REPORT

THIRLMERE LAKES
Surface Water Balance Assessment

Prepared for: Tahmoor Coal Pty Ltd

Apr-12
J1201-1.rSD1j.docx
EXECUTIVE SUMMARY

Background

The Thirlmere Lakes are a series of five interconnected Lakes located 90 km southwest of Sydney. An inquiry is being held to investigate recent reductions in Lake water levels. Xstrata Coal’s Tahmoor colliery (an underground mine) has been in operation since 1981 and has to date operated in areas east and south of the Lakes. The closest operations, which were mined from 1996 to 2002, are located no nearer than 600m east of the Lakes. It has been postulated that the Lake levels may have been impacted by mining operations, although the Lakes are well beyond the predicted effect of any mine-related subsidence. This has been previously investigated by the NSW Office of Water (NOW) and Pells Consulting (Pells, 2011). This study has been undertaken to investigate surface water related matters and their effect on the water levels in Thirlmere Lakes. The study has included developed of a water balance model of the Lakes and reviewing and critically analyzing the work of Pells (2011).

Pumped flow measurements from the underground mining operations are only available as estimates from 1995 to 2002 and as direct flow measurements from 2009 onwards. Data indicates a slowly increasing trend in estimated underground mine water make from 1995 to 2002, while the data recorded since 2009 appears to be declining.

The five Lakes (Gandangarra, Werri Berri, Couridjah, Baraba and Nerrigorang) have an estimated total catchment area of 4.51 km$^2$, with 12% of the catchment comprising the Lakes themselves. The Lakes comprise dense fringing vegetation with sedges and grasses within the Lake area. The Lake bed soils, where exposed, have a propensity to crack when drying. A recent survey of the Lakes has shown that, although at high water levels, the most upstream three Lakes can form one water body, they form three distinct, separate Lakes at lower water levels. The total surface water capacity of the Lakes has been estimated at 1,725 ML. A significant depth of alluvium has accumulated beneath the Lakes and forms an integral part of the Lake water system – when the alluvium is saturated, surface water ponds form, while during dry periods, water levels fall below the lowest point of the Lake floors, into the alluvium.

Regional rainfall data indicates that average and daily rainfall can vary across the area. Mean annual rainfall is approximately 820 mm/year while mean annual pan evaporation is approximately 1,450 mm/year. Analysis of long-term rainfall data indicates that the area has been in a drying cycle since 1993. Regional streamflow records confirm this trend.

Water Balance Modelling

Historical lake water levels were used as a basis for comparing against model predictions. Historical lake water levels have been estimated by overlaying available aerial photographs on contour plans developed from recent survey. Indicated uncertainty using this method is nominally ± 0.5m but could be greater. It has been assumed in this method that current topography is applicable to historical aerial
photography and this is clearly not the case, with natural siltation and human intervention likely having occurred. The potential error associated with anecdotal interpretations of records other than aerial photography was considered to be too large to provide a reasonable estimate of Lake water levels.

Historical information on pumped extractions for steam train use from Lake Couridjah have been developed from available records and included in water balance modelling.

A daily time-step water balance model was set up to simulate the water volume of each Lake, including sub-surface (alluvial) storage. Rainfall and evaporation data used in the model was sourced from available regional records spanning 123 years. Direct rainfall on the water surface of the Lakes was explicitly modelled. Catchment rainfall runoff was simulated using the Australian Water Balance Model (AWBM) – a nationally-recognised catchment-scale water balance model. AWBM parameters were calibrated based on 10 years of streamflow data available from a nearby, hydrologically similar catchment. Direct evaporation from the surface of the lakes was included in the model by simulating the (daily varying) water surface area multiplied by pan evaporation records times an appropriate pan factor. In addition, Lake evapo-transpiration was calculated from the exposed Lake bed floor where these areas were saturated to within 0.5m to 2m of the Lake surface. Evapo-transpiration in flow between Lakes was also allowed for. Groundwater transfer down-gradient between Lakes was simulated, while deep groundwater recharge rates were set to provide a reasonable fit between modelled and historically estimated lake water levels from aerial photography. Fitted deep groundwater recharge rates were kept constant with time and only varied with individual Lake water level.

Model results in terms of simulated Lake water levels versus time for the period of available historical estimated water levels, are shown in Figure ES-1. The simulated average difference between modelled and historically estimated water levels (derived from all available aerial photography) is tabulated below.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Gandangarra</th>
<th>Werri Berri</th>
<th>Couridjah</th>
<th>Baraba</th>
<th>Nerrigorang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Difference (m)</td>
<td>0.73</td>
<td>-0.01</td>
<td>0.42</td>
<td>0.71</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Most noteworthy from the model results is that the model appears to be predicting estimated recent Lake water levels fairly closely, while not consistently under-predicting earlier levels (which would be the case if deep groundwater recharge rates had been over-predicted or if these varied with time).

Model results were found to be sensitive to which regional rainfall data set was adopted as well as to deep groundwater recharge rates. Results were less sensitive to variations in rainfall-runoff (AWBM) parameters.
Figure ES-1  Modelled and Historically Estimated Lake Water Levels

- Dashed lines represent lake dry levels
- Dotted lines represent lake spill levels

The review was based on our interpretation of the material presented in a printed copy of the report, without access to digital data. Information on some of the modelling used and the results of those models was not fully reported. In these instances our review comments have been based on what was presented in the report and reasonable inferences. Key points of difference between the water balance modelling of Pells (2011) and the modelling reported herein were:

1. Stage-storage relationships of the Lakes,
2. Treating lakes distinctly as opposed to lumping them together,
3. Effect of lake water level on groundwater, and
4. Model calibration and prediction of Lake levels

The level-storage relationships given in the Pells (2011) report differed significantly from those derived from the recent topographic survey and the Pells (2011) report appears to have overestimated the total capacity of the Lakes. The recent survey data indicates a total Lake capacity of approximately 1,725 ML compared to an inferred capacity of approximately 3,600 ML in Pells (2011). The higher total Lake volume would tend, in water balance modelling, to over-estimate the relative period of time that water is contained in the Lakes.

In our opinion simulating any of the Lakes as a single water body may significantly affect estimates of evaporation and runoff and would not account for possible losses during spill transfers between Lakes.

In the Pells (2011) modelling, it was not apparent whether groundwater inflows/outflows were calculated as a function of the Lake levels. Net groundwater movement into and out of the Lakes is dependent on the lake water levels.

With regard to the rainfall-runoff models used in the Pells (2011) water balance, there was no explicit documentation of model calibration and it is inferred that rainfall-runoff model calibration was achieved by varying parameters within bounds that were “reasonable and appropriate” in order to best match Lake water levels. In the modelling reported herein, the AWBM was used to estimate rainfall-runoff and was calibrated closely to recorded streamflow data from a nearby catchment. The effects of the smaller catchment of Thirlmere Lakes (compared with the nearby calibrated catchment) are likely to manifest themselves as a reduced baseflow proportion. A baseflow reduction was tested as part of sensitivity analyses and was not found to significantly affect model results and to certainly not affect the pattern of both under and over prediction of historical estimates of Lake water levels over time.

Use of historical estimated Lake water levels to compare with modelled Lake water levels was also a notable point of difference. The possible inaccuracy of data derived from anecdotal observations (no aerial photographs) was considered too large to produce useable estimates of Lake water level. Significant differences were noted in water levels estimated from aerial photographs between Pells (2011) and our estimates. A significantly greater number of aerial photographs were used in this study.
For Lake Werri Berri, seven out of the ten Pells (2011) historical levels are overestimated by modelling. By contrast, for the base case modelling reported herein, for Lake Werri Berri, nine out of the 16 historical estimates are over estimates (56%). Similarly for Lake Nerrigorang, eight out of the nine Pells (2011) historical levels are over-estimated by modelling, whereas for the modelling reported herein only half the model predictions are over estimates.

**Conclusion**

Based on our assessment of historical data on Lake water levels we conclude that there is a significant uncertainty in the Lake water levels obtained from historical aerial photography, which together with the less reliable anecdotal evidence, is currently the only source of information on historical Lake water levels. Based on results of our water balance modelling of the Lakes we conclude there is significant uncertainty in the accuracy of our model predictions of Lake water levels (and by inference the model predictions in the modelling conducted by Pells), and that a wide range of Lake water level predictions can be obtained.

Model results indicate that water loss rates to the underlying groundwater system and groundwater interactions are an important component of the water balance of most of the Lakes. There does not however appear to be a trend or change in groundwater leakage with time which would explain the difference between Lake water levels evident from the available aerial photography estimates and model predictions. This is evident by the fact that mismatches between the model predictions and historical estimates from the aerial photographs occur as both under and overestimates over time. This does not eliminate the possibility that mining *may* have had an effect on Lake water levels and the water balance of the Lakes. However, it does in our opinion prevent this from being a sound conclusion that we can draw from our hydrological analysis.
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1.0 INTRODUCTION

Gilbert & Associates Pty Ltd was retained by Tahmoor Coal Pty Ltd to provide expert advice in relation to the Thirlmere Lakes Inquiry. This work specifically related to the water balance of the Thirlmere Lakes and the resulting water levels in the Lakes.

1.1 Background

The Thirlmere Lakes are located within Thirlmere Lakes National Park. The park is located in New South Wales, just west of the town of Thirlmere which is approximately 90 km southwest of Sydney and 10 km southwest of Picton. The Lakes are a series of five interconnected Lakes (in order from most upstream to downstream): Gandangarra, Werri Berri, Couridjah, Baraba, and Nerrigorang (refer to Figure 1-1). The catchment of the Lakes is primarily forested with some agricultural land use in the eastern portion. Lake Nerrigorang discharges to Blue Gum Creek which is a tributary of Little River. Little River discharges to the Nattai River which then flows into Lake Burragorang (which is formed by Warragamba Dam).

The Tahmoor Colliery is located immediately east of the National Park. The mine has been operating since 1981 and is currently operated by Xstrata Coal. The nearest underground longwall panels were mined approximately 600 m east of Lake Couridjah.

In January 2012, four of the five lakes had no ponded water with a small volume of water remaining in Lake Couridjah. The cause of low lake levels was questioned by the former NSW State Opposition in 2010. Following a change in Government in 2011, an inquiry was established to investigate the recent reduction in water levels in Thirlmere Lakes. It has been postulated that the Lake levels may have been impacted by longwall mining at the Tahmoor Colliery. This hypothesis was investigated by the NSW Office of Water (see Section 2.1) and Pells Consulting (see Section 2.2).

1.2 Scope of Work

The purpose of this report is to investigate surface water related matters and their possible effect on the water levels in Thirlmere Lakes. Specifically, the scope of work included the following:

1. Undertaking a detailed assessment of the impact or potential impact of operations at the Tahmoor Colliery on Thirlmere Lakes water levels;
2. Developing a water balance model of the Thirlmere Lakes;
3. Reviewing and critically analysing the work undertaken by Pells Consulting; and
4. Preparation of a report addressing Items 1, 2 and 3.

The first version of this report was submitted to the Thirlmere Lakes Inquiry in March 2012. Following discussions with the Inquiry Committee, additional terrestrial survey of the Lakes was undertaken. This resulted in revision of Lake capacity estimates and ultimately revision of the water balance modelling of the Lakes. This version of the
report (April 2012) is based on the most recent terrestrial survey and hence supersedes the March 2012 report.

Figure 1-1 Location of Thirlmere Lakes
2.0 BACKGROUND AND SUMMARY OF PREVIOUS REPORTS

2.1 Thirlmere Lake Groundwater Assessment (NSW Office of Water, 2010)

The NSW Office of Water (NOW) conducted a groundwater assessment of Thirlmere Lakes to investigate possible causes of the reported lake water level declines. The assessment was based on climatic, hydrologic and hydrogeologic observations from the area. Observations showed regional rainfall to be in decline which was postulated to have resulted in a reduction in runoff and groundwater recharge. At the Tahmoor mine, observations found groundwater levels dropped in the vicinity of individual longwall panels during mining but recovered following panel completion.

The report found no evidence to suggest a relationship between mining and the Thirlmere Lakes water levels. The Lakes were outside of the area where mine subsidence would be expected. The nearest longwall to the lake, at 660 m, was more than double the distance where mine subsidence would be expected to have an effect. Furthermore, there was no evidence of far field fracturing in the field. It was suggested that deep fracturing would be minor and would therefore not affect groundwater reaching the Lakes. The report concluded that the “there was no evidence to suggest that mine fracturing or subsidence has affected the water levels in Thirlmere Lakes in any substantial way” and that decline in Lake levels was a result of the recent dry period.

2.2 Report on the Water Levels of Thirlmere Lakes (Pells, 2011)

Pells Consulting (Pells, 2011) completed a study assessing the Lake water levels in 2011. Pells (2011) analysis included the following:

- a historical assessment of the Lake conditions,
- surface water modelling of the Lakes and their catchments, and
- 2-dimensional modelling of the groundwater system beneath the Lakes.

Relevant findings and postulations from Pells (2011) are quoted below.

“Findings:

Historically, the water levels in Thirlmere Lakes have been very low at times. These low levels have occurred prior to mining and have resulted from climatic processes and pumping of water from the lakes. The fall in water levels since 1990 have been accompanied by net deficit in rainfall in this period. It is clear that climatic forces go some way to explaining the current low water levels

However, the hydrologic modelling presented in this chapter suggests that climatic variables do not fully explain the current low water levels. Notwithstanding the uncertainty in modelling, and subsequent to undertaking of numerous iterations using various parameters, it was evident that:

- Models which reasonably approximated historical levels do not predict recent levels well. The current water levels in the lakes are lower than predicted by such models
- Models tweaked so that they match current levels under-predict historical levels significantly
• Since the onset of mining, Lake Nerrigorang has exhibited lower levels relative to other lakes. These lower levels are not represented in the SWMM modelling of Lake Nerrigorang.
• The lakes are currently 1.5 to 2.5 m lower in level than predicted by the models presented which are considered to be the most robust.

Therefore, the models indicate that the historical water balance at the lakes that applied between 1900 and 1990 prior to mining of longwalls 3 and onwards, does not give a reasonable simulation of recent levels – the inference is of loss of additional water from the balance for current water levels to occur.

Postulations

An impact to the hydrological balance that could be expected from longwall mining is an increase in ‘deep recharge’ (D), as water is drawn downwards to replace that removed from mine dewatering. From Figure 5.11 above, it is evident that this would impact on the supply of baseflow interactions with the lakes. It is a rational that increases to “D” following mining would explain the recent changes in water balance of the lakes as suggested by hydrologic modelling.

Significant water level decline in Lake Nerrigorang commenced in 1991, about 4 years before significant decline commenced in Lake Werri Berri and Couridjah. Lake Nerrigorang was empty by late 2009, and there is robust anecdotal evidence it was not empty in WW2. We hypothesize that the paleovalley beneath Nerrigorang is eroded through the Bald Hill Claystone (see Figure 3.3) and this has allowed a greater increase in “deep recharge” (D) compared with the other lakes.

It is important to note that such an increase in “deep recharge” (D) would not impact on the immediate infiltration and runoff processes that occur during large rainfall events. An impact of mining through the change in “D” does not preclude Thirlmere Lakes refilling under large rainfall events. However, the changes to “D” would impact subtly on the duration and persistence of lake water levels, such as how long higher water levels in the lakes would persist after refilling."

More details on the methodology used by Pells (2011) and key points of difference with modelling presented herein are presented in Section 8.1.

2.3 Mining and Mine Dewatering History

Mining at Tahmoor began in 1981 and was undertaken by Clutha Development. Since then, the colliery has been operated by a number of companies. It has been operated by Xstrata Coal NSW (Xstrata) since 2007. The colliery accesses coal using underground (longwall) mining methods. The longwall panels recover coal from the Bulli Seam which is approximately 400m to 500m below the surface. The nearest longwall panels are located approximately 600m from Lake Couridjah. Mining of these panels occurred between 1996 and 2002 (refer to Figure 1-1).

The mining process requires pumping of water from the underground operations. Monitored pumping rates since April 1995 were provided by Xstrata. In addition,
estimates of potable water pumped into the underground were provided from June 1997. Net mine water make was estimated by subtracting the potable water pumped into the mine from volumes of water pumped from the mine. Where estimates of potable water volume pumped into the mine were not available (i.e. from April 1995 to May 1997) a long term average rate was used. Estimated net water make to the mine is plotted in Figure 2-1. Inflow rates ranged up to approximately 4.5 megalitres per day (ML/d).\(^1\)

Direct flow measurement of water pumped from underground operations was not undertaken until recently. Estimated pumping rates from April 1995 to June 2002 were based on the operating hours of all of the underground pumps and assumed that the pumps ran at full capacity during that period. Therefore, these estimates may overestimate underground pumping rates. From July 2002 to January 2009, the specific volume of water pumped from the underground activities was not monitored. Rather, the mine recorded the rate of water discharged (under licence) from the mine to a local watercourse, which included the volume pumped from the underground as well as site stormwater runoff from the 83 ha surface facilities area, less water recycled to the coal handling and processing plant (CHPP).\(^2\) The recorded values for this period were not considered to be representative or indicative of the amount of water pumped from the underground. Retrospective water balance modelling of the surface facilities and the CHPP would be necessary to calculate the net volume pumped from underground operations during this period. From January 2009, flow meters have been used to directly record the volume of water pumped from the underground operations.

\(^1\) 1 ML = 1,000,000 litres
Figure 2-1 indicates a slowly increasing trend in estimated net mine water make from 1995 to 2002, while the data recorded since 2009 appears to be declining. There does not appear to be a significant difference between net mine water make recorded in recent years to that estimated during the period of longwall mining nearest to Thirlmere Lakes (1996 to 2002).
3.0 LAKE AND CATCHMENT AREA CHARACTERISTICS

3.1 Surface Characteristics

The surface geology within the catchment of Thirlmere Lakes is dominated by extensive areas of Hawkesbury Sandstone which outcrop on the valley sides and ridges. In places there is a capping of Wianamatta Shale. The upper valley sides generally comprise a thin sandy soil mantle, while the lakes themselves are underlain by a significant depth of alluvium (Pells, 2011).

There is significant topographic relief within the catchment. Surface elevations vary from approximately 350 m Australian Height Datum (AHD) down to approximately 300 m AHD at the outfall of Lake Nerrigorang.

Catchment ground cover is primarily undisturbed eucalypt woodlands with some cleared land located along the eastern and north-western boundaries. The majority of the catchment lies within the Thirlmere Lakes National Park, however cleared land at the head (north-eastern side) of the catchment and the north-western and southern sides of the catchment is privately owned (refer Figure 1-1).

The Lakes themselves generally comprise dense fringing vegetation around their perimeter (near top water level) with sedges and grasses within the inundation area (refer Plate 1). The very centres of the upstream three lakes, and most notably Lake Couridjah, lack vegetation. These areas comprise organic fine silty soils with a propensity to desiccate and crack when drying (refer Plate 2).
The catchment of the Lakes in total is estimated at approximately 4.5 km$^2$ with the largest portion of the catchment area reporting to Lake Gandangarra. The individual estimated lake catchment areas are given in Table 3-1. The inferred catchment boundaries of the individual Lakes are indicated on Figure 1-1. The catchment boundary between Lakes Couridjah and Baraba, south of Lake Couridjah, was inferred from ground reconnaissance and survey. The creek shown on the 1:25,000 scale plan south of Lake Couridjah was found to report to Lake Couridjah rather than Lake Baraba.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Catchment Area (km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gandangarra</td>
<td>1.54</td>
</tr>
<tr>
<td>Werri Berri</td>
<td>0.66</td>
</tr>
<tr>
<td>Couridjah</td>
<td>1.06</td>
</tr>
<tr>
<td>Baraba</td>
<td>0.69</td>
</tr>
<tr>
<td>Nerrigorang</td>
<td>0.56</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4.51</td>
</tr>
</tbody>
</table>

A terrestrial topographic survey of the Lakes was undertaken in early 2012 by DTS Group Qld Pty Ltd. Derived surface storage characteristics (level-volume) for each Lake (up to its individual spill level) are summarized in Figure 3-1.
Capacities of the Lakes ranged from 42 ML in Lake Gandangarra to 338 ML in Lake Nerrigorang. The survey of the Lakes indicated the Lake outlet elevation was higher than the lake inlet elevation for the three most upstream lakes (Gandangarra, Werri Berri, and Couridjah) – refer Figure 3-2. Therefore, at certain Lake levels, once the Lake level was greater than the next downstream Lake inlet elevation, the Lakes would form one larger Lake. Lake Gandangarra and Lake Werri Berri would form one water body when the water level in the two Lakes rose above 302.82 m AHD. Lake Gandangarra, Lake Werri Berri, and Lake Couridjah would form one water body once the water level rose above 302.86 m AHD. Note that these levels are very close (within 4cm – likely within the bounds of survey accuracy) and it may be that Lakes Werri Berri and Gandangarra do not form one water body prior to combining with Lake Couridjah. However, it seems clear that with the much higher spill level from Lake Couridjah downstream (305.86 m AHD) the three Lakes would form one water body prior to spilling downstream.

The capacity of the combined Lake Gandangarra and Lake Werri Berri water body is estimated to be 279 ML, while the capacity of the combined three lakes (Gandangarra, Werri Berri and Couridjah) is estimated to be 1,258 ML. Storage characteristics for the combined lakes are shown in Figure 3-3.

The surveyed spill level for Lake Baraba at 305.73 m AHD is close to but lower than the surveyed spill level of the upstream three Lakes at 305.86 m AHD and therefore Lake Baraba forms an independent water body from the other Lakes. Significant effort was undertaken to survey either end of Lake Baraba over a wide area. The estimated capacity of Lake Baraba is 129 ML.
Lake Nerrigorang appears to form an independent water body from the other Lakes – refer Figure 3-2. An access track constructed across Blue Gum Creek, near the Lake outfall, appears to at present control Lake water levels – forming an effective weir at 305.21 m AHD. The nature and permeability of the access track materials is unknown however numerous holes were noted in this embankment during site inspections. For the purposes of modelling it has been assumed that the Lake full level is located at the lower level of approximately 304.29 m AHD, the base of the access track embankment. The estimated capacity of Lake Nerrigorang to this level is 338 ML.
3.2 Climate

Climate data for the Lakes and the surrounding region was sourced from the Data Drill\(^3\) system (http://www.longpaddock.qld.gov.au/silo/index.html). Daily data is available for the period 1889 to present. Daily data was sourced from a grid of points (at 0.05° intervals) over the catchment area and surrounds. Average annual rainfall for the points was calculated and used to generate isohyetal (average annual rainfall) contours for the region – refer Figure 3-4. Figure 3-4 shows that average annual rainfall is quite variable across the region, with average rainfall higher to the south-east and north-west and lower to the north-east. Also shown on Figure 3-4 is the Data Drill point closest to the centroid of the catchment of the Lakes which was used for subsequent rainfall analysis (below) and water balance modelling (Section 5.0).

---

\(^3\) The Data Drill is a system which provides synthetic data sets for a specified point in Australia by interpolation between surrounding point records held by the Bureau of Meteorology (BoM). It is based on Jeffrey et al. (2001).
Additional daily rainfall data was also collected for nearby BoM rainfall stations at Picton Council Depot (Station no. 68052) and Buxton Amaroo (Station no. 068166 – which is the nearest BoM rainfall station to Thirlmere Lakes – refer Figure 3-4). A complete (uninterrupted) data set for Picton was sourced from the Patched Point data system\(^4\) (http://www.longpaddock.qld.gov.au/silo/index.html) from - 1889 to present. Patched point data for Buxton data was not available and therefore BoM records (http://www.bom.gov.au/climate/data/) were used directly, spanning the period 1

\(^4\) Patched Point data uses original Bureau of Meteorology measurements for a particular meteorological station, but missing data are filled (“patched”) with interpolated values.
January 1967 to 31 March 2012. Data gaps in the Buxton record were infilled using the nearest Data Drill. There are only 5 missing days of data in the record from March 1979.

On average the majority of the annual rainfall at Thirlmere Lakes occurs in the months around summer between October and April (refer to Figure 3-5). Mean annual rainfall at the Lakes is approximately 820 mm/year and mean annual pan evaporation is approximately 1,450 mm/year – i.e. an excess of 630 mm/year of evaporation over rainfall on average.

![Average Monthly Rainfall](image)

**Figure 3-5   Average Monthly Rainfall**

Temporal trends in precipitation over the period of available data were analysed using residual rainfall plots. Residual rainfall calculates the cumulative amount of rainfall relative to the long-term daily average rainfall. Positive slopes are indicative of periods of high rainfall and negative slopes of dry or drought periods. The residual rainfall plot for Thirlmere Lakes (Data Drill), shown as Figure 3-6, demonstrated a dry period from 1900 to 1946. Currently, the Lakes appear to be in a dry period which commenced in 1993. Rainfall data from Picton and Buxton BoM records showed similar trends (refer Figure 3-7 and Figure 3-8 respectively – plotted with a common horizontal scale). The drying cycle at Picton appears to have extended from 1935 through 1947 and the recent drying cycle commenced in around 1990-92. The Buxton data set, although shorter, likewise indicates the start of the most recent drying cycle around 1990-92. All residual rainfall plots indicate that the region was in a drying cycle from the early 1990s until at least late 2011. The residual rainfall plot for Buxton is re-plotted in Figure 3-9 with magnified scales. A rise in the residual rainfall plot from November 2011 may be an indication of the start of a wetter period; however it is probably too early to tell if the dry period of the last two decades has ended.
3.3 Regional Streamflow

No streamflow data was able to be sourced for Blue Gum Creek. Streamflow data was sourced from the nearest available streamflow gauging stations near Thirlmere Lakes in similar catchments (i.e. mainly undisturbed). Streamflow data for the following stations was obtained from the NOW database (Pinneena) - refer Figure 3-10.

- O’Hares Creek at Wedderburn (GS 213200),
- Bungonia Creek at Bungonia (GS 215014).
The recorded data from the two streamflow gauges demonstrate that long-term trends in streamflow parallel trends in rainfall (refer to Figure 3-11 and Figure 3-12). Rainfall data for the gauging stations’ catchment was sourced from Data Drill. Plotted residual streamflow has been divided by catchment area to give streamflow in millimetres (i.e. per unit catchment area). Gaps in the plotted residual streamflow indicate gaps in the streamflow daily record.
3.4 Groundwater

A significant depth (possibly more than 50m) of alluvium has accumulated below the Lake beds (Pells, 2011). Groundwater within this alluvium forms a perched system above the deeper water table within the bedrock. Alluvial groundwater is recharged by the Lakes. When the alluvium is saturated, surface water ponds form within the Lakes. Alluvial groundwater migrates slowly down-gradient (i.e. down-slope), with the groundwater flow rate likely dictated by lake water levels or, when there is no ponded water, by the alluvial water table levels, and the hydraulic conductivity of the alluvium. Surface water-groundwater interactions within the Lake and alluvial systems are an important component of the Lake water balance. Perched groundwater within the alluvium will also recharge the deeper bedrock water table.
4.0 HISTORICAL INFORMATION

4.1 Lake Water Levels

Historical Lake water levels were sourced in order to provide comparison against water balance model predictions. Levels were estimated from aerial photographs and current observations. Department of Lands aerial photographs and Google Earth images from 1955, 1966, 1969, 1975, 1979, 1983, 1988, 1990, 1994, 1998, 2002, 2005, 2006, 2009, 2010 and 2011 were used. Aerial photographs were scaled and Lake surface areas estimated. These were then used to estimate a volume from level-volume-area relationships developed from contour plans derived from the recent topographic survey. With the exception of periods when the Lakes were dry, estimates based on this methodology are subject to a degree of error given the photography was not rectified and a degree of distortion is inevitable – although Department of Lands photographs were chosen, where possible, on the basis that the Lakes were as near as possible to the centre of the photo, to minimize this error.

Anecdotal information was included in the Pells (2011) report. The potential error associated with anecdotal interpretations of Lake water levels was considered to be too large to provide a reasonable estimate of the Lake water levels.

Recent observations of Lake levels were also used - as of 17th January 2012, all of the Lakes were dry with the exception of Lake Couridjah. The estimated depth of water in Lake Couridjah was less than 1m (refer Plate 2). There is also anecdotal evidence that the Lakes were dry during both the “Federation” drought and the 1940s drought.

Estimated historic Lake water levels are shown on Figure 4-1. For each observation, uncertainty in the level was estimated to be ± 0.5 m, for consistency with Pells (2011). We noted that when aerial photographs were overlaid on the surveyed 0.5m interval contour plan, the edge of the Lakes in the photographs occasionally crossed more than one contour, indicating that this uncertainty in level could be greater on occasions.

Implicit within the method used to derive estimates of historical water levels is the assumption that topographic contours derived from recent survey are applicable to the entire period of historical data. This is clearly not the case and particular changes to the Lakes’ geometry could have occurred, such as natural erosion and deposition and the excavation of connecting channels between Lakes, as noted in Pells (2011). This introduces additional uncertainty in the estimation of historical water levels.
4.2 Water Extractions

Water extractions from the Lakes were used as data in the water balance model.

The Pells (2011) report noted that water was pumped from the Lakes for steam trains in the late 19th century and early 20th century and for local landholder use in the 1980s.

The following estimates of the water demand for steam trains were provided by Mr. Ian Sheppard:

- Estimates are conservatively based on a single 13 class tank locomotive completely refilling its 1,100 imperial gallon (5,000 L) water tanks on each trip through Couridjah.
- From 1920 to 1931 it was estimated that 13 trains per week (return) would pass through Couridjah weekly – based on the 1929 NSW Government Railways public timetable.
- In 1932 steam train operations reduced to six trains weekly, following the introduction of a rail motor – based on the 1939 timetable.
- In 1949 this was reduced to five trains per week – based on the 1949 timetable.

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5 Chairman of the Illawarra Division of NSW Rail Transport Museum, who is also Environment and Community Manager at Tahmoor Colliery
• From 1958 only two trains per week ran – based on the 1958 timetable.
• Finally in 1965, steam train operations ceased.

The above estimates assume that trains were empty prior to refilling and did not account for possible losses from the pumping system. These estimates are considered to be conservatively high. A summary of the calculated train demands is presented in Table 4-1. No data was able to be sourced for steam trains prior to 1920; therefore, a rate of 8 ML/month was used for consistency with Pells (2011).

<table>
<thead>
<tr>
<th>Dates</th>
<th>Number of Trains per Week</th>
<th>Weekly Water Demand (kL*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1920 – 1931</td>
<td>13</td>
<td>130</td>
</tr>
<tr>
<td>1932 – 1948</td>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>1949 – 1957</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>1957 – 1964</td>
<td>2</td>
<td>20</td>
</tr>
</tbody>
</table>

* kL = kilolitres or 1,000 litres

Based on data given in Pells (2011), it is concluded that water was pumped from Lake Nerrigorang in the 1980s for several weeks by a landholder in the adjacent Cedar Creek watershed. Pumps were used for several weeks and ran 24 hours per day at a reported rate of 1000 gal/min (63 L/s). Visual evidence of pump infrastructure was present in Lake Nerrigorang in January 2012 – refer Plate 3 below. The infrastructure did not appear to be more than 20 years old and it appears likely that water extractions from Lake Nerrigorang may have occurred more recently.

![Plate 3 – Polyethylene Pipe in Lake Nerrigorang](image)
4.3 Bushfire

Fires are a natural phenomenon in the Australian natural landscape. The most recent bushfires documented in the region occurred in September 2006 and January 2009\(^6\). Studies have shown that evapo-transpiration rates from vegetation re-growing after bushfire naturally increase for many years following fire (Kuczera, 1985). Increased evapo-transpiration in recent years from both the catchment and Lakes would tend to decrease rainfall runoff reporting to the Lakes and increase evapo-transpiration losses from the Lakes themselves (refer Section 5.2.3).

\(^6\) [www.bargo.rfsa.org.au/history/bargovrb.htm](http://www.bargo.rfsa.org.au/history/bargovrb.htm) and Wollondilly Advertiser, 14 Jan 2009
5.0 WATER BALANCE MODEL - DESCRIPTION

5.1 Objective and Modelling Approach

The goal of the water balance model was to simulate lake water levels in all five of the Thirlmere Lakes. The water balance model was developed using the Goldsim® modelling package. Lake levels were simulated using the model and compared to historic water levels (Section 4.1).

The water balance model is a daily time-step mass balance model. The model simulates daily changes in the volume of water in each of the Lakes in response to inflows and outflows. For each Lake the model calculates the volume of water (V) in each lake using the following mass balance:

\[ V_f = \text{Inflows} - \text{Outflows} + V_i \]

Where:

\[ V_i = \text{initial volume} \]
\[ V_f = \text{final volume} \]

The model simulates the following inflows and outflows:

**Inflows:**
- Incident rainfall onto the lake (P)
- Runoff (R) from lake catchments, including surface runoff (R_s) and baseflow (R_b). (R = R_s + R_b)
- Groundwater (G_in)
- Spills from upstream lakes (S_in)

**Outflows:**
- Evaporation/Evapotranspiration (from lake surface) (E)
- Seepage from the lake bed (seepage was either lost to deep groundwater (D) or transmitted to the subsequent lake (G_out))
- Spills from lakes (S_out)
- Extractions (Trains and Farm demand)

A generalized schematic of the inflows and outflows is presented as Figure 5-1. Details of each inflow and outflow are presented below (Section 5.2).
As stated in Section 3.1, the lake outlet elevation was higher than the lake inlet elevation for the three most upstream lakes. This can result in a larger combined lake forming and potential backflow of water to more upstream lakes.

### 5.2 Model Components

#### 5.2.1 Rainfall and Evaporation Data

A 123 year daily rainfall sequence (1889 to 2012) was obtained from the Data Drill data set located nearest to the Lakes (refer Figure 3-10 and Section 3.2). Rainfall on
each Lake's water surface is added to the water balance with no losses (when the Lakes contain water). Daily pan evaporation data was also sourced from the Data Drill for the same period as the rainfall data.

5.2.2 Catchment Runoff Simulation

The Australian Water Balance Model (AWBM) (Boughton, 2004) was used to simulate runoff from rainfall on the Lake catchments. The AWBM is a nationally-recognised catchment-scale water balance model that estimates streamflow (a combination of rainfall runoff and baseflow) from rainfall and evaporation. The structure of the AWBM is illustrated in Figure 5-2. Key parameters in the AWBM are:

- Surface storage capacities ($C_1$, $C_2$ and $C_3$): the capacities (in mm) of the surface storage component of the model – once the three model surface storages are filled, they spill to generate either runoff or baseflow recharge. This may be thought of as similar to catchment interception and soil storage capacity which is the amount of rainfall required to saturate a catchment before runoff occurs.

- Partial areas ($A_1$, $A_2$ and $A_3$): the proportions of the sub-catchment for each of the three surface stores.

- Baseflow Index (BFI): the proportion of spill from the model surface stores that recharges the baseflow store. Baseflow is derived from slow drainage of groundwater and, in catchments with non-zero BFI, it dominates the flow hydrograph during periods of no rainfall.

- Recession Constant (K): the rate at which baseflow diminishes in the absence of rainfall.
Figure 5-2 AWBM Structure

The AWBM parameters used were taken from a calibrated AWBM for O’Hares Creek at Wedderburn (NOW GS213200). The catchment of O’Hares Creek was considered to be hydrologically similar to that of the Thirlmere Lakes and that therefore the AWBM parameters should be applicable to the nearby Thirlmere Lakes catchment – use of rainfall runoff from hydrologically similar catchments is accepted practice in Australia. A summary of the calibrated AWBM parameters is presented in Table 5-1.

Table 5-1 AWBM Parameters

<table>
<thead>
<tr>
<th></th>
<th>Surface Store</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Capacity, C (mm)</td>
<td>4</td>
</tr>
<tr>
<td>Proportion of Area, A</td>
<td>0.164</td>
</tr>
<tr>
<td>BFI</td>
<td></td>
</tr>
<tr>
<td>K_b</td>
<td>0.21</td>
</tr>
<tr>
<td>K_s</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Note: An AWBM evaporation factor of 0.85 was used in the model as recommended by Boughton (2006).

Figure 5-3 provides a flow duration curve of recorded and modelled streamflow.

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7 As reported in Gilbert & Associates (2009).
5.2.3 Lake Storage Characteristics, Evaporation and Evapotranspiration

Surface storage characteristics (Lake level, volume and area) were derived from the 2012 topographic survey (refer Section 3.1). In the model, on each day, Lake water surface area was calculated from modelled volume using these characteristics. The model calculates water evaporation using pan evaporation data multiplied by a pan factor multiplied by the Lake water area. Pan factors were derived from CSIRO data (http://www-data.wron.csiro.au/ts/climate/evaporation/donohue - Donohue et al [2010]) spanning the period 1981 to 2006 and were calculated for each month – Table 5-2 gives values used.

<table>
<thead>
<tr>
<th>Month</th>
<th>Pan Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.917</td>
</tr>
<tr>
<td>February</td>
<td>0.926</td>
</tr>
<tr>
<td>March</td>
<td>0.940</td>
</tr>
<tr>
<td>April</td>
<td>0.960</td>
</tr>
<tr>
<td>May</td>
<td>0.960</td>
</tr>
<tr>
<td>June</td>
<td>0.951</td>
</tr>
<tr>
<td>July</td>
<td>0.976</td>
</tr>
<tr>
<td>August</td>
<td>0.960</td>
</tr>
<tr>
<td>September</td>
<td>0.964</td>
</tr>
<tr>
<td>October</td>
<td>0.946</td>
</tr>
<tr>
<td>November</td>
<td>0.944</td>
</tr>
<tr>
<td>December</td>
<td>0.916</td>
</tr>
</tbody>
</table>
Additional storage capacity exists in the alluvial deposits that exist below the floor of the Lakes. Consistent with Pells (2011), subsurface storage was assumed to extend down from each Lake’s shore line (at spill level) at a slope of 4 horizontal(H): 1 vertical(V). This slope was based on the valley characteristics described in Pells (2011) which assumed the alluvium/bedrock interface would follow the surrounding valley slope of 4H:1V (see Figure 5-4). The storage capacity was calculated based on a porosity of 0.25 for the alluvium (consistent with Pells, 2011). Storage characteristics for each lake with the combined subsurface and surface storage are presented in Figure 5-5 through Figure 5-9.

It was recognised that although the Lakes may at times contain no surface water (and therefore no direct ponded water evaporation would occur), evapo-transpiration would occur from fringing and lake bed vegetation as well as from the dark-coloured exposed lake bed material itself. Therefore the sub-surface area subject to evapotranspiration was also calculated. Evapo-transpiration was modelled to occur when the water table was within 0.5m to 2 m of the lake surface\(^8\). The concept is illustrated in Figure 5-4. A pan factor of 0.85 was used to convert records of daily pan evaporation to an evapo-transpiration rate (consistent with the rate used in the AWBM – refer Section 5.2.2). Lake evapo-transpiration was only calculated from lake bed and bank areas (below Lake spill level) that were within either 0.5m, 1m or 2m of the surface and were not inundated by ponded Lake water.

It is recognised that the above is a simplification of the likely complex phenomenon of lake bed evapo-transpiration and that the rates of water loss likely differ between the thickly vegetated perimeter, the bed of the Lakes which are covered with reeds and sedges and the bare centre of the Lakes themselves. Nevertheless the above approximation is included in the model to allow for this process which will significantly affect the lake water balance and lake water levels during periods of low water level.

\(^8\) Model runs were undertaken with 0.5, 1m and 2m evapo-transpiration depths.
Figure 5-5  Sub-Surface Storage Characteristics – Lake Gandangarra

Figure 5-6  Sub-Surface Storage Characteristics – Lake Werri Berri

Figure 5-7  Sub-Surface Storage Characteristics – Lake Couridjah

Figure 5-8  Sub-Surface Storage Characteristics – Lake Baraba

Figure 5-9  Sub-Surface Storage Characteristics – Lake Nerrigorang
5.2.4 Groundwater Flow

Groundwater transfer (seepage) between Lakes was simulated using Darcy’s Law, i.e.

\[ Q = kiA \]

Where

- \( Q \) = groundwater flow rate (m\(^3\)/s)
- \( k \) = hydraulic conductivity (m/s)
- \( i \) = groundwater hydraulic gradient (m/m)
- \( A \) = cross-sectional area (m\(^2\))

A hydraulic conductivity \( (k) \) of \( 5 \times 10^{-6} \) m/s was assumed for the alluvial material (reported as being sandy clay material – Pells [2011]). The groundwater hydraulic gradient \( (i) \) was calculated from the relative lake water levels and an assumed constant distance between the Lake centroids. The distance between Lake centroids was based on the 2012 terrestrial survey. The cross-sectional area of flow \( (A) \) was calculated from the simulated water level in the Lake bed alluvium and the assumed 4H:1V alluvium cross-sectional geometry (refer Section 5.2.3).

Deep groundwater (bedrock) recharge rates were set to provide a reasonable fit to estimated historical water levels. Table 5-3 summarises recharge rates adopted.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Estimated Recharge Rate (kL/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lake Empty</td>
</tr>
<tr>
<td>Gandangarra</td>
<td>220</td>
</tr>
<tr>
<td>Werri Berri</td>
<td>130</td>
</tr>
<tr>
<td>Couridjah</td>
<td>140</td>
</tr>
<tr>
<td>Baraba</td>
<td>50</td>
</tr>
<tr>
<td>Nerrigorang</td>
<td>100</td>
</tr>
</tbody>
</table>

5.2.5 Pumped Extraction

Values for external pumping were based on historic information presented in Section 4.2. In the model, train demand followed the estimates presented in Table 4-1. Local landholder extraction from Lake Nerrigorang was represented by three pumping campaigns which lasted for six weeks each. Pumping was assumed to be 1000 gal/min for 24 hours a day (1.44 million gal/d, 5.5 ML/d). However, in the water balance model, water was only pumped if there was water available in the Lake on the given day.

5.2.6 Spills – Transfers between Lakes

As each Lake fills and spills to the adjacent Lake evapo-transpiration losses occur in the linking channels. Evapo-transpiration area was estimated using a constant width and the distance between the upstream lake spill level and the downstream lake water.
Evapo-transpiration rate was again calculated as daily pan evaporation multiplied by 0.85.

As described in Section 3.1, because of topography, Lake Couridjah and Lake Werri Berri can spill in both upstream and downstream directions, depending on the Lake water levels relative to spill levels and adjacent lake water levels (refer Figure 3-2).
6.0 WATER BALANCE MODEL – SIMULATION RESULTS

Figure 6-1 shows modelled total surface water volume in all Lakes for the “base case” of evapo-transpiration modelled when the modelled water table was within 1m of the lake surface. Figure 6-1 also shows estimated historical total water volumes, shown as coloured points, including volumes corresponding to ± 0.5m difference in estimated historical water levels. Such a plot gives an indication, in a total sense, of how accurately the model is able to simulate the overall system behaviour. Figure 6-1 shows that the model reasonably simulates total Lake water volume, with some over-prediction at certain points in time (e.g. 1966) and under-prediction in others (e.g. 2005). Figure 6-2 shows the same plot for the case of evapo-transpiration modelled when the modelled water table was within 0.5m of the lake surface. This plot shows that for the decreased evapo-transpiration depth the modelled Lake volumes are higher, but not necessarily closer to the historical estimates.

Table 6-1 shows a summary of the average difference between model predicted water levels and historical estimates (averaged over all historical estimate data points) for the three different lake bed evapo-transpiration depths. A positive difference indicates that the model is over-predicting water levels relative to water levels estimated from aerial photographs. These numbers indicate a single “goodness of fit” estimate of the model to the data. In general it was considered that the 1m evapo-transpiration depth gave the best fit to historical estimates.

<table>
<thead>
<tr>
<th>Lake:</th>
<th>Gandangarra</th>
<th>Werri Berri</th>
<th>Couridjah</th>
<th>Baraba</th>
<th>Nerrigorang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Difference (m):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5m ET depth</td>
<td>1.01</td>
<td>0.4</td>
<td>0.76</td>
<td>0.83</td>
<td>0.50</td>
</tr>
<tr>
<td>1m ET depth</td>
<td>0.73</td>
<td>-0.01</td>
<td>0.42</td>
<td>0.71</td>
<td>0.24</td>
</tr>
<tr>
<td>2m ET depth</td>
<td>0.40</td>
<td>-0.55</td>
<td>-0.14</td>
<td>0.57</td>
<td>-0.12</td>
</tr>
</tbody>
</table>

Figure 6-3 and Figure 6-4 show plots of simulated and estimated historical individual Lake water levels for the adopted “base case”. The latter figure shows the period since 1955, when historical estimates (from aerial photographs) are available, for greater clarity. Also shown on these figures are dotted lines representing individual Lake spill levels and dashed lines showing estimated Lake empty levels. Figure 6-3 indicates the model simulates known historical droughts (the “Federation” drought and the 1940s drought – refer Pells [2011]) fairly well – reflecting the anecdotal evidence that the Lakes were dry during both those droughts. In these periods, Lake water levels were simulated to drop below the bed level, taking time to recover afterwards. It is also apparent that both the Federation drought and the 1940s drought are predicted to have resulted in the Lakes drying for significantly longer periods than the current/recent dry period.

Figure 6-4 shows that the model simulates estimated historical water levels in Lake Werri Berri, Lake Couridjah, Lake Baraba and Lake Nerrigorang reasonably, including...
recent declines in water level. Historical estimates of water levels in the Lakes were significantly underestimated in late 2005 (refer also Section 7.1) and Lake Werri Berri underestimated in 1983 and 1988. Historical estimates of most of the Lake levels were overestimated in 1966, 1969, 1975, 1979 and 1990. A potential contributing factor in the mis-match is temporal variation in rainfall. Figure 6-5 shows a plot of monthly rainfall totals in the months preceding the 2005 aerial photo for the Data Drill point used in the water balance model and recorded data at Picton and Buxton BoM stations (Buxton is the nearest station physically to Thirlmere Lakes). This plot shows that there was significantly higher rainfall recorded in February 2005 at the Buxton gauge than in the Data Drill data. This higher rainfall, if it occurred in the Thirlmere Lakes catchment, would have contributed to greater inflows to the Lakes in 2005.

The modelled water level in Lake Baraba during dry periods (low Lake water level) is simulated well with under-estimates being less than 0.5m. However the model appears to significantly over-predict estimated Lake water levels during and following wet periods. The estimated historical water levels in Lake Baraba (refer Figure 4-1) do not rise above 303.5m AHD (more than 2m below the Lake spill level) for the full period of record, even when the other Lakes appear full or nearly so (e.g. in 1955). A possible cause for this could be the presence of a high permeability zone connecting Lake Baraba to Lake Nerrigorang. A 4m depth of peat (usually a high permeability material) was logged in a shallow cored borehole in Lake Baraba as described in Black et al (2006).

The modelled water level in Lake Werri Berri “lags” behind the two adjacent lakes at time by virtue of its smaller catchment area. As shown on Figure 3-2, the channel linking Lake Couridjah and Lake Werri Berri has been assumed blocked at the Lake Werri Berri end (per recent survey), however this channel would have been open at some time in the past (following its excavation) allowing flow from Lake Couridjah to Lake Werri Berri at a lower level. This would explain the under estimation of Lake Werri Berri water levels in 1983, 1988 and 2002 (with much higher modelled Lake Couridjah water levels at the same time).

It is noteworthy (refer Section 5.2.5) that pumped extraction from Lake Nerrigorang was simulated in the 1980s. In the model, the total extractive demand of 686 ML (attempted to be sourced in three, six week pumping campaigns) could not be extracted without pumping Lake Nerrigorang dry and only 158 ML could be extracted in total. This indicates that the anecdotal pumping record is likely inaccurate. Figure 6-6 shows model predicted Lake water levels with no pumped extraction from Lake Nerrigorang in the 1980s. It may be seen from this figure that the model prediction of Lake water levels more closely matches historical estimates for this period.

Modelled Lake water levels in Lake Gandangarra tend to somewhat over-predict historical estimates for much of the period of available data. There are several potential causes for this:

a) Model over-estimation of rainfall runoff. The model estimates a total runoff yield (runoff as a proportion of baseflow) of 17.8% for this Lake’s catchment. It is noteworthy that the catchment of Lake Gandangarra (outside the National Park) contains a number of farm dams and contour banks (estimated to
intercept 12% of the Lake’s catchment area). These would tend to affect the model results in wet periods directly following dry periods, when the dams would need to fill and spill before contributing runoff to the Lake.

b) Under-estimation of deep groundwater recharge rates for this Lake.

c) A higher rate of seepage from this Lake to Lake Werri Berri via a higher permeability zone between the lakes.

d) Higher evapo-transpiration losses from this Lake (compared with other Lakes).

e) A combination of some or all of the above.

Most noteworthy from the model results is that the model appears to be predicting estimated recent Lake water levels fairly closely, while not consistently under-predicting earlier levels (which would be the case if deep groundwater recharge rates had been over-predicted). It is reiterated however that there is inherent uncertainty in the estimation of historical Lake levels.

A summary of the Lake water balance for the modelled base case for each Lake is presented below in Table 6-2. The results show that runoff was the largest inflow contributor to the balance of all the Lakes except Lake Werri Berri where surface water transfers (spill in from other Lakes) was the largest contributor. Spill from Lake Baraba to Lake Nerrigorang was almost as large an inflow to Lake Nerrigorang as runoff. The greatest outflows comprised spills for Lake Nerrigorang and deep groundwater recharge for Lake Gandangarra, while evaporation/evapo-transpiration losses comprised the highest outflow for the remaining Lakes.
Figure 6-1 Modelled Total Lake Volume (0.5m ET Depth Limit)
Figure 6-2  Modelled Total Lake Volume (1m ET Depth Limit)
Figure 6-3  Modelled Lake Water Levels (1m ET Depth Limit) From 1900
Figure 6-4  Modelled Lake Water Levels (1m ET Depth Limit) From 1955

Dashed lines represent Lake dry levels
Dotted lines represent Lake spill levels
Figure 6-5  Monthly Rainfall Data 2004-05
Figure 6-6  Modelled Lake Nerrigorang Water Levels (1m ET Depth) without Pumped Extraction

Dashed lines represent Lake dry levels
Dotted lines represent Lake spill levels
### Table 6-2 Summary of Modelled Lake Inflows and Outflows (1m ET Depth)

<table>
<thead>
<tr>
<th>Component</th>
<th>Lake Gandangarra</th>
<th>Lake Werri Berri</th>
<th>Lake Couridjah</th>
<th>Lake Baraba</th>
<th>Lake Nerrigorang</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (ML)</td>
<td>Proportion (%)</td>
<td>Total (ML)</td>
<td>Proportion (%)</td>
<td>Total (ML)</td>
</tr>
<tr>
<td><strong>INFLOWS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Rainfall</td>
<td>30199</td>
<td>100</td>
<td>28562</td>
<td>100</td>
<td>26897</td>
</tr>
<tr>
<td>Runoff</td>
<td>25455</td>
<td>84</td>
<td>9583</td>
<td>34</td>
<td>17291</td>
</tr>
<tr>
<td>Alluvium Seepage In</td>
<td>1.9</td>
<td>0.01</td>
<td>282</td>
<td>0.99</td>
<td>9</td>
</tr>
<tr>
<td>Spill inflow from adjacent Lake</td>
<td>535</td>
<td>2</td>
<td>10934</td>
<td>38</td>
<td>5485</td>
</tr>
<tr>
<td><strong>OUTFLOWS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation &amp; Evapo-transpiration</td>
<td>9570</td>
<td>32</td>
<td>15253</td>
<td>53</td>
<td>8527</td>
</tr>
<tr>
<td>Alluvium Seepage Out</td>
<td>227</td>
<td>0.8</td>
<td>55</td>
<td>0.04</td>
<td>55</td>
</tr>
<tr>
<td>Deep Groundwater Recharge</td>
<td>11693</td>
<td>39</td>
<td>7505</td>
<td>26</td>
<td>8196</td>
</tr>
<tr>
<td>Spills</td>
<td>8753</td>
<td>29</td>
<td>6020</td>
<td>21</td>
<td>8285</td>
</tr>
<tr>
<td>Train Pumping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1902</td>
</tr>
<tr>
<td>Local Landholder Use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Numbers in parentheses refer to proportion of total inflows and outflows**
7.0 MODEL SENSITIVITY

7.1 Rainfall

The base case model simulation was undertaken using Data Drill from a point located to the north of Thirlmere Lakes (refer Figure 3-4). The sensitivity of model results to rainfall was assessed by running the model using climatic data from two other locations: located to the south of Thirlmere Lakes (34.25°S, 150.55°E) and to the south-west (34.25°S, 150.50°E). Figure 7-1 and Figure 7-2 show predicted Lake water levels for these two model simulations. In addition, a third sensitivity run was undertaken, substituting the Data Drill record with data from the BoM Buxton gauge (refer Section 3.2) from 1967 onwards (refer Figure 7-3). Table 7-1 summarises the average difference between model predicted water levels and historical estimates for these three model simulations and the base case. It is clear from these figures and Table 7-1 that variations in rainfall data have a significant effect on model predicted Lake water levels. For example, the significant difference between predicted Lake Werri Berri water level in the 1980s for the base case (refer Figure 6-4 and Section 6.0) is significantly less using the Data Drill from 34.25°S, 150.55°E (Figure 7-1) and with the substituted Buxton data (Figure 7-3).

<table>
<thead>
<tr>
<th>Lake:</th>
<th>Gandangarra</th>
<th>Werri Berri</th>
<th>Couridjah</th>
<th>Baraba</th>
<th>Nerrigorang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Difference (m):</td>
<td>Base Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Drill 34.25°S, 150.55°E</td>
<td>1.37</td>
<td>1.02</td>
<td>1.21</td>
<td>0.96</td>
<td>0.89</td>
</tr>
<tr>
<td>Data Drill 34.25°S, 150.50°E</td>
<td>0.99</td>
<td>0.46</td>
<td>0.75</td>
<td>0.73</td>
<td>0.52</td>
</tr>
<tr>
<td>Data Drill 34.25°S, 150.55°E with Buxton data from Jan 1967</td>
<td>1.08</td>
<td>0.62</td>
<td>0.86</td>
<td>0.75</td>
<td>0.59</td>
</tr>
</tbody>
</table>
Figure 7-1  Modelled Lake Water Levels with Data Drill from 34.25°S, 150.55°E (South of Lakes)

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
Figure 7-2  Modelled Lake Water Levels with Data Drill from 34.25°S, 150.50°E (South-West of Lakes)

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
Figure 7-3  Modelled Lake Water Levels with Data Drill from 34.20°S, 150.55°E with Buxton Record from Jan 1967

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
7.2 Deep Groundwater Recharge Rates

Modelled Lake to deep ground water recharge rates (refer Table 5-3) were varied by +/-20% to assess their impact on model predictions. Figure 7-4 and Figure 7-5 show predicted Lake water levels for these two model simulations, while Table 7-2 shows the average difference between model predicted water levels and historical estimates for these two model simulations and the base case.

Table 7-2 Model Average Difference from Historical Estimated Water Levels for Deep Groundwater Recharge Sensitivity Runs

<table>
<thead>
<tr>
<th>Lake</th>
<th>Gandangarra</th>
<th>Werri Berri</th>
<th>Couridjah</th>
<th>Baraba</th>
<th>Nerrigorang</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Difference (m):</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Case</td>
<td>0.73</td>
<td>-0.01</td>
<td>0.42</td>
<td>0.71</td>
<td>-0.24</td>
</tr>
<tr>
<td>-20%</td>
<td>1.12</td>
<td>0.47</td>
<td>0.90</td>
<td>0.83</td>
<td>0.53</td>
</tr>
<tr>
<td>+20%</td>
<td>0.47</td>
<td>-0.45</td>
<td>-0.03</td>
<td>0.62</td>
<td>-0.04</td>
</tr>
</tbody>
</table>
Figure 7-4  Modelled Lake Water Levels with 20% Reduction in Deep Groundwater Recharge Rates

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
Figure 7-5  Modelled Lake Water Levels with 20% Increase in Deep Groundwater Recharge Rates

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
7.3 Catchment Yield

Modelled AWBM surface store capacities (refer Section 5.2.2) were varied by +/- 20% to assess the sensitivity of potential variation in catchment runoff parameters on model predictions. It is recognised that the AWBM calibrated for the O’Hares Creek gauging station (73 km² catchment area) is being applied to a much smaller catchment at Thirlmere Lakes (4.5 km²). Based on advice from the model’s author, the main effect of the smaller catchment area, in an otherwise physically similar catchment, would be to reduce the proportion of baseflow. Therefore a third sensitivity run was undertaken with the AWBM baseflow index halved. Figure 7-6 to Figure 7-8 show predicted Lake water levels for these three model simulations, while Table 7-3 shows the average difference between model predicted water levels and historical estimates for these three model simulations and the base case. The effect on modelled Lake water levels is most noticeable in those Lakes with the greatest catchment area, but is overall less than the effect of varying rainfall or deep groundwater recharge rates. The model was most insensitive to the change in baseflow index which is likely to be the main effect of using AWBM parameters calibrated for a larger catchment than Thirlmere Lakes.

<table>
<thead>
<tr>
<th>Lake:</th>
<th>Gandangarra</th>
<th>Werri Berri</th>
<th>Couridjah</th>
<th>Baraba</th>
<th>Nerrigorang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Difference (m):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Case</td>
<td>0.73</td>
<td>-0.01</td>
<td>0.42</td>
<td>0.71</td>
<td>0.24</td>
</tr>
<tr>
<td>-20% C</td>
<td>1.09</td>
<td>0.52</td>
<td>0.88</td>
<td>0.82</td>
<td>0.58</td>
</tr>
<tr>
<td>+20% C</td>
<td>0.53</td>
<td>-0.48</td>
<td>0.10</td>
<td>0.59</td>
<td>-0.02</td>
</tr>
<tr>
<td>Half BFI</td>
<td>0.72</td>
<td>0.00</td>
<td>0.42</td>
<td>0.69</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Figure 7-6  Modelled Lake Water Levels with 20% Reduction in AWBM Surface Store Capacities

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
Figure 7-7  Modelled Lake Water Levels with 20% Increase in AWBM Surface Store Capacities

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
Figure 7-8 Modelled Lake Water Levels with Halved AWBM Baseflow Index

Dashed Lines represent Lake dry levels
Dotted lines represent Lake spill levels
8.0 REVIEW OF PELLS (2011) REPORT

8.1 Summary of Report

As indicated in Section 2.2, Pells (2011) undertook hydrological modelling to estimate historical Lake water levels – specifically two surface water modelling methods were used together with a groundwater model. Both surface water models were based on the following inflows and outflows:

Inflows:
- Runoff from lake catchments (including surface runoff, throughflow and shallow groundwater)

Outflows:
- Evaporation (from the catchment and lake surface)
- Down valley groundwater flow
- Surface water flow downstream
- Pumped extraction

The generalized mass balance equation used was:

\[ F + T + B = E + G + W + \Delta S_L \]  
*(Equation 1)*

Where:
- \( F \) = Surface runoff
- \( T \) = Throughflow
- \( B \) = Baseflow (shallow groundwater)
- \( E \) = Evaporation (from lake surface)
- \( G \) = Down valley groundwater flow
- \( W \) = Surface water flow downstream
- \( \Delta S_L \) = Change in lake volume

The first surface water modelling approach was undertaken using a parametric analysis to first establish ranges for each of the inflows and outflows. The Lakes were treated as one water body and steady state conditions were assumed (i.e. there was no change in the lake levels and no outflows downstream). *SimHyd* was then used to estimate catchment runoff (runoff = F + T + B). These estimates were used, together with Equation 1 and estimated area vs level and volume vs level relationships, in a spreadsheet to estimate historical Lake water levels. With no allowance for pumping from the Lakes, and varying model parameters within “reasonable” bounds, it was found that “…models which approximated the higher levels between 1950 and 2000 would not acceptably simulate the lower levels of recent times and the 1940’s” and vice versa. With allowance for pumped extraction and with parameter adjustment to well represent the 1950’s to 2000’s levels, “…reasonable simulations of historical water levels” were achieved, however “…the models predict higher post-2000 lake levels than those observed”.

The second surface water modelling approach was completed using *SWMM 5*, a USEPA hydrologic/hydraulic simulation package. For this model, the Lakes were
treated as three separate reservoirs with runoff reporting to each. The first three Lakes, Gandangarra, Werri Berri, and Couridjah, were treated as the first (i.e. a single) reservoir, Lake Baraba as the second and Lake Nerrigorang as the last. No cognisance appears to have been made of the “separation” of these three Lakes at low water levels. With no inclusion of estimates of Lake pumping, modelling again either reasonably simulated levels prior to 2000 or post 2000; but not both. With the inclusion of estimates of Lake pumped extraction, lake levels “…up to approximately 2007” were simulated well, but the model “… over predicted the currently observed low levels”.

8.2 Review

It is important to preface this review by acknowledging some key limitations. The review presented in this section is based on Gilbert & Associates interpretation of the material presented in Pells (2011). Information on some of the modelling used and the results of those models was not fully reported. In these instances our review comments have been based on what was presented in the report and reasonable inferences. It is recognised that additional information may clarify and potentially resolve some of these issues.

There appear to be several points of difference between the water balance modelling of Pells (2011) and the modelling reported herein. Points of difference were:

1. Inflows and outflows from the Lakes,
2. Stage-storage relationships of the Lakes,
3. Treating lakes distinctly as opposed to lumping them together,
4. Effect of lake water level on groundwater, and
5. Model calibration and prediction of Lake levels

8.2.1 Inflows and Outflows

Regarding the mass balance, it is not apparent from Figure 5.11 and the descriptions of the SimHyd and SWMM 5 models whether incident rainfall onto the Lakes’ surface was included as an input. In the modelling described herein, direct rainfall into the Lakes accounted for 14% to 27% of inflows in the base case simulation. In addition, it is unclear if either surface water modelling method allows for potential evapotranspiration losses between the Lakes.

There were notable differences in the estimates for train demand between the modelling reported herein and Pells (2011). A comparison is shown in Figure 8-1. From Figure 8-1 it can be seen that Pells (2011) estimate is significantly greater than the estimates used herein from 1920 onwards. Model simulations however indicate that the overall effect on predicted water levels is not great.
8.2.2 Stage-storage relationships

The level-storage relationships given in the Pells (2011) report differed significantly from those derived from the recent topographic survey. The level-storage characteristics (surface storage) reported in Pells (2011) are compared to those derived from the 2012 survey in Figure 8-2 to Figure 8-6. Note that the plots of Pells (2011) data in these figures are derived from a printed copy of the report (therein Figure 5.5) rather than from digital data. It is also noteworthy that for the most upstream three Lakes, given the fact that the Lakes merge at higher water levels, for the purposes of plotting and comparison, the Lakes were partitioned at their individual spill levels.
It is unclear what Lake full level was assumed in Pells (2011) – possibly 310m AHD. The above storage characteristics indicate that even using lower Lake full water levels, Pells (2011) appears to have overestimated the total capacity of the Lakes. The 2012 survey data has led to a calculation of total Lake capacity of approximately 1,725 ML compared to an inferred capacity of approximately 3,600 ML in Pells (2011).

The higher total Lake volume used in Pells (2011) would tend, in water balance modelling, to over-estimate the relative period of time that water is contained in the Lakes and, conversely, under-estimate the periods of time that the Lakes are substantially dry.

8.2.3 Modelling Individual Lakes Distinctly

In our opinion, simulating the five Lakes as a single water body (as was undertaken in the SimHyd water balance modelling) may significantly affect estimates of evaporation and runoff and would not account for possible losses during spill transfers between
Lakes. Likewise, simulating the most upstream three Lakes as a single water body (as was undertaken in the *SWMM 5* modelling) may also affect model predictions.

8.2.4 Groundwater

In the Pells (2011) modelling, it was not apparent whether groundwater inflows/outflows were calculated as a function of the Lake levels. Net groundwater movement into and out of the Lakes would be expected to be dependent on the lake water levels.

8.2.5 Model Calibration and Prediction of Lake Levels

With regard to the rainfall-runoff models used in the Pells (2011) water balance, there was no explicit documentation of model calibration (either *SimHyd* or *SWMM 5*). It is inferred that rainfall-runoff model calibration was achieved by varying parameters within bounds that were “reasonable and appropriate” in order to best match Lake water levels. In the modelling reported herein, the AWBM was used to estimate rainfall-runoff and was calibrated to recorded streamflow data from a nearby catchment - O’Hares Creek at Wedderburn (NOW GS213200). We were able to obtain a close calibration of the rainfall runoff component of the Lake catchment water balance independently using a 10 year period of continuous data from the nearby and hydrologically similar O’Hares Creek catchment.

Use of historical estimated Lake water levels to compare with modelled Lake water levels was also a notable point of difference. With the exception of periods when the Lakes were dry, using un-rectified aerial photographs to estimate approximate lake levels, is subject to possible errors of the order of at least 0.5 m (refer Section 4.1). It is expected that there would be even more uncertainty with anecdotal observations and photographs. The possible inaccuracy of data derived from anecdotal observations was considered too large to produce useable estimates of Lake water level. A comparison between estimated historical Lake water levels that we have estimated (by comparing Department of Lands aerial photography with surveyed lake storage level relationships) and those provided in Pells (2011) is provided in Table 8-1 below. Table 8-1 shows significant differences between the two sets of estimates and also indicates a significantly greater number of aerial photographs used in this study.
Table 8-1 Summary of Lake Water Level Interpretation from Department of Lands Aerial Photography

<table>
<thead>
<tr>
<th>Date</th>
<th>Pells Estimate as per Figure 5.12 (pp. 69)*</th>
<th>Equivalent G&amp;A Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lake Level (mAHD) Werri Berri Nerrigorang</td>
<td>Lake Level (mAHD) Werri Berri Nerrigorang</td>
</tr>
<tr>
<td>1/07/1947**</td>
<td>305</td>
<td>302.4</td>
</tr>
<tr>
<td>5/07/1955</td>
<td>306.5</td>
<td>306</td>
</tr>
<tr>
<td>22/03/1966</td>
<td>306.5</td>
<td>307</td>
</tr>
<tr>
<td>29/06/1969</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2/04/1975</td>
<td>-**</td>
<td>305</td>
</tr>
<tr>
<td>26/06/1979</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>27/10/1983</td>
<td>306</td>
<td>-</td>
</tr>
<tr>
<td>21/03/1988</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25/09/1990</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4/01/1994</td>
<td>307</td>
<td>305.2</td>
</tr>
<tr>
<td>14/10/1998</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22/02/2002</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20/12/2005</td>
<td>304</td>
<td>301.6</td>
</tr>
</tbody>
</table>

* Where no observations were reported in Pells (2011) this is indicated by "-".

** Inconsistency between Pells (2011) Table 2.4 and Figure 5.12.

Note: Tabulated dates and Lake levels taken from Pells (2011) were obtained by scaling from printed hardcopy of Figure 5.12 therein.

Table 8-2 provides a comparison between Lake water level obtained by Pells (2011) from historical estimates and using the SWMM model and those obtained from our historical estimates and the base case model reported herein on days when aerial photography is available. It should be noted that the Pells (2011) data was derived from printed figures in a hardcopy of the report rather than from digital data.

Table 8-2 shows that for Lake Werri Berri, seven out of the ten Pells (2011) historical levels are over-estimated by modelling. By contrast, for the base case modelling reported herein, for Lake Werri Berri, nine out of the 16 historical estimates are over estimates (56%). Similarly for Lake Nerrigorang, eight out of the nine Pells (2011) historical levels are over-estimated by modelling, whereas for the modelling reported herein only half the model predictions are over estimates. The difference between base case modelled Lake water levels and historical estimates for these two Lakes is shown in Figure 8-7 and Figure 8-8 where the model difference is plotted as the model predicted water level minus the historical estimate. These plots highlight the frequency of both under and over estimates. These plots also exhibit a weak trend downwards in the model difference with time – an increase in deep groundwater recharge rate with time would be indicated by model over-predictions of water level in recent years and a trend upwards in these plots with time.
Table 8-2  Comparison of Historical Estimated Lake Levels to Model Predictions

| Date       | Lake Werri Berri Water Level (m AHD) | Lake Nerrigorang Water Level (m AHD) |  |
|------------|--------------------------------------|--------------------------------------|  |
|            | Historical Estimate | Modelled | Historical Estimate | Modelled | Difference: Model to Historical Estimate | Historical Estimate | Modelled | Difference: Model to Historical Estimate |  |
| 1/7/1947   | 305.0 | 301.5 | - | - | -3.5 | - | 302.4 | 301.1 | -1.3 | - |
| 5/7/1955   | 306.5 | 307.6 | 304.1 | 304.1 | 1.1 | 0.0 | 306.0 | 306.8 | 0.8 | 0.3 |
| 22/3/1966  | 306.5 | 307.3 | 301.7 | 303.2 | 0.8 | 1.5 | 307.0 | 307.3 | 0.3 | 1.1 |
| 29/6/1969  | - | - | 302.5 | 303.5 | -1.0 | - | - | 299.9 | 300.5 | - | 0.6 |
| 2/4/1975   | - | - | 302.7 | 303.6 | - | 0.9 | 305.0 | 306.4 | 1.4 | 0.1 |
| 29/6/1979  | - | - | 302.6 | 304.6 | - | 1.9 | - | - | 300.1 | 302.6 | - | 2.4 |
| 27/10/1983 | 306.0 | 306.3 | 302.7 | 300.6 | 0.3 | -2.1 | - | - | 299.8 | 298.6 | - | 1.2 |
| 21/3/1988  | - | - | 302.9 | 300.1 | - | -2.8 | - | - | 300.4 | 297.8 | - | 2.7 |
| 25/9/1990  | - | - | 303.4 | 305.9 | - | 2.5 | - | - | 301.2 | 304.3 | - | 3.1 |
| 4/1/1994   | 307.0 | 306.9 | 303.1 | 303.4 | -0.1 | 0.3 | 305.2 | 306.9 | 299.9 | 300.9 | 1.7 | 1.0 |
| 14/10/1998 | - | - | 302.6 | 303.0 | - | 0.4 | - | - | 300.3 | 300.1 | - | 0.3 |
| 22/2/2002  | - | - | 302.3 | 300.8 | - | 1.4 | - | - | 298.7 | 299.0 | - | 0.3 |
| 20/12/2005 | 304.0 | 304.0 | 302.0 | 299.5 | 0.0 | -2.5 | 301.6 | 303.5 | 298.8 | 297.8 | 1.9 | -1.0 |
| 1/1/2009   | 304.0 | 305.2 | - | - | 1.2 | - | - | - | - | - | - |
| 31/10/2009 | - | - | 303.0 | 300.9 | - | 0.6 | - | - | 297.8 | 298.7 | - | 0.0 |
| 1/1/2010   | 302.5 | 304.2 | - | - | 1.7 | - | 301.1 | 303.3 | - | 2.2 | - |
| 13/4/2010  | - | - | 300.1 | 300.3 | - | 0.2 | - | - | 297.8 | 297.8 | - | 0.0 |
| 1/1/2011   | 302.1 | 304.0 | - | - | 1.9 | - | 301.1 | 303.1 | - | 2.0 | - |
| 10/2/2011  | - | - | 300.1 | 299.5 | - | 0.6 | - | - | 297.8 | 297.8 | - | 0.0 |
| 1/10/2011  | 302.1 | 304.9 | - | - | 2.8 | - | 301.1 | 303.7 | - | 2.6 | - |

Note: Tabulated dates and water levels taken from Pells (2011) were obtained by scaling from printed hardcopies of graphs
Figure 8-7  Lake Werri Berri Modelled Lake Water Level Compared with Historical Estimate

Figure 8-8  Lake Nerrigorang Modelled Lake Water Level Compared with Historical Estimate
9.0 CONCLUSIONS AND RECOMMENDATIONS

Based our assessment of historical data on Lake water levels we conclude that there is a significant uncertainty in the Lake water levels obtained from historical aerial photography, which together with the less reliable anecdotal evidence, is currently the only source of information on historical Lake water levels. Based on results of our water balance modelling of the Lakes we conclude there is significant uncertainty in the accuracy of model predictions of Lake water levels and that a wide range of Lake water level predictions can be obtained by varying model parameters over credible ranges. There are also uncertainties associated with climatic data used in modelling. The effects of fire on catchment response and evapo-transpiration as well as human activity may also add variability which adds to the uncertainty in model prediction.

Model results indicate that water loss rates to the underlying groundwater system and groundwater interactions are an important component of the water balance of most the Lakes. There does not however appear to be a trend or change in groundwater leakage with time which would explain the difference between Lake water levels evident from the available aerial photography estimates and model predictions. This is evident by the fact that mismatches between the model predictions and historical estimates from the aerial photographs occur as both under and overestimates over time. This is further evidenced by the sensitivity analyses which show model uncertainty is at least as great as the mismatches. This does not eliminate the possibility that mining may have had an effect on lake water levels and the water balance of the Lakes. However, it does in our opinion prevent this from being a sound conclusion that we can draw from our hydrological analysis.

It is recommended that automated water level monitoring be set up within each of the Thirlmere Lakes. This should be in the form of commercially available pressure sensors and loggers installed at fixed locations near the lowest points of each Lake. Sensors should be established to record water level to AHD. Duplicate sensors should be installed (at second locations) in each Lake in case of sensor failure or vandalism.

Two automatic rain gauges (pluviometers) should be established within the catchment of the Thirlmere Lakes. These should be installed at separate locations to counter the possibility of vandalism.

The data collected from the above installations should be used to annually review the Lake Water Balance and improve the understanding of the Lake hydrology.
10.0 REFERENCES


