0	10	14	0	24
Run 1	3276	0	31	103	0	134
Run 2	988	0	25	38	0	63
Run 3	331	0	10	15	0	25
Run 4	331	0	11	15	0	26

Notes:
1. 'In' and 'out' volumes accord with MODFLOW convention and are from perspective of groundwater system, that is lagoon leakage 'in' indicates flow to the groundwater system from lagoon, lagoon leakage 'out' indicates flow from groundwater system to lagoon.

6.4 Conclusion

With the exception of the worst case sensitivity/uncertainty run (increase to kxyz and recharge by one order of magnitude), sensitivity/uncertainty runs indicate that changes to model parameters do not materially change assessment outcomes. It is noted that the model was not calibrated to the parameter values used in the sensitivity runs and that these parameter values are generally quite severe and improbable.

The entire range of drain rates are considered to be manageable through mitigation with appropriate dewatering pumps and the range of reductions to lagoon flow are considered manageable through mitigation should this be required.

In the context of the proposed quarrying scenario mean daily surface water inflow to the lagoon of 1034 m^3/d and mean daily lagoon evaporation of 631 m^3/d (both computed in the lagoon water balance model discussed in Section 7), leakage represents a minor component of the lagoon's water balance.

The worst case sensitivity/uncertainty results in a significant increase to drain rate and lagoon leakage out of the lagoon to the groundwater system. However, these outcomes are considered unlikely given the assigned parameters. Notwithstanding this these outcomes are still considered manageable.

The transient predictive simulation and sensitivity models indicate a drawdown of approximately 1 m at the end of year 20 to Layer 1 head at bore GW060313. The steady state predictive model and the range of sensitivity models indicate a Layer 1 drawdown at this bore ranging from 4 to 5 m. However, it should be noted that results from the steady state models are severe since storage of the groundwater system is assumed to be zero. Hence under these conditions there is no buffering of drawdown due to storage within the modelled system. Consequently, the transient predictive simulation and drawdown at bore GW060313 would be the more probably outcome.

Negligible drawdown is considered likely at GW101125 based on interpretation of the modelled results with respect to the bores location within the inactive model domain.

7 Killalea Lagoon Water Balance Model

7.1 Overview

A daily water balance spreadsheet model was created to compare existing quarrying lagoon water levels with those with proposed quarrying.

7.2 Method

7.2.1 Existing Quarrying

The parameters detailed in Table 18 were used in the existing quarrying water balance model.

7.2.2 Proposed Quarrying

The proposed quarrying water balance model was altered from the existing quarrying model as follows:

1. Lagoon catchment area was decreased from 730,446 m^2 to 721,446 m^2 to reflect catchment loss due to proposed quarrying.

2. Groundwater inflow this was reduced from 10 m^3/d (groundwater discharge to lagoon) to -14 m^3/d (water leakage from lagoon to groundwater) as modelled in the steady state groundwater model (Table 16).

Table 18: Lagoon water balance model parameters.

Parameter	Parameter Value	Comment
Runoff coefficient	0.4	
Pan evaporation factor	0.77	Taken from Table S6 – Nowra RAN value from McMahon *et al* (date omitted)
Groundwater inflow (m^3/d)	10	Modelled pre-quarry steady state groundwater flow to lagoon (Table 14)
Lagoon area (m^2)	170,000	Represented in groundwater model with 272 river cells each 625 m^2
Lagoon catchment area (m^2)	730,446	Measured in CAD, excludes sand barrier at south of lagoon
Starting lagoon water depth (m)	1	
Maximum lagoon water depth (m	1.2	Based on mean water depth observed during vibracoring of 1.14 m. Water above 1.2 m overflows to ocean.
Critical rainfall (mm)	2	Rainfall greater than 2 mm is excluded from runoff calculations. Rainfall greater than 2 mm is taken as observed rain less 2 mm for the purpose of runoff calculations
Rainfall and evaporation record source, duration and period		Source: Nowra Treatment Works Duration – 15 years 1990 to 2004 (inclusive) – chosen as period has relatively low rainfall. Mean annual rain based on mean daily rain was 925 mm. Mean annual rain over 1897 to 2009 was 1037 mm

7.3 Results

Lagoon water levels for the modelled period of 1990 – 2004 were reviewed and summarised (Table 19). Results indicate that the reduced catchment and change in leakage to and from the lagoon result in minor lagoon water level changes. Statistical analysis of daily water levels indicate that the median water level in the lagoon is reduced by only 19 mm, this is likely to be well within the resolution of the modelling and does not represent a significant change in the lagoon water level.

When considering the 5th percentile 'lowest' levels the reduction in modelled lagoon water level is 40 mm, again this is considered negligible in the context of the monitored natural lagoon water level range of 0.9 m (Table 2). A plot showing existing and proposed quarrying lagoon water depths is provided as Figure 42.

Table 19: Lagoon water balance model results.

Percentile	Existing Quarrying Lagoon Water Depth (m)	Proposed Quarrying Lagoon Water Depth (m)	Change (mm)
90	1.191	1.189	2
75	1.165	1.158	8
50	1.102	1.083	19
25	0.976	0.951	25
10	0.852	0.813	39
5	0.791	0.751	40
1	0.718	0.681	37

8 Results Summary and Discussion

8.1 Dewatering Rates

Dewatering rate peaks in the west pit at the end of year 11 at a rate of 231 m^3/d.

Dewatering rate peaks in the east pit at the end of year 20 at a rate of 301 m^3/d.

Combined dewatering rate for both pits peaks at the end of year 20 at 479 m^3/d. Of this inflow approximately 206 m^3/d is flow directly from the ocean to the void.

Significant portions of the total quarry void 'groundwater inflow' as assessed in this report are directly sourced from the adjacent ocean. The proportion of water sourced from groundwater and ocean varies through the transient modelling period, it peaks at approximately 72% in year 30 and is 43% when the total quarry inflows are at their highest (year 20).

8.2 Killalea Lagoon

8.2.1 Leakage

The flow of water in and out of Killalea Lagoon is critical in understanding the influence of the quarry. A base case scenario assessed through steady state pre-quarrying simulations indicates that approximately 10 m^3/d of groundwater discharges from the groundwater system to the lagoon.

All modelling simulations indicate that proposed quarrying will result in reduced flow from the groundwater system to the lagoon, and all modelling simulations with the exception of the high storage sensitivity run indicate that the proposed development will result in a reversal of leakage. That is, proposed quarrying will cause a shift from groundwater discharging from the groundwater system to the lagoon, to discharge from the lagoon to the groundwater system.

With respect to the transient predictive model, the influence is largest at the end of year 30 where a net leakage from the lagoon to groundwater system of 12 m^3/d was modelled. From this point onwards the net leakage rate begins to recover slowly and equilibrates about 170 years after quarry closure. The equilibrated net leakage rate is approximately 13 m^3/d from the groundwater system to the lagoon and is higher than the steady state pre-quarrying leakage rate of 10 m^3/d. The reason the equilibrated net leakage rate is higher than pre-quarrying is due to the levels to which surface water/groundwater recovers to within the east and west pits (7.8 mAHD).

Net leakage is similar to pre-quarrying steady state net leakage after approximately 120 years following quarry closure.

The steady state predictive model indicated a marginally increased influence compared to the transient model and predicted a net leakage of 14 m^3/d from the lagoon to the groundwater system with both pits modelled at -40 mAHD. With the pre-quarrying net leakage of 10 m^3/d from the groundwater system to lagoon, this represents a reduction in flow 'to' the lagoon of 24 m^3/d.

8.2.2 Water Depths

Daily water balance modelling for the dryer than average period of 1990 - 2004 indicate changes to lagoon catchment and groundwater interactions lead to insignificant changes to lagoon water levels. The median modelled water level over the 14 year period is lowered by 19 mm which is considered to be within the resolution of the assessment and not considered to be significant for the ecological values of the lagoon.

8.3 Drawdown at Surrounding Bores

The transient predictive simulation model indicates a maximum drawdown of approximately 2 m to Layer 1 head at bore GW060313 60 years following quarry closure.

Negligible drawdown is considered likely at GW101125 based on interpretation of the modelled results with respect to the bores location within the inactive model domain.

On the basis of above 'make good provisions' for these bores is not considered necessary in accordance with the NSW Aquifer Interference Policy (2012).

8.4 Pit Water Level Recovery

Following quarry closure, water level recovery (Figure 35) within both pits occurs slowly. Water level in the west pit recovers to approximately 0 mAHD approximately 75 years after quarry closure. Water level in the east pit recovers to approximately 0 mAHD approximately 125 years after quarry closure.

Equilibrium water level is achieved in the west pit approximately 160 years after quarry closure at approximately 7.8 mAHD. Equilibrium in the east pit's water level is achieved approximately 200 years after quarry closure at approximately 7.8 mAHD. The equilibrated water level of 7.8 mAHD occurs due to the quarry's existing discharge pipe.

9 Impact Mitigation

9.1 Killalea Lagoon During Quarrying – Flow Supplementation

9.1.1 Overview

Modelled reductions to lagoon water levels are considered negligible and therefore no flow supplementation is considered necessary.

9.2 Killalea Lagoon Post-Quarrying

9.2.1 Overview

Reductions to Killalea Lagoon's net leakage persist approximately 120 years after quarry closure. This is due to slow recovery of water levels within the east and west pits.

Equilibrated east and west pit water levels are above the modelled pre-quarry groundwater table mound of 5 mAHD being approximately 7.8 mAHD. This establishes slightly higher head and therefore increased discharge of groundwater into the lagoon (13 m^3/d) from that which is derived from the pre-quarrying model (10 m^3/d). This increase in discharge is considered negligible in the context of the lagoon's water balance and therefore no mitigation is considered necessary.

9.2.2 Mitigation of Slow Filling of Voids

Post quarry void water levels are modelled to recover to 0 mAHD approximately 75 years and 125 years after quarry closure for the west and east pits respectively. Final equilibrium water level of approximately 7.8 mAHD is modelled to occur approximately 160 years and 200 years after quarry closure for the west and east pits respectively. It is considered prudent for licensing purposes to reduce this water level recovery time period and therefore increased connectivity with the ocean could be achieved with underbore(s).

Underbore(s) would be constructed with connection to the ocean at a level as low as practical with consideration to management of breakthrough affects. A level near to the lowest tide is likely to be adopted. The final dimension of underbore(s) is to be determined. Filling time periods to achieve void water levels of approximately 0 mAHD are estimated based on underbore diameter at 10 years (300 mm), 3 years (450 mm) and 1 year (600 mm).

10 Monitoring Program

A site specific groundwater and Killalea Lagoon water level and water quality monitoring program is to be formulated in consultation with NOW and any other relevant agencies following project approval.

11 Water Licensing

11.1 Overview

The project is located within the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011.

It is anticipated that a Water Access License (WAL) and Aquifer Interference Activity Approval with sufficient share component for the taking of water shall be required. The grant of the WAL and the management of allocation and share component which attach to it are bound by the rules within the Water Sharing Plan.

Any water taken from a WM Act regulated water source as part of or as a result of the Project must be authorised by a Water Access License.

As a consequence of Section 75U of the EP&A Act, approvals under Section 89 – Water Use Approval, 90 – Water Management Work Approval or 91 – Controlled Works Approval are not required for the Project should a Project Approval be granted under Part 3A of the EP&A Act.

12 Conclusions and Recommendations

Numerical groundwater modelling including combined sensitivity/uncertainty analysis indicates that the proposed development can proceed with an acceptable level of impact to stakeholders (environment and licensed bore users).

The primary concern is influence to Killalea Lagoon which comes about due to quarrying to -40 mAHD which reverses the hydraulic gradient from the groundwater system to the lagoon, to the lagoon to groundwater system.

The impacts of the proposed quarry extension at Hanson's Bass Point Quarry are considered acceptable. The quarry shall not impact on the local hydrogeological system in such a way as to have significant detrimental effects for nearby groundwater users or ecological systems.

No mitigation measures are required to address hydrogeological impacts. An underbored connection between the void and the ocean may be used to reduce the time to fill the voids and thus reduce the need for ongoing groundwater licensing.

13 References

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