Rockwater
PROPRIETARY LIMITED

REVIEW OF LAKE JUALBUP EVALUATIONS

JANUARY 2012

REPORT FOR
“SAVE OUR JEWEL”
GROUP

(Report No. 317.1/12/01)

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1 INTRODUCTION

This review is a technical assessment of the evaluation of Lake Jualbup hydrology by Geoffrey Dean in his report "The Secret Life of Water in Lake Jualbup" (Dean, 2011; www.saveourjewel.org/hydrology.pdf). It also contains comments on the hydrology component of the Proposals for Restoring Lake Jualbup by "Save our Jewel" (SoJ) Group (www.saveourjewel.org); and comments on the review of lake level management options by RPS Consultants (2011; www.lakejualbupaccord.subiaco.wa.gov.au).

A map of Lake Jualbup and the Shenton Park reserve is presented in Figure 1 of this review.

2 DEAN REPORT - METHODOLOGIES (COLLECTION OF DATA)

Dr Dean has undertaken detailed measurements of water levels in Lake Jualbup, generally daily, for several years. These measurements appear without exception to be accurate, and closely correlate with those taken monthly by Rockwater. He has utilised rainfall data from measuring stations at Subiaco Wastewater Treatment Plant (Lemnos Street) and Floreat (Brockway Road) and averaged them to obtain the most accurate data available for the Lake Jualbup area.

Estimates of evaporation from the lake were initially obtained from the Perth official pan evaporation multiplied by 0.7 (a reasonable value). Because this adjustment tends to over estimate evaporation in summer, and underestimate it in winter, the technique has subsequently been refined.

Transpiration by the three most common trees was discussed with reference to measurements by McFarlane, and found to be very minor.

The collection of data by Dean has been in a very professional and detailed manner.

3 DEAN REPORT – EVALUATIONS OF DATA

3.1 RAINFALLS AND WATER LEVELS

Several plots in the report by Dean (2011) show in close detail the response of lake water levels to rainfalls. A plot of water level change against size of rainfall event on his page 21 illustrates similar trend lines from three researchers (McFarlane, Sim, and Dean) including some scattering of data, particularly for small rainfall events.

The pumpage from the Water Corporation's Aberdare Road (QEII Hospital) compensating basin was noted to affect the amount of water level rise produced by rainfall. This pumping from Aberdare Rd is irregular. It is incorporated in calculations for such pumping periods by adding a factor for Aberdare Rd pumping to the factor for inflow from local street drainage.

Based on an average from three studies, rainfall events of more than about 5 mm were indicated to raise the lake water level by 10.2 times the rainfall (10 mm of rain raises the level by 102 mm i.e. 10.2 cm). In periods when water is pumped from Aberdare Rd to Jualbup, the lake water level was indicated to be increased by 19.4 times the rainfall (10 mm of rain raises the lake water level by 194 mm i.e. 19.4 cm).

3.2 LAKE WATER LEAKAGE

It has been established by several researchers that after water ceases to flow into the lake (from rainfall events and/or pumping from Aberdare road) the lake water level declines mainly as a result of seepage through the lake bed, together with several lesser factors: evaporation, transpiration, and lateral seepage through the walls.

Dean (2011) has extended the work of others in providing detailed plots of water level with time, and the rates of water-level reduction at a range of lake water levels from near-empty to near-full (about 190 cm; to the top of the wall surrounding most of the lake; about 5 m AHD elevation). He provides comparisons of results for summer and winter (his pages 25 and 26). In summary, the results show water-level declines of between 1 and 5 centimetres per day (cm/d) of which evaporation consumes between 0.1 and 1 cm/d. The values are similar to those calculated or adopted by others.

The rates of water-level decline are highest when the lake water levels are highest. For a given water level, the rates are higher in summer than in winter. This is the result of a lower water table (in the shallow aquifer beneath and adjacent to the lake) in summer, and higher rates of evaporation in summer.

3.3 EVALUATION OF WATER-LEVEL DECLINES

Dean (2011) used plots of water-level ratios – one day's water level divided by the previous day's water level, and vice versa - to obtain equations for calculating lake water levels at daily intervals at times of no rain (his pages 28 and 29). From the trends of data-plots he developed the following empirical relationships.

(1) At high lake water level (60 to 190 cm above lake bed; 0 to 130 cm below top of wall).

Measurements of water levels below top of wall were subtracted from 190 cm to calculate **depths of water above adopted lake-bed elevation.** These values were then used to calculate ratios of water depth 'today' to water depth 'yesterday'; the ratios were then plotted against the water level below top of wall.

From the slope of an approximate straight-line plot of data the following relationship was calculated between daily ratio and water-level elevation below top of wall:

Tomorrow's depth (TD) = today's depth (D) x 0.9786 minus daily evaporation (in cm).
Tomorrow's water-level elevation below top of wall (TL) = TD –190 cm.

Advancing the calculation, Dr Dean introduces a 'leakage factor', LF, stated to have a value of 1 for the existing lake leakage. The equation is changed to:

Tomorrow's depth (TD) = D x (1 - 0.0214 x LF) minus daily evaporation (in cm).

Should the leakage factor be reduced to zero by the use of an impermeable layer on the lake floor, the equation becomes:

Tomorrow's depth (TD) = D x 1 minus daily evaporation. Therefore, there would be no water-level decline caused by leakage (seepage).

(2) At low lake water level (0 to 60 cm above lake bed; 130 to 190 cm below top of wall).

Measurements of water levels below top of wall were used to calculate ratios of water level 'yesterday' to water level 'today'; the ratios were then plotted against the water level below top of wall.

From the slope of an approximate straight-line plot of data the following relationship was calculated between daily ratio and water-level elevation below top of wall:

Tomorrow's water level (TL) = today's water level (L) / 0.9948 plus daily evaporation (in cm).

Using the 'leakage factor' concept, the equation is changed to:

Tomorrow's level (TL) = L / (1 – 0.0052 x LF) plus daily evaporation (in cm).

Should the leakage factor be reduced to zero, the equation becomes:

Tomorrow's level (TL) = L plus daily evaporation. There would be no water-level decline caused by leakage (seepage).

3.4 ASSESSMENT OF METHOD

The graphs presented by Dean (his page 31), comparing his calculated lake water levels with those observed, show a close correspondence at most times. There are some divergences between the plots, mainly as a result of water added to the lake during part of 2010 by pumping from Aberdare Rd, from dewatering of building sites and therefore unrelated to rainfall. At other times, the information on rainfall-generated pumping from Aberdare Rd has been incomplete, creating divergences in the water-level plots.

Overall, the method of relating lake water levels to rainfall and natural water losses (mainly seepage) is successful on an empirical basis.

The 'leakage factor' is a coefficient that is related to a combination of factors, most of which cannot be accurately quantified but have been estimated in some studies. The main factors are listed below:

- Lake-bed permeability
- Permeability of the sand strata (aquifer) extending to about 20 m depth beneath the lake, and laterally.
- Groundwater levels adjacent to the lake, affecting hydraulic gradients towards or away from the lake.
- Hydraulic gradients downwards from the lake to the base of the shallow aquifer and laterally, at times when the lake has 'high' water levels.
- Evaporation is treated separately.
- Transpiration is included with evaporation or taken to be a minor item.

In view of the complexities and limited data on most of the factors, an empirical approach is justified in assessing the lake recharge and discharge relationships. The alternative approach is numerical modelling such as was undertaken previously (Rockwater, 2005a). Additional information available since 2005 would allow the modelling to be refined, although the results might not differ significantly from those arrived-at in 2005.

4 DEAN REPORT – THE EFFECT OF REDUCED LEAKAGE

To examine the water levels that might arise if the lake-bed permeability is reduced by, say, the use of low-permeability polymers, Dean (2011) re-calculated the lake water-level hydrographs for the period 2000 to 2008 using a 'leakage factor' (LF) of 0.25 , i.e. 25% of the value for the existing lake as noted in Section 3.3 above. It is not known if the leakage factor can actually be reduced to 25% of its present assigned value, because of the several undefined items on which it depends (Section 3.4, above). Our assessment proceeds on the assumption that the factor can in fact be reduced to this extent.

The hydrograph plots on page 32 of Dean (2011) show that with a leakage factor of 0.25 the lake water levels (as calculated) would exceed the top of the wall in all nine years assessed. The results would be:

- Increased water flows through the outflow pipe.
- Additional flooding events and increased extent of flooding outside the perimeter of the lake.
- Reduced recharge to the shallow aquifer beneath and adjacent to the lake; the greatest effect would be to lower the water table on the southern side of the lake.

A hydrograph plot on page 34 of Dean (2011) shows the effect of a leakage factor of zero. The lake would have overflowed for more than half of each year, and the lake would never have been less than half full. The effects noted above would all be increased, and remedial measures would most likely be required to reduce the likelihood of flooding outside the park confines.

It is noted that in practice, leakage from the lake is unlikely to be reducible to zero because of permeability of the lake walls and difficulty in achieving a perfect bottom-seal.

5 THE EFFECT OF RAISING OR BLOCKING THE OUTLET DRAIN

On page 39 of his report, Dean (2011) examines the anticipated effect of causing water to flood over the lake surrounds rather than allowing it to flow into the outlet drain at its present elevation. The purpose would be to allow the overflow water to infiltrate through the grassed areas to the underlying shallow aquifer. The issues are: the area of inundation that will provide the infiltration, the rates of infiltration, and volume of available storage in the aquifer.

To examine a similar effect to blocking the outlet drain, this report provides calculations of the effects of raising the elevation of the outlet drain by 1 m. This elevation is taken as an example only; neither Dean nor SoJ have proposed that the outlet be raised by as much as 1 m.

Figure 2 of the present report shows a north-south cross section of Lake Jualbup and adjoining grassed area. It is approximately to scale, but has vertical exaggeration of about 10 x. It shows measured summer and winter lake water levels and groundwater levels, and the water/groundwater levels that would result from allowing the water level in the lake and surrounds to rise one metre above the level of the perimeter path. The shaded areas are cross sections of the material that is unsaturated pre-flooding, but may become saturated as a result of flooding of 15 m width of the lake surrounds.

The calculations in this report use simplified geometry: lake dimensions of 150 m x 180 m, rectangular shape. We examine the effects of raising the flooded-lake water level by 1 m above the path. With the reported grass-perimeter slope of 1:15, the flood water level would cover an additional 15 m-wide strip around the lake. The area of this strip is 10,800 m^2, and the volume of water overlying it to an average depth of 0.5 m (0 m on the outside and 1 m on the inside of the strip) would be 5,400 m^3.

5.1 IN SUMMER

In late-summer the unsaturated material directly beneath the 15 m-wide strip is about 2.5 m deep, and has an area of 10,800 m^2. With a porosity of 0.2, its pore volume would be 2.5 x 10,800 x 0.2 = 5,400 m^3.

The initially-unsaturated material beneath the perimeter strip could accept the water lying above it (with average depth of 0.5 m) in a matter of hours if the infiltration rate is similar to sand permeability, say, 6 m/d. In fact, the early infiltration rate is likely to not exceed 0.2 m/d, and the unsaturated material would take 2 days to fill. All the pore space would then be full, up to the lake water level. Two factors would then apply:

(1) Further seepage of water would take place laterally into the shallow aquifer under the prevailing hydraulic gradients, which would be a small fraction of the vertical hydraulic gradient of about 1, that applies for vertical flow in unsaturated material. Infiltration rates would reduce from about 6 m/d (adopted by Dean) to values of say 0.1 m/d.

(2) The lake level would at the same time decline at its usual peak rate of about 0.05 m/d (5 cm/d) – a lower rate than the early infiltration around the perimeter - therefore the lake will for some time contribute additional water by surface flow to the perimeter strip. This factor was noted by Dean (2011).

Thus, in summer the 15 m perimeter strip is likely to provide rapid infiltration of volumes of water (about 5,400 m^3) equivalent to that which would occupy the strip to a depth of about 1 m above the path level. Subsequent infiltration will be at slower rates, akin to the rates of decline of the lake, as the water will have to flow laterally in the aquifer.

A wedge of unsaturated aquifer in a wider strip, say 90 m wide outside the 15 m strip around the lake, will eventually become saturated by lateral flow from infiltration from a summer flood event to 1 m above path level. Its volume is calculated to be about 24,000 m^3, based on an area of 91,800 m^2, average thickness of 1.3 m, and porosity of 0.2. By this calculation it is suggested that in summer the aquifer could slowly accept another four times the volume of water that would overlie the 15 m strip to a depth of 1 m. This water would in fact flow from lake storage, in the event of a very large summer rainfall.

In summary, for a very large summer rainfall with the elevation of the outlet drain raised by 1 m, the roughly-calculated volumes are: 5,400 m^3 of water infiltrated quickly into the 15 m strip, and 24,000 m^3 of water flowing slowly, laterally, into a wider area around the lake.

5.2 IN WINTER

The water level in the lake, at its winter maximum, can be at or near the path level. Here we take, hypothetically, a rainfall event adding 1 m of water to the lake at a time when the water level is at the path. Water level can rise 1 m because the drain outlet has been set 1 m higher than at present. The unsaturated material directly beneath the 15 m-wide strip is about 0.5 m deep (the average across the width of the strip), and has an area of 10,800 m^2. With a porosity of 0.2, its pore volume would be 0.5 x 10,800 x 0.2 = 1080 $m^{3.}$

The volume of water overlying the 15-wide strip is about 5,400 m^3, and it would quickly fill the underlying unsaturated material with a pore-space volume of 1080 m^3; if the vertical permeability was 6 m/d the unsaturated material would be filled in about 24 minutes. If the vertical permeability was 0.2 m/d, the unsaturated material would be filled in 12 hours.

Further seepage of water can only be laterally, into the thin wedge shown in Figure 2 (winter, worst case) to be only 1 m thick at the path, tapering to zero. Infiltration rates would be very low, probably 0.01 to 0.05 m/d because the lateral hydraulic gradients will be very low. The volume of this wedge is calculated to be about 11,000 m^3, based on an area of 91,800 m^2, average thickness of 0.6 m, and porosity of 0.2.

In summary, for a winter rainfall event with the elevation of the outlet drain raised by 1 m, the roughly-calculated volumes are: 1,080 m^3 of water infiltrated quickly into the 15 m strip, and 11,000 m^3 of water flowing slowly, laterally, into a wider area around the lake.

5.3 DISCUSSION ON RAISING OR BLOCKING THE OUTLET DRAIN

The volumes of water that can infiltrate through the perimeter grassed areas (15 m wide in the selected case) into the underlying unsaturated sand above the water table have been calculated to be relatively small, in the range of 1,100 to 5,400 m^3 in the initial few hours, and 11,000 to 24,000m^3 over many days or weeks. The initial volumes are equivalent to about 0.04 to 0.2 m depth of water in the lake (of area 27,000 m^2). The later volumes are equivalent to about 0.4 to 0.9 m depth of water in the lake.

From the above values, it is seen that flooding of a narrow perimeter strip cannot provide sufficient infiltration to meet the objective of transferring water rapidly to the water table, should the water level actually reach about 1 m above the path. In practice, the perimeter would remain flooded for many days or weeks. However, with the current decade's water inflows, and with the present lake bed, it is unlikely that lake water levels would actually reach 1 m above the path level if the outlet drain was raised. The estimate of overflow discharge in 2008 by Dean (2011, page 36) is 12,000 m^3. Estimates by McFarlane (1984) for overflow discharges were 148,000 m^3 in 1981 and 164,000 m^3 in 1982; an estimate by Sim (1995) for 1995 was about 60,000 m^3. These water excesses might have raised lake levels up to 1 m above the path, had the drain outlet been raised or blocked, but this depends on intensity and duration of the rainfalls. Given the current lower water table and lower rainfall, water excesses are unlikely to achieve the earlier amounts if the lake bed permeability is unchanged.

Raising the drain outlet would produce a desirable result of decreasing outflow to the ocean and increasing lake level and infiltration to the water table. With the present lake-bed condition and a raised drain, the water lost to the drain in 2008 would have added 0.3 to 0.4 m to the lake water-level, and some extra water to the shallow aquifer via infiltration through grass around the lake perimeter and via seepage from the lake.

The height to which the drain outlet can practically be raised will depend on potential flooding outside the park area. If necessary, the ground height to the west of the lake could be increased, to prevent flooding across Herbert Road. The Water Corporation would need to assess and approve any modifications to the drain outlet and the ground contours. There are likely to be problems with road sumps located west of the park, if the water level rises to more than 6 m AHD.

Raising the drain outlet would be an important adjunct to any procedures to reduce the permeability of the lake bed. Unless the drain outlet is raised, a much larger amount of water would discharge to the drain rather than infiltrate to the shallow aquifer as at present. Water-table levels would decrease.

Blocking the drain outlet completely would create conditions for flooding, in the event of extremely large rainfall events, or if the permeability of the lake bed is deliberately decreased to a small percentage of the present permeability. Under these conditions, infiltration through the grassed areas outside the path would not consume sufficient water to prevent water from flooding beyond the park. Blocking the drain outlet is not recommended. It is noted that neither Dean nor SoJ have proposed this option.

6 THE EFFECT OF REDUCING LAKE-BED PERMEABILITY

In this section, the graphs of calculated lake water levels presented by Dean in his 2011 report are accepted as correct. In particular, the graphs on his page 41 show calculated water levels for the nine years 2000 to 2008 with lake leakages at 100% and 25% of the existing amounts. The reduced lake leakage might be achieved using polymer treatment of the lake bed.

The graphs indicate that (as calculated) under existing leakage conditions the water would have overflowed the path in six of the nine years, with the largest one-day depth of submergence being 34 cm. With the lake leakage reduced to 25% of the existing amount, the water would have overflowed the path for up to about ten days in all nine years, with the largest one-day depth of submergence being 85 cm.

7 CONCLUSIONS

The information in Dr Dean's 2011 report is useful and relevant to the examination of options for maintaining water levels in Lake Jualbup. His empirical formulae developed from measured data have allowed reasonably accurate correlations between calculated and measured lake water levels. His graphs of lake water levels – that would result if leakage through the lake bed was reduced to 25% of the current leakage rates – appear to be valid in back-calculations for the selected period of 2000 to 2008.

I do not agree that vertical infiltration rates of about 6 m/d should be used in calculations of infiltration of water through a 15 m wide strip of grassed area around the lake perimeter. Values of about 0.2 m/d might apply for the initial short period when the sand above the water table is unsaturated; after saturation is achieved, the infiltration rates would become even lower. Using a value of 6 m/d over-estimates the rates and the amounts of water that can be infiltrated from this strip.

If it is true that water infiltration through the peripheral strip will reduce to low rates, then the excess surface water overflowing the lake (because of the 25% leakage rate) will not be infiltrated simply by raising the elevation of the overflow drain outlet. Raising it by 1 m has been examined in Section 5 of this report for making calculations, but this amount has not been proposed by Dean or SoJ. Even with the raised outlet – which in itself may be desirable – the amount of water flowing down the drain, and thence to the sea, will be much more than at present. The effect will be that less water will reach the aquifer, and the water table will be lowered. This will in turn tend to increase infiltration through the lake floor.

I recommend that the engineering feasibility of raising the drain outlet by 0.3 or 0.5 m be investigated, particularly with respect to protection against flooding beyond the park boundaries, notably to Herbert Road. The Water Corporation would be expected to have the final say.

8 COMMENT ON THE "SAVE OUR JEWEL" PROPOSAL

The proposal has admirable aims, but reducing the lake seepage by 75% and raising the drain outlet significantly (say, 0.3 to 0.5 m) will cause additional flooding of the lake perimeter. Also, a larger proportion of the water that presently seeps to the water table will flow into the drain. The water-table levels beneath the lake and adjacent area would become lower than they are with the current hydraulic connection between lake and aquifer.

9 COMMENTS ON THE RPS CONSULTANTS' RECOMMENDATIONS

9.1 MANAGED AQUIFER RECHARGE (MAR)

A managed aquifer recharge scheme such as an infiltration gallery or an injection bore is unlikely to fulfil the objective of storing excess water from the lake at times of very heavy or prolonged rainfall (that causes the lake to overflow). The reasons are as follows.

- An infiltration gallery as depicted in the RPS report would allow only slow injection of water. The take-up would be a very small proportion of the overflow from the lake. Temporary storage of water would be required, and no suitable facility has been identified. Siltation and other blockage problems will entail high maintenance. There is only a small thickness of unsaturated sand above the water table in the Lake Jualbup Reserve area, therefore, the volume of water that can be stored subsurface locally is quite small.
- Injection bores require the use of very high purity water, to prevent clogging and gross inefficiency; air-entrainment is an additional deleterious factor. High installation and maintenance costs are likely to be prohibitive. Additionally, there is limited scope for increased groundwater levels adjacent to an injection bore located in the Reserve area. In Figure 8 of the RPS report, the injection bore is shown as

having the groundwater level nearly at ground surface, giving no scope for water-level rise and the creation of the required hydraulic gradients. If they were to be utilised, injection bores would need to be located more than a hundred metres to the north of the lake.

10 SUGGESTED ALTERNATIVE LAKE SCENARIO

The following course of action might provide satisfactory conservation of water as well as maintaining surface water in the lake. Biological aspects would need to be evaluated.

(1) Create a seal in the base of the lake, as proposed by SoJ group, to reduce the lake-bed seepage by about 75%, i.e. to about 25% of the current seepage.
(2) Raise the outlet drain by about 0.3 m.
(3) Install soakwells in about one third of the suburban streets in the Shenton Park drainage catchment.

The rationale is that the inflow, to the lake, of suburban street run-off water would be reduced by about 30% of the present volume from this source. Because of the decreased seepage from the lake bottom, the lake will fill seasonally in most years, and will become dry in about three years in ten. These predictions are based on back-calculations by Dean (2012) based the past 10 years rainfall data.

The calculations predict that the outflow from the lake (to the ocean) will be reduced by more than 20%.

The above suggested changes to the lake regime could be further evaluated by numerical modelling. The latter would include simulating the staging of the implementation to maintain a balance between water inflow to the lake, and seepage out of it. However, there is reasonable confidence in the calculations to hand; also, corrective action - if required - could easily be undertaken by changing the numbers and/or efficiency of the street soakwells.

10.1 BORE WATER-SUPPLY AS A SUPPLEMENT

In addition to the above modifications, an additional option would be to use a shallow-aquifer bore to maintain a low water level in the lake in very dry years.

The amount of water added to the lake from a bore, to replenish the seepage and evaporation from the lake, would be set to not exceed the water added to the shallow aquifer by the soakwells.

The operation would in effect become one of 'aquifer storage and recovery', which is an environmentally-favourable practice. The Department of Water is likely to permit the use of a bore to draw water from the shallow aquifer for lake preservation if soakwells are used to infiltrate the same amount of water, or more.

The very approximate volumes are:

Seepage loss through lake floor, reduced to 25%	40,000 m^3/yr
Evaporation from the lake	35,000 m^3/yr
Total water make-up from bore	**75,000 m^3/yr**

Infiltration from soakwells in Shenton Park drainage basin in an average year (1/3 of total drainage basin)	**107,000 m^3/yr**

The alteration of the lake bed will need to be approved in principal.

Dated: **20 January 2012** **Rockwater Pty Ltd**

Passmore

J R Passmore
Principal

FIGURES

Figure 1

● LJ1	Piezometer
2.3	Water Level Contour (m AHD), 30 April 2009

317.1/Surfer/11-01/Fig 1 Lake Jualbup.srf

CLIENT: 'Save Our Jewel' Group

PROJECT: Lake Jualbup Evaluation

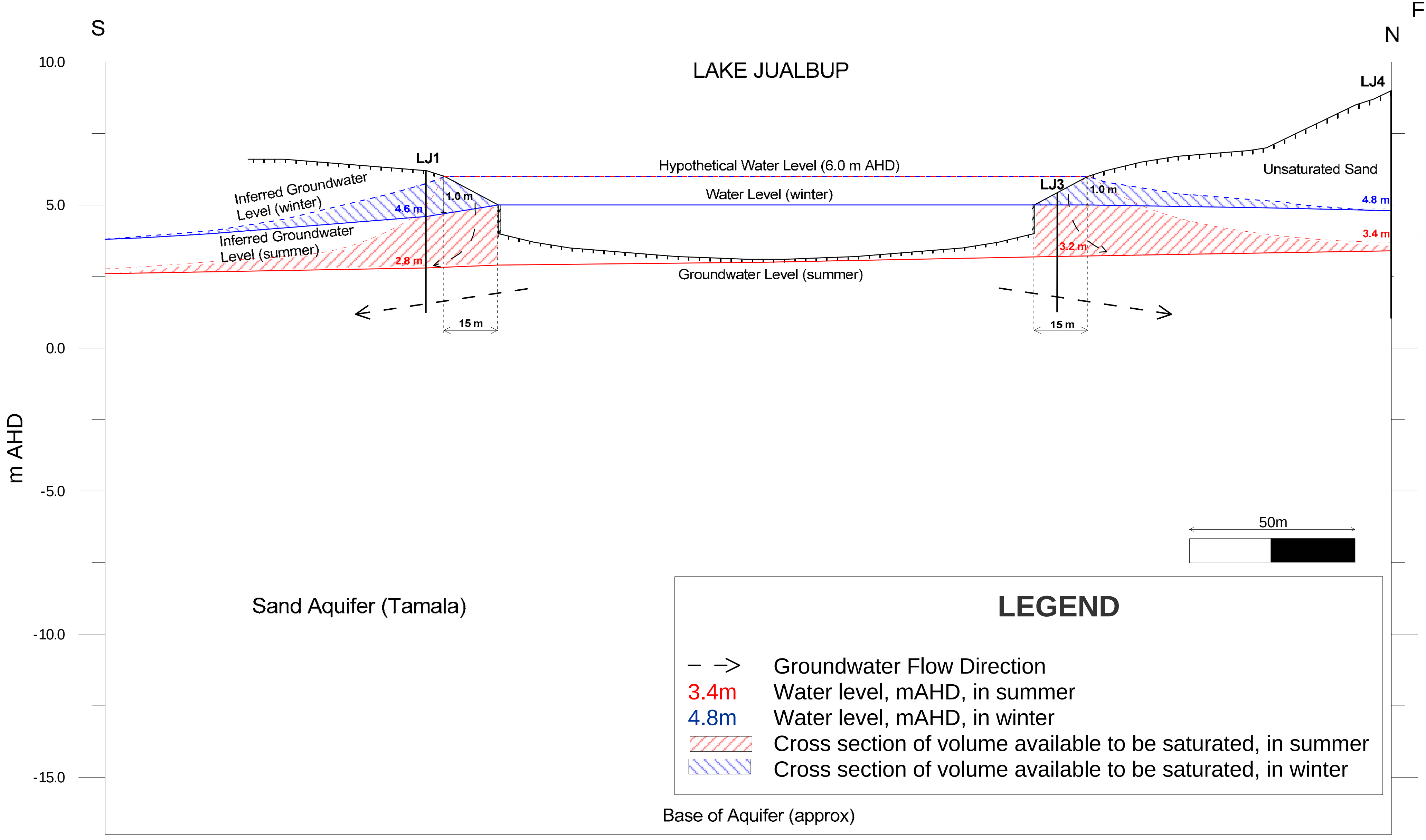
DATE: December 2011

Dwg No: 317.1/11/1-1

LAKE JUALBUP LOCALITY MAP AND WATER LEVEL CONTOUR MAP (m AHD) April 2009

Rockwater Pty Ltd

Figure



I://317-1/Grapher/Lake Jualbup Cross Section.grf

Client: 'Save Our Jewel' Group

Project : Lake Jualbup Evaluation

Date : December 2011

Dwg. No: 317-1/11/1-2

LAKE JUALBUP NORTH TO SOUTH CROSS SECTION

Rockwater Pty