GROUNDWATER MODELLING ASSESSMENT

Lot 6 Banksia Road, and
Lots 300 and 301 Boomerang Road, Oldbury

Prepared by:

RPS

290 Churchill Avenue, SUBIACO WA 2008
PO Box 465, SUBIACO WA 6904
T: 618 9382 4744
F: 618 9382 1177
E: admin02@rpsgroup.com.au
W: www.rpsgroup.com.au

Prepared for:

ROCLA QUARRY PRODUCTS

130 Fauntleroy Avenue
REDCLIFFE WA 6104

Report No: C09021
Version/Date: Rev 0, April 2009

RPS Environment and Planning Pty Ltd (ABN 45 108 680 977)

Document Status

Version	*Purpose of Document*	*Orig*	*Review*	*Review Date*	*Format Review*	*RPS Release Approval*	*Issue Date*
Rev 0	*Final for Issue*	*StuCam*	*CarlDav*	*31.03.09*	*SN 06.04.09*	*P. Bourgault*	*07.04.09*

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1.0 INTRODUCTION

RPS Environment and Planning has been commissioned to develop a three dimensional numerical groundwater model to estimate the potential increase in water levels due to clearing of vegetation at the proposed sand quarry within Lot 6 Banksia Road and Lots 300 and 301 Boomerang Road, Oldbury (Figure 1). The purpose of the model is to specifically address a Department of Environment (DoE) comment regarding the sand extraction licence application:

'Clearing of vegetation from a sandy rise adjacent to wetlands could impact the hydrogeology of the wetland including increase in recharge and water logging'

Some of the applications and limitations of this model include:

- By nature, a model is based on a limited amount of information and so will not be able to capture all of the inherent geological complexity at a site;
- Literature values will be used for model parameters such as the hydraulic conductivity and recharge rates because no site specific testing has been conducted;
- The proposed model is designed to simulate steady state groundwater conditions.

Despite these limitations, groundwater modelling provides the best available option for simulating the current groundwater conditions at the site, and for predicting the potential impact of vegetation clearing on groundwater levels.

2.0 GEOLOGY AND HYDROGEOLOGY

2.1 Geology

The 1:50,000 Environmental Geology Series maps for Rockingham, Fremantle, Armadale and Serpentine (Jordan, 1986; Gozzard, 1983) indicate the model domain is principally located on either the Bassendean Sand or Bassendean Sand overlying Guildford Formation. The Bassendean Sand is described as light grey, fine to medium grained sand of eolian origin. Sandy Clay of the Guildford Formation is encountered at the south-eastern part of the model domain, with a small area of Clayey Sand to the south of the site. The surface geology associated with the wetland directly south of the site consists of dark grey and black, peaty sand. The site itself is underlain by the Bassendean Sand unit. The geological units are shown in Figure 2.

The saturated thickness of the superficial aquifer ranges from approximately 30 m at the north-western part of the model domain down to approximately 8 m at the eastern part of the domain (DoE, 2004). The saturated thickness of the superficial aquifer is approximately 22 m beneath the site. The site is underlain by the Pinjar Member of the Leederville Formation (Davidson, 1995).

2.2 Hydrogeology

2.2.1 Groundwater Elevation and Flow Direction

According to Davidson, the site is located on the Jandakot Mound. The DoE (2004) Perth Groundwater Atlas (which shows contours for May 2003) indicates that groundwater beneath the site migrates in a south to south-westerly direction under a hydraulic gradient of approximately 0.004. The atlas indicates that the groundwater elevation at the site ranges from approximately 14 to 16.5 mAHD.

According to an investigation conducted by GHD, the groundwater level determined from a bore at the northern part of the site and a test pit at the south-western part of the site were both approximately 16 mAHD. This groundwater elevation is in close proximity to the DoE Atlas (2004), however the hydraulic gradient was lower than the atlas represents. The groundwater contours as shown on the Perth Groundwater Atlas are shown on Figure 3.

2.2.2 Wetlands

Portions of Resource Enhancement and Multiple Use wetlands are located in the south western corner of the site, with excavation no closer than 50 m to these wetlands. A Conservation Category Wetland is located 160 m south-west of the site, with the proposed excavation activities taking place at least 300 m from this wetland. The wetland areas are shown on Figure 9.

3.0 MODEL DESIGN

3.1 Modelling Software

The groundwater flow modelling was undertaken using the industry standard Modflow 2000 (Harbaugh et. al., 2000) and the Groundwater Modelling System (GMS) graphical user interface (Brigham Young University, 2002).

3.2 Grid Design

The model domain is approximately 8 km east–west by 6 km north–south (Figure 4), with 37,500 cells. The cell size was 10 m within the site and the wetland area, and progressively increased (by 10%) to a maximum of approximately 100 m at the model boundaries. The small cell size within the area of interest was necessary to predict the impacts of clearing more accurately at the wetland.

3.3 Model Boundaries

The model boundaries were based on the Perth Groundwater Atlas (DoE, 2004) contours and set as:

- Northern boundary: Specified head at the centre of the northern boundary to coincide with the 20 mAHD contour of the Jandakot mound. The sides of the northern boundary are no flow boundaries.

- Southern, eastern and western boundaries: Specified head to coincide with the 8 mAHD contour of the Jandakot mound.

- Bottom boundary: No Flow Boundary interpolated from DoE (2004) contours for the base of the superficial aquifer.

- Top boundary: Constant flux (rainfall recharge).

The model boundaries are shown on Figure 4.

3.4 Model Parameters

3.4.1 Hydraulic Conductivity

The hydraulic conductivity (K) is a measure of a material's ability to transmit water. The K of the Bassendean Sand is estimated to have an average of 15 m/day (Davidson and Yu, 2006), and to range from 10 to 30 m/day (Davidson, 1995). The K of the Guildford

Clay is estimated to be between 0.1 to 1 m/day, which is an average that includes low permeability silts and clays and high permeability sand lenses (Davidson and Yu, 2006). Davidson (1995) provides estimates of 0.4 m/day for clay, 1m/day for clayey sand and 4 m/day for silty sand. The locations of the geological units are provided in Figure 2.

3.4.2 Rainfall

The nearest weather station to the site is the Medina Research Centre, located approximately 12 km to the north. The average annual rainfall since 1983 (when the weather station began operating) is 780 mm.

3.4.3 Groundwater Recharge

3.4.3.1 Overview

Groundwater recharge is the percentage of rainfall that infiltrates into the groundwater. The recharge rate will depend on the landuse type, vegetation, the infiltration capacity of the soil and the depth to groundwater. Aerial photographs indicate the western part of the model domain is covered in bushland while the eastern half is predominantly cleared. A literature review of recharge rates pertinent to the site follows.

3.4.3.2 Recharge Estimation by Groundwater Area

The site is located on the Jandakot Mound. Davidson (1995) estimates recharge to the Jandakot Mound is between 0 and 24% of rainfall, with an average of 15%. The variation in recharge rates in the Jandakot Mound is due to the hydraulic conductivity of the soils and the depth to the water-table. Shallow water-table depths and low K materials typically result in lower recharge rates. Davidson (1995) estimates the recharge rate in clayey areas of the Jandakot Mound to be 5% and in sandy areas to be 15%.

3.4.3.3 Recharge Estimation by Land Use

Banksia Woodland

Sharma and Pionke (1984) estimate 12% of rainfall recharges the superficial aquifer beneath native bushland, while Farrington and Bartle (1991) estimate 22% of rainfall recharges the aquifer beneath Banksia. Recharge beneath low, medium, and high density Banksia woodland has been estimated to be approximately 38%, 18% and 10% respectively with a deep water-table (Silberstein et al., 2004).

Pasture / Cleared Land

Recharge rates beneath pasture in the Perth area have been estimated at 45% by Silberstein et al. (2004). Based on a local investigation on pastoral land near Lake Pinjar with a water depth of between four and seven metres, Sharma et al. (1988) estimated between 50 and 60% of rainfall recharging the aquifer. Pasture with shallow water-tables or low conductivity materials will typically have lower recharge rates than these literature values due to increased evaporation and run-off.

3.4.3.4 Recharge Rates Used for the Model

Based on the literature estimates and an annual rainfall of 780 mm, the following recharge rates were assigned to the model:

- Woodland – 15%. (0.00032 m/day).
- Regional areas of the Jandakot mound that are predominately cleared – 25% (0.00053 m/day).
- Guildford Formation – 5% (0.00011 m/day).
- Peaty Sand (wetland) – 5% (0.00011 m/day).

The recharge rate for the proposed quarry has been conservatively set at 75%, which is above the recharge value provided by Sharma et al. (1988) of between 50 and 60%. The recharge zones used in the model are provided in Figure 5.

3.4.4 Specific Yield.

The specific yield (Sy) is the volume ratio of water released by gravity drainage and is required for the model predictions. A value of 0.2 was assigned to the Bassendean Sand (Davidson, 1995). A Sy value of 0.07 was applied to the sandy clay (Kresic, 2007), with 0.12 for the clayey sand.

4.0 MODEL RESULTS

4.1 Groundwater Head Calibration

The simulated groundwater heads were compared with 118 'dummy' observation points that were based on the Perth Groundwater Atlas (DoE, 2004) contours. The K value was adjusted within appropriate ranges until the Mean Absolute Residual Head (MARH) difference between the simulated groundwater contours and observation points was minimised. The following table provides the MARH difference with associated K values.

Table 1: Mean Absolute Residual Head Difference

Test	Bassendean Sand K (m/day)	Clayey Sand K (m/day)	Sandy Clay K (m/day)	MARH (m)	Groundwater Elevation Range Across the Site (mAHD)
1	20	2	2	1.99	14.9–16.4
2	15	15	15	1.55	13.3–14.4
3	5	5	5	2.76	17.7–19.2
4	**10**	**10**	**10**	**1.21**	**14.4–15.8**
5	10	5	5	1.75	15.6–17
6	12	10	10	1.28	14.2–15.4
7	10	7.5	7.5	1.4	14.8–16.3

A K value of 10 m/day was assigned over the entire model domain. There are several reasons for this:

- The simulated groundwater elevation using a K of 10 m/day was between 14.4 and 15.8 mAHD across the site which is in close proximity to the DoE (2004) Atlas contours and site investigation water levels.

- Using low values for the Guildford Formation materials resulted in the groundwater flow direction migrating in a more westerly direction compared to DoE (2004) groundwater contours and these values also resulted in higher MARH differences (Table 1).

- The simulated flow direction using a K of 10 m/day was to the south-west, directly towards the wetlands which is similar to the DoE (2004) Atlas flow direction.

- The MARH of 1.2 m was lower than all other scenarios. This MARH difference is 10% of the head drop across the model domain. The MARH difference calculated from 28 wells in an area approximately 3 km^2 directly around the site was 0.7 m.

- The assigned K value of 10m/day for the Bassendean Sand is at the lowest range provided in the literature (Davidson, 1995). This value is reasonable as it also includes some areas of Guildford Formation throughout the model domain.

The simulated groundwater contours are shown on Figure 6.

4.1.1 Water Balance

The water balance (water coming into the system minus water flowing out of the system) information is provided in the table below.

Table 2: Water Balance Information

WATER IN (m3):	
STORAGE	0.00
CONSTANT HEAD	468.82
RECHARGE	10886.07
TOTAL IN	**11354.88**
WATER OUT (m3)	
STORAGE	0.00
CONSTANT HEAD	11355.09
RECHARGE	0.00
TOTAL OUT	**11355.09**
IN - OUT	**-0.20**
PERCENT DISCREPANCY	**0.00**

The water balance discrepancy is 0.00%, which is within the 0.1% value considered ideal for groundwater modelling simulations (Anderson and Woessner, 1991).

4.2 Vegetation Clearing Simulation

4.2.1 Proposed Clearing Program

The clearing is proposed to take place in seven stages (Figure 7) over a period of 10 years. For the purposes of the model, it has been assumed that the time taken to clear each stage is proportional to the area of the stage. The recharge rate was assumed to increase linearly during the clearing period, reaching a maximum of 75% when all of the area was cleared. It was also assumed that work on each new stage would commence immediately upon completion of the prior stage. The stage areas and estimated commencement and completion times for each stage are shown in Table 3. The commencement and completion times are expressed as the time after commencement of the first stage.

Table 3: Stage Clearing Information

Stage	Area (m^2)	Start Clearing (Days)	End Clearing (Days)
1	18000	0	360 (1 Year)
2	28500	360 (1 Year)	930 (2.5 Years)
3	17400	930 (2.5 Years)	1280 (3.5 Years)
4	18800	1280 (3.5 Years)	1655 (4.5 Years)
5	23500	1655 (4.5 Years)	2125 (6 Years)
6	18100	2125 (6 Years)	2485 (7 Years)
7	57900	2485 (7 Years)	3645 (10 Years)

Cleared areas are proposed to be revegetated and restored to a condition closely approximating natural Banksia woodland. For the purposes of the model, it was conservatively assumed that restoration work would not commence until clearing had been completed on all areas adjacent to the stage. It was further assumed that it would take five years for re-vegetation to reduce the recharge rate from 75% to that of Banksia woodland, and that the recharge rate would decrease linearly during that time. The estimated commencement and completion times for re-vegetation of the stages are shown in Table 4.

Table 4: Stage Re-vegetation Information

Stage	Start Re-vegetation (Days)	End Re-vegetation (Days)
1	1655 (4.5 Years)	3480 (9.5 Years)
2	1655 (4.5 Years)	3480 (9.5 Years)
3	2125 (6 Years)	3950 (11 Years)
4	2125 (6 Years)	3950 (11 Years)
5	3000 (8 Years)	4825 (13 Years)
6	3000 (8 Years)	4825 (13 Years)
7	3645 (10 Years)	5470 (15 Years)

4.2.2 Results and Discussion

The vegetation clearing simulation predicted that the groundwater elevation at the site will increase as clearing progresses, before decreasing to pre-clearing levels as the re-vegetation program progresses. Contours of the predicted increase in groundwater elevation after approximately 10 years are shown in Figure 8. This is the time at which the model predicts maximum impact upon the groundwater level adjacent to the Conservation Category Wetland (CCW).

The predicted increase in groundwater elevation was measured at three locations across the model domain (Figure 9). Point 1 is located at the site, Point 2 is located at the north-eastern edge of the CCW and Point 3 is located at the northern edge of the Resource Enhancement Wetland (REW). The maximum predicted groundwater elevation increase at the site is 0.25 m, which occurs approximately 8 years (3000 days) after the commencement of clearing (Figure 10). The maximum predicted groundwater elevation increase at the CCW is 0.14 m, which occurs approximately 10 years (3700 days) after the commencement of clearing (Figure 11). The maximum predicted groundwater elevation increase at the REW is 0.21 m, which occurs approximately 8 years (3000 days) after the commencement of clearing (Figure 12). Predicted groundwater levels in all simulations return to within 0.05 m of pre-clearing levels after a time of approximately 15 years.

The predicted increase in groundwater levels of 0.14 m adjacent to the CCW is considered minimal as it is significantly less than the estimated annual fluctuation of 0.65 m in the Bassendean Sand of the Jandakot Mound and 0.95 m in the Guildford Clay (Davidson, 1995).

5.0 MANAGEMENT STRATEGIES

As part of ongoing management, it is proposed to monitor the groundwater level at the south-west corner of the site. This will involve installing one monitoring well and monitoring annual high groundwater levels (October) and annual low groundwater levels (April).

According to the model, the increase in groundwater levels at the south-western corner of the site will be up to 0.21 m. A measured groundwater level that is 0.5 m above the model simulated groundwater increase at this location will be assigned as the trigger for potential management strategies.

If the trigger level is reached, monthly monitoring will be conducted to determine the length of time the groundwater level exceeds the trigger value. If the trigger is exceeded for a period of more than two months, the following management actions will be considered:

- Re-vegetation. The modelling prediction that groundwater will return to pre-development levels is based on healthy re-vegetation of bushland species. The re-vegetation program will be assessed and accelerated if required to decrease groundwater levels.

- Groundwater Abstraction. A groundwater abstraction bore(s) installed along the southern boundary will decrease groundwater levels in this area. The groundwater from this bore could potentially be used for dust suppression or to accelerate re-vegetation of bushland. The groundwater model could be used to estimate the abstraction rate that will result in negligible impact to the CCW resulting from both the vegetation clearing and groundwater abstraction.

- Tree Planting. Planting of trees along the southern boundary of the site, between the excavation and CCW wetland. These tree would be phreatophytes (obtain water from the saturated aquifer) and have high transpiration rates (such as pines) to reduce water levels.

6.0 CONCLUSIONS

The groundwater model predicts that staged clearing of the vegetation at the site will result in a groundwater increase of up to 0.25 m at the site, and up to 0.14 m at the Conservation Category Wetland located at least 300 m south of the excavation area.

It is proposed to monitor groundwater levels at the southern edge of the site for the duration of the clearing works. Where groundwater trigger levels are exceeded for a period of more than two months, management strategies may include accelerated re-vegetation of previously cleared areas, planting of phreatophytes along the southern boundary and/or groundwater abstraction.

The predicted increase in groundwater levels as a result of the vegetation clearing is significantly less than the groundwater fluctuation of the Bassendean Sand across the Jandakot Mound, and so is not expected to have a detrimental impact on the wetland ecosystem. On the basis of a drying climate, the slight increase in groundwater levels at the CCW is more likely to result in an improvement to the wetland ecosystem.

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