Thirlmere Lakes Inquiry

Final Report of the Independent Committee

23 October 2012

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This report was produced by the Independent Thirlmere Lakes Inquiry Committee, consisting of Dr Steven Riley (Chair), Prof. Max Finlayson, A/Prof. Damian Gore, Dr Wendy McLean and Mr Kevin Thomas.

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0.1 COMMUNITY CONCERNS

The Thirlmere Lakes Inquiry was commissioned by the NSW Government, through the Minister for the Environment, to examine the reasons for the low levels of Thirlmere Lakes. The inquiry resulted from community concerns about lake levels, expressed by the local member, Jai Rowell MP, Wollondilly Shire Council, and community groups.

The community presented a number of concerns about Thirlmere Lakes to the Independent Committee established to undertake the Inquiry. There was uncertainty about the cause(s) for the lake levels falling in the last 20 years. Some members of the community suggested that drying was related to longwall coal mining immediately to the east of the lakes.

The Committee found the following:

Re: Lake levels, droughts and modelling

1. The Lakes have been dry before, as recorded by European and Traditional Custodian sources, and in the geologic and geomorphic record of the sediments of the lakes (Section 5.3).
2. The 1992 to 2008 drought (the Millennium Drought) was one of the three most significant droughts recorded in the Picton district. Two of the droughts, the Federation Drought and the World War 2 Drought, resulted in significant drying of the lakes (Section 4.4.3).
3. The lack of rainfall during the 1992 to 2008 drought was similar to that of the two other most significant droughts that occurred between 1889 and 2012 (Section 4.4.3).
4. When considering the influence of drought the important factor is not whether the drought is the most severe on record but whether the drought has the potential to dry the lakes (Section 4.4).
5. There is substantive evidence that lake levels declined by more than 2 m in less than a year (1974-75), and this could only be due to evaporation and groundwater drainage as it was prior to mining in the area (Section 5.3.2).

6. There is considerable uncertainty about the precise levels of the lakes in the period 1889 to 2012 (Section 5.3).

7. The community use the term “dry” even when there is some water in the bed of the lakes. It is more correct to say the lakes were “substantially dry”, which means a large section of the lake bed was exposed and cracked due to desiccation, when referring to the historic and oral records of lake levels (Section1.3.4).

8. Even if the evidence is ambiguous about the lakes being dry, which means absolutely no water in them, there is substantial evidence that all the lakes, including Lake Nerrigorang, were substantially dry in droughts previous to the Millennium Drought (Section 5.3).

9. The hydrology models predicting lake levels developed by Pells Consulting (2012) and Xstrata's consultant, Gilbert and Associates Pty Ltd (2012), have considerable uncertainty and are weakly predictive of lake levels (Section 5.3).

10. The hydrology models cannot be used as strong evidence that the lakes have dried either as a result of drought alone or as a result of drought and mine water extraction (Section 5.4).

11. Limited monitoring of water levels undertaken by the Independent Committee suggests that reductions in lake levels since the substantial rainfall of January to March 2012 are probably related to evaporation and not significant groundwater loss (Section 5.3.3).

12. The catchment areas of some of the lakes may have changed over the last 60 years, which would impact on the accuracy of hydrology models that did not take account of these changes (Section 5.3.7).

13. There is evidence from several studies conducted elsewhere that evaporation rates may have increased over the last four decades as a result of increasing temperatures and recent fires (Section 4.4.4).

Re: Geology and Mining

14. It is unlikely that natural erosion and consequent cutting into the bedrock during the geological history of Thirlmere Lakes has resulted in the Bald Hill Claystone being breached in the western section of the Thirlmere valley. The Bald Hill Claystone is known with certainty to be more than 100 m below the bed of the lakes on the eastern shore of Lake Couridjah (Section 3.1.4).

15. The Bald Hill Claystone does not stop groundwater from passing through it, but it does greatly slow the rate of vertical flow of groundwater when compared to the sandstones above and below it (Section 6.3.1).

16. There are clay beds at depth within the sediments of the lakes which would slow the flow of groundwater to greater depths. The groundwater studies undertaken by Pells Consulting and Xstrata's consultants, Heritage Computing, have not investigated the significance of these clay beds on groundwater flow (Section 8.4.2).

17. There is no evidence that longwall mining to the east of the Picton-Mittagong Loop Line (the Loop Line) has created any structural damage to the rocks to the west of the line including those rocks and lake sediments underlying Thirlmere Lakes (Section 8.4).

18. There are recorded instances in the Thirlmere region of private bores in the Hawkesbury Sandstone aquifers experiencing catastrophic decline in groundwater level and going dry or experiencing a reduction in yield when longwall mining passed near or under them. There are also instances of private bores not being affected and of affected wells recovering following mining and of water rising in some wells (Section 6.4).

19. Groundwater models developed by Pells Consulting and Xstrata's consultant, Heritage Computing, have considerable uncertainty associated with them (Section 8.4.2).

20. The impact of mining on groundwater in the Hawkesbury Sandstone is poorly known (Section 8.4).

21. In general, based on the limited data, groundwater levels in the Hawkesbury Sandstone to the east of Thirlmere Lakes have probably declined over the last 30 years, but there is no clear spatial trend in these declines.

22. It is not possible to separate the impact on groundwater levels of private bores accessing groundwater, the reduction in recharge as a result of drought, and longwall mining to the east of the Loop Line (Section 6.2).

23. No depressurisation is evident in a bore located near the outlet of Lake Nerrigorang, which raises considerable doubt that breaching of the Bald Hill Claystone has occurred and dewatering in the mine has depressurised the aquifer underneath Lake Nerrigorang and caused the lake to dry out (Section 6.5).

Conclusions and Recommendations

24. There is no evidence of a direct impact of mining on the lakes (see Section 8.4).

25. Changes in lake levels can be accounted for by droughts and heavy rains and some groundwater losses down Blue Gum Creek and into the surrounding Hawkesbury Sandstone (see Section 4.4).

26. There is a possibility of reducing groundwater losses from the lakes using aquifer injection to the east of the lakes, but investigations are required before the veracity of this recommendation can be assessed (see Section 9.3).

27. A substantial research program needs to be commissioned to gain information on lake levels (hydrology) and groundwater (see Section 9.2).

28. The Plan of Management of the Lakes needs to be updated (see Section 9.1).

0.2 RESPONSES TO SOME COMMUNITY ISSUES AND QUESTIONS

In discussions with the community a number of issues were identified and questions raised, which the Independent Committee would like to address:

1. ***The lakes have never been dry***. Not true – they have dried out before and were all probably substantially dry during the World War 2 and Federation Droughts.

2. ***Warragamba Dam is full, so the lakes should be full***. The catchment area that supplies water to Thirlmere Lakes is 450 ha, only nine times larger than the area of the lakes (50 ha). The catchment area that supplies water to Warragamba Dam is 9050 km^2, 120 times larger than the area of Lake Burragorang (75 km^2). The average annual rainfall for the Warragamba Dam catchment is 840 mm, similar to that of Thirlmere Lakes. Lake Burragorang will fill before Thirlmere Lakes.

3. ***My farm dam is full so Thirlmere Lakes should also be full***. Most farm dams have catchment areas (areas that supply water to them) many tens of times larger than the area of the dams. The dams are often fed water from relatively impermeable surfaces like roadways, lined drains, and ground surfaces compacted by human and animal activities.

4. ***The Committee did not pay attention to community contributions***. The Independent Committee evaluated all information that was sent to it or that it received in meetings. All information was critically reviewed to determine its accuracy and usefulness for addressing specific details raised during the enquiry.

5. ***Panel 500 in the Xstrata Tahmoor Colliery is closest to Thirlmere Lakes and leaks a lot of water***. Panel 500 is on the eastern side of the mine, east of the Bargo River and near the mine portal (access tunnel). It is designed to receive all water from the workings to the west, as it is on the downslope (lower) side of the coal seam. It is impossible to know exactly where the water is coming from as many longwalls and panels drain into Panel 500. Inspection of a section of Panel 500 showed it to be dry.

6. ***The Committee is not independent because members have worked for Xstrata***. No members of the Committee have worked for Xstrata. Except for the community member, all members of the Independent Committee have experience in relation to mining, working through Federal and State

Government agencies, Universities and other recognised research organisations. Members of Pells Consulting also have experience in relation to mining, including having worked for mining companies.

7. ***The Committee members are making a lot of money out of the inquiry and being paid by Xstrata***. The Committee members are not paid by Xstrata, either directly or indirectly, and are not charging consultant fees of the Government for the substantial amount of work they have undertaken. One member of the Independent Committee took leave of absence during sitting days, without pay.

8. ***The Committee is not undertaking independent work***. The Independent Committee undertook its own surveys and near-surface groundwater and lake level monitoring, and other field work. The Independent Committee has also sought out and reviewed a very substantial body of literature and talked to a number of experts in discipline areas relevant to the study.

9. ***The Committee has ignored the work of Pells Consulting***. The Independent Committee reviewed all relevant work, including the Pells Consulting reports available on the Web. Pells Consulting did not submit its reports to the Committee. The Independent Committee was able to organise one meeting with members of Pells Consulting, in which they informed Pells Consulting of errors in their October 2011 report, including substantial errors in their surveying and hydrological modelling, subsequently acknowledged in Addendum 3 (Pells Consulting, May, 2012).

10. ***The Committee has not been independent and even-handed in its evaluations of reports***. Members of the Independent Committee insisted on independence when they accepted positions on the Committee. Members of the Committee have indicated to both Pells Consulting and Xstrata's consultants issues they had with their respective reports and passed across information.

11. ***The Committee should adopt the Precautionary Principle***. The Precautionary Principle is a legal instrument used in planning approval processes, in which it is an important consideration. However, scientific investigations are conducted under risk assessment processes and ethics guidelines, and the Precautionary Principle does not direct research methods or findings.

12. ***The Committee should recommend restrictions on coal mining***. Apart from the implication that such comments have about the cause of fluctuations in lake levels, the Terms of Reference of the Independent Committee are very clear – to identify the reason(s) for the lake levels being low by examining ALL the factors that may have contributed to changes in the levels of Thirlmere Lakes. The Committee can make recommendations on management of the lakes. The Independent Committee is not empowered to make policy decisions. Such decisions lie with Government.

13. ***The Committee should make recommendations regarding Coal Seam Gas***. Coal Seam Gas is not relevant to Thirlmere Lakes and is thus outside of the remit of the Committee.

0.3 EXECUTIVE SUMMARY

In response to community concerns about the low water levels in Thirlmere Lakes the NSW Minister for the Environment appointed an Independent Committee of Inquiry to establish the reasons for fluctuations in the levels of the Thirlmere Lakes and, if relevant, recommend management actions to address these changes. The Committee was appointed in late October 2011 with a reporting date of 30 June 2012.

The Committee, consisting of four scientists and one community member, undertook a survey of available data and information, completed several desktop evaluations, collected field data to check information, and received a number of contributions from the community, industry and local and state governments.

Calls for submissions, notices of the meetings, and activities of the Committee were publicised via a website, local newspapers and radio, and direct contact with community, industry and local government. Two community consultation meetings were held, on 30th and 31st March 2012. The draft report was released for community comment on 26th June 2012 and there was a public meeting for feedback to the Committee at Thirlmere on 6th July 2012. All submissions and the draft report were made available on the Inquiry website.

The Committee examined information on rainfall, lake levels, geology and geomorphology, regional hydrology, groundwater, seismic activity, mining and its relation to groundwater, mine subsidence, bushfires, and European and Traditional Custodian records of the lakes. The Committee received information from the community, mining company (Xstrata) and local government, and also undertook its own library and database searches and some limited field work and monitoring.

Most of the time involved in sittings of the Committee was spent in the field, examining the environment of Thirlmere Lakes. The Committee was fortunate in that during January to March 2012 there was more than 600 mm of rainfall in the catchment, which enabled the hydrologic response of the catchment to be observed and, in a limited way, measured.

The Committee’s attitude to data and information was to cross-check all data and information in order to test the veracity and robustness of the information.

The Committee used a combination of inductive and deductive processes in developing and testing its own hypotheses and hypotheses presented by others.

The Committee maintained its independence throughout the study. The confidentiality and privacy of individuals and organisations was respected at all times.

The Thirlmere Lakes valley occupies a topographic high in the landscape, and contains a “perched” lake system embedded within the eastward dipping Hawkesbury Sandstone. The lakes have a well-established human and geologic record of fluctuations, drying and filling in response to climatic fluctuations. Human impacts of the last 200 years have involved minor landscape changes within the catchment. The significance of other human impacts on the hydrologic system, and how these impacts are reflected in variations in lake levels, is less well known.

The Committee investigated all possible causes for variations in lake levels. A number of human interactions with the environment were examined, including the impact of longwall mining. The possible impacts of anthropogenic climate change, with reported increased temperature and changed rainfall regime, were also examined. The Committee’s conclusions are based on all the evidence made available to it and that it was able to glean for itself.

The Committee recognises that there is nothing that can be done about climatically-related (droughts and heavy rains) changes in lake levels. However, the Committee examined some management opportunities, and in reviewing these opportunities the Committee was mindful of the need to preserve the environment of Thirlmere Lakes catchment, the majority of which lies within Thirlmere National Park, a sub-catchment of the Warragamba water supply catchment.

The Committee was not empowered to make any policy decisions. Its brief was to investigate the reasons for the fluctuations in the levels of the Thirlmere lakes and to recommend actions for management and additional research, if required.

The Committee tested the robustness of its report in both the scientific and community domains.

0.4 FINDINGS AND RECOMMENDATIONS

The Committee found:

1. The lakes have fluctuated between substantially dry and full conditions within European, Traditional Custodian and Geological time frames and the present low levels are not unprecedented.

2. The only cause for lake level fluctuations prior to European settlement was climatic (droughts and heavy rains).

3. There is clear evidence from 1974 and 1975 and other times that lake levels declined by more than 2 m in less than one year, and this could only be as a result of evaporation and groundwater drainage as it was prior to coal mining in the area.

4. While changes in rainfall (natural climate change)) were undoubtedly responsible for the majority of the change in lake levels in the last 30 years there may be other factors involved in the present low levels.

5. Hydrology models applied to the lakes are based on water level data with significant errors. The models do not represent the dynamic and changing nature of the catchments and their hydrologic regime. The hydrology models have significant variance in optimisation to the water level data and are weakly suggestive of discordance/accordance between rainfall, runoff and lake levels.

6. There is no direct evidence that mining has breached geologic containment structures underneath the lakes, including the Bald Hill Claystone bed.

7. There is substantive evidence of groundwater leakage from the lakes towards the east and east-northeast within the Hawkesbury Sandstone aquifers.

8. There is leakage of groundwater towards the west and down Blue Gum Creek, but it is not possible to determine the relative groundwater flows from the lakes towards the east and west.

9. There is substantive evidence of the steepening of the hydraulic groundwater gradient and lowering of the groundwater table in the Hawkesbury Sandstone towards the east of the lakes over the last 30 years, which would have potentially increased the rate of groundwater flow towards the east.

10. There is evidence to suggest that mining has contributed to changes in groundwater tables and hydraulic gradients in the Hawkesbury Sandstone but it is not possible to disentangle groundwater changes due to mining, from those due to private bores, which access the groundwater, natural climate

change (droughts), and anthropogenic climate change (primarily increased temperature).

11. There is evidence that the Hawkesbury Sandstone aquifer beneath Lake Nerrigorang has not been depressurised.

12. It is not possible to say whether the impact of mining on groundwater in the Hawkesbury Sandstone is temporary or long-lasting. There is evidence from local private and Xstrata bores of both possibilities.

13. The Plan of Management for the lakes needs to be reviewed and there are gaps in ecological knowledge.

The Committee recommends:

1. A socio-economic study of the lakes be commissioned, aimed to assess community values and community opportunities to realise all the potential values of the lakes in whichever hydrologic state they are in.

2. A consortium of suitably qualified researchers are invited to undertake a geomorphic study of the lakes, comprising geophysical investigations, coring, and a suite of studies, including but not limited to, palaeontologic, mineralogical and ecologic investigations.

3. A hydro-meteorology study be initiated to investigate the hydro-geomorphic relations within the catchment of Thirlmere Lakes and to gather the information required to develop a robust hydrology model.

4. The existing private bores to the east of the lakes be monitored for water levels and pumping volumes and groundwater hydraulic information be obtained in order to: a) develop a robust groundwater model for the lakes and immediate area, and b) to investigate the relation between longwall mining and groundwater in the region.

5. Review existing Thirlmere Lakes National Park management approaches and nominate the lakes for listing under the Ramsar Convention on Wetlands.

6. Undertake ecological investigations to address gaps in the information about the lakes and their surrounds.

In relation to direct action to manage lake levels the Committee recommends:

1. There is value in investigating the opportunity of developing a “groundwater mound” to minimise groundwater loss to the east from the lakes if investigations prove it to be a viable management strategy.

2. The groundwater mound could be formed readily via aquifer injection.

3. The water for the re-injection could be supplied from the treated water presently discharged by the mine into the Bargo River.

It is recommended that a Supervisory Committee be appointed to assist in the implementation and management of the programs of research. The Independent Committee has made suggestions about how to implement the above recommendations and has prioritised them.

0.5 ACKNOWLEDGEMENTS

The Committee’s work would not have been possible without the assistance of a number of individuals and organisations. Our apologies if we have omitted anyone.

- Mr Ben Owers, Ranger, Nattai Area, provided administrative and secretarial support to the Committee and his efforts are greatly appreciated.
- Mr Alistair Henchman, Director Metropolitan Branch, National Parks and Wildlife Service (NPWS), provided the interface with NPWS and Minister’s Office and ensured that the Committee could undertake its work efficiently.
- Public and private submissions from a number of people were appreciated, including contributions by Rivers SOS and the Blue Mountains Conservation Society. The names of contributors (where we have permission to publish them) appear in the list of submissions (Appendix 2-5).
- Detailed scientific contributions from Pells Consulting, Xstrata, Dr Scott Mooney, A/Prof Patricia Fanning, and Dr Brian Marshall are appreciated.
- Detailed data from Wollondilly Shire Council, John Smyth, Mr Maidla, NSW Office of Water, and NSW Land and Property Information.
- Assistance with field work from Dr Tim Ralph, Claire Agnew, Danelle Agnew, Ashleigh Brice, Emily Butcher, Therese Canty, Travis Lander, Sarah Lynch, Kylie Morrow, Rhys Newey and Albina Thomas of Macquarie University, and Scott Barling of Ultimate Positioning.
- Assistance from the Traditional Custodians of Thirlmere Lakes, the Dharawal people.
- Mr Robert Wynne for chairing the community forums.
- Public Relations and publication groups within NPWS.
- Members of the community.

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1.0 INTRODUCTION

1.1 CONTEXT

The Minister for the Environment, the Hon Robyn Parker, established on 25th October 2011 an Independent Inquiry into the recent variations in lake levels at Thirlmere Lakes, NSW. The Committee was required to report to the Minister by the end of June 2012. This deadline was extended because of unforseen delays although the Draft Report was completed by 12th May 2012.

This inquiry was a response to community concerns about the loss of water in the lakes, a popular recreational area for many decades, and suggestions that there may be anthropogenic impacts on the hydrology of Thirlmere Lakes. Some of the community concern centred on the impact of longwall mining to the east of the lakes and east of the rail Loop Line.

The Independent Committee had a wide professional expertise, including the knowledge domains of surficial and groundwater hydrology, geomorphology, geochemistry, environmental and hydrological aspects of mining, and ecology. The Committee included a community representative. The Committee examined available data, information and knowledge related to the lakes. The Committee ensured that the community contributed to, and had the opportunity to comment on, their deliberations. This Final Report is the result of the Committee’s deliberations. Details of the Committee, its Terms of Reference, and the manner in which it addressed the terms of reference are detailed in Chapter 2.

The Committee visited the lakes on a number of occasions and undertook observations and some limited monitoring of the environment. National Parks and Wildlife Service (NPWS) personnel assisted them in this work.

The Committee recognised that its primary focus was to address the question, “What factor or factors have contributed to the low water levels presently observed in the Thirlmere Lakes?”

The Committee did not have the brief nor the resources, especially time, to undertake major field-based investigations. It was asked to examine available evidence, undertake limited studies, mostly desk-top, and clearly define the work that needed to be done to address any uncertainties that may impact on its conclusions. Contributions from those with the necessary resources and time were greatly appreciated.

The Committee was not briefed to make recommendations on policy related to mining. The Independent Committee’s primary brief was the science related to the factors that may be involved in the recent changes in water levels in Thirlmere Lakes. The Committee had neither the resources nor the brief to conduct investigations that might lead to policy recommendations on management outside of Thirlmere Lakes.

While some members of the community suggested that the Committee should consider the Precautionary Principle, the Committee considers that, with due cognisance of Workplace Health and Safety and Ethics Issues, the Precautionary Principle is a policy-related tool, not a scientific tool, although its implementation and interpretation is dependent on good science. The Committee employed the process of inductive and deductive reasoning, and rigorous analysis of data and information within the resources allocated to it.

1.2 BACKGROUND

Thirlmere Lakes is located approximately 100 km to the southwest of Sydney, a 90 minute drive from the Sydney CBD (Fig. 1-1) and easily accessible from the M5 South Western Motorway via the Bargo Rd or Picton Rd turnoffs.

Thirlmere Lakes National Park is part of the Greater Blue Mountains World Heritage Area. Thirlmere National Park abuts Nattai National Park to the west, and is at the edge of the Warragamba hydrological catchment draining via the Little River and Nattai River to Warragamba Dam.

There are five lakes in the system. Lake Gandangarra is the furthest upstream, and it drains into Lake Werri Berri, and then into Lake Couridjah. There is a drainage line between lakes Couridjah and Baraba and a very shallow and indistinct channel between lakes Baraba and Nerrigorang (Fig. 1-2). The lake system would drain into Blue Gum Creek if full to overflowing. Blue Gum Creek discharges into the Little River to the west and Little River flows into Lake Burragorang.

Dry Lake, which is to the northwest (upstream) of Lake Gandangarra, is located in the Cedar Creek catchment which drains to the northeast. Dry Lake is outside of Thirlmere Lakes National Park but there is a strong suggestion that its geomorphic history is linked with Thirlmere Lakes. While Dry Lake is not the subject of this inquiry it will be mentioned at several points in this report.

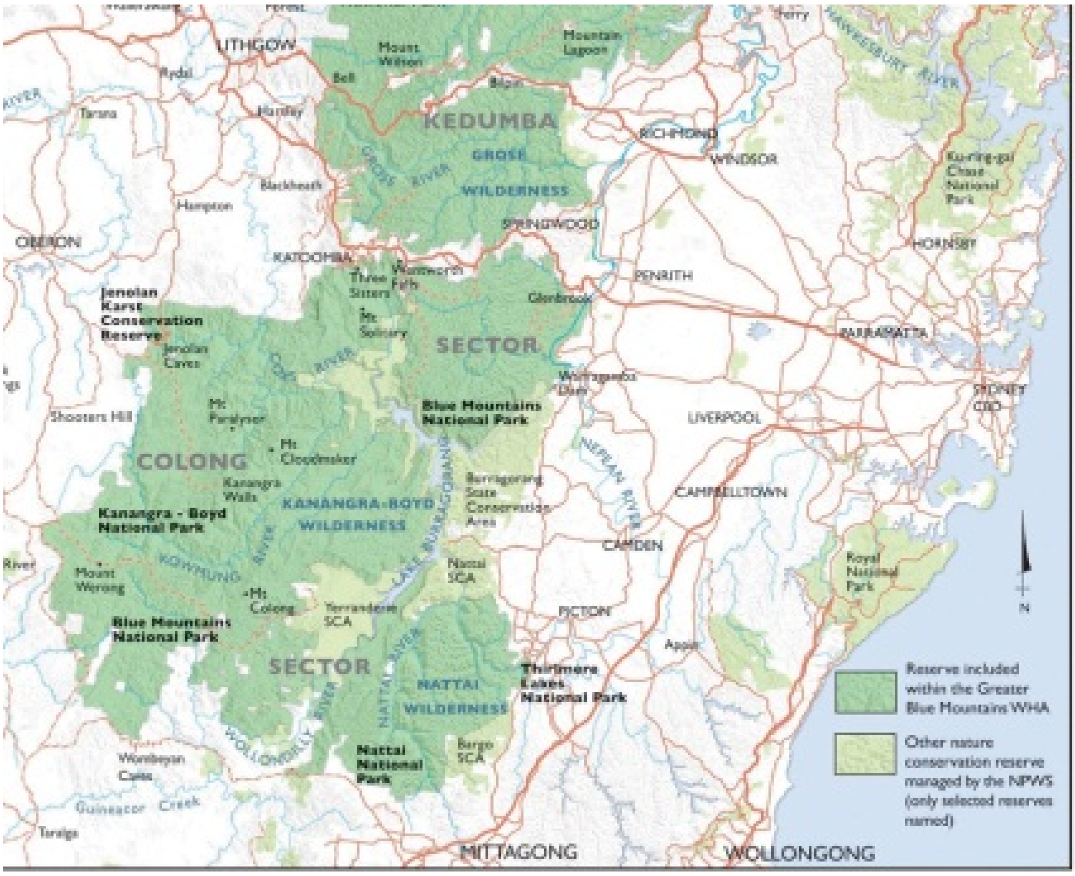


Figure 1-1. Location map of Thirlmere Lakes and environs (source: NPWS).

The lakes have been used for recreation and water supply. They have also been dry in the past, as will be detailed in Section 4.

The lakes were substantially dry during the initial period of the Committee’s deliberations (November 2011). Lakes Gandangarra, Werri Berri, Couridjah and Baraba had a small amount of water; while Lake Nerrigorang was dry (Fig. 1-3). Water tables in the dry section of lake beds were within 1 m of the surface. Storms during the period of the Committee’s deliberations added water to the lakes, as discussed in Section 4. The total area of the lakes, when full, is approximately 50 ha. At the time of the Committee’s early visits to the lakes the water surface area was much less than 10 ha.

The lakes are thought to be relics of an abandoned Tertiary river system originally draining to the west, although there is some debate about this hypothesis, as will be discussed in Section 3. The lakes are within the bedrock of the Triassic Hawkesbury Sandstone, which gives rise to the sandstone cliffs and quartzose sand deposits within the valley.

The annual rainfall of the area is approximately 800 mm and annual pan evaporation approximately 1300-1400 mm. The surface catchment area is approximately 450 ha. The groundwater supply catchment to the lakes is probably larger than the surface catchment area, but not much larger, as discussed in Section 4.

The catchment of the lakes is dominated by dry sclerophyll forest. There are some endangered and rare species within the lakes, details of which are given in Section 7.

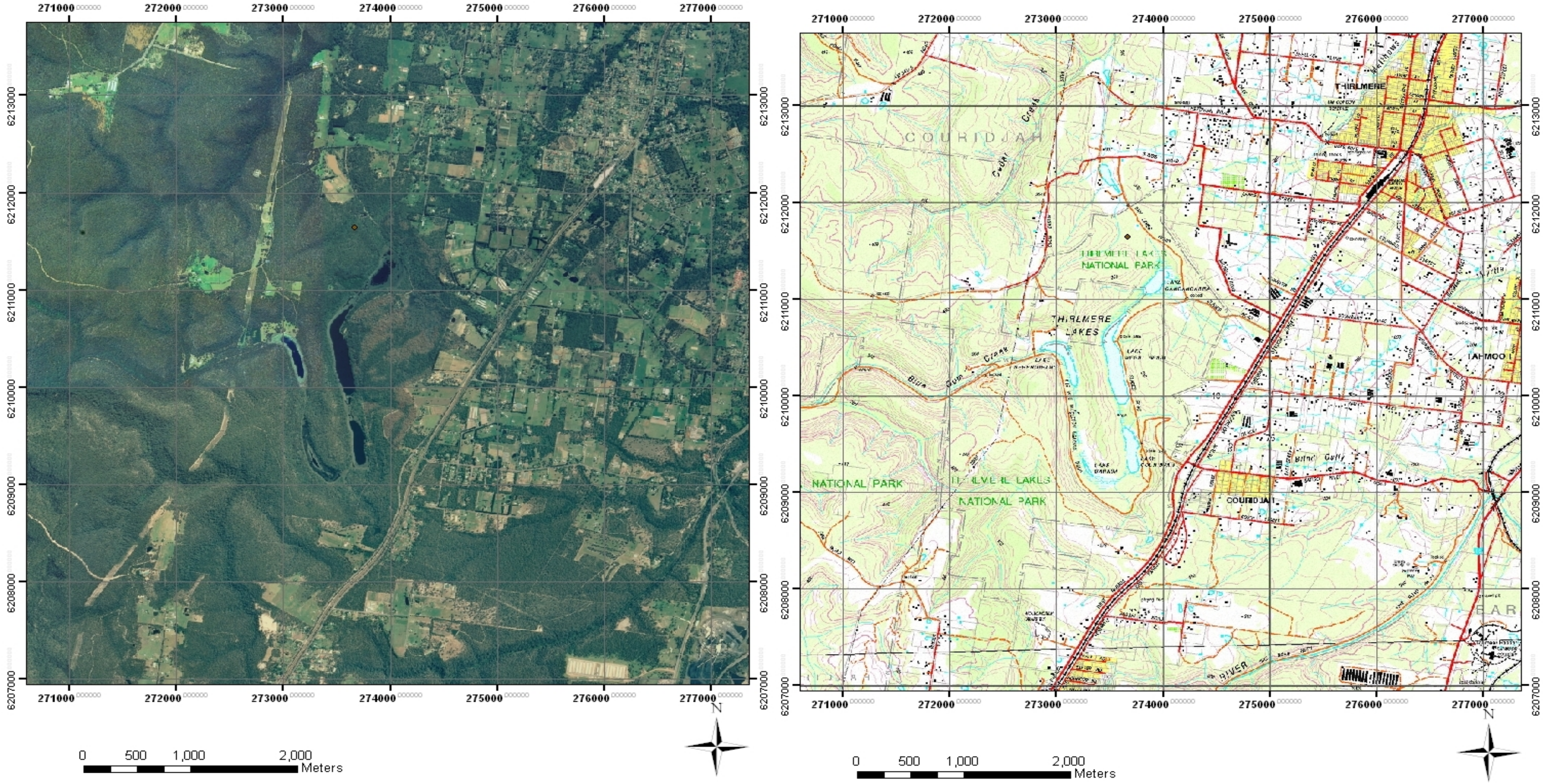


Figure 1-2. Orthophoto and topographic maps of Thirlmere Lakes (NSW Dept. of Lands, Picton 9029-4S, 3rd Ed. Map grid lines are spaced at 1000m. With permission ©NSW Dept of Finance and Services, Land and Property Information).

Figure 1-3. Pictures of Thirlmere Lakes, early February 2012. From top left, clockwise, Lake Couridjah, Lake Baraba, Lake Werri Berri and Lake Gandangarra.

1.3 LANDUSE & LAKE HISTORY

1.3.1 Traditional Custodian landuse

Evidence from Traditional Custodians (Dharawal people) and the archaeological evidence (occupation sites) suggest use of the lakes by Traditional Custodian communities prior to European settlement. The lakes are identified as culturally significant (Moggridge, 2010). There is no evidence of any substantial modification of the lakes by Traditional Custodians and recent work by Black (2006) suggests that increased periods of fire over the last 40,000 years may been a result of climatic change and not Traditional Custodian management practices.

1.3.2 European landuse

The European landuse history of Thirlmere Lakes is detailed in Pells Consulting (2011, Section 1.3). In brief, the lakes were first sighted by Europeans in 1798, used to supply water to the southern railway from 1867 when a pumping station was built at Lake Couridjah (the pumping station can still be seen), and used for water supply for local agricultural and residential purposes. Some of the land in the surrounding area was cleared for pastoral activities in the 19th Century. Thirlmere Lakes National Park was initially reserved as a State Park in 1972 and was redesignated a National Park in 1974. The use of Thirlmere Lakes as a water supply for the railways declined when the Main Southern Line railway was re-routed in 1919. Gilbert and Associates (2012, Table 4.1, p. 20) provide a record of the decline in use of lake water by the railways. The lakes have been used for over a century for recreational purposes, including boating and swimming. The construction of wharves and retaining walls in the period 1950 to 1980 was related to their recreational use.

1.3.3 Present landuse

A large proportion of the Thirlmere Lakes catchment is within Thirlmere Lakes National Park. A small area to the south of the catchment and a larger area to the northeast are rural. Pastoral activities dominate, with a few sheds and some small orchards. The area is not extensively cultivated. Less than 75 ha of the catchment is disturbed or shows signs of disturbance prior to being incorporated into the National Park.

There are some small farm dams and roads in the catchment, but nothing large enough to significantly influence catchment hydrology or flow paths over time. Most of the development pre-dates 2000.

There are a number of rural water supply bores in the catchment, outside of the National Park. Details of these bores are given in Chapter 6.

1.3.4 Recorded history of lake levels

The lakes have been dry within the period of European records. The connections between lakes Werri Berri, Couridjah and Gandangarra were enhanced at a period of low lake level in order to assure water supply to the pump station. A later excavation between lakes Couridjah and Werri Berri was undertaken to improve recreational opportunities but the Committee was unable to ascertain the exact date or reason. At the public hearings, a local community member recounted his granduncle stating that he was required by the railways to undertake the excavations. There are reports from locals and other sources of the lakes being "dry" in the Federation and World War 2 drought periods. The Committee had many reports of first-hand experience and of conversations with now deceased residents that horses were ridden across lakes Gandangarra, Werri Berri and Couridjah and of race courses established around the margins of the lakes. Pells Consulting (2011, p. 12) reports that in the 1980's water from Lake Couridjah (also known as the swimming lake, but actually thought to be Gandangarra: interview with a local resident), was pumped into Cedar Creek via Dry Lake at rates of 65 L/s (1000 gallons per minute), which seems somewhat large.

A detailed compilation of historical records of lake levels is provided in Appendix D of Pells Consulting (May, 2012, p. 41). Gilbert and Associates (2012) and Pells Consulting (2011 and June, 2012) used the NSW Department of Lands aerial photographs or Google Earth images from 1955, 1966, 1969, 1975, 1979, 1983, 1988, 1990, 1994, 1998, 2002, 2005, 2006, 2009, 2010 and 2011. Estimates of lake levels from this imagery by Gilbert and Associates (2012) are summarised in their Fig. 4-1 (Gilbert and Associates, 2012, p. 19). The aerial photographs and satellite imagery is considered the most accurate source of information on lake levels for the period 1955 to present, notwithstanding that it has been supplemented with terrestrial imagery.

There is no debate that the lakes have been dry in the past. Exactly which lakes were dry and when is open to debate. However, there are sufficient European, Traditional

Custodian and environmental records to attest to periodic dryness. Detailed information on lake levels will be presented in Chapter 5.

There is some ambiguity in the use of the terms “dry” and “full” by the community and in the literature. A lake floor with no observable water on its surface, which implies the groundwater surface is below the floor of the lake, is obviously dry. But the fact that someone can walk across a lake does not mean there is no water in it. A dry lake may mean one that is too shallow to canoe or swim in. Similarly, the meaning of “full” is also difficult to quantify. There is undebatable evidence that Thirlmere lake levels fluctuate significantly even when they are described as “full”.

It is probably better to describe the lakes as “substantially dry” when discussing the evidence for the lakes being dry. By the use of this term the Committee means water occupies a very small part of the area of the floor of each lake or there is no water evident on the lake floor. The concerns that the community has about the “dry” lakes in 2009-2010 was at a time when there was some water in the lakes (as shown in many photographs, e.g. Figs 1-3, 1-4 and 1-5). In this report the description of the lakes as being “dry” can refer to them being completely dry or “substantially dry”.

The expressions and contexts of community presentations concerning the present lack of water in the lakes was often in the historical-social milieu of the recreational use of the lakes and their environmental values. This is expressed in some community presentations as a demand that water be returned to the lakes.

Figure 1-4. From Rivers SOS submission 19 Jan 2012. Lake Werri Berri, Sept 2011. Note the water in the background.

Figure 1-5. From Rivers SOS submission 19 Jan 2012. Lake Nerrigorang in Sept 2010.

1.3.5 The issue

Leaving aside the ambiguity of language, the primary concern expressed in community forums and presentations is not that the lakes are “dry”, but that the lakes are dry because of some human interference, and longwall mining at Tahmoor Colliery was identified as the cause in many submissions. As the mayor of Wollondilly Shire Council stated, “*If the loss of water from Thirlmere Lakes is natural and part of a cycle then we should all feel privileged to be here at this time in history to see it. If the loss is man-made and permanent then we should be ashamed.*” (Wollondilly Shire Council Submission, 20 Jan 2012, Appendix 2-5).

The subtlety of the science challenging this Committee was to disentangle the natural from the anthropogenic. As Pells Consulting (2011, p. 74) states “*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*”.

2.0 THE INQUIRY PROCESS

2.1 TERMS OF REFERENCE

The Terms of Reference (Appendix 2-1) gave the Independent Committee of Inquiry the opportunity to examine any factors that it considered "*relevant to the reasons for or responses to water levels in the Thirlmere Lakes*" (item 6).

Specifically, the Committee was asked to gather evidence from "*a wide range of information sources including, but not limited to: scientific data and studies including paleo-climatological studies; expert opinion; climate or other modelling; comparative information across the region; data from similar water bodies; historical information; private records (such as family photos or private data collections); and submissions from the public*".

As part of its brief the Committee considered that it was necessary to conduct some of its own observations, analyses and field measurements. Towards this end the Committee undertook a number of trips to the lakes and was able to observe the response of the lakes immediately following storms. Some very limited groundwater and stratigraphic investigations were undertaken by the Committee in order to verify data made available to it. A number of desk-top studies by the Committee involved analysis and modelling using available data and information.

Because of limited time the Committee recognised it was not possible to do all the studies it considered important in understanding the factors influencing lake levels. One of the items in its brief was to recommend further studies, particularly if there was uncertainty about the causes for the variations in lake levels (item 5 of the Terms of Reference).

Subject to the certainty of its findings, the Committee was commissioned to recommend management actions and/or studies that would lead to improvement in management of the lakes in terms of addressing those manageable factors that contributed to the present low water levels.

2.2 THE COMMITTEE

The Independent Committee consisted of five people. The fifth member joined in late February 2012. The members of the Committee were:

Dr Steven Riley (chair)

Prof Max Finlayson

A/Prof Damian Gore

Dr Wendy McLean

Mr Kevin Thomas.

Brief Curricula Vitae of the members are presented in Appendix 2-2. Together, the Committee members have professional experience (employment, research, publications, consulting) covering all the areas of study relevant to the inquiry. Mr Kevin Thomas represented the local community.

Most importantly, the Committee considered that it was independent and acted as such. It also endeavoured to maintain maximum transparency of its process, primarily through its website, community meetings and the opportunity for the community to input data, information and knowledge, and to comment on the draft report.

The Committee had no partisan views on what was influencing lake levels and applied a rigorous scientific and verifiable approach to its deliberations and the information it was able to collate. It further sought feedback based on local knowledge and from other scientific sources.

2.3 COMMITTEE PROCESS

The Committee was provided with access to internet facilities, data, references and meeting facilities by NPWS. It also used its own resources to access data and references and to undertake limited field work. Mr Ben Owers, Ranger Nattai Area, provided administrative services to the Committee. NPWS also provided public relations services for the Committee. While welcoming the administrative support, the Committee maintained its independence in how it directed its work, who it talked with, and the data it accessed.

The Committee applied a recognised scientific method to its work, collecting information, developing hypotheses, testing the hypotheses, revising, reformulating and re-testing against data. It was a combined inductive and deductive approach which started by looking at data first rather than starting with existing hypotheses and then trying to match hypotheses to the data.

2.3.1 Committee meetings

The Committee sat on the days indicated in Table 2-1. Summaries of its meetings were placed on the web (Appendix 2-3). Some of these meetings were primarily field trips and data gathering exercises.

2.3.2 Data, information and knowledge sources

The Committee had access to a large body of published and unpublished reports that related directly or indirectly to the inquiry (Table 2-2). The Committee was also able to talk with a number of people with expertise and data related to the inquiry, and are grateful for their contribution. The committee would especially like to thank Pells Consulting for the significant effort they put into their reports. Pells Consulting did not make a submission to the Inquiry other than a list of questions for Xstrata. A/Prof Patricia Fanning (Vorst), whose pioneering work at Thirlmere Lakes formed the basis of many subsequent studies, is thanked for her submission as is Dr Scott Mooney, who has undertaken research and supervised a number of studies at Thirlmere Lakes. Chapter 10 records all references consulted by the Committee. Xstrata also made a submission, with its consultants Heritage Computing and Gilbert and Associates providing reports, and provided a large amount of information relevant to the inquiry.

Mr Ian Sheppard is thanked for his willing assistance. Submission were not made by the GBMWHA Advisory Committee nor the Metro South Western Regional Advisory Committee that otherwise provide advice on the management of the Area.

Table 2-1. Meetings of the Committee

Date	**Venue**	**Major outcomes**
23 Nov 2011	Tahmoor	Initial meeting and visit to Lakes
16 Dec 2011	Sydney	Development of Inquiry process
20 Jan 2012	Thirlmere Lakes	Data gathering
27 Jan 2012	Sydney	Review of progress on studies
8, 10, 12 Feb 2010	Thirlmere Lakes	Surveying and observation of geomorphology and hydrology
24 Feb 2012	Sydney	Review of progress on field work and discussion of hydrological processes in the lakes
7, 9, 14, 15 March 2012	Thirlmere Lakes	Collection of data on lakes, bores, and surveying
16 March 2012	Sydney	Review of data and studies of processes
19 March 2012	Thirlmere Lakes	Surveying
30 March 2012	Tahmoor	Community meeting
31 March 2012	Sydney	Community meeting
4 April 2012	Thirlmere Lakes	Surveying and observations
11 April 2012	Picton and Thirlmere Lakes	Meeting with Wollondilly Shire Council officers and observations at Lakes
20 April 2012	Sydney	Review of draft report
23 April 2012	Sydney	Meeting with Pells Consulting to exchange information
22 May 2012	Picton	Presentation at Wollondilly Shire Council Forum
14 June 2012	Thirlmere Lakes	Field work
2 July 2012	Sydney	Briefing Office of Environment and Heritage (OEH)
6 July 2012	Thirlmere	Community information session
13 July 2012	Picton	Media presentation
17 July 2012	Campbelltown	Media presentation
27 July 2012	Tahmoor	Presentation to local member
17 August 2012	Sydney	Review of submissions
18 August 2012	Thirlmere Lakes	Collection of data
5, 6 Sept 2012	Thirlmere Lakes	Surveying, hydrocensus
7 Sept 2012	Sydney	Review of final report
17 Sept 2012	Thirlmere Lakes	Field work at Lake Baraba
21 Sept 2012	Tahmoor	Visit to Tahmoor Colliery
8 Oct 2012	Thirlmere Lakes	Field work at lakes Baraba and Nerrigorang

Table 2-2. Sources of information.

Source	**Information**
Library	See reference list (Chapter 10), includes Pells Consulting's reports
Public Including answers to specific questions	See submissions (Appendix 2-5)
Technical submissions	A/Prof Fanning Dr B Marshall Dr Mooney Mr J Smyth Xstrata
Supplied information on request	Mine Subsidence Board NSW Office of Water Wollondilly Shire Council Pells Consulting Xstrata
Technical information	Aerial photographs and satellite imagery on Google Earth Geological reports Reports on bores

2.4 COMMUNITY CONSULTATION AND INVOLVEMENT

2.4.1 Call for submissions

The Committee called for submissions in December 2011 and subsequently made an additional call for submissions following the release of its Draft Report on 26th June 2012. The first call for submissions was placed in newspapers as advertisements; informative material was sent to local media outlets; the Inquiry’s website included the call and process for submissions; and letters or emails were sent to a number of stakeholders, organisations and individuals. Table 2-3 contains details of the first call for submissions. Appendix 2-4 has details of individuals and organisations contacted and the website page calling for submissions in both cases.

The Committee was aware that the first call for submissions during the December 2011 to January 2012 period, while necessitated by the reporting deadline of the end of June 2012, might not have provided sufficient time for some organisations and individuals to contribute. It was clearly stated in the Call for Submissions that submissions would be received at any time, and that the opportunity would be provided for further submissions during the public meetings and on release of the draft report.

Table 2-3. First call for submissions.

Contact process	**Details**
Print media	A media release was put out to all local media outlets. Stories were run by the Wollondilly Advertiser, Macarthur Chronicle and ABC local radio.
Public notice	A paid public notice was placed in the Macarthur Chronicle, Wollondilly Advertiser and Illawarra Mercury.
Web	A website with information on how to provide a submission was established on the Office of Environment and Heritage internet site.
Letters and emails	An email was sent to all interested stakeholders, approximately 30, and letters were sent to an additional 10 stakeholders.

A number of submissions on the first call were received by the Committee, including those made during the public meetings. Details are presented in Table 2-4. A list of submissions and the submissions are presented in Appendix 2-5.

Table 2-4. Summary of responses to first call for submissions.

Group	Primary Submission	Oral presentation at public meeting and in private consultation
Individuals	26	5
Organisations	6	3
Government	2	1
Industry	1	1

The Committee prepared its Draft Report by 12th May 2012 and it was released for public submissions on 26th June 2012.

The call for submissions on the Draft Report was placed in newspapers as advertisements; informative material was sent to local media outlets; the Inquiry's website included the call and process for submissions; and letters or emails were sent to a number of stakeholders, organisations and individuals (Table 2-5). Table 2-6 contains details of the submissions on the Draft Report. Appendices 2-4 and 2-5 have details on the distribution list and submissions

Table 2-5. Details of information dissemination on call for submission on Draft Report.

Contact process	**Details**
Print media	A media release was put out to all local media outlets. Stories were run by the Wollondilly Advertiser, Macarthur Chronicle, The District Reporter and 2GB radio.
Public notice	A paid public notice was placed in the Macarthur Chronicle and Wollondilly Advertiser
Web	A copy of the draft report, and information on how to make comment was placed on the OEH website.
Letters and emails	An email was sent to all interested stakeholders, approximately 80.

Table 2-6. Summary of responses to call for submission on Draft Report.

Group	Primary Submission
Individuals	10
Organisations	2
Government	1
Industry	1

2.4.2 Public hearings

In relation to the first call for submissions public hearings were held at Tahmoor on Friday 30th March and Sydney on Saturday 31st March. The agenda for the meetings is presented in Appendix 2-6.

Notice of the meetings was advertised via substantial articles in three local newspapers (Macarthur Chronicle 27/3/2012, The District Reporter 12/3/2012 and the Wollondilly Advertiser 14/3/2012) and mentioned a number of times on the local radio station C91.3FM. All people who made submissions up to March 2012 were also notified by either letter or email, as were people who registered interest in the inquiry via the website.

More than 40 people attended the Tahmoor public meeting and 6 people attended the Sydney public meeting. There were also private submissions at each meeting. Mr Robert Wynne chaired and facilitated the meetings.

The meetings comprised presentations by individuals and groups, followed by some questions and answers from both the Committee and members of the public. Each meeting had a session which gave the community the opportunity to ask questions of the Committee.

The Draft Report was released on 26th June and three weeks were given for comments to be received. Because there was a delay in getting the report onto the website the deadline for submissions was extended to 20th July 2012 following discussion with those who attended the information session on 6th July 2012.

In relation to the call for submissions on the Draft Report the Committee held an Information Meeting on the evening of 6th July at Thirlmere Public School hall, to answer questions about the Draft Report, receive comments from the community and provide the opportunity for the science of the report to be explained. The meeting was an open forum, with questions and comments being received from those attending.

Notice of 6th July 2012 meeting was advertised by substantial articles in the Macarthur Chronicle (28/6/12), Wollondilly Advertiser (4/7/12) and The District Reporter (6/7/12) and it was also mentioned on radio, including 2GB. All people who made submissions or had registered an interest with the Committee via the website were notified. More than 60 people attended. Mr Robert Wynne chaired the meeting.

2.4.3 Community concerns

There were a variety of opinions placed before the Committee relating to the cause(s) for the lakes being low. Many individuals expressed concern about the loss of amenity, referring back to their recreational use of the lakes in the 1950's to 1990's. No one the Committee talked with expressed an opinion about the amenity value of the lakes if they were in a "dry" condition and how they could be valued if "dryness" was natural.

The Committee asked Wollondilly Shire Council if it had conducted any socio-economic surveys of the value of Thirlmere Lakes, in writing, at a public meeting, and in subsequent private meeting. The question posed was "*Does Council have any data on the value to the local economy of the lakes when they are full and used for recreation to their fullest extent?*" The response was that there were "*previous Asset maps and surveys which show that residents' value of the Lakes is consistently high over the time we have been conducting the Assets survey.*" However, these maps were not made available to the Committee. Wollondilly Shire Council's response to the Draft Report indicated that they had conducted a survey in 2010 of Shire Villages. For the Thirlmere area they found (Wollondilly Shire Council, 18 July 2012, p.7, Submission 50):

Of the people surveyed in Thirlmere the Lakes were prominent in their responses.

- *When asked what their town was known for – the Lakes were equal top to the Rail Museum.*
- *When asked what the most important Natural Asset was – Thirlmere Lakes was number one.*
- *81% believed that our natural assets should be protected.*
- *61% were concerned about the water loss in the Lakes with one quote being "Investigate the loss of water in Thirlmere Lakes – a beautiful area damaged".*
- *When asked what they were proud of they also told us they felt "embarrassed", "sad" or "ashamed" in regard to the state of the Thirlmere Lakes.*
- *When asked about other issues or needs for Thirlmere they identified one of the issues as the "effects of long wall mining".*
- *When asked about what they thought Council could do to help with these issues, 2 of the top responses were "limiting mining" and "allowing independent investigation of Thirlmere Lakes".*

The survey results support the Committee's observation about the community relation to Thirlmere Lakes, but there is much that is not known about the community values of Thirlmere Lakes and how the community embed "dry lake" conditions into their views of the lakes.

There is a need for a detailed socio-economic study of the lakes and community assigned values. Work needs to be done on whether the lakes, in a "dry condition", can fit into the social and economic life of the community. There appears to be no discussion about linking the rail museum and lakes, such as educational tours and re-enactments of lakeside picnics and bushwalks.

2.5 COMMITTEE REPORT

The Committee prepared a draft report on 12th May 2012 for public comment prior to finalising and submitting the report to the minister. The draft report of the Committee was made public on 26th June 2012.

This Final Report is structured around the primary factors that the Committee considers provide evidence on what is affecting lake levels or could be factors in influencing lake levels. ***It is the factors that influence the hydrologic regime of the catchment that are of importance in understanding variations in lake levels.***

The elements of the hydrological cycle are complicated by spatial and temporal variations, which is why predictive hydrology is difficult and at times leads to uncertain results. Some of the elements are extremely difficult and/or expensive and time consuming to measure, even with remote sensing and digital technology.

An example of the hydrologic complexity of Thirlmere Lakes is groundwater flow that returns to the surface at, for example, rock faces. A number of community members commented to the Committee about the reappearance of drip lines and "wet patches" along the cliff faces in valley of Thirlmere Lakes following the February and March 2012 storms. An observer wandering along the exposed cliff faces before a storm may see patches of damp on the exposed rock surfaces. During or following a storm these patches may grow into drips and sheens of water flowing over the rocks surfaces (Fig. 2-1). But they are not continuous downhill to the lakes and they change in area and flow rate over time. The Committee observed a number of places where groundwater emerged from the slope only to infiltrate back into the soil some short distance downslope. The extent and duration of the flow observed on rock surfaces and in the gutters along the roads at any time depends on how much time passed since rainfall, and the magnitude (duration and intensity) of that rain. The pathway of water flow is convoluted, over the surface, through the rock and soil material, and through the biological elements (mostly vegetation). The majority of rainfall (>80%) never makes it down slope to the lake and is lost either to evapotranspiration or deep groundwater seepage. Weathering and erosion subtly alter water flow pathways over time. Human activity can also alter these pathways.

Figure 2-1. Flow emerging onto a rock face in Thirlmere Lakes Valley only to infiltrate further downslope.

The Committee has tried to systematise the way in which at the report examines the multitude of spatially and temporally variable factors that may This report presents The Committee examined the factors that may contribute to fluctuations in Thirlmere Lake levels, and they are presented in this Final Report in the following order:

1. Geology
2. Geomorphology
3. Hydrology
4. Lake levels and hydrology models
5. Hydrogeology
6. Biodiversity
7. Landuse and its impacts.

The Committee summarises its conclusions and makes recommendations on future actions.

3.0 GEOMORPHOLOGY AND GEOLOGY

3.1 GEOLOGIC SETTING OF THIRLMERE LAKES

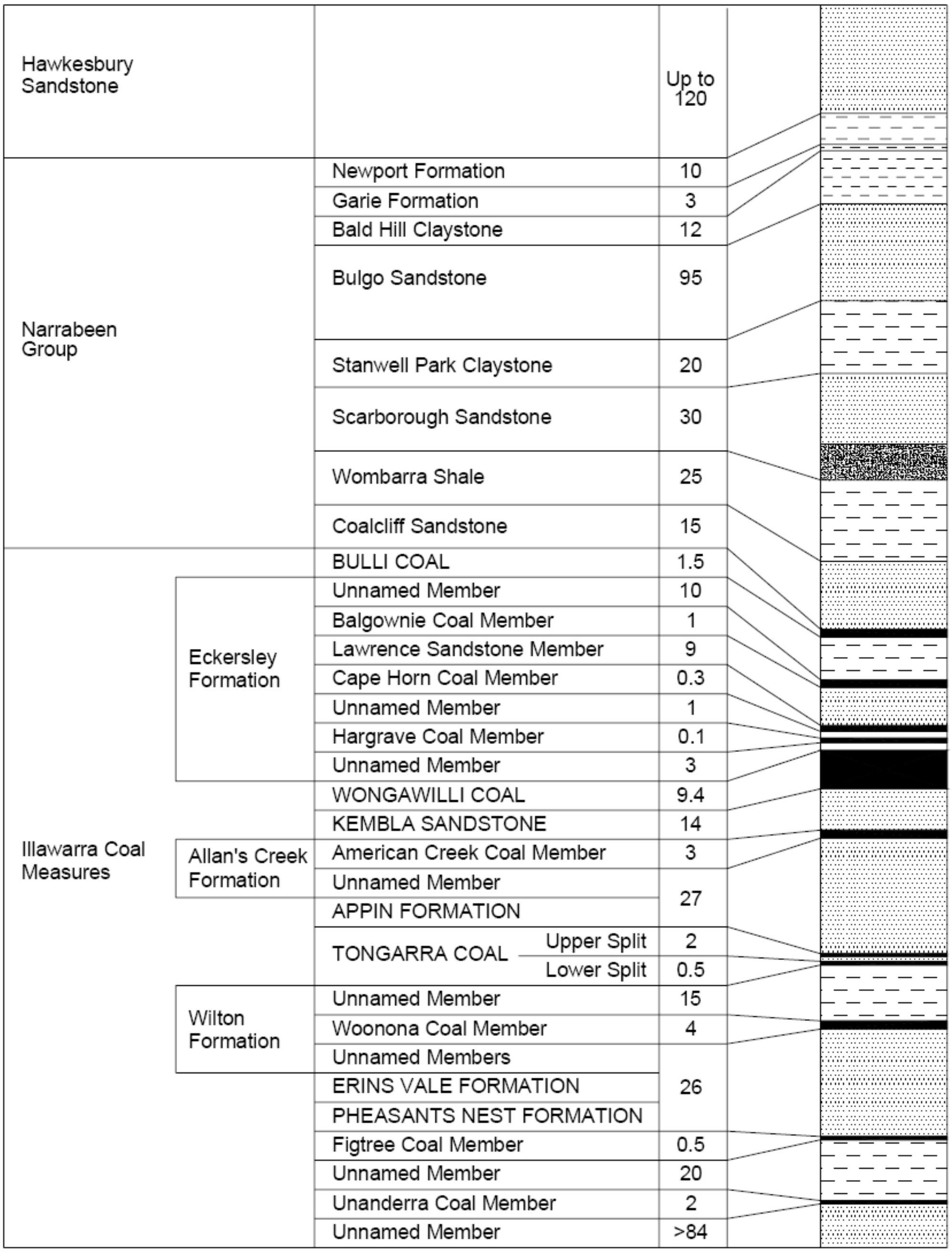
The valley of Thirlmere Lakes is cut into the Hawkesbury Sandstone of the Permo-Triassic Sydney Basin. The geology of the Southern Coalfields has been studied for some time and the stratigraphy is well understood (Moffitt, 2000; Fig. 3-1).

3.1.1 Lithology

The Ashfield Shales of the Wianamatta Group is found to the south and east of Thirlmere Lakes (Fig. 3-2), which suggests that the higher elevations of the catchment are near the top of the Hawkesbury Sandstone, that is, the Hawkesbury Sandstone depth is likely to be greater than 100 m. No Mittagong Formation is mapped in the area.

Sheet and massive facies dominate the Hawkesbury Sandstone, which is 90% quartzose sandstone with some thin beds of siltstone and claystone. Coarse gravel beds can be found in the sandstone, as can mudstone clasts. The sheet facies are planar to trough cross beds ranging in the order of centimetres to metres thick (Moffitt, 2000, p. 54). The massive beds are thick beds, often of homogenous grain size, and frequently form the prominent rock faces in the valley containing Thirlmere Lakes.

The underlying Gosford Subgroup (Garie and Newport formations) of the Narrabeen Group, which can be 10-20 m thick, are not exposed (mapped) in the region of Thirlmere Lakes, nor is the underlying Bald Hill Claystone. The Newport Formation is "*dominantly fine-grained sandstone interbedded with light to dark grey, fine grained sandstones, siltstones and minor claystones*" (Moffitt, 2000, p. 54). The Garie Formation is a recognised marker bed in the southern Sydney Basin, consisting of "*cream, massive, kaolinite-rich pelletal claystone which grades upwards to grey, slightly carbonaceous claystone containing plant fossils*" (Moffitt, 2000, p. 53).



Hawkesbury Sandstone			Up to 120
Narrabeen Group		Newport Formation	10
		Garie Formation	3
		Bald Hill Claystone	12
		Bulgo Sandstone	95
		Stanwell Park Claystone	20
		Scarborough Sandstone	30
		Wombarra Shale	25
		Coalcliff Sandstone	15
Illawarra Coal Measures		BULLI COAL	1.5
	Eckersley Formation	Unnamed Member	10
		Balgownie Coal Member	1
		Lawrence Sandstone Member	9
		Cape Horn Coal Member	0.3
		Unnamed Member	1
		Hargrave Coal Member	0.1
		Unnamed Member	3
		WONGAWILLI COAL	9.4
		KEMBLA SANDSTONE	14
	Allan's Creek Formation	American Creek Coal Member	3
		Unnamed Member	27
		APPIN FORMATION	
		TONGARRA COAL Upper Split	2
		Lower Split	0.5
	Wilton Formation	Unnamed Member	15
		Woonona Coal Member	4
		Unnamed Members	26
		ERINS VALE FORMATION	
		PHEASANTS NEST FORMATION	
		Figtree Coal Member	0.5
		Unnamed Member	20
		Unanderra Coal Member	2
		Unnamed Member	>84

Figure 3-1. Stratigraphic section of the Southern Coalfield below the Wianamatta Group and Mittagong Formation, showing thickness of each unit (from Fig. 4, p. 21, NSW Dept. Planning, 2008; © State of New South Wales through the Department of Planning).

The Bald Hill Claystone consists of "*massive chocolate-coloured and cream pelletal claystones and mudstone, and occasional fine-grained channel sand units towards its base*" (Moffitt, 2000, p. 53) and ranges in thickness from 6 m to over 67 m. If Thirlmere Lakes are towards the upper part of the Hawkesbury Sandstone then it would be reasonable to expect that the Bald Hill Claystone was at least 80 m below the lakes, given that the sandstone hills immediately surrounding the lake are 20 to 30 m high.

Separating the Bald Hill Claystone from the Bulli Coal Seam is the Bulgo Sandstone, which is up to 119 m thick, the Stanwell Park Claystone, the Scarborough Sandstone (up to 25 m thick), the Wombarra Claystone, which becomes sandier towards the west, and the Coal Cliff Sandstone. The upper two thirds of the Bulgo Sandstone sequence are "*characteristically green, uniformly fine-to medium-grained" sands derived for altered intermediate to basic volcanic rocks*" (Moffitt, 2000, p. 52).

3.1.2 Structural characteristics

A number of structural elements are mapped in the vicinity of the lakes and some are evident in the rock exposures of the Thirlmere Lakes valley. Immediately to the east of the lakes is the Thirlmere Monocline. There are faults in the vicinity, aligned with the long-axis of the lakes and the valley. These faults have orientations approximately NNW-SSE.

There are four sets of joints in the region, with strike directions aligned 005°, 055°, 105° and 155° (true north). "*These sets are parallel to, and at right angles to, the principal fold axes in the region*" (Moffitt, 200, p.70).

Dykes in the area have strikes similar to the faults and joints (Moffitt, 2000, p. 63).

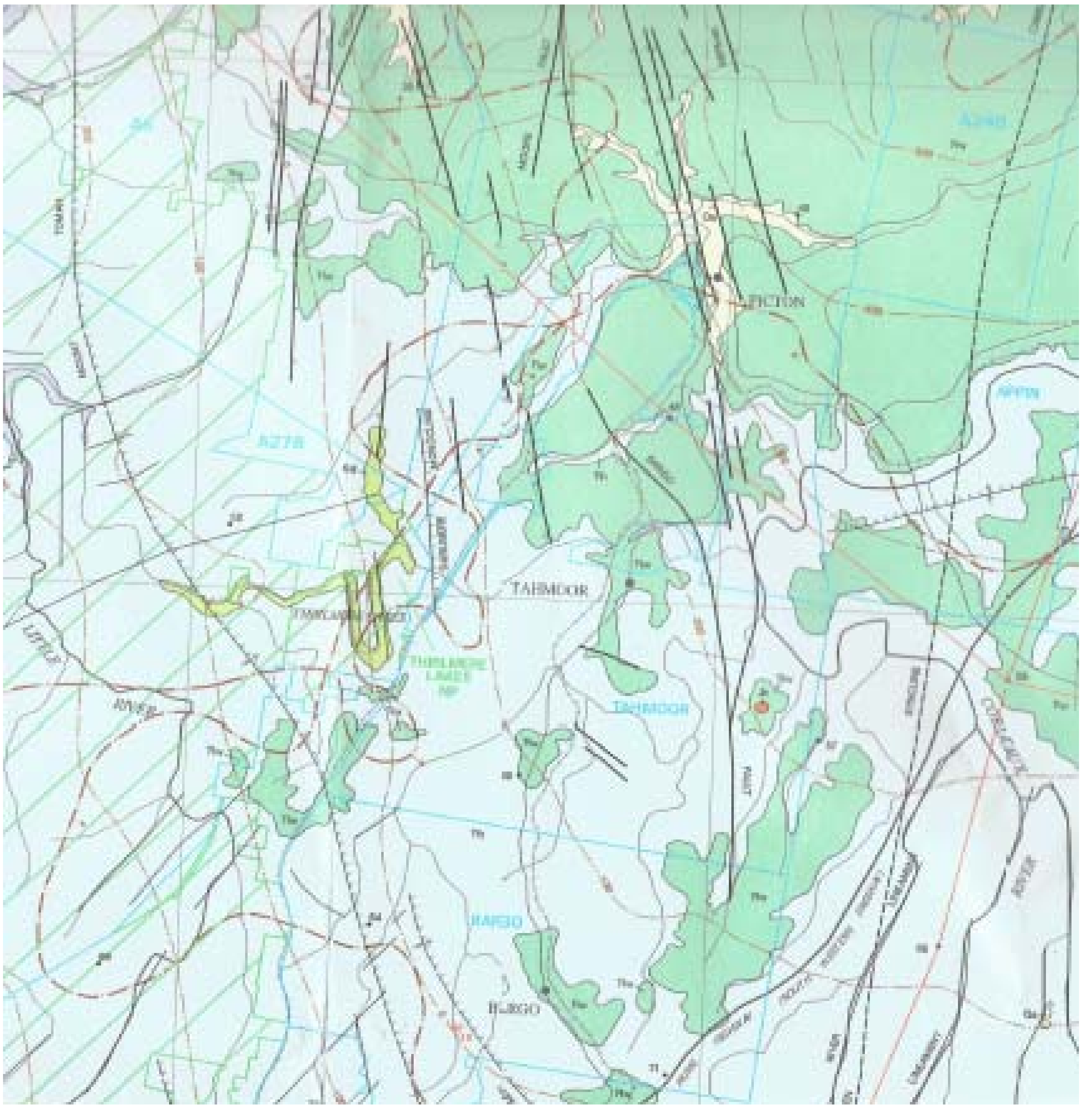


Figure 3-2. Geology including structural elements of the Thirlmere Lakes region (extract from 1:100,000 Southern Coalfields Regional Geology Map, 1999: Dept. of Mineral Resources, Geological Survey of NSW); ©NSW Trade and Investment. (see original for scale and key).

A number of lineaments have been identified from aerial photos and satellite imagery Lohe et al., 1992). They are not randomly distributed, but have principal directions of N-S (156°-198°), NNE-SSW and NE-SW (019°-079°), ENE-WSE and ESE-WNW (080°-155°), NW-SE (290°-315°), and NNW-SSE (330°-340°).The majority of the lineaments probably represent joint sets (Lohe et al., 1992, p. 7-20) and it is suggested that "*long-standing structural trends in the basement are significant factors in determining* *their orientation*” in addition to uplift, denudation, horizontal stretching, gravitational unloading and contraction through cooling. The long-axes of the lakes and Thirlmere valley are aligned with these lineaments and represent part of the lineament pattern (Fig. 3.3).

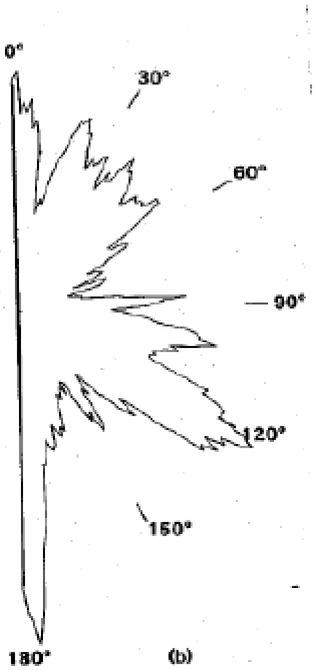


Figure 3-3. Rose diagram showing the orientation patterns of lineaments for the southern part of the Sydney Basin (Modified from: Lohe et al., 1992, Fig. 7.6).

The lineaments appear as joints in the rock exposures in the Thirlmere Lakes valley and provide planes along which blocks of rock separate from each other and along which water flows (Fig. 3-4). They are preferred lines of erosion, probably because of enhanced rates of water penetration, weathering and structural weakness. Not all joints are necessarily related to regional trends. Local pressure unloading of rocks as a result of erosion, undercutting and tree root pressure may also account for some of the joints.

Figure 3-4. Structural elements in Thirlmere Lakes valley. Each image shows sub-horizontal bedding planes and steeply dipping joints contributing to the detachment of blocks of rock from the cliff faces.

Joints and bedding planes are often preferred zones of groundwater flow. If there are any compressional or tensional forces on the rocks they are likely to lead to weakening and separation of rock masses, the development of voids and even fracturing along these joint planes. The prominence of NE and SE trending lineaments suggests preferential flow paths in these directions. Further details of the relation between structural elements and hydrogeology are given in Chapter 6.

3.1.3 Regional dip slopes

The regional bedrock dip in the vicinity of Thirlmere Lakes is towards the ENE (060°-070°) (Fig. 3-5), as shown in the west-east cross sections presented in Moffitt (2000) and in geological cross sections in Pells Consulting (2011) and Heritage Computing (2012). Dip slopes are in the order of 2°-3° (3-5%). There is some variation in these dip slopes and clearly they change significantly in association with folds and other structural elements.

The eastward dip slope and orientation of the lineaments suggests that groundwater flow will be towards the east, particularly as the elevation of the land surface also declines towards the east (Fig. 3-6). There is no barrier to the eastward drainage of groundwater.

3.1.4 Detailed geology and location of Bald Hill Claystone

The position of the Bald Hill Claystone has assumed significance in the discussion on the role of geology in the loss of water from the lakes (Pells Consulting, 2011). The Claystone is assumed to be an aquitard which, it is argued by Pells Consulting (2011), has been breached. This discussion will be revisited in Chapter 5. For the time being the analysis below relates to the vertical position of this claystone in relation to the lakes.

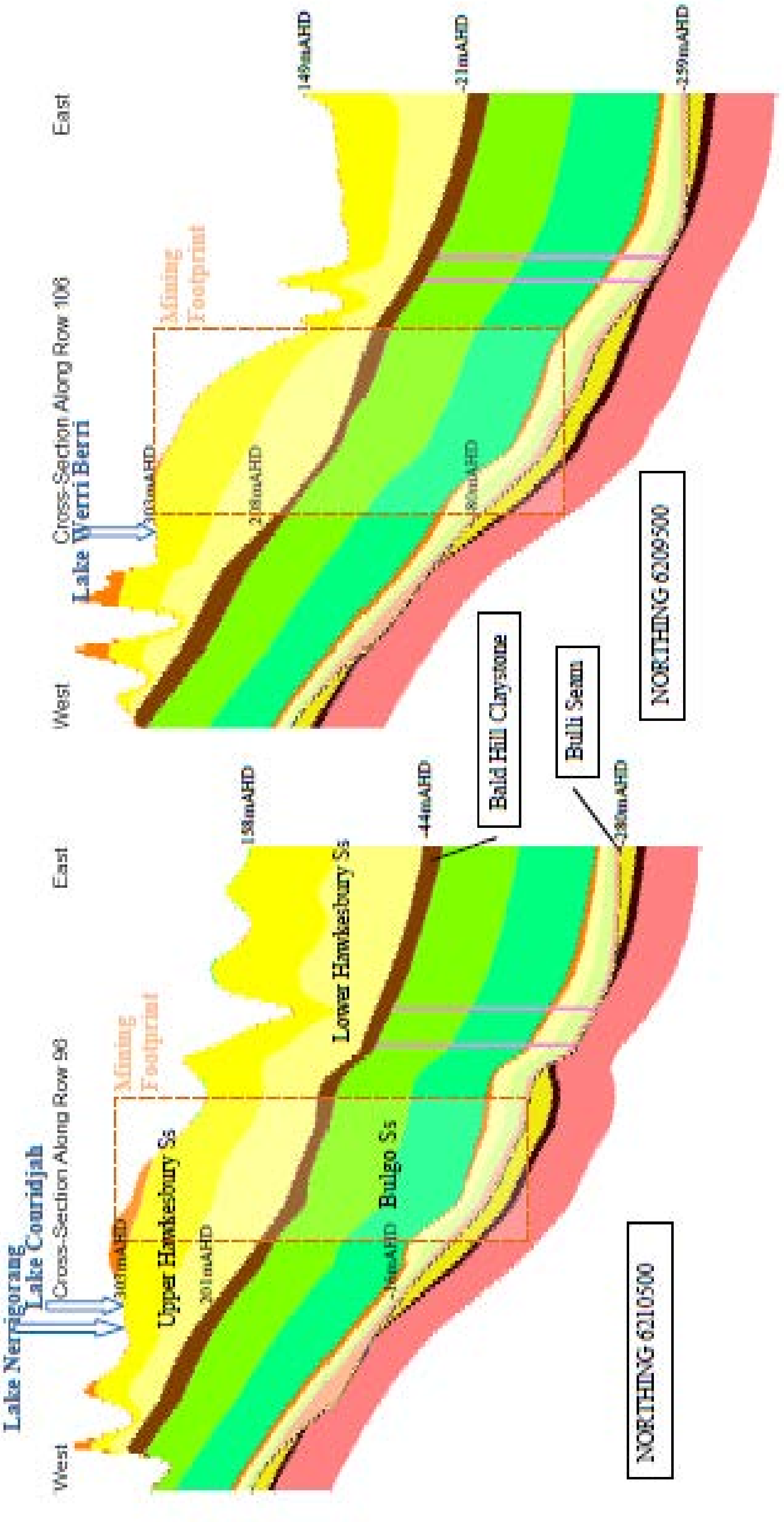


Figure 3-5. Regional dips in the bedrock (from Heritage Computing, 2012, p. 22: With permission, Xstrata and Heritage Computing).

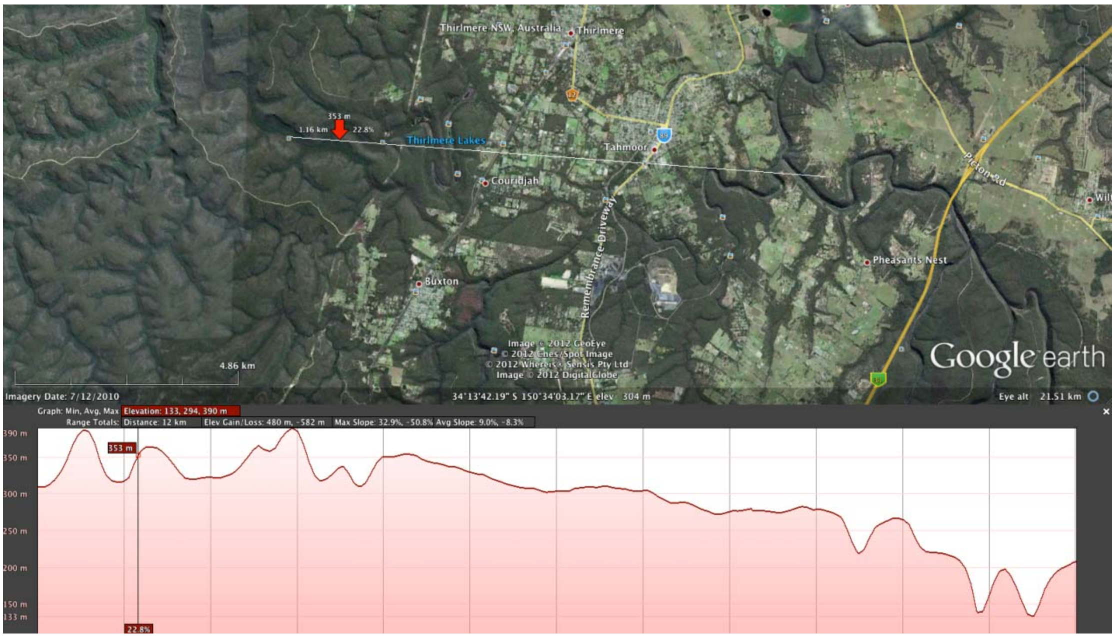


Figure 3-6. Cross section drawn from Google Earth showing Thirlmere Lakes topographically above much of the land surface to the east (copyright; Google Earth; 2012 ©Whereis®Sensis Pty Ltd; Image©2012GeoEye).

There are several pieces of information that allow a determination of the vertical position of the Bald Hill Claystone:

a) The NSW Office of Water drilled five bores for piezometer studies along the margins of Thirlmere Lakes in 2011. Some were cored and one was drilled to 100 m using Rotary Air Blast (RAB) drilling, with chips recovered every 1-2 m (Russell, 2012, p. 6. Table 2). Examination of the 100 m core by a number of people, including members of the Inquiry, shows Hawkesbury Sandstone throughout, which means that the depth of the Hawkesbury Sandstone extends to at least 207 mAHD[1] at the eastern shore of Lake Couridjah (elevation of top of hole approximately 307 mAHD: Gleeson, 2012).

b) There are four exploration cores in the region, TNC25, TNC26, PMX3 and DDH6, whose locations are shown on Fig. 3-7. The logs of these four bores (Appendix 3-1) are discussed in the following section.

c) Data from logs of private water bores near the lakes.

d) 1966 Australian and Oil Gas Corporation mapping (Foskett et al., 1966) showing contours of the base of the Wianamatta Shale.

e) Pells Consulting, who reported Bald Hill Claystone exposed in the Blue Gum Creek valley walls to the west of Thirlmere Lakes (Pells Consulting, May 2012).

Xstrata also provided contour maps of the Thirlmere Lakes region showing the depth of cover and thickness of the Bald Hill Claystone. While the Committee reviewed these data from Xstrata it focused on the information obtained from the immediate area provided by the bores and exploration cores and its own field work.

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[1] AHD = Australian Height Datum, the datum to which all Australian topographic heights are related to mean sea level (see http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/australian-height-datum-ahd.html)

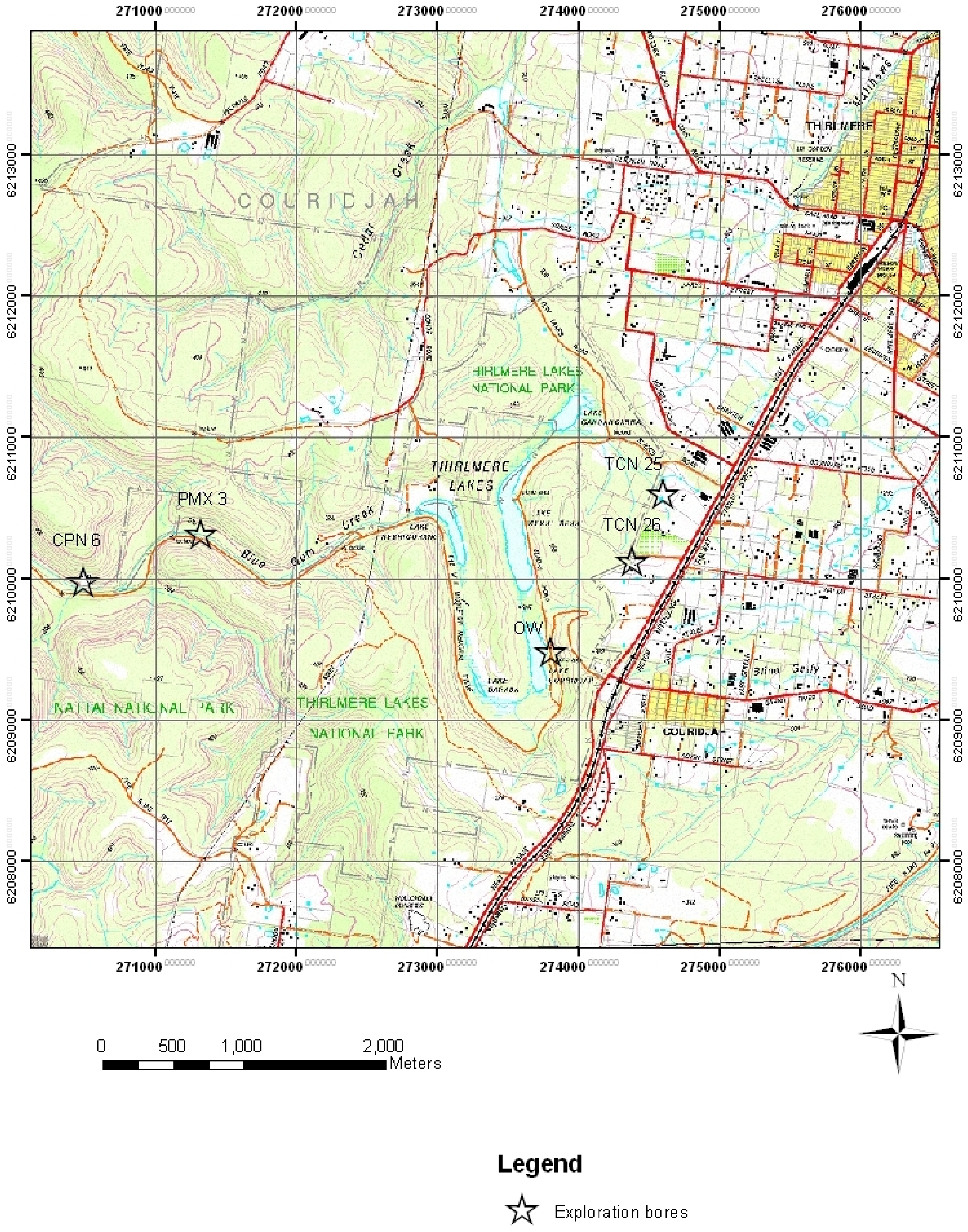

Figure 3-7. Exploration bore locations.

Table 3-1. Details of location of Bald Hill Claystone (notes on Bores at the end of the table).

Exploration Bore	**Easting**	**Northing**	**Elevation of ground surface (mAHD)**	**Depth to Bald Hill Claystone (m)**	**AHD top of Bald Hill Claystone (m)**	**Comments**
TCN25	274582.6	6210557.4	330	152	178	
TCN26	274154.4	6209991.6	348.4	167	182	
OW GW075409/2	273772	6209569	307.6	>100	<207	Office of Water Bore
PMX3	ANG Coordinates 351200 MGA Coordinates 271200 (to nearest 100 m) 271362 GPS Survey by Committee	772600 6210300 (to nearest 100 m) 6210290 GPS survey by Committee	(960 ft) 290 m	(180 ft) 55 m	235+/- 5 m or 260 m if “lutite” layer used	ANG[2] coordinates in yards (1” to 1 mile Camden sheet)
CPN6 (DDH6)	ANG Coordinate 350500 MGA Coordinates 270700 (to nearest 100 m)	772100 6209900 (to nearest 100 m)	(932 ft from barometer reading) 284 m	71	213 Committee assumes unknown	ANG coordinates in yards (1” to 1 mile Camden sheet)

The Committee examined the 1966 Australian Oil and Gas Corporation Ltd geology map (Forkett et al., 1966), which uses the 1:63,360 Camden topographic sheet, and the Picton 1:25,000 sheet, in order to convert ANG co-ordinates to MGA co-ordinates for PMX3 and DDH6 exploration bores. It did this conversion by comparing the coordinate positions on the former with the positions on the latter. In addition, it discovered the capped casing for PMX3 and measured its location using GPS.

Some details on the bores, extracted from the logs (Appendix 3-1) are given in the following.

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[2] ANG – Australian National Grid – an older map coordinate system, in yards. See http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/historical-datums-of-australia/australian-national-grid.html

Exploration bore PMX3

- Located in Blue Gum Creek valley floor.
- Specifies depth to bottom of Burralow Formation, which overlies the Bald Hill Claystone, as 180 ft (55 m). However, there is red "lutite" (a non-specific term for a fine-grained sedimentary rock) at 95-121 ft (29-37 m) and 104-164 ft (32-50 m). If the upper lutite is Bald Hill Claystone it would give the top of the BHC as 260 mAHD.
- A valley fill of 95 ft (29 m).
- Elevation of 290 mAHD for ground surface agrees with DGPS survey of elevations undertaken by the Committee at Fence Piezometer. The sites PMX3 and CPN6 are near the Fence Piezometer.
- Pells Consulting (April 2012), in conversation and in a supplementary addendum to the report by Pells Consulting (Pells Consulting, May, 2012, p.9, Figure 7), argues that the Bald Hill Claystone is exposed in the Blue Gum Creek bed at Picton 712104, near the Independent Committee's Fence Piezometer, which has an elevation of approximately 291 mAHD (our surveying), and further downvalley at an elevation of 330 mAHD at Picton 709098. The Independent Committee searched for the exposures on several occasions. No outcrop of Bald Hill Claystone was found at the Fence Piezometer. If it exists it is below 290 mAHD. An excellent exposure of bedrock between 390 mAHD and 315 mAHD is provided in the northward flowing creek that extends from Picton 708095 to 710099, near where bore CPN6 is located. Below 315 mAHD the bedrock is covered by a colluvial toeslope. Members of the Committee traversed the valley walls and stream bed from approximately 400 mAHD to the colluvial toeslope and could find no exposure of Bald Hill Claystone. The Independent Committee assumes that it is buried within the colluvial toeslope and is at an elevation less than 315 mAHD at this location. There is no mention of Bald Hill Claystone in the transect conducted by Tomkins et al. (2004) much further downvalley, 4.5 km from the lakes at Nattai 692103. However, the Illawarra Coal Measures outcrop at the confluence of Blue Gum Creek and Little River (see Tomkins et al., 2004), another 3 km to the west and 4 km to the north. The groundsurface elevation at the confluence is approximately 165 mAHD.

Exploration bore CPN6 (DDH6)

- Located in the valley floor of Blue Gum Creek.
- Appears to have drilled through Burralow Formation between 119 and 321 ft (36-98 m) and also penetrated the Bald Hill Claystone ("*at the base of section is a fine arkose underlying browny grey shale*"). The base of the Bald Hill Claystone is then 321 ft (97 m) below ground level, giving 187 mAHD for the base, and if the Claystone is 26 m thick at this point the top of the BHC is 71 m below top of hole, or 213 mAHD. This analysis assumes the correct identification of the Burralow Formation. The Committee suggests this may be an error (giving a very low elevation for the Bald Hill Claystone) and that there is no information in the log on the location of the Bald Hill Claystone.

- See note above about Pells Consulting (May, 2012) claims on the location of Bald Hill Claystone in this locality.

Exploration boreTCN26

- 1995 exploration hole east of Lake Werri Berri.
- Bald Hill Claystone between 167 m and 182 m below top of hole, giving elevation of the top of the Bald Hill Claystone as 182 mAHD.

Exploration bore TCN25

- 1995 exploration hole east of Lake Werri Berri.
- Top of Bald Hill Claystone at 152 m depth (178 mAHD), and it is below the Garie Formation marker bed.

The Foskett et al. (1966) geology map also shows a contour map of the base of the Wianamatta Shale. This contouring can be used to infer the elevation of the Bald Hill Claystone. By extrapolation from the contours, and using the base of the Wianamatta Shale as a reference point, the elevation of the top of the Bald Hill Claystone for each of the exploration bores is shown in Table 3-2. Using the Wianamatta Shale as a reference to locate the top of the Bald Hill Claystone is referred to as “Extrapolated 1” in Figure 3.8.

Table 3-2. Inferred elevation of top of Bald Hill Claystone.

Exploration Bore	Wianamatta Shale base; Foskett et al. (ft)	Wianamatta Shale base; Foskett et al. (m)	Top of Bald Hill Claystone (known) (mAHD)	Depth below base of Wianamatta Shale (m)	Top of Bald Hill Claystone (inferred) (mAHD)
TCN25	1110	342	178	164	
TCN26	1130	349	182	167	
OW GW075409/2	1175	363		165 (assumed)	198
PMX3	1400	432		165 (assumed)	267
CPN6 (DDH6)	1450	448		165 (assumed)	283

The known elevation of the Bulli Coal seam in the four exploration bores can be used as a reference point to estimate a possible elevation of the Bald Hill Claystone at PMX3 and CPN6. The vertical distance between the top of the Bald Hill Claystone and the top of the Bulli Coal Seam for TCN25 and TCN26 is 222 and 210 m respectively. It is assumed in the following that the difference is 220 m. For PMX3 the Bulli Coal Seam is intersected at 770 ft (235 m) below the top of the bore, which is an elevation of 59 mAHD, giving the assumed top of the Bald Hill Claystone as 280 mAHD. For CPN6 the log states that the Bulli Coal Seam is located to 430 ft (131 m) asl, but this is thought to be in error, as the first coal is reported in the log at 569 ft (173 m) below the top of the bore, or 113 mAHD. This gives the top of the Bald Hill Claystone as 330 mAHD. This analysis using the Bulli Coal Seam as a reference is referred to as “Extrapolated 2” in Fig. 3-8.

Finally, following the discussion with Pells Consulting and the Committee’s own independent field work, the Independent Committee also assumed that the Bald Hill Claystone was at the ground elevation of the DDH6 exploration core (291 mAHD) and at 315 mAHD near exploration bore PMX3.

The results of these several assumptions are presented in Fig. 3-8. The “Top of BHC” uses the assumptions presented in Table 3-1, using the higher point in each case. “Extrapolated 1” uses the extrapolation from the 1966 Foskett map (Table 3-8), “Extrapolated 2” is based on analysis of the Bulli Coal Seam, and “Exposed” assumes the Bald Hill Claystone is exposed in the valley walls at DDH6 and PMX3 based on conversation with Pells Consulting and the Independent Committee’s own work.

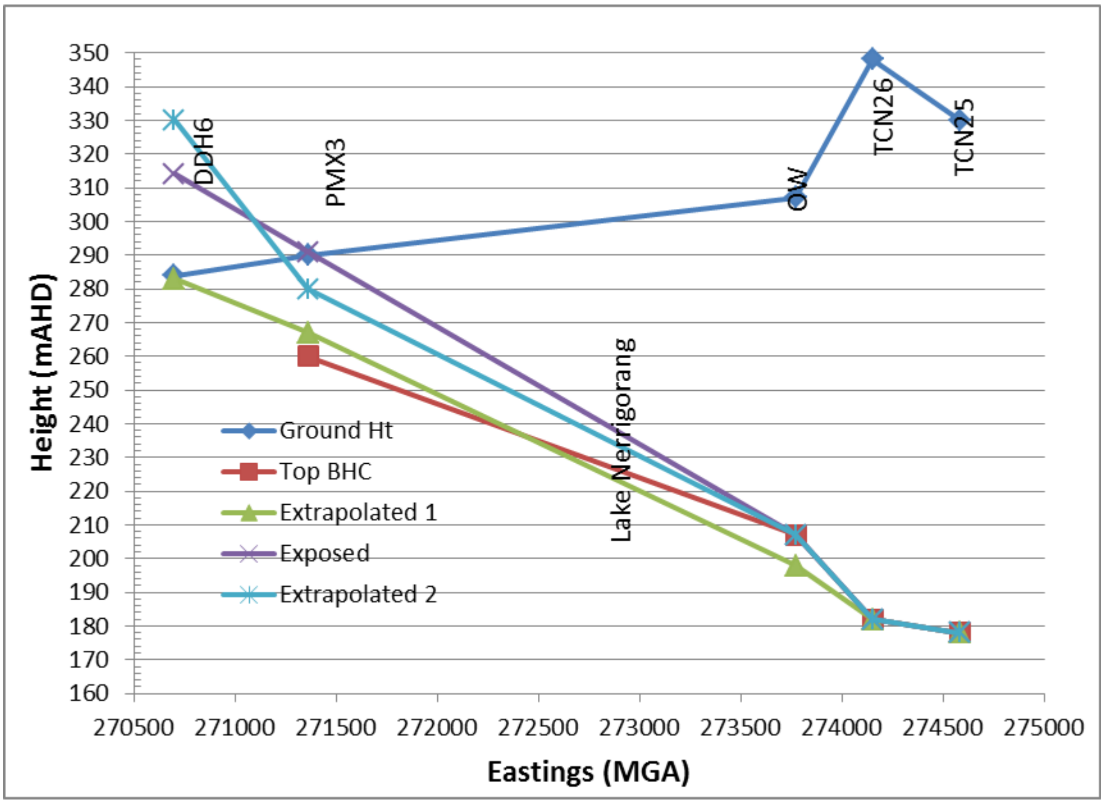


Figure 3-8. A linear plot of the top of the Bald Hill Claystone. The bed of Lake Nerrigorang is approximately 298 mAHD.

Figure 3-8 shows the top of the Bald Hill Claystone bed under the western arm of the Thirlmere Lakes is between 220 mAHD and 236 mAHD. If the bed of Lake Nerrigorang is 298 mAHD the Bald Hill Claystone is 62 to 78 m below the bed of Lake Nerrigorang. The four plots show that the Bald Hill Claystone is greater than 60 m below the bed of Lake Nerrigorang and, on the basis of the assumptions, probably deeper. The plot based on Pells Consulting position for the Bald Hill Claystone suggests that the claystone is at least 60 m below the bed of the lake.

Xstrata contouring places the top of the Bald Hill Claystone between 220-230 mAHD in the vicinity of Lake Nerrigorang (Heritage Computing, 2012, Fig. 10), at least 65 m below the bed of the Thirlmere Lakes, including Lake Nerrigorang, the most westerly of the lakes. Thus, if the valley is incised to a depth of 50 m it will not intersect the

Bald Hill Claystone, although it may intersect some of the formations below the Hawkesbury Sandstone.

It is unlikely that there is a major structural discontinuity, such as a fault, in the traverse between the east and western arms of Thirlmere Valley, which would be the only way of producing a sudden rise in the height of the Bald Hill Claystone towards the west in order for a 50 m deep valley to incise into it.

The thickness of rock strata and their dips can vary over short distances, which gives rise to some uncertainty in predicting the exact position of beds. However, the various options for the elevation of the Bald Hill Claystone underneath Thirlmere Lakes are consistent with regional dip slopes and consistent among themselves. It is highly likely that the Bald Hill Claystone is more than 60 m below the bed of the lakes, at the shallowest point, and not intersected by natural erosion that may have occurred in the geologic past in the Thirlmere valley.

Recommendations for groundwater monitoring made subsequently in this report by the Independent Committee (Section 9.2.4) would provide more information to plot the position of the Bald Hill Claystone.

3.1.5 Seismic activity

There is no suggestion that earthquakes have been sufficient to bring about topographic changes in Thirlmere Lakes and environs within the last century, but they can have other effects. Vibrations can weaken and loosen materials, consolidate sediments, and cause wave activity in water. There is no evidence from the literature of thixotropic clays in the area, but that does not mean they do not exist. Some silts and organic rich materials can be thixotropic. Earthquakes may weaken or even open joints and bedding planes.

The flow of material within the lakes under the stress associated with earthquakes, and changes in porosity and permeability that may have resulted, are possible consequences of earthquakes that cannot be ignored.

Appendix 3-2 presents a list of earthquakes in the region since 1955. The Picton earthquake of 9th March 1973 is remembered by many people, being the largest of the local earthquakes, although it was small in comparison with those commonly encountered on plate margins.

Noakes (1998, p. 99) has an account of the effect of the Picton 9th March 1973 earthquake on the lakes and talks about a possible impact.

"*Ms. C. Shaw, Communications Division, ANSTO, was camping by Lake Werri Berri at the time of the earthquake. According to Shaw (pers. Comm., 1998), a "huge uplift of water" threw sediment from the lake high into the air. Sediment near the shoreline was sent about 5 m up the bank. It is assumed that the sediment in Lake Couridjah would have been affected in a similar manner*".

Tomkins and Humphreys (2005, p. 7) comment on earthquakes stating that they "*are less recognized although data from the Geoscience Australia earthquake database shows that a total of 541 earth movements of between 0 – 9.99 magnitude have been recorded in the Warragamba area (-33.5° to -35° S; 150° to 151° E) since 1872 (Figure 3.9). Earth movements may trigger slope failures where sediments are close to the threshold angle of stability (Summerfield 1991) or where structural characteristics of the lithology such as vertical joints promote dislodgement of blocks and rockfall. Subsidence, which is demonstrably associated with underground coal mining, is widespread (Cunningham 1988) but the full impact has yet to be assessed*".

They note (p. 13): "*It may be possible that movement along the Lapstone Structural Complex (LSC) which includes the Lapstone Monocline and a series of faults to the west of Sydney (Branagan and Pedram 1990) could also trigger a similar erosion-sedimentation response particularly where the zone of movement coincides with steep upper and middle valley sidewalls formed of more weathered Triassic and Permian rocks (Bryan 1966; Rose 1966). Such movement has also been proposed to account for the formation of Thirlmere Lakes, an unusual landform located in the Nattai catchment. Fanning (1982) suggested that* *upwarping along an axis to the south of the LSC truncated the headwaters of the lakes and triggered infilling and therefore linked this event to the Lapstone Monocline. Bishop et al. (1982) place an age on the monocline as 15 ± 7 Ma, but more recent work indicates that faulting may have extended into the Quaternary (Pickett and Bishop 1992). Certainly, seismic movement has been measured in the area since European settlement (Figure 5), the most recent of which was a mild earthquake measuring 4.2 on the Richter scale that occurred in the Southern Highlands on 11 December 2003 and a smaller movement measuring 2.5 on the Richter scale that occurred at Narellan in the south-west of Sydney on 29 December 2004 (Geoscience Australia earthquake database). It is likely that more severe earthquakes associated with deep seated basement adjustments (Branagan and Pedram 1990) could trigger mass movement events in this region.*"

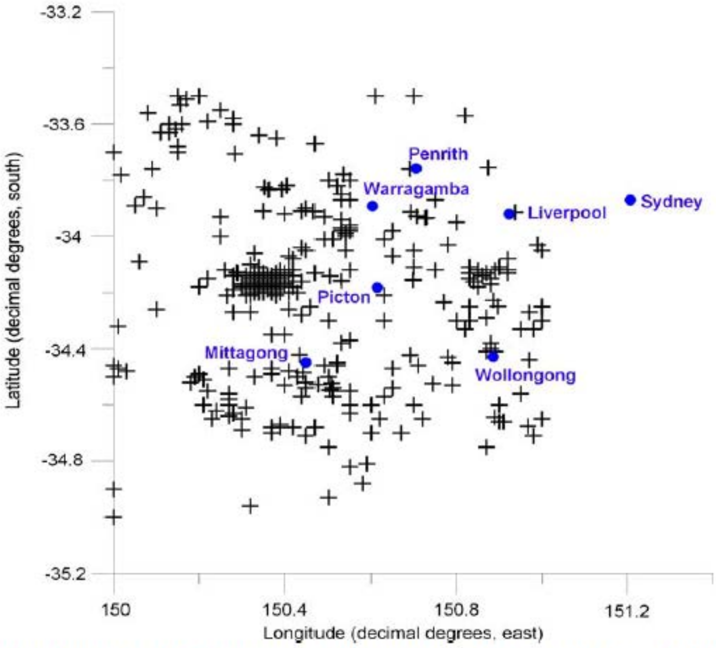


Figure 5. Distribution of earthquakes recorded between 33.5° to 35° S and 150° to 151° E. (Source: Geoscience Australia earthquake database)

Figure 3-9. Earthquake distribution (Tomkins and Humphreys, 2005: Permission Sydney Catchment Authority).

Evidence suggests that larger earthquakes can disturb sediments in Thirlmere Lakes and it is highly likely that other sedimentary changes have occurred due to seismic activity. However, there is no evidence to say exactly what these changes have been or to assess their impact on the hydrology of Thirlmere Lakes. In short, seismic activity is an unknown factor in the lake's hydrology at this time.

If there is a fault aligned with the axis of the east arm of Thirlmere Lakes, passing beneath the lakes, then it is possible that seismic activity may have triggered events to make this a more permeable vertical plane than in the past. The Southern Coalfields map (Moffitt, 2000) shows a reverse fault to the north of the lakes, the Thirlmere Monocline to the east, two lineaments aligned with the main axes of the two arms of Thirlmere Lakes valley, and the Mount Tomah monocline to the west. All structural elements, apart from the Mount Tomah Monocline, have a similar strike.

It is possible that acoustic emissions could be used to identify some of the disturbance due to low level seismic activity, whether natural or a result of mining. The use of acoustic emissions was brought to the Committee's attention at the public hearings by a member of the public, who subsequently wrote to the inquiry outlining the possible value of examining acoustic emissions (Submission 35, Appendix 2-5). "*I think that by extending data available at the high frequency/low energy end of the spectrum of earthquake events, we might be able to make inferences about manmade changes at Thirlmere. My expectation is that if there has been coal mining nearby, the normal power relationship of earthquake events (energy released and frequency of occurrence are inversely related) will change. I would expect many more low energy earth movements resulting from mine subsidence. Although we may not know the details of movements in the strata between the coalmine and the Lakes, knowing that there has been a change in seismic activity will enable a conclusion to be drawn that coal mining has been a factor in rock permeability or the surface height of the lakes. It may even be that by measuring acoustic emission (and changes in ground tilt) at increasing distances from the edge of longwall mining, probabilities of damage can be estimated*". The Committee has not had the opportunity to pursue this line of investigation and understands that while acoustic emission measurements have been used in the Sydney Basin and Southern Coalfield in particular it knows of no relevant data or studies for the Thirlmere Lakes region. The use of this technology may be of value to Thirlmere Lakes (see Hardy, 2003; http://www.cat.csiro.au/dem/msg/seismic/seismic.html).

3.2 GEOMORPHOLOGY

The geomorphology of Thirlmere Lakes has interested earth scientists since the early days of geoscience work in NSW. Griffith Taylor and others have long hypothesised about the origin of Thirlmere Lakes. An account of the hypotheses prior to 1974 is presented and summarised in Vorst (1974). The most widely accepted hypothesis is that the lakes were formed in an abandoned Tertiary-age valley of a westward flowing stream whose headwaters were truncated. This truncation occurred with the tectonic activity that gave rise to the faults and monoclines to the south and east. The current estimate of the age of the valley is 15 million years, based on the age of the Lapstone Monocline, following the work of Bishop et al. (1982) and Pickett and Bishop (1992). Since the time of truncation and abandonment the valley has been infilling. Work on the development of the monocline and tectonic history of the Sydney Basin is on-going (Fergusson, 2006; Carter, 2011; see biennial Sydney Basin Symposia proceedings; in 2012 the 38th symposium was held).

An alternative hypothesis that the Independent Committee presents for consideration is that Thirlmere Lakes Valley is the structurally-controlled headwater valley of Blue Gum Creek, where the Hawkesbury Sandstone has not been breached by incision and hence still controls the geometry of the valley in cross section and planform. This alternative hypothesis does not mean that the valley is young. There are many analogues in Australia of hard lithologies dictating valley geometry in upstream sections of catchments. The Kombologie Sandstone Formation of the Arnhem Land Plateau is one such example.

3.2.1 Catchment area and description

Thirlmere Lakes are incised into a plateau. The catchment elevation ranges from approximately 390 mAHD at the highest to 298 mAHD in Lake Nerrigorang near its outlet. Since the plateau slopes downwards towards the east, the highest areas in the catchment are in the west, the direction of drainage of the lakes and their outlet, Blue Gum Creek. The direction of flow in Blue Gum Creek is opposite to the general slope of the land surface.

Thirlmere Lakes occupy a topographic high. The town of Tahmoor is lower than the bed of the lakes (see Fig. 3-6). While the topography rises west of the lakes the deeply incised streams, such as Blue Gum Creek, are lower than the bed of the lake. Any regional groundwater drainage would be away from the lakes so they are not a regional groundwater sink.

The surface catchment area is ~450 ha. Pells Consulting (2011, p. 57) identifies the catchment area as 445.2 ha: comprised of sub-catchments listed in Table 3-3. Measurement of catchment areas always has certain subjectivity, especially in this situation where the information is derived from 1:25,000 topographic maps with contour intervals of 10 m. The Committee's own measurements suggest an area of 450-470 ha.

Table 3-3. Catchment areas (Pells, 2011 and Gilbert and Associates, 2012).

Sub-catchment	Pells Consulting (2011) (ha)	Gilbert and Associates 2012 (Table 3.1, p8) (ha)
Gandangarra	144.7	154
Werri Berri	67.7	66
Couridjah	63.7	106
Baraba	103.7	69
Nerrigorang	65.4	56
Total	445	451

Streams draining into the lakes have lengths generally less than 1 km. The longest stream is in the northeast of the Thirlmere Lake catchment, immediately to the south of Slades Road. It is approximately 1.3 km long and has an average gradient of approximately 3%. The valley of this stream is wide.

Vorst (1974, p. 25) measured the lake area but it is thought there is an error in her measurements. Lake area will obviously change depending on lake level. It is not easy to identify lake boundaries simply because water levels fluctuate. Interpreting lake boundaries is difficult during long periods of low lake levels because vegetation invades the lake margins. Significant new growth is evident along all the lake margins (Fig. 3-10).

The Committee's measurement of lake area is, at best, an interpretation and subject to error of the order of hectares (Table 3-4). The Committee used the 1998 aerial photography that formed the basis of the Picton 1:25,000 orthophotomap. The interpreted lake margin tree-line was used as the marker for the lake boundary. Use of this line probably overestimates the lake area. Issues that arose in estimating the area of the lakes were:

a. The boundary between Lake Gandangarra and Lake Werri Berri is not marked by a tree line (the narrowest point was used)

b. Lake Baraba, in a number of aerial photographs which show the other lakes full, seems to have a relatively small body of standing water but a large area of circumventing swamp vegetation before the tree line.

Based on the Committee's measurements, the combined area of the lakes when full is 46 ha, with an error factor of at least 5 ha. During February 2012 the free standing water surface area was estimated at less than 10 ha although subsequent rains in February to June 2012 increased the area as the lakes rose. It is estimated that at no time during the period November 2011 to September 2012 was total lake area greater than 25 ha. Noakes (1998) estimated lake area when full as approximately 50 ha. A detailed sub-decimetre DGPS survey would better define the geometry of the lakes.

Table 3-4. Lake area at high stage.

Lake	Area (ha), this report
Gandangarra	11.5
Werri Berri	14.5
Couridjah	6.25
Baraba	7.5
Nerrigorang	6.5
Total	**46.3**

3.2.2 Relict lake shore features

At the time of the early inspections of the Lakes by the Independent Committee (November 2011 – January 2012) the lakes were low, and a number of relict lake shore features were observed for each lake, indicating several phases of higher lake levels (Fig. 3-11). It was not possible to survey and correlate these abandoned shore features, or undertake a stratigraphic investigation of the features.

The old shorelines were clearly indicated by relict reed swamps, benching and distinct grain size differentiation across the surface suggesting some form of wave-winnowing.

The benches were several metres higher than the beds of the lakes and at least four sets of old lake shore features were identified for some lakes in elevations up to 7 m above the lake floors. How long it takes for these features to form is not known. It is not possible to use the evidence of previous lakes levels in this report to indicate the period of long-standing water levels or to date these higher lake levels, as the data on their ages are not available. It would be a worthwhile exercise to undertake a geomorphic survey of the abandoned lake shores, using relevant absolute and relative dating techniques.

Figure 3-10. Vegetation encroachment on margins of lakes Nerrigorang (upper image) and Werri Berri (lower image) (January, 2012).

Figure 3-11. Abandoned lake shore features, Lake Nerrigorang. Nov 2011. Upper image shows a washed beach feature and lower shows relict lacustrine vegetation.

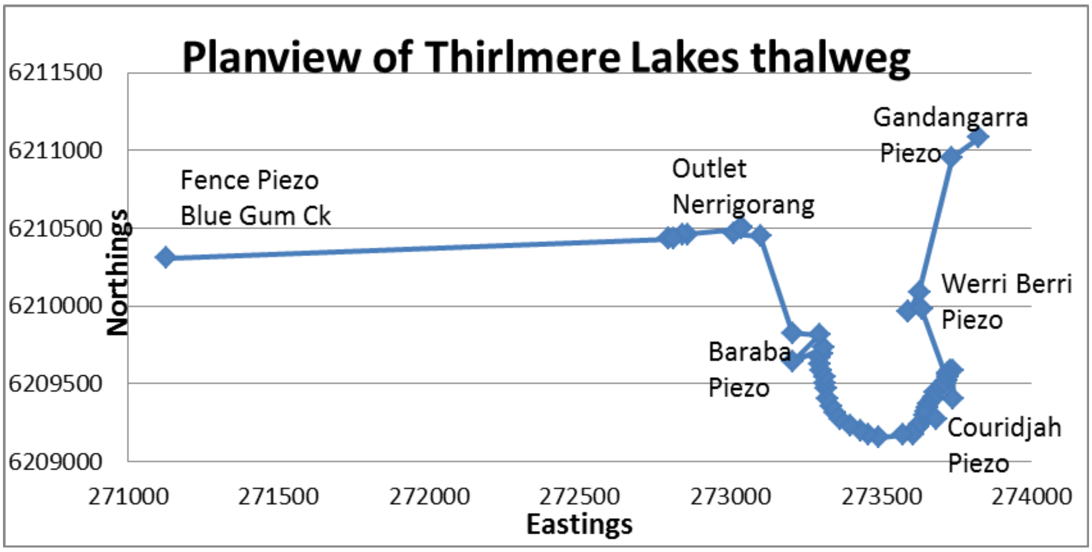
3.2.3 Description of the long-profile (thalweg) of Thirlmere Lakes

A Differential GPS (DGPS) survey was undertaken along the thalweg of the lakes, recording the height of cols between the lakes, where possible, water levels in areas with free-standing water, and groundwater levels in piezometers installed by the Independent Committee. The lowest elevation in each lake was not recorded when it contained water as it was not possible to safely wade through the mud to locate the low points. Details of the DGPS methods are given in Appendix 3-3. The DGPS survey was supplemented by a detailed Total Station survey between lakes Couridjah and Baraba and subsequently by limited automatic level surveys.

Figure 3-12 shows the water level information along the thalweg and the cols between some of the lakes (cols between lakes Gandangarra and Werri Berri, between lakes Baraba and Nerrigorang).

The DGPS data suggest that lakes Gandangarra, Werri Berri and Couridjah are interconnected when water in the lakes is 2 to 3 m deep (elevation of 302.8 mAHD) and that Lake Baraba becomes part of the continuous lake system upstream to Lake Gandangarra when water levels are of the order of 305.8 mAHD. Lake Nerrigorang remains separated as a surface water body from the upstream four until the col between it and Lake Baraba is overtopped at an elevation of approximately 305.5 mAHD. The bed of Lake Nerrigorang occupies a lower position in the topography and is potentially the deepest of the lakes.

The outlet from Lake Nerrigorang may be controlled by an alluvial fan, which is evident on aerial photographs. Vorst (1974) makes the same suggestion. Local residents talk about significant sedimentation in the vicinity of the area, burying stream beds draining the sandstone area to the immediate north of the outlet and blocking the Blue Gum Creek outlet. If true, the height control on the outlet of Lake Nerrigorang may be dynamic over time, being subject to erosion by the discharging lakes and sedimentation by the alluvial fan. At present, the outlet of Lake Nerrigorang (304.2 mAHD) is lower than the col between lakes Baraba and Couridjah, but this may not have always been the case so it may be that at times, the Nerrigorang outlet controls the highest levels of lakes Gandangarra through to Nerrigorang while at other times (such as now), the Couridjah/Baraba col controls the highest level of lakes Gandangarra, Werri Berri and Couridjah.



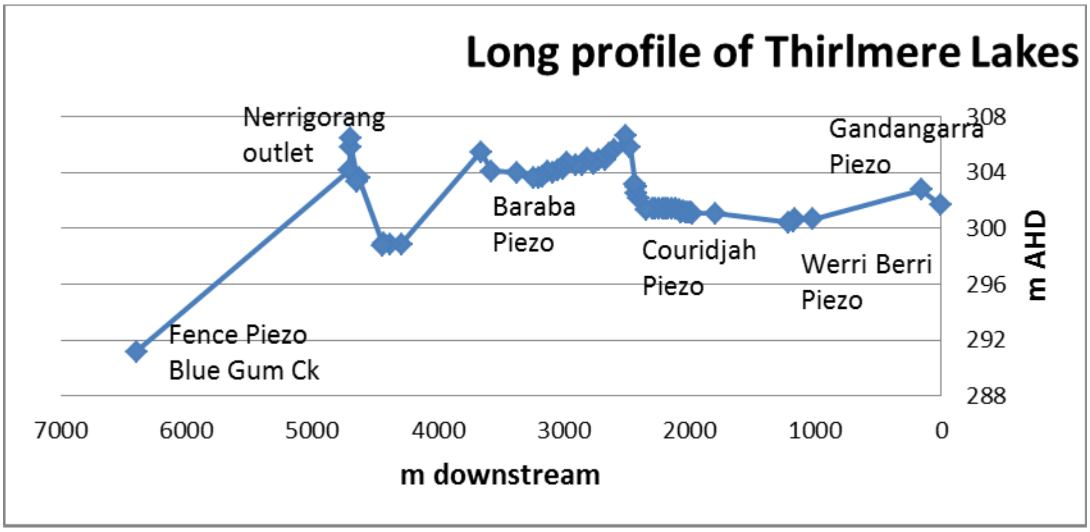


Figure 3-12. Plan view and long profile (thalweg) of Thirlmere Lakes Valley.

This assessment of the thalweg of the Thirlmere Valley is at variance with that of Gilbert and Associates (2012, p. 10). They show (Fig. 3-13) that Lakes Gandangarra, Werri Berri and Couridjah become combined when water levels reach 302.86 mAHD, with the height of the col between lakes Gandangarra and Werri Berri being slightly less than the height of the col between lakes Werri Berri and Couridjah. However, the difference is less than 4 cm and is considered within the error normally encountered in surveying of geomorphic features. So the three lakes are connected at approximately 302.8 mAHD.

Gilbert and Associates show that the col between lakes Baraba and Couridjah is slightly higher than that between lakes Baraba and Nerrigorang (305.86 and 305.73 mAHD respectively). The Committee measured the height of the col at the point it estimated as the lowest in the overflow between lakes Baraba and Nerrigorang, at Easting 273207 and Northing 6209825, as 305.46 mAHD. After careful examination of the ground and stereo-pairs of aerial photographs under binocular mirror stereoscope the Committee could not identify a clearly defined channel through this col. All that it found was a line of Melaleucas running between the lakes, with well-developed communities of Eucalyptus and Banksia on either side. The interpretation of the geomorphology-vegetation association is that a groundwater seepage line connects the two lakes, rather than channel flow. Discussions with A/Professor Fanning indicated that during the 1974 wet period (Vorst, 1974) she saw a shallow sheet of water flowing over the col from Lake Baraba to Lake Nerrigorang.

The Committee surveyed across the col between Lake Couridjah and Lake Baraba using a total station. The height of the col between the two Lakes from the survey (305.80 mAHD) appeared to be higher than that between lakes Baraba and Nerrigorang. The Committee was not sure that their survey crossed the lowest point in the col between lakes Couridjah and Baraba. Combining the DGPS and total station data, and the work of Gilbert and Associates (2012), it is evident that the lowest point in the col between lakes Couridjah and Baraba is slightly less than 306 mAHD.

Clearly, the surveying suggests that when the upper three lakes reach a level of approximately 306 mAHD, they spill downstream into Lake Baraba and then into Lake Nerrigorang, which then overflows into Blue Gum Creek. There is a limit to the amount of water that can be stored in Thirlmere Lakes before they overflow. The lakes are not a closed system, as earlier discussion of their “perched” nature in the landscape showed.

The Committee examined stereo pairs of aerial photographs of the col between Baraba and Couridjah and it appears that in the earlier photos (1955-1980) there was a drainage line between lakes Baraba and Couridjah, in the western section of the col. It appears that between 1955 and 2005 there was a transformation in the drainage system between lakes Baraba and Couridjah, which has impacted on catchment areas (see Chapter 6 for more detail).

Pells Consulting (2011, p. 52) provides a long section of the Thirlmere Lakes Valley but it is not sufficient to identify elevations in detail. A long-section profile does not appear in the addenda that followed Pells Consulting revision of their surveying.

The critical surveying data for Thirlmere Lakes, with results obtained by the Independent Committee, Pells Consulting, and the Xstrata consultants Gilbert and Associates, are presented in Table 3-5. There are some obvious discrepancies.

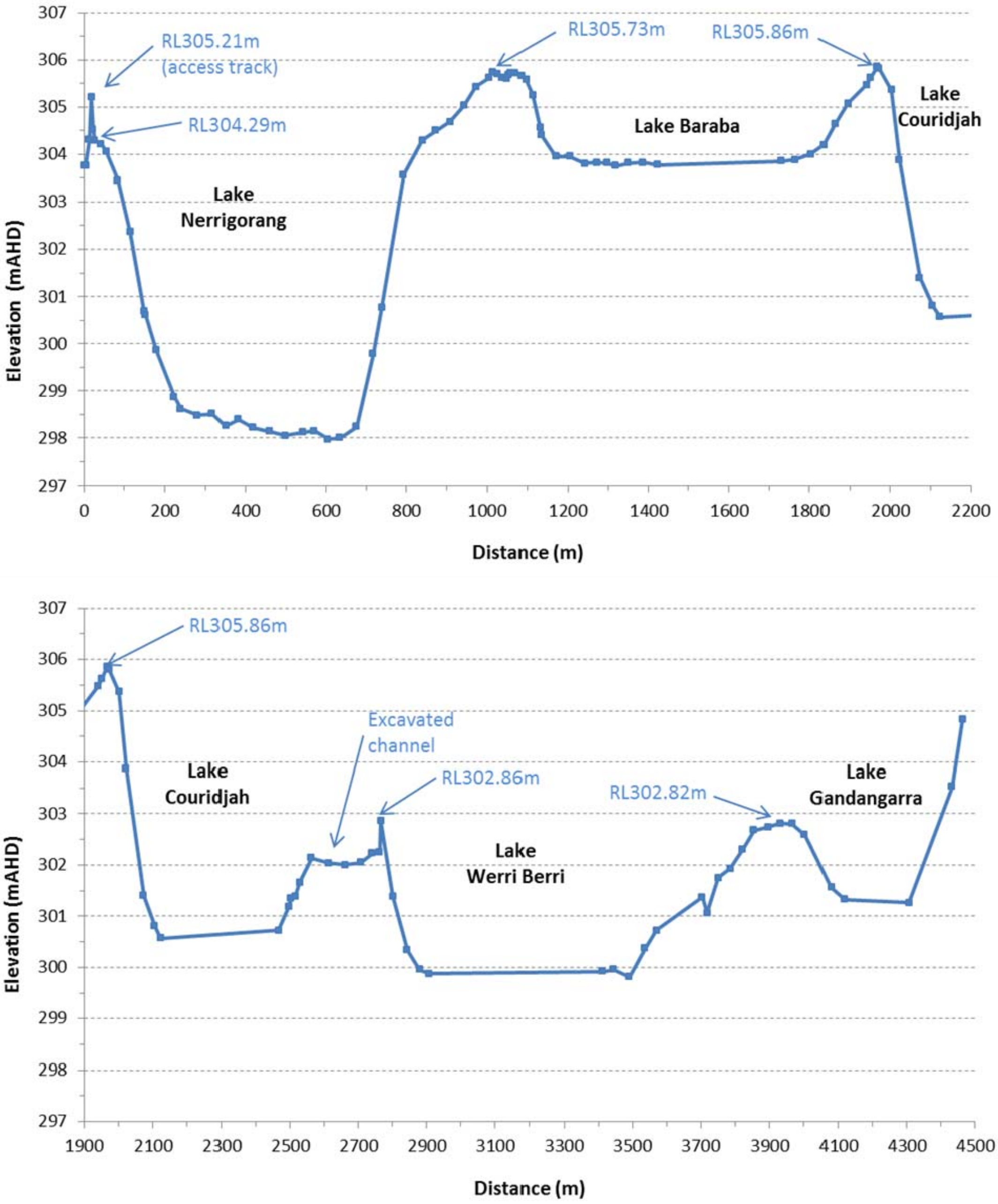


Figure 3-13. Long profile of Thirlmere Lakes from Gilbert and Associates (2012, p. 10). (With permission Xstrata and Gilbert and Associates).

Table 3-5. Key Thirlmere Lake survey data – Pells Consulting, Gilbert and Associates and Independent Committee.

Position	Independent Committee surveying (mAHD)	Pells Consulting (mAHD)	Gilbert and Associates (April 12) (mAHD)
Lake Gandangarra			
Bed	NS[1]	302.9[4]	301.0[2]
Committee's Piezometer base	301.67		
Highest beach level in lake, near Dry Lake Rd	306.2		
Col with Lake Werri Berri and Committee's Outlet Piezometer base	302.76	305[5]	302.82
Lake Werri Berri			
Bed	NS	300.0[3] 299.9[4]	299.5[2]
Committee's Piezometer base	300.66		
Col with Lake Couridjah	NS	304[5]	302.86
Top of Concrete Wall eastern side	306.95		
Lake Couridjah			
Bed	NS	300.0[3] 300.4[4]	300.0[2]
Committee's Piezometer base	301.31		
Col with Lake Baraba	305.80	305[5]	305.86
Top of Concrete Wall eastern side	306.47		
Lake Baraba			
Bed	NS	303.7[3] 302.9[4]	303.2[2]
Committee's Piezometer base	304.00		
Col with Lake Nerrigorang	305.46	305[5]	305.73
Lake Nerrigorang			
Bed	NS	298.3[3] 297.4[4]	297.8[2]

Committee's Piezometer base	298.97		
Base of log wall above beach and downslope of Office of Water Piezometer GW075410	304.1 to 304.8		
Committee's Piezometer Base: Outlet to Blue Gum Creek	304.8 Resurvey September 2012 304.2-304.4	305[5]	304.29
Top of access road across Blue Gum Creek	306.47 Resurvey 305.2-305.6		305.21
Bed of Blue Gum Creek			
Committee's Fence Piezometer	291.84		

1. NS= not surveyed
2. Estimate from Fig. 4.1 Gilbert and Associates (April, 2012). Other elevations from within the report.
3. Pells Consulting, Addendum 3, 16 May 2012, p.2
4. Pells Consulting, Addendum 4, 1 June 2012, p.4, Table 2.
5. Pells Consulting, Addendum 4, 1 June 2012, p.7, Table 7, assumed weir levels for modelling.

3.2.4 Long profile (thalweg) of Blue Gum Creek and Thirlmere Lakes Valley

The long profile of Blue Gum Creek, taken from the 1:25,000 topographic maps, is convex in the downstream direction (Fig. 3-14) which is unusual. Determination of the profile geometry was aided by some limited DGPS surveying. Towards the downstream end of the profile the slope of the stream is 2.6%, while near the outlet from Lake Nerrigorang it is 0.5%. This steepening could be due to several factors:

a. Resistant bedrock in the upstream area.

b. A retreating knickpoint or "headwall" that is still actively cutting back into the plateau.

c. An increase in the erosion capacity of Blue Gum Creek, either as a result of increase in discharge (catchment area), decrease in sediment delivery to the stream, or both.

d. A combination of two or three of the above.

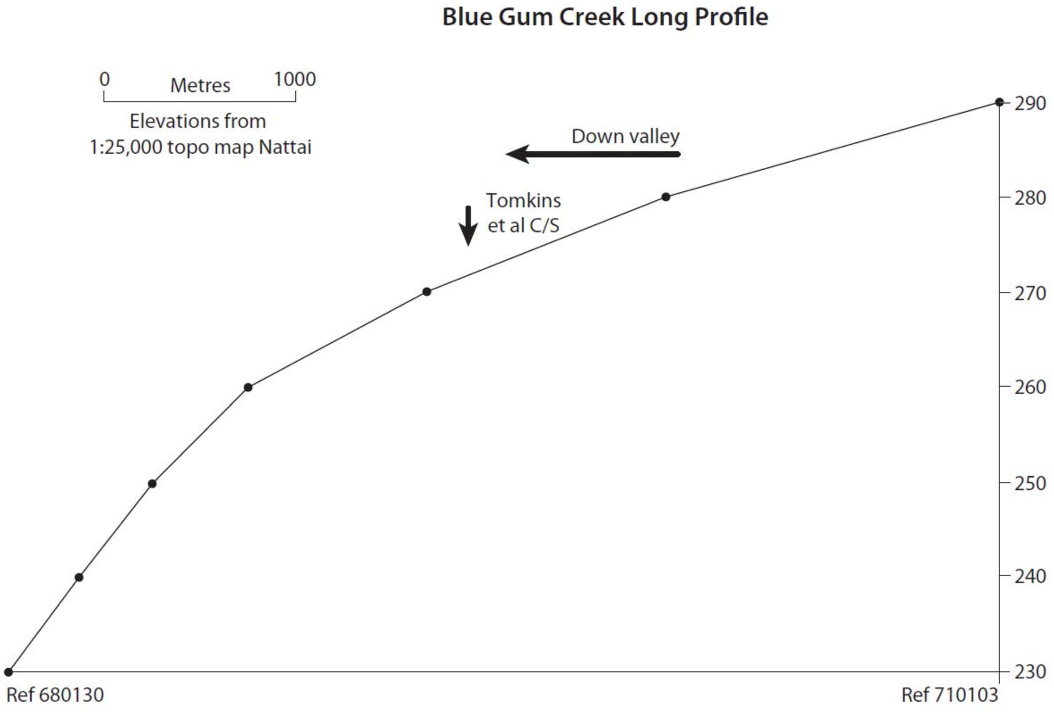


Figure 3-14. Long profiles of Blue Gum Creek, from Picton 711103 to Nattai 680130.

The stream power relationship $\Omega = \gamma QS$

where

Ω = stream power
Q = Discharge (bankfull or mean annual flow)
γ= specific weight of water
S = slope

suggests that, for a constant discharge along Blue Gum Creek, stream power increases by a factor of 5 as a result of a change in slope. Discharge obviously increases downstream, but in the absence of discharge measurements catchment area was used as a surrogate for discharge (Fig. 3-15). There is a significant increase in surrogate stream power along Blue Gum Creek, assuming discharge is linearly related to catchment area (Fig. 3-16). It appears that Blue Gum Creek has an increasing capacity to carry sediment in the downstream direction. The implication is that Blue Gum Creek has an increased capacity to erode and incise into the valley floor, subject to there being no rapid increase in sediment delivery from the catchment. There is a very large increase in catchment area between the 290 and 280 mAHD elevation points along the thalweg of Blue Gum Creek. This increase delivers a significant increase in discharge and hence stream power to Blue Gum Creek.

The downstream increase of stream power suggests that Blue Gum Creek is actively eroding upstream. Whether or not there is a litho-stratigraphic control on this erosion is uncertain.

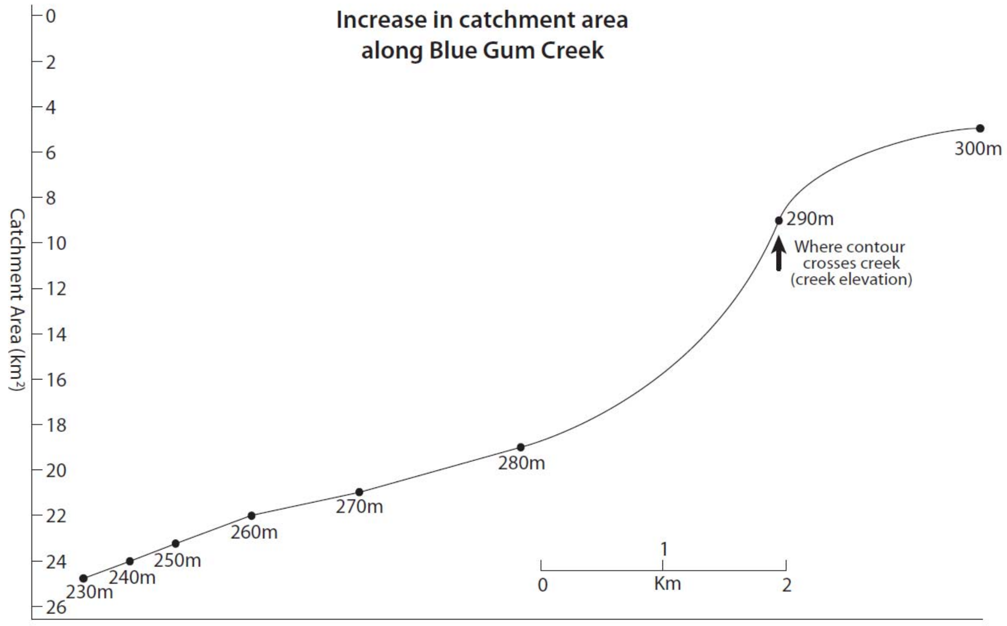


Figure 3-15. Increase in catchment area along Blue Gum Creek from Picton 728104 to Nattai 680130.

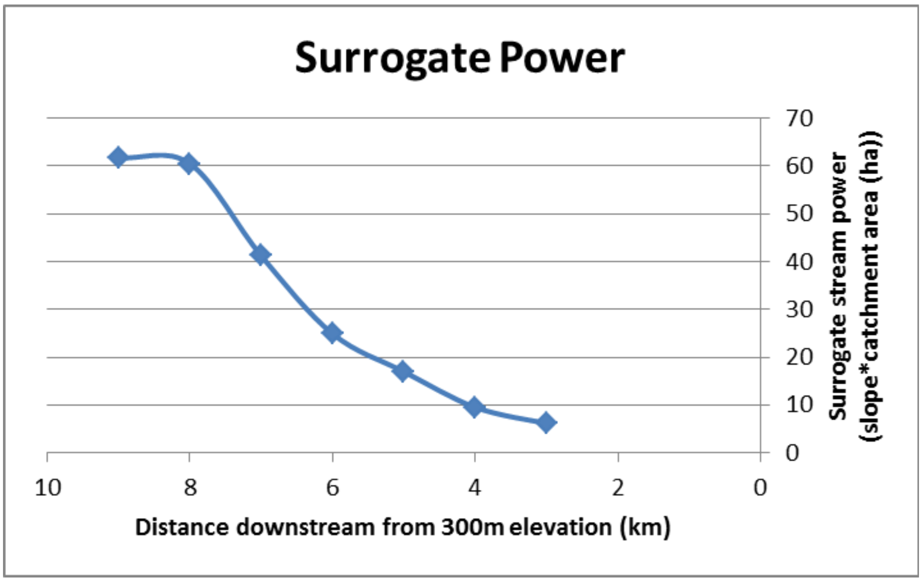


Figure 3-16. Change in surrogate stream power in the downstream direction.

If this hypothesis of active erosion upstream is correct, there is a potential problem with explaining the stability of deep alluvial sediments over a long time period (15 million years). Either:

a) there is a very resistant bedrock shelf retarding headward erosion in Blue Gum Creek, or

b) the stream power upstream of the 300 mAHD elevation is insufficient to move the alluvial and colluvial sediment that has accumulated in the lakes, and which in some cases blocks the lakes, or

c) the sediment transport rate in the upstream area of the catchment (the Lakes) is less than the sediment delivery rate to the valley floor (i.e. it is an aggrading system).

It may be a combination of these factors.

The hypothesis of a protective resistant bedrock layer raises the question of why the sediment accumulation in Thirlmere Lakes is so deep. If the sediment is 50 m deep, as discussed in the following section on the geomorphic history of the lakes, then its basement is at approximately 250 mAHD. This elevation is well within the zone of an active and energetic Blue Gum Creek where stream power, i.e. erosion capacity, is significant. In short, it is a mystery why the sediment in the Lakes has remained in-place for 15 million years.

3.2.5 Weathering and erosion processes

Present day weathering and erosion processes help understand not only the development of Thirlmere Lakes valley and the lakes but also the hydrology of the catchment.

The valley walls are being eroded by a combination of processes.

The bedrock exposures show clear evidence of chemical weathering as a result of groundwater movement and interaction with elements of the biosphere, such as lichen, moss and the breakdown products of vegetation decomposition (Lambert, 1980; Bell, 1984). Chemical weathering etches out the sheet facies in the sandstone, which often form re-entrants into the exposed rock faces.

Rock falls occur as a result of undercutting and stress release along planes of weakness. Animal burrowing and root heaving contribute to block movement. Blocks of rocks which fall from exposed rock faces are deposited downslope where they are subjected to repeated cycles of weathering and breakdown similar to that seen upslope (Fig. 3-17).

Surface wash, either in concentrated flow lines or as sheet flow, moves finer particles downstream or provides preferential zones of infiltration and saturation.

Few streams discharge into the lakes. Alluvial fans occur in their lower sections, and tributary valleys are generally wide. Water flow in the small streams is intermittent, and obviously highly correlated with rainfall events, as the Committee observed in February and March 2012. The lack of clearly identifiable drainage channels (even at the scale of rills) from the slopes into the lakes suggests that the majority of flow reaching the lakes is moving through the colluvium and rock material as interflow/groundwater flow. Sheet and rill flow appears to dissipate in the lower colluvial slopes. Litter accumulation since the last major runoff event and/or bushfire may be obscuring evidence of sheetflow and micro-rilling.

The texture of colluvial slope material fines downslope. Towards the base of the colluvial slopes brown coloured soils are evident. Ants appear to be a major factor in bioturbation of the colluvial slopes, although avian scratching of the surface is also evident. Wombat holes are abundant in the lower slopes and near the lake margins, while other animals are excavating underneath the rock ledges. Debris dams attest to some overland flow.

Figure 3-17. Weathering, erosion and deposition in Thirlmere Lakes Valley.

Thirlmere catchment is subject to bushfires. Evidence from elsewhere shows that runoff and erosion increase significantly in the Hawkesbury Sandstone catchments following fires (Blong et al., 1982; Tomkins and Humphries, 2005). The work of Black (2006), who examined a core from Lake Baraba, attests to frequent influxes of charcoal into the lake sediment.

In areas where there has been compaction and reduction of infiltration capacity by human activity, such as roads and walkways, the drainage lines are more prominent. These compacted areas are located near the margins of the lake and connect to local channels and the lake. These anthropogenic drainage lines are often associated with alluvial fans of washed sand, derived from material eroded upstream in the artificial drainage lines. The clean washed sand deposition shown in the bottom right of Figure 3.17 is probably the deposit of an eroding channel created by a culvert and associated road works.

Quarztose sand forms the majority of the inorganic sediment in the colluvial slopes. However, sand does not appear to be as abundant in the sediments of the valley floor. Hawkesbury sandstone, upon weathering, has up to 40% clay. Cores taken from the lakes and lake margins frequently texture as sandy clays (Vorst, 1974; Noakes, 1998; Black, 2006).

3.2.6 Bushfires and Hydrology

Thirlmere Lakes have been subject to intensive fires, and many residents attested to the severity of the 2001 and 2006 bushfires. The 2006 fire resulted in the peat in the floors of the lakes catching fire (Fig. 3-18). The complete fire history of the area over the 20th century is poorly documented, and although local knowledge will go much of the way to documenting the timing of those fires, understanding fire intensities will remain elusive because the energy released by a fire depends on fuel loading, the size distribution of the fuel, soil and fuel moisture content, slope, wind direction and ambient temperature, all of which can vary around the catchment and many of which can vary over time. Because of the complexity of the controls on fire intensity and duration, the effects will be variable. However, some generalities can be drawn from studies of fire elsewhere in Australia.

Wildfire increases suspended sediment loads in lakes and streams for several years (Blong et al., 1982; Smith et al., 2012) until stream runoff returns to pre-fire levels. The annual yield of water flowing from heavily forested Victorian catchments devegetated by fires can increase by 40-90% or even more (Lane et al., 2006) for several years after fire. In the Snowy Mountains in south-eastern NSW, these effects have been noted to persist for up to five years following fire (Brown, 1972). In contrast, in the savannah of the Northern Territory, lower intensity fires did not increase the volume of water or nutrient flux after fire (Townsend and Douglas, 2004). Similarly, wildfire in the Nattai catchment downstream of Thirlmere Lakes, had no detectable impact on the amount of surface runoff at the large catchment scale for three years following the high-intensity 2001 fires (Tomkins et al., 2008), although scale effects are important for runoff yields from such large catchments and might hide patterns evident in smaller sub-catchments. The stark contrast in these different responses in the flow of water and sediment in the first few years following fire is largely due to the variability of fire. The retention of soil canopy cover and leaf litter acts to reduce water and sediment runoff, whereas water repellency enhanced by bushfire and reduced ground cover increase water and sediment loss (Prosser and Williams, 1998). Wildfire can either destroy or enhance soil water repellency, depending on the temperature and duration of the fire (Shakesby et al., 2003; Shakesby and Doerr, 2006) which is part of the reason for the complex responses of catchments to fires.

In the period 5 to 30 or more years after major wildfire, water yield can be less than the long-term average as young, regrowing trees add leaf and wood mass (Erskine, 2001). Shorter, younger trees are also more effective at lifting water from the soil (Borg and Stoneman, 1991). This effect can persist until the vegetation attains maturity.

In the Thirlmere Lakes catchment, severe wildfire probably occurs more frequently than a single cycle from regrowth to maturity of the affected vegetation. A further complication is the variable impact of fires in a catchment as it would be a rare for a wildfire to devegetate a catchment totally. The Australian flora, particularly in the Sydney Basin, is fire adapted (e.g. Gill, 1981) and indeed many plants require periodic burning, or proximity to fire smoke, in order to propagate or seed successfully.

Study of lake sediment cores from Thirlmere Lakes shows the common occurrence of fire, creating charcoal which washes into the lake sediments. Where the peat on the bed of lakes catches fire (Fig. 3-18) it is oxidised and converted to mineral ash that can be removed in the smoke column or blown or washed away. The exact role of fire in determining the sedimentology of Thirlmere Lakes is poorly known.

Figure 3-18. Lake Gandangarra basin alight following 2006 bushfire. View looking east from northwest of the lake.

The Committee is not aware of any data from the area that would allow it to directly assess the impact of fire on subsequent lake hydrology. Insufficient data exist on the pattern of fire distribution and intensity that would allow modelling to be undertaken, and given the complexity of possible responses outlined in Erskine (2001), it is possible that no simple hydrological response to fire exists for this catchment. However, the Committee believes that the open woodland around the catchment of Thirlmere Lakes has a light enough fuel loading, and burns frequently enough, that any hydrological and sedimentological responses to wildfire are probably minor and overlapping each other so that there has not been a single, large response to wildfire over the past five decades or more. On the basis of available evidence, the present low levels of the lakes cannot be causally related to recent bushfires.

3.2.7 Lake sedimentology

Apart from understanding something of the history of the development of Thirlmere Lakes, understanding the Tertiary stratigraphy of the valley will also assist in understanding the hydrology of the catchment. Unconsolidated sediments with high sand contents are likely to be more permeable than the nearby Hawkesbury Sandstone bedrock. Thus if there is a mass of alluvial fill extending into the valley of Blue Gum Creek it can be expected that this will be a preferred direction of groundwater drainage and hence, lake drainage. If the lakes are accumulating fine grained sediments there may be one or more clay beds in the lakes that retard vertical groundwater flow and promote lateral groundwater flow, in the down-valley direction.

There are community and Traditional Custodian reports of springs in Blue Gum Creek which do not appear to have an immediate source of water. The Independent Committee found return flow (groundwater returning to the surface) along the south-eastern margin of Lake Baraba in April and May 2012. This flow was probably groundwater flow returning to the surface and feeding Lake Baraba rather than interflow as there had been a long period between significant rainfall and observation of the return flow.

The sediments of Thirlmere Valley have been studied and reported by Vorst (1974), Rose (1981), Clark (1997), Dixon (1998), Noakes (1998), Gergis (2000), Black (2006), and Rose and Martin (2007). Rose and Martin's study was in Dry Lake. Tomkins et al.'s (2004) study was of a colluvial slope in Blue Gum Creek, approximately 5 km downstream of Thirlmere Lakes outlet (Fig 3.15), and mostly in valley walls composed of the Narrabeen Group.

Vorst's 1974 study is highly significant because it is the only one to have deep drilling. Black's single core extended to 6 m. He undertook detailed ^{14}C dating of the core (Fig. 3-19). Gergis (2000) took a 262 cm core from the southern part of Lake Couridjah, which he dated using radiocarbon dating, estimating the age at the core's base to be 15 ka BP. All other cores were less than 2 m deep, and while significant in understanding recent sedimentology, are less relevant to understanding the longer term history of Thirlmere Lakes.

Vorst's (1974) cores revealed predominantly sandy clay although there are beds of clay and sandy clay with colours in the "N" range on the Munsell colour chart (Fig. 3-20). Only BH2 revealed sponge spicules at depth, and this was in the peat. None of the other deep bores revealed peat. Other deep cores, by Black (2006) and Gergis (2000) clearly penetrated peat and lacustrine clays.

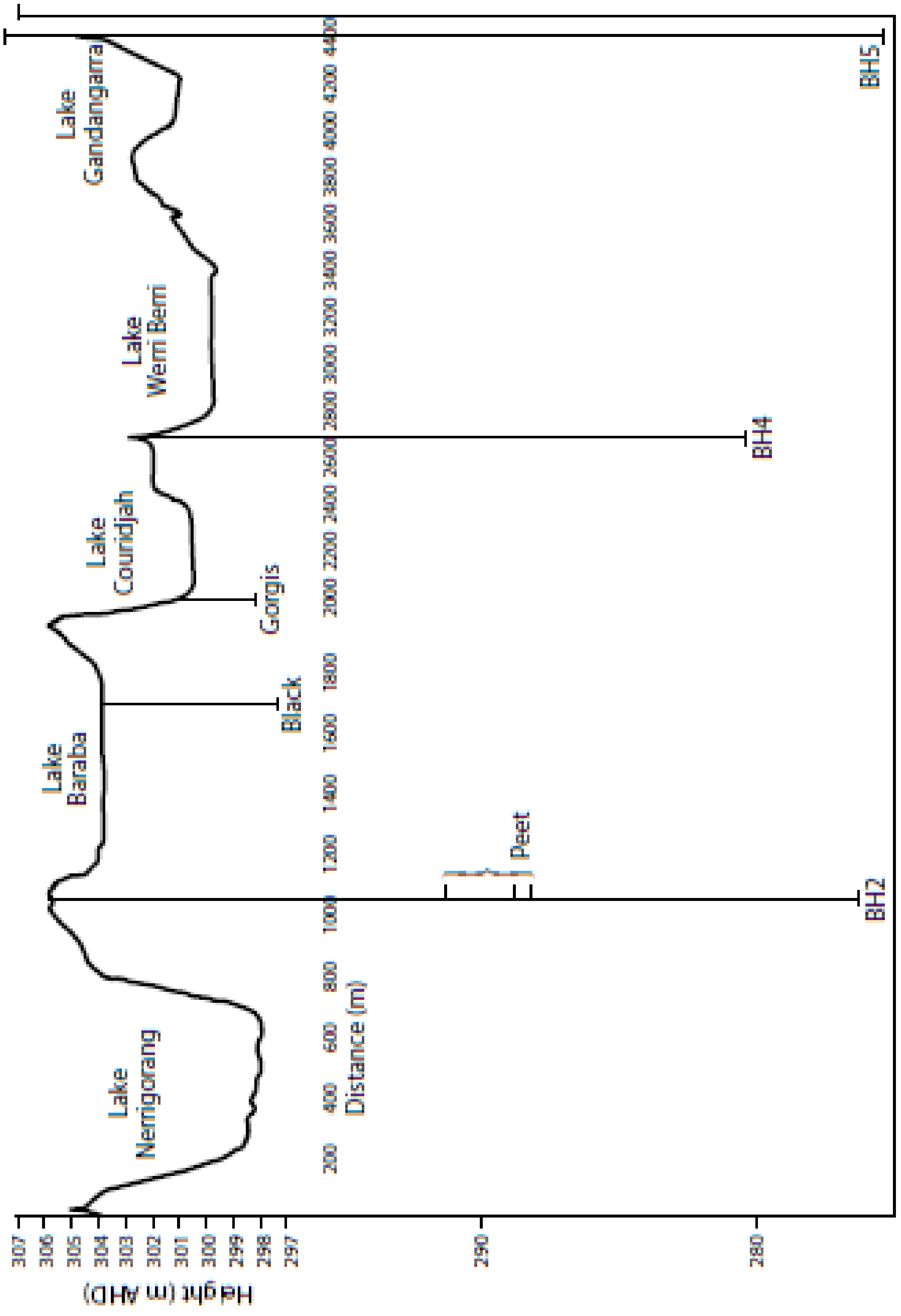


Figure 3-19. Location and depth of cores studying the sedimentology of Thirlmere Lakes.

3.2.8 Issues with the age and origin of Thirlmere Lakes

The truncated river hypothesis has its primary roots in the fact that the valley, with its U-bend planform, looks like one of the incised river valleys of the lower Hawkesbury River. The work of Vorst (1974), Gergis (2000) and Black (2006) has shown considerable age and depth of the valley fill. In summary, Black showed, in a 6 m core, that the lake sediments were more than 43,000 years old. Vorst showed that the valley fill was probably more than 30 m deep, based on one sample recovered at 17.3 m which contained fibrous peat, charcoal and sponge spicules (BH2). All other samples recovered at depth in the other three deep bore holes drilled by Vorst textured mostly as sandy-clays, did not contain spicules, but were interpreted as lacustrine because the cores intersected dark-coloured clays and sandy clays. The work of Rose and Martin (2007) suggests an age for Dry Lake extending back into the Quaternary.

Vorst’s work includes some geophysical refraction studies undertaken in 1974 by Dr Tayton. Dr. Tayton was careful to note the problems presented with refraction studies in narrow valleys and with highly weathered bedrock that resembles the deposited material derived from it. Henry and Riley (1987) faced the same problem with their geophysical and drilling exploration in the Mellong Plateau. While there is no question of the interpretation made at the time, with the tools at hand, geophysical technology has advanced over the last 40 years, including improvements in data processing. Taking account of Tayton’s concerns, there is doubt about the interpretation of a 50 m deep alluvial fill, and the survey needs to be revisited.

Vorst (1974) recognised peat deposits approximately 1.5 km downstream of Lake Nerrigorang, in Blue Gum Creek. However, as she told the Committee, they were not analysed and there is no certainty that they are the same peats she discovered in her drill hole BH2. A review of potential swamp areas along Blue Gum Creek showed that swamp deposits were accumulating today in areas where alluvial fans of tributaries form a barrier to Blue Gum Creek. The swamp at the western edge of Thirlmere Lakes National Park (our location, Fence Piezometer) owes its origin to an alluvial fan impeding flow in Blue Gum Creek.

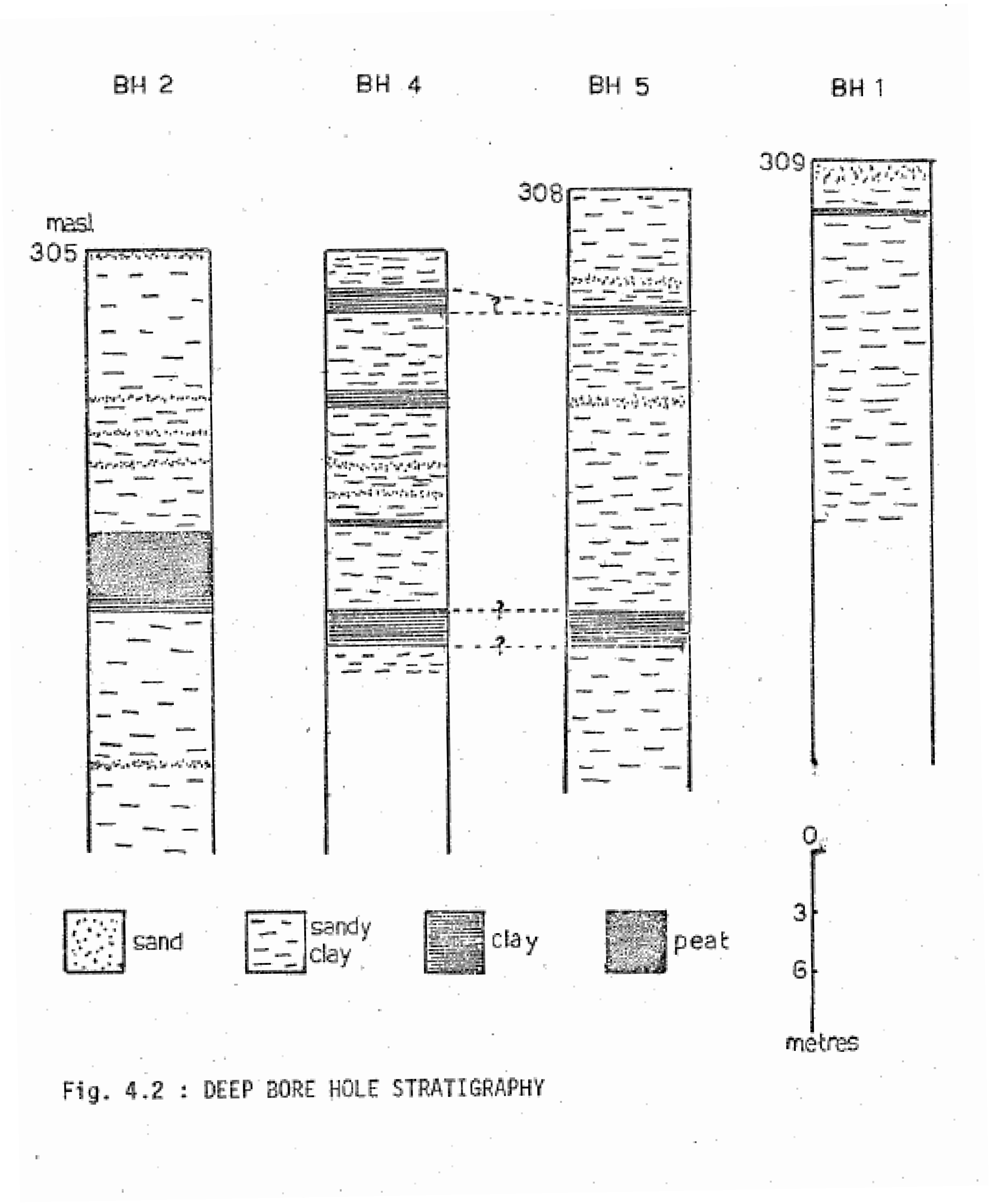


Figure 3-20. Stratigraphic logs from Vorst (1974, Fig. 4.2) (Copied with permission A/Prof Fanning [Vorst]).

If the valley fill is 50 m deep then the basement of the valley would be at approximately 245 to 250 mAHD. This elevation is intersected by Blue Gum Creek approximately 5 to 6 km downstream from Nerrigorang outlet (Nattai Map ref.

680126). If Blue Gum Creek is not the former valley of Thirlmere Lakes, allowing for modifications during 15 million years of erosion and deposition, then the palaeochannel that formed Thirlmere Lakes valley has a dead-end, which is impossible. The Committee could not find any alluvial sediment high up on the valley walls of Blue Gum Creek, although if they existed they probably would have been removed by erosion.

Alluvial fans appear to block the lakes and provide cols between lakes Baraba and Nerrigorang, Nerrigorang and Blue Gum Creek, Werri Berri and Couridjah, Baraba and Couridjah, and possibly Gandangarra and Werri Berri. The existence of these blocking fans suggests that sediment delivery from the fans exceeds the capacity of the stream running through the lakes to erode and transport the sediment.

The consolidated nature of the sediment in the col between lakes Baraba and Nerrigorang suggests fans sediments re-cementing and re-forming sandstone. On the other hand, the consolidated sediments may be highly weathered *in situ* sandstone. There appears to be discordance in the size of the tributary stream presently contributing to the blockage between lakes Baraba and Nerrigorang and the extent of the blockage, which is a fan. Possible down-valley spilling of the fan between lakes Baraba and Couridjah may account for some of the sediment in the area between lakes Baraba and Nerrigorang as it may have been washed down-valley.

There are modern analogies of deep “holes” in the bedrock floor of streams in the Sydney region, most notably those in the Nepean River, which can be 30 to 40 m deep (Gutteridge Haskins and Davey, 1980; Warner, 1983). It is possible that there are intermittent deep sections along the Thirlmere Lakes valley, interspersed with shallow sections, all of which are now filled with sediment. However, for the deep holes to exist by mechanisms seen in the present day Nepean River it has to be assumed that Thirlmere valley is a paleochannel of a substantial river.

Lake Baraba appears to be a perched lake in the system of 5 lakes. It is topographically higher than the other lakes, and has a small surface water capacity compared with the other lakes. A sequence of aerial photographs from 1955 to 2005 shows only a small body of water in Baraba and an extensive reed bed, even during times when the other lakes have obviously high (full?) water levels. Lake Baraba has considerable depth of peat, as shown by Black (2006). It is possible that it could have a greater accumulation of organic or inorganic sediment than the other lakes, and is literally “rising” above the other lakes by sedimentation.

These are some of the issues that are presented by Thirlmere Lakes:

a. If the valley sediments are 30-40 m or even 50 m deep, why are they not obvious along Blue Gum Creek?

b. If the sediments are 30-40 m deep what has prevented them being stripped from the valley and transported downstream?

c. If the sediments are not deep, what has caused the then obvious over-deepening of the lakes (lacustrine sediment depths to 17 m in one case, and more than 6 m in another)?

d. What is the nature of the ridge between lakes Baraba and Nerrigorang, which appears to be weathered bedrock in shallow auger holes and sustains a vegetation community that is not indicative of a lake or swampy environment?

e. Why does Lake Baraba not hold much water, even when the other lakes are full and water is flowing in Blue Gum Creek?

f. Where is the rest of the Tertiary incised valley that is represented by Thirlmere Lakes?

Dr. Mooney of the University of NSW commented that a study of the alluvial sequence in Thirlmere Lakes could be as important as the Lake George cores. This Committee agrees with this view, not only from the point of view of understanding the geomorphic history of the area, but also the insights it would give into the hydrology of the lakes. There is not enough known about the stratigraphy of the lakes to inform the Committee of their significance in the groundwater hydrology of the area. Intuitively, the accumulation of fines in the bed of the lakes should, over time, provide a plastic aquitard reducing vertical percolation. While A/Prof Fanning and Dr Mooney commented on finding clay at depth in their cores, and it is clearly shown in the deep cores of Vorst (1974), neither scientist could attest as to whether or not it was extensive and continuous along the whole length of the Thirlmere Lakes valley.

It is possible that the Thirlmere Lakes valley is a litho-stratigraphic and structurally controlled headwater valley of Blue Gum Creek, rather than a palaeo-channel. The Hawkesbury Sandstone may be dictating valley geometry. There are numerous examples in Australia and overseas of the headwaters of catchments where valley geometry is controlled by resistant bedrock with associated structures. The Kombolgie Sandstone and the valley geometry in the Arnhem Land Plateau is one example, and the structurally controlled valleys just east of the Newnes Plateau in Wollemi National Park are a further, local example. Either hypothesis would allow for either deep or shallow sediments in Thirlmere Lakes of varying texture, with interbedded lucastrine, alluvial and colluvial deposits.

3.3 CONCLUSIONS

1. Lake morphology is dominated by the Hawkesbury Sandstone and the structural elements within it (Section 3.2.1).
2. There are significant structural elements in the bedrock (joints, faults, dykes etc.) which have an important impact on the morphology, weathering and erosion within the Thirlmere valley and undoubtedly on groundwater movement into and out of the lakes (Section 3.1.2).
3. The origin of the lakes is open to debate and needs additional research (section 3.2.7).
4. Both the geology in which the Thirlmere Lakes are located and the stratigraphy of the lake sediments is heterogeneous, complicating any assessment of the movement of groundwater into and out of the lakes (Sections 3.2 and 3.3).
5. The Bald Hill Claystone is more than 100 m below the lakes on their eastern margin and probably at least 60 to 70 m below the bed of Lake Nerrigorang on the western margin of the lake system (Section 3.1.4).

6. There is considerable sedimentary fill within the Thirlmere valley but its depth is uncertain and needs confirmation (Section 3.2.6).

7. Blue Gum Creek appears to have the power to erode back into its headwaters, suggesting that the lake sediments are protected by a resistant bedrock, or the Creek is in the process of eroding into its headwaters, or lake sediments are a dynamic deposit, with periods of aggradation and excavation (Section 3.2.3).

8. There is a divergence in the measurement of catchment areas of individual lakes and key lake levels by Pells Consulting and Xstrata consultants Gilbert and Associates, which the Independent Committee has redressed by its own field work (Section 3.2).

9. There is significant geomorphic evidence of fluctuations in lake levels in the recent past and within the geologic time frame (Section 3.2.2).

10. Recent seismic activity is unlikely to have changed the groundwater or surface water hydrology of the lakes (Section 3.1.5).

11. While bushfires can have a significant effect on runoff and evapotranspiration their impact on the hydrology of Thirlmere Lakes is uncertain, but probably minor (Section 3.2.5).

12. Thirlmere Lakes is a “perched” lake system, occupying a topographic high. It is higher than Tahmoor (Section 3.1).

4.0 HYDROLOGY OF THIRLMERE LAKES

4.1 CATCHMENT AREA

There are two catchment areas for Thirlmere Lakes. The first is the surface catchment area, i.e. where all potential overland flow in the area (from the interfluve or catchment boundary) flows into one or more of the lakes. The second is the groundwater catchment, which is the potential source of water from surrounding rocks, i.e. groundwater sources. The two catchments are similar for Thirlmere Lakes.

4.1.1 Surface catchment area

The surface catchment is not static in time. In the geomorphic time frame, erosion and deposition may alter the position of the interfluve. For abutting catchments headwater erosion always leads to one catchment enlarging at the expense of another. Tectonic forces modify catchments, as illustrated by the argument for the formation of Thirlmere Lakes. However, recent tectonic activity is not considered significant in altering present catchment geometry. Recent human activity has impacted slightly on catchment area.

Roadways and walkways, construction, vehicle traffic, ploughing and compaction of catchment soils by hooved animals, farm dams, and culverts and drainage channels may have slightly changed both surface catchment geometry and the infiltration capacity of soils. Increased fire activity in the catchment associated with the last 200 years of settlement may have created conditions for enhanced erosion, changed transpiration losses, and reduced infiltrability of soils.

In previous studies of Thirlmere Lakes the surface catchment area has been defined from the 1:25,000 Picton topographic map, with aerial photograph interpretation to enhance the placement of the catchment boundary. At a scale of 1:25,000, a 0.5 mm thick line has a ground width of 12 m. For a catchment boundary of 5 km this represents an area on the ground of 6 ha. The standard for the location of 10 m contour intervals in the 1:25,000 maps is within 5 m for 90% of the time, and less for dense vegetation (1:25,000 Picton legend) and the horizontal position is within 12.5 m for 90% of the time. Examination of the Thirlmere Lakes catchment interfluve suggests that even on the ground it is not easy to identify the catchment boundary. The general problem of catchment geometry uncertainty and its impact on analysis of catchment hydrology has been noted by others (Walker and Willgoose, 1999; Liu et al., 2005).

4.1.2 Groundwater catchment area

The errors and uncertainty associated with identifying the surface catchment are an order of magnitude greater when attempting to identify the groundwater catchment. There is a strong reliance on inference and interpretation in drawing groundwater catchment boundaries.

Like surface water catchments, the groundwater catchment can change in both the short term and long term. Erosion can result in groundwater pathways to a catchment being truncated or enhanced, as can tectonic activity. These are long-term changes. Short-term changes, putting aside those associated with climatic variations (droughts and heavy rains), are usually a result of human interference, most notably groundwater pumping. Changes in groundwater gradients as a result of pumping can be significant. The effects of pumping radiate outwards from the bore or mine pit, and may take some time to be seen at a distance from the bore, depending on the permeability of the rocks, hydraulic gradient around the bore and recharge processes. Regional geology and groundwater gradients affect the pattern of the radiating change in groundwater pressure gradient.

The Hawkesbury Sandstone is not geologically uniform either vertically or spatially, so variations in the hydraulic conductivity of the rock are considerable and the

Hawkesbury Sandstone cannot be treated as a uniform aquifer. There is an east to east-northeast dip in the sandstone and the highest points in the catchment surface are to the west. However, in the west are a number of deep valleys which intercept the eastward flow of water into the valley containing Thirlmere Lakes.

Further details of the groundwater regime are given in Chapter 6.

All areas of the landscape surrounding Thirlmere Lakes at 300 mAHD or above were identified (Fig. 4-1). This level (300 mAHD) is approximately the same as that of Thirlmere Lakes. To the east the land surface is lower than the lakes. Surrounded by deep valleys and lower topography, Thirlmere Lakes is “perched” in the topography. It is assumed that in an open aquifer groundwater would preferentially drain towards the lower levels. In the west this means that groundwater flows into the valleys. Towards the east the groundwater interfluve will be affected by the eastwards dip of the sandstone beds, so it will be further to the west than a simple bifurcation based on elevation suggests. The water movement to the east is further complicated by the Thirlmere Monocline, whose throw will add an additional gradient towards the east.

Figure 4-1 presents an estimate of the likely groundwater catchment for Thirlmere Lakes based on analyses of topography and geology. The western groundwater catchment boundary is probably 200-500 m to the west of the surface catchment. The eastern groundwater catchment boundary probably coincides with the surface catchment boundary, or may even be slightly to the west of the surface catchment boundary because of the eastward dip of the sandstone. At the most, the groundwater catchment potentially discharging into the lakes is probably of the order of 600 ha, compared with the surface water catchment area of ~450 ha.

Groundwater flow is slow relative to surface flow. It commonly makes up the majority of baseflow in a stream. Direct groundwater flow into the lakes will replenish some water lost from the lakes by evaporation, transpiration, drainage into Blue Gum Creek and any deep drainage into groundwater systems below the lakes.

If the unconfined piezometric surface is below lake level (lowest level in lakes ~298 mAHD) then a significant proportion of groundwater movement in the catchment will by-pass the lakes, and the lakes themselves will drain into an aquifer that is below 298 mAHD.

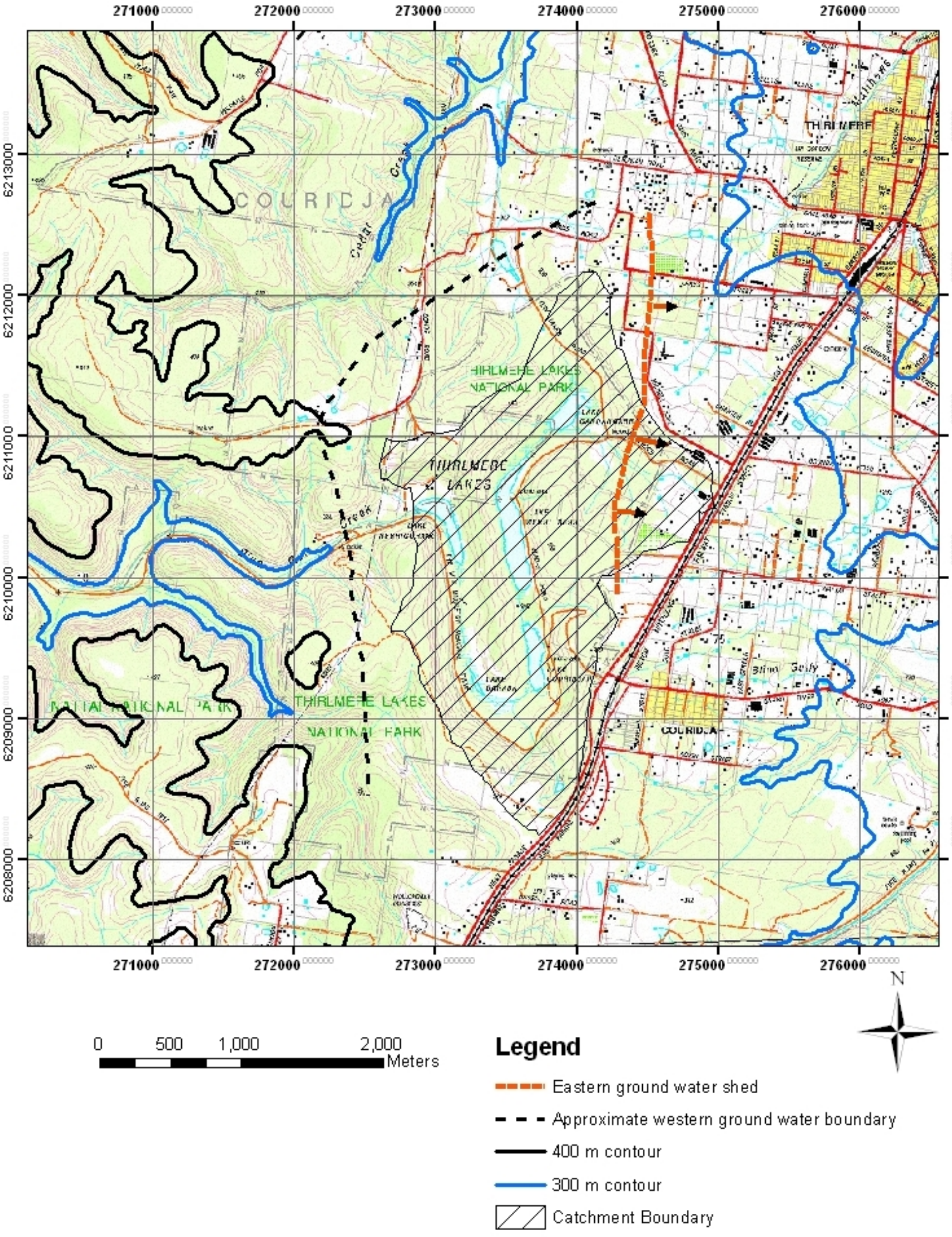


Figure 4-1. Surface and Groundwater catchments for Thirlmere Lakes. Scale is given by the MGA easting and northing grid lines which are spaced at 1 km. (Modified from the Picton 1:25,000 topographic sheet; reproduced with permission ©NSW Dept of Finance and Services, Land and Property Information).

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4.1.3 Observations of hydrology during the storms of February and March 2012

During February and March 2012 there were several storms in the Thirlmere Lakes region. The Committee was able to observe the runoff from slopes and groundwater flow returning to the surface. Prior to these storms the catchment was relatively dry. Inspection of slopes prior to the storms showed no stream flow and all of the rock faces and caves were dry. Details of rainfall during the period of the Committee's field work are given in Section 4.2.

The following observations were made:

1. Overland and stream flow from the slopes was highly dependent on rainfall but where there was groundwater flow returning to the surface, small streams developed. The larger groundwater-fed streams were seen crossing the roads or flowing along the gutters of the roads.

2. The caves, bedding planes and joints of exposed bedrock were very wet soon after the storms, and remained wet for as long as the Committee examined them (several weeks after the storms). The rapidity with which these sandstone structures became wet suggests that there is relatively rapid groundwater movement, at least near the surface, with velocities of the order of metres per day. It is acknowledged that groundwater flow estimates near exposed cliff faces are difficult to extrapolate to the whole of the rock mass. However, observations suggest that hydraulic conductivities in fractured rocks near the surface may be in the higher part of the range of saturated hydraulic conductivities recorded for Hawkesbury Sandstone.

3. Flow was observed crossing the col between lakes Baraba and Couridjah, apparently flowing from Lake Baraba into Lake Couridjah. A number of groundwater-fed streams flowed across the W.E. Middleton Memorial Drive, between Lake Couridjah and the northern end of Lake Baraba. It was initially thought that all of the water crossing the Drive entered Lake Baraba and then flowed into Lake Couridjah. It is now thought that the surface flow from the south and southwest of Lake Baraba is discharging into both lakes, with the groundwater/interflow discharging into Lake Baraba and overland flow discharging into Lake Curidjah. This will be discussed in more detail in a subsequent section of the following chapter.

4. The surface catchment bounded by Slades Rd, Michell Rd and Dry Lakes Rd was saturated. For some days after the storms the hill slopes discharged water into small streams flowing down and across Slades Rd into Lake Gandangarra.
5. Surface water flow also persisted for days from the slopes draining to the north and northwest into Blue Gum Creek downstream of Lake Nerrigorang, filling the creek bed in the area near the most downstream piezometer (Fence Piezometer).

Based on observation the time of concentration for the catchment and sub-catchments of Thirlmere Lakes is less than 1 hour.

4.2 RAINFALL ANALYSIS

Five Bureau of Meteorology stations have been used in several studies to estimate rainfall at Thirlmere Lakes. There are also a number of rainfall and weather stations that are managed, funded and maintained by locals (Table 4-1). Three of the stations are automatic stations recording rainfall, temperature, dew point, radiation, wind speed and direction, and making these data available in real time on the web (Fig. 4-2). Unfortunately these private automatic stations have been operating for less than 6 years. The rainfall stations are variable in size of gauge and location. One manually read raingauge, Maidla, is considered important to this study, as it has been read daily for over 30 years, and is a 100 mm diameter “Nylex” gauge. It has some missing data, but these are not easily identified. None of the private stations meet World Meteorological Organisation or Bureau of Meteorology standards for installation and position but they represent a consistent set of data and are the closest to the lakes.

These local privately-run weather stations and raingauges are important because they can be used to supplement and correct the more distant Bureau of Meteorology stations. Local residents are to be applauded for the effort they have put into developing and maintaining these local meteorology monitoring sites.

Figure 4-2. Elements of the Thirlmere Lakes Automatic Weather Station. From top left, clockwise, anemometer, tipping bucket raingauge, and temperature and pressure probe housing.

The proximity of recording stations close to the lakes is important because a number of local residents have told the Committee that the rainfall at Thirlmere Lakes is not the same as at Tahmoor, Buxton or Picton, and storm cells can often be seen tracking around the lakes and missing them.

Manual raingauges maintained by the Bureau of Meteorology (BoM) are read at 0900 h each day, at the local time. Automatic raingauges operated by the BOM also report daily rainfall 0900 h - 0900 h. This means the rainfall recorded for the day is for the preceding 24 hours, of which 15 hours occurs in the preceding day. All readings are in local time. In areas with daylight saving, one day of the year records 23 hours of data and another 25 hours. The private automatic weather stations run on a 0000 h-2400 h period, so daily rainfall readings are not the same as the BoM rainfall readings for any one day. The Maidla raingauge is read at 0900 h every day, consistent with BoM standard reading time, so the daily data are directly comparable to the BoM data, except that the Maidla data are recorded for the day before the reading, whereas BoM data are recorded for the day of reading. The Maidla data were corrected to bring the two data sets into alignment in terms of day of recording.

Not all of the available private rainfall stations are recorded in this report but would be of some value in a more detailed analysis of rainfall in the Thirlmere Lakes area. Historical private records are problematic because it is difficult to identify the site conditions and nature of the instruments.

4.2.1 Regional correlations

Studies of the hydrology of the Thirlmere Lakes which have attempted daily hydrological modelling have had to come to terms with a substantial amount of missing data. Picton is missing 8% of daily rainfall data, Buxton 10%. Douglas Park is missing only 1%, but is much further from the lakes. The usual process to replace the missing data is to use some regional-based method of estimation, whether least squares, kriging interpolation, thiessen polygons, contouring or others. While the techniques to estimate missing rainfall data are well established, they introduce a bias towards regional averaging. Our search for data that were recorded at or near Thirlmere Lakes was not only to ensure continuity of a record of rainfall for Thirlmere Lakes, but also reduce potential bias arising for the use of stations some distance from the Lakes.

Table 4-1. Summary of rainfall and weather stations.

Rainfall Station[3]	Location	Period of record	Missing records (% days)
Picton Council Depot BoM 068052	Lat: 34.17 S Long: 150.61 E Elev: 165 m Easting: 279705 m Northing: 6216416 m	1/1/1880 to present	8
Buxton (Amaroo) BoM 068166	Lat: 34.24 S Long: 150.52 E Elev: 420 m Easting: 271597 m Northing: 6208450 m	1/12/1962 to present	10
Oakdale (Cooyong Park) BoM 068125	Lat: 34.09 S Long: 150.51 E Elev: 440 m Easting: 270269 m Northing: 6225065 m	1/2/1963 to present	34
Douglas Park (St Mary's Tower) BoM 068200	Lat: 34.21 S Long: 150.71 E Elev: 165 m Easting: 289024 m Northing: 6212188 m	1/2/1974 to present	1
Cawdor (Woodburn) BoM 068122	Lat: 34.10 S Long: 150.64 E Elev: 132 m Easting: 282291 m Northing: 6224241 m	1/12/1962 to present	14
Maidla	Easting: 274251 m Northing: 6212066 m Elev: 338 m	1/1/1989 to present	<0.5?
Thirlmere	Lat: 34.207 S Long: 150.588 E Elev: 990 ft (301 m)	April 2008 to present	?

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[3] Bureau of Meteorology rainfall data obtained from http://www.bom.gov.au/climate/data/index.shtml

	Easting: 277774 m Northing: 6212261 m Hardware: WS-3600 Weather Station Software: WUHU216HW http://www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=INSWTHIR2&month=4&day=10&year=2012		
Thirlmere Lakes	Lat: 34.229 S Long: 150.568 E Elev: 900 ft (274 m) Easting: 275989 m Northing: 6209777 m Hardware: WS-3600 http://www.jeffsplaceonline.com/	Feb 2006 to present	?
Morse Weather, Nangarin, Picton	Lat: 34.164 S Long: 150.570 °E Elev: 850 ft (259 m) Easting: 276001 m Northing: 6216991 m Hardware: Weather Display Weather Station Software: WeatherDisplay:10.37 http://www.morseweather.com/	August 2008 to present	?

All UTM coordinates are MGA, converted from latitude and longitude using Redfearns formulae.

Considerable use has been made of Picton data in rainfall analyses for Thirlmere Lakes. However, the Picton station is at an elevation of 165 mAHD, whereas Thirlmere catchment ranges in elevation between 298 mAHD and 390 mAHD. Orographic effects may be significant, and discussions with the community confirmed this. Many recounted instances of storm cells missing Thirlmere Lakes, of specific rain-bearing winds, and recognisable differences in rainfall amounts for individual storms and days. For this reason the focus for more recent rainfall data is on Buxton, and local private weather records, while Picton and other stations are used for long-term records.

Examination of the correlation of annual rainfall between Picton and Buxton, Picton and Oakdale, and Buxton and Douglas Park, for complete data sets, shows coefficients of determination (R^2) of 0.91, 0.76, and 0.83 respectively (Fig. 4-3). Some idea of the variability between the stations is gained when the daily rainfall for Picton is compared with that for Buxton. The three graphs show the total data set and then, with the same trend line, the relation for rainfalls 50 mm or less and 10 mm or less. The coefficient of determination for the total data set is 0.64. For 10 mm or less there is no relation (Fig. 4-4).

A good example of the spatial difference in rainfall was the storm of 10th February 2012. This storm resulted in severe localised flooding in Picton and was well publicised in the local and state media. Picton raingauge recorded 36.2 mm for 10th February 2012 and 89.9 mm for the three day period 11-13th February 2012..Buxton recorded 44 mm and 12.8 mm, and Maidla 36 mm and 9 mm respectively for 10th and 11th February 2012. Automatic Weather Station (AWS) Thirlmere Lakes recorded 14 mm (there is some uncertainty about this value) and 12.4 mm while AWS Thirlmere recorded 51.1 and 17.5 mm for 10th and 11th February 2012.

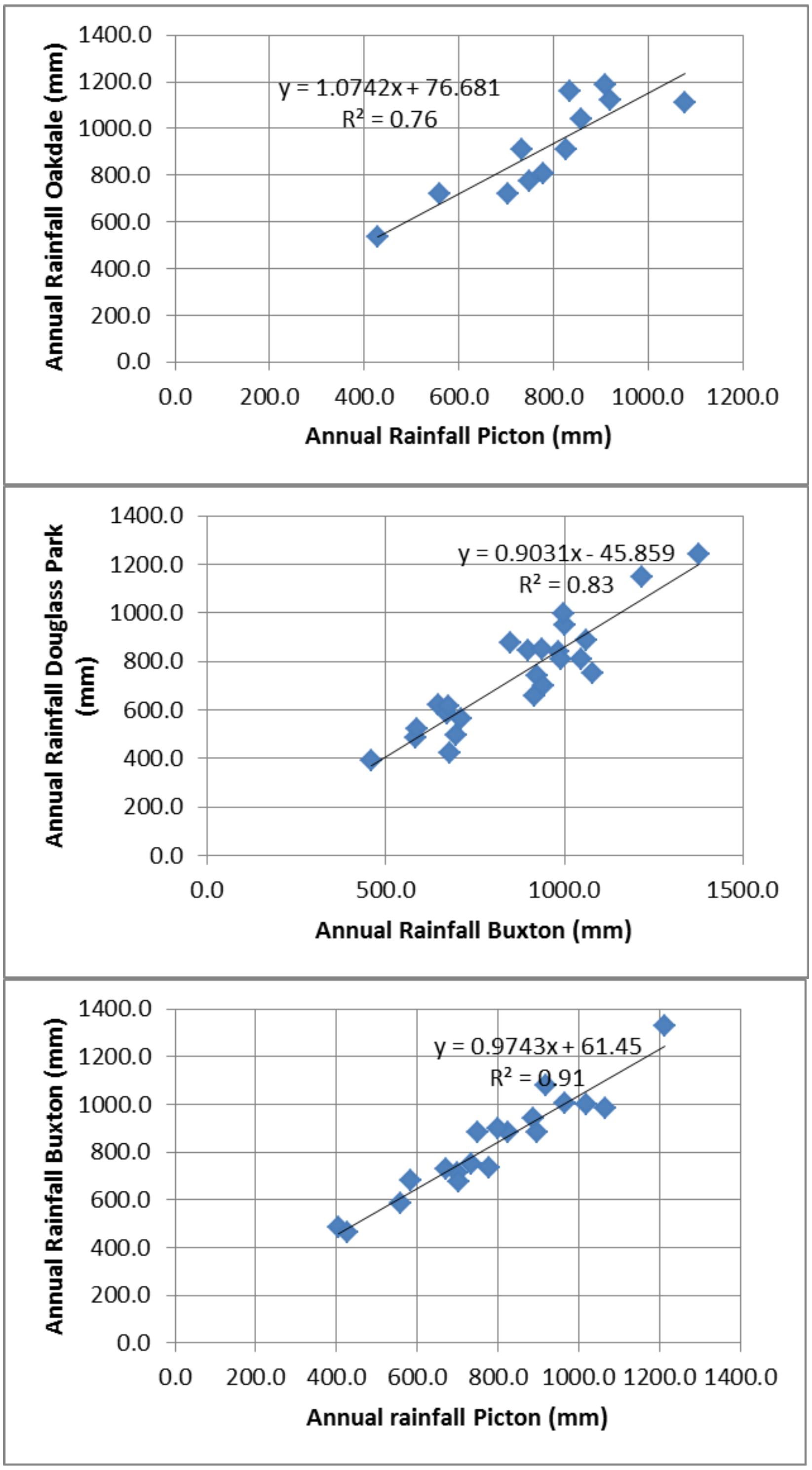


Figure 4-3. Comparison of annual rainfalls for common periods for Picton (from 1880), Buxton (from 1967), Oakdale (from 1963) and Douglas Park (from 1974).

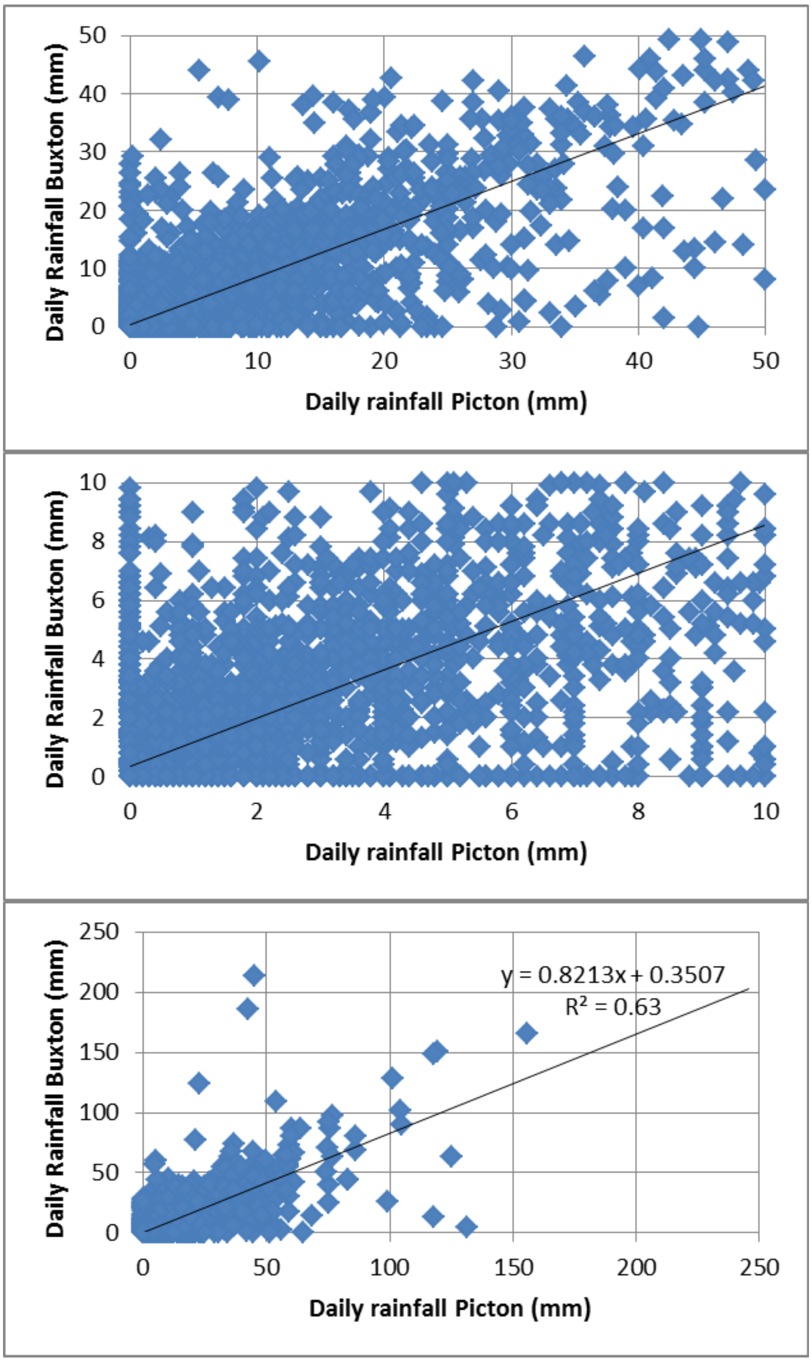


Figure 4-4. Relation between Picton and Buxton for all daily rainfall, and for ≤50mm and ≤10mm rainfalls for common period to February 2012.

A comparison of Maidla, the private raingauge, with the Buxton and Picton BoM raingauges, for daily rainfall (Fig. 4-5) shows that the correlations between the stations are no weaker than between the Buxton and Picton raingauges (Fig. 4-4). The slope of the regression line between Buxton and Maidla and the slightly higher coefficient of determination than between Picton and Maidla suggests that Maidla and Buxton may be a better pair of stations to compare. Maidla rainfall data are presented in Appendix 4-1.

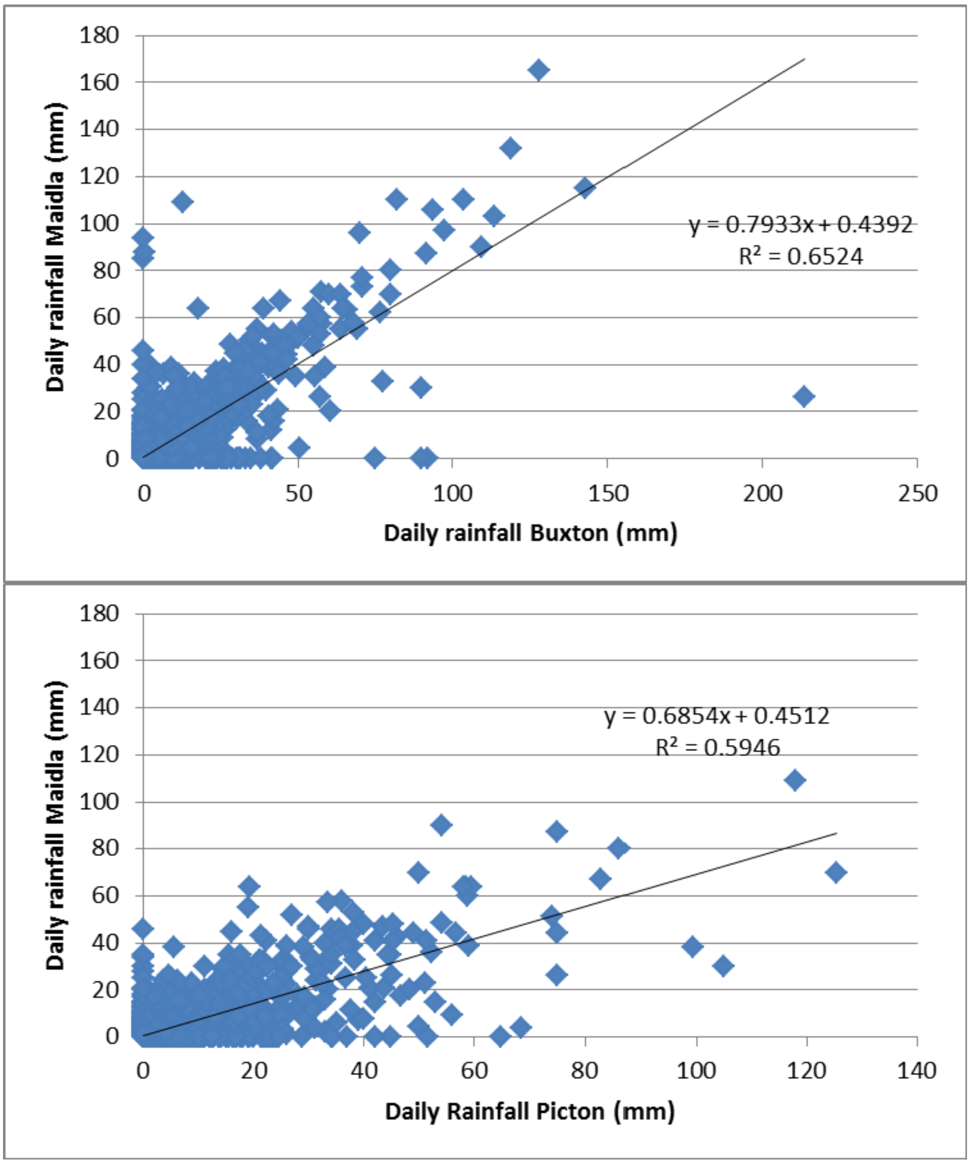


Figure 4-5. Daily rainfall comparisons for Maidla and respectively Buxton and Picton for common period to February 2012.

Thirlmere Lakes is a small catchment (<4.5 km^2). It is not uncommon for storms in the Sydney region to have cells with intense rainfall producing rainfalls for small areas within the major storm (Riley et al., 1985; Mathews and Geerts, 1995). The importance of the position of storm cells for local rainfall accords with observations reported in conversations with residents of the Thirlmere Lakes region and the pattern of storms seen in Bureau of Meteorology radar imagery for the period November 2011 to March 2012.

4.2.2 Rainfall during Committee's deliberations

During the period of the Committee's initial field work there was significant rainfall on the following occasions: 22nd -25th Nov 2011, 2nd -3rd Feb 2012, 9th -10th Feb 2012, 19th -20th Feb 2012 and 29th Feb 2012 (Fig. 4-6). The total rainfall for the period of 1st Nov 2011 to 29th Feb 2012 was 604.7 mm for Maidla and 563.8 mm for Buxton. For Picton the total rainfall for the period was 567.2 mm.

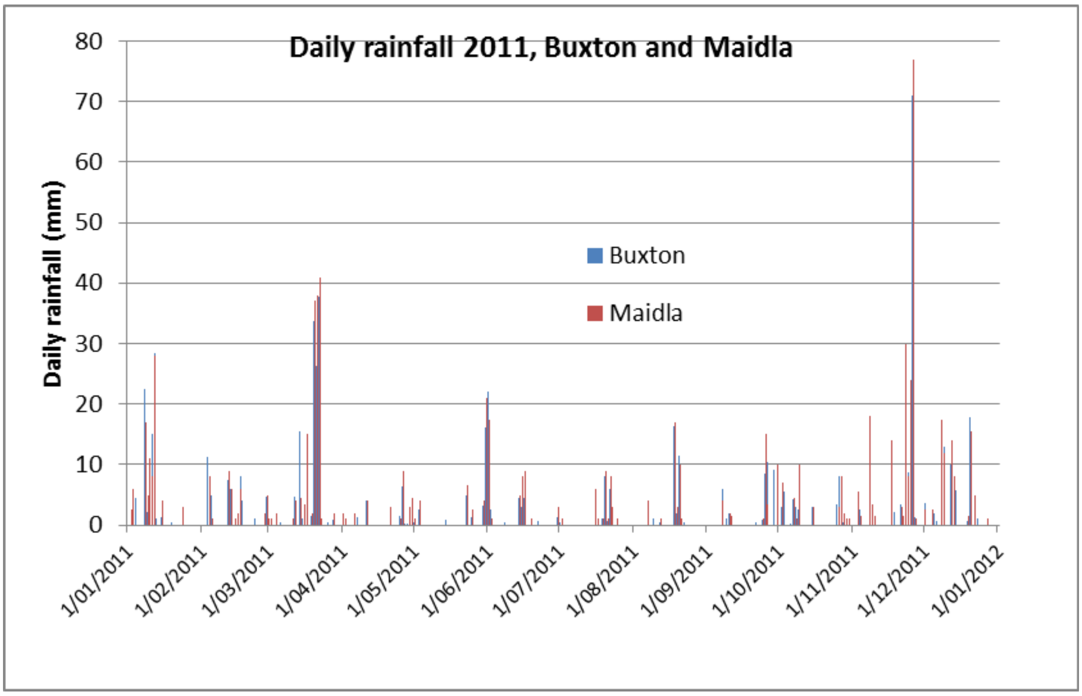
Approximately 75% of the annual rainfall was received in four months of the initial field investigations. A number of residents within the Thirlmere Lakes catchment commented that they had not seen, for many years, their properties as wet as they were at the time of our visits. Farm dams were full, soils were saturated to the point of bogging tractors, and return flow feeding small streams was evident in many places.

During the period March to August 2012 (inclusive) the total rainfall at Picton was 416.2 mm, with 173 mm in March 2012 and 124 mm in April 2012. For the period January to August 2012 inclusive the total rainfall at Picton was 758.6 mm, nearly the average annual rainfall. In November 2011 the total rainfall was 168.4 mm and 56.4 mm in December. In 2011 Picton received a total of 777.7 mm, slightly less than the annual average. Details of rainfall at the stations are given in Table 4.2.

Prior to the Committee's first field trip to Thirlmere Lakes on 23rd November 2011 the total rainfall for 2011 to that period was very low. On the 26th November there was more than 70 mm of rainfall, but 2011 still had below average rainfall as recorded at Picton, Buxton and Maidla (Table 4.2, Fig. 4-6).

Table 4-2. Rainfall data for Picton, Buxton and Maidla.

Rainfall Period	**Picton BOM** (mm)	**Buxton BOM** (mm)	**Maidla** (mm)
Total for 2011	777.7	735.6	802
Total for Period Nov 2011 to February 2012	567.2	563.8	604.7
Total for Period March to August 2012	416.2	410.6	408.5
Total January to August 2012	758.9	735.2	745.2
November 2011	168.4	163.8	191
December 2011	56.4	75.4	77
March 2012	173	147.4	137.5
April 2012	124	149.6	137.5



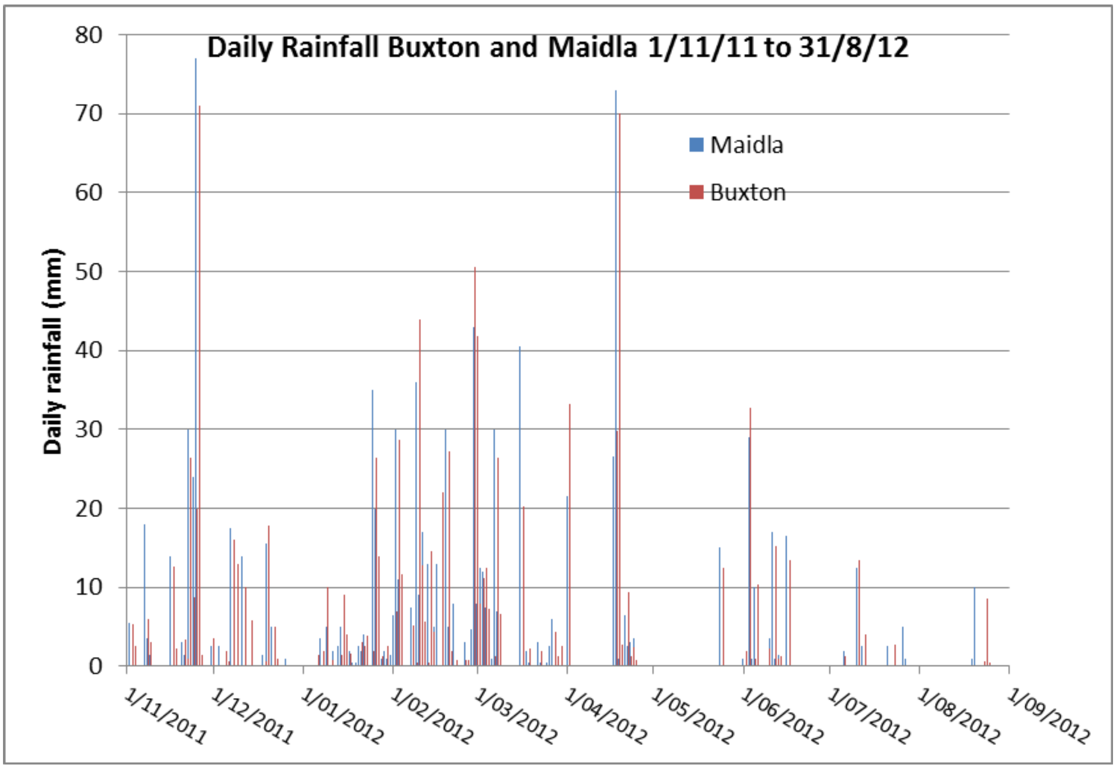


Figure 4-6. Daily rainfall for the periods 1 Jan 2011 to 31 Dec 2011 and 1 Nov 2011 to 31 Aug 2012, Maidla and Buxton.

4.2.3 Temporal patterns of rainfall

For the period January 1989 to February 2012 (22 years of data) Buxton and Maidla show similar patterns of the cumulative deviation from the mean daily rainfall (Fig. 4-7).

The cumulative deviation from the mean is a technique which allows periods of below or above-average rainfall to be identified. For this study the mean is the daily average rainfall (in mm) for each site. When the slope of the graph is negative (values declining) then rainfall is below average for the period. A long period of below average rainfall is identified as a drought. When the slope is positive rainfall is above average, a wet period. When the slope is near horizontal the rainfall is oscillating around the mean or average rainfall.

Both stations show similar peaks in time and magnitude (1992, approximately an accumulation of 1000 mm over the preceding 4 years) and both show the same minimum in time and magnitude (2007, approximately a minimum cumulative deviation of -400 mm, or a deficit from the mean of 1400 mm over the 15 year period). These patterns are typical of rainfall variation over time seen elsewhere in the Hawkesbury-Nepean Catchment. The graphs show that there was a period of above average rainfall from 1989 to 1992, there was a decline from 1992 to 2007, which steepened in 2002, and since 2007 there has been an oscillation around the average rainfall. The steepening in 2002 could be described by the expression “the drought intensified”.

The period 2008 to 2011 shows a small decline, with a recovery since 2011. Hence, while the period from 2007 to 2009 was above average (the “breaking of the drought”) there was a dry period in the following 2 years, followed by above average rainfall.

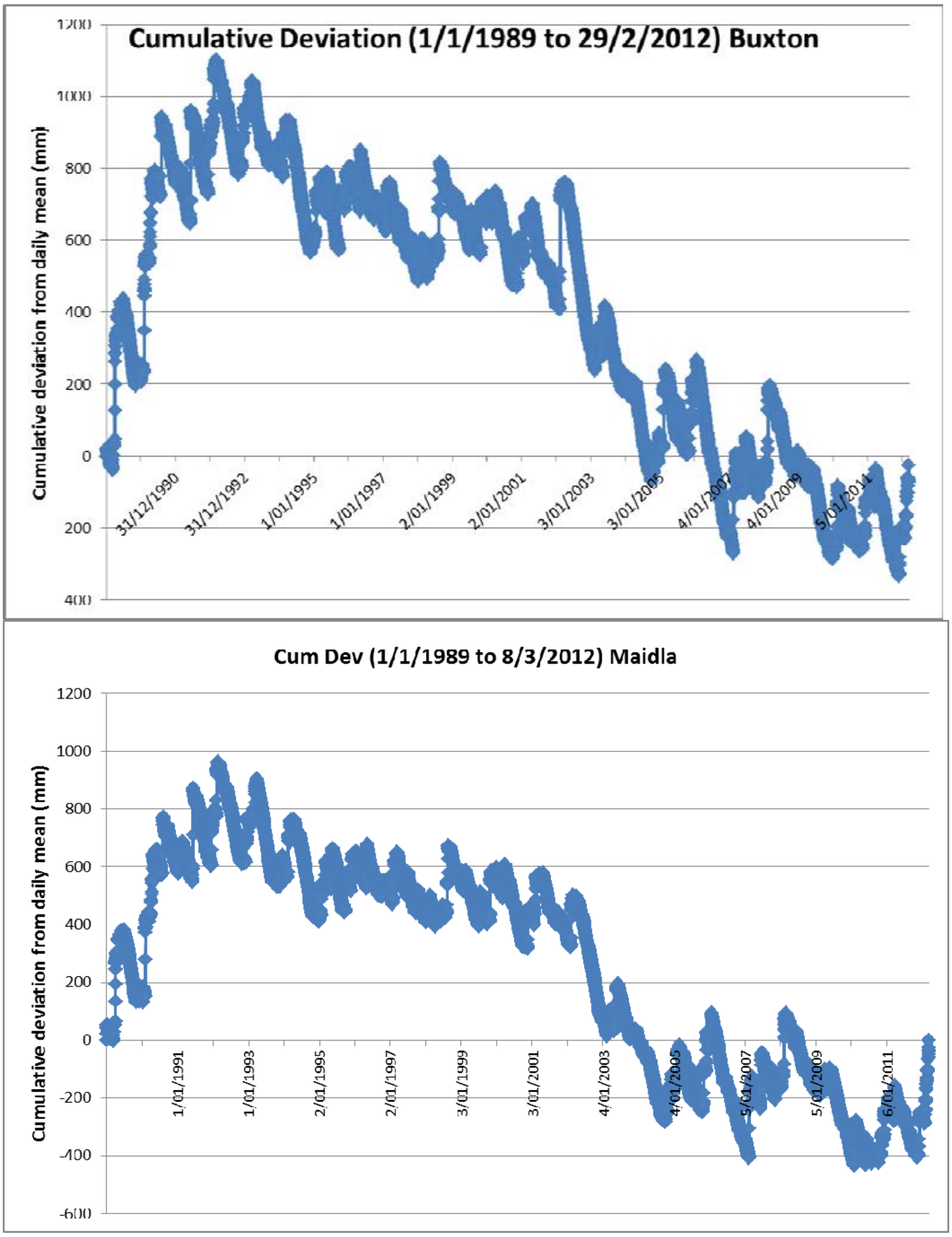


Figure 4-7. Temporal variations in rainfall for the period 1989 to 2012, Buxton and Maidla.

The Maidla site is within the Thirlmere Lakes catchment, so it is directly relevant to the hydrology of the catchment. It also reflects a pattern seen at Buxton and a regional trend in rainfall identified throughout the Hawkesbury-Nepean catchment.

This period of drought (1992 to 2007/2009) is part of a recurring pattern of drought- and flood-dominated regimes in Eastern Australia.

4.3 FLOOD- AND DROUGHT-DOMINATED REGIMES

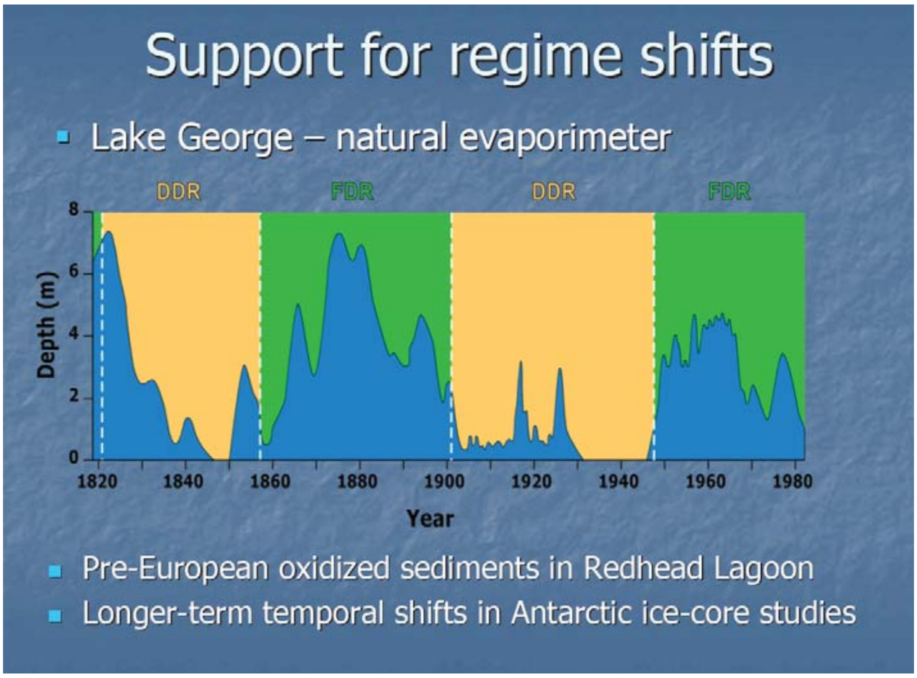
It has been known for more than 30 years that there are extended periods of low rainfall and high rainfall, accompanied by low and high flood frequency regimes. These periods were named drought- and flood-dominated regimes by Warner (1987, 2007, 2009), Sammut and Erskine (1995), and Erskine and Warner (1998). They are well recognised for Eastern Australia.

Warner (2007, 2009) presents a schematic representation of the regimes for Lake George (Fig. 4-8) which he states are also seen in the sedimentology of Redhead Lagoon and Antarctic ice cores. The drought-dominated regimes extended from 1820-1860 and 1900 to 1946-8, with small periods of higher rainfall within these multi-decadal drought regimes.

Shrestha et al. (2009) in their analysis of more than 20 rainfall stations in the Hawkesbury-Nepean Catchment show the consistent nature of the regimes but also that there are differences in magnitude of the trends throughout the catchment (Fig. 4-9).

Erskine and Townley-Jones (2009) who analysed the annual rainfall of 16 rainfall stations on the Central Coast of NSW showed "multidecadal periods of alternating high and low rainfall" that is, flood- and drought-dominated regimes. They showed:

- 1863 and 1900 – high rainfall.
- 1901 and 1948 – low rainfall (decrease of up to 22% on previous period).
- 1949 and 1990 – high rainfall (increase of up to 38% on previous period).
- 1991 and 2008 – low rainfall (decrease of 27% on previous period).



Support for regime shifts

- Lake George – natural evaporimeter

- Pre-European oxidized sediments in Redhead Lagoon
- Longer-term temporal shifts in Antarctic ice-core studies

Figure 4-8. Drought- and flood-dominated regimes illustrated for Lake George (Reproduced with permission from Warner 2007; based on Bureau of Mineral Resources data).

Warner (2009) suggests that the latest drought-dominated regime may still be operating, and that recent rainfalls may be one of the short periods of average or above average rainfall that occur during these drought-dominated regimes. He also states that the intensity of the drought-dominated regime and its length may be extended because of anthropogenic climate change, operating either through reduced rainfall or increased evapotranspiration with higher temperatures.

All the available evidence from the temporal rainfall data suggests that the pattern of drying identified for Thirlmere lakes over the last 100 years is entirely consistent with the pattern seen in other lakes and in the rainfall record. If the lakes dried out in the previous drought-dominated regimes they would be expected to be dry in the present regime.

However, there is no evidence that the drought-dominated regime is continuing. The concept of drought- and flood-dominated regimes is not a climatic predictive tool, although Warner suggests that recurrent patterns in the period of the regimes may indicate future trends (i.e. the drought-dominated regime continues).

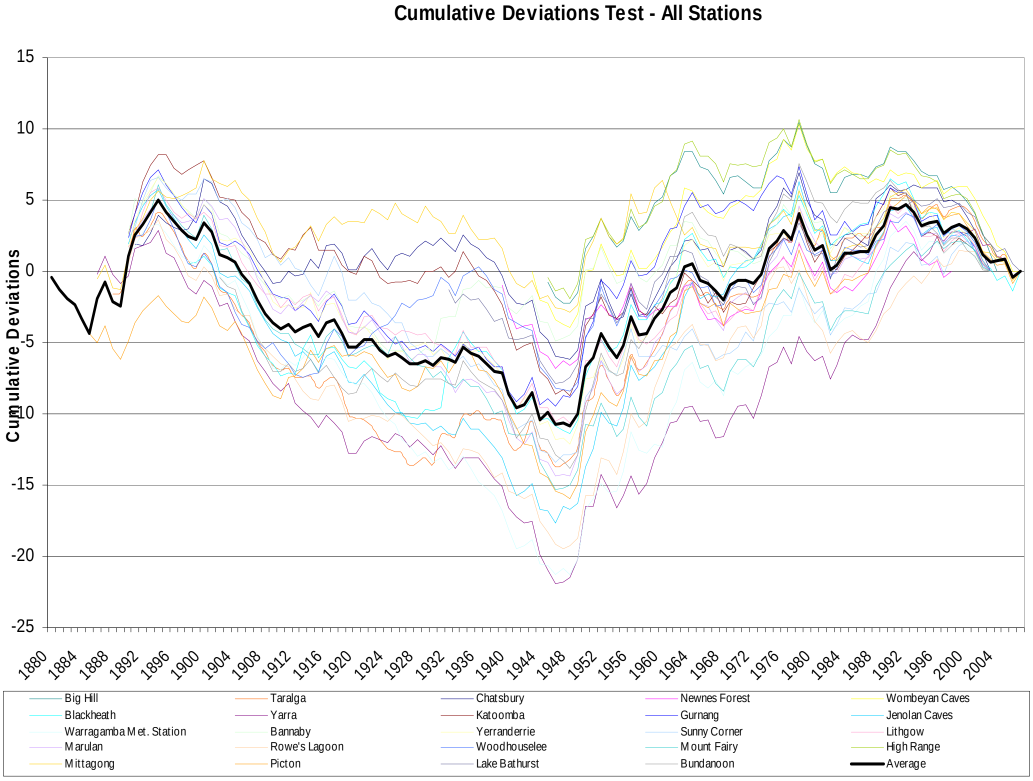


Figure 4-9. Long-term rainfall records from the Hawkesbury-Nepean Catchment showing cumulative deviations from the mean for each rainfall station (Reproduced with permission Shrestha et al., 2009).

It is clear from the rainfall data for Maidla and Buxton that rainfall over the last 5 years is oscillating around the 23 year average or, showing patterns of 12 to 18 months of wet followed by 12-18 months of below average rainfall. The period November 2011 to March 2012 was very wet.

4.3.1 Implications of regime change for Thirlmere Lakes levels

The drought-dominated regimes are periods of low levels or dryness in Lake George, and small and low numbers of floods in the rivers of the Hawkesbury-Nepean Catchment. For flood-dominated regimes the levels of Lake George are high and the floods are frequent and high in the rivers.

It is always dangerous to draw hydrologic correlations across geographic areas with diverse climatic regimes, but the consistency of the drought- and flood-dominated regimes in Eastern Australia suggest that variations in water levels in Thirlmere lakes would be consistent over time with these regimes. Drawing further similarities with Lake George is complicated because of the difference in annual rainfall (Lake George average rainfall is ~600 mm). Lake George occupies 16% of its total catchment area of 984 km^2 which is a similar proportion to Thirlmere lakes and its catchment. Lake George is a closed basin whereas the Thirlmere lakes can overflow into Blue Gum Creek and have a net loss of groundwater because of their high topographic position. At present only 50% of the floor of Lake George is covered with water (Google Earth Imagery, June 2012). The history of Lake George water levels presented in Pells Consulting (2011, p. 20) shows that the highest lake levels were approximately in the 1820’s and 1885 at 7 to 8 m, and that the high levels remembered by many people from the 1950’s to 1960’s were only 4 to 5 m. The 1990 high level in Lake George reached 3 m. If there is a parallel between Lake George and Thirlmere lakes, the suggestion is that the longest and highest periods of lake level were in the 19th Century. The present low water levels in Thirlmere lakes are consistent with the drought-dominated regimes of the last two decades. However, this correlation does not prove that regional drought or rainfall deficit is the sole reason for the low water level in Thirlmere lakes at the present time.

4.4 DROUGHTS AND FLOODING RAINS IN THE PICTON AREA

Much has been made of the severity of droughts in the Thirlmere Lakes region and the significance of the most recent drought. The issue is not the ranking of droughts but whether the recent drought was sufficient to cause the lakes to dry out (groundwater table below ground and no water on the surface) or to become substantially dry (only a small amount of water on the lake bed, as observed in October 2011 - January 2012).

There are a number of definitions of droughts, as the term commonly has a socio-economic significance and is geography specific. The terms “rainfall deficiency” and “rainfall excess” are less socio-economic in their definition as they focus on the rainfall characteristics of the region and hence reduce the geographic component of the definition of a drought, as well as the socio-economic context. For this study two rainfall indices of drought are used, the Bureau of Meteorology decile ranking approach and the Standard Precipitation Index. The latter can also be used to identify periods of extreme rainfall.

4.4.1 Bureau of Meteorology definition of rainfall deficiency

The Bureau of Meteorology defines areas of serious rainfall deficiency as those places with “rainfall above the lowest five per cent of recorded rainfall but below the lowest ten per cent (decile 1 value) for the period in question” and a severe rainfall deficiency as “among the lowest five per cent for the period in question” (http://www.bom.gov.au/climate/glossary/drought.shtml) with the period being at least three months.

As previously stated, the longest period of rainfall records for the region is the Picton station. This station has 8 to 9% missing data, but as it extends back to 1888 it is worthwhile using it. The SILO system of patching data was used to complete the missing data, and the following analysis is based on monthly data for the period January 1898 to July 2012. Details of the Picton monthly data set derived from the SILO patch is given in Appendix 4-2.

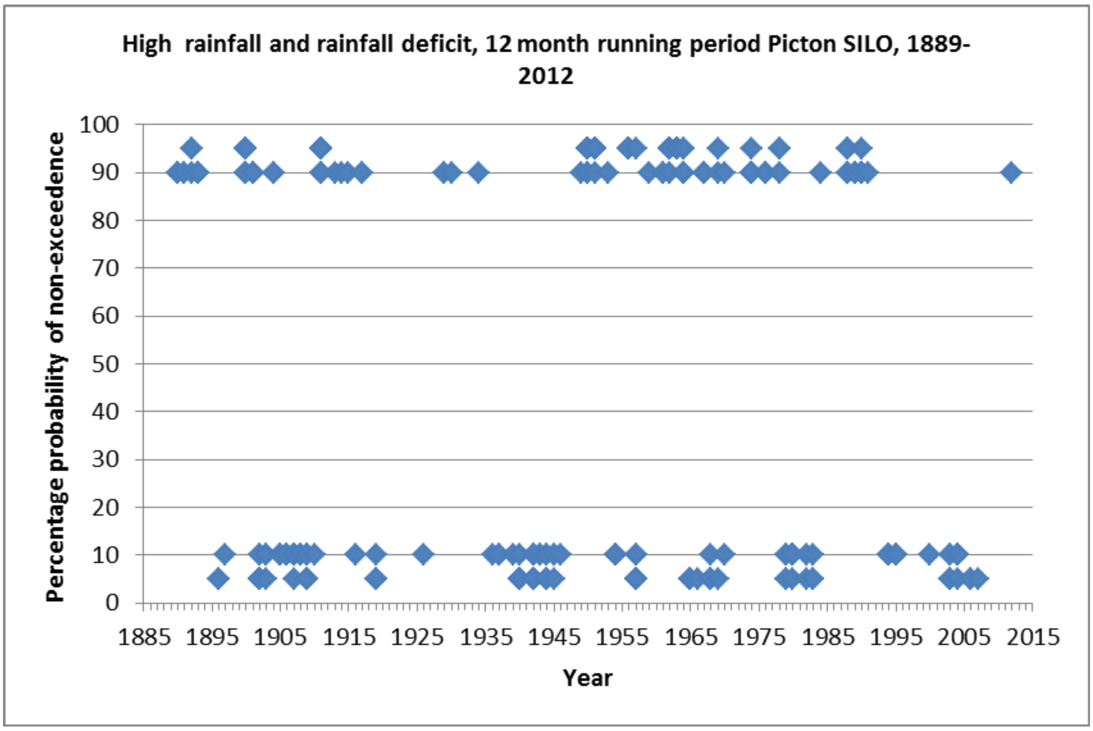
There is a statistically significant difference in the monthly rainfall for the period 1889 to 2012, which reflects the seasonality of the record (Appendix 4-2). Hence, it would be expected that if periods of less than 12 months were examined for rainfall deficiency there would be a clustering of extreme rainfalls around the wetter months and clustering of serious and severe rainfall deficiency in the drier seasons. For this reason the subsequent analysis is based on time periods of 12 months or more, which removes the seasonality factor.

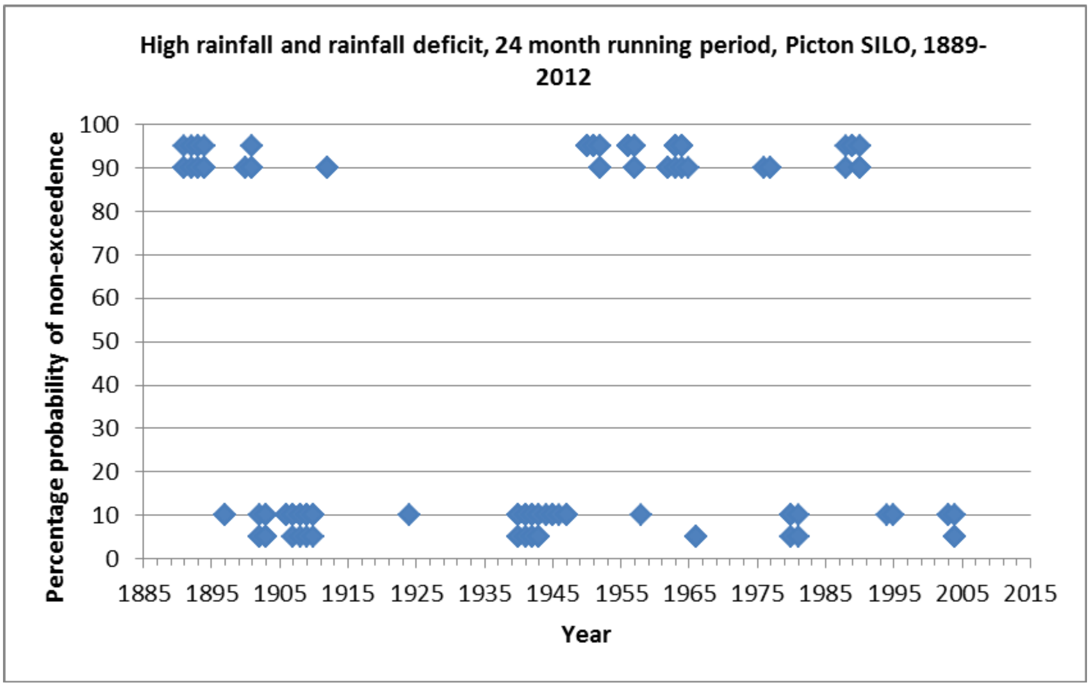
The 12 month, 24 month and 60 month totals over the period 1889-2012 were calculated as running totals. For the different periods Picton SILO data were ranked largest to smallest and ascribed a probability using the Vand der Waerden scoring method:

$P= n_i/(n+1)$; where n_i is the rank of n occurrences

The Bureau of Meteorology does not have an index for rainfall excess similar to that for rainfall deficit, but for this study the 95 percentile and larger rainfalls were classified as extreme rainfall and the 90 to 95 percentile rainfalls as very high. The Bureau's extreme deficit (less than 5 percentile) and severe deficit (10 to 5 percentile) terms are used for the drought definitions.

Over the 60 month period (Fig 4.10) the extreme and severe rainfall deficits are in the period 1895-1900, 1902-1907 (the position on the graph is at the end of the 60 month period), 1930-1947, and two periods between 1992 and 2007. There are almost twice as many 24 month periods with extreme and severe rainfall deficits and many 12 month period periods with extreme and severe rainfall deficits (Fig 4.10).


High rainfall and rainfall deficit, 12 month running period Picton SILO, 1889-2012
Percentage probability of non-exceedence
100
90
80
70
60
50
40
30
20
10
0
1885
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
2015
Year


High rainfall and rainfall deficit, 24 month running period, Picton SILO, 1889-2012
Percentage probability of non-exceedence
100
90
80
70
60
50
40
30
20
10
0
1885
1895
1905
1915
1925
1935
1945
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1965
1975
1985
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2015
Year

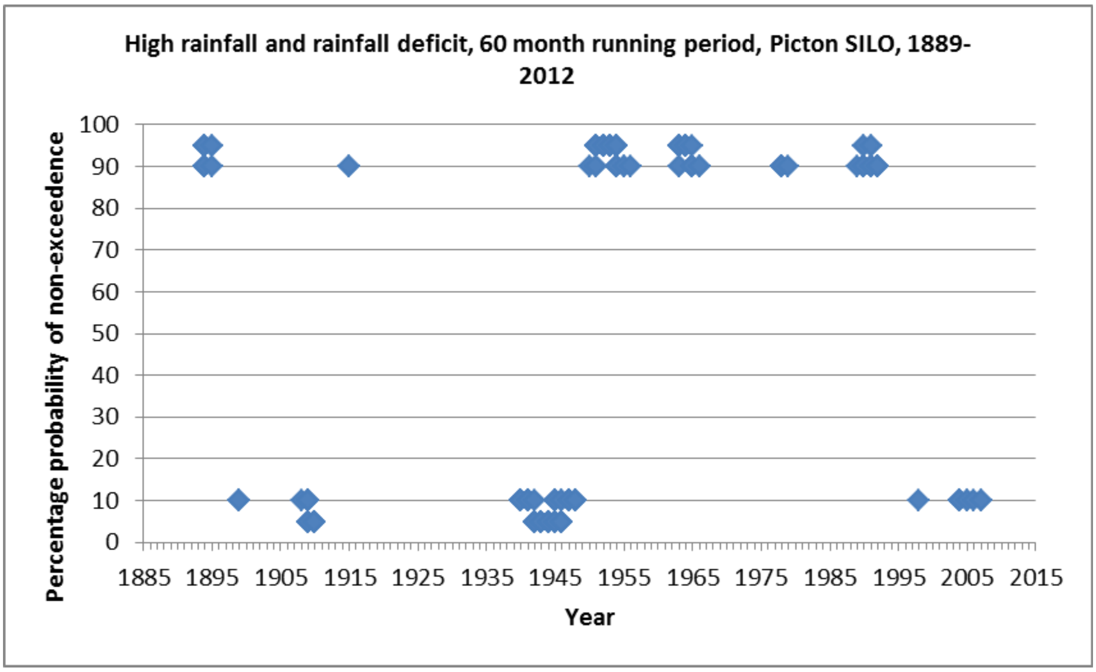

Figure 4-10. Heavy rainfall and rainfall deficiency for 12, 24 and 60 month running periods, Picton SILO monthly rainfall data, 1889-2012.

These analyses are based on running totals, which means the periods are not independent of preceding periods, as can be seen by the sequences for the 12 month running periods. The data show the clustering of deficit periods.

Equally informative are the periods of extreme and very high rainfall. For the 60 month running totals the periods are 1889 to 1894, 1910 to 1915, 1947 to 1956, 1960 to 1965, 1975 to 1979 and 1985 to 1991.

In case it is assumed that the use of monthly data is biasing results, the analysis was repeated using annual rainfall totals for the period 1889 to 2011. The 2 and 5 year estimates of high and low rainfalls are based on running totals for 2 and 5 years over the period 1889 to 2011 (Fig. 4-11).

The patterns of rainfall highs (90 and 95 percentiles) and lows (10 and 5 percentiles) are similar to those for the monthly data (Figs 4.10 and 4.11).

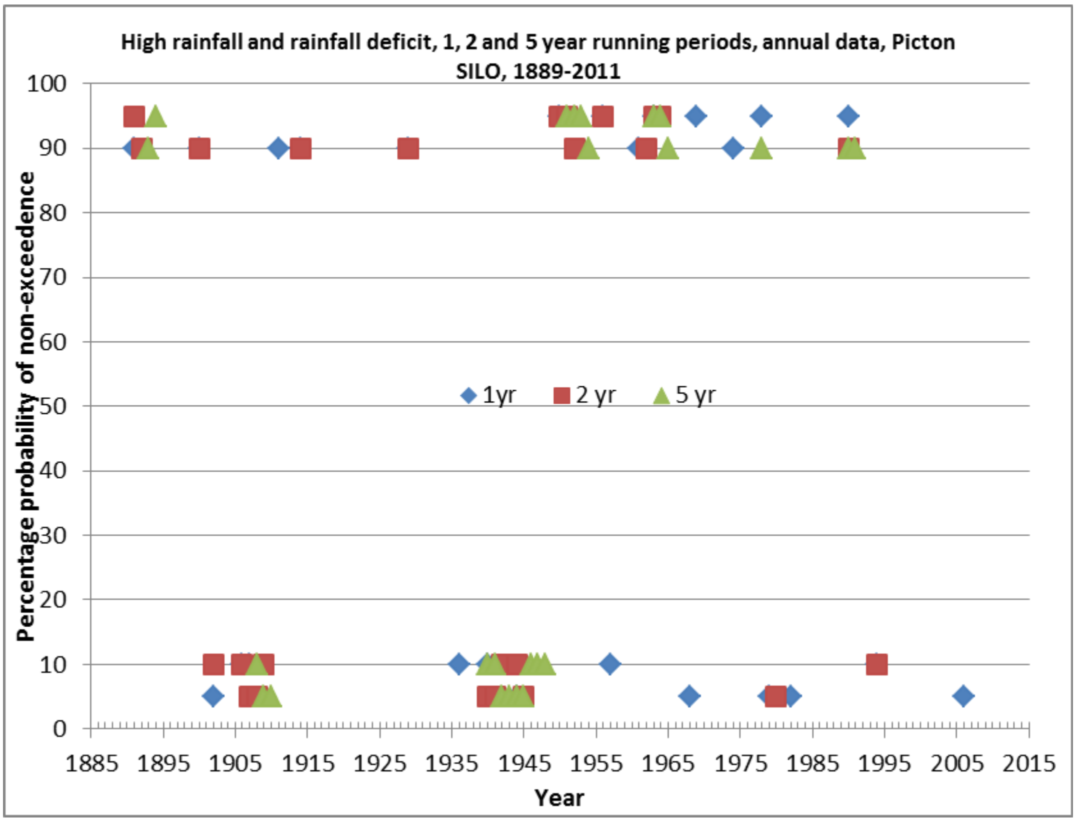

Figure 4-11. Rainfall highs and deficits for Picton SILO, 1889-2011, using annual data.

4.4.2 Standard Precipitation Index

The Standard Precipitation Index (SPI) is a recognised index of extreme rainfall and drought. Developed by McKee et al. (1993), the index is based on the probability of precipitation for a given time period. The SPI is widely used (Guttman, 1996) and has been used in Australia (Osti et al., 2006).

The classification values of SPI, for the designated time period, are given in Table 4-3.

The Picton SILO data for the period 1889 to 2012 were analysed for periods of 12, 24, 36 and 60 months. As previously indicated, the statistically significant seasonality in monthly rainfall precludes the use of time periods of less than 12 months, other than to indicate trends.

Table 4-3. Standard Precipitation Index classification.

SPI Value	Drought Category
2.00 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 and less	Extremely dry

The SPI program available at the National Drought Mitigation Centre (NDMC), University of Nebraska-Lincoln, was used in this analysis (http://drought.unl.edu/AboutUs.aspx). Monthly rainfall totals are required as input and it is recommended by the NDMC that 60 years of data are available for the analysis.

The SPI graph for all the SPI values is a confusing picture and is disentangled in the following by only showing values of SPI =>1.5 and <= -1.5.

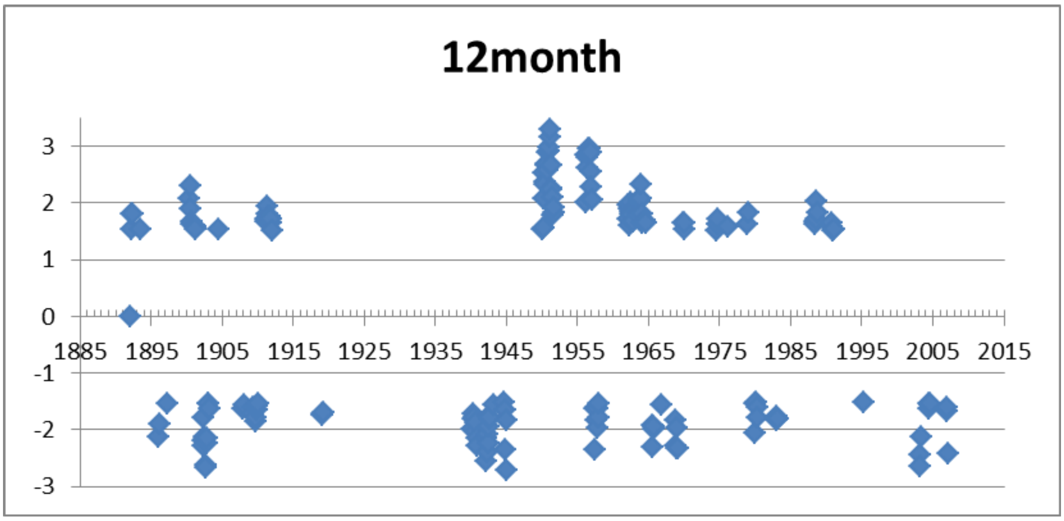

Figure 4-12. 12 Month Standard Precipitation Index for Picton SILO, 1889 to 2011. Only values greater than 1.5 or less than -1.5 are shown.

The 12 month period (Fig 4.12) shows 9 periods of significant rainfall (SPI >1.5) and 10 periods of significant rainfall deficiency (SPI <-1.5).

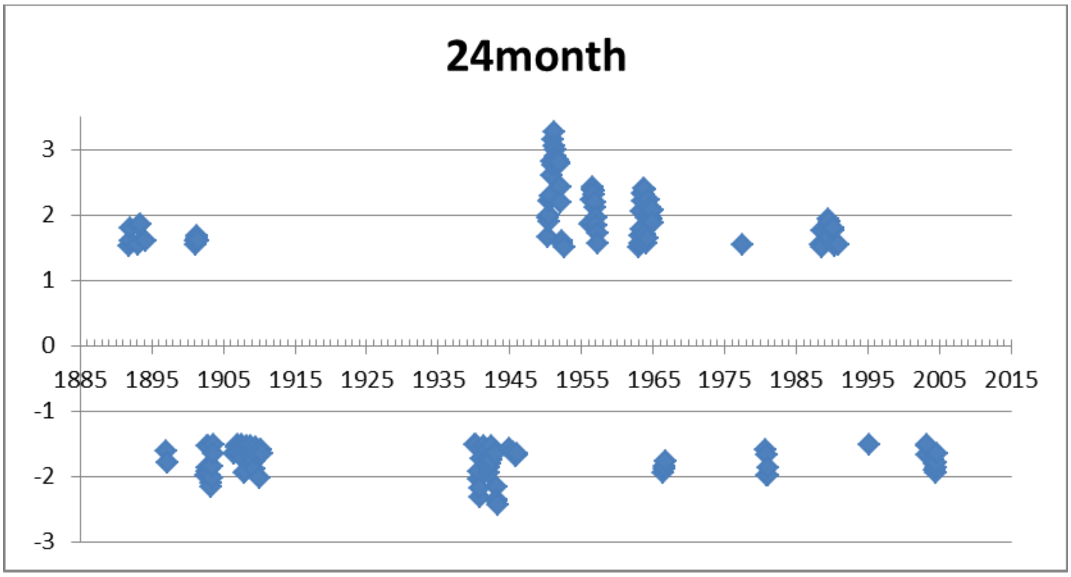

Figure 4-13. 24 month Standard Precipitation Index for Picton SILO, 1889 to 2011. Only values greater than 1.5 or less than -1.5 are shown.

The 24 month period (Fig 4.13) shows 7 clusters of high rainfall (SPI >1.5) and 8 clusters of rainfall deficiency (SPI <-1.5).

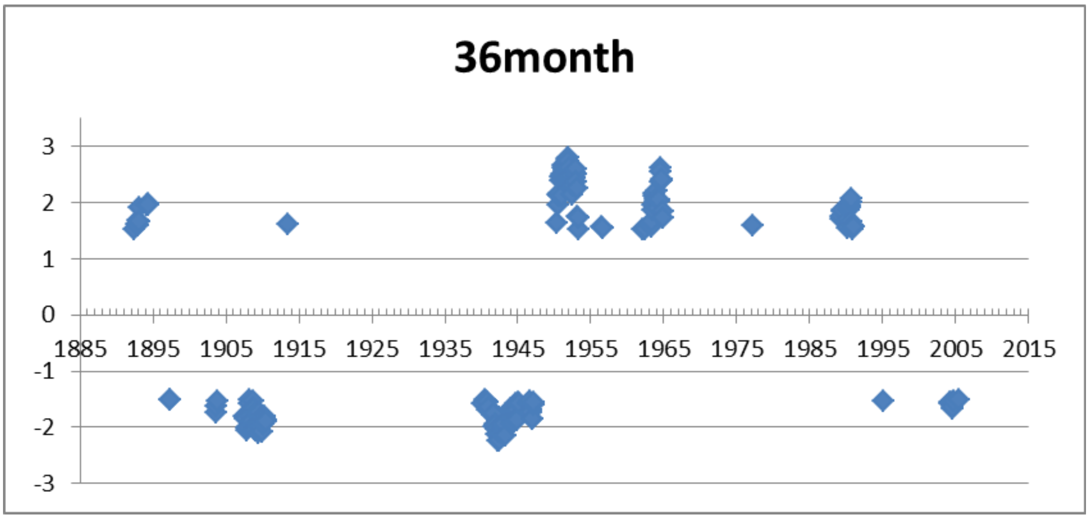

Figure 4-14. 36 month Standard Precipitation Index for Picton SILO, 1889-2011. Only values greater than 1.5 or less than -1.5 are shown.

The 36 month period (Fig 4.14) shows 6 clusters of significant rainfall (SPI >1.5) and 6 clusters of significant rainfall deficiency (SPI <-1.5).

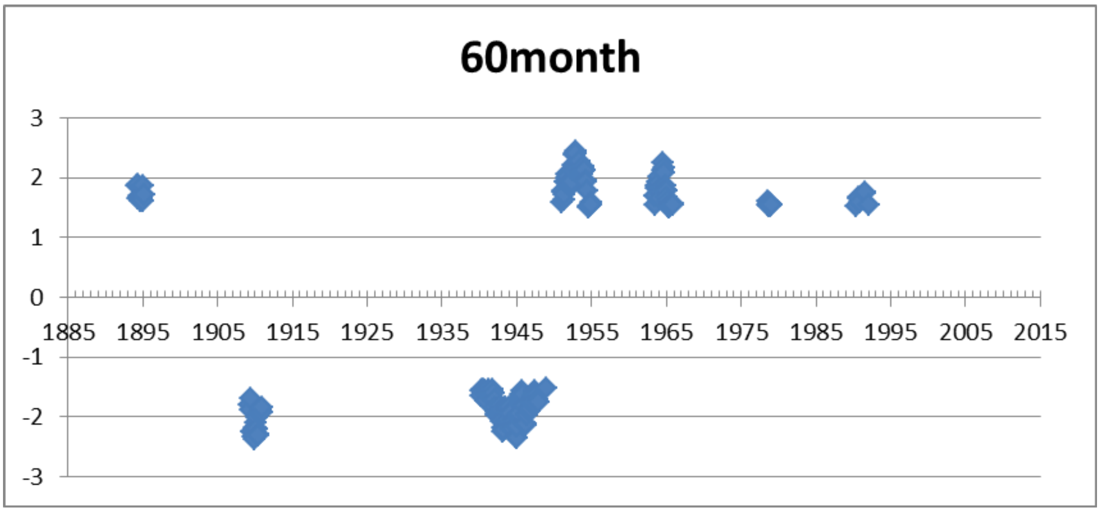

Figure 4-15. 60 month Standard Precipitation Index for Picton, SILO, 1889-2011. Only values greater than 1.5 or less than -1.5 are shown.

The 60 month analysis (Fig 4.15) shows 5 periods of significant rainfall (SPI >1.5) and 2 periods of significant rainfall deficiency (SPI <-1.5).

The Standard Precipitation Index shows a pattern through time of high and low rainfall periods similar to the decile approach of the Bureau of Meteorology.

4.4.3 Severity of the droughts – onset

The cumulative deviation from the mean for the monthly rainfall decreases in value when successive monthly rainfalls are below the average monthly rainfall for the period of record. These decreases indicate periods of rainfall deficit (below average)

The cumulative deviation from the mean for the monthly data for Picton over the period January 1889 to June 2012 shows three distinct periods of drying (Fig. 4-16). These are from:

- 1904 to 1909
- 1935 to 1947
- 1992 to 2009.

The three drought periods are known within the literature as the Federation Drought, the World War 2 Drought (sometimes referred to as the WW2 Drought) and the Millennium Drought. This sequence of drought and flood dominated regimes has been discussed previously (section 4.3).

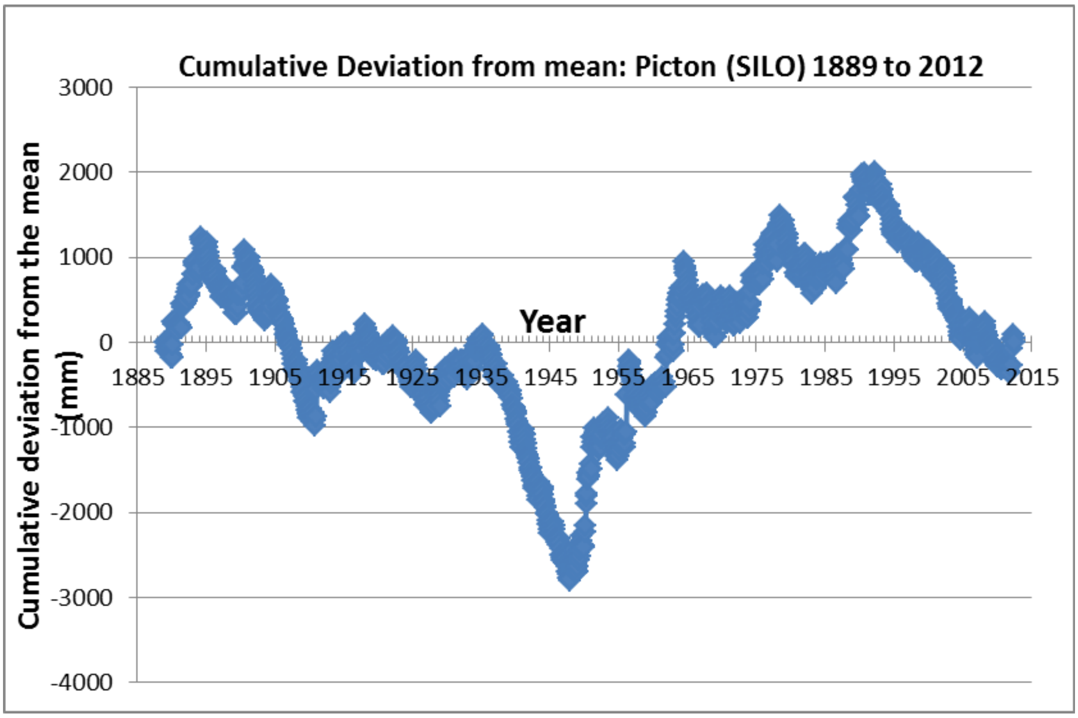

Figure 4-16. Cumulative deviation from the mean for monthly rainfall, Picton (using SILO data set) January 1889 to June 2012.

There is a statistically significant (P<0.001 Analysis of variance) linear regression between the cumulative deviation from the mean (mm) and time (year and month) for each of the three drying periods (Figs 4-17-4-19). The three figures specifically show each of the droughts and the decline in the value of the cumulative deviation from the mean monthly rainfall over the period of each of the droughts. The decline in the cumulative deviation of the monthly mean rainfall during the WW2 Drought is the steepest of the three and the shallowest is the Millennium Drought. However, the Millennium Drought extended for the longest time (longest period of decline in the cumulative deviation of monthly rainfall from the mean). Even if the drought from 1900 to 1902, which preceded the major drought of 1904 to 1909, is included in the Federation Drought record the Millennium Drought is the longest lasting.

The Millennium Drought commenced after a prolonged period of high rainfall (hence the initial high values for the cumulative deviation from the mean), but it lasted the longest and was as intense in terms of drying (decrease in cumulative deviation from the mean) as the WW2 Drought, and more so than the Federation Drought.

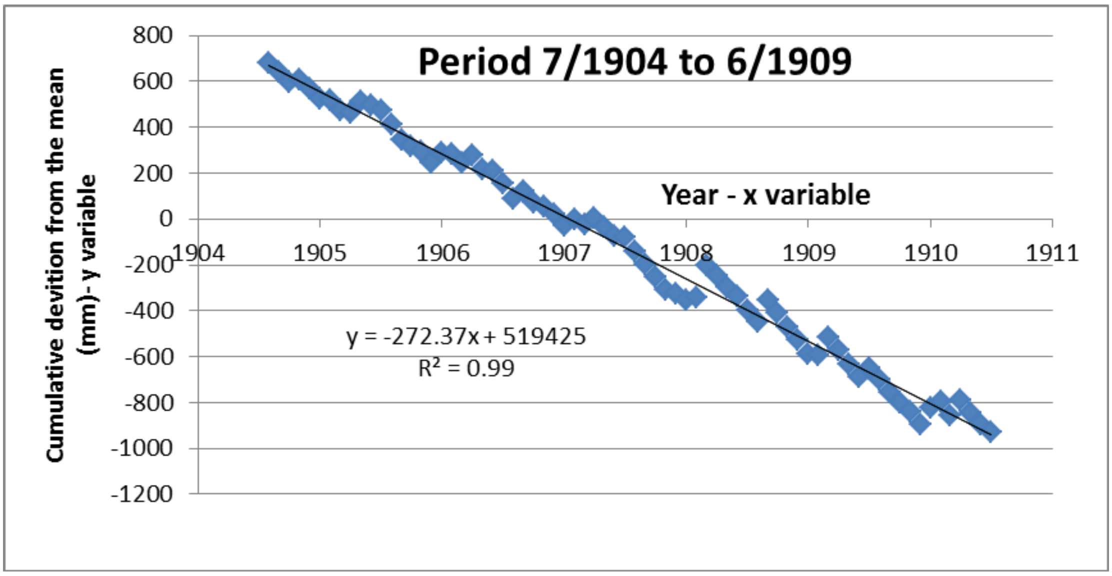

Figure 4-17. Decline in the cumulative deviation from the mean monthly rainfall for the period July 1904 to June 1909 (Federation Drought) and linear trendline.

The gradients of the three regression lines (mm/year), -272, -227, -113 respectively, suggest that the drying of the region per month (monthly rainfall below the mean monthly rainfall) was most severe during the Federation Drought, slightly less severe during the WW2 Drought, and least severe during the Millennium Drought. However, the decrease in moisture as indicated by the reduction in rainfall over the period (from high to low value of the cumulative deviation from the mean) was largest for the WW2 Drought (-2700 mm), followed by the Millennium Drought (-2200 mm) and the Federation Drought (-1600 mm).

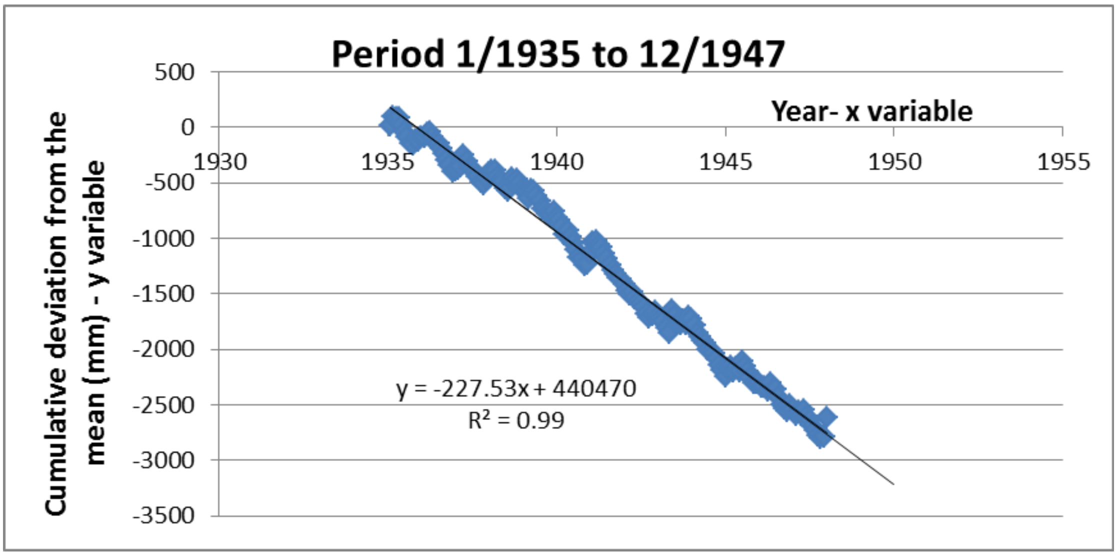

Figure 4-18. Decline in the cumulative deviation from the mean monthly rainfall for the period January 1935 to December 1947 (World War 2 Drought) and linear trendline.

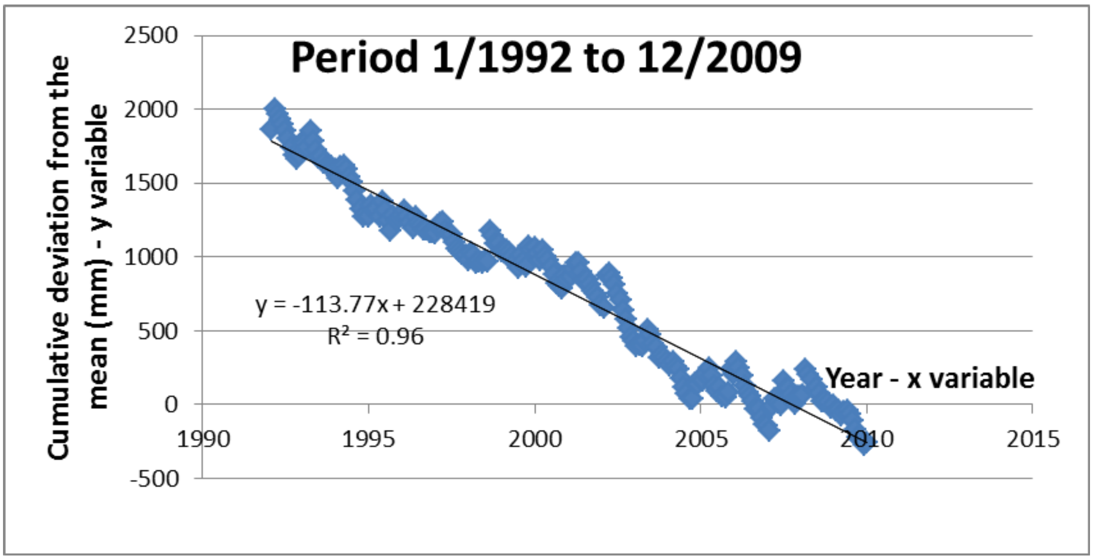

Figure 4-19. Decline in the cumulative deviation from the mean monthly rainfall for the period January 1992 to December 2009 (Millennium Drought) and linear trendline.

Comparison of droughts and their intensities is always a vexed issue, because all long periods of dryness have periods of rain. The often quoted assertion that the Millennium Drought ended in 2006 is partly true, because there was a period of rainfall above the average. However, as the data show (Fig. 4-19), it was succeeded by two below average rainfall periods, in 2007 and 2008-2009. There is nothing to suggest that the 1992 to 2009 drought was not as capable of drying the lakes as the Federation and WW2 Droughts, both of which caused the lakes to dry out or to substantially dry out. If the period from 1992 to 2006 is taken as the Millennium Drought period the decrease in the moisture is similar to that for the period to December 2009 but the gradient of the regression line is steeper.

The amount of drying (rainfall deficit) to cause the lakes to go dry need only exceed a critical value. Once the lakes are dry additional dry weather will only reduce the groundwater level below the lakes. In short, once all the water has evaporated from a lake there is no more open water evaporation that can take place. It appears, using the Federation Drought as the model, that a rainfall deficit (sum of the amount of rainfall below average) over a period of 5 to 10 years need only exceed 1600 mm for Thirlmere Lakes to go dry. Any differences among the Thirlmere lakes in the rate and period of reduction in water levels are probably related to differences in natural groundwater inflow specific to each lake.

4.4.4 The Millennium Drought in Eastern Australia

There is a body of literature that suggests the Millennium Drought was the most severe on record in Eastern Australia (Department of Sustainability, Environment, Water, Population and Communities, 2011; Gergis et al., 2012). CSIRO (2011) describe the drought between 1997 and 2009 as “the most persistent rainfall deficit since the start of the 20th century”. There is also literature that debates this point (Osti et al., 2006). As the preceding analyses show, there is a consistency throughout Eastern Australia in the times of heavy rainfall and extreme or severe rainfall deficit in the period 1889 to 2011. However, the three main droughts differ in their periods of rainfall deficit, total rainfall deficit over their duration, rate of onset, and severity classification.

The critical issue is not whether any particular drought was more severe than any other drought. The critical issue is whether the rainfall deficit was sufficient for the lakes to lose more water from evaporation and groundwater seepage than they gained from rainfall and groundwater inflow. Given that the balance between groundwater inflow and outflow is nearly constant (an assumption that needs to be further investigated) and that pumping was not a significant contributor to loss in the long-term (an issue for the Federation and WW2 droughts), the critical factor is the balance between rainfall and evapotranspiration, and for the Millennium Drought the rainfall deficit was sufficient to dry-out the lakes.

4.4.5 Evaporation

The long term average annual pan evaporation estimate using SILO gridded data for Thirlmere Lakes, for the period 1979 to 2011 is 1395 mm. The evaporation is seasonally variable (Fig. 4-20). Given that pan correction factors for open bodies of water are approximately 0.95, depending on season (see discussion in Gilbert and Associates, 2012), the water levels in the lake, without rainfall and groundwater inflow, would be expected to decline by approximately 1300 mm per annum. At an average depth of 5 m the lakes would easily dry out in 4 years provided there was no runoff from the catchment into the lake and no groundwater inflow or outflow.

The period 1979 to 2011 is too short to look in detail at trends in the annual evaporation. Nevertheless, an examination is worthwhile to assess whether there is any statistically significant patterns. A t-test assuming unequal variances was undertaken to see if there was a statistically significant difference in the annual evaporation data from 1979 to 1993 and 1993 to 2011. The test showed a significant difference ($P<0.01$). However, when the monthly data were examined the t-test showed that only June, July and August had statistically significant different mean monthly evaporation for the two periods ($P<0.02$ for al l three months). These are the months with the lowest evaporation rate. When the two periods were examined using monthly data rather than annual data no statistically significant difference was found (P>0.05) between the two periods.

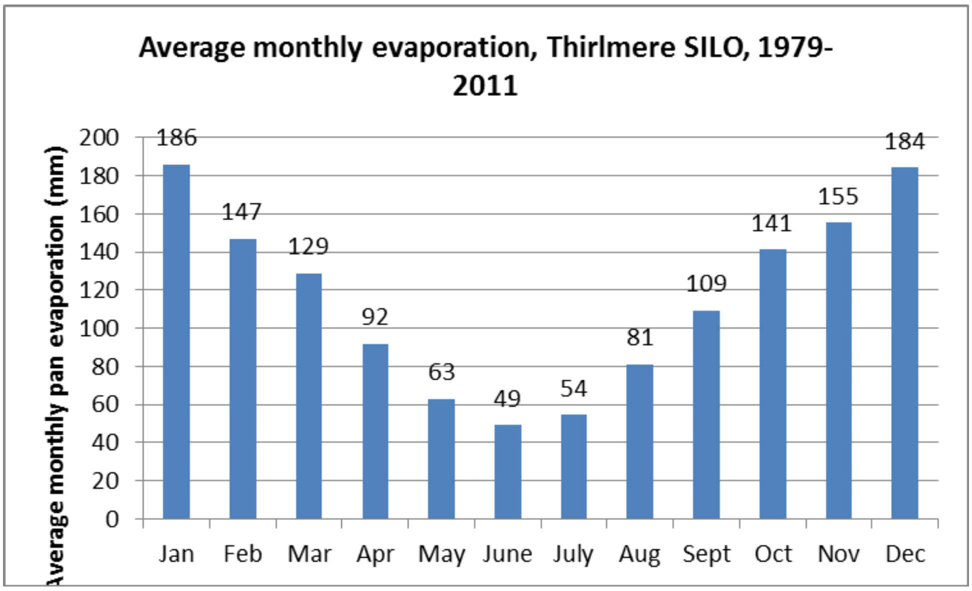

Figure 4-20. Average monthly pan evaporation, 1979-2011, Thirlmere Lakes SILO grid data estimate.

The difference between the two periods was examined in more detail by looking at the maximum average monthly temperature. No statistically significant difference was found between the two periods for each of the months (two-tail t-test for unequal variances). If there is an increase in average maximum monthly temperature then it is not evident in the gridded SILO data for Thirlmere Lakes.

Not too much can be made of this analysis as the evaporation and temperature data are estimates based on SILO grid techniques using regional data and there may be a considerable amount of error associated with the estimates. Nevertheless, there is a suggestion that evaporation has not changed over the period and if anything, may have decreased during winter. This seems to contradict assertions that temperatures have risen and as a result so too have evaporation rates.

4.5 CONCLUSIONS

1. The Committee was able to observe the dynamic hydrology of the lakes during the storms of November 2011 to March 2012 (Section 4.1.3).
2. The lakes appear to fill most rapidly from overland flow and ephemeral streams, but return flow in the form of springs, which lasts for some time after the storms, also contributes to lake water storage (Section 4.1.3).
3. Average annual rainfall of Thirlmere Lakes is of the order of 800 mm while average annual evaporation is greater than 1300 mm (Section 4.2).
4. While there are many private rainfall and weather stations in the immediate vicinity of Thirlmere Lakes none of them meet Bureau of Meteorology standards. However, they are useful for assessing the applicability to Thirlmere Lakes of official meteorological stations that are some distance from the lakes (Section 4.2).
5. The small area of the catchment of Thirlmere Lakes suggests that it will be significantly affected by small storms with high intensity rainfalls but, equally well, it can easily miss the path of such storms (Section 4.2).
6. The rainfall record suggests frequent periods of drought and heavy rain at Thirlmere Lakes, which would result in significant variations in lake levels over short periods (Section 4.3).
7. There are regionally consistent patterns of droughts and heavy rainfall in the rainfall records available for Thirlmere Lakes and surrounding areas (Section 4.4).
8. While there is debate about whether the 1992 to 2007/9 drought (Millennium Drought) was the most severe on record, the rainfall data from Picton suggests that the drought was one of the three most severe on record, the Federation Drought and World War 2 Drought being the other two (Section 4.4.4).
9. The rainfall deficit during the Millennium Drought was similar to that of the Federation and World War 2 droughts, and hence would have resulted in the lakes drying out, as they did in the two earlier droughts (Section 4.4).
10. Both average monthly rainfall and average monthly evaporation have significant seasonal differences (Section 4.4 and Appendix 4.2).
11. There is no significant difference between average annual rainfalls of the periods 1889 to 1947 and 1948 to 2011, but there are significant differences in the average monthly rainfalls between the two periods for some of the months (Appendix 4-2).

5.0 LAKE LEVELS AND HYDROLOGY MODELS

5.1 CATCHMENT STORAGE AND INTER-BASIN FLOWS

The Committee installed a temporary piezometer in each lake and also at the cols between lakes Gandangarra and Werri Berri and Lake Nerrigorang and Blue Gum Creek. The Committee also installed a piezometer in Blue Gum Creek at the boundary between the end of the public road and Nattai National Park (Fig. 5-1; Table 5-1). These piezometers were installed to monitor groundwater and also surface water levels should lake levels rise (which they did during the monitoring period). They extend to a depth of 2 m and protrude 1 m above ground level.

In every case, because of heavy rainfall, the piezometers became staff gauges for surface water as the lakes began to fill. Observing rainfall events in the catchment and information from the piezometers and DGPS surveying enabled the Committee to better understand the dynamics of the hydrology of Thirlmere Lakes.

Table 5-1. Location and ground height of Piezometers (NSW Office of Water and Thirlmere Lakes Inquiry).

Lake	Position	Easting (m)	Northing (m)	Ground Ht (mAHD)
Gandangarra				
Piezometer	Office of Water piezometer GW075411	274224	6211003	307.4
Piezometer	Gandangarra Lake piezometer	273824	6211083	301.7
Piezometer	G-WB col piezometer	273735	6210955	302.8
Werri Berri				
Significant point	Concrete top retaining wall steps	273555	6210548	307.0
Piezometer	Werri Berri Lake piezometer	273591	6209961	300.7

Couridjah				
Piezometer	Office of Water piezometer 100m depth GW075409/2	273769	6209569	307.6
Piezometer	Couridjah Lake piezometer	273685	6209273	301.3
Significant point	BM concrete top step	273775	6209423	306.5
Baraba				
Bore hole	Approx position of BH2 (Vorst)	273207	6209825	305.5
Piezometer	Baraba Lake piezometer	273205	6209640	304.0
Nerrigorang				
Piezometer	Office of Water piezometer GW075410	273034	6210587	307.0
Piezometer	Nerrigorang Lake piezometer	273038	6210508	299.0
Piezometer	Nerrigorang Lake outlet piezometer	272841	6210456	304.4 (averaged and from surveying)
Blue Gum Ck				
Piezometer	Blue Gum Ck Fence piezometer	271129	6210307	291.1

5.1.1 Basin configuration

Surveying, observations following storms, and water levels measured in the piezometers suggested the following configuration for the basins during early March 2012 (Fig. 5-2):

a) Lake Gandangarra is separated from Lake Werri Berri by a low col with a height of approximately 302.8 mAHD, probably an artefact of excavation as suggested in the discussion on the history of the lakes.

b) Water level in Lake Gandangarra was 302.3 mAHD, and the groundwater level in the piezometer at the col was also 302.3 mAHD, similar to the level of Lake Gandangarra.

Figure 5-1. Piezometer at outlet from Lake Nerrigorang.

c) Water level in Lake Werri Berri was 300.4 mAHD, which means it is lower than Lake Gandangarra and has water at a lower level than the two surrounding lakes (Gandangarra and Couridjah).

d) Water in Lake Couridjah was at 301.3 mAHD. No elevation was taken on the col between lakes Couridjah and Werri Berri, but observation suggests it is low and the history of the lakes records that it was excavated to improve flow between the two.

e) Water level in Lake Baraba was 304.3 mAHD and water was observed flowing in a channel between lakes Baraba and Couridjah. This water came from a stream draining the catchment on the left-hand side of the valley and to the southeast of Lake Baraba. Gilbert and Associates (2012) argue that the water in the channel by-passes Lake Baraba and flows directly from the south, across the road, and into Lake Couridjah via this channel. Subsequent work by the Committee confirmed their interpretation.

f) Lake Baraba and Lake Nerrigorang are separated by a col that shows no sign of gullying or channel formation, although a line of Melaleucas at the lowest point of the col, where the Committee augered a hole 2.5 m deep, and near where Vorst (1974) drilled BH2, suggests groundwater flow and occasional saturation. The lowest elevation of the col appears to be 305.4 mAHD, more than a metre higher than the water level observed in Lake Baraba at the time.

g) Lake Nerrigorang had a water level of 298.8 mAHD, making it the lowest water level (not necessarily the shallowest) recorded in the five lakes.

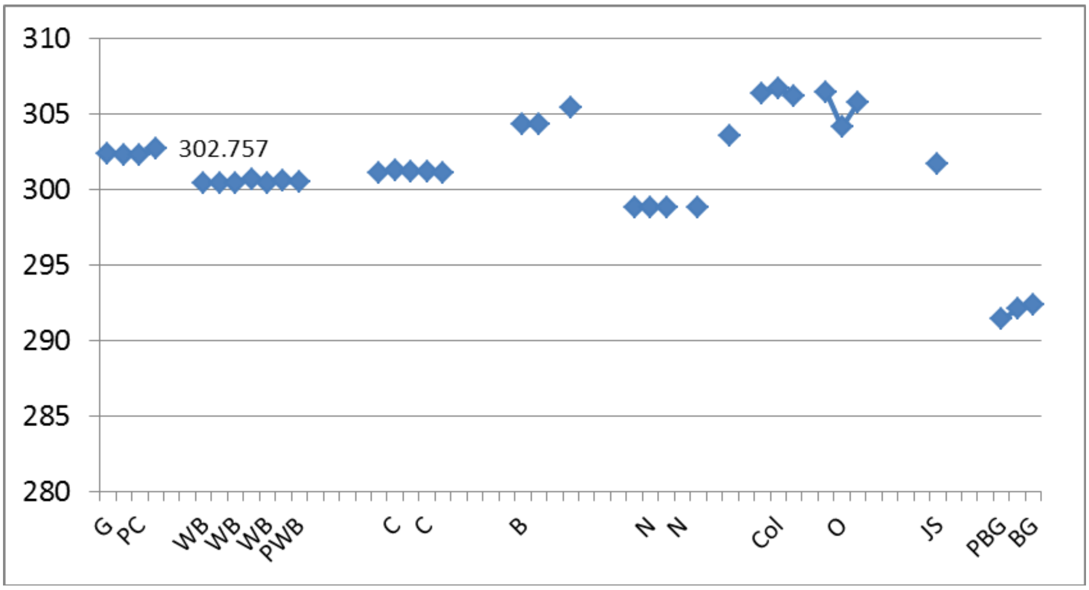

Figure 5-2. Water levels as surveyed and recorded in piezometers in March 2012. Initials on the horizontal axis refer to monitoring stations or lake water levels.

h) The outlet for Lake Nerrigorang is less than 305 mAHD. There is some uncertainty in this DGPS reading due to overhanging vegetation, so several readings were taken on separate occasions and the height presented is an average of the readings. Gilbert and Associates (2012, p. 10) measured the height of the col as 304.3 mAHD. Subsequent surveying by the Committee of the maximum level of Lake Nerrigorang at the beach area below the NSW Office of Water (NOW) piezometer, using the NOW piezometer elevation and optical surveying, confirmed that the maximum lake level had to be between 304.1 and 304.8 mAHD. Configuration of the beach suggests that the maximum lake level is probably between 304.1 and 304.4 mAHD. Irrespective, the outlet dictates that water depths in Lake Nerrigorang have to reach 6 to 7 m before it overflows into Blue Gum Creek. This depth accords with readings taken by Vorst (1974) when the lake was full. To complicate matters, there is some suggestion by the community that the outlet may have been partially dammed with several loads of sand to enhance levels in Lake Nerrigorang and also excavated to remove “mosquitoes and weeds”. The lake was used by as a commercial holiday camp facility in the past.

i) The groundwater level recorded in the piezometer at the outlet to Lake Nerrigorang was approximately 0.5 m below ground surface, which suggests there is a disconnection in the groundwater flow through the outlet col from Lake Nerrigorang to Blue Gum Creek. In fact, groundwater may be flowing back into Lake Nerrigorang in the vicinity of the outlet rather than discharging downstream into Blue Gum Creek.

j) The groundwater elevation measured downstream at the Smyth property and the water level in Blue Gum Creek at this point was approximately 301 mAHD, which suggests a groundwater gradient upstream towards Blue Gum Creek when water levels in Lake Nerrigorang are less than 301 mAHD. The bed of Lake Nerrigorang is less than 299 mAHD, so at least two metres of water have to accumulate in the lake before groundwater flows out of the lake downstream.

Piezometer data suggest groundwater and surface water flow directions between the lakes. These are shown for the monitoring period February to August 2012 in Figure 5-3.

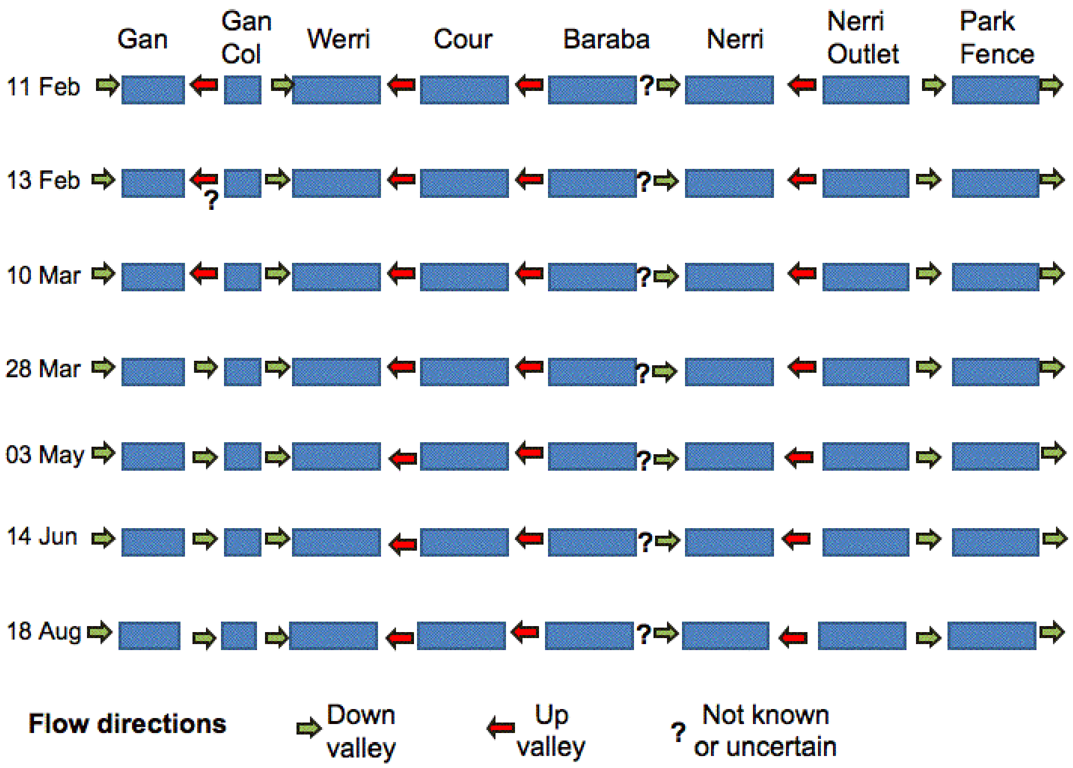

Figure 5-3. Groundwater flows between lakes as inferred from piezometer data for period February-August 2012.

Hence, the model for the Thirlmere Lakes is a series of five basins (elevations have been rounded out to the nearest metre for this discussion).

1. Lakes Gandangarra, Werri Berri and Couridjah link together with a modest rise in water level, and even when not connected are linked by groundwater flow focused on Lake Werri Berri.
2. Lake Baraba acts as a store for the three upstream lakes and only becomes part of these lakes when water levels rise to approximately 306 mAHD. Lake Baraba may also discharge groundwater into Lake Nerrigorang, although this connection has not yet been proven.
3. Lake Nerrigorang acts as an independent water body, although it may be fed by groundwater from Lake Baraba, but when the four upstream lakes rise to approximately 306 mAHD they discharge into Lake Nerrigorang as sheet flow over the col between lakes Nerrigorang and Baraba, which has a height of approximately 306 mAHD. The fact that there is no distinct channel between

lakes Baraba and Nerrigorang suggests that overflow does not happen very often and/or lacks the power to erode.

4. Lake Nerrigorang overflows into Blue Gum Creek, but probably only rarely and when water depths are of the order of 6 to 7 m deep, and possibly only when Lake Baraba overflows into Lake Nerrigorang.

5. Lake Baraba, with its elevation and thickness of peat, may be considered as a reservoir that will probably supply groundwater flow to the first three lakes, and possibly Lake Nerrigorang, and partially augment their losses to evapotranspiration and groundwater flow. At a height of 3 m above the other lakes, and with an area of 7.5 ha, it represents a potential store of 75,000 m^3 of water (for 30% peat porosity). For every metre drop in the level of the other lakes there is a potential storage inflow from Lake Baraba of approximately 20,000 m^3. This storage would act as a buffer reducing fluctuations in the level of the first three lakes until such time as their water levels decline to the point that they disconnect at the low cols between them.

The connection between lakes Baraba and Couridjah appears to have changed over recent time. The implications of this change will be discussed in Section 5.3.6.

5.1.2 Lake hydrology

The lakes are largely supplied by local rainfall and groundwater as stated in earlier discussion. Groundwater flow into the lakes is important, as it was observed returning to the surface, at significant rates of flow, several days after rainfall, along many sections of Slades Road and The W.E. Middleton Memorial Drive. Furthermore, there are complex interconnections between the lakes in terms of surface and near surface groundwater flows.

Lakes Gandangarra and Baraba have the largest ratios of catchment area to lake area (Table 5-2), using Pells Consulting (2011) estimates of catchment area. Lake Couridjah has the largest ratio using the Gilbert and Associates (2012) estimates, followed by Lake Gandangarra. The Committee’s observations from February to August 2012 show that Lake Gandangarra rose significantly more than the other lakes. The Committee initially thought that Lake Baraba discharged most of its “excess” water into Lake Couridjah. However, following its own field work, it is clear that the flow the Committee observed crossing the track along the col between lakes Baraba and Couridjah was from a tributary stream and not from Lake Baraba. Lake Baraba appeared to expand the most (in terms of area) following the storms in February and March 2012, which is consistent with it being a wide and shallow lake.

The small ratio for Lake Werri Berri (Table 5-2) may account for why it has not risen as much as the other lakes (see subsequent discussion). It is a net receiver of water from the other sub-catchments and associated lakes when water levels rise sufficiently in Lakes Gandangarra and Couridjah to spill over the cols into Werri Berri.

Water was observed entering Blue Gum Creek between the outlet of Lake Nerrigorang and Fence Piezometer from the catchments along the south side of Blue Gum Creek, after flowing across W.E. Middleton Memorial Drive in several places.

Table 5-2. Ratio of sub-catchment area to lake area, Thirlmere Lakes.

Sub-catchment	Pells Consulting Catchment Area (ha)	Gilbert and Assoc Catchment Area (ha)	This report: Lake Area (ha)	Ratio Catchment area (Pells Consulting) to Lake area	Ratio Catchment area (Gilbert) to Lake area
Gandangarra	144.7	154	11.5	12.6	13.4
Werri Berri	67.7	66	14.5	4.7	4.6
Couridjah	63.7	106	6.25	10.2	17.0
Baraba	103.7	69	7.5	12.8	9.2
Nerrigorang	65.4	56	6.5	10.1	8.6
Total	445	451	46.25		

5.2 HYDROLOGY MODELS FOR THIRLMERE LAKES

5.2.1 A simple Hydrology Model

The Committee constructed a simple hydrology model for the catchment based on annual averages of key hydrologic parameters. This simple analysis was designed to give a broad picture of the hydrology of the Thirlmere Lakes catchment and identify any obvious issues in catchment hydrology.

A number of assumptions are made:

- Catchment area: 450 ha
- Lake area: 50 ha
- Annual average pan evaporation: 1300 mm (BoM)
- Annual average rainfall: 800 mm (Picton Council Depot, BoM).

To simplify calculations it was also assumed that:

1. Lakes are rectangular in cross section (i.e. depth is a linear function of volume, area is constant).
2. There are no losses other than evaporation from the lake, with a runoff coefficient taking account of evapotranspiration and groundwater loss from non-lake areas.

Model:

$Q_L = R*(CA_C+A_L)-E$

Q_L = annual average lake volume change

A_C = catchment area (without lakes) = 400 ha

A_L = lake area = 50 ha

E = volume of annual average evaporation from lake = $50ha*10{,}000*1.3 = 6.5*10^5\ m^3$ (no pan correction factor applied)

R = depth of annual average rainfall in catchment = 0.8 m

C = Mean annual runoff (8%: Annual water resources Australia 2005, http://www.water.gov.au/MapPdfs/Fg19_BRS2010_mean_ann_runoff.pdf)

Assume C=0.08

$Q_L = 0.8 * (0.08*400 + 50)*10^4 - 6.5*10^5 = (6.56-6.5)*10^5\ m^3$

Within the errors of this elementary analysis, the volume Q_L is approximately zero. The system is near balanced, although groundwater inflows and outflows are not considered except in the term C.

Q_L would be a positive number if the pan correction factor of 0.95 for the evaporation from the lakes was applied.

The analysis suggests that the lakes are sensitive to rainfall, runoff and evaporation. Slight changes in evaporation or runoff would tip the system from either a positive or negative storage system to the other, assuming the groundwater gains and losses are equal.

5.2.2 How much rain and how long will it take for the lakes to fill?

The Committee sought to answer the question of how much rainfall and how long it would take for the lakes to full. The following analysis is not only designed to appreciate the issues of the hydrology of the catchment but also to see if there is an explanation for the assertion made by community members that the lakes seem to rapidly decline in volume following an infilling flush.

It is assumed that:

1. The lakes are rectangular in cross section, which means that increases in depth do not result in increases in area.
2. That the lake full position is uniform for the whole valley, at 305 mAHD, a number chosen for the present calculations.
3. That the present level of the lakes is 300 mAHD.
4. That the groundwater level is equilibrated with lake level at 300 mAHD and that there are no external dynamic situations draining the groundwater (a closed system is assumed).
5. That lake level must be equilibrated with groundwater levels in surrounding sediments and rock.
6. That the porosity of the sandstone is 5% (see Liu et al., 1996). This is the lower end of porosity measurements in the Hawkesbury Sandstone.

7. There is no aquifer discontinuity between the colluvium of Thirlmere valley and the adjacent bedrock underlying the catchment.
8. All rainfall flows into the lake or into the groundwater store. There are no losses to groundwater or evapotranspiration.

Under the assumptions, the lake levels have to rise by 5 m to reach a “full state” of 305 mAHD and groundwater, supplied from the lakes, has to also rise by 5 m. The equilibration assumption implies that the lakes fill as a result of all of the rainfall in the catchment flowing into the lakes, then some of the lake water flows into the adjacent groundwater store to bring groundwater levels up to that of the lakes.

The equation for calculating the amount of rainfall to fill the lake and associated groundwater store is:

Rainfall = Volume/Area

= ((area of Lakes * depth increase) + (area of catchment minus lakes*depth increase*porosity))/ total area

= ((50 ha*5 m) + (400 ha*5 m*0.05))/450 ha

= (250 ha.m+100 ha.m)/450 ha

= (35 0 ha.m)/450 ha

= 780 mm

The analysis suggest that it would take almost a whole year’s rainfall (Picton average rainfall is 802 mm: BoM) to fill the lakes and associated groundwater stores.

This estimate of the amount of rain and hence time required to fill the lakes is an obvious underestimate as the porosity of the sandstone/colluvial groundwater aquifer is likely to be more than 0.05. Furthermore, there would be considerable loss due to evapotranspiration and groundwater flow. The assumption of a non-dynamic aquifer (i.e. a basin with no connections outside the surface catchment area) is wrong because there is an eastward gradient in the unconfined surface aquifer (Chapter 6) and there is some groundwater flow down Blue Gum Creek (assuming no overflow in this scenario). No account is taken of groundwater use in the catchment. The assumption that the present groundwater aquifer is at the same elevation as the lake is also debatable (see Chapter 6). Finally, and most importantly, there are no losses due to evapotranspiration factored into this model.

The lake-groundwater linkage is a dynamic one, and it takes time for the water to flow from the lake into the groundwater storage. Furthermore, there will be a direct flow of water through catchment surface infiltration into the groundwater stores.

With loss by evaporation and transpiration of the order of 80 to 90% or more of rainfall, and still considering the catchment system to be closed to external groundwater losses, it would take a minimum of 4 to 5 years for the lakes to fill to an average depth of 5 m. With groundwater loss this time would extend significantly. Unless there was a large input of water in a short period of time, i.e. annual rainfalls well above the average, the lakes will always appear to fill after a storm and then drain.

Under a dynamic model of groundwater loss and lake infilling, a rise in water level in the lakes would result in either an increased groundwater loss or rise in the groundwater table to match the increase in lake level. The water for the groundwater loss or rise in groundwater table can come only from the lakes or direct infiltration from the catchment surface.

The basis for the preceding calculations is the hypothesis that the lake-groundwater dynamics in the lakes is one in which the lakes partially fill, the rise in lake elevation depending on the amount and intensity of rainfall, and this water then percolates laterally into the groundwater stores on the lake margins. This drainage into groundwater stores accounts for the “draining” of the lakes after “filling” reported by a number of people. Where this groundwater subsequently flows to is another question.

If this analysis has any merit, it suggests that it will take many years of above average rainfall for the lakes to “fill”.

5.2.3 A revised hydrology model for Thirlmere Lakes

A number of conceptual hydrology models for Thirlmere lakes have been proposed (Russell et al., 2010; Pells Consulting, 2011 and 2012; Gilbert and Associates, 2012). A conceptual hydrology model will help inform the computer model chosen for assessing the hydrology of the lakes and can also be used to assess the choice of numerical model used to predict catchment hydrology.

Based on its observations, the Committee considers that a hydrology model of the lakes need not have time-steps less than 1 day, as there is no need to route flow through the channels of the catchment in order to explain the response of lake level over time. A time step of this order simplifies the dynamic view of the catchment.

It should also be noted that all models are abstractions of reality (Konikow and Bredehoeft, 1992; Woolhiser, 1996; Sivapalan et al., 2003; Wagner and McIntyre, 2005; Tedeschi, 2006; Hughes et al., 2010). Many models of catchment hydrology use parameters that may appear to have a basis in reality, but experience teaches that it is next to impossible to measure the parameters by independent means and have the model accurately predict an aspect of catchment hydrology. Most models require some form of calibration, which is one of the reasons why Pells Consulting (2011 and 2012) and Gilbert and Associates (2012) put significant effort into estimating lake levels. In the absence of information, other than rainfall, their models are calibrated on lake levels. There are differences between the two models and their calibration approaches, as discussed in a subsequent section of this report.

A conceptual model is presented in Figure 5-4. It can be applied to the whole lake system or subsystems. The model is a volumetric one, with a time-step of one day.

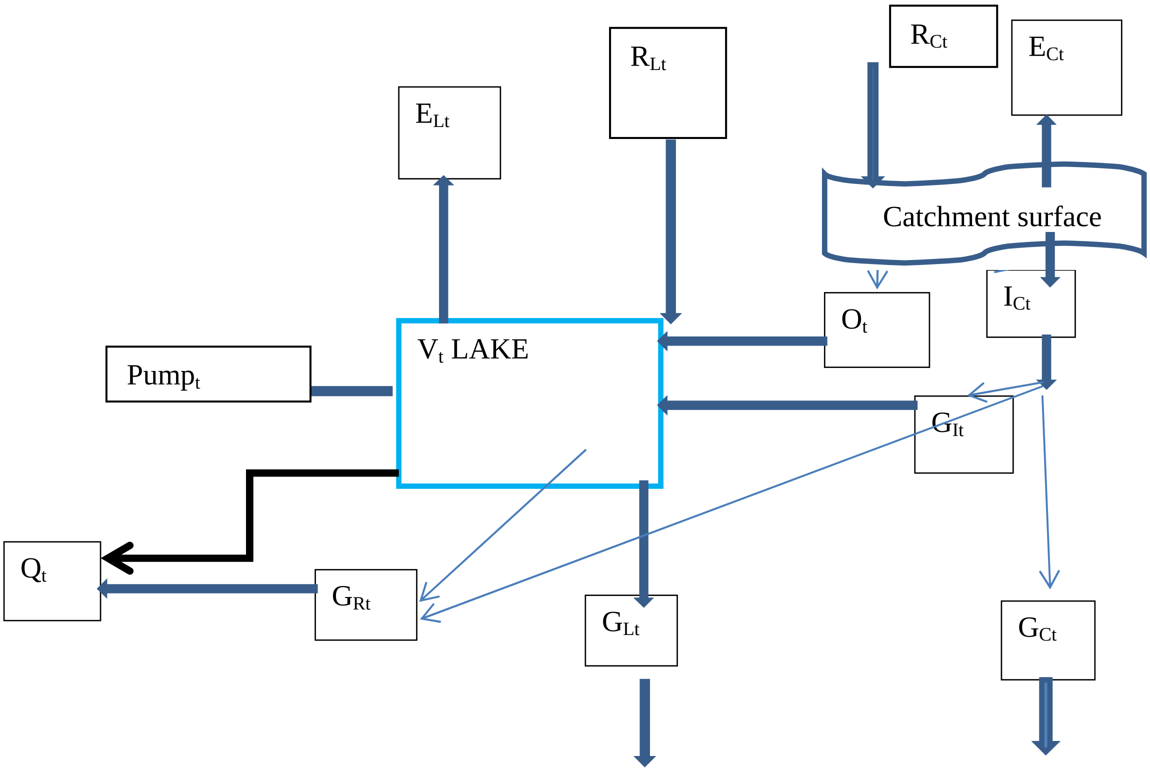

Figure 5-4. Committee's conceptual hydrological model for Thirlmere Lakes.

E_{Lt} –Evaporation from Lake at time t
R_{Lt} – Rainfall directly into Lake at time t
R_{Ct} – Rainfall into catchment at time t
E_{Ct} – Evapotranspiration from catchment at time t
O_t – Overland and channel flow into Lake at time t
I_{Ct} – infiltration from catchment surface into ground/soil at time t
G_{it} – Groundwater flow into Lake from catchment at time t
G_{Ct} – groundwater loss from Catchment at time t
G_{Lt} – Groundwater loss from Lake at time t
G_{Rt} –Groundwater loss from lake and catchment that returns to outlet (Blue Gum Ck) at time t
Q_t – Outflow Blue Gum Ck
$Pump_t$ –extraction via pumping
V_t – Volume of water in Lake at time t

Hydrology Model

Total Rainfall = $R_{Lt} + R_{Lt}$
Total inflow to Lake = $R_{Lt} + O_t + G_{it}$
Total outflow = $Q_t + G_{Lt} + Pump_t$
Total evapotranspiration = $E_{Lt} + E_{Ct}$

Model for change in lake volume (and level) between time periods t and t1

$$V_{t,t1} = (R_{Lt,t1} + O_{t,t1} + G_{it,t1}) – (Q_{t,t1} + Pump_{t,t1} + G_{Lt,t1}) - E_{Lt,t1}$$

Similar models for changes in soil moisture storage, runoff, and groundwater storage can be constructed. What this model shows is that attempting to quantify a hydrology model for Thirlmere Lakes will require significantly more information from the catchment than is presently available. Of all the parameters listed above only rainfall is reliably recorded. If lake levels can be measured then it is possible to assess lake volumes, but there are no direct records of lake levels from staff gauges. Up until recently all water levels are estimates based on interpretation of several sources of information. Until recently there were no direct measurements within the catchment of groundwater levels. There are no measurements of:

- runoff from the catchment or in the outlet of Blue Gum Creek
- groundwater flows
- evaporation from the lakes
- evapotranspiration from sedges and the catchment surface
- soil moisture
- infiltration.

There is no hydrometeorology station within the catchment that meets Bureau of Meteorology (and World Meteorological Organisation) standards for data monitoring.

5.3 ANALYSIS OF VARIATIONS IN THIRLMERE LAKE LEVELS OVER TIME

The Inquiry was a response to community concerns about the present low levels of Thirlmere lakes, and the focus of the Inquiry by the Independent Committee is an investigation of the catchment to seek an explanation or explanations for the fluctuations in lake levels.

This section examines the evidence for lake level fluctuations.

5.3.1 Geologic and geomorphic evidence

Vorst (1974, p. 31) discusses the formation of peat islands in Thirlmere Lakes. Floating peat islands (also known as “floating islands”) are unusual geomorphic features well known from elsewhere in the world including South America, North America, the UK and the Himalaya (Van Duzer, 2006). They are, however, rare in Australia (Burns et al., 1985). Perhaps the most celebrated peat islands in Australia are the floating islands of Pirron Yallock, which were first observed in 1952 when a peaty swamp floor became inundated due to impeded drainage (Gippel, 1993). As the water level rose, a number of large islands of peat, some with trees, detached from the bed of the lake and drifted continuously around the lake for 30 years. The islands covered about 30% of the lake area. Following the 1982/83 drought, the islands became grounded on the lake bed and have not been seen to float since (at least to 1993). Perhaps coincidentally, the lake level at Pirron Yallock dropped critically due to the coincidence of a meteorological drought with water extraction by a nearby motel, and pumping of water for fire fighting (Gippel, 1993).

The model Vorst (1974) presents for peat islands also requires fluctuations in lake levels to float the islands, with lower levels exposing peat, resulting in the decay of the central tissue of rhizomes, thus leaving air pockets, while the epidermal and cuticular tissue remains, forming buoyant cylinders. When the water level rises the peat is lifted off the bed. She identified peat islands of different ages, which suggested periodic lake level fluctuations. She dismissed the suggestion that all of the peat islands formed as a result of the refilling of the lakes after the drought in the 1940’s, although she reports a conversation with W. Racklyeft (Vorst, 1974, p. 34) that a number of peat islands formed when the lakes filled after the drought. Rather, Vorst (1974) presents evidence that the lakes fluctuated in level on several occasions between the 1940’s and 1974, sufficient to expose peat, and form peat islands when the water rose again. There is no mention of the range of lake level fluctuations, but they have to be sufficient to expose peat on the margins of the lakes, suggesting lake level fluctuations of at least 2 or 3 m, and more than 3 m from the highest level of all but lake Baraba.

The lakes were high in 1974 Vorst (1974). Vorst (1974) observed in May, 1974 that "*forest species on the perimeters of the lakes are becoming submerged*" (Vorst, 1974, p. 41) indicating that at that time the lakes had reached their highest level for some time. She also found tree stumps beyond the reed margin in water depths up to 4 metres, arguing that from the tree stumps and other vegetation water level depths had been more than 4 m lower than in May 1974. Vorst (1974, p. 46) argues that the lakes may not have been as high as they were in May 1974 for about 100 years. Vorst (1974, p. 45) observed after the storm of 25 May 1974 that lake level rose by 20 cm in a week, but then fell to the previous level in a "*matter of weeks*".

An attempt has been made by the Committee to relate the high water level reported by Vorst (1974) back to the Australian Height Datum. A/Prof Fanning (Vorst) supplied an image of Lake Couridjah and the jetty to the Committee (Fig. 5-5). The water appears to be approximately 0.5 m below the jetty walkway. NPWS have a photograph of the jetty when it was being removed. The walkway is approximately at the level of the top of the block-concrete wall and this and other photos suggest that the walkway of the jetty is near horizontal. The top of the block wall is 306.5 mAHD (Table 5-1). It appears that at the time the photograph was taken in May 1974 the water level was approximately 306 mAHD. At this level (see Chapter 3: Fig. 3-13) the lakes would have been overflowing, or near to overflowing. A/Prof Fanning reports in her thesis (Vorst, 1974) that the lakes were discharging into Blue Gum Creek, probably for the first time in 100 yrs.

Figure 5-5. Upper photograph, taken by Vorst in May 1974 showing water level relative to jetty (source: Fanning) and lower photograph, taken late 1997 shows jetty relative to concrete wall (source: NPWS).

If lake levels had been 4 m or lower, as described above for the relic tree stumps, the water level (Couridjah and Werri Berri) would have been less than 302 mAHD. This lowering of the lake levels would be sufficient to isolate all the lakes from each other (see Chapter 3: Fig. 3-13).

The deep bore holes drilled by Vorst (1974) suggest alternating phases of lacustrine and terrestrial (alluvial fan) sedimentation, although it is not possible to determine from the data whether or not there were extensive dry periods in the record. The fact that one spot in the valley floor shows alternating dry and wet phases does not mean that the lakes were not present elsewhere in the Thirlmere Lakes valley during the “dry” phases. Alluvial fan sedimentation would obviously alter the configuration of the lakes.

The work of Dr Mooney and his students (see Chapter 3) has focused on the upper 6 m of the alluvial sequence (Fig. 3-19 and associated text). Black et al. (2006) suggest that bands of oxidised sediment in a core from Lake Baraba show lake level fluctuations before the Last Glacial Maximum (21-28 ka BP) but that lacustrine conditions existed subsequently, with possible dry periods, such as between 6 and 5.2 ka BP. There is a discussion in Black et al. (2006, p. 3009), about whether or not the sedimentary record of Lake Baraba “*at a minimum, may indicate no more than the variation in moisture balance seen in historical times*”. The reason why Lake Baraba moved from a lake to swamp environment approximately 8.5 ka ago may be related to the aggradation that gave rise to its topographic high position in the landscape, with sedimentation resulting from a variety of processes (lacustrine, alluvial fan, debris dams). There is the question of why there was not a continuous flow of water through Lake Baraba from the upstream lakes (Gandangarra, Werri Berri, Couridjah), keeping open a channel from the headwaters of the catchment to Blue Gum Creek. The processes involved in Lake Baraba becoming a topographic high may have been enhanced by lower stream flows and, consequently, lower lake levels upstream.

In summary, the geologic and geomorphic evidence suggests a dynamic lake system with accumulation of sediment, alternating periods of wet and “dryness’, and rapid changes in lake levels, at least in more recent times.

5.3.2 Evidence of rapid changes in lake levels

Vorst (1974) recorded that in mid-1974 all the lakes were full and overflowing, as described in the previous section. Aerial photographs for the following year (section 5.3.6, Table 5-5) suggest that the lakes in April 1975 were at least 2.5 metres lower. In less than a year the lakes had decreased in depth by approximately 50%. There is some issues with the estimate of lake levels interpreted from the aerial photographs. Nevertheless, Pells Consulting and Gilbert and Associates show the 1975 Werri Berri lake level as 303.5 and 302.7 mAHD respectively (Table 5-5). The Committee’s own inspection under binocular mirror stereoscope of the aerial photographs supports the estimate of a much lower lake level.

A drop in water level of 2 to 3 m can only be explained by a considerable groundwater loss. The total rainfall at Picton from June 1974 to May 1975 (inclusive) was 701 mm (100 mm below average). Evaporation would only, at most, have accounted for 1.3 m of the loss, leaving the other 1 to 2 m of loss in water level to be solely related to either groundwater or pumping. It was unlikely to be pumping.

A conservative estimate is that in the 1974-1975 period, over less than a year, approximately 2 m depth of water was lost from the main lakes by groundwater, suggesting a groundwater loss of 500 ML (one-third of the lake-full volume of 1.5 GL). This would give a daily groundwater loss from the lakes of approximately 1.3 ML/day.

Further evidence of rapid declines in lake levels is shown in Submission 37. The photographs from Lake Couridjah show that it was high (approximately 306 mAHD) in 1986, 1990 and 1991, yet evidence from aerial photos show low levels (approximately 303 mAHD) within a few months (Table 5-5 and subsequent discussion).

Why the lakes do not continue to fall at this high rate once they are at approximately 50% full is an issue. It may be related to changes in the hydraulic conductivity of lake-basin boundaries and surrounding rocks at the lower levels, or to a balance between evaporation, rainfall and groundwater loss being established at this lower level, a balance that is not sustainable at the higher lake levels.

This rapid decline in lake levels is not prominent in community memories, but the evidence for it is clear. Conversations with the owners of the recreational area beside

Lake Nerrigorang suggest that fluctuations in lake levels must have been frequent as they talk about regularly clearing debris at lower lake levels.

Between 1949 when the lakes refilled after the WW2 Drought and 1974, when Vorst (1974) did her field work, there must have been several oscillations in lake levels of the order of at least 3 m to account for multiple occurrences of the floating of peat beds to form peat islands.

It is entirely reasonable to assume that the general level of water in the lakes during wet periods is not at the “lake full” condition but probably closer to the half full level. The lakes only appear to rise to the “full” condition during periods of significant above average rainfall (see section 4.4).

The hydrology modelling undertaken by Pells Consulting (2012) and Gilbert and Associates (2012) show rapid changes in lake levels of the order of 2 to 3 metres in short periods.

5.3.3 Evidence from Traditional Custodians

Traditional Custodians of Thirlmere Lakes recount the following concerning the lakes:

1. There is an account that the Lakes were connected to the Nepean River and a series of large storms and the resulting floods separated the lakes from the river (Story of the Worrondirri and the evil Rainmaker).

2. The lakes are a very significant area for Traditional Custodians for several reasons, including the medicinal properties of a number of plants, and the waters of the lakes themselves.

3. The lakes have been dry in the past. There is at least one account of a drought lasting several generations which resulted in the lakes drying out.

4. Even when the lakes are dry, water can be obtained by digging into them.

5. The lakes refilled from large, long lasting storms, over a long period of time.

6. The lakes are fed by groundwater, rather than rainfall, and the lakes appear to dry out when the springs cease to flow.
7. The present lake levels are out of synchronization with other factors, such as the Season of the Dreaming Cycle. The drying of the lakes previously occurred following a Time of Great Cold, rather than during the Time of Fire.

On the basis of this traditional knowledge there is evidence of lakes drying out and filling, at least in several cycles, within the time frame of the Traditional Custodians.

The story about the separation of the Nepean River and the Lakes is intriguing, and may be a clue to why Thirlmere Lakes has such a poor and ill-defined link with Blue Gum Creek, particularly the first four lakes in the sequence.

5.3.4 Recent changes in lake levels

The Independent Committee installed a number of piezometers, which could act as staff gauges, in the lakes in January 2012 and has monitored them up to August 2012. All the piezometers were initially installed in dry areas on the margins of the lakes and were recording water table levels.

Significant rainfall in late February and early March 2012 resulted in a rise in water levels in all the piezometers although the initial response at Nerrigorang was negligible (Fig 5.6). Water levels at Nerrigorang declined during late April and early May, despite rises in the other Piezometers, but then rose significantly in the following periods to the middle of June when there was little or no rainfall. Since June all the piezometers have shown water level declines of the order of centimetres except for the piezometer at the outlet to Nerrigorang, which only records groundwater levels, and which shows a significant decline in the period. The August reading for the Nerrigorang outlet piezometer is problematic because the piezometer was dry, so the value is the base of the piezometer, not the groundwater level. The decline in the groundwater level at the outlet piezometer is probably due to groundwater drainage into both Blue Gum Creek and back towards Lake Nerrigorang.

There is a possible explanation for the decline in water levels at the Nerrigorang piezometer during April to May. When all the piezometers were installed in early February 2012 the beds of the all the lakes except Nerrigorang were damp with pools of water at the surface. The bed of Lake Nerrigorang, on the other hand, was dry and the water table was at least 50 cm below the surface (Figs. 5.6 and 5.7). Inspection of the Nerrigorang piezometer in August 2012 suggested that the ground level around the piezometer had risen by approximately 3 cm and the surface was “spongy”. Unlike the other lakes, it is thought that the bed sediment of Lake Nerrigorang absorbed a large amount of water into the peat as the water table rose. The peats in the other lakes were already saturated at the time of installation of the piezometers.

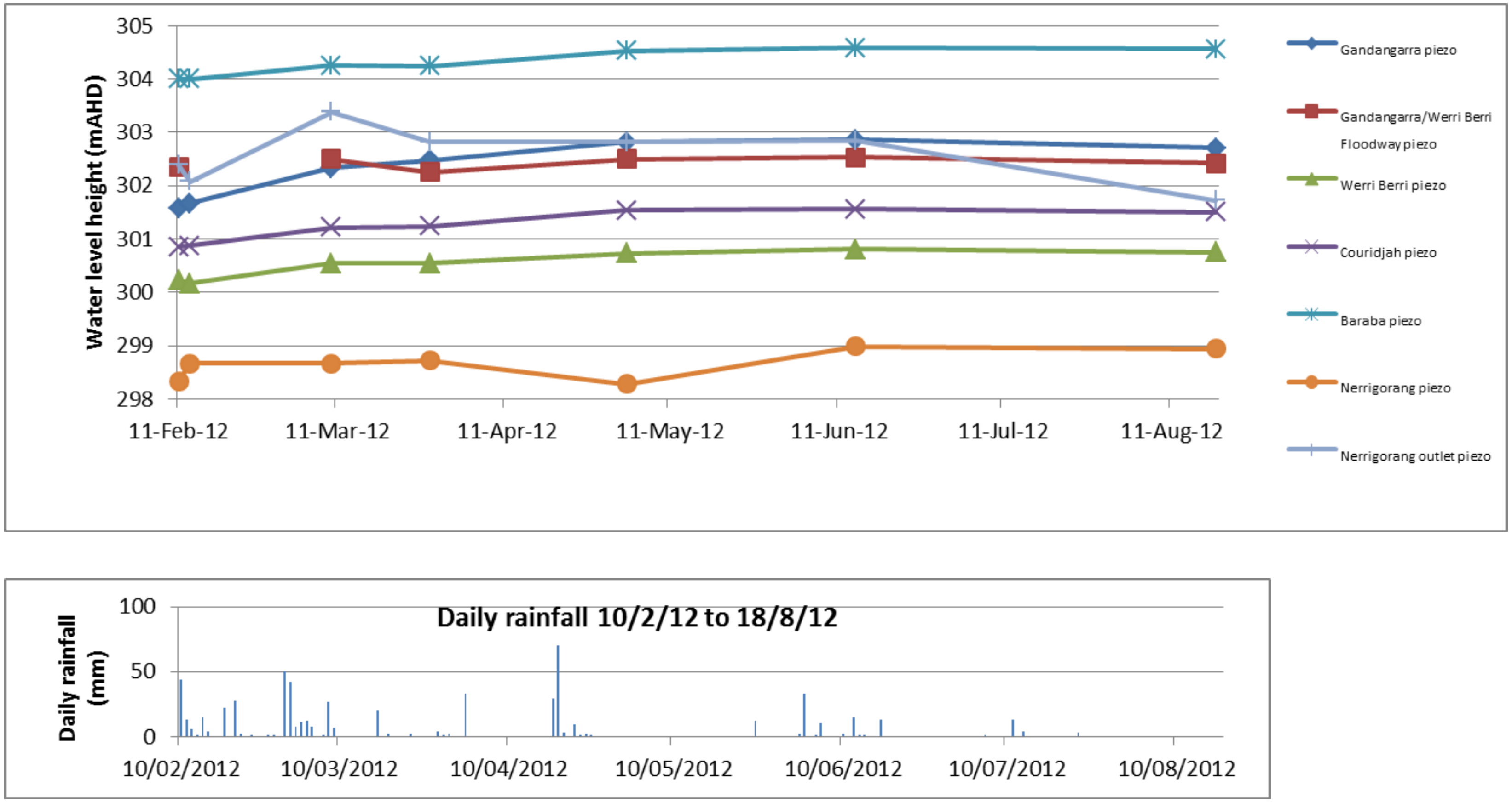

Figure 5-6. Variations in water levels at piezometers and Buxton daily rainfall period 11 Feb to 18 Aug 2012.

Figure 5-7. Nerrigorang Piezometer. Left is Sept 2012, right is February 2012.

Examination of the difference in water levels at the 5 piezometers in the lakes shows Gandangarra had the greatest fall of 0.15 m between June and August while all the others showed water level falls of the order of 3 to 6 cm (Table 5-3).

Total evaporation estimated from the Thirlmere Lakes SILO data for June and July was 81mm. The fall in lake levels (Table 5-3) is consistent among all the lakes except Gandangarra and within the range that would clearly identify evaporation with a small amount of groundwater loss as the main cause. The rainfall during this period was negligible. Lake Nerrigorang has not shown anomalous behaviour and it would be difficult to argue that it shows the impact of depressurisation in groundwater, more than the other piezometers.

Table 5-3 Reduction in lake levels over the period 14 June to 19 August 2012.

Piezometer location	Difference 14 Jun to 19 Aug (mm)
Gandangarra piezo	0.15
Werri Berri piezo	0.055
Couridjah piezo	0.06
Baraba piezo	0.03
Nerrigorang piezo	0.05

The decline in the water level of Lake Gandangarra can be attributed to some groundwater drainage, probably leakage into Lake Werri Berri.

The falls are consistent with evaporation rates from the lakes, taking account of the small amount of rainfall in the period and the losses to groundwater that would have occurred during the period. There is nothing in the last four months of records of lake levels to suggest that there is any unusual decline in water level beyond what would be expected with evapotranspiration and possibly some groundwater drainage. Community reports of the water being “sucked” into the bed are not evident in the water level data.

5.3.5 Anecdotal, historic and terrestrial imagery evidence

Pells Consulting (2011 and 2012) collected a significant amount of information on the history of Thirlmere lake levels, including information on pumping from the lake. Pells Consulting (May 2012, p. 41ff, Appendix D, Table 2-4) brings together anecdotal, terrestrial and aerial photographic, and satellite evidence.

The earlier surveying in Pells Consulting (2011) was revised in subsequent addenda (Pells Consulting, May 2012 and June 2012), following surveying information collected by the Independent Committee being communicated to them. The key surveying information and discrepancies of most recent data are identified in Table 3-5 of this report.

The Committee also had the opportunity to check a number of levels using historical terrestrial photographs that it and Pells Consulting (2011, May 2012, June 2012) collected. There were considerable difficulties in relating the water levels shown in the photographs with ground points as the scenery had changed significantly and few of the photographs have reference points that survive to the present. The late 1997 levels of lakes Werri Berri and Couridjah are an example.

Figure 5-8 shows Lake Werri Berri in late 1997. The top of the concrete-block wall is 307.0 mAHD. The photograph suggests that the level of the lake is approximately 2.5 m below the top of the wall, given that the cars, from chassis to roof are approximately 1.5 m high, their roofs must have been below water level (maximum is 306 mAHD), and the lake appears to be 0.5 to 1m below the cars. The cars were obviously dumped by pushing them out into a lake much higher than shown in the photograph. The estimate of relative elevations gives an elevation for the lake of 303.5 mAHD, possibly lower. Figure 5-9 shows the scene in early September 2012. A DGPS survey of the position of water level estimated from Fig 5.8 gave a height of 302.4 mAHD. Cross checking with the scene in Fig 5.10 (see below) would suggest that the DGPS survey point was wrongly positioned and has underestimated the water level elevation, and that it is probably closer to 304 mAHD.

Figure 5-10 shows the scene in late 1997 when the jetty at Lake Couridjah was being dismantled. The water level is approximately 2 to 2.5 m below the walkway of the jetty. Given that the walkway is approximately 306.5 mAHD (see previous discussion) the water level is approximately 304 mAHD, which is similar to that estimated for the scene in Figure 5-8 but much higher than the DGPS survey suggests for the scene in Fig 5-8.

A detailed comparison of lake levels estimated from surveys and from simulations is given in a subsequent section.

Figure 5-8. Terrestrial photograph of Lake Werri Berri and the retaining wall, late 1997 (source: NPWS).

Figure 5-9. Looking towards position of boat ramp Sept 2012 (use break in wall alignment as reference point with Fig 5.8).

Figure 5-10. Lake Couridjah at the time of dismantlement of the jetty, late 1997 (source: NPWS).

The Committee emphasises that, even with terrestrial imagery, there are difficulties in assessing lake levels and anecdotal evidence needs to be checked at several levels. The Committee does not wish to be misinterpreted as saying the anecdotal and terrestrial imagery is of no value. Far from it, as illustrated by the Committee's evaluations of Figures 5-8 and 5-10. However, a great deal of caution has to be applied to all interpretations or estimates of lake levels from terrestrial imagery.

5.3.6 Aerial imagery of lakes

The best evidence of the lake level fluctuations is a sequence of aerial photographs for the period 1955 to 2005, combined with subsequent satellite imagery publicly available on Google Earth (Figs 5-11-5-21).

It is difficult to identify water levels precisely in the imagery because fringing reed beds obscure the water-land interface. The Committee did not have the time or resources to undertake a detailed stereoscopic analysis of the lakes, using standard techniques for estimating heights with the precision and accuracy required for this study. This should be the matter for further study. However, stereo pairs of the aerial photographs were examined under a binocular mirror stereoscope. It was noted that two other primary studies, by Pells Consulting (2011 and 2012) and Gilbert and Associates (2012) did not use stereo analysis techniques.

Rather than attempt to measure lake levels in metres AHD, the aerial photographs were examined to establish whether lake level had risen or fallen from the previous photos. There was great difficulty in accurately identifying lake levels and the margin between water and land, even under a binocular mirror stereoscope. The fringing vegetation obscures the position of the water margin. Water was seen through the sedges. In addition, if the water level was low, the black peat floor of the lake was not easily distinguished from the water, through which the peat colour was transmitted.

The 1955 imagery shows the lakes at their highest level, with lakes Gandangarra, Werri Berri and Couridjah connected. This high level is not repeated in any other aerial imagery available to the Committee. Lake Baraba’s exposed water surface remains remarkably constant in position and size for all of the aerial photographs. Lake Nerrigorang is not connected to the upstream lakes, as shown in the aerial photographs (Figures 5-11-5-21).

The aerial photographs suggest the following:

1. A decline in water levels for all lakes between 1955 and 1966 (Figs 5-11 and 5-12).
2. A slight rise in water levels between 1966 and 1975 for all lakes (Figs 5-12-5-14).
3. A similar water level for all lakes between 1975 and 1988 (Figs 5-14-5-16).
4. A rise in water level for all lakes between 1988 and 1990 (Figs 5-16 and 5-17.
5. A decline in water levels between 1990 and 1994, more noticeable in lakes Werri Berri and Nerrigorang (Figs 5-17 and 5-18).
6. A fall in water level of all lakes between 1994 and 1998, with a very small channel between lakes Werri Berri and Gandangarra (Figs 5-18 and 5-19).

7. A fall in water level of all lakes between 1998 and 2002, with lakes Werri Berri and Gandangarra disconnected and lakes Werri Berri and Nerrigorang appearing to show a more significant lowering than lakes Couridjah and Gandangarra (Figs 5-19 to 5-20).
8. A fall in water levels for all lakes between 2002 and 2005, with lakes Couridjah and Werri Berri disconnected and a greater apparent fall in levels in lakes Werri Berri and Nerrigorang (Figs 5-20 and 5-21).

The Picton SILO data for 1889 to 2012, previously analysed for temporal trends, and specifically for the cumulative deviation from mean monthly rainfall (see Fig. 4-16), is used to identify rainfall trends in the intervals between the aerial photographs being taken (Table 5-4).

Between January 1945 and July 1955 (lowest to highest) there was a cumulative rainfall (sum of amount of rainfall above average) of 1909 mm. Between August 1955 and March 1966 (lowest to highest) there was a cumulative above average rainfall of 2184 mm. Despite the similar above average rainfall in the two periods the first three lakes show extensive sedge growth across their cols, probably as a result of a fall in lake level sometime between 1955 and 1966. The imagery shows that since 1955 the lakes have never reconnected with a significant water body, and whatever connection has existed is through the sedgelands. From 2002 onwards the lakes appear to have declined rapidly in elevation. The period 1966 to 2002 does not show the dramatic fall seen in the 1998 to 2005 photos.

Lake Baraba does not show significant changes in the exposed water surface. This is consistent with the concept that it occupies a high point in the Thirlmere valley long profile and acts as a storage buffer for the first three lakes.

Figure 5-11. July 1955 aerial photograph (NSW Dept. Lands, NSW 581-5034, Warragamba Catchment, Run 10, 5.7.55: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-12. March 1966 aerial photograph (NSW Dept. of Lands NSW 1440-5019, Wollongong, Run 6C, 22.3.66: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-13. June 1969 aerial photograph (NSW Dept. of Lands, NSW 1623-1544, Wollongong, Run 4C, 29.6.69: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

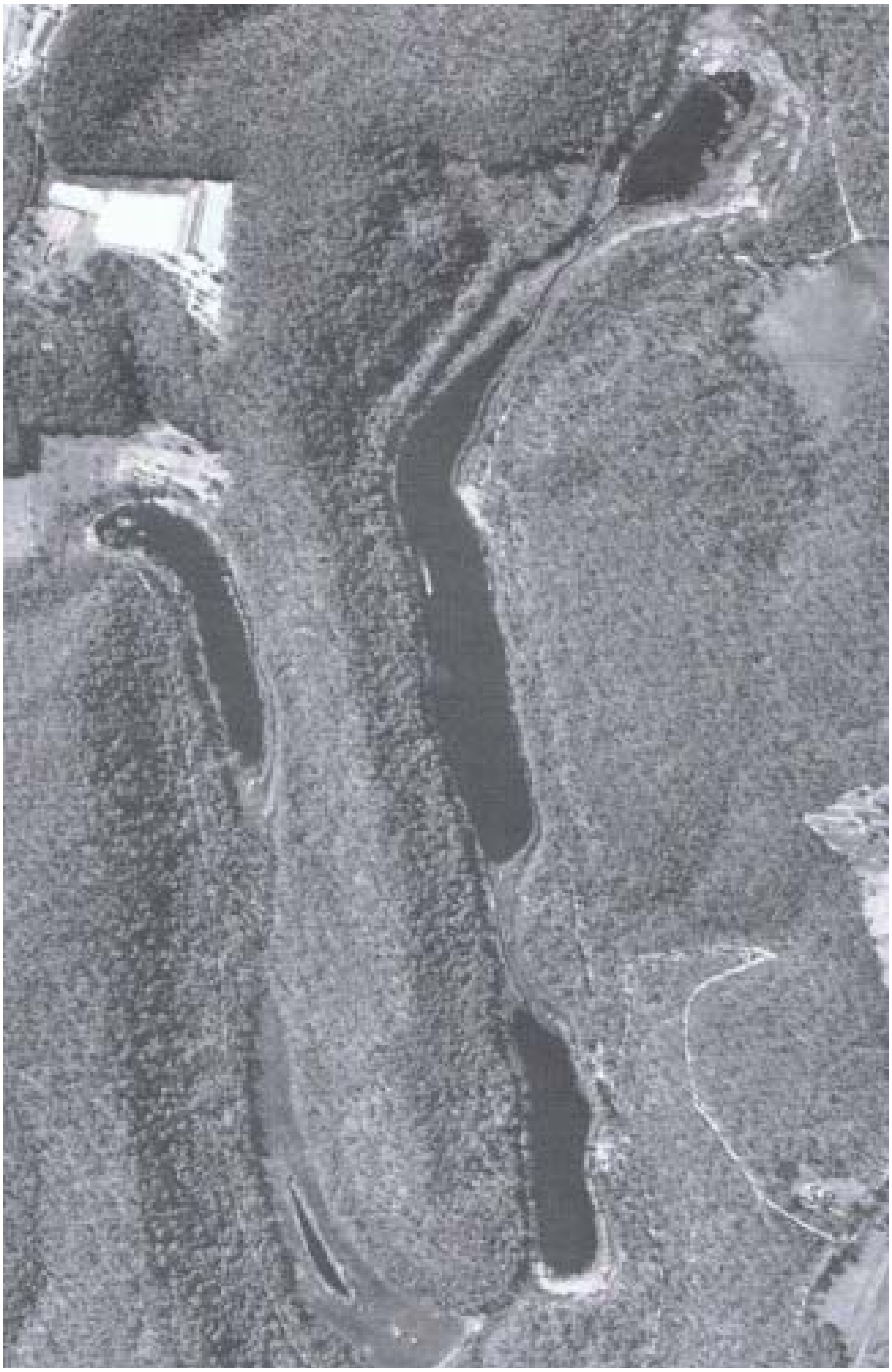

Figure 5-14. April 1975 aerial photograph (NSW Dept. of Lands, NSW 2300-61, Wollongong, Run 4, 2.4.75: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-15. October 1983 aerial photograph (NSW Dept. of Lands, NSW 3341-230, Wollongong, Run 4, 27.10.83: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-16. March 1988 aerial photograph (NSW Dept. of Lands, NSW 3609-42, Wollongong, Run 11W, 21.3.88: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-17. September 1990 aerial photograph (NSW Dept. of Lands, NSW 3751-213, Wollongong, Run 11, 25.9.90: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-18. January 1994 aerial photograph (NSW Dept. of Lands, NSW 4178 163-184, Wollongong, Run 6, 4.1.94: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-19. October 1998 aerial photograph (NSW Dept. of Lands, NSW 4455, Wollongong, 142-154, 14.10.98: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-20. February 2002 aerial photograph (NSW Dept. of Lands, NSW 4599, Wollongong, 175-200, Run 6, 22.2.02: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Figure 5-21. December 2005 aerial photograph (NSW Dept. of Lands, NSW 4942, Wollongong, 59-83, Run 6, 20.12.05: With permission ©NSW Dept. of Finance and Services, Land and Property Information Copyright NSW Government).

Table 5-4. Rainfall characteristics Picton SILO for intervals between aerial photographs.

Year	Different between highest and lowest deviation from mean	Slope of trend
1945-1955	1909	+
1955-1966	2184	+
1966-1969	512	-
1969-1975	597	+
1975-1983	920	+ (both rising and falling significantly in period)
1983-1988	650	
1988-1990	683	+
1990-1994	472	+
1994-1998	662	-
1998-2002	431	-
2002-2005	855	-

Vorst (1974) reported that the lake levels in May 1974 were as high as they are likely to get, and this was verified in the preceding discussion with reference to surveying information and terrestrial photographs. However, the lake levels shown in the 1975 aerial photographs do not suggest the lakes were as high as they were in 1955, although possibly higher than in 1966 and 1969. The inference is that lake levels vary rapidly, and between May 1974 and April 1975, when the aerial photograph was taken, there had been a significant drop in water levels in all the lakes, as discussed in the previous section. The general trend in water levels shown in Pells Consulting (2011, p. 31) between 1955 and 1990, which is one of variations of the order of 1 - 2 m, with a peak in 1974, is confirmed by the Committee's analysis. The Committee also agrees that from 1990 to the present the trend has been one of declining water levels.

Gilbert and Associates (2012, p. 19) forwarded to the Committee their estimate of water levels based on their interpretation of the aerial photographs and satellite imagery (Fig. 5-22). There are some obvious differences in elevation among lakes Gandangarra, Werri Berri and Couridjah in the Gilbert and Associates (2012) report, which suggest the magnitude of errors possible with the aerial photographs. Lakes Gandangarra, Werri Berri and Couridjah, should be at the same height once one of them reaches an elevation of approximately 302.8 mAHD, the height of the two cols between the three lakes.

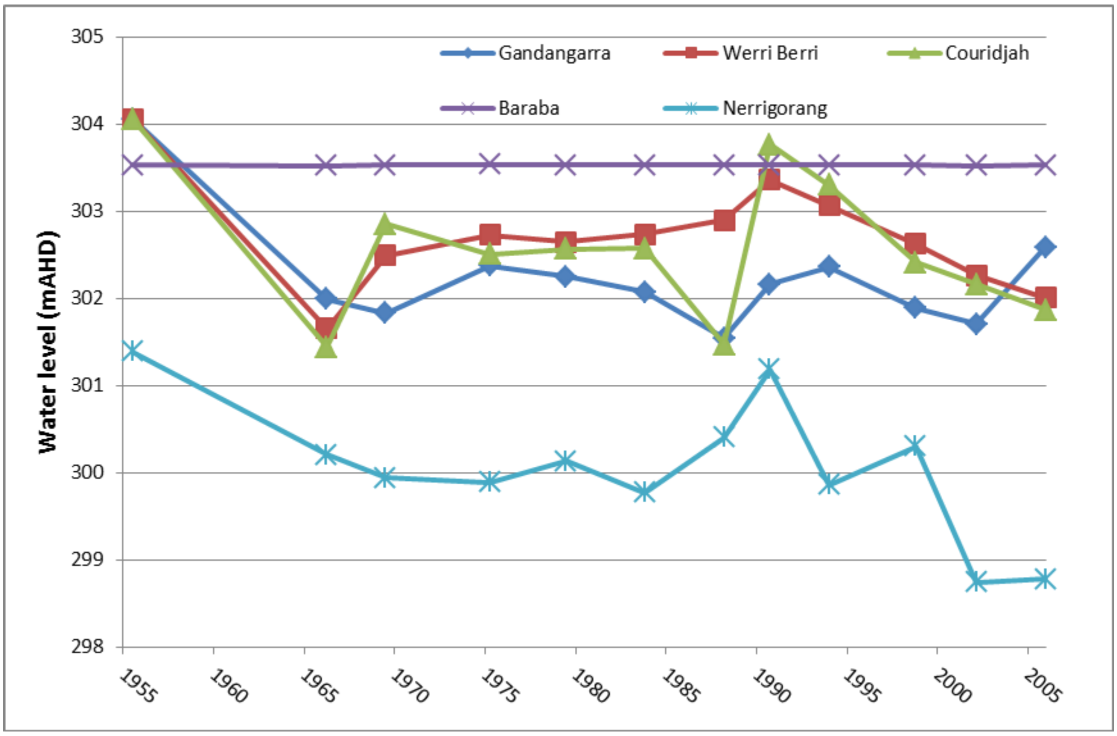

Figure 5-22. Modified from Gilbert and Associates (April, 2012, p. 19 and Table 8.1, p 57: original data supplied by Xstrata and Gilbert and Associates) estimate of lake levels 1955-2010 for five Thirlmere lakes.

The Committee has doubts about the estimate of lake levels for Lake Nerrigorang presented by Gilbert and Associates (2012), and suggests that the level for the period 1966 to 1990 may be higher than they show. The Committee also has doubts that the levels for lakes Werri Berri and Couridjah were as low as Gilbert and Associates suggest, particularly as they show lakes Couridjah and Gandangarra with low levels in 1988, levels below the col with Werri Berri, while Lake Werri Berri has a high level of approximately 302.8 mAHD.

Gilbert and Associates (2012) also present a comparison of their estimates of water levels with that obtained by Pells Consulting (2011). Pells Consulting (July, 2012, p.16, Table 8-1) corrected their data and re-presented the comparison. The comparison with Pells Consulting corrected data is presented in Table 5-5. Pells

Consulting have not estimated water levels for all of the aerial photographs. Figures 5-23 and 5-24 compare the estimates of water levels in lakes Werri Berri and Nerrigorang based on the aerial photograph interpretation.

Equally, the Committee considers that there is error in the water levels estimated by Pells Consulting (using data in written correspondence to Peter Turner, July, 2012, Table 8-1) from the aerial photographs. Pells Consulting water level estimates are discussed in the following section.

Table 5-5. Comparison Pells Consulting (Written correspondence to Peter Turner, 2012) and Gilbert and Associates (April, 2012) summary of lake levels based on aerial photographs.

Date	**Pells Consulting estimate as per their Table 8.1**		**Equivalent G&A Estimate**	
	Lake Level (mAHD)		*Lake Level (mAHD)*	
	Werri Berri	*Nerrigorang*	*Werri Berri*	*Nerrigorang*
5/07/1955	304.5	304	304.1	301.4
22/03/1966	303	304	301.7	300.2
29/06/1969	-	-	302.5	299.9
2/04/1975	303.5	303	302.7	299.9
26/06/1979	-	-	302.6	300.1
27/10/1983	303	303.5	302.7	299.8
21/03/1988	-	-	302.9	300.4
25/09/1990	-	-	303.4	301.2
4/01/1994	303.5	302	303.1	299.9
14/10/1998	304	303.5	302.6	300.3
22/02/2002	302	301	302.3	298.7
20/12/2005	302.5	3001.6	302.0	298.8

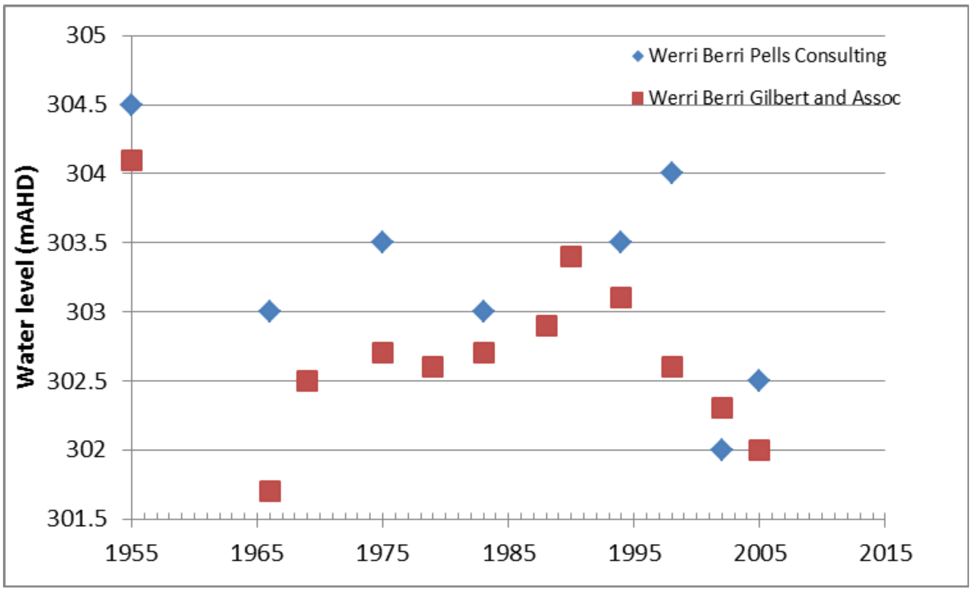

Figure 5-23. Comparison of Pells Consulting and Gilbert and Associates water levels of Werri Berri based on aerial photograph interpretation.

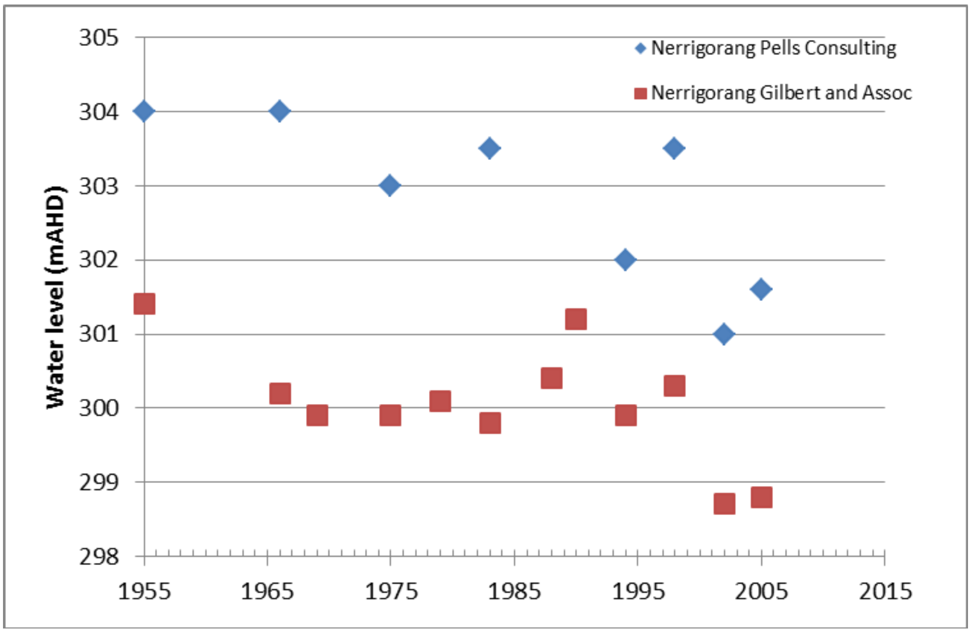

Figure 5-24. Comparison of Pells Consulting and Gilbert and Associates estimates of water levels in Nerrigorang based on aerial photograph interpretation.

5.3.7 Pumping

The Committee has paid less attention to pumping, as most of this pre-dated the declaration of Thirlmere National Park and the present phase of lake desiccation. There are some observations and a lot of detail presented in Pells Consulting (2011 and 2012).

Pells Consulting (2011, p. 11 and again in May 2012, p. 1) asserts that in the dry time of the 1980's water was pumped from the swimming lake (Lake Couridjah) at least 3 times, for several weeks, at 1000 gallons per minute (24 hr of pumping a day), into Cedar Creek. If this occurred it represents a weekly withdrawal of (1 imperial gal = 4.54 litres) 45.7 ML for a pump with a capacity of 76 L/s. This is a very large capacity pump. The report may not be accurate. First, any pumping into Cedar Creek was unlikely to have taken place from Couridjah, and instead the Committee suggests that Lake Gandangarra was a more likely source of water based on community information and observation of the remains of the pumping operation. Second, the Committee conducted its own interview with local residents and, based on the description of the pumping time and pipe (6" suction and 4" delivery), the size of the pump (probably a 350 GPM (25 L/s) Kelly and Lewis 4" centrifugal pump), the time it took the water to flow into the dam once pumping commenced (2 weeks), and the power of the tractor (45 hp Hanomag: =33 kW) and the lift up the hill (15 to 20 m to point of gravity flow in trench), a lower pump rate seems appropriate. The lower rate also accords with an estimate by a local resident of the amount of lowering of Lake Gandangarra (Reedy Lake) of 30 cm as a result of the pumping. Pumping ceased after the license lapsed in 1982/83. Finally, there is a NPWS report (NPWS, 1976?, p.14)) which states:

"Prior to the dedication of Thirlmere Lakes National Park a license to pump water from Lake 1 [Lake Gandangarra] was granted by the Water Conservation and Irrigation Commission to a nearby landholder, Mr. R. Silm. The license (No.31338) terminated on 13th March 1976. The pumping operation is performed by a portable unit (driven by a tractor temporarily parked beside the water's edge), which directs water along 140 yards of temporary 6" fibro pipeline to a small channel cut into the adjacent hillside, along which the water flows by gravitation from the Park to a small lagoon (The Dry Lake) north of the Park. Mr. Silm also has a license to pump water from The Dry Lake to a nearby creek (Cedar Creek) and thus only exercises his pumping rights within the Park when the level in The Dry Lake is too low

for pumping. A condition of the existing license is that water shall not be pumped when the level of the lake falls 6.5 feet (1.95 metres) below a bench mark on a nearby tree.

Some of the factors relevant to the management decisions of PART II regarding this matter are:

1. *There is no vehicular access to the lake edge.*
2. *The temporary pipeline has to pass over an existing access track and thus a trench is cut across the track and the pipeline temporarily buried during the pumping period (sometime for a number of weeks)*
3. *The channel cut into the hillside may disrupt the natural water flow.*
4. *Because Mr Silm operates a commercial orchard large quantities of water are involved at times.*
5. *The effect upon the lake of reducing the water level by 6.5 feet (1.95 metres) is unknown.*
6. *Mr Silm ha increased water storage sites on his property since the license was first issued.*
7. *Mr Silm has not pumped from the lake since 1969."*

Gilbert and Associates (2012) report that the demand for water by steam trains was approximately 60 kL/week in 1949-57, 20 kL/week in 1957 to 1964 and non-existent after that.

5.3.8 Temporal changes in Lake Baraba's catchment

Analysis of the aerial photographs using a binocular mirror stereoscope shows what appears to be a zone of sedges or vegetation with similar reflectance characteristics to that around Lake Baraba along the right hand side of the valley floor between lakes Baraba and Couridjah in the 1955 aerial photographs (Fig. 5-11). There is a distinct absence of trees in this zone. The zone exists in the 1969, 1975 and 1983 aerial photographs. However, it is not present in the 1988 and subsequent aerial photographs (Fig. 5-16 and following). In the 1990 aerial photograph (Fig. 5-17) a channel of a tributary stream from the south appears to bypass the southeast corner of Lake Baraba and flow directly into Lake Couridjah. It is possible that development of the alluvial fan of this tributary eventually diverted it from Lake Baraba to Lake Couridjah.

If the tributary changed course then there would have been a change in the hydrologic dynamics of the lakes, with Couridjah increasing its catchment area at the expense of Baraba. If there is a connection between lakes Baraba and Nerrigorang the diversion may have reduced the groundwater flow into Nerrigorang from Baraba.

The Committee examined this hypothesis in more detail with some field surveying. The channel across the col between lakes Baraba and Couridjah, which it had observed previously flowing immediately after a storm, does not have any Melaleucas along it and appears to be actively undercutting Eucalyptus tree roots in its bank. The channel is well-formed for approximately 30 m towards Baraba and then breaks into a number of indistinct tributary channels trending towards the southeast and W.E.Middleton Drive.

Along the left hand bank of Lake Baraba, approximately 100 m downstream (valley direction) of the track across the col between Baraba and Couridjah, a number of "springs" were identified discharging water into Lake Baraba (April and May, 2012). After this zone of "springs", further downstream, there was no surface expression of groundwater, but a number of flooded wombat holes attested to the closeness to the surface of the groundwater table. Directly towards the W.E. Middleton Drive several culverts were actively discharging water onto the slope from gutters across the road at the time of inspection, but this water disappeared into the ground in a short distance.

It appears that during and immediately following rainfall any significant runoff from the catchments immediately to the southeast of the col is directed into the new channel. Groundwater and interflow, in the long term, appears to pass directly into Lake Baraba.

Hence, it is possible to have two catchment areas for Lake Baraba. The larger one includes the drainage clearly evident in early aerial photographs. The smaller takes account of stream capture of an area of catchment south east and across the W.E. Middleton Drive.

What has caused this change in catchment geometry is a matter of conjecture. It could be related to natural processes of stream capture, or it may be related to disturbance of the drainage system by the road.

One of the implications of this catchment diversion is that less water reaches Lake Baraba during and immediately after storms than had been the case prior to the 1990's. This would reduce the amount of water flowing into Lake Baraba while increasing the amount of water flowing directly into Lake Couridjah. Changes in lake levels and groundwater may be impacting on any groundwater flow across the col between lakes Baraba and Nerrigorang. The water level in Lake Nerrigorang declined during April, but recovered a short time after (Fig. 5-6), while the water level in the other lakes appears to have increased consistently, except for the last two months. Lake Gandangarra's level seems to fluctuate the most and certainly has risen the most of the five lakes. If Lake Nerrigorang receives less groundwater from upstream and is still discharging groundwater into Blue Gum Creek then the explanation for it apparently drying out rapidly in recent times is probably more related to catchment capture dynamics than any enhancement in groundwater leakage through the bed of the basin of Lake Nerrigorang.

5.3.9 A note on Lake Nerrigorang and cols

Lake Nerrigorang features significantly in reports by Pells Consulting (2011, 2012) because of the suggestion that the Bald Hill Claystone beneath the lake has been breached in the geological past by natural erosion, prior to sedimentation in the Thirlmere Lakes valley. The argument is that groundwater loss caused by mining has taken advantage of this breach.

Lake Nerrigorang is the lowest of the lakes in terms of the elevation of its bed (297.8 to 298.3 mAHD) and when discharging into Blue Gum Creek (at 304.2 mAHD) its maximum depth is less than 7 m. Overland or unchannelised sheet flow from Lake Baraba drops at least 1 m from the col between Baraba and Nerrigorang (col height is 305.8 mAHD) into Lake Nerrigorang when the latter is full, and more than this when Lake Nerrigorang is below the overflow level into Blue Gum Creek.

It has been argued by some in the community that Lake Nerrigorang did not dry out during the World War 2 Drought. On the other hand there is a report in Vorst (1974, p.34) of an interview with W. Racklyeft, stating that during 1938 to 1940 a substantial portion of the bottom of Lake IV (Lake Nerrigorang or Racklyeft Lake) was exposed. The report doesn’t say the lake was dry, but the bed was exposed. The report is in the context of the formation of floating peat islands, which would have required the lake to fall to at least 299 mAHD to expose some of the peat bed if bed levels of the present are typical of those of the 1940s.

There is a suggestion that the outlet of Lake Nerrigorang is unstable in its elevation. Some community members report significant sedimentation associated with a stream flowing from the north, which was known to rapidly fill in its own bed and the outlet of Nerrigorang into Blue Gum Creek. It is reported that this outlet was blocked by sediment and had to be excavated at times, with sedimentation up to more than a metre in depth being reported. One resident claims that the present outlet is higher than it was 30 or more years ago.

There is an alluvial fan on the northern side of the outlet of Lake Nerrigorang. Vorst (1974) also noted this fan. It is clearly active and it is possible to conceive that the fan temporarily blocks the lake until the blockage is overtopped and washed downstream.

There are reports of some minor excavations in Lake Nerrigorang, although it is claimed that this was only to clear rubbish during low levels and prepare for “beach sand” to be added to the foreshore of the lake to enhance its recreational character. The excavation of the outlet, by hand, is also documented. There is also a report of some limited pumping for several weeks in the early 1990’s to lower the lake levels as part of an attempt to reduce “weed and mosquito problems” with stagnant water near the outlet to Blue Gum Creek. The excavation may also have been an attempt to reduce this “weed and mosquito problem”.

Further complicating the hydrology of Lake Nerrigorang is the fact that the water level in Blue Gum Creek near the causeway into the property downstream of the lake was 301 mAHD (some uncertainty because of trees interfering with the GPS signal) in March 2012. The water surface at this time was higher than in Lake Nerrigorang, whose water level was 298.7 mAHD, although the groundwater level in the outlet piezometer was 303.8 mAHD.

None of the preceding explains why the lake was dry, but there is a suggestion that the col between Baraba and Nerrigorang, which appears to be composed of consolidated sediment, may mark the transition between two systems of lakes. Upstream of the col the lakes are controlled by the cols at either end of Lake Baraba, which appear to be substantive structures composed of consolidated sediment. Lake Nerrigorang appears to be controlled by a less stable and unconsolidated sediment plug, which would appear to be more porous that the upstream cols, and less permanent.

Augering by the Committee established the difference in the consolidation of the sediment at the cols and at the outlet to Nerrigorang. The sediments blocking Lake Nerrigorang are less consolidated and appear more porous and permeable than the sediments comprising the Baraba-Nerrigorang col.

Dynamic Cone Penetrometer (DCP) tests to a depth of ≥2 m were undertaken in two transects across the valley floor, one at the col between Baraba and Nerrigorang at the position of the Vorst (1974) BH2, and the other at the Outlet Piezometer for Lake Nerrigorang. Well pump-in tests using the method of Talsma and Hallam (1980) were also applied to examine the saturated hydraulic conductivity of the upper two metres of soil, or of the soil material above and below the depth to refusal (defined by ≥21 hammer blows per 10 cm) in the DCP tests.

The hydraulic conductivity tests suggest that the outlet of Lake Nerrigorang is permeable, and the DCP tests did not meet refusal over a depth of 3.5 m in a number of points along a 40 m cross section through the outlet col. The geometric means of the saturated hydraulic conductivity readings of the top 50 cm of the sediments of each of the cols (0.029 mm/s for the Nerrigorang-Baraba col and 0.019 mm/s for the outlet col of Nerrigorang) are not significantly different ($P>0.05$, unequal variances t-test) although the number of replicates were small ($n=4$ at traverse 1, the Nerrigorang-Baraba col, and $n=5$ at T2, the traverse at the outlet col).

The DCP transect survey shows that there is a highly resistant layer across the Baraba-Nerrigorang col (Fig.5-25), at an elevation approximately the same as the water level in Lake Baraba at the time of survey (Sept 2012), while the transect across the outlet of Lake Nerrigorang did not intersect a resistant layer except at the margins of the transect, near the valley walls. The saturated hydraulic conductivity of the two layers (0.029 mm/s for the upper 0.5 m and 0.0079 mm/s for the lower layer) are not significantly different ($P>0.05$, unequal variances t-test) although this probably reflects the limited sample size (5 tests for each layer). In general, the pooled hydraulic conductivity for the upper layer at both sites (0.023 mm/s; $n=9$ measurements) is nearly four times faster than for the lower layer (0.006 mm/s; $n=5$ measurements). Insufficient time and resources were available to do more detailed surveys of the col sediments.

It is possible that the apparent relative instability and porosity of the outlet of Lake Nerrigorang can change not only the “lake full” level but also the rate of groundwater leakage downstream into Blue Gum Creek.

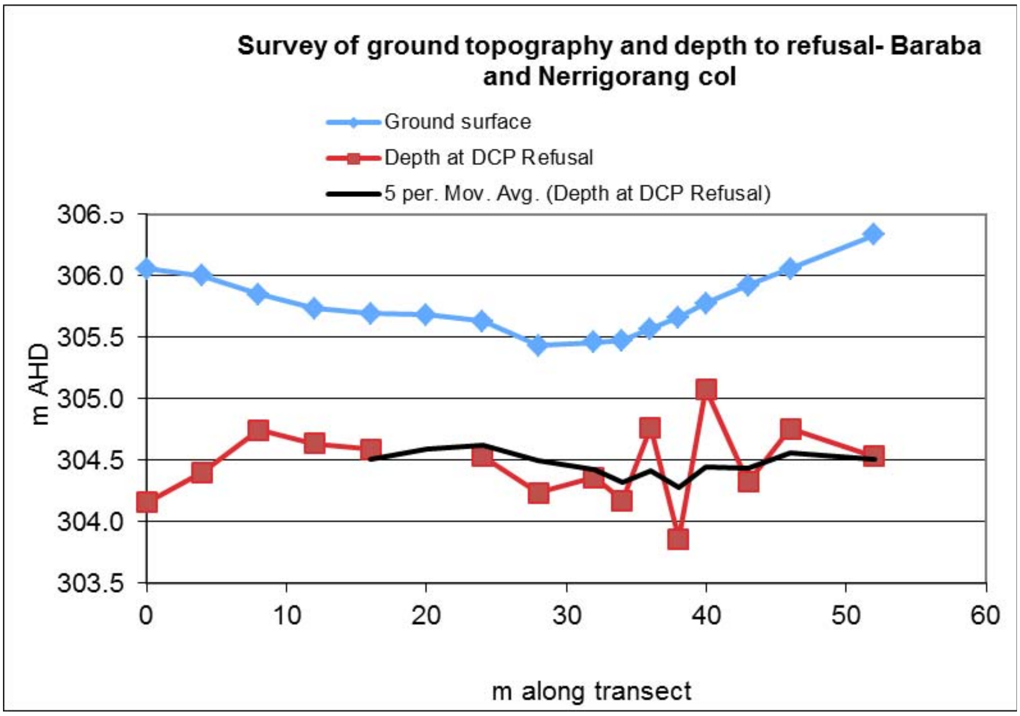

Figure 5-25. Dynamic Cone Penetrometer transects across the cols at either end of Lake Nerrigorang.

5.3.10 Evaluation of water levels derived from terrestrial photographs

Pells Consulting (2011, 2012) collected a significant body of information on lake levels from historical sources. The Independent Committee did not have the resources to assess all of this information, but undertook limited checking using its own DGPS survey and the photographs provided in the reports of Pells Consulting (2011, 2012). Pells Consulting forwarded to the Committee a table with its estimated lake levels for Werri Berri, Couridjah and Nerrigorang. To this table the Committee added the estimates of lake levels by Gilbert and Associates (2012), the assessment of lake levels when the Committee surveyed levels interpreted from terrestrial photographs, and prediction of lake levels available from Gilbert and Associate (2012) and Pells Consulting (June, 2012) modelling (Table 5.6). In the latter case the predicted levels were read from the graphs of model predictions prepared by Pells Consulting (June, 2012). Details on the table are presented in Appendix 5-1.

A check on water level estimates is required because the modelling undertaken by Pells Consulting (2012) is dependent on calibrating against known water levels. There are suggestions of discrepancies in elevations determined by Pells Consulting, Gilbert and Associates, and the Independent Committee (Section 5.3.5).

There are considerable discrepancies among Pells Consulting, Gilbert and Associates and the Independent Committee in the estimated levels of the lakes over time (Figs. 5-26-28).

For Werri Berri the Committee has higher lake levels than either Pells Consulting or Gilbert and Associates, while in general Gilbert and Associates have lower lake levels than Pells Consulting (Fig 5-26). For Couridjah the Committee again has higher levels while Pells Consulting has lower lake levels (Fig 5-27). In the case of Lake Nerrigorang Gilbert and Associates appear to have the lower lake level estimates but Pells Consulting have lake levels higher than the overflow level.

Table 5-6. Lake level estimates and model predictions. Data from Pells Consulting, Gilbert and Associates and Committee's surveys.

Date	Werri Berri	Werri Berri	Werri Berri	Werri Berri	Werri Berri	Couridjah	Couridjah	Couridjah	Couridjah	Couridjah	Nerrigorang				
	Pells Depth	Pells Predicted	Gilbert Depth	Gilbert Predicted	Committee Depth	Pells Depth	Pells Predicted	Gilbert Depth	Gilbert Predicted	Committee Depth	Pells Depth	Pells Predicted	Gilbert Depth	Gilbert Predicted	Committee Depth
1/12/1902	301	303				301	300.4								
24/12/1902	305	302.8				305	300.4								
1/08/1906	303.5	303.1				303.5	300.4								
4/04/1913	302	304.7				302	303.1								
4/06/1916											303	303.8			
1/07/1925	304	304				304	304				304	303.1			
3/11/1926	303	303.3				303	303								
1/03/1933	303	303.7				303	303.3				303	303.5			
1/07/1944	300	301.9				300.5	300.4				300	299.9			
31/03/1949	300.5	302.8				300.5	301.8				300.5	300.5			
10/12/1953											305	304.3			304.2
5/07/1955	304.5	304.3	304.1	304.5		304.5	304.1	304.3	304.1		304	304	301.4	301.7	
15/12/1955	305.5	304.1													
20/12/1955	304	304.3				304	304.1				302	304.8			304.2
1/01/1959	304.5	303.9													
1/01/1965											303.9	303.2			
22/03/1966	303	303.2	301.7	303.2		303.5	303.4	301.44	303.16		304		300.2	301.3	

29/06/1969			302.5	303.5				302.85	303.52				299.9	300.5	
10/12/1971	303.5	303.8													
1/05/1974										306					
1/11/1974						304.8	304.8								
2/04/1975	303.5	304.5	302.7	303.6		303.5	304.3	302.51	303.63		303	304.4	299.9	300	
26/06/1979			302.6	304.6				302.57	304.56				300.1	302.6	
27/10/1983	303	304.9	302.7	300.6		302.5	304.7	302.58	302.3		303.5	303.6	299.78	298.6	
1/04/1984										304.5					
1/03/1987											303.5	304.3			
21/03/1988			302.9	300.1				301.47	301.92				300.4	297.8	
1/04/1988											305	304.9			304.2
1/01/1989										306					
1/04/1989						305	304.5			306					
1/07/1989											305	304.9			
1/12/1989						305	304.5								
1/01/1990											304.5	304.3			
1/02/1990	304	304.7													303.5
25/09/1990			303.4	305.9				303.77	305.85				301.2	304.3	
1/12/1990					305.7	305.5	305								
10/01/1993	304	304.4			306										
4/01/1994	303.5		303.1	303.4		303.5	303.3	303.31	303.41		302	303.2	299.9	300.9	
1/04/1994	304	303.7													299.8
1/10/1997					304					304					
4/10/1998						304				303					
14/10/1998	304	304	302.6	303		304	303.9	302.41	303		303.5	302.9	300.3	300.1	

10/12/1998	303.5	303.4				304.5	304.3								301.2
10/01/2002										305					
22/02/2002	302	303	302.3	300.8		302.5	302.9	302.27	302.49		301	301	298.7	299	
1/03/2002											300.5	301			299.6
20/12/2005	302.5	302.9	302	298.9		302.5	302.9	301.87	300.62		300.5	300.4	298.8	297.6	
29/07/2006											299	300			
13/06/2008	304														
1/11/2008	303.5														
31/10/2009	303	303.4	300.3	300.9		303	303	301.29	301		298	299.9	297.8	296.93	
1/01/2010	301.5	302.9													
13/04/2010	301.5	302.5	300.1	300.3		301.5	302.1	300.99	300.79		298		297.8	297.2	
1/01/2011	300.7	301.9				300.4	302.8								
10/02/2011	300	303.1	300.1	299.3		300	303	301.2	300.89		298	299.3	297.8	297.08	
9/05/2011	300.5					300.5					298				
22/08/2011	300					300.2					298				
1/10/2011	300					299.9	303								
19/01/2012	300					300					298				
25/03/2012	300.5					300.5					298				
18/05/2012	301					301.5					298.3				

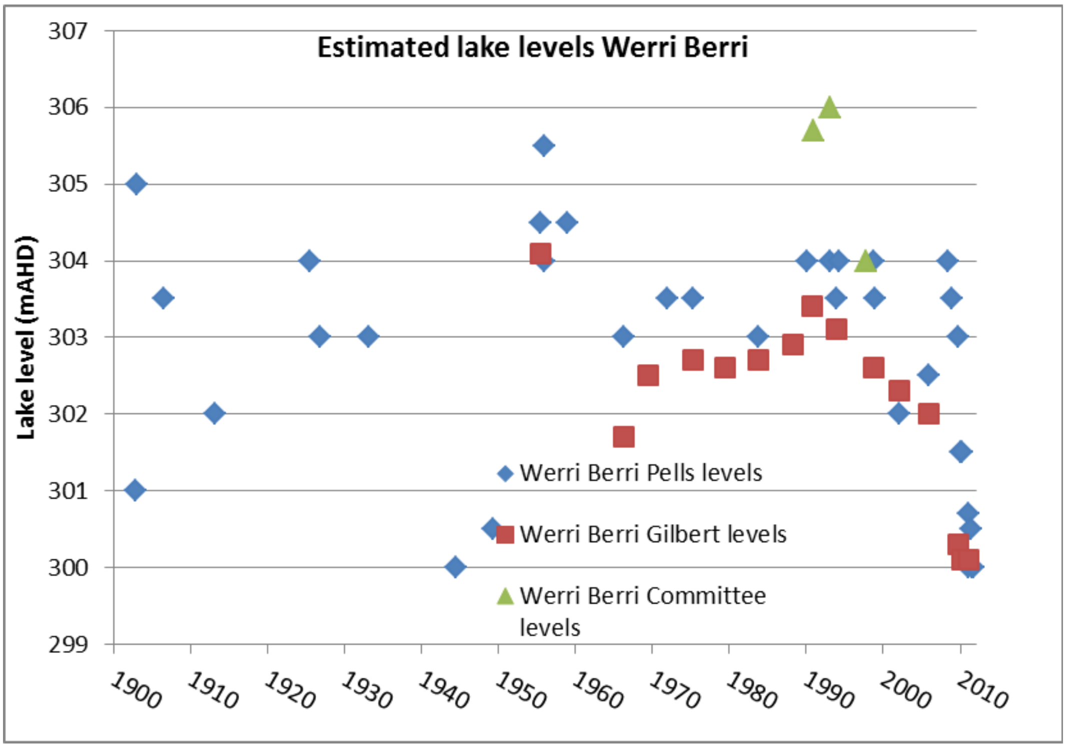

Figure 5-26. Estimated lake levels Lake Werri Berri.

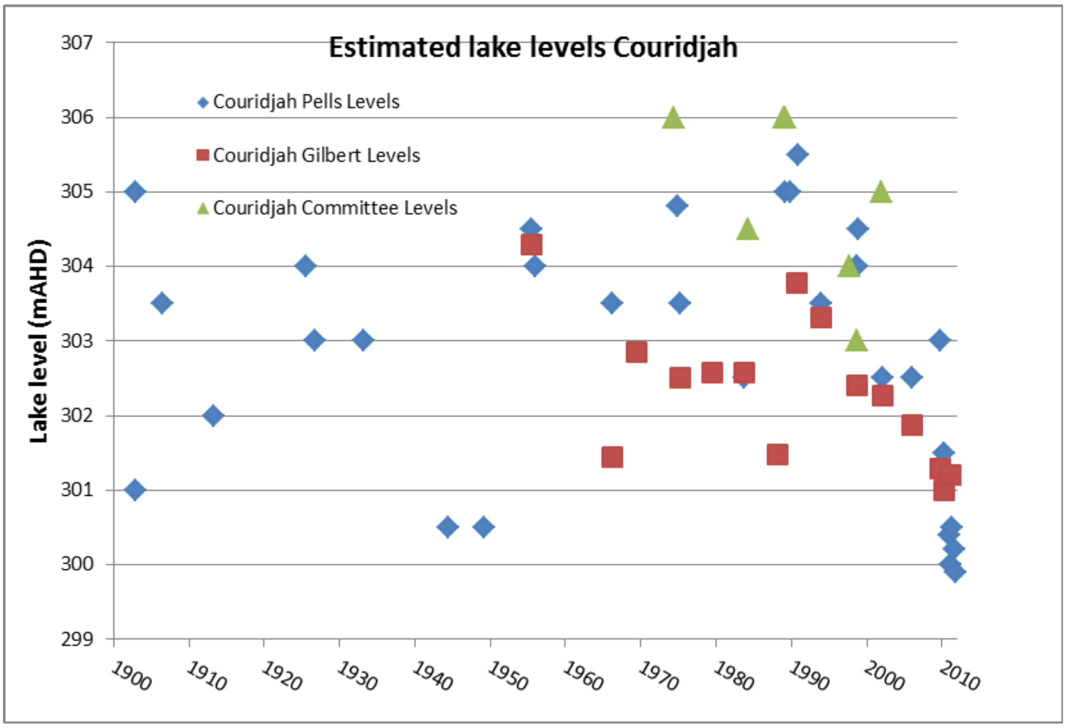

Figure 5-27. Estimated lake levels Lake Couridjah.

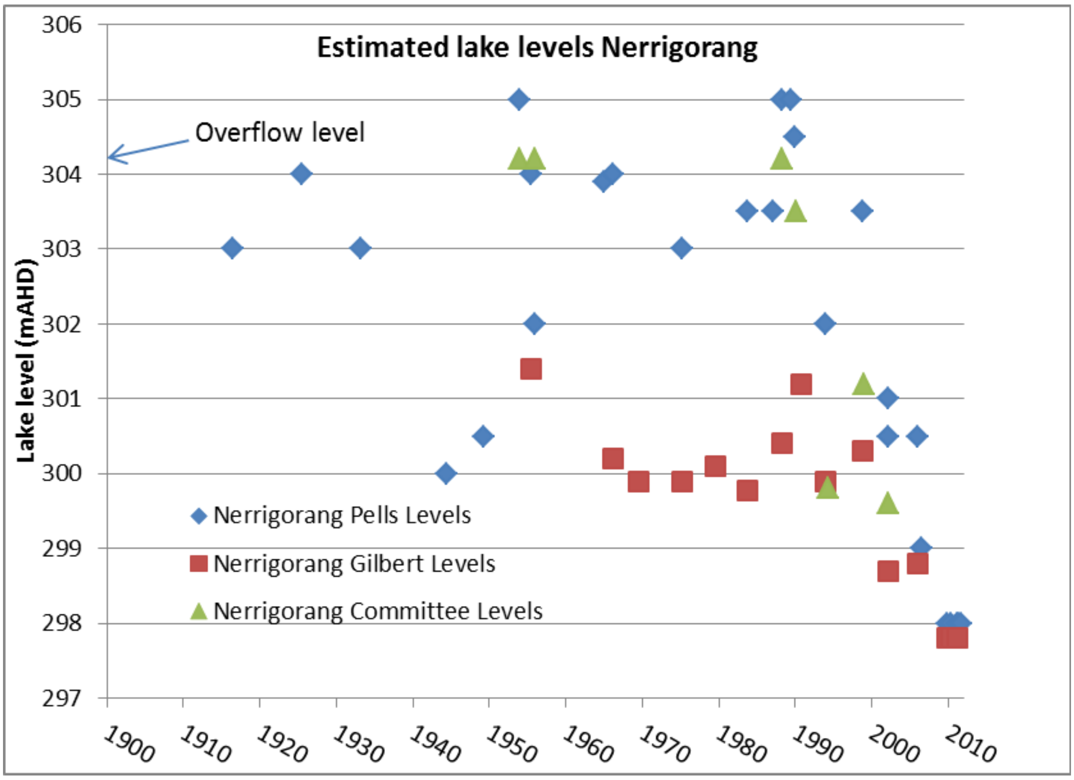

Figure 5-28. Estimated lake levels Lake Nerrigorang.

It is informative to compare the estimates of the levels of lakes Couridjah and Werri Berri obtained by Pells Consulting and Gilbert and Associates (Figs 5.29 and 5.30). The lakes merge with each other and with Gandangarra when the water level in one of the lakes reaches the point where it overflows the col(s) separating it from the adjacent lake(s). The cols between the lakes are approximately 302.8 mAHD. Hence, there should be no difference in the estimated lake levels when either Couridjah or Werri Berri lake level is greater than 302.8 mAHD. This is not the case for either the Pells Consulting or Gilbert and Associates estimates. There is obviously considerable error in the estimates of lake levels.

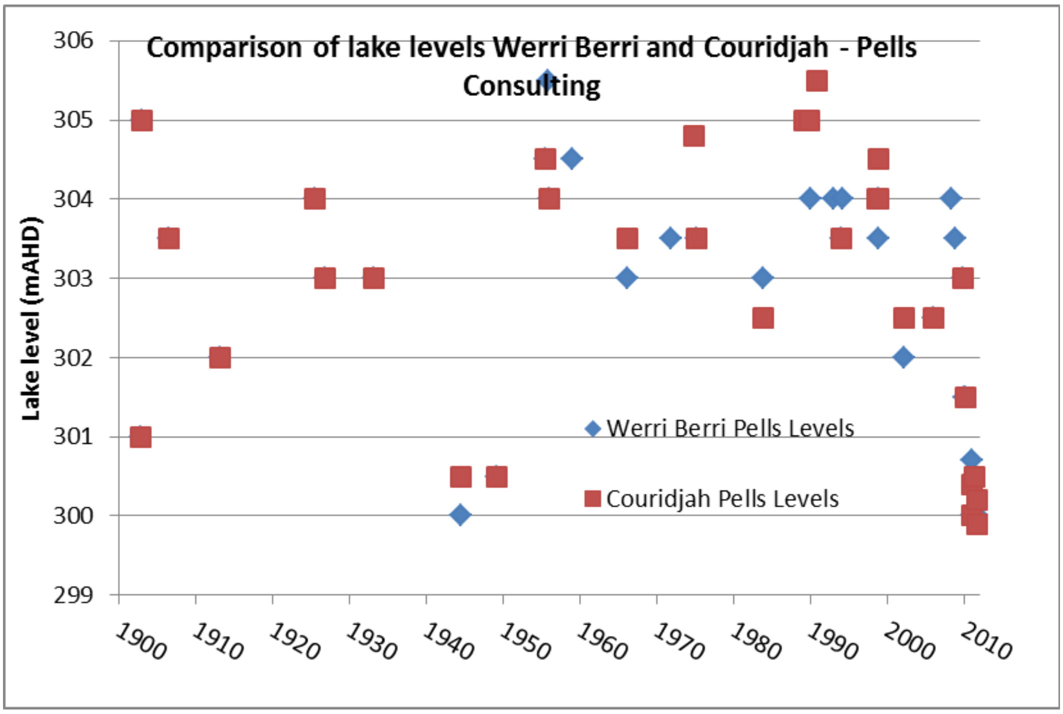

Figure 5-29. Comparison of lake levels for Lakes Werri Berri and Couridjah using Pells Consulting estimates.

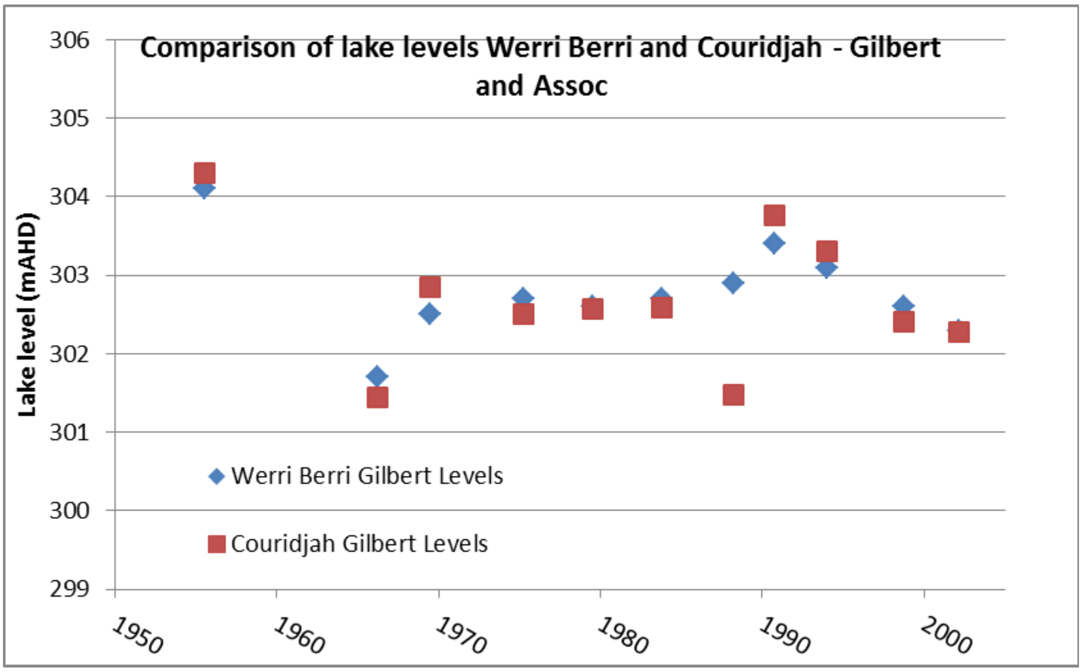

Figure 5-30. Comparison of lake levels for Lakes Werri Berri and Couridjah using Gilbert and Associates estimates.

5.3.11 Conclusion

The aerial photographs show a very high level for the lakes in 1955, with the first three lakes, Gandangarra, Werri Berri and Couridjah connected. At this time Lake Nerrigorang was not connected to the other lakes and Baraba appears as a mainly swamp feature with only a small area of exposed water. From 1955 to 1998 lake levels fluctuated, but were lower than in 1955, as shown in the aerial photographs. From 1990 to the present day lake levels have declined.

The anecdotal and terrestrial photographic evidence suggests that fluctuations in lake levels of the order of 2 to 3 m or more within periods of 12 to 24 months were not uncommon and it is known that the 1974 high lake levels do not appear in the 1975 aerial photograph. Hence, the aerial photographs may not have captured the actual variations in lake levels. Recent changes in lake levels will be captured more often by the satellite imagery.

There are differences among lake levels estimated by the Committee, Pells Consulting (2012) and Gilbert and Associates (2012). Lake levels are critical in the modelling presented by Pells Consulting (2012) and Gilbert and Associates (2012). Uncertainty in the lake levels increases the uncertainty of the results obtained by the modelling.

Further complicating matters is the possibility that the catchment areas may be dynamic, responding to hydrologic conditions in the catchment and changing over the decades. This is particularly true of the catchments of lakes Couridjah and Baraba.

Lake Nerrigorang has featured in an argument that it may be significantly affected by depressurisation in the Tahmoor Colliery through breaching of the Bald Hill Claystone. However, the lake has an unclear history. Not only is there the possibility of geomorphic induced changes in lake levels arising from alluvial fans but there has been some, probably minor, disturbance of the outlet channel. It has not behaved anomalously over the period June-August, 2012 and fluctuations are consistent with evaporation and movements in the levels of the other four lakes.

5.4 EVALUATING THE HYDROLOGY MODELS FOR THIRLMERE LAKES

5.4.1 Introduction

The first hydrology model the Committee used in order to understand the sensitivity of the Thirlmere Lakes to hydro-meteorologic conditions was the annual average model (Section 5.2.1). There could be nothing simpler than this model, but it immediately highlighted a problem. For the lakes, there is only information on lake levels (lake volumes with survey information) and rainfall. None of the other critical parameters used in hydrology modelling, namely, groundwater storage and flows, evaporation and evapotranspiration, and overflow into Blue Gum Creek, are measured. They can only be calculated by using relevant formulae and data, estimated by extrapolation from stations nearby where they are measured, or interpolated from appropriate case studies of similar environments.

Lake levels are a critical parameter of interest in Thirlmere Lakes. It is the parameter that is to be predicted by the hydrology models. Any errors in the value of lake levels can become a significant source of error in modelling as the modelling is optimised on lake levels.

No hydrology model is a perfect representation of the hydrologic system it models. Hydrology models are abstractions that encapsulate the critical parameters of the hydrologic system of the catchment. For this reason a number of hydrology models may be relevant in modelling water levels in Thirlmere Lakes. No model is necessarily the “right” model, but some models, by virtue of their structure, are more appropriate and relevant than other models.

Hydrology models are commonly optimised against estimates of the predicted variable. It is common to split data sets into two periods, the first set of data being used to calibrate the model and the second used to test the outcomes or predictive capacity of the model. For Thirlmere Lakes the data set is the record of lake levels. The best modelling scenario would be to have an accurate record of a cycle of drought-dominated and flood-dominated regimes for calibration (optimisation). The model would then be applied to the present cycle as a predictive tool. However, there is neither a complete and accurate record of lake levels nor sufficiently long period of record to split the record for independent optimisation. An alternative approach is to derive model parameters from similar terrains, which removes some of the uncertainty, but again, the estimates of lake levels are still being used to optimise the model.

The two hydrology models applied to Thirlmere Lakes (Pells Consulting, 2012; Gilbert and Associates, 2012) use the available and imperfect data set of lake levels to optimise (fit) the models and then use the models to make predictions about what the lake levels should be during the period of interest (1990 to 2011). There is some circularity in the argument.

5.4.2 Hydrology models of Thirlmere Lakes

Pells Consulting (2011, p. 65) first used a water balance model to estimate the range of key hydrologic parameters. They then used the rainfall-runoff model SimHyd to estimate daily runoff volumes into the lakes. The model was optimised to fit the lake volume (lake level) data, ensuring that estimated parameters were "*reasonable and appropriate*". The model predicted higher levels than those observed. A second simulation was undertaken using SWMM 5[4] (Pells Consulting, 2011, p. 70). "*Iterations of the model were undertaken with different parameters until a model was found that provided both a sensible balance of quantities, and a good representation of historical lake levels*". It is important to note that the model was predicting Lake Nerrigorang levels of 308-309 mAHD and Werri Berri and Couridjah levels of the same magnitude for 1955 to 2000, with significant fluctuations of the order of 1 to 2 m in this period.

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[4] SWMM = Storm water management model

Subsequent modelling by Pells Consulting (May 2012 and June 2012) was undertaken when the Independent Committee notified Pells Consulting of significant surveying errors in their October 2011 report. The new modelling resulted in a reduction in the combined volume of the lakes from more than 3 GL to approximately 1.77 GL (Pells Consulting, June, 2012, p.4).

There are still errors in the revised analysis of Pells Consulting (June, 2012, p.4ff). This is best seen in relation to Lake Gandangarra, to which both Pells Consulting (June 2012) and Gilbert and Associates[5] (April 2012, p.9) attribute a volume of approximately 50 ML. In Pells Consulting (June, 2012, p. 9, their Fig. 3) their simulation shows the lake level oscillating between 303 mAHD and 305.5 mAHD (approximately). The Committee established a piezometer on this lake at a time when it was low, but with approximately 1m depth of water in its lowest section (we did not measure the lowest elevation of the bed (Figure 5-31). The base of the Gandangarra piezometer (i.e. lake bed at the piezometer) is 301.67 mAHD. Lake Gandangarra does not overflow into Lake Werri Berri until the water level is at 302.8 mAHD. The Committee photographed the Gandangarra piezometer in March 2012 (Fig. 5-32) and May 2012 (Figs 5-33 and 5-34). It is clear from the May 2012 photographs (water level at 302.8 mAHD and within 20 cm of overflowing into Lake Werri Berri) that the lake has approximately 2 m of water in it before it overflows into Werri Berri, at which point the control on height in Lake Gandangarra is the col between Lakes Baraba and Couridjah, which is at 305.8 mAHD. At the water level of May 2012 another 3 m of water are required before Lake Gandangara is full to overflowing into Lake Baraba, via Werri Berri and Couridjah. Lake Gandangarra probably has a volume (lake area is approximately 11.5 ha) of at least 100 ML before it overflows into Werri Berri. When full, Lake Gandangarra has a volume of at least 300 ML and

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[5] There is some uncertainty about the volume estimate as they report lakes Gandangarra, Werri Berri and Couridjah merging at 302.86 mAHD, which is correct, but the graph (their Fig 3.1 and 3.3) does not show a step in the water-level volume curve for either Werri Berri or Couridjah that would occur on amalgamating with Gandangarra.

probably closer to 400 ML (lake full level measured as approximately 306 mAHD on northern edge).

Figure 5-31. Lake Gandangarra piezometer at installation, 10 February 2012.

Figure 5-32. Lake Gandangarra piezometer 9th March 2012.

Figure 5-33. Lake Gandangarra piezometer, 3 May 2012. The cap can just be seen protruding from the water.

Figure 5-34. Lake Gandangarra piezometer, 3 May 2012, with similar wide angle view to Fig. 5-31.

Gilbert and Associates (2012, p. 24) used the AWBM[6] model. They calibrated the parameters on O'Hares Creek, whose catchment (73 km^2) is significantly larger than Thirlmere Lakes catchment although it is in the same Hawkesbury Sandstone terrain. Groundwater recharge rates were optimised to the aerial photography and satellite imagery estimates of lake levels (1955-2011). Hence, there is only one parameter being obtained by optimisation, but the implication is that the values of the other parameters are known, and are the same as O'Hare's Creek. The groundwater recharge rates were 1.14 ML/d for when the lakes were full and 0.64 ML/d when the lakes were dry (Gilbert and Associates, 2012, p. 29). Over a 50 ha area a 1.14 ML/d groundwater loss represents a loss of 23 mm of water per day or 16 cm per week (which accords with Vorst's (1974) observation of the rate of fall of the lakes following a storm) but ignores evaporation of several mm per day. Gilbert and

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[6] AWBM = Australian Water Balance Model

Associates (2012) estimated lake volume as 1.7 GL (Gilbert and Associates, 2012, p.i).

Some of the groundwater loss from Thirlmere Lakes is undoubtedly groundwater discharge down Blue Gum Creek. The hydraulic gradient down Blue Gum Creek, using water levels at the Nerrigorang and Fence piezometers, is 7.3 m over 2000 m (ignoring the occasional possibility that the groundwater slopes towards the lake, i.e. upstream, in the vicinity of the outlet). Assuming that the sediments in Blue Gum Creek are 50 m wide and 2 m deep, the hydraulic conductivity of the sediments, for the larger groundwater recharge rate of 1.14 ML/d is approximately 3100 m/day (0.035 m/s). Unconsolidated sediments (gravels and sands) can have hydraulic conductivities ranging from 1 to 10^{-5} m/s. Measurements of saturated hydraulic conductivity at the outlet of Lake Nerrigorang gave an geometric average of 0.019 mm/s (1.9 10^{-5} m/s) . So it is unlikely that all of the groundwater loss through “recharge” is groundwater leakage down Blue Gum Creek. More likely there is recharge of local and deep aquifers on the margin and beneath the lakes as well as loss of water due to groundwater flow down Blue Gum Creek. Further supporting Gilbert and Associates (2012) estimates of groundwater loss is the obvious rapid decline in lake levels previously described (Section 5.3.2) and which could only be attributed to groundwater loss unrelated to mining. As indicated previously, the groundwater loss is probably highly variable, depending on lake levels. It is high when lake levels are high and lower, maybe lower than suggested by Gilbert and Associates, when lake levels are low. The important point is that the “recharge rates” of Gilbert and Associates are possible when the complexity of groundwater flow paths is considered.

Using Gilbert and Associates’ (2012) estimate of groundwater recharge rates the lakes would drain within approximately 5 years without rainfall and runoff adding to the water storage.

Comparison of estimated and predicted water levels for lakes Werri Berri and Nerrigorang using the AWBM (Gilbert and Associates, 2012) indicates that there are some significant discrepancies of up to 3 m between estimated and predicted (Fig. 5-

35). Gilbert and Associates (2012) present graphical details of their modelling for all five lakes (their Figures 6.3, p. 36; Figure 6.4, p. 37; Figure 6.6, p. 39 and following) for the period 1955 to 2011. Comparison of the predicted levels of lakes Gandangarra, Werri Berri and Couridjah for elevations above 302.8 mAHD should be the same. The elevation at which the lakes flow into each other is 302.8 mAHD. There is a significant accord in predicted levels above the critical 302.8 mAHD, but the levels are not exactly the same for the whole period. Comments have already been made about the estimate of water levels from the aerial photographs for the lakes. Errors in these estimates, particularly when they relate to the amalgamation of lakes Gandangarra, Werri Berri and Couridjah, may have significant impact on the model predictions. The wide range in fluctuations in Lake Gandangarra if its bed is assumed to be at less than 301 mAHD (Gilbert and Associates, 2012 have the bed at 301 mAHD) and divergence from the other two lakes, Werri Berri and Couridjah, are not as evident as might be expected in Gilbert and Associates' (2012) graphical presentations of the simulations, particularly for elevations below 302.8 mAHD.

Comparison of Pells Consulting estimates and predicted water levels for lakes Werri Berri, Couridjah and Nerrigorang (Fig 5.36) indicates that there are a number of differences greater than 1 m although the majority of predictions are within 1m. This agreement between estimated levels and predicted is not unexpected as SWMM was optimised on the estimated lake levels.

For both models a difference of 1 m in lake elevation represents more than 15% of the deepest depth of the lakes (maximum depth 6-7 m). The differences between predicted and estimated water levels are not inconsequential in making conclusions from the modelling.

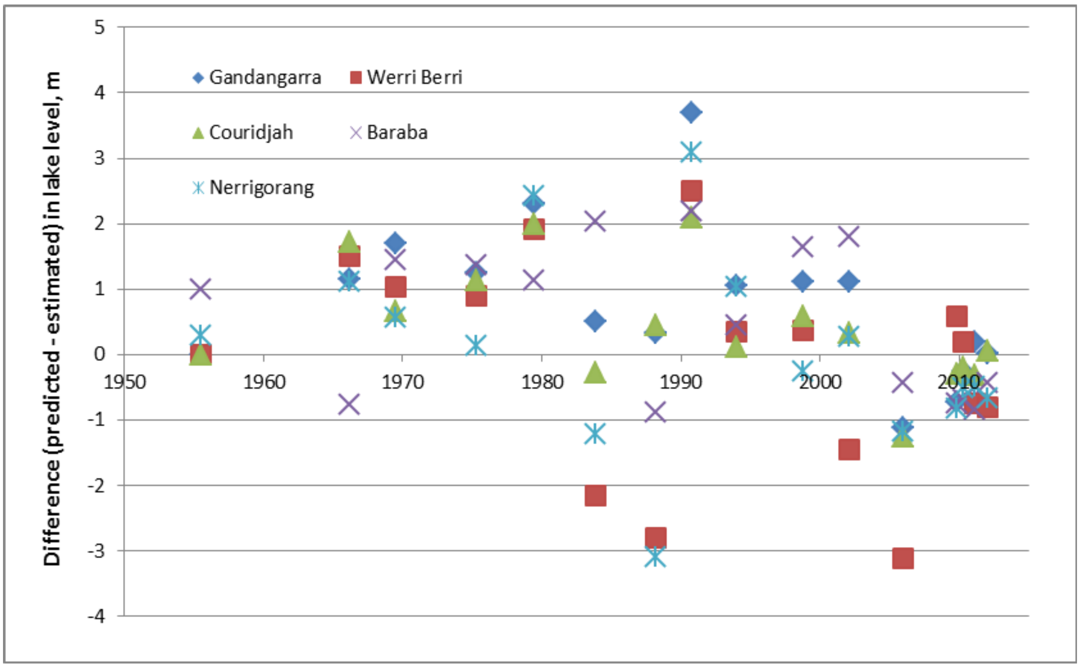

Figure 5-35. Differences between estimated and predicted water levels, using AWBM model, for all lakes (Gilbert and Associates, 2012).

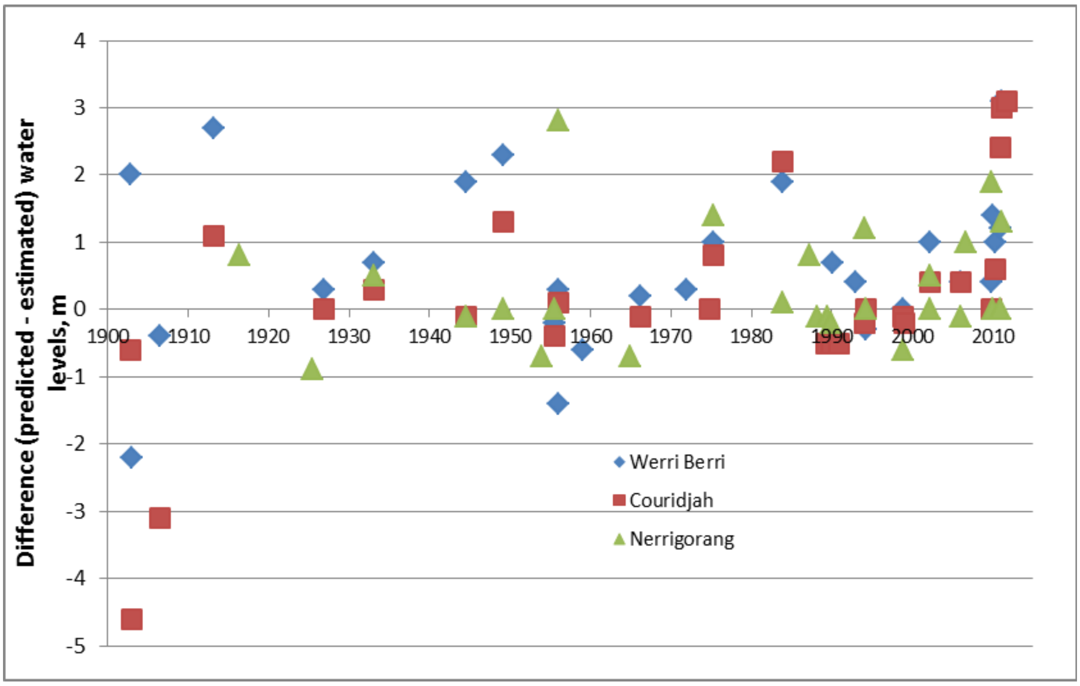

Figure 5-36. Difference between estimated and predicted water levels using SWMM5 model, for lakes Werri Berri, Couridjah and Nerrigorang (Pells Consulting, 2012).

The SWMM and AWBM models use lake level data with potentially significant errors. There is no “right” hydrology model for Thirlmere Lakes. Pells Consulting (June, 2012) argue that their model, with the revised data set corrected for elevation, shows the lakes have fallen more than predicted, and, in particular, Lake Nerrigorang is much lower than predicted. Pells Consulting (June, 2012) argue that enhanced groundwater loss in Lake Nerrigorang is a result of depressurisation of the aquifer due to subsurface mining. Gilbert and Associates (2012) argue that their model shows that the variations in lake levels are as predicted by climatic factors.

There is a salutary lesson in the modelling presented by Pells Consulting (2011 and June 2012) and Gilbert and Associates (2012). With a halving of the estimated volume of the lakes and significant changes in estimates of lake levels, Pells Consulting (June, 2012) still get the same answer as their earlier work (Pells Consulting, October 2011), i.e. the lakes, and Lake Nerrigorang in particular, are lower than predicted in the last decade.

Errors in estimates of elevations and errors with regard to Lake Gandangarra storage capacity suggest any conclusion based on either model (SWMM or AWBM) has to be treated with great caution.

The Pells Consulting (June, 2012) assertion that there is clear evidence in the modelling of anomalous low levels in Lakes Werri Berri, Couridjah and Nerrigorang has to be treated with great caution. Similarly, the Gilbert and Associates (2012) assertion that the lakes are simply responding to changes in climate variations (droughts and heavy rains) has also to be treated with caution.

Many people have relied on the earlier Pells Consulting (2011) SWMM model to justify their stance that mining has caused the lake levels to drop. The uncertainty of the data used in the models, and hence the models themselves, do not justify this stance. Monitoring over the last 3 months by the Independent Committee suggests that fluctuations in lake levels can be explained by evaporation with possibly some groundwater transfer among the lakes and with Blue Gum Creek.

Further complicating the modelling work is suspected non-stationarity in the hydrologic system as a result of dynamic changes in catchment areas, which is not included in either model. In addition, there is a body of evidence, still under discussion, that there have been changes in the rainfall-runoff relation in catchments in southeastern Australia as a result of the Millennium Drought (Petheram et al., 2011; Potter et al., 2011). If a system is non-stationary the parameters that define the hydrologic behaviour of the system change, and calibrations based on earlier sets of data may not be appropriate for prediction. Calibrations based on data which encompass system change and assume steady state will be questionable as predictors of system behaviour.

The Committee saw no benefit in trying to repeat the modelling with yet another model. The data uncertainties do not warrant another attempt and nothing would be proved. Furthermore, the hydrologic system is probably non-stationary, further complicated by the impact of natural and human-induced climate change, most notably temperature rises, and the impact of bushfires on rainfall, runoff and evaporation regimes.

It is clear that a better set of hydrologic data is required. Some of the ambiguity in assessing how well the models fit the lake-level data would be removed with a more complete hydro-meteorology data set. At the very least a hydro-meteorology station needs to be established collecting information from the Thirlmere Lakes catchment on:

- Rainfall
- Lake levels
- Groundwater levels
- Radiation
- Wind speed and direction
- Soil moisture levels
- Blue Gum Creek flows
- Wet and dry bulb temperatures.

Such information, collected over a period of 3 to 5 years, should be sufficient to build a robust hydrologic model of the catchment and the lakes.

5.4.3 An explanation of the divergence between estimated and predicted lake levels

It is clear from the SWMM5 and AWBM modelling that there is divergence between model predictions and estimated (measured) levels of the lakes. Some of this can be attributed to errors in surveying, some to errors in estimates of previous lake levels on which the models are calibrated, SWMM5 more so than AWBM, some to changes in catchment geometry, and some to the fact that the significance of Lake Gandangarra has been underestimated.

Lake Gandangarra has the largest sub catchment area of the 5 lakes (144.7 ha according to Pells Consulting, July 2012). The Gandangarra catchment area is 33% of the total Thirlmere Lakes catchment. Lake Nerrigorang on the other hand has a sub catchment area of 65 ha, which is 15% of the total catchment area.

The Committee’s observations have shown that Lake Gandangarra can store a large volume of water before it overflows, and when it merges with Lakes Werri Berri and Couridjah it represents a significant volume of the storage in the three lakes. The significance of Lake Gandangarra is somewhat disguised by the dense reeds that surround it, hence its local name of “Reedy Lake”.

Lake Gandangarra is the headwater control of the Thirlmere Lakes system. Werri Berri has too small a catchment area relative to its volume (or surface area) to fill rapidly and, as the lower lake in terms of bed elevation, requires overflow from Couridjah and Gandangarra to fill. Once the cols between the lakes are overtopped the three lakes behave as one, with the catchment of Gandangarra being the dominant supply source for the three lakes.

Lake Couridjah has a catchment area of approximately 64 ha according to Pells Consulting (June 2012), but a larger catchment area in reality if the dynamic behaviour of the area to the south east of the lake is considered, as previously discussed (106 ha according to Gilbert and Associates, April 2012). Using the Pells

Consulting estimate of catchment areas the 3 upper lakes account for 62% of the total catchment area (72% according to Gilbert and Associates, April 2012). Lake Baraba is a buffer as it occupies a high level in the valley floor, is literally a sponge, and has cols at either end that are approximately the same elevation (within 0.3 m) and resistant to erosion. Groundwater can be discharged in either direction, although the gradient towards Lake Couridjah would favour the upstream direction when Couridjah is low.

Lake Nerrigorang, on the other hand, is isolated from the interbasin dynamics upstream of the Baraba-Nerrigorang col. It is entirely dependent on local runoff and groundwater flows until overflow and groundwater flow from upstream contributes to its stored water. Complicating the capacity for Lake Nerrigorang to hold a significant quantity of water is the potential for groundwater leakage into Blue Gum Creek, which probably accounts for a significant loss of water from the lake. It is not unexpected that Lake Nerrigorang behaves differently from the other four lakes, particularly when water levels are low in all the lakes. It is highly likely that as the lakes dry out in a rainfall deficit period (drought) Lake Nerrigorang becomes less hydrologically attached to the upstream lakes and hence appears to behave “erratically’.

In effect there is a three-part hydrological system. Gandangarra, Werri Berri and Couridjah form the upper component, with Gandangarra having a significant role in the behaviour of the system (response to rainfall and fluctuations in lake levels). Lake Baraba is something of a “buffer” between the three upstream lakes and Lake Nerrigorang. Finally, Lake Nerrigorang is an independent lake system in times of rainfall deficiency (drought) but is linked to the upstream system when upstream lake levels are high and sufficient water can move downstream either by overland flow or through groundwater seepage.

5.5 CONCLUSIONS

1. There is clear evidence that the lakes have been dry in the past, but the extent of “dryness” in the last 100 years is open to debate. (Section 5.3).

2. Under average rainfall conditions it would take nearly a decade for the lakes to fill (Section 5.2.2).

3. Very heavy rainfall, where the runoff as a percentage of the rainfall is high, is probably the mechanism by which the lakes fill, as observed by the Committee during the January to March 2012 storms (Section 5.3.4).

4. Rapid falls in lake levels following initial filling are explained by water discharging from the lakes into local groundwater stores or being absorbed into the peat (Section 5.3).

5. There are errors in estimates of lake levels and volumes by Pells Consulting (June 2012) and Gilbert and Associates (2012), as identified by the surveying undertaken by the Independent Committee (Section 5.3).

6. Recent fluctuations in levels of the lakes monitored by the Independent Committee are consistent with evaporation and local rainfall, and do not need to be explained by enhanced levels of groundwater loss (Section 5.1).

7. Fluctuations in lake levels of the order of 2 or 3 m in less than a year, recorded prior to mining, suggest that groundwater losses are a significant natural part of lake hydrology (Section 5.3).

8. The sub-catchments are dynamic and this will affect modelling. Neither SWMM nor AWBM, as applied to Thirlmere Lakes, take account of this dynamic behaviour (Section 5.4).

9. It is highly likely that the hydrologic system is non-stationary, which will affect optimisation of the models and predictions based on the results of the optimisation (Section 5.4).

10. Lake Nerrigorang is a semi-independent water body in the five lake system (Section 5.3.9).

11. Lake Gandangarra has a significant role in the behaviour of the three upstream lakes and can store a large volume of water (Section 5.4.3).

6.0 HYDROGEOLOGY OF THIRLMERE LAKES

6.1 A GROUNDWATER REGIME

Thirlmere Lakes occupy a topographic high, which means that groundwater will flow away from the lakes, especially for the area outside of the zone that could be classified as within the groundwater catchment of the lakes. The topographic position of the lakes suggests that there must be a net loss of groundwater from the lakes.

The east to east-northeast dip of the bedrock imposes a hydraulic gradient on the groundwater towards the east. The following explains the significance of this eastwards dip.

In a simple perched-lake system, with horizontal strata, one of which is an aquitard below the bed of the lakes, the groundwater geology looks something like Fig. 6-1 for the steady state condition[7].

In the steady state condition, with a balance of inflows and outflows and no overflow into Blue Gum Creek, the following equations apply:

$$I = Et + G1 + G2 + Gv$$
$$G1 = G2$$
$$G1 \text{ and } G2 \gg Gv$$

Where

I = rainfall input
Et = evapotranspiration loss
G1 = groundwater loss to right (or east)
G2 = groundwater loss to left (or west)
Gv = small leakage of groundwater through aquitard
(gwd = groundwater divide)

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[7] These figures are schematic and not to scale and it is assumed that the topography is symmetrical in cross section around the centre line of the lake. It is assumed for simplicity that there is no overflow of excess water into a stream. In all conditions rainwater entering the soil/rock infiltrates vertically downwards until it joins the water table.

For the steady state condition the groundwater divide lies beneath each of the high points and has reached a position that balances the water level in the lake, the evapotranspiration loss from the lake and slopes, and the groundwater flows into the lake, and onto the hillsides wherever the water table intersects the ground surface to the west and east. There is a small leakage of groundwater through the aquitard.

Whenever there is a heavy rainfall, a pulse input, the lake level will rise more rapidly than the groundwater table, so there will be a period when water from the lake flows out via groundwater into the surrounding hillsides, until the steady state condition is re-established.

In a dry period, when the lake itself is dry (= water table below the lowest point in the lake) there will be a diminished flow of water via groundwater onto the surrounding hill slopes, and in extreme dry conditions the groundwater flows G1 and G2 may cease.

In all cases the groundwater divide (gwd) remains either in the centre of the lake or the centre of the symmetrical hills.

The groundwater situation changes when beds dip (non-horizontal beds). In the second schematic diagram (Fig. 6-2) it is assumed that the aquitard dips to the east (right). There is a section of the groundwater body that cannot flow west (left) because the aquitard acts as a barrier for flow towards the west. This is shown as the stippled part underneath the western hill. In effect there is a body of groundwater perched on the aquitard, and over this the groundwater flows either east or west. The groundwater immediately above the aquitard in the western (left) arm of the diagram will flow towards the east (right) as it is recharged by vertically infiltrating water.

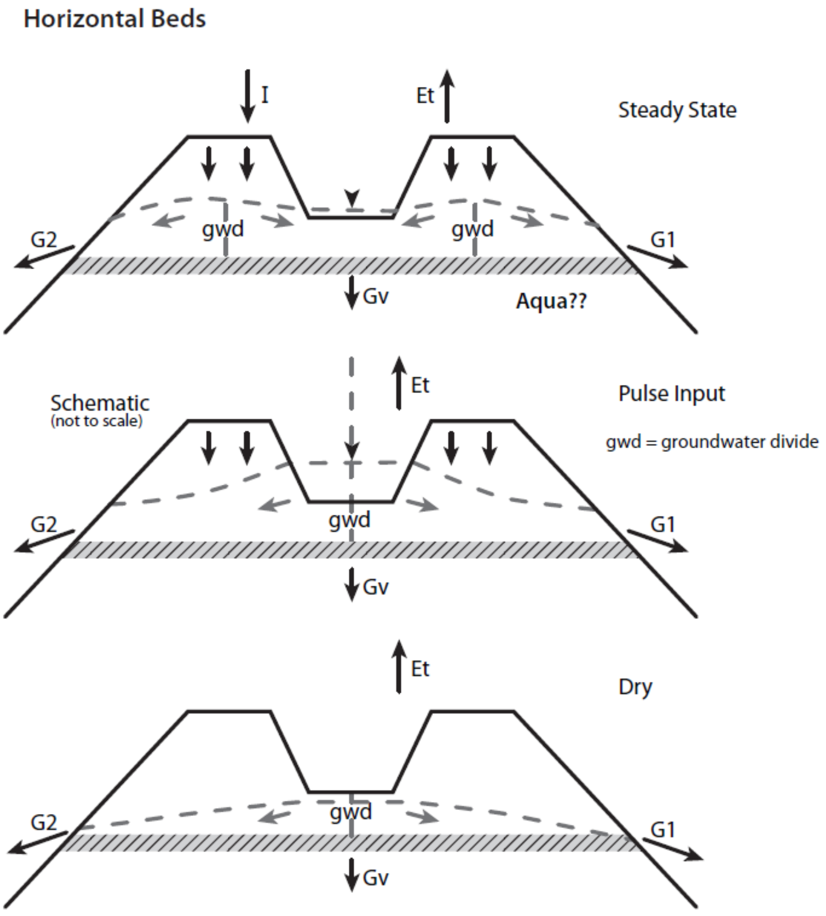

Figure 6-1. Groundwater conditions for perched lakes with horizontal beds.

For the steady state condition the inclined bed scenario results in the groundwater divide being moved towards the up-dip direction, or towards the west (left). As a result, the groundwater discharging to the west is less than that discharging to the east. i.e.

G1 > G2

If the catchment receives a pulse of water and the lake fills, the discharge of water from the lake into the groundwater will occur both to the west and east, but again, the majority of discharge by groundwater will be towards the east (G1). In the situation of rapid filling of the lakes the groundwater divide is at the centre of the lake and will remain so until the water level in the lake declines to a point where it is below the level where the inclined aquitard intersects the western (left) slope. When the lake reaches this level the groundwater divide will migrate towards the west.

In dry conditions (when the groundwater table is below the lowest point in the lake) all the water will eventually drain to the east (left) once the groundwater table drops below the level of the intersection with the western slope. In such a case G2 = 0.

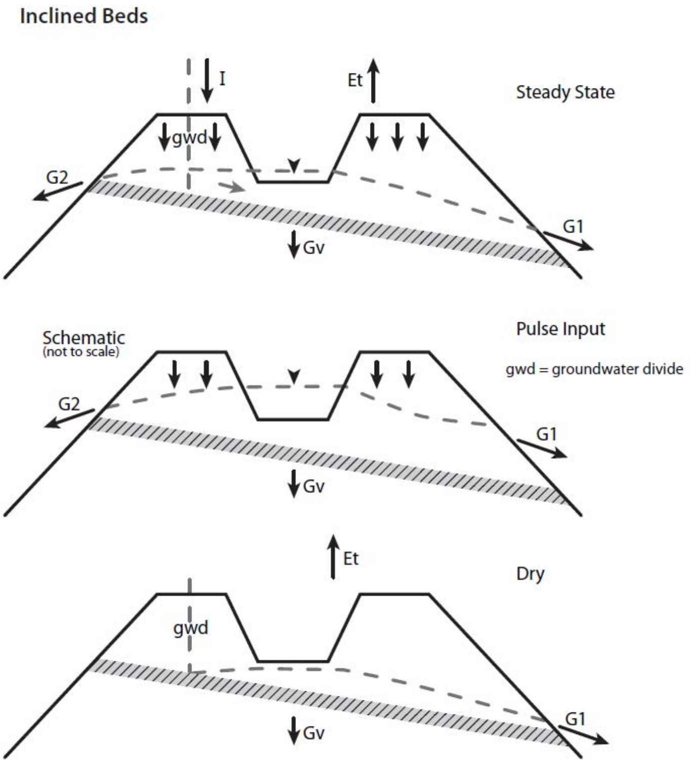

Figure 6-2. Groundwater conditions for perched lakes with inclined beds.

There continues to be some groundwater leakage through the aquitard (Gv), but this will vary in magnitude depending on the head of water. In the dry scenario the vertical leakage will be near zero towards the west.

6.1.1 Significance for Thirlmere Lakes

The two scenarios, shown in schematic form in Figs 6-1 and 6-2, help understand what is happening to groundwater around Thirlmere Lakes. There is a regional dip in the bedrock geology towards the east-northeast, of 2° to 3°. While this does not appear significant, over a kilometre it represents a fall (in the down dip direction) of approximately 34 m for 2° and 52 m for 3°. Irrespective of whether there are one or more aquitards beneath Thirlmere Lakes, the regional bedrock dip and lower topography towards the east suggests that most groundwater flows towards the east.

There is evidence for this hypothesis. The regional mapping of groundwater undertaken by Xstrata as part of their submission (Heritage Computing, 2012) and mapping by this Committee show an eastwards groundwater gradient from Thirlmere Lakes towards the east. The groundwater gradients to the west of the lakes are more complicated.

There are indications in the landscape of this eastward groundwater flow. The railway cutting to the north of the bridge where Bargo River Rd crosses the Main Southern Railway shows groundwater discharging from the east facing slope (Fig. 6-3). The rock is Hawkesbury Sandstone and the elevation is 270 to 275 mAHD. The discontinuity of flow from individual bedding planes and the heterogeneity of discharge points from the rock face are evident as groundwater flow from the west returns to the surface at this cutting. While the Committee acknowledges that the emergent flow is shallow groundwater, it nevertheless demonstrates an eastward flow as there is no seepage on the opposite face.

6.1.2 Groundwater levels underneath the Thirlmere topographic high

The NSW Office of Water (Russell et al., 2010) and Heritage Computing (July, 2012) have argued that there is a high in the groundwater table underneath the topographic high area to the east of the lakes (between the lakes and to the east of the rail Loop Line, Russell et al., 2010, p. 22, Fig. 21 reproduced below; Fig. 6-4). If this high exists then it will suggest that there is little or no movement of groundwater to the east from Thirlmere Lakes.

Figure 6-3. Groundwater emerging from the east-facing slope on the railway cutting at Bargo River Rd.

The Committee undertook a hydrocensus of bores in the vicinity of this topographic high to assess the nature of the shallow (<150 m) groundwater regime in the area. Details are given in the following section.

6.2 GROUNDWATER MAPPING

Independently, the Committee and Heritage Computing (2012) mapped the groundwater contours in the vicinity of Thirlmere Lakes. These two maps are based on slightly different data, so comparison will identify the robustness of the model of the eastward flow of groundwater.

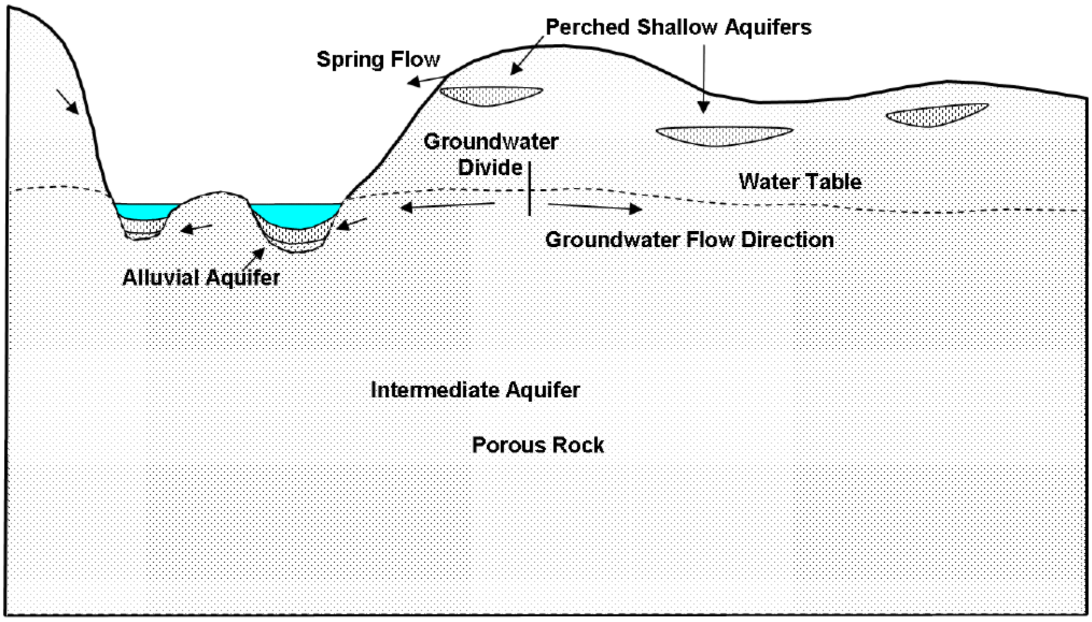

Figure 6-4. Schematic picture of groundwater divide underneath the high area to the east of Thirlmere Lakes (Russell, et al., 2010, p.22, Fig. 2.1).Copyright NSW Government. With permission.

6.2.1 Groundwater mapping by the Committee

A search of the NSW Office of Water database identified 65 private bores for the area between Thirlmere Lakes and Tahmoor. Summary data (bore ID, drilling date, easting, northing, hole depth, depth to water (at time of drilling), yield and lithology) are provided in Appendix 6-1 and Fig. 6-5.

The private bores have been drilled over several decades, with the earliest recorded bore drilled on 1st October 1943 and the last recorded bore drilled on 18th August 2008. Private bores are used locally for stock and domestic water supply, with irrigation or poultry farming being the primary registered groundwater use. Groundwater entitlements attached to these bore licences typically range from 1 ML/year up to 19 ML/year, although Tahmoor Colliery has a groundwater extraction licence of 1,642 ML/year for mine dewatering.

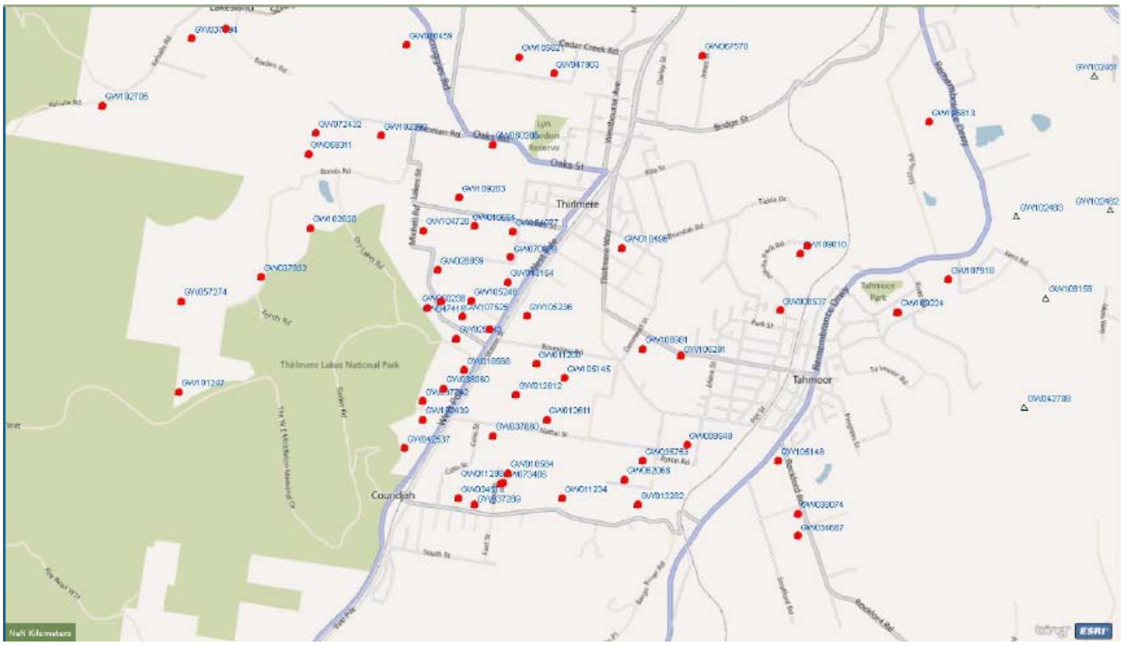

Figure 6-5. Location of bores used in this study.

The majority of bores are open hole construction with multiple water bearing zones contributing to overall bore yields. The recorded bore yields range from 0.113 L/s to 6.69 L/s, with an average of 1.12 L/s.

The data on these bores extend over several decades and reflect the time of drilling and commissioning of the bores. At these times water level is usually recorded, and historical water levels range from 5.7 m below ground level (mbgl[8]) to 94 mbgl. None of the private bores have an automatic water level recorder and none of the bores are manually read for water depth on a regular basis. While water levels in some of the bores have been read at infrequent intervals, these readings are not official recordings and often the record is not kept by the owner.

The bores extend to different depths, with recorded bore depths ranging from 39.6 m and 175 m. It is highly likely that many intersect several aquifers rather than reflecting the water level in any one aquifer. All appear to be located within the Hawkesbury Sandstone above the Bald Hill Claystone.

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[8] bgl = below ground level

The groundwater table was contoured using the recorded water level. Since no survey data (elevation) were available water levels were converted to groundwater elevations (mAHD) using the NSW 3 second DEM. What it shows is an eastward hydraulic gradient, with the groundwater level in the vicinity of Thirlmere Lakes being approximately 310 mAHD (Fig. 6-6). There is a depression in the groundwater surface to the northeast of the lakes.

An attempt was made to stratify the bore data based on information prior to 1980 and that from 1980 to present (Figs 6-7 and 6-8). This is considered to be the pre-mining and mining/post-mining data. The second period also encompasses the Millennium Drought.

Stratifying the data decreases the accuracy of the groundwater contour mapping because there are fewer data points for each map from which to draw the contours. However, comparison of the two maps shows a consistent westward movement of any particular contour. That is, for any particular point, the groundwater surface was lower during the period 1980 to present than it was prior to 1980. The accuracy of the contours has to be taken into account when trying to estimate the extent of the lowering, but it appears to be of the order of 10 to 20 m, reducing towards the west. There is a strong indication from the comparison of the two contour maps that the groundwater table has lowered and steepened towards the east, from the lakes, between the two periods.

Splitting the groundwater data set at 1980 does not imply that changes in groundwater levels between the two periods reflect the impact of mining. A number of factors may be impacting on groundwater levels in the post 1980 period, including reduced rainfall and associated reduced aquifer recharge, and increased pumping from the groundwater reservoirs. Mining is a potential factor, but the data do not prove a direct relation.

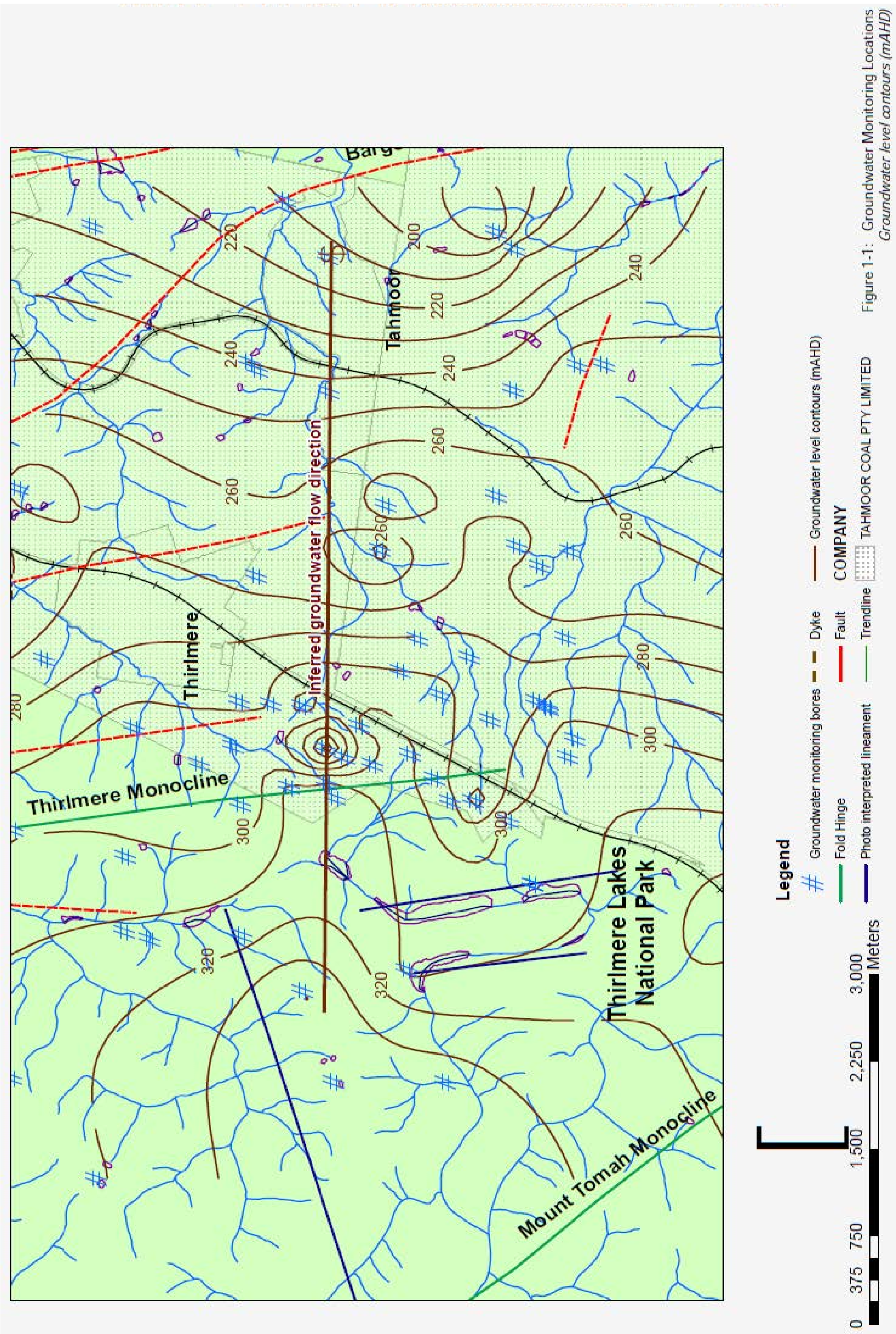

Figure 6-6. Groundwater contours (all data).

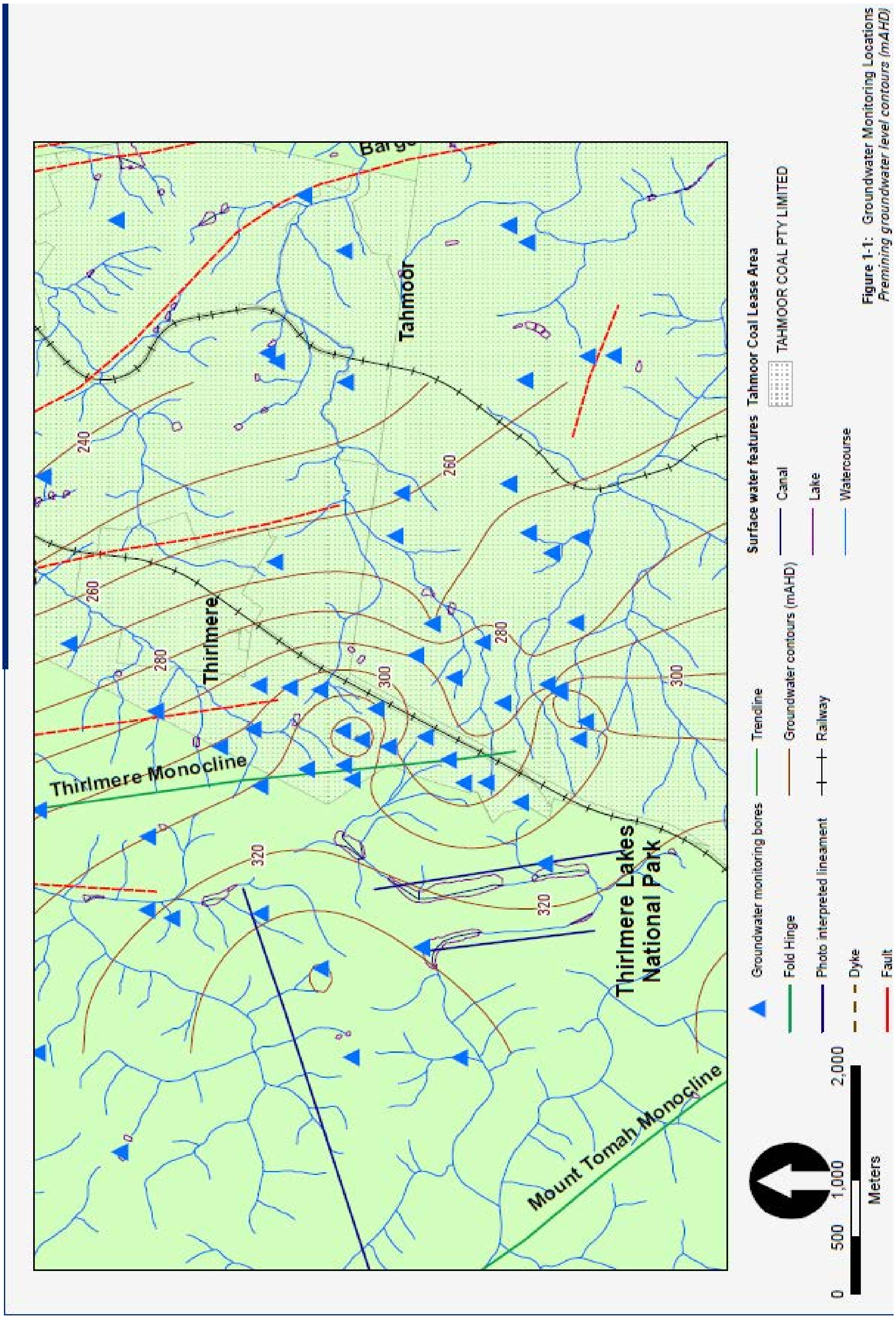

Figure 6-7. Pre 1980 groundwater contours.

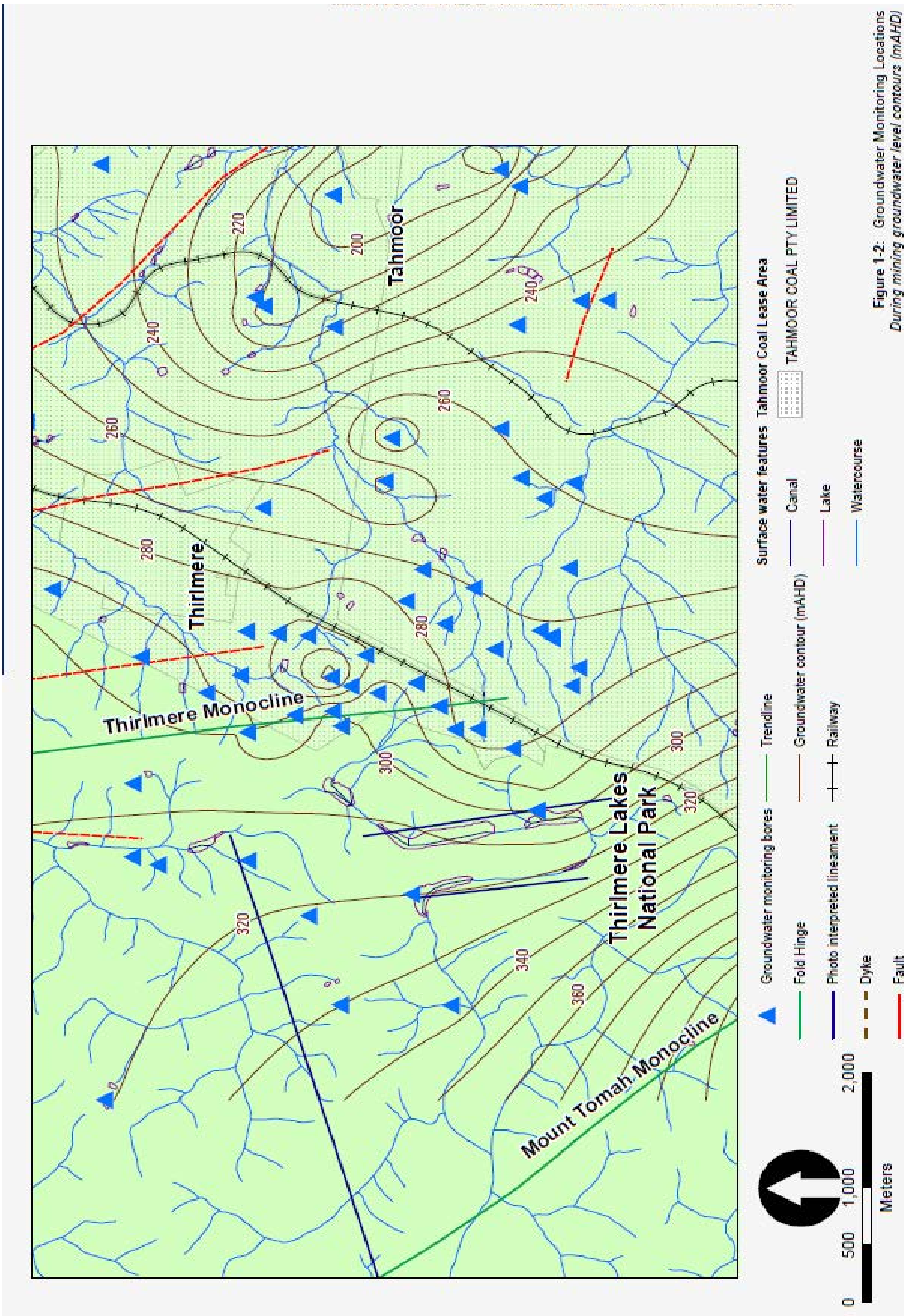

Figure 6-8. Post 1980 groundwater contours.

6.2.2 Groundwater mapping by Heritage Computing (2012)

Heritage Computing (2012) provided two maps of groundwater contours. The first covered a larger area than the second, which was focused on Thirlmere Lakes. The Committee used the former in its analysis because there was an interest in the groundwater to the east of the lakes (Fig. 6-9).

There are some complications with the contours in the vicinity of the lakes. The 300 mAHD groundwater surface contour appears as a very small mound under Lake Couridjah and there is also a 300 mAHD contour high on Blue Gum Creek approximately 1 km downstream from the outlet of Lake Nerrigorang.

The groundwater divide and the orthogonals to the contours were drawn by hand by the Committee in order to identify flow paths in the groundwater (Fig. 6-10) in the horizontal plane. The orthogonals to the contours show the groundwater flowlines in the horizontal plane and does not imply there is no vertical flow at the same time. The uncertainty in the groundwater divide becomes immediately obvious as it is possible to show the divide passing through the eastern arm of the lakes or well to west of the lakes. For the time being it is assumed that the divide is as shown with the dashed line (through the eastern arm of the lakes) and not the line with question marks.

The position of the groundwater divide suggests that groundwater flow from the three eastern lakes (Gandangarra, Werri Berri, and Couridjah) is towards the east. Because the higher Lake Baraba discharges into the upstream lakes, it is likely that water in this lake also discharges groundwater that flows towards the east.

Lake Nerrigorang is another matter. Groundwater flow may be either towards the west or east, depending on where the groundwater divide is placed. Based on the Committee’s observations of groundwater flow in Blue Gum Creek and at the outlet, it is likely that shallow groundwater flow is towards the west, into Blue Gum Creek, but deeper groundwater flow beneath the lake is another matter. If the uncertainty in the contouring in the vicinity of Nerrigorang is a result of a localised high in the groundwater table (a groundwater mound) then it is more than possible that flow could be both east and west from this mound.

The flow lines (Fig. 6-10) suggest a significant flow towards the east and east-northeast. There appears to be convergence in the flow lines, which means that, other things being equal, the flow rates per cross sectional area (transverse to the flow) will be greater in this area. The convergence of flow lines in the north may also explain a report by a community member at the public hearings on 31st March 2012. He reported that groundwater flow in the Thirlmere area around the centre of town was a problem in the past.

The conclusion to be drawn from the analysis of the Heritage Computing (2012) groundwater map, within the context of the schema outlined in Fig. 6-2, is that Thirlmere Lakes have preferred groundwater drainage towards the east. The magnitude of this drainage will be a function of hydraulic gradient and the transmissivity of the aquifers.

The western arm of the lakes, particularly Lake Nerrigorang, may be draining towards the west, but this is not certain.

The spread of the flow lines from Thirlmere Lakes towards the east suggest that there is more than a 6 km length along easting MGA 276000 where any extraction of groundwater will impact on groundwater gradients and hence flow from Thirlmere Lakes. By easting MGA 278000 this has spread to a 7 km wide area.

The 300 mAHD groundwater surface contour is in the vicinity of the Lakes. The beds of the lakes are approximately 298-306 mAHD which is within the likely uncertainty in these contours. In other words, the groundwater surface and the lake levels appear to be similar in elevation.

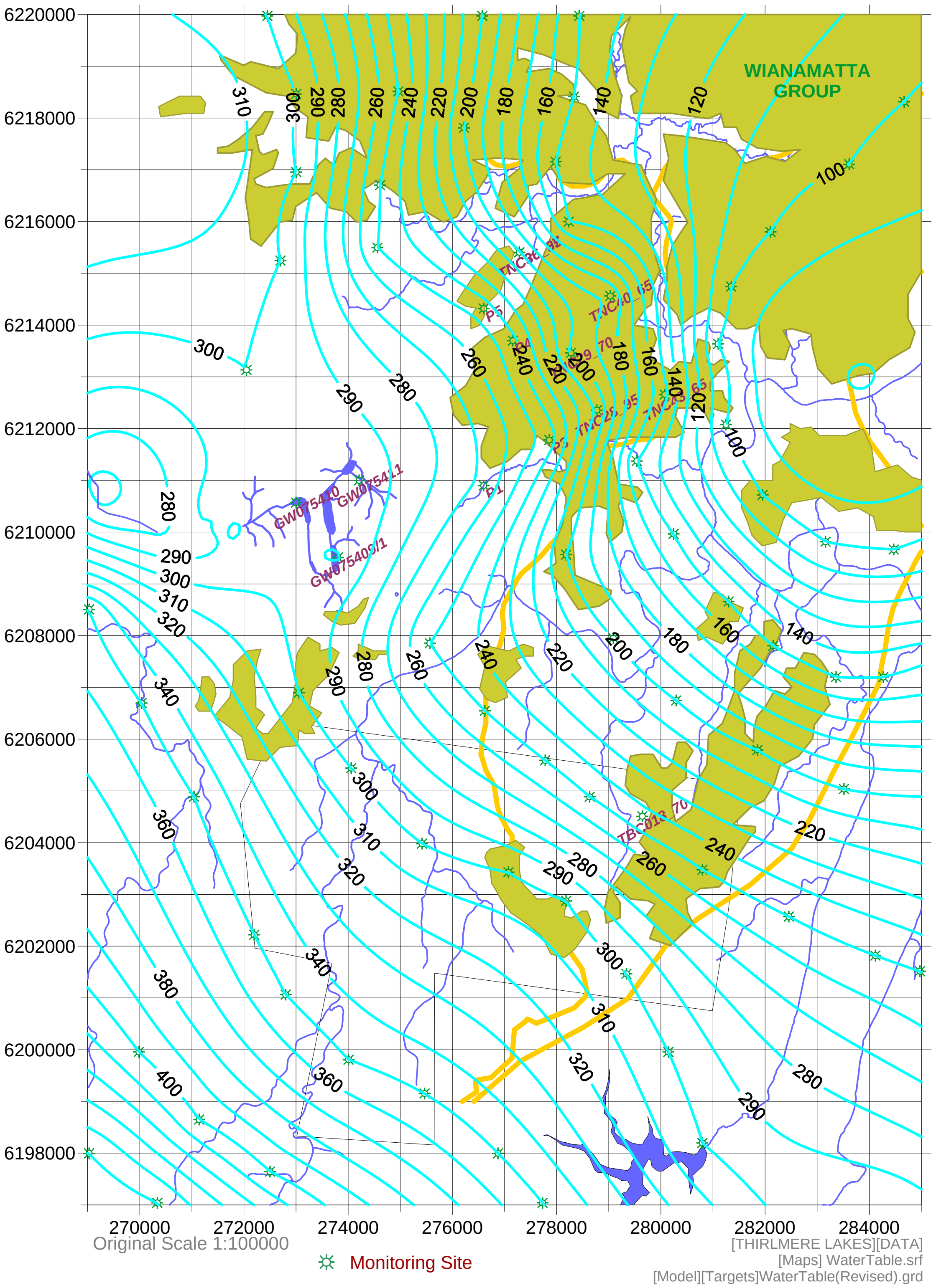

Figure 6-9. Groundwater contours from Xstrata submission (Heritage Computing, 2012) (with permission Xstrata and Heritage Computing).

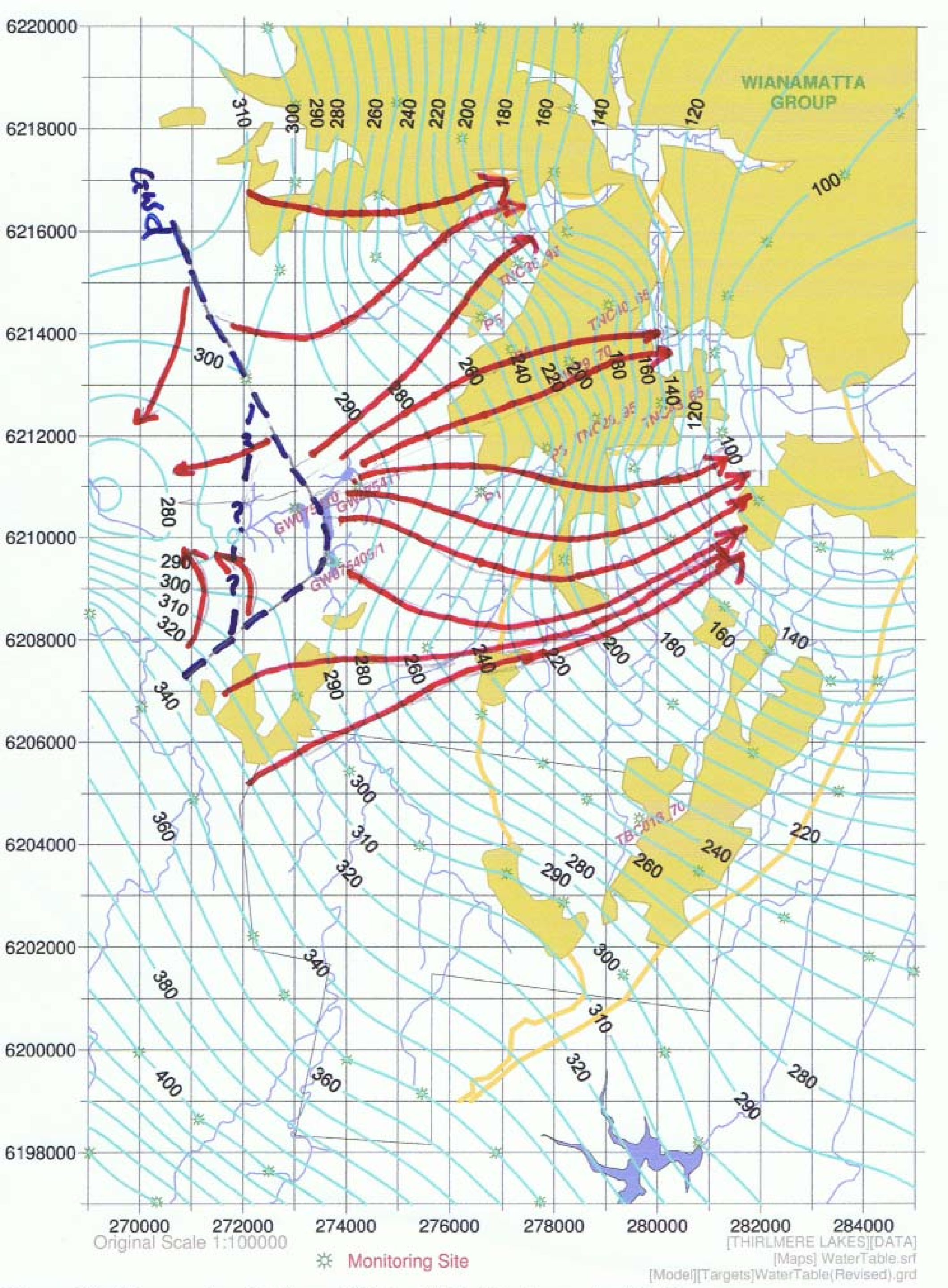

Figure 13. Observed and Inferred Water Table Contours [mAHD]

Figure 6-10. Groundwater divide and flow lines for groundwater in the vicinity of Thirlmere Lakes. The divide and flowlines have been added to the Heritage Computing (2012) groundwater contour map. (Base map with permission Xstrata and Heritage Computing.)

6.3 GROUNDWATER AND AQUIFERS TO THE EAST OF THIRLMERE LAKES

To the east of Thirlmere Lakes the stratigraphy, as discussed in Chapter 3, is dominated by sandstone, primarily the Hawkesbury Sandstone, but also the underlying sandstones of the Gosford subgroup. The Bald Hill Claystone, which is assumed to be a significant aquitard in the stratigraphic column, lies at least 150 m below the surface.

There is a detailed account of the relation between geology and groundwater by Fawcett and Rose (1978) which details the problems they encountered when constructing shafts 1 and 2 and the drift for Tahmoor Colliery. Their account was subsequently supported by an account given by a community member at the public hearing on 30th March at Tahmoor, where he detailed the issues with the drift.

His presentation is reproduced below:

"In 1976 my company were invited by John Downs, the chief engineer of Clutha to take care of "Deviations of Contracts" between the owners, Clutha, and the three main contractors. The 'Drift' contracted by Cementation P/L, the air vent shaft contracted by Phil Crams P/L and Tissen P/L who were building a much larger shaft at Rockford Road for 'man riding' and ventilation.

The three aforementioned companies were highly skilled and experienced hard rock engineers and miners. The contract price for each company was reliant on a specific job description, if for any reason a problem arose outside their contract, it would be resolved by Clutha, under 'Deviations of Contracts".

The main 'Drift' when completed, would be used to bring the coal to the surface by conveyor and stored for shipment. During construction a temporary winder was used to remove "muck" from the working face and also transport miners to and from the rock face. A rail track was used to allow the cable driven wagon to travel up and down the drift.

Sandstone naturally contains other minerals and water. Water is ever present dripping from the rock face, usually containing iron oxides, which makes it a brownie red colour. The volume of water was minimal, but gravity means that it ponds at the working face, making working very difficult or impossible.

At thirty five man hole water was collected as it ran down the drift and was directed into a cut out in the rock on the drifts side. A pumping station was built and the water was pumped to the surface to a settling dam. This system was repeated at different levels (man holes) until the coal seam and yet to be built underground hoppers was reached. During this time the *water table level was reduced by around ten meters. Clutha deepened a number of bores belonging to local farmers who were without water.*

Man riding and ventilation shaft at Rockford Road.

Building a shaft is a different proposition to a drift. Unlike a drift the rock circular walls are concreted 150 mm thick, as the shaft descends. Having learned the danger depths for water tables all care was taken as we approached the presumed level. We had long passed the water level we had calculated, not a drop.

The following morning we returned to site, the three deck working platform was no where to be seen under the water that had burst through the working face. The three deck platform was winches upwards until it was clear of the water. The water that was entering the shaft was only able to get in via the shaft floor, as the walls were a six inch concrete tube.

With divers and eighty 38mm grouting pipes we began the job of grouting the shaft floor and the lower walls that had not yet been concreted. In two weeks we were able to pump out the water and begin production again. The shaft was sunk to 420 metres, with a 15 meter sump at the bottom. We installed three 110 HP twenty stage pumps, one as a spare to keep the shaft dry. These 20 stage pumps were designed to pump at 750 PSI at 20 Litres per second to the surface.

When the shaft was completed the amount of water seepage was small. "

Fawcett and Rose (1978) report that they sank the shafts and drift through approximately 170 m of Hawkesbury Sandstone. Within the sandstone they encountered aquifers that discharged water at 20.8 L/s into the No. 1 shaft. It appeared that the "*inflow came from a distinct underground void in the sandstone which formed a stream path and intersected only a part of the area of the shaft*" (p.80). In the drift they encountered increasing water flow to 13.7 L/s, despite grouting, all within the sandstone.

Fawcett and Rose (1978) obtained some hydraulic characteristics for the sandstone aquifer: a transmissivity of 3.7-9.9 cm^2/s (32 m^2/day to 79 m^2/day[9]) and storage coefficient of 0.27 to $0.750*10^{-3}$. Remnant water inflow increased to 33 L/s in the drift but once the "chocolate shales" were encountered no more significant problems arose with groundwater inflow.

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[9] It is interesting to note that a transmissivity of 32 m^2/day over a 6 km width of rockface and a groundwater slope of 2% gives a groundwater flow of 3.8 ML/day.

Fawcett and Rose (1978) also report encountering zones of friable sand, suggesting that all the cement of the Hawkesbury Sandstone had been removed (possibly through chemical weathering and leaching by groundwater) which may have increased the porosity and hydraulic conductivity of the aquifer in this region. They also obtained an age estimate of pre-1954 for the groundwater via tritium dating.

The account at the public hearing and the paper by Fawcett and Rose (1978) imply that:

a. there was significant lowering of the groundwater table in 1975-1978 near the works as a result of the construction of the drift and shafts;
b. the encountered flows were significantly greater than reported yields in other private bores in the area (typically);
c. there were obvious eastward flowing groundwater paths through the Hawkesbury Sandstone;
d. the Bald Hill Claystone was a significant aquitard;
e. the rate of flow from the east was significant but that the water had been in the aquifer for a period of at least 20 years prior to the construction of the drift.

The report at the public hearing about the localised lowering of the groundwater table accords with the Committee’s analysis of changes in the groundwater table based on groundwater levels pre- and post-1980.

6.3.1 Xstrata details on local groundwater conditions

There is an extensive data set on the hydraulic characteristics and geology of the Tahmoor lease area. A number of packer tests have been conducted by Xstrata consultants (Figs 6-11 and 6-12) at regular intervals to depths of 500 m. Packer tests measure the (largely) horizontal hydraulic conductivity of rock material in a bore hole over a specific depth within the hole. Inflatable bladders or “packers” are used to isolate sections to ensure the tests are specific to a section of the hole. Xstrata has conducted packer tests in 26 bores spread across the lease area, although the majority of the tests are in the eastern section of the lease and there do not appear to be any tests undertaken immediately to the east of Thirlmere Lakes and in the central section of the lease, primarily because this section was mined before packer testing commenced (Fig. 6-12).

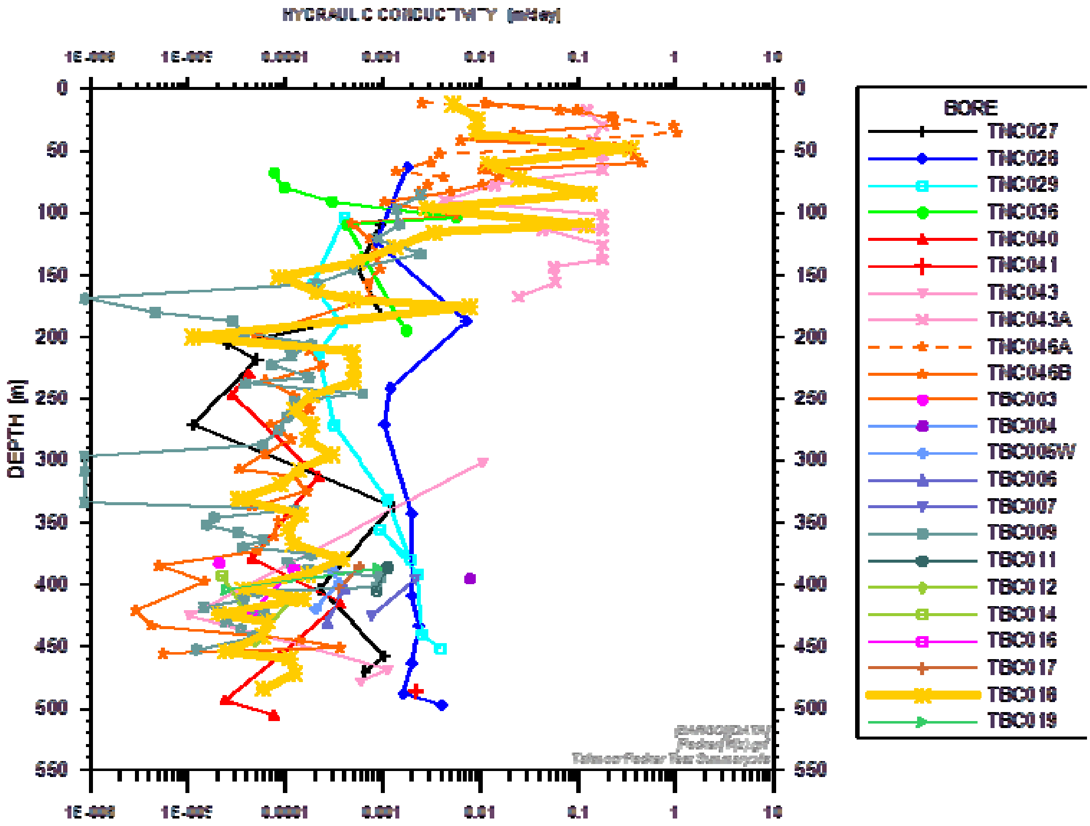


Figure 6-11. Hydraulic conductivities from Tahmoor packer tests. Data courtesy Xstrata and Heritage Computing, 2012. For location of sites see Fig. 6-12.

The packer tests show that there is a significant decline in the hydraulic conductivity in the first 150 m below ground and that below this level the hydraulic conductivities, while exhibiting a wide range of values, are similar. The first 150 m of the bore holes is predominantly Hawkesbury Sandstone. Below this level the Narrabeen Group rocks dominate before the Illawarra Coal Measures are encountered at approximately 400 m depth (depth depends on site). These data formed the basis of Heritage Computing's (2012) groundwater modelling. The probability distributions of the hydraulic conductivities determined by the packer tests at Tahmoor clearly show a difference between the Hawkesbury sandstone and all the lithologies (Fig. 6.13). It is understood that Pells Consulting (2011, 2012) did not have this site information and used more general regional data sets in their analysis.

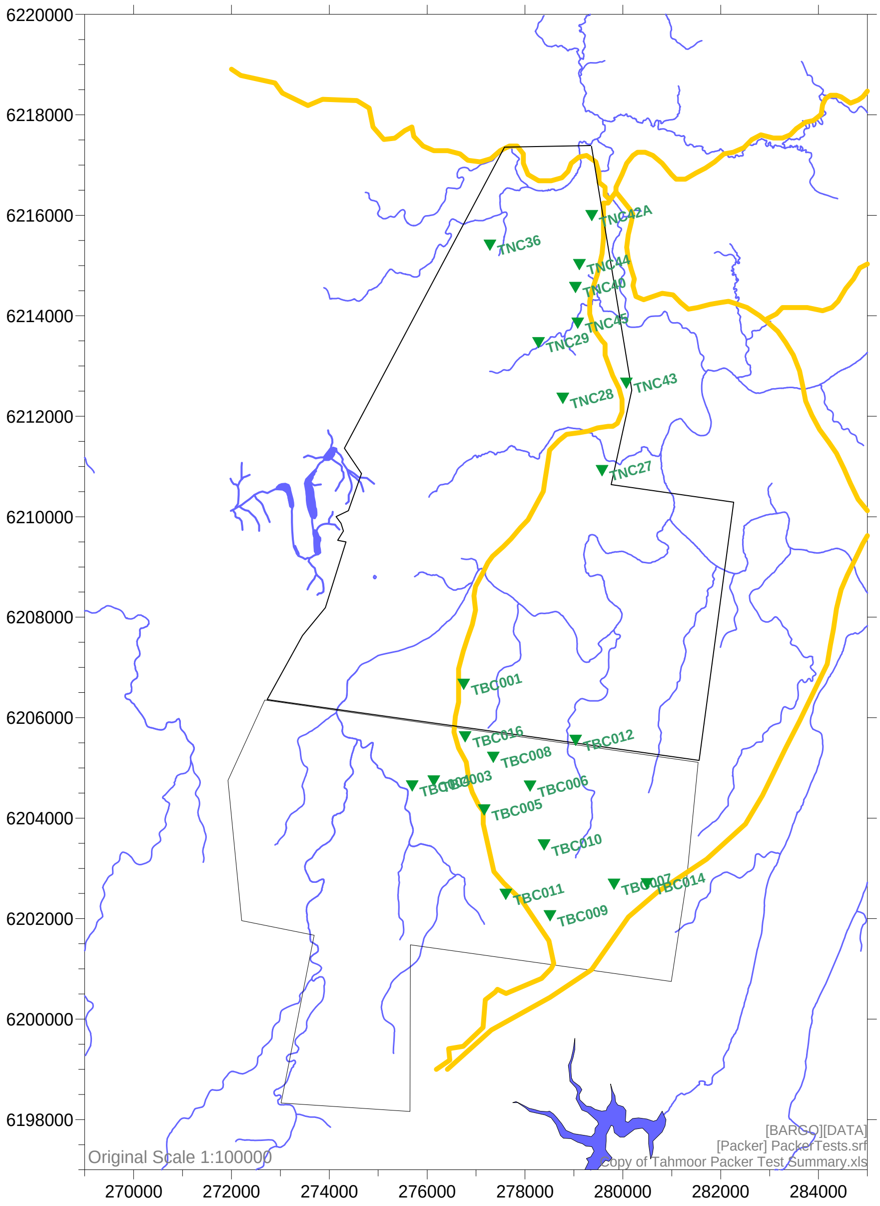


Figure 6-12. Packer test sites (see Fig. 6-11), Tahmoor Colliery. Data courtesy Xstrata and Heritage Computing (2012).

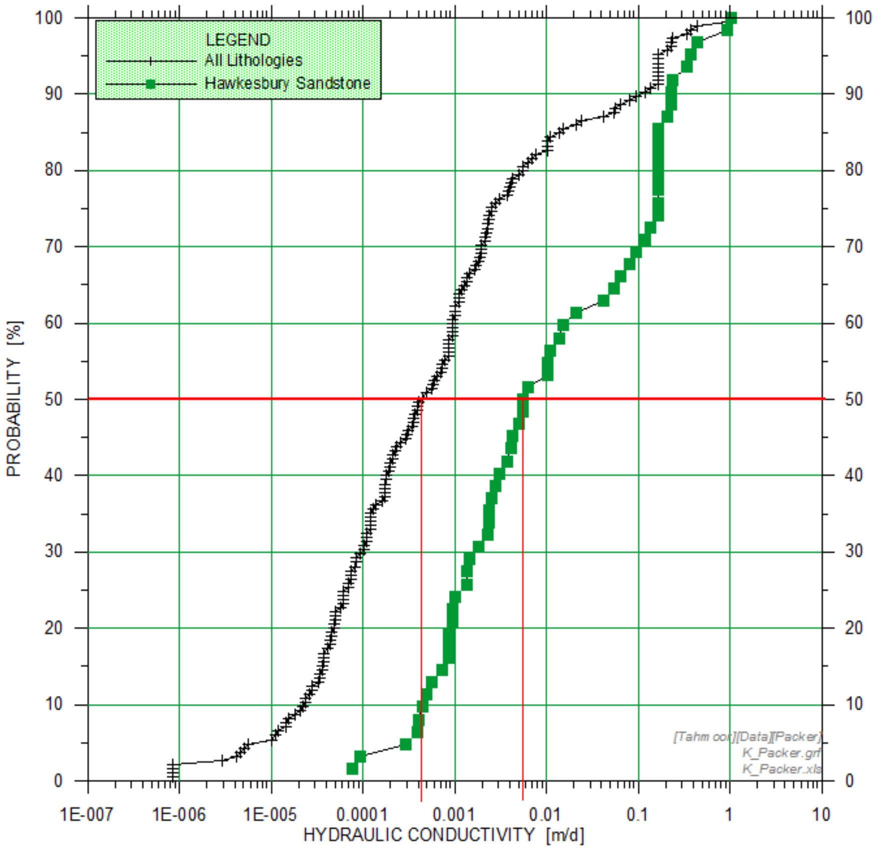


Figure 6-13. Probability distribution of hydraulic conductivities determined by packer tests in the Tahmoor lease area, Data courtesy Xstrata and Heritage Computing (2012).

6.4 GROUNDWATER MONITORING

6.4.1 NSW Office of Water Monitoring Bores

In June 2011 the NSW Office of Water drilled and installed four groundwater monitoring bores at Thirlmere Lakes. Monitoring bores were installed at Lake Gandangarra (GW075411, Site A), Lake Couridjah (GW075409/1 and 2; Site B) and Lake Nerrigorang (GW075410; Site C) (Fig. 6-14). Details of drilling methods, lithology and bore construction are presented in the NSW Office of Water drilling report (Russell, 2012). Survey data for the monitoring bores is given in Gleeson (2012). The monitoring bore details are summarised in Table 6-1.

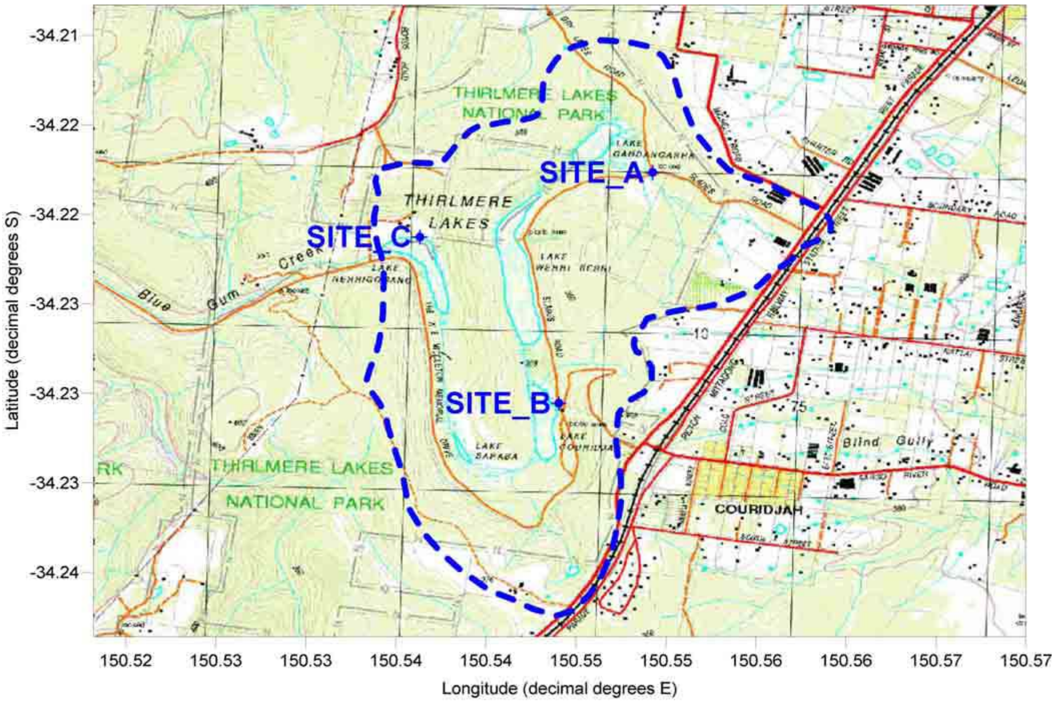


Figure 6-14. Location of NSW Office of Water monitoring bores (Russell, 2012). (with permission: copyright NSW Government).

Data loggers were installed in the four monitoring bores to record automatic groundwater levels in October 2011. Automatic groundwater level monitoring records are available from October 2011 to June 2012 and presented update in Figs 6-15 and 6-16.

It is thought that the data logger in the monitoring bore on the margin of Lake Nerrigorang (GW075410) is malfunctioning, which explains the sudden drop in water levels. Nevertheless, if the sharp drops are ignored, it shows an increasing trend in the level of the groundwater surface similar to the other two shallow monitoring bores.

The automatic groundwater level monitoring data collected by the NSW Office of Water indicates that:

a. The water table measured in the shallow monitoring bores shows a correlation with rainfall. The magnitude of response to rainfall recharge is similar in the monitoring bores at Lake Gandangarra (GW075411) and Lake Couridjah (GW075409/1) and greatest at Lake Nerrigorang (GW075410).
b. The water level in the deeper Hawkesbury Sandstone (GW075409/2) is about 8 m lower than in the shallower colluvium and weathered Hawkesbury Sandstone (GW075409/1), indicating a downward hydraulic gradient beneath Lake Couridjah.
c. The water level response to rainfall is more subdued in the shallow colluvial monitoring bore than the deeper Hawkesbury Sandstone monitoring bore at Lake Couridjah.
d. The groundwater elevations indicate that in dry times groundwater in the shallow (perched) aquifer flows from Lake Couridjah northwards towards Lake Werri Berri, and potentially towards Lake Nerrigorang.
e. By the end of June 2012 the shallow groundwater levels were (mAHD) 300.3 at Couridjah, 296 at Gandangarra, and 303 at Nerrigorang (the latter is probably an error as water level downstream at GW0101247 was approximately 301 and there would have been groundwater flow into the lake if the level was 303).

Table 6-1. NSW Office of Water monitoring bore details.

Work No.	Bore depth (mbgl)	Screened interval (mbgl)	Ground elevation (mAHD)	Measuring point elevation (mAHD)	SWL when drilled	GW Elevation when drilled (mAHD)	Aquifer
Site B GW075409/1	15	3.0-13.0	307.585 Top of cover	307.425	8.35	299.075	Colluvium to 10 m/ then Weathered Hawkesbury Sandstone
Site B GW075409/2	100	72.0-84.0	307.60 Top of cover	307.37	16.99	290.38	Colluvium to 15 m then weathered Hawkesbury Sandstone to 44 then HS with interbedded shale
Site C GW075410	18	2.5-14.5	307.81 Top of casing	307.55	9.18	298.37	Alluvium to 10 m/ then weathered Hawkesbury Sandstone
Site A GW0754011	28	14.5-26.5	307.34 Top cover	307.00	12.74	294.26	Alluvium to 6 m/ then weathered Hawkesbury Sandstone

It is important to note that the water level in the three shallow monitoring bores (Fig 6-15) continued to rise in May and June, relatively dry months, supporting the Committee's hypothesis of groundwater recharge from the lakes.

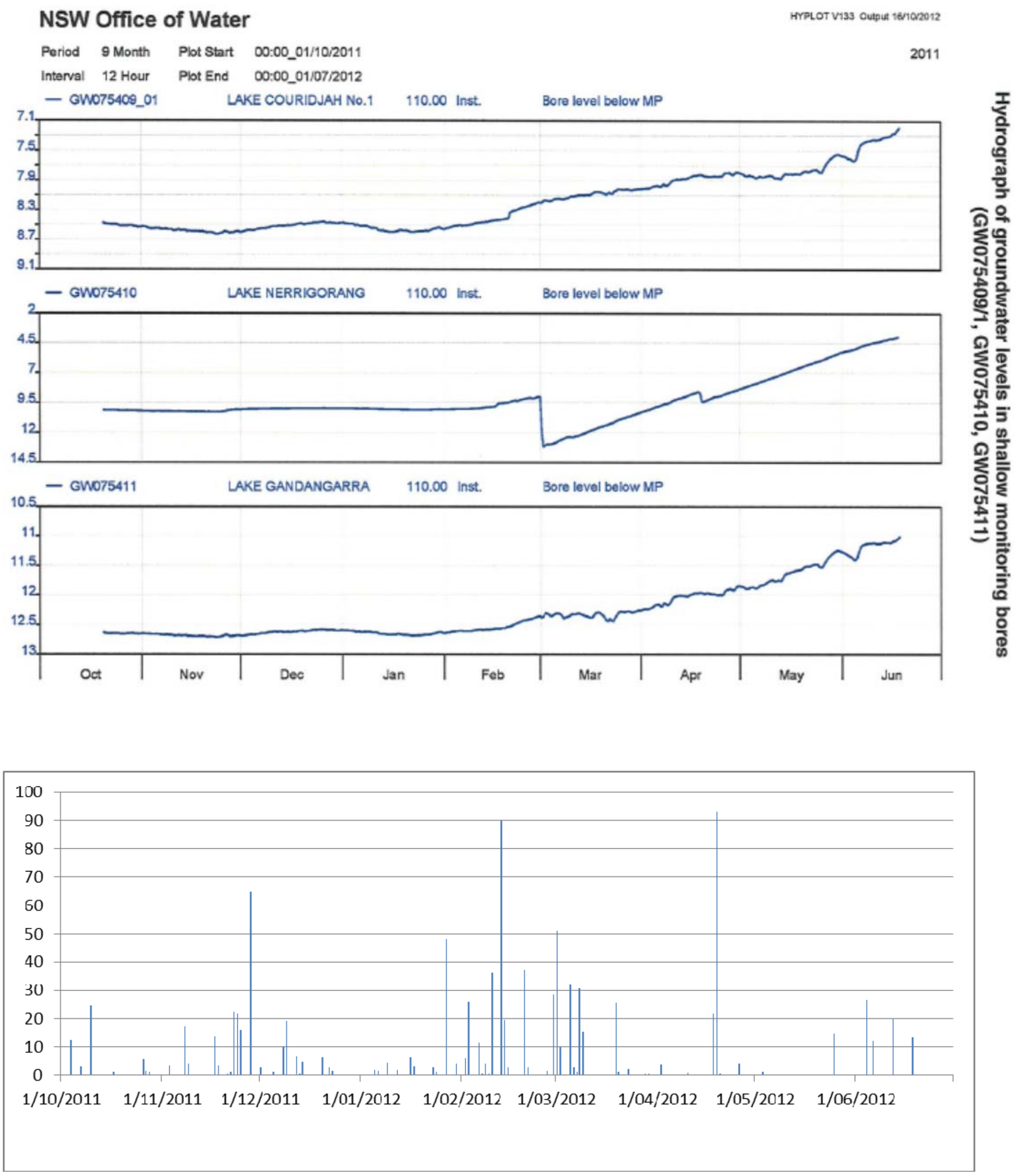


Figure 6-15. Hydrograph of groundwater levels in shallow monitoring bores (GW075409/1. GW75410 and GW75411 October 2011 to June 2012 (from NSW Office of Water: with permission; copyright NSW Government) compared to rainfall from weather station at Maidla.

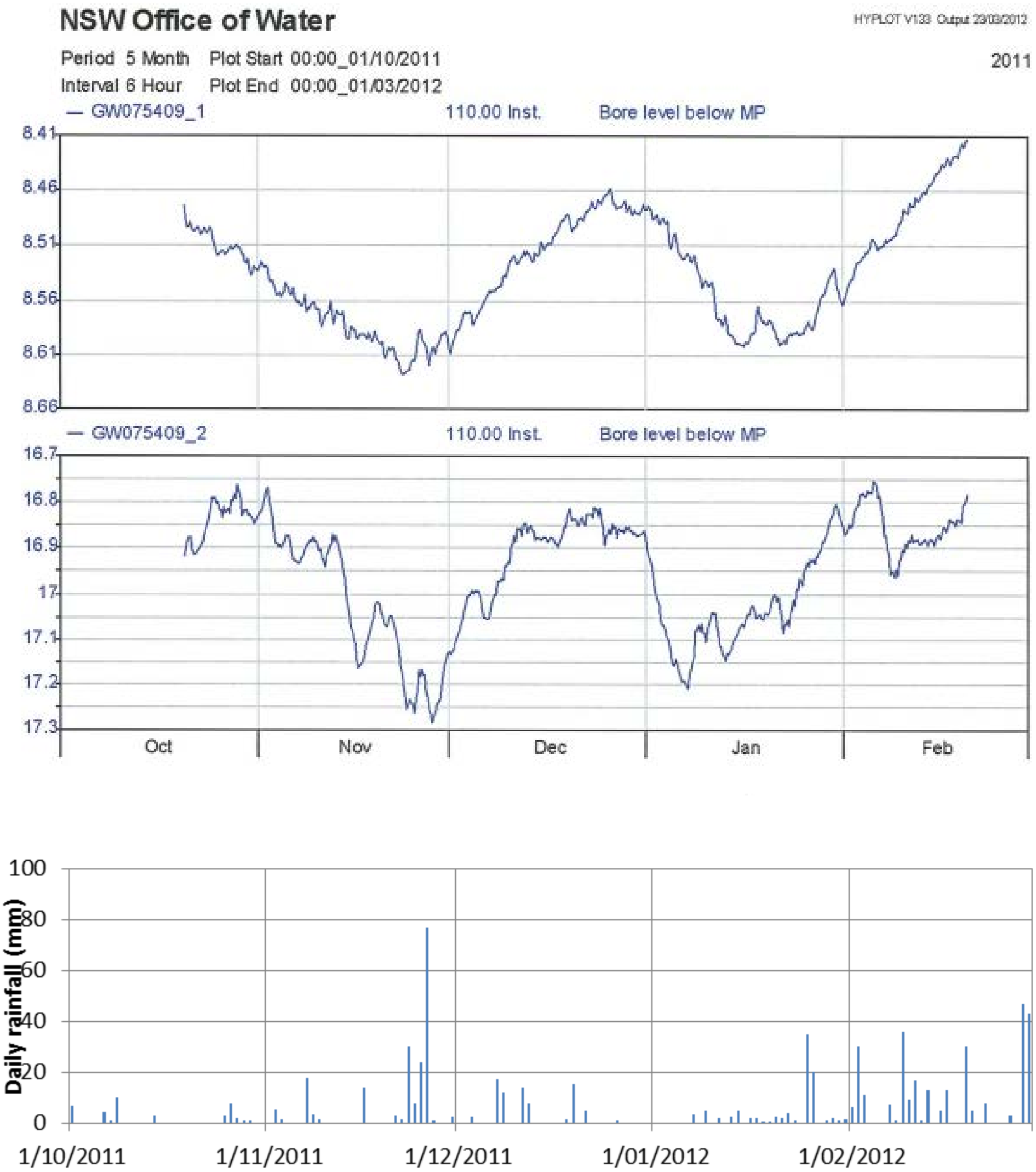


Figure 6-16. Hydrograph of groundwater levels in adjacent shallow and deep monitoring bores October 2011 to February 2012 (GW075409/1 and GW075409/2: from NSW Office of Water: with permission; copyright NSW Government) compared to daily rainfall from Maidla.

6.4.2 Xstrata Monitoring Bores

Regular manual and automatic water level monitoring (using data loggers) began in June 2004 (Longwall Panel 22). Vibrating wire piezometers were installed in coal exploration bores after August 2008 to measure pressures within the various strata form the upper Hawkesbury Sandstone down to the Bulli Seam. The Tahmoor Mine monitoring network includes the following bores (see Figure 6-17):

- P1 to P8: all Hawkesbury Sandstone, screened from 48 m to 150 m depth (Fig 6.18-20)
- TCN28, 29, 36, 40 and TNC43: vibrating wire piezometers, settings at 27 m to 502 m depth (Fig 6.21-22).

Details of P1 to P8 and TCN 28 to 29 are provided in Tables 6-2 and 6-3.

Table 6-2. Bores and Piezometer Details (from Geoterra 2011).

Bore ID	Drilled	Depth (m)	Aquifer (mbgl)	Yield (L/s)	EC (mg/L)	Purpose
P1 (GW106281)	2004	48	18-20	0.75	2650	Monitoring
P2	-	150	-	-	2295	Coal explor
P3	-	100	-	-	850	Coal explor
P4 (GW067570)	1988	85	-	0.22	8210	Domestic
P5 (GW063525)	1954/1990	76/91	60-66&70-91	1.0	3550	Stock dom irr
P6 (GW042788)	1976	148	105-135	1.52	-	Agriculture
P7 (GW1104354)	2008	100	95-100	0.76	968	Monitoring
P8 (GW110436)	2008	105	90-105	V. low	822	Monitoring

Table 6-3. Vibrating Wire Piezometer Installation (from Geoterra 2011).

Piezometer	Intake depth (mbgl)	Formation	Piezometer	Intake depth (mbgl)	Formation
TNC28	95	Hawkesbury Sandstone	TNC29	70.96	Hawkesbury Sandstone
	195	Hawkesbury Sandstone		165.06	Hawkesbury Sandstone
	245	Bald Hill Claystone		182.06	Bald Hill Claystone
	270	Bulgo Sandstone (top)		215.06	Bulgo Sandstone (top)
	430	Scarborough Sandstone		382.56	Scarborough Sandstone
	490	Bulli Seam		441.56	Bulli Seam

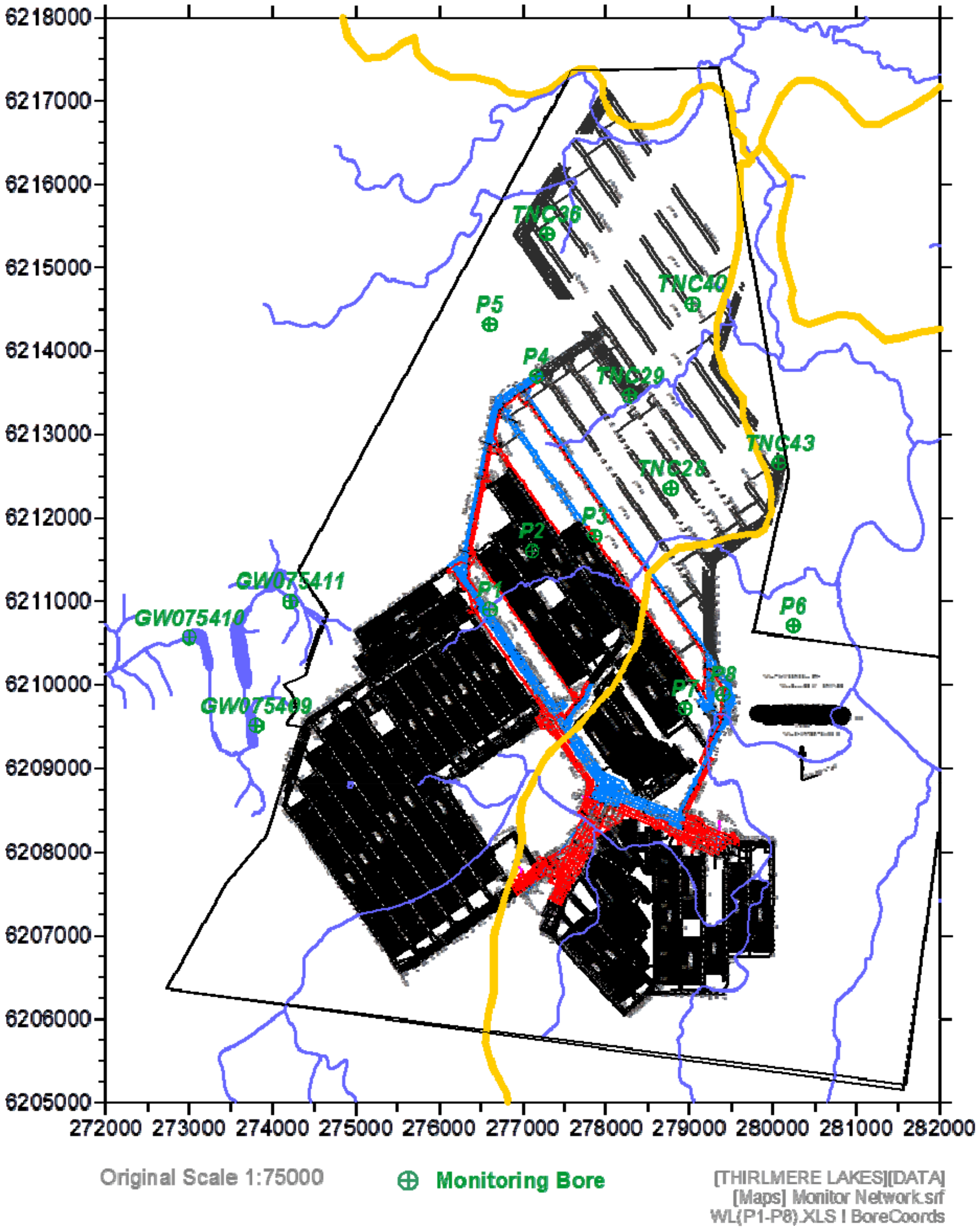


Figure 6-17. Groundwater monitoring locations, Xstrata (from Heritage Computing 2012). With permission Xstrata and Heritage Computing.

Water levels are presented in Figures 6.18 to 6.22 and water level trends are discussed in detail in Geoterra (2011), Russell et al. (2010), and Heritage Computing (2012).

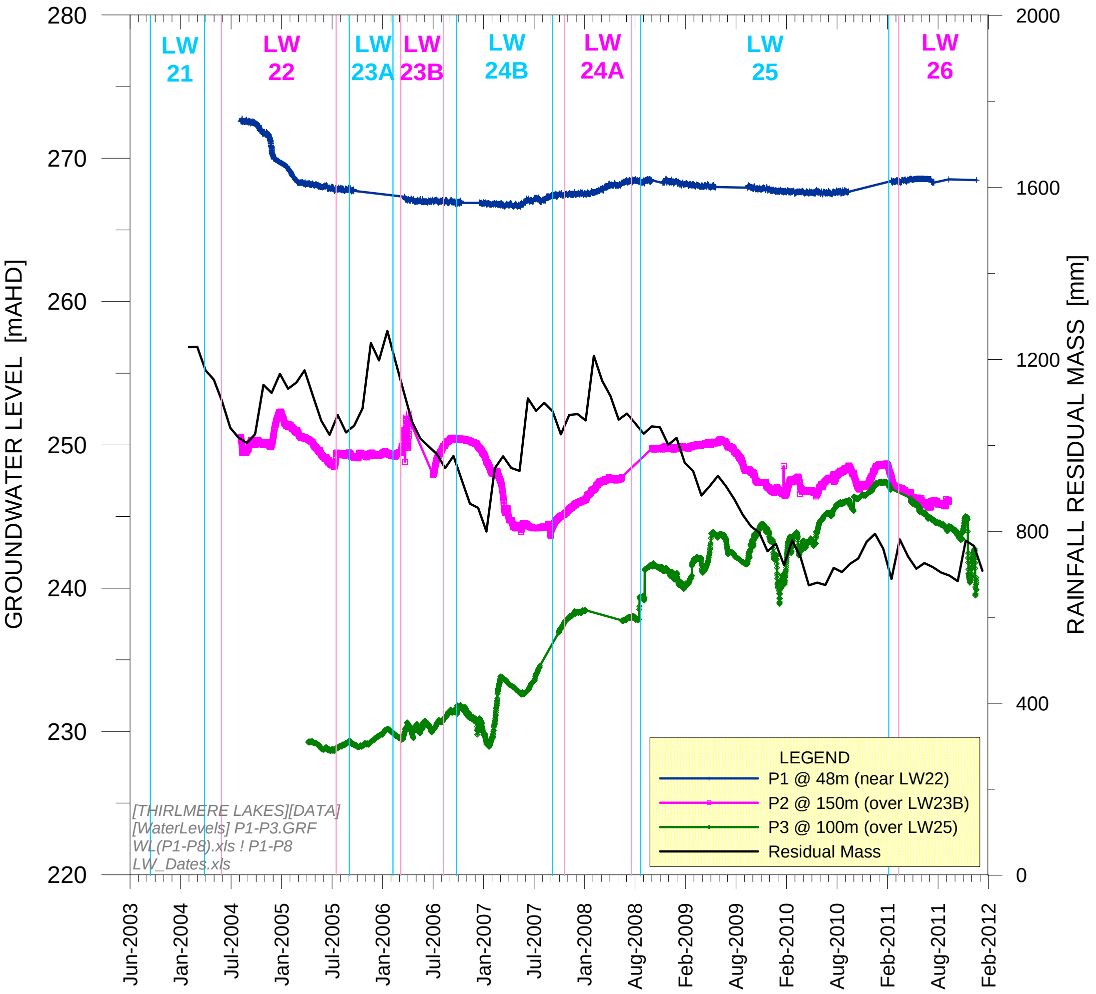


Figure 6-18. Hydrographs of P1 to P3 (from Heritage Computing 2012). With permission Xstrata and Heritage Computing.

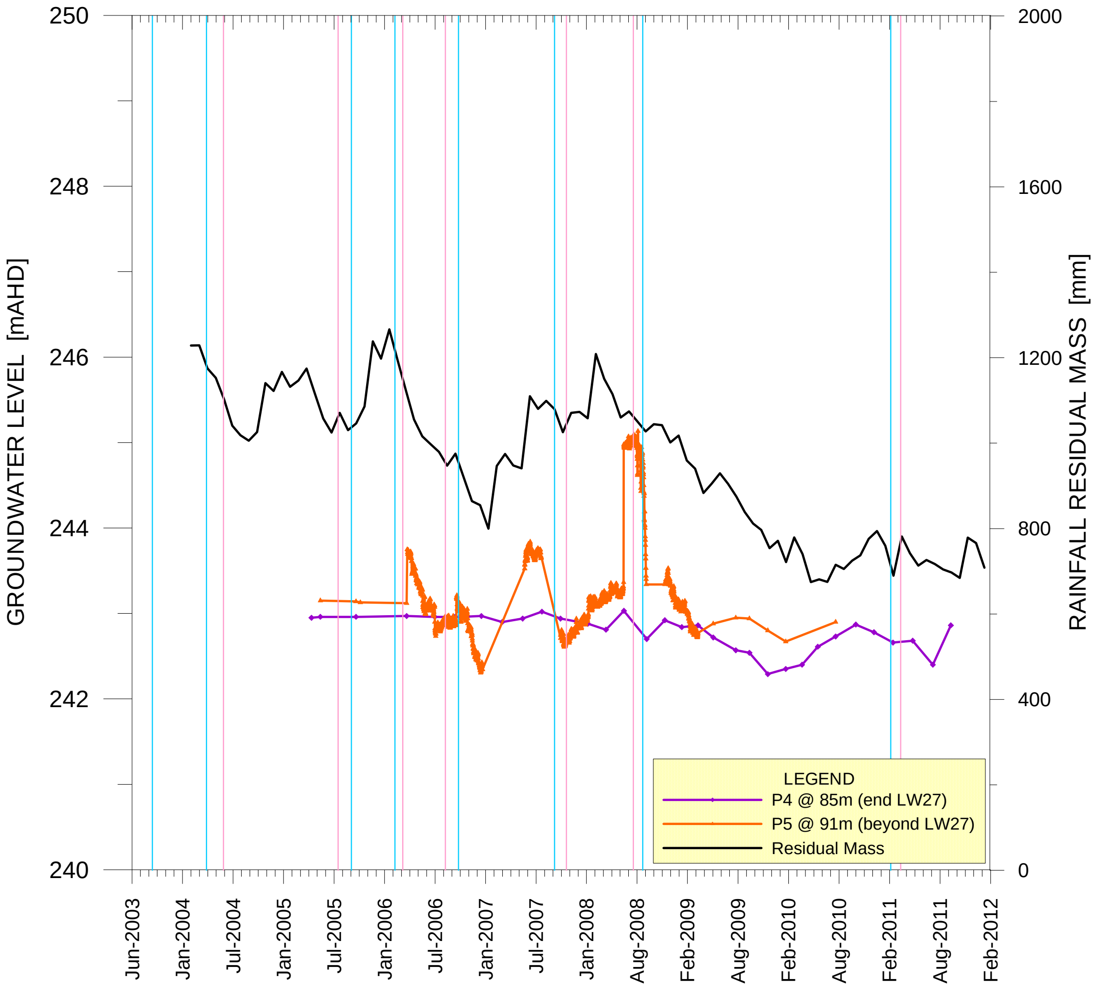


Figure 6-19. Hydrographs of P4 and P5 (from Heritage Computing 2012). With permission Xstrata and Heritage Computing.

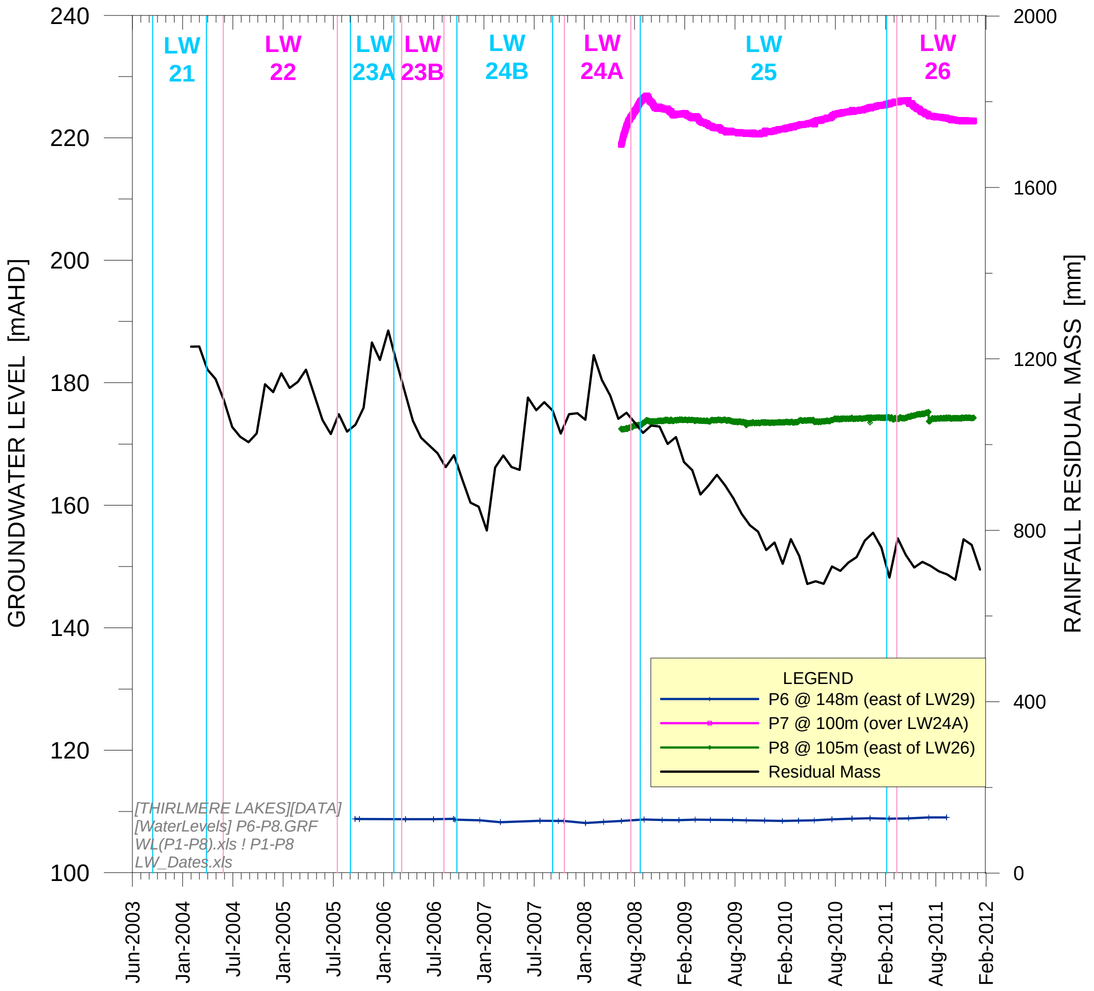


Figure 6-20. Hydrographs of P6 to P8 (from Heritage Computing 2012). With permission Xstrata and Heritage Computing.

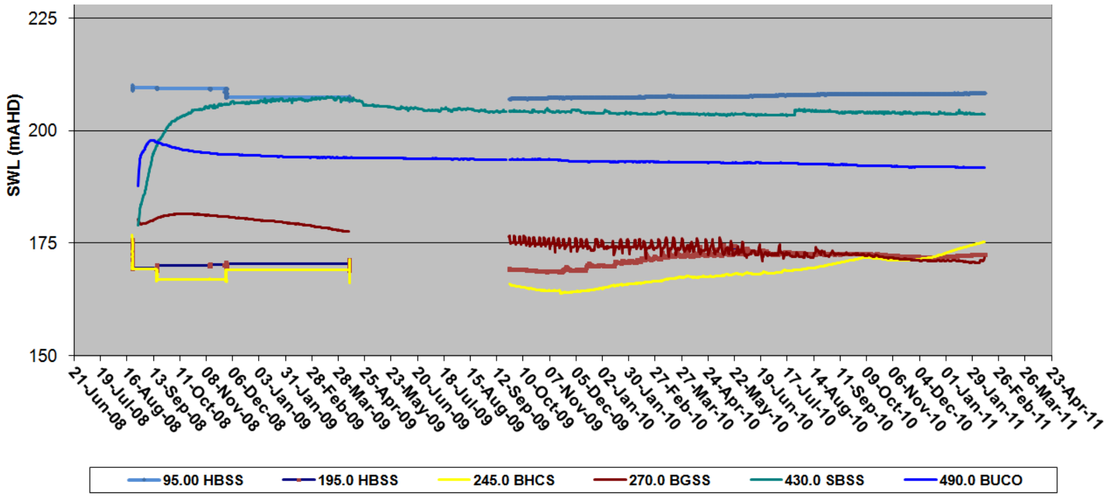


Figure 6-21. TCN28 Vibrating Wire Piezometer Groundwater Levels. With permission Xstrata and Heritage Computing.

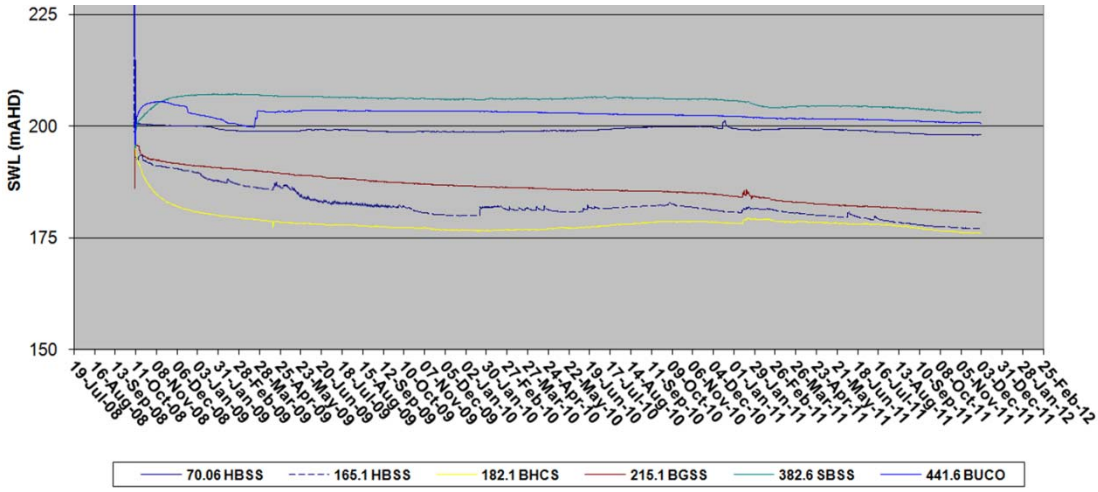


Figure 6-22. TCN29 Vibrating Wire Piezometer Groundwater Levels. With permission Xstrata and Heritage Computing.

In summary:

- Piezometer P1 (screened in Hawkesbury Sandstone; 48 m) showed a decline in water level associated with mining during 2004 which continued until early 2007 (Fig 6.18).

- Piezometer P2 (screened in Hawkesbury Sandstone; 150 m) showed declines of up to 10.3 m during mining of longwalls 23B to 25 (Fig 6.18).

- Piezometer P3 shows a rising trend and is believed to be faulty (Heritage Computing, 2012) (Fig 6.18).

- Piezometer P4 (screened in Hawkesbury Sandstone; 85 m) has not been undermined and shows no water level effect (Fig 6.19).

- Piezometer P5 (screened in Hawkesbury Sandstone, 91 m) is located 4 km northeast of Lake Gandangarra and has not been undermined. Water levels have dropped by 0.5 m which may be natural (Fig 6.19).

- Piezometer P6 has not been undermined and shows minimal fluctuations (Fig 6.20).

- Piezometer P7 (screened in Hawkesbury Sandstone, 100 m) is located ~400 m from Bargo River. Water level showed a recovery after extraction of Longwall Panel LW24A, and then a subsequent decline during extraction of LW25. Water level started to recover midway through the extraction of LW25, and the increase appears to commence prior to rainfall recharge (Fig 6.20).

- Piezometer P8 (screened in Hawkesbury Sandstone, 105 m) is 250 m from Bargo River and has shown a gradual recovery since 2008 (Fig 6.20).

- In VWP TNC28 (located 750 m from LW26), depressurisation of 3.75 to 7.3 m has been observed in the Bulgo Sandstone, Scarborough Sandstone and Bulli Seam since August 2008 (LW25 and LW26) (Fig 6.21)

- In VWP TNC29, depressurisation has been observed in all aquifers and aquitards, with a maximum of 17.7 m in the Bald Hill Claystone and 13.2 m in the lower Hawkesbury Sandstone, although Geoterra (2011) attribute the majority of the reduction to equilibration of the VWP with surrounding formation after installation (Fig 6.22).

In summary:

- Groundwater level data are available for monitoring bores from within the Hawkesbury Sandstone from July 2004 (Longwall 22 onwards).

- From the bores that are monitored by the mine within the Tahmoor SMP, groundwater levels have declined by up to 10 m in Hawkesbury Sandstone monitoring bores positioned over active longwalls. Water levels in Hawkesbury Sandstone monitoring bores affected by mining in the SMP have shown partial or complete recovery.

- In VWP TNC29 depressurisation has been observed in all aquifers and aquitards, with a maximum of 17.7 m in the Bald Hill Claystone and 13.2 m in the lower Hawkesbury Sandstone, although Geoterra (2011) attribute the majority of the reduction to equilibration of the VWP with surrounding formation after installation.

6.5 HYDROCENSUS

Between 9th March 2012 and 6th Sept 2012, visits were made by the Committee to a number of private bore owners in the vicinity of Thirlmere Lakes. Water levels were also monitored in the NSW Office of Water monitoring bores. Water levels were measured using an electronic water level meter and elevations recorded using a DGPS. Water levels were converted to a groundwater elevation (mAHD) and compared to historical water level data (recorded at the time of drilling) available from the NSW Office of Water database. Water level information is provided in Table 6-4. Details of these bores are recorded in Pells (2011 and 2012) and the Annual Environmental Monitoring Reports for the Tahmoor Colliery (2004 -2010).

Water level data collected during the hydrocensus confirm a groundwater gradient towards the east. These bores are in the Hawkesbury Sandstone and hence not accessing/monitoring groundwater levels in the underlying strata. The water level at time of construction was available for a number of bores, but not for all. The census was undertaken over 5 months, but the Committee does not consider that water levels in the bores would have changed significantly in this period.

Bore GW0104720 was drilled in March 2003, a time when a number of nearby bores recorded declines in water levels or yields. Anecdotal evidence from the bore owner indicated that yields were low or negligible above 80 m, so the bore was drilled to its final depth of 91 m where sufficient yields for small scale irrigation were encountered. Water level has increased from 54 mbgl at the time of drilling to 43.22 mbgl in March 2012.

The owner of bore GW047416 reported a catastrophic decline in water level in a single day, with the water level falling below the pump intake at approximately 40 mbgl. The pump burnt out and was subsequently replaced by the mining company and installed to a depth of 48 mbgl. The owner could not remember the date of water level decline but reported it to be when the mining was closest to the railway line (probably Longwall LW21; September 2003 to March 2004; at a distance of ~1.2 km). This bore is located 0.6 km directly east of Lake Gandangarra. During the site visit, the owner removed a cable from within the bore, and both iron oxide/hydroxide deposits (red/orange in colour) and iron sulphide (black deposits) were observed on the cable. The water level measured in March 2012 had recovered to 35.59 mbgl but was still lower than the water level measured at the time of drilling. Prior to the site visit, significant rainfall had occurred and water was observed seeping from hillslopes on the property.

The owner of bore GW029143 (located 1.3 km ENE of Lake Werri Berri) reported a decline in yields after extended periods (4 to 6 hours) of pumping.

Following the hydrocensus on 9th March 2012, the Committee spoke to a number of other private bore owners, but did not have the opportunity to measure present water levels. A number of these bore owners, some of whom wished to remain anonymous, reported loss in yields or decline in water levels. The owner of bore GW035753 reported his bore which is 126 m deep went dry in 1993 (although it is not known at what depth the pump was placed at). The owner of bore GW062068 reported a decline in yields about 2 years ago.

The Committee undertook a detailed analysis of changes in water levels and groundwater gradients in a west-east transect. The Committee used data taken at the time of construction of the bores, where available, and its own survey

Figure 6-23. Location of bores examined in the hydrocensus conducted by the Committee. The bores circled with blue show rises in water levels since installation and those circled with green show falls.

The initial readings at the surveyed bores, at time of construction, were taken over several decades (Appendix 6-1). The location of the bores is shown in Figure 6-23. Details of the bores examined in detail by the Committee are presented in Table 6-4.

Table 6-4. Bores examined in detail by the Committee.

Bore number	Elevation top of bore (mAHD)	Depth of bore (m)	Date of installation	AHD Water level at installation	AHD water level at census
GW0104720	331.3	91	6/03/2003	276.887	287.287
GW047416	329.8	64	1/11/1979	305.258	293.958
GW029143	337.8	73.1	1/10/1968	296.425	290.575
GW0101247	309.2	42	31/01/1998	301.874	300.634
GW075409/1	307.6	15	28/06/2011	299.415	299.545
GW075409/2	307.6	100	28/06/2011	290.83	291.12
GW075411	307.3	28	28/06/2011	294.98	295.5
GW075410	307.8	18	28/06/2011	297.62	
GW035753	298.8	142	1/10/1972		265.873
GW034518	325.3	76.2	1/07/1970	300.858	295.868
GW018568	329.8	63.4	1/11/1961	296.818	291.518
GW062068/1	294.9	150	21/12/1987		265.886
GW062068/2	294.8		21/12/1987		266.079
GW057274	404.0	115	1/01/1982		356.712
GW037742	341.0	112.8	1/01/1972	287.553	302.833
GW102439	340.9	115	30/07/1998	268.536	288.566

The elevation of water levels at time of construction and at the time of the census were plotted in a west-east transect (Fig 6.24). The two western bores GW057274 and GW0101247 are in different topographic positions. The former is on the plateau (highland) to the north-west of the lakes while the latter is in the valley of Blue Gum Creek. The four NSW Office of Water monitoring bores (GW 075409/1 and /2, GW 075410 and GW075411) are on the margins of the Thirlmere lakes. The remaining bores are on the plateau (highland) area to the east of the lakes.

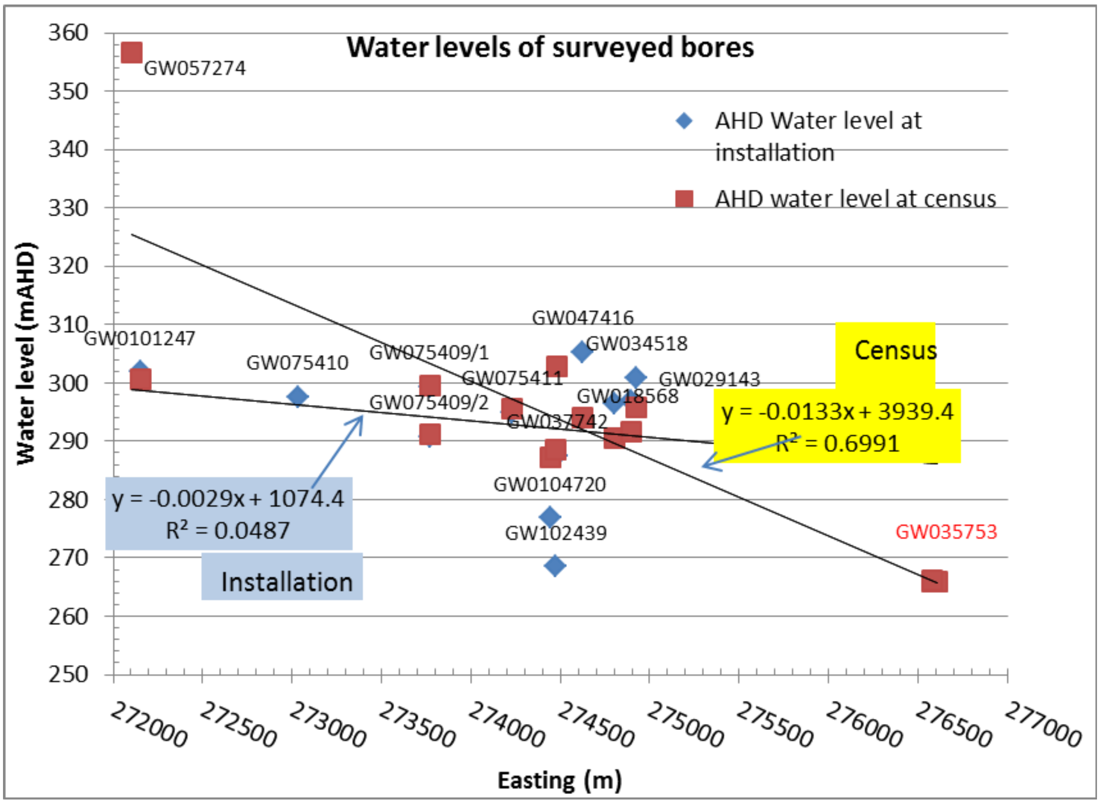


Figure 6-24. Water elevation in bores from west to east, showing levels at time of construction and during the census. Regression lines and equations are also shown.

Several features are evident in Fig 6.24:

1. Even if the western highland bore GW057274 is ignored, there is a general eastward slope in the present-day groundwater surface, although this slope is more pronounced eastward from easting 274500. The regression equation of height of water level at the time of the census (including all bores in the regression) against easting value, is statistically significant (Analysis of Variance) at P<0.01. Comparing the difference in gradient of the two regression lines (Fig 6.24) is complicated by the different data sets used to construct the regression equations.
2. There is no strong evidence of mounding of groundwater underneath the highland immediately to the east of the lakes (274300 and eastward) either at the time of construction or at the time of the census. The lack of water mound is contrary to the suggestion based on a schematic (conceptual) model in

Russell et al (2010) that groundwater would be higher under the highland area immediately to the east of the lakes and hence flow towards the lakes.

3. The groundwater surface in the bores is at or below the level of the lakes (maximum elevation of lakes is 306 mAHD and beds between 298 and 304 mAHD). This relative elevation of lakes and groundwater surface to the east suggests that the groundwater levels are dependent on water levels in the lakes.
4. There is an obvious eastward groundwater gradient from the Blue Gum Creek bore (GW101247) towards Lake Nerrigorang (NSW Office of Water piezometer GW075410). On the other hand, the two piezometers at Lake Couridjah (GW075409/1 and /2) suggest that there is a groundwater gradient towards the east and/or a vertical flow of water as seen in the deeper piezometer and a groundwater gradient towards Lake Nerrigorang as seen in the shallower piezometer.

The trend of an eastward sloping groundwater gradient in the west-east transect as demonstrated in Fig 6.24 supports the regional contouring of the groundwater surface by the Committee and Heritage Computing, which shows this eastward dipping groundwater surface.

While the Committee was not able to find the depths to water level at time of construction for all the bores there is nevertheless a most interesting pattern in the west to east trend in the difference in water levels between construction and the time of our census (Fig 6.25).

1. In the north-south alignment along easting 274500 (approximately) three bores have recorded significant rises in water level since the time of construction but the pattern is not consistent as other bores along the alignment show a fall in water level (Figs 6.23 and 6.25).
2. In the Committee’s census only one bore was located over the longwalls that had a record of water level at the time of installation (GW034518, installed in 1970). As reported above, water level problems were reported for other bores over the longwalls. GW035753, which is 142 m deep (126 m according to

owners), is reported to have dried up in 1993, but now the water level is 32.6 m below the top of the bore. Unfortunately there is no record of water level at the time of installation. Bores GW062068/1 and GW062068/2, which are beside each other and also near GW035753, were reported to have had pumping problems, although the water level is now 28.8 m below the top of the bores.

3. Exactly what is causing this variable behaviour of rises and falls is unknown. Bore GW102439 was installed in 1998, but has not been used for over a decade. It shows a rise in water level but this may reflect the fact that it was installed at the time the longwalls were being excavated to the east. On the other hand the nearby bore GW037742 has been in use since it was constructed in 1972, before mining, also shows a rise in water level since construction. Bore GW0104720, constructed in 2003, shows an 11 m rise since construction, suggesting a recovery in aquifer if mining had impacted on the aquifer previously. What is not known is whether this recovery is a result of reduced use of groundwater in the area, increased recharge, or reduced loss to deeper aquifers. Bore GW047416, constructed in 1979, is reported to have fallen approximately 10 m in 2003 when Longwalls 20 and 21 were being mined immediately to the east. Bore GW029143, constructed in 1968, is reported to have declining yields, and has fallen nearly 6 m since installation, although the owner was not sure the decline was mining, drought, or use related.
4. The data suggest that the argument that mining has reduced the water levels in all the bores is not strong, as the water level in several bores has risen. Longwall mining may have affected some bores, but not others.

Of considerable importance are the elevations of the water surface in bore GW0101247 at time of construction and time of the census. They are similar. If there was a significant dewatering of the aquifer in the vicinity of Lake Nerrigorang the difference in water levels would be much greater than shown. GW0101247 is approximately 500 m downstream of the outlet to Lake Nerrigorang and is located within Hawkesbury Sandstone. There is a groundwater gradient towards Lake Nerrigorang. The hypothesis of a depressurisation of the aquifer below Lake Nerrigorang is not supported by the limited groundwater data available to the Committee.

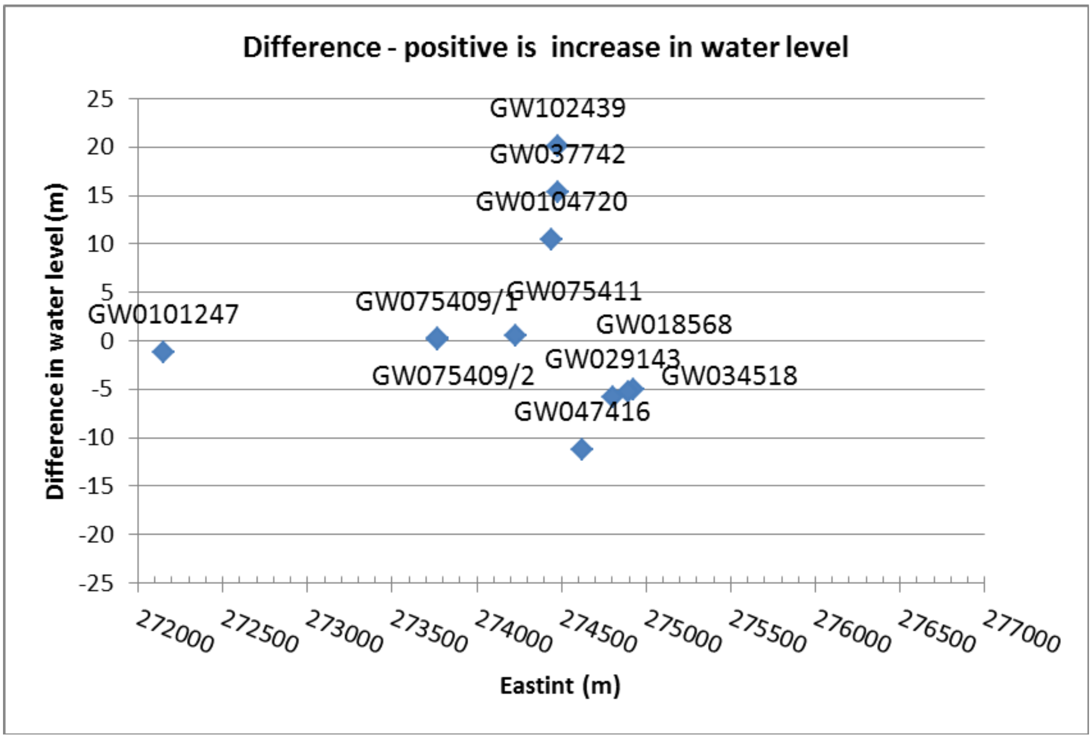


Figure 6-25. Change in water level for bores with depth to water readings at time of construction and at the time of the Committee's census.

6.5.1 Conclusion

1. There is a groundwater gradient towards the east from the lakes, which appears to steepen towards the east, within the range of bores surveyed in the census.
2. There is a variable pattern of rises and falls in water levels between the time of construction of the bores and the time of the Committee's census.
3. There is no obvious groundwater mound to the east of the lakes, underneath the higher plateau area between the lakes and the Loop Line.

4. The pattern of groundwater gradients suggested by the piezometers and bores within and around Thirlmere Lakes suggests a dynamic pattern of groundwater flows linked to variations in lake levels.
5. There is strong evidence that the aquifers in the vicinity of Lake Nerrigorang have not been depressurised by mining.

6.6 GEOLOGIC LINEAMENTS AND GROUNDWATER

Previously (Chapter 3) the significance of lineaments in the rocks and their potential impact on Geology has been discussed. Pells Consulting (2011, p. 42) reports two structural lineaments that may have an impact on groundwater in the vicinity of Thirlmere Lakes. The first is a NW-SE trending fault and dyke zone which Pells identifies as the T1 Fault and relates to the inflows that occurred during the excavation of the incline and Number 3 Shaft. The second, which he terms the T2 Fault, appears to have a SW-NE trend. While the two faults have been identified within the seam this does not mean that they extend to the surface, as acknowledged by Pells Consulting (2011). However, they do represent zones of weakness above the mine and may have been affected by the mine subsidence, which could have extended into the overlying Hawkesbury Sandstone. The two faults intersect with Thirlmere Lakes, if extended, but there is no evidence that they connect, or that they extend sufficiently high enough within the strata to impact on the lakes.

It is worth noting that a large number of the private bores that reported a reduction in water level and/or yield appear to be aligned with the Thirlmere Monocline and close to the dyke reported by Xstrata in Longwalls 20 and 21 (mined between 2002 and 2004). The combination of structures may have some impact on the hydraulic gradients and flow rates within the Hawkesbury Sandstone. However, there is no means of confirming this association of structures and groundwater at present.

6.7 MINE OPERATION AND GROUNDWATER

Section 8.4 contains a discussion on mine subsidence and its potential impact on the hydrology of a region and in particular the Tahmoor area. This section focuses on the hydrogeology of the area, with a short explanation of the Tahmoor Colliery mining operation and history as it may relate to geohydrology.

6.7.1 History

Geological exploration in the Tahmoor region started in the early 1970's and development commenced in September 1975, with Clutha Development Pty Ltd sinking a drift portal and two vertical shafts (Shaft No. 1 and Shaft No. 2). Mining commenced in 1979 with coal extracted using bord and pillar methods. Clutha changed its name in 1986 and longwall mining commenced in 1987, with the extraction of LW1 and LW2. Since this time there have been several owners of the colliery with CRA Ltd purchasing it in 1989, Austral Coal Ltd in 1997, Centennial Coal Company Ltd in 2004 and Xstrata Coal Pty Ltd in 2007. Tahmoor Colliery has development consent to produce up to 3 Million Tonnes Run of Mine of coal per annum.

6.7.2 Mining process

Longwall mining involves removing gas in the proposed mining area to reduce risks, including outbursts (Wynne, 2002), cutting access roadways and headings, also called gate roads (given the name of panels with a number) and then the coal between these roadways and headings is mined in a continuous longwall operation (Fig 6.26). Each of the longwalls is given a number. The actual section of coal being mined in the longwall is called a "longwall panel". In longwall mining the roof collapses into the goaf (space) behind the mining equipment at the coal face.

The issues associated with this inquiry are related to the mining that took place immediately to the east of Thirlmere Lakes (Figs 6.27, 6.28), and in particular the area associated with longwalls 14 to 21, which were mined between 1995 and 2004 (Fig 6-28; Table 6-5). Longwall Panels 3 to 9, which are also immediately to the east of the lakes, were mined between 1988 and 1992. The longwall operations are summarised by Russell et al. (2010). The closest longwall panels to Thirlmere Lakes are longwalls LW17, LW18 and LW19, mined between February 1999 and July 2002. Their distances from Lake Couridjah are 660 m, 700 m and 820 m, respectively. Mining occurred in the Bulli Seam at a depth of approximately 300 m.

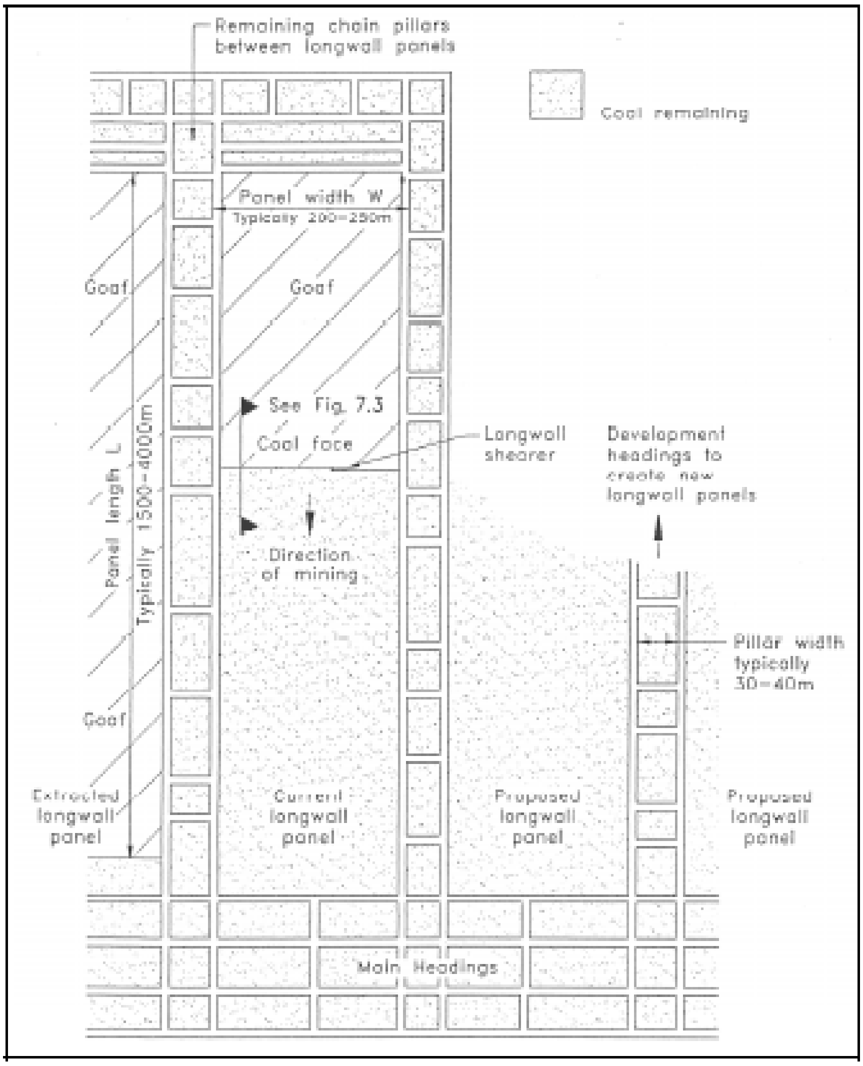
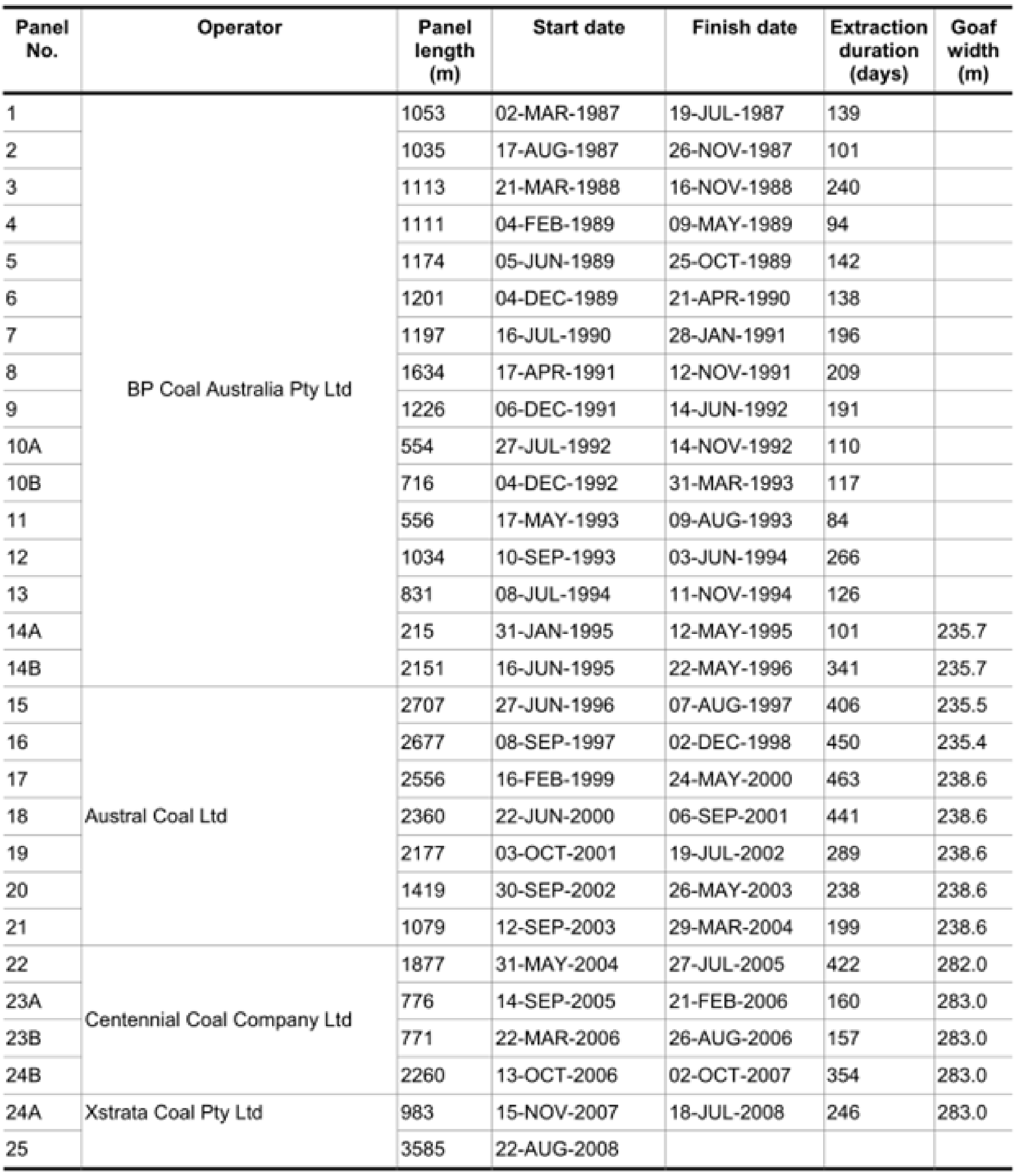


Figure 6-26. Explanation of longwall layout and terminology (Russell et al., 2010, Fig 27, p.31). Copyright NSW Government. With permission.

Table 6-5. Longwall panel extraction records for the southern and northern lease areas (data supplied by Xstrata Coal and reported in NSW Office of Water, 2011).



Panel No.	Operator	Panel length (m)	Start date	Finish date	Extraction duration (days)	Goaf width (m)
1	BP Coal Australia Pty Ltd	1053	02-MAR-1987	19-JUL-1987	139	
2		1035	17-AUG-1987	26-NOV-1987	101	
3		1113	21-MAR-1988	16-NOV-1988	240	
4		1111	04-FEB-1989	09-MAY-1989	94	
5		1174	05-JUN-1989	25-OCT-1989	142	
6		1201	04-DEC-1989	21-APR-1990	138	
7		1197	16-JUL-1990	28-JAN-1991	196	
8		1634	17-APR-1991	12-NOV-1991	209	
9		1226	06-DEC-1991	14-JUN-1992	191	
10A		554	27-JUL-1992	14-NOV-1992	110	
10B		716	04-DEC-1992	31-MAR-1993	117	
11		556	17-MAY-1993	09-AUG-1993	84	
12		1034	10-SEP-1993	03-JUN-1994	266	
13		831	08-JUL-1994	11-NOV-1994	126	
14A		215	31-JAN-1995	12-MAY-1995	101	235.7
14B		2151	16-JUN-1995	22-MAY-1996	341	235.7
15	Austral Coal Ltd	2707	27-JUN-1996	07-AUG-1997	406	235.5
16		2677	08-SEP-1997	02-DEC-1998	450	235.4
17		2556	16-FEB-1999	24-MAY-2000	463	238.6
18		2360	22-JUN-2000	06-SEP-2001	441	238.6
19		2177	03-OCT-2001	19-JUL-2002	289	238.6
20		1419	30-SEP-2002	26-MAY-2003	238	238.6
21		1079	12-SEP-2003	29-MAR-2004	199	238.6
22	Centennial Coal Company Ltd	1877	31-MAY-2004	27-JUL-2005	422	282.0
23A		776	14-SEP-2005	21-FEB-2006	160	283.0
23B		771	22-MAR-2006	26-AUG-2006	157	283.0
24B		2260	13-OCT-2006	02-OCT-2007	354	283.0
24A	Xstrata Coal Pty Ltd	983	15-NOV-2007	18-JUL-2008	246	283.0
25		3585	22-AUG-2008			

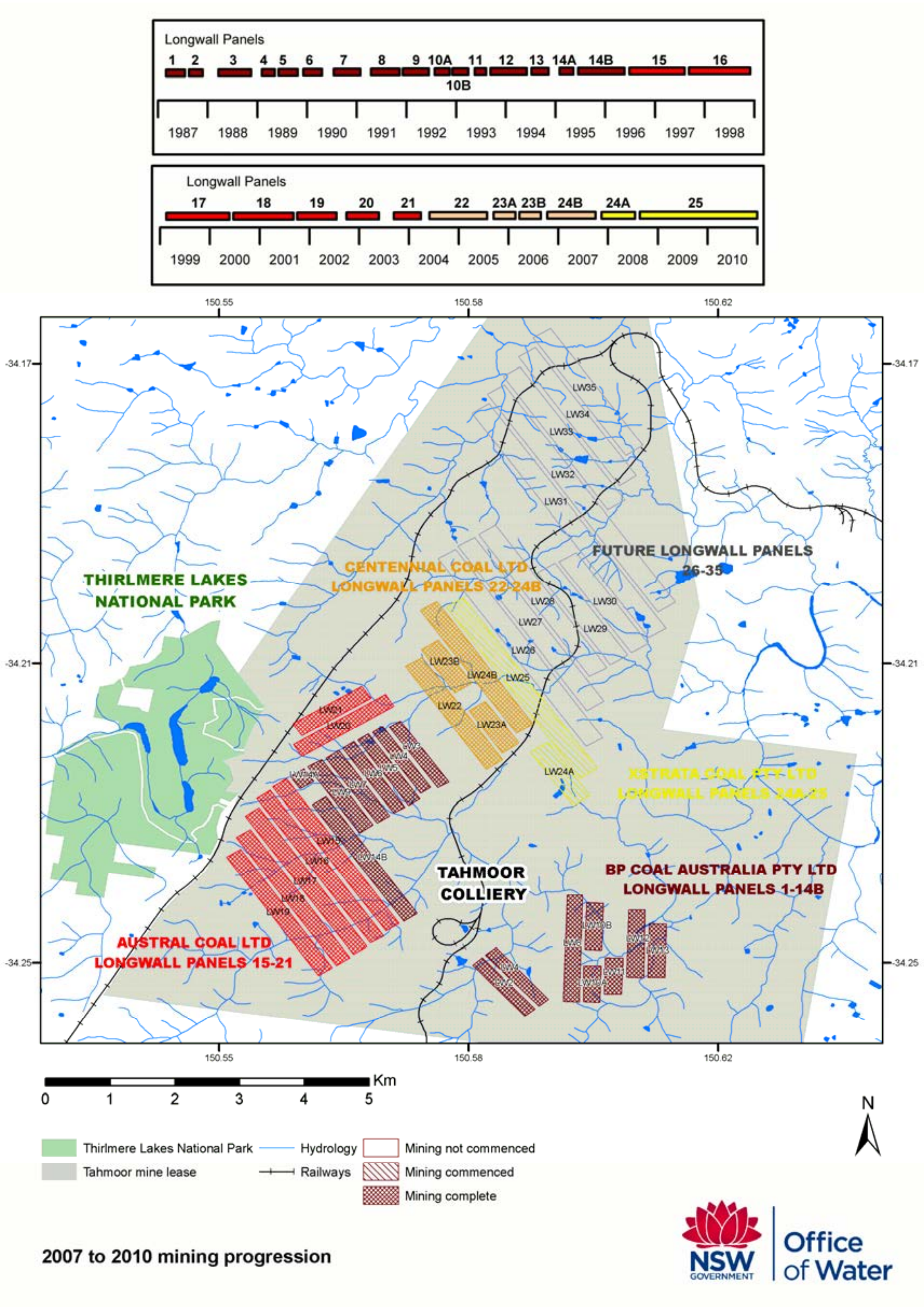


Figure 6-27. Tahmoor Colliery lease areas and longwall panel layout (Russell et al., 2010). With permission. Copyright NSW Government.

Figure 6-28. Layout of panels and longwalls of Tahmoor Colliery in the vicinity of Thirlmere Lakes, showing dates of commencement of mining of longwalls (Figure courtesy Xstrata, 2012).

6.7.3 Impact of mining on groundwater

When a mine opens a cavity underground it releases pressure in all the surrounding rocks. The pressure release comes about because the support that the removed rock (or coal) provided and the forces it transferred to lower rocks or rocks on either side has gone.

There are several consequences of pressure release. Any gas and water previously under compression can now move into the cavity and rocks expand towards the cavity. Geotechnical engineers model carefully the consequences of the pressure release in mines and tunnels as it needs detailed engineering management to prevent adverse consequences such as blowouts, roof collapse and floor upsidence. There are reports of temporary “springs” occurring in the floor of the mine at Tahmoor, a response to the pressure on the water beneath the floor of the workings being released and discharging into the cavity.

The fact that pressure has been released by mining does not mean that surrounding groundwater will immediately flow into the cavity (mine). While the reduction in pressure can move through the rock with some speed, the movement of water is dependent on the media through which it has to move. In short, a pressure force towards the mine does not necessarily translate to a significant increase in flow, and an initial outflow is not necessarily sustained under the hydraulic conditions. Pells and Pells (2012a, section 4) point out that the time frame for the depressurisation wave to move through a column may be minutes to centuries. A number of mines in the Southern Coalfields are dry, and as Pells and Pells (2012b, section 4) state, this is not necessarily related to depressurisation but to the combination of the change in pressure, hydraulic conductivity and the complication of boundary conditions such as geologic discontinuity (joints, dykes, folds etc.).

The vertical flow of groundwater is highly reliant on the hydraulic properties of rocks well above the mine cavity. Continuity of flow through different rock layers is maintained by variations in the pressure head through the vertical profile. When the pressure-flow changes result in unsaturated flow conditions there can be significant reductions in water flow in short times. It is well known that fractured rocks create significant problems for modelling the impact of groundwater movement (Cook, 2003).

6.7.4 Tahmoor Colliery and groundwater

Any water moving into a mine is channelled downslope to a collection point. There is an east-north-east dip in the Bulli Coal Seam at Tahmoor, so water is channelled towards sumps on the east side of the workings. At these sumps the water is pumped either to other sumps in the water management line or to the surface for treatment, and either recycled for mine use or discharged. Tahmoor Colliery has a water recycling system, so some of the water discharged to the surface is returned underground for use in various mining operations (approximately 1 ML/d). While records are kept of the water pumped from the sumps to the surface there is no record of where the water comes from that flows into the sumps, nor could there every be any practical way of monitoring the sources as they are many and vary in location and magnitude as mining progresses.

Pumping is not continuous and there are days in which no pumping takes place as a consequence of equipment maintenance and changes. The daily pump values do not relate directly to water discharging into the mine workings from the rock faces.

Much has been made in submissions of the “flooding” of Panel 500, which it is claimed in submissions, is closest to Thirlmere Lakes. This “flood” of water into Panel 500 is taken as evidence that the mining breached some structural weakness between the lakes and the mine and caused water to pour into the mine from the lakes.

There are several problems with the submissions relating to Panel 500. Panel 500 is at the eastern end of longwalls 14 to 19, the down-dip end of the longwalls, and under the mine headworks. Water drains from these longwalls down the gates into Panel 500 or sump 508 in Panel 508, and then is pumped to the surface in No.3 Shaft, near the intersection of Panels 500 and 506. Panel 500 is more than 2 km from Thirlmere

Lakes and receives water from more than 3 km^2 of underground mine workings. Longwalls 14 to 19 and associated panels are now sealed off, for safety reasons and because mining has been completed in this section of the lease, but some water continues to flow into 508 sump. The water from longwalls 20 and 21 and 3 to 9 flows in the down-dip direction (ENE) to sumps connected to Pit Bottom sump, which also receives water from other former workings and active workings. There are only two sites from which water is pumped from the coal seam area to the surface (Pit Bottom and No.3 Shaft), but there is also a sump in the mid location of the Drift (Drift Sump) capturing water discharging from the Hawkesbury Sandstone into the Drift (Fig 6.29).

The main pit bottom pumping station is located near the base of the main access drift (inclined tunnel) and has two operational and one standby (spare) pump. Each pump is a twelve stage “Worthington” pump designed to lift the water almost 500 m to the surface (Fig 6.30 and 6.31). Water is pumped to the surface through the main drift, via two pipelines, to the surface dams. The Committee has seen the calibration certificate for the pumps (WTF 8-12, 500 KW, rated at 25 L/s at 600m head in Sept 1990, when new).

Approximately 1/3 of the way down the drift, a secondary sump and pump are located to collect groundwater that makes its way into the upper areas of the main drift. This water is pumped into one of the two drift water pipelines for discharge to the surface dams.

The second pumping site for discharge to the surface is 500 Panel pumping station, located near the base of the No 3 shaft. It has a single “Worthington” pump. Water is collected at this point from two sources, either from the No 3 shaft or from the old mining areas from longwalls 14 to 19 (508 sump). Water from this pumping station was pumped to the surface via a pipeline in No 3 shaft until the end of 2009, when a new borehole pipeline installed adjacent to the No 3 shaft, replaced the pipeline in the shaft.

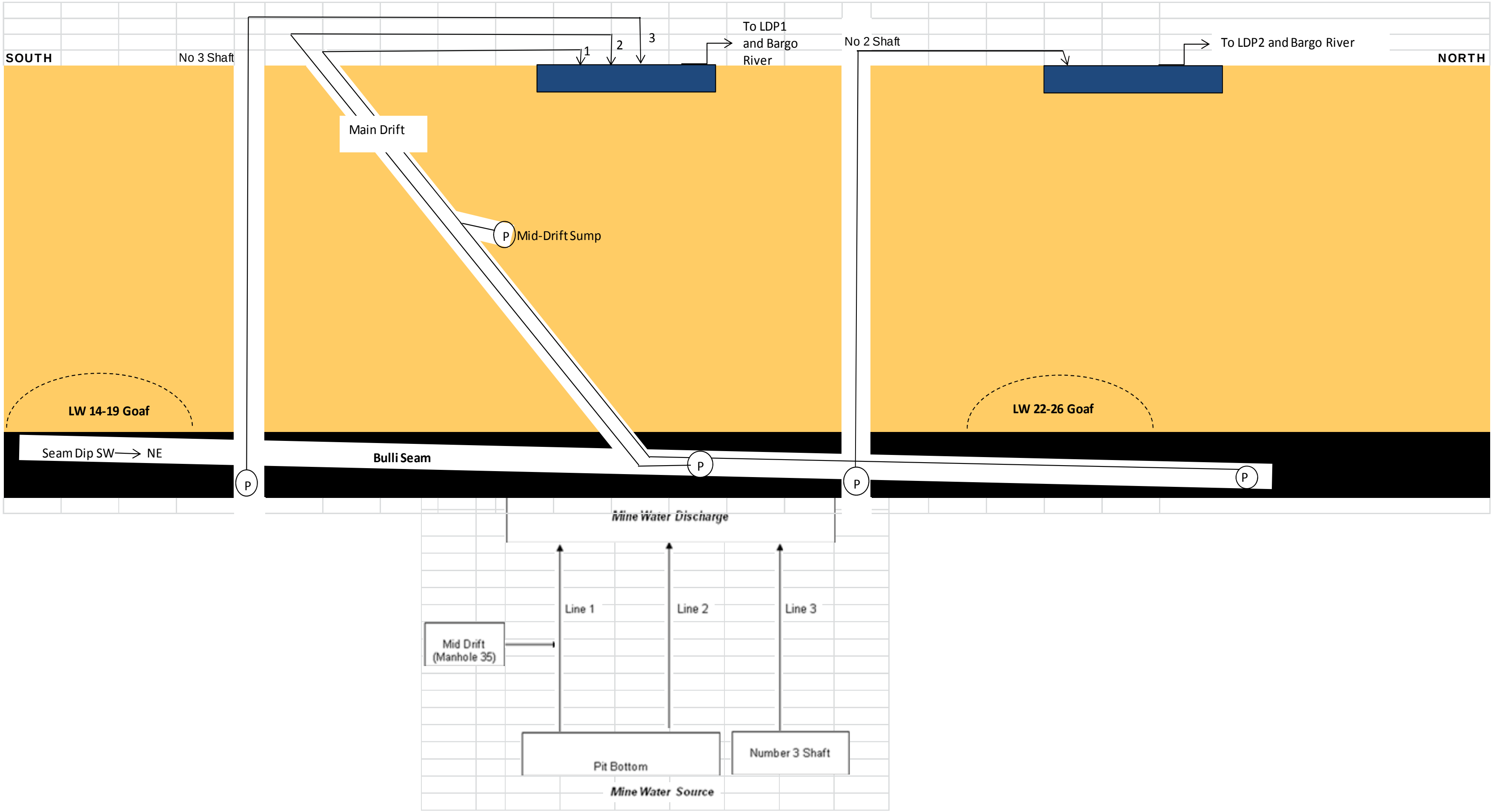


Figure 6-29. Schematic of mine water pumping (courtesy of Xstrata).

From April 1995 to June 1999, a third seam to surface pump was located at the base of No 2 shaft, pumping water from the shaft sump directly to the surface for discharge via a shaft pipeline. From June 1999, the pumping arrangements were changed and all water from No 2 shaft was pumped to the main pit bottom pumping station to then be pumped to the surface.

To recap (Tables 6-6 and 6-7):

1. Up to 1995 there were three mine-to-surface pipelines (two from Pit Bottom and one from No 3 Shaft). Maximum capacity (two 25 L/s at Pit Bottom, one 25 L/s at No3 Shaft, and one 15 L/s mid Drift) with total capacity 90 L/s or 7.7 ML/day.
2. April 1995 to June 1999 there were four mine to surface pipelines with the addition of No 2 Shaft pump (13 L/s), bringing the total capacity to 103 L/s or 8.9 ML/d.
3. June 1999 to present: same as for 1.

Russell et al. (2010) have a detailed description of the mine water pumping operation for Tahmoor.

Table 6-6. Location of lines and sumps Tahmoor Colliery (from Russell et al., 2010).

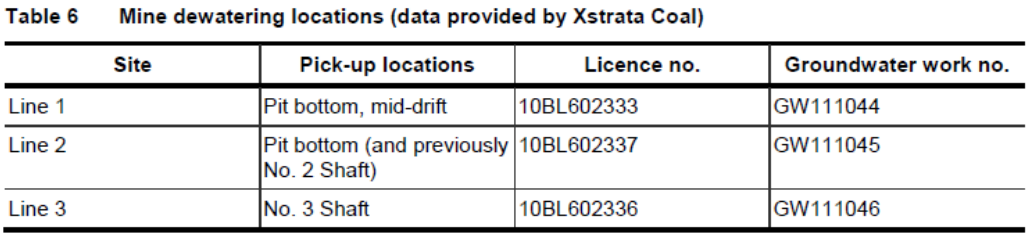


Table 6 Mine dewatering locations (data provided by Xstrata Coal)

Site	Pick-up locations	Licence no.	Groundwater work no.
Line 1	Pit bottom, mid-drift	10BL602333	GW111044
Line 2	Pit bottom (and previously No. 2 Shaft)	10BL602337	GW111045
Line 3	No. 3 Shaft	10BL602336	GW111046

Table 6-7. History of pumps Tahmoor Colliery (from Russell et al., 2010).

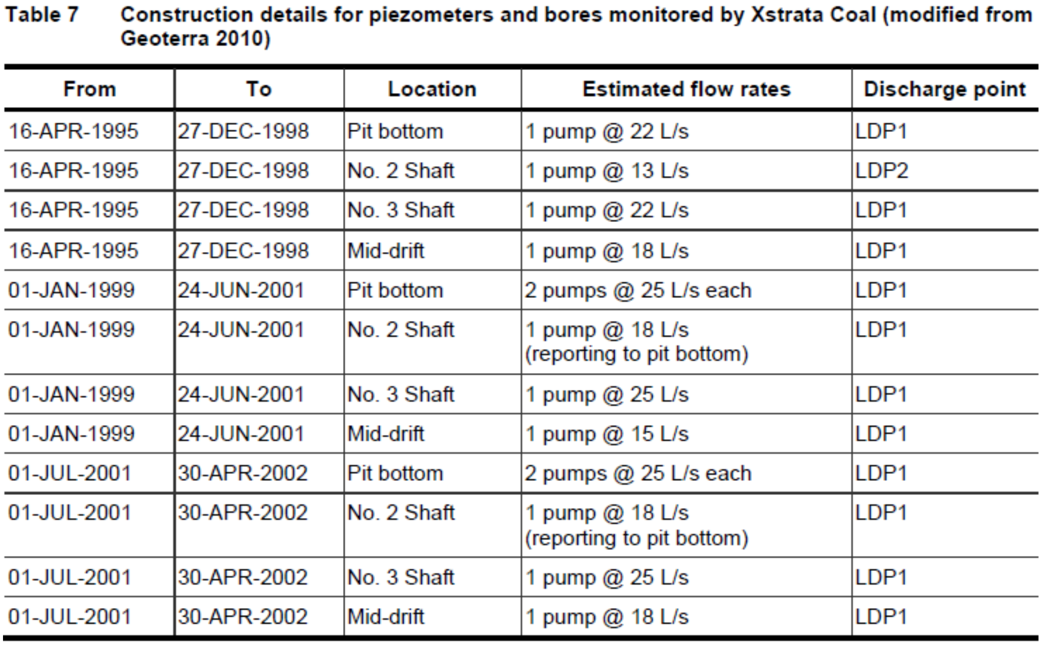


Table 7 Construction details for piezometers and bores monitored by Xstrata Coal (modified from Geoterra 2010)

From	To	Location	Estimated flow rates	Discharge point
16-APR-1995	27-DEC-1998	Pit bottom	1 pump @ 22 L/s	LDP1
16-APR-1995	27-DEC-1998	No. 2 Shaft	1 pump @ 13 L/s	LDP2
16-APR-1995	27-DEC-1998	No. 3 Shaft	1 pump @ 22 L/s	LDP1
16-APR-1995	27-DEC-1998	Mid-drift	1 pump @ 18 L/s	LDP1
01-JAN-1999	24-JUN-2001	Pit bottom	2 pumps @ 25 L/s each	LDP1
01-JAN-1999	24-JUN-2001	No. 2 Shaft	1 pump @ 18 L/s (reporting to pit bottom)	LDP1
01-JAN-1999	24-JUN-2001	No. 3 Shaft	1 pump @ 25 L/s	LDP1
01-JAN-1999	24-JUN-2001	Mid-drift	1 pump @ 15 L/s	LDP1
01-JUL-2001	30-APR-2002	Pit bottom	2 pumps @ 25 L/s each	LDP1
01-JUL-2001	30-APR-2002	No. 2 Shaft	1 pump @ 18 L/s (reporting to pit bottom)	LDP1
01-JUL-2001	30-APR-2002	No. 3 Shaft	1 pump @ 25 L/s	LDP1
01-JUL-2001	30-APR-2002	Mid-drift	1 pump @ 18 L/s	LDP1

Up to 2002 the water discharged from the mine was measured using the time of operation of the pumps, and during this period the reports changed from weekly to daily records. From 2002 to 2010 water was measured at the release point from the mine site, and included all local runoff. Currently measurements using flow meters are taken of water pumped from the mine, the recycled water pumped down into the mine, and the total runoff from the mine site.

The data provided by Russell et al. (2010) show mine water make (Fig 6.32) daily discharges ranging from 2 to 14 ML/day (average of 23 L/s to 162 L/s), and annual discharges from 0.5 to 2 GL/y (average of 15 L/s to 63 L/s).

Complicating the assessment of the actual amount of water discharged from the mine pit is the different methods of measuring discharge:

1. 1996-2002: water pumped from underground calculated on hours
2. 2002 to present: all water discharged from the site (includes stormwater and sewage less recycled)
3. 2009 to present: measurement of recycled water, water pumped from underground and water discharged from site.

These changes are shown in Figure 6-33.

In their submission to the Inquiry, Heritage Computing (2012) provided a refined assessment of mine inflow for 2009 onwards which is shown in Figure 6-34. Dewatering flows have typically been between 2 and 4 ML/day.

Much has been made in some submissions of the peak in annual and daily discharge evident in 2002-2003, although the record shows daily total peak discharges of similar magnitude in 2005, when the annual discharge was low and 2007 and 2008, when the annual discharges were less than in 2003 (Fig 6-32).

The highest or peak daily discharge in 2003 was approximately 14000 kL/day (162 L/s), which is higher than the pump capacity. The annual discharge for 2003 was 2000 ML, which is equivalent to an average daily discharge of 5500 kL/day. The maximum quantity of water that could have been pumped from the mine in 2003 on any one day was 7.7 ML. The remainder of the 6.3 ML for the daily flow shown on the spikes has to be storm runoff, as suggested by the rainfall data plotted in Figures 6-32 and 6-33. It is highly likely that the stormwater runoff was much more than this but, at the very least, 50% of the spike has nothing to do with water in the mine and mine dewatering.

Over the period shown in Figures 6-32, 6-33 and 6-34 the total water discharge appears to have oscillated between 2 and 8 ML/day with a slight decline in the general value of surface licence discharge over the last decade. The accurate monitoring of underground pumping to the surface over the last three years shows that the discharge can vary between zero and 5 ML/day, with a general trend of 3.5 ML/day.

None of the mine discharge data available to the Committee shows any “flooding” of the mine and the spikes are clearly related to stormwater runoff at the mine surface and not underground pumping increasing in any spectacular way.

6.7.5 Committee inspection of Panel 500 and water system

In September 2012 two members of the Committee, accompanied by NPWS and Xstrata personnel inspected Panel 500, and the pumps at Pit Bottom and No.3 Shaft, and the mid-Drift Sump (Fig 6-30).

The Committee examined approximately 1.5 km of Panels 500 and 506, the blocked Panels along Panel 500 that previously provided access to longwalls 14 to 19. The majority of the floor, walls and roof of Panel 500 was dry and there was no continuous flow along the gutters or drains in Panel 500 nor was there discharge from the blocked access panels (Panels 509-514) to longwalls 14 to 19. Water was streaming down the walls of No.3 shaft, into a sump in its bed, consistent with the flow from the Hawkesbury Sandstone. The flow rate was not high and at the time the Shaft was undergoing upgrading.

Figure 6-30. Committee inspection of Tahmoor Mine and Pit Bottom pump station.

The Committee noted the three pumps at Pitt Bottom, two pumps at No.3 shaft and some pumps in the intermediate sumps. The three pumps at Pit Bottom are not run concurrently (Fig 6-30). Only one or two pumps are in operation at any one time. The third pump is a backup. At the time of the visit the pumps were not working continuously, and it was evident that long periods of time elapse between pumping. The pumps are switched on and off with a float valve in the sump.

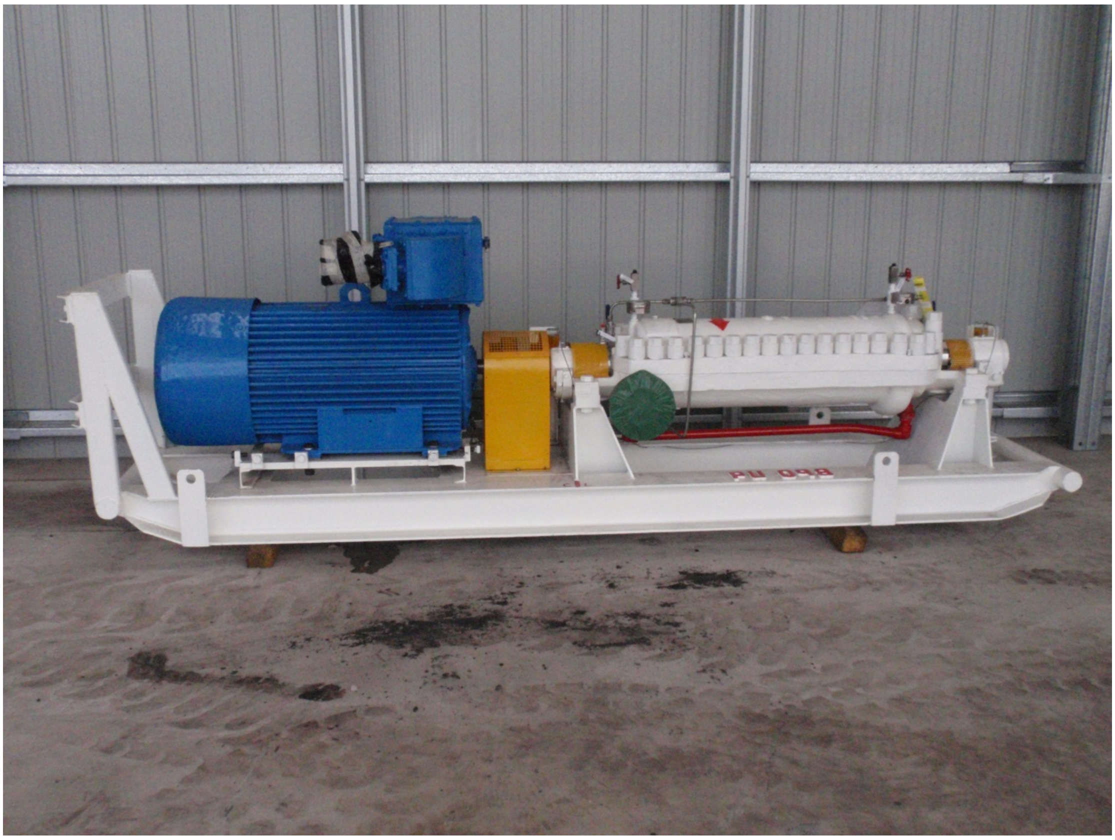


Figure 6-31. Worthington pump at surface after overhaul.

While there were sections near the Drift where the floor was wet, the mine in general, for the area inspected by the Committee, appeared dry. As Panel 500 is to the east of the Bargo River, it would be expected that if there was a direct connection with the surface a lot more water would be flowing into the mine. The site inspection by the

Committee did not suggest such a connection. The wettest section of the mine was the Drift, primarily in the Hawkesbury Sandstone.

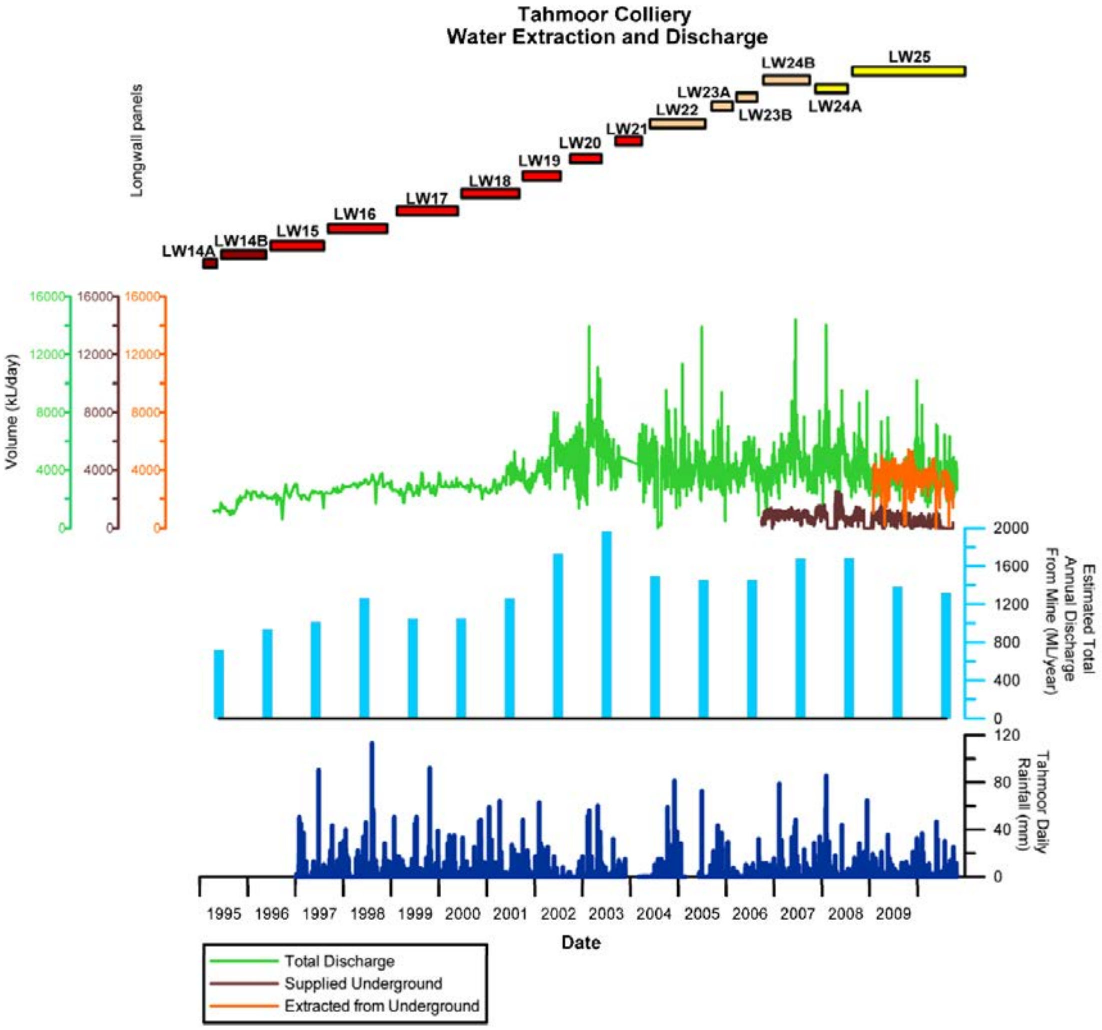


Figure 6-32. Mine water make at Tahmoor Colliery (From Russell et al., 2010, Fig 41, p.46.). Copyright NSW Government. With permission.

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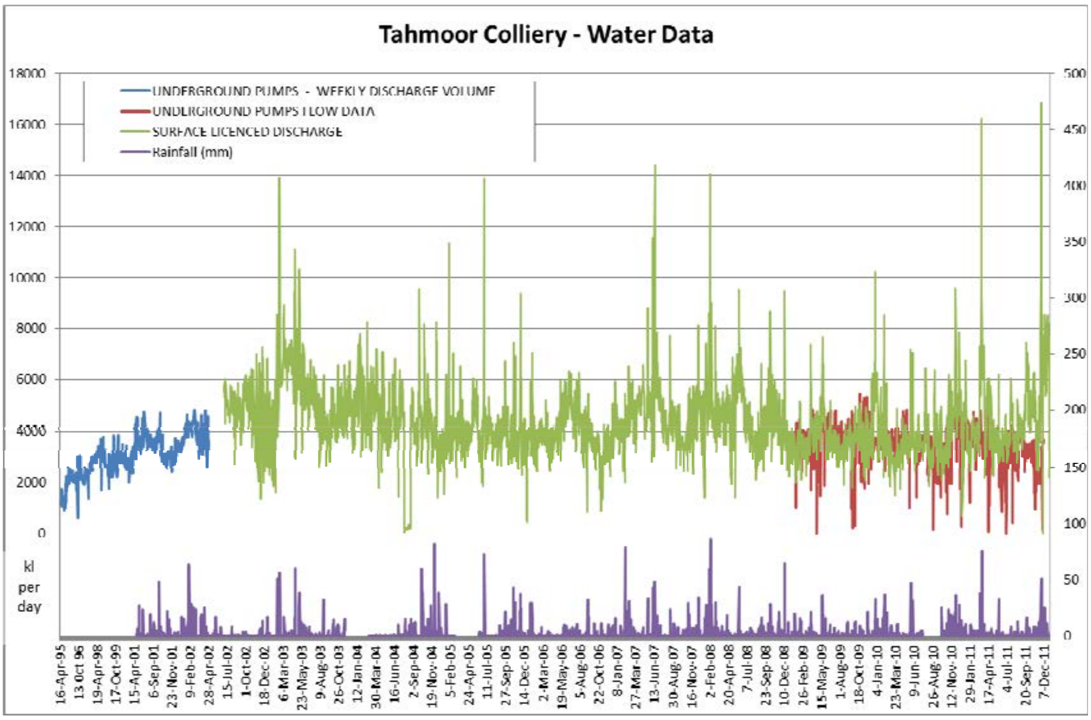

Figure 6-33. Records of mine water discharge, showing periods of different measurement 1995-2011 (Courtesy Xstrata).

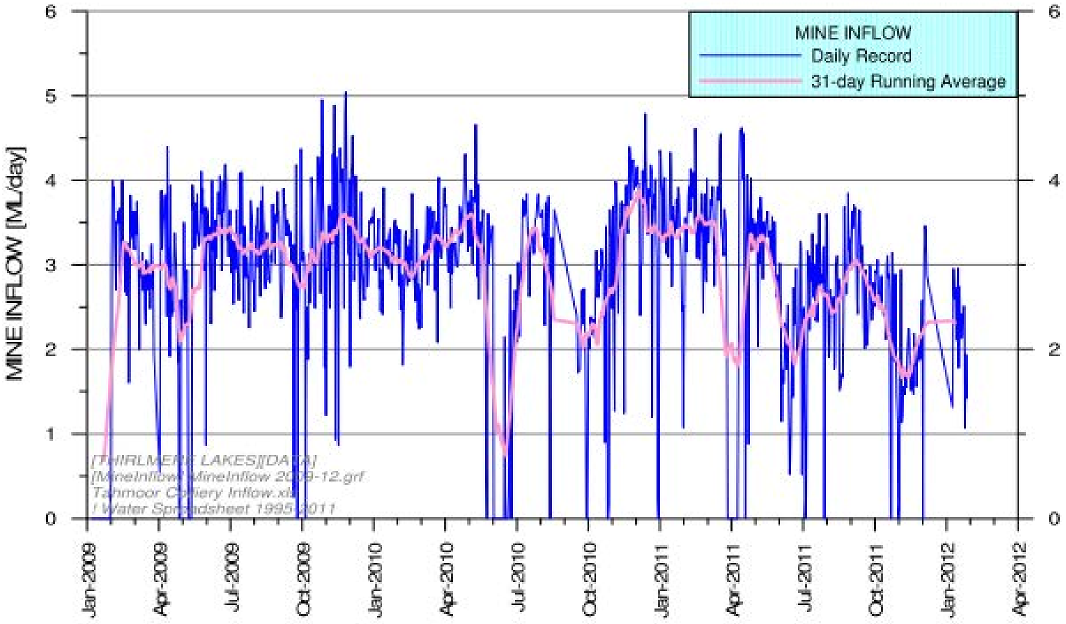

Figure 6-34. Tahmoor Colliery mine water make 2009 -2012 (Heritage Computing 2012). With permission, Xstrata and Heritage Computing.

6.7.6 Groundwater in the Hawkesbury Sandstone and mining

There are multiple datasets and reports indicating that a loss of yield/decline in water level within the Hawkesbury Sandstone has occurred since longwall mining commenced, including:

- Annual Environmental Monitoring Reports (Australia Coal 2004; Centennial Coal 2005 and 2006; Xstrata 2007-2011)
- Pells Consulting's hydrocensus (Pells Consulting, 2011 and 2012)
- Committee Hydrocensus
- Water level monitoring data from monitoring bores and VWP at Tahmoor Colliery (reported in Geoterra, 2011; NSW Office of Water, 2011).

During 2003, two bore owners, a poultry farmer and market gardener were identified by the mine as having a low risk of reduction in bore supply due to their proximity to Longwall 21. A subsidence management plan was prepared and, as part of this, both properties were connected to mains supply. One poultry farmer, who reported water loss in his bore drilled to 61 m in 1980, had a new bore drilled to a depth of ~120 m (Centennial Coal, 2005). The new bore had such a high iron content that the farmer's misting system in the poultry shed suffered clogging problems. It has been argued that aquifers towards the base of the Hawkesbury Sandstone are prone to high iron contents while shallower aquifers are of a higher water quality. There was no way that the Committee could verify this assertion with the resources at hand.

Pells (2011, 2012) undertook a hydrocensus in September and October 2011 and subsequently in 2012. He reported four bore owners with decline in water level or loss of yield when mining occurred beneath or within 1 km: GW049796, GW042537, GW011200 and GW037860. All bores were 60 to 120 m deep, pumped from one or more aquifers in the Hawkesbury Sandstone and with yields of <3 L/s. Of the four monitoring bores, bore GW042357 is located closest to the lakes, and is approximately 0.6 km east of Lake Couridjah. Pells reports other bore owners who stated they were not affected by mining, although one land owner had only purchased the property after it had been undermined.

The committee also interviewed a number of private bore owners who reported a decline in water level or loss of yield when mining occurred beneath or nearby (see Chapter 5). Three of these bores were located between the Loop Line and Thirlmere Lakes and all penetrated one or more aquifers within the Hawkesbury Sandstone. One private bore owner (GW047416) reported a catastrophic decline in water level in a single day, when the mining was closest to the Loop Line (probably Longwall LW21; September 2003 to March 2004; at a distance of ~1.2 km). This bore is located 0.6 km directly east of Lake Gandangarra.

Groundwater level data are available for Xstrata monitoring bores from within the Hawkesbury Sandstone from July 2004 (Longwall 22 onwards). Although these data are taken from monitoring located at least 5 km from the lakes, they show typical pressure responses to longwall mining in the Hawkesbury Sandstone. From the bores that are monitored by the mine within the Tahmoor SMP, groundwater levels have declined by up to 10 m in Hawkesbury Sandstone monitoring bores positioned over active longwalls (LW22 to 26). Water levels in Hawkesbury Sandstone monitoring bores affected by mining in the SMP have shown partial or complete recovery since 2004.

Some of the uncertainty about the direct connection between water discharging into the mine and Thirlmere Lakes could be addressed with dating of groundwater obtained from the mine.

6.8 CONCLUSIONS

1. Accurately describing the groundwater regime is problematic because it has been modified by the mining, there is considerable uncertainty about the hydraulic characteristics of the rocks in the area, and the nature of the hydraulic connectivity through the rock mass is unknown (Section 6.1).

2. There appears to be a lowering and steepening of the groundwater surface towards the east and over the last 40 years, but it is not possible to determine the relative contribution of drought, pumping from groundwater sources, and the extraction of water from the mine (Section 6.2).

3. There is no high area of groundwater (groundwater mound) evident in the bores between Thirlmere Lakes and east of the Loop Line, which suggests that groundwater can, and probably does, flow towards the east from Thirlmere Lakes (Section 6.1).

4. It is not possible to separate and assess the quantities of groundwater flowing east from the lakes and those flowing west and also downstream in Blue Gum Creek (Section 6.2).

5. Some bores in the area were not affected when mining passed near them, some were affected and have not recovered, and some lost water and have either partially or fully recovered (Section 6.4).

6. There is no consistent spatial pattern in the different ways that bores have been affected by mining, but there is a suggestion that some of the affected bores are associated with structural discontinuities (dykes, faults, joints) (Section 6 2.).

7. The available evidence from piezometers around Lake Nerrigorang does not suggest that mining has depressurised the aquifer below the lake (Section 6.3).

8. Changes in water levels in bores are not necessarily evidence of a direct connection between the water in those bores and the groundwater discharging into the mine (Section 6.4).

9. Tahmoor Colliery has not mined underneath Thirlmere Lakes (Section 6.7).

10. Panel 500 is not located near the lakes. It is more than 2 km to the east, and east of the Bargo River, and receives groundwater from more than 3 km^2 of mine workings, including a number of longwalls that were mined in the period 1997 to 2003 (Section 6.7).

11. It is not possible to ascribe the water flowing into the sump in Shaft 3, associated with Panel 500, to any particular part of the mine (Section 6.7).

12. There is no evidence that the depressurisation in the mine has translated to a significantly increased groundwater flow towards the mine cavity.

13. There may be localised areas within the mine cavity where depressurisation has increased flow, but the extent, location and duration of the change in flow is unknown.

14. It is not possible to ascribe water flowing into the mine to Thirlmere Lakes, and it is unlikely that there is water flowing directly from the lakes to the mine.

15. Spikes in the daily mine water discharge records are well in excess of the ability of the mine to pump water to the surface, and are a result of significant contributions from surface flows to mine water make.

7.0 BIODIVERSITY

7.1 CONSERVATION AND MANAGEMENT

Thirlmere Lakes is part of the Greater Blue Mountains World Heritage Area (GBMWHA). The GBMWHA covers approximately 10,326 km^2 and was inscribed in the World Heritage List in 2000 on the basis of its outstanding natural values, including its' biodiversity with a wide range of plant and animal lineages and communities, many of which are restricted largely or entirely to the Area. It also provides the principal habitat for many threatened species of plants and animals. Further information on the World Heritage listing is available at http://www.environment.gov.au/heritage/places/world/blue-mountains/values.html (accessed 14 Sept 2012). Listing as a World Heritage Area implies that governments and relevant community-based organisations to promote cooperation to protect the area for current and future generations.

The management of the GBMWHA is subject to a Strategic Plan (NSW National Parks and Wildlife Service 2009) which has the purpose to "*assist in meeting Australia's international responsibility under the World Heritage Convention. It will ensure that appropriate consideration is given to the GBMWHA's World Heritage values by managers when developing management prescriptions for the GBMWHA reserves, and that they are developed and implemented in a consistent and coordinated way*." It also provides a public statement of the commitment by the management agencies to the future of the GBMWHA with detailed management prescriptions being contained within the plans of management for the individual reserves, such as Thirlmere Lakes National Park, that comprise the GBMWHA. The Plan will remain in place for 10 years from 2009 and will be reviewed after 5 years; the outcomes of this report into the "drying of the Thirlmere Lakes" should be taken into account during this review along with relevant feedback from other community feedback, including relevant formal committees and community-based organisations.

The Strategic Plan is used as a guide by the GBMWHA Advisory Committee which is made up of scientific, technical, Aboriginal and community members appointed by the State and Commonwealth Environment Ministers, to provide advice to those Ministers regarding issues relevant to the Area, including changes in the water level of the Lakes. The Metro South West Regional Advisory Committee also provides advice on the management of the Area. These committees have not made submissions to the Inquiry. Nor has the Inquiry been informed if concerns over the drying of the Lakes had been previously reported to the World Heritage Convention. The absence of any input to the Inquiry from these advisory committees is somewhat surprising given their formal roles and functions.

Thirlmere lakes are not specifically identified within the description of the World Heritage values, although there is recognition that the wetlands (which are defined to include lakes in the sense adopted by the Ramsar Convention on Wetlands; Finlayson, 2012) are an important component of the biodiversity of the Area. The lakes were explicitly described in the GBMWHA Strategic Plan as a series of “perched” perennial freshwater lakes of considerable geomorphological and biological significance because of their great age and geomorphic stability. As the protection of these values is an integral component of managing individual reserves, as well as the GBMWHA as a whole, the Lakes are covered by the intent within the Strategy to conserve the GBMWHA’s biodiversity and to maintain the ecological viability and capacity for ongoing evolution of its World Heritage and other natural values.

The protection and management of the reserves within the GBMWHA are subject to the NSW National Parks and Wildlife Act 1974 and the Wilderness Act 1987. World Heritage is also considered as a ‘matter of national environmental significance for the purposes’ under the Federal Environment Protection and Biodiversity Conservation Act (EPBC Act) which ensures the protection of World Heritage values. Developments or activities with potential major impacts on the GBMWHA are listed in the GBMWHA Strategic Plan and include a reference to the potential impacts from adjacent or underlying mining operations. While the control of developments or activities such as these is beyond the direct control of the GBMWHA's State management agency, they may be subject to the EPBC Act if it is considered that such developments or activities will or are likely to have a significant impact on World Heritage values. The EPBC Act contains a referral process with outcomes, including any requirements for environmental management or monitoring, being determined by the Federal Minister for the Environment.

The Lakes are not listed under the Ramsar Convention on Wetlands as a Wetland of International Importance (known as a Ramsar site), although they would seem to meet several of the criteria for listing, in particular those covering,

i) rare or unique examples of a wetland type, and

ii) vulnerable, endangered, or critically endangered species.

While a formal assessment of the international importance of the Lakes was not undertaken by this Inquiry, an indication of the importance of the Lakes can be obtained from the entry in the Directory of Important Wetlands in Australia (Table 7-1). As the information in the Directory was supplied by the NSW National Parks and Wildlife Service this can be taken as an official assessment of the importance of the Lakes, and, as such, backs the suggestion that the Lakes meet the criteria for listing as a Ramsar site. Listing would also imply a commitment to monitor the Lakes in order to ensure their ecological character was not undergoing adverse change (in the sense defined by the articles of the Convention).

Listing as a Ramsar site would explicitly commit Australia to maintain the ecological character of the Lakes and to formally report to the Convention any likely or actual (adverse) change in ecological character, as required under Articles 3.1 and 3.2 of the Convention (see Pittock et al., 2010). The Lakes are already subject to the wise use provision within the Convention which, since 2005, has been defined as ensuring the ecological character of all wetlands are maintained, although not with the same reporting requirements as those associated with a formally listed Ramsar site (see

Finlayson et al., 2011). Listing as a Ramsar site may provide a mechanism for further funding support from the Commonwealth Government given its' support for Ramsar-listed wetlands in recent years, specifically for describing the ecological character and developing management plans for listed wetlands. Given the unique features of Thirlmere Lakes it could be listed under both Ramsar and World Heritage and hence subject to the provisions of both Conventions which are implemented in Australia through joint arrangements between the States/Territories and Commonwealth Governments. Listing under both Conventions would send a signal that Governments were committed to managing the Lakes in line with the provisions outlined by both Conventions, and further indicate their intent to do this in a transparent and participatory manner. The latter are considered as important components of the implementation of both Conventions, and although there is every indication that consultation, including representation from advisory bodies, does occur, the absence of any input to the Inquiry from the formally established advisory bodies raises concerns over their effectiveness, or capacity to contribute to complex technical issues.

Effective management of the GBMWHA is constrained by limited knowledge of the ecological requirements of species and communities, and best practice management. Botanical collections have been undertaken in the vicinity of Thirlmere Lakes, although for major wetland species, such as *Lepironia articulate*, these records do not go back earlier than the 1960s. Hence, whilst such records can be used to confirm that specific species were present in the lakes at that time, they do not provide much historical information about past conditions. Compared to some other World Heritage listed properties in Australia there does not seem to be a systematic and concerted effort to overcome this constraint, beyond acknowledging in official documents that it exists. The extent of information that is available is inadequate, for example, to ascertain if the ecological character of the lakes has changed in response to anthropogenic pressures, or possibly even to describe the ecological character using accepted protocols (see Department of the Environment, Water, Heritage and the Arts, 2008). The current lack of ecological information is at odds with the community concern being expressed over the ecological condition of the Lakes and commitments made under the World Heritage Convention. Explicit attention to these commitments is possible through the existing management and advisory arrangements; the absence of an effective assessment and monitoring regime, with feedback to local communities, is a major shortcoming in existing arrangements and should be rectified.

7.2 CONSERVATION FEATURES

The management of Thirlmere Lakes National Park is subject to a Plan of Management (NSW National Parks and Wildlife Service, 1997); as this was developed some 15 years ago it is surprising that an updated version has not been produced, or an addendum produced that specifically addresses the concerns over the drying of the lakes and possible influence of longwall coal mining on the biodiversity and ecology of the Lakes. This is a major shortcoming in planning or responding to community concerns over a valued asset of the GBMWHA. As it stands the Plan will be reviewed as required in 2014; given the changes in the Lakes and the acknowledged paucity of relevant information for management purposes, a review and the explicit incorporation of an adaptive and participatory management process, including relevant monitoring is required immediately, noting that it could then feed into the statutory review of the management plan in 2014.

In addition to the general objectives for managing National Parks in NSW a number of specific objectives were agreed for the management of the Thirlmere Lakes National Park, including ensuring the protection of the lakes in a stable and unpolluted condition to protect the scientifically important physical and ecological features of the Lakes; this can be equated with the Ramsar requirement to maintain the ecological character of the Lakes (refer to the previous comments). The emphasis of management in the National Park for the lifetime of the Plan of Management was on the protection of the area and on programs necessary for the maintenance of the natural features and processes that sustain these. It is difficult to see how this intent could be achieved without the implementation of a comprehensive description of the ecological character (or features) of the Lakes and supported by an ongoing, hypothesis-based, monitoring program. The ongoing reference to the absence of information about important features of the Lakes raises doubts about the effectiveness of both the management planning and implementation and advisory arrangements in place.

The information presented below has been extracted from the Plan of Management as one of a small number of documents that provide an overview of the biological and ecological features of the Lakes; again, it is stated that it is surprising, given the World Heritage status of the wider area, and the uniqueness of the lake system, that further material is not available. The Plan of Management provides an overview of the conservation features of the Park, including a summary of the native vegetation of the lakes that can be broadly divided into two major types, based on growth form and habit of the plant species, and includes:

- the lentic environment that supports many hydrophytic species, including *Brasenia schreberi* which is commonly seen as a relative of the water lilies, and the tall sedge, *Lepironia articulata*, which is at the southern extremity of its range
- the lake margins and colluvial/alluvial flats that support a diverse array of littoral and riparian species, including the paperbark, *Melaleuca linariifolia,* as well as the locally significant river peppermint, *Eucalyptus elata*.

The vegetation of Lake Baraba (Black et al., 2006) is largely dominated by sedges, including Pithy Sword-sedge (*Lepidosperma longitudinale*), Scalerush (*Lepyrodia muelleri*) and Zig-zag Bog-rush (*Schoenus brevifolius*), and also Tall Sedge (*Lepironia articulata*), Tall Spike-rush (*Eleocharis sphacelata*), Woolly Frogmouth (*Philydrum lanuginosum),* Water Lily (*Brasenia schrebi*) and the alga *Chara fibrosa*, with the paperbark tree, *Melaleuca linariifolia,* growing along the edges of the water. Detailed analyses of spatial changes in the vegetation in the Lakes over time are not available, and while some information may be derived from aerial photographs, it is may not be sufficiently accurate to determine how the vegetation has reacted to historical rainfall and inundation. Detailed survey and mapping over the recent drought and flooding events could have been used to ascertain the responses of key or indicator species to wetting/drying, and to determine whether specific species are sufficiently adapted to survive such changes, and able to (potentially) re-establish. Not to have done this, especially given the public concerns over the condition of the Lakes, is a surprise.

The Lakes also support an important population of the prostrate, mat-forming plant, *Rulingia prostrata* that had apparently colonised the lake shores that had been exposed by the decline in water levels in recent years. These sites were seemingly once intermittently or permanently inundated by the lakes and are now largely dominated by shrubs. However, *Rulinga prostrata* was also seen in areas fringing the lakes and in the seasonally or intermittently inundated areas between the lakes. While the decline in lake water levels may have created new habitat for this plant it has long been present in this area and has probably adapted to natural variations in lake levels. It also seemed to favour disturbed sites and does best in areas with little or no competition. It was most common around Lake Gandangarra with progressively less being found around the downstream lakes. The plant is considered vulnerable and is subject to a national recovery plan (Cater and Walsh 2010). The scant records available suggest that this species has long been a component of the flora of the Lakes; more specific ecological investigations of this and other species could provide an indication of the biotic responses to the historical pattern of wetting and drying. As is stands, the scant level of information available only allows speculative responses to the successional patterns associated with wetting and drying, both inter-seasonally and over decades.

A generalised map of the vegetation of the Lakes (Figure 7-1), based on sampling undertaken in 1981, was provided by Rose and Martin (2007), and shows the distribution of "*Melaleuca linariifolia* low closed or low open forest" mostly fringing the lakes and along the parts of Blue Gum Creek" and a "closed sedgeland" which formed a "*continuous fringe around and between each lake*". The distribution of some aquatic plants in the sedgeland had changed in recent years, such that *Eleocharis sphacelata* has been reduced to a patchy distribution on both the landward and lakeward sides of *Lepironia articulatae,* possibly caused by lower water levels since 1974. At the time, Lake Baraba was almost dry and covered by the sedge, *Lepidosperma longitudinale*, with encroaching paperbarks. The history of Dry Lake is summarised in the abstract, pasted below, from Rose and Martin (2007).

"At the beginning of the Holocene, Dry Lake was a lake, with a fringe of cyperaceous reeds. Eucalyptus and Allocasuarina were the dominant trees with shrubs and herbs prominent in the understorey. Between 8 ka and 2 ka, the lake became shallower, and the reeds grew over the surface of the developing swamp, forming peat. A hiatus in peat deposition between 5 ka and 2ka was followed by the formation of a thin layer of diatomite. Eutrophic conditions would be required to allow large populations of diatoms and burning seems the most likely way of increasing the nutrient mobility on the poor sandstone soils of the catchment.

By 2 ka, the lake had become a peat swamp. Angophora/Corymbia pollen had increased dramatically, most likely representing Angophora on these alluvial flats. The shrub layer had also become more diverse. Allocasuarina did not decrease through the Holocene, unlike the record of many other Holocene sites. The likely reasons for this difference are probably related to site-specific environmental conditions. With European settlement, all trees decreased dramatically and grasses increased. Today, Dry Lake only contains water in exceptionally wet periods."

A brief outline of the terrestrial vegetation is also provided in the Plan of Management and described by Black et al. (2006) based on information derived from several sources. It is seen a being typical of that which occurs across the Hawkesbury Sandstone complex; is diverse with over 400 species from 250 genera; comprised of dry sclerophyll woodland and forest formations of mixed *Eucalyptus/Corymbia/Casuarina*; with Sydney Peppermint (*Eucalyptus piperita*) and Red Bloodwood (*Corymbia gummifera*) also being common. Details of the distribution and age structure of the terrestrial vegetation were not provided, nor were details of the recent fire history; when combined this information may provide a means of determining the effect of the vegetation on the runoff from the catchment to the Lakes (refer to section 3.2.5). Further investigations on the age structure and density of the vegetation may be required whereas information on fire patterns could be obtained from that collected each year as part of the fire management policy for the Park, as outlined in the Plan of Management.

As with the wetland vegetation described above, the extent of ecological information on the terrestrial vegetation is inadequate to enable the relationships between the vegetation and the hydrology of the catchment to be readily identified; a situation that should be rectified wherever possible to enable the biodiversity outcomes from wetting/drying and the relationships with fire and runoff to be described. Similarly, the effect of past grazing by ungulates on the Lakes and fringing vegetation does not seem to have been investigated. With the information available it is not possible to determine how much impact grazing may have had on the presence/absence or relative abundance of plants in the lakes and their catchments, and whether or not this interacted, directly or indirectly, with the wetting/drying patterns to limit or promote the spread of any plant species. It is also unknown if grazing, most likely in association with the wetting/drying cycles since European settlement of the area have affected the formation and survival of the peat layers in the Lakes.

Given the geomorphic evolution of the Lakes they support many organisms which are restricted or largely restricted to the Lakes. These include a number of planktonic and bottom-dwelling protozoans (single-celled animals that may also occur in colonies) that are present along the shores and in the top layer of open waters. Crustaceans are present in the bottom-dwelling fauna. A freshwater sponge, *Radiospongilla sceptroides,* is present in the Lakes and is thought to be confined within the Warragamba catchment and is of ecological significance as it exhibits physiological features in response to the perennial status of the Lakes. Other significant taxa include true worms, a mussel and various microscopic organisms. Planktonic midge larvae from the genus *Chaevorous* which are known only from a small number of other lakes in Australia, also occur. Furthermore, it is remarked that some organisms often found in lakes, such as Trematodes (endoparasitic flukes), are absent from the lake sediments.

The vulnerable Australasian bittern, *Botaurus poiciloptilus*, which relies on wetlands for nesting and foraging, has been recorded within the park. Similarly, the Japanese snipe, *Gallinago hardwickii,* a species listed under the bilateral agreement between Japan and Australia for the protection of migratory birds (JAMBA), has been recorded foraging at the Lakes when water levels were low and the muddy shores were exposed.

7.3 ECOLOGICAL INTERACTIONS

The general descriptive information about the lakes does not cover in any depth the complex ecological interactions that occur between the biota and the physical environment, in particular the effect of wetting/drying on the survival of key or rare species and the influence of fire and terrestrial vegetation and runoff from the catchments. The general ecological requirements for some species are mentioned in terms of them being aquatic and hence requiring water to survive, but very little about the more complex effects of rainfall or drought, or indeed, the potential for aquatic species to survive under prolonged dry conditions. The latter could benefit from further literature-based investigations of the traits that enable various plant species to reproduce and disperse, particularly in relation to wetting/drying events or cycles, although it may be difficult to obtain suitable information to describe the impact of multiple years of drought, or the cumulative impact of decadal or longer-term cycles. An analysis of the seeds and other propagules (collectively covered by the term “seedbank”) in the sediment of Thirlmere Lakes could assist in further explaining the resilience of at least some of the plant species in the Lakes, although not all propagules may be detected using any one method of analysis.

The drying of the lakes has had an obvious impact on the peat substrate in many of the lakes, but measures to assess this, or indeed, to prevent it from happening, do not feature in the Plan of Management. This raises an interesting ecological and management issue that can only be answered by further ecological investigation. In particular, how long has it taken the peat to form and to desiccate? The latter can be, to some extent, surmised from local information and knowledge about the extent of drying through the recent drought. Black et al. (2006) sampled Lake Baraba in 2003 and reported that peat accumulation started about 8.5ka BP. More specific investigation may provide further information into the inundation patterns experienced by the Lakes. Black et al. (2006) noted that the Lakes were known to recede significantly during drought. One thing is certain – the current dried peat will not be replaced quickly. The loss of this material represents a significant change in the ecological character of the lakes, that is unquestionable, but whether or not it is part of natural climate variability or caused by human activities is not as readily answered, and is the subject of other parts of this report. The analysis of the vegetation history of Dry Lake (Rose and Martin, 2007) and Lake Baraba (Black et al., 2006) provides examples of the type of analyses that may shed more light on the recent vegetation and wetting/drying history of the Lakes, especially given the current questions about the causes of changes in the hydrology of the Lakes. It is surprising, under the circumstances, that these investigations have not been extended.

The complexity of changes in the vegetation of Thirlmere Lakes is illustrated by the presence, possibly at different times and population levels, of the water lily-like *Brasenia schreberi*, as well as other aquatic plants that require wet conditions to survive and disperse, the sponge, *Radiospongilla sceptroides,* that has a specific physiological response to perennial conditions, *Rulingia prostrata* that responds to dry conditions, and the Japanese Snipe that uses exposed mudflats. The balance between wetting over time and across the lakes is likely to be a determinant in the presence and survival of species requiring very different conditions, but our knowledge of the requirements for specific species is largely lacking, beyond that obtained from some general correlative relationships. This level of information belies the recognised importance of the Lakes.

Overall, ecological information on Thirlmere Lakes is sparse and inadequate for determining whether changes in the biota reflect natural variability, or have been caused by anthropogenic influences. An analysis of the ecological character of the lakes, using, for example, the comprehensive procedure outlined for Australian

Ramsar listed wetlands (Department of the Environment, Water, Heritage and the Arts, 2008), would provide a better information base, noting that this in itself may not provide more than a snapshot of the ecological character, and would require ongoing monitoring of key components, or indicators of these components, if the extent and effect of natural variability and anthropogenic influences were to be determined. An analysis of past ecological change in the Lakes would add considerable value and assist in ascertaining how much the past hydrology and ecology of the lakes has varied. These are basic requirements for determining whether the ecological character of the lakes has changed, or is changing in both the long and short term, and whether any remedial or restoration activities are necessary or feasible, as would be expected in an area afforded World Heritage recognition, or wetlands that met the criteria for being listed as Ramsar sites (see Pittock et al., 2010 for a commentary on the requirements for managing Ramsar sites).

While sufficient information about the hydrological and ecological interactions that have helped shape the ecological character of the lakes is not available, it is not beyond reason to expect that increased drying, or desiccation, as the consequence of an anthropogenic change in the hydrology could result in major changes to the current ecological character, including the biota, of Thirlmere Lakes. At the same time, further change in the climate could also induce ecological changes and potentially the decline, expansion, or presence of particular species. These uncertainties support the need for the above recommended ecological investigations, including the history of change in as much detail as possible, and ongoing monitoring, in an adaptive framework; expectations that are within the scope of obligations and recommended practices under the World Heritage, Biological Diversity and Wetland Conventions that Australia has signed.

The current management and advisory approaches, including the dearth of information, derived from hypothesis-based monitoring, for decision making, seem at odds with the obligations and recommended practices outlined through these Conventions. A review of the existing management approaches should be conducted and placed within the context of whether or not the current management structures should be adjusted, or even replaced. The review should in particular consider whether or not the current practices are sufficiently adaptive (incorporating effective assessment and monitoring and feedback to managerial decision making) and participatory, and can ensure the maintenance of the ecological character of Thirlmere Lakes.

Table 7-1. Description of Thirlmere Lakes from the Directory of Important Wetlands in Australia (information from Environment Australia 2001).

Location: On the edge of the Southern tablelands approximately 10 km south west of Picton. Thirlmere Lakes include Gandangarra, Werri-Berri, Couridjah, Baraba and Nerrigorang lakes.

Wetland type: Permanent freshwater lakes (> 8ha); Peatlands

Area: 50 ha **Elevation:** 300 m ASL

Criteria for inclusion in Directory:

1. It is a good example of a wetland type occurring within a biogeographic region in Australia
2. It is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.
3. It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail.
4. The wetland supports 1% or more of the national populations of any native plant or animal taxa.
5. The wetland is of outstanding historical or cultural significance.

Hydrological features: A series of five shallow, perennial, elongated freshwater lakes in a horse-shoe bend in a ancient river valley of the Hawkesbury Sandstone. Blue Gum Creek drains westward from the lakes into Little River. The maximum depth of the deepest lake is 6m. Three of the lakes are interconnected by artificial canals, and when water levels are high, water flows through the whole system.

Ecological features: The lakes have extensive aquatic flora, including the sedge, *Lepironia articulata*. The lake margins and colluvial / alluvial flats support a diverse array of littoral and riparian species including the paperbark, *Melaleuca linariifolia*, River Peppermint (*Eucalyptus elata*), Slender Cord-rush (*Restio gracilis*), Zig-zag Bog Rush (*Schoenus brevifolius*), Black Bog-rush (*Schoenus melanostachys*), Hairy Bog-rush (*Schoenus villosus*), Swamp Club-rush (*Isolepis inundata*), Floating Club-rush (*Isolepis fluitans*), Pithy Sword-sedge (*Lepidosperma longitudinale*) and Variable Sword-sedge (*Lepidosperma laterale*). The sedges Tall Spike-rush (*Eleocharis sphacelata*) and *Eleocharis atricha* also occur here.

Notable flora: The sedge, *Lepironia articulata*, reaches the southern limit of its range in Thirlmere Lakes; the water plant *Brasenia schreberi* which is considered rare in Australia. Unusual species include Pondweed (*Lemna trisulca*) and Bladderwort (*Utricularia* sp.).

Notable fauna: The Australasian Bittern (*Botaurus poiciloptilus*) which is vulnerable at a state level and the Latham’s Snipe (*Gallinago hardwickii*) which is listed under JAMBA and CAMBA have also been recorded within the lakes. The freshwater sponge, *Radiospongilla sceptroides*, is thought to be found only in the Warragamba catchment and occurs in Thirlmere Lakes. The lakes sustain a large population of planktonic midge larvae of the genus *Chaevorous* which are generally associated with unpolluted fresh waterbodies and know from few other locations within Australia.

Land tenure: On site: National Park. Surrounding area: National Park, freehold

Conservation measures: On site: Nature conservation, recreation. Surrounding area: Nature conservation, recreation, urban area, agriculture

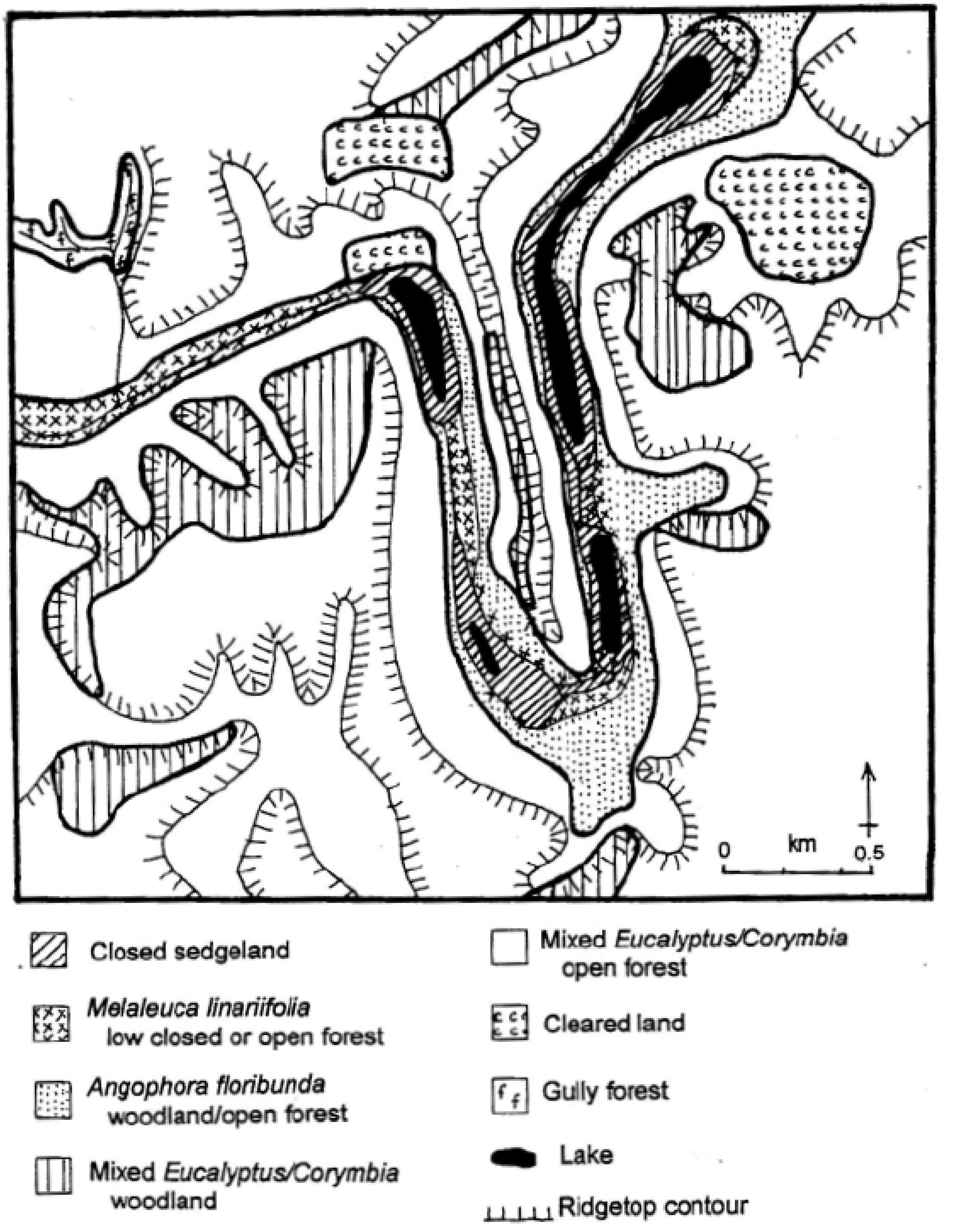

Figure 7-1. Vegetation map of Thirlmere Lakes from 1981 (source: Rose and Martin, 2007: reproduced with permission of authors).

8.0 LANDUSE AND ITS IMPACTS

8.1 IMPACTS ON SURFACE WATERS

8.1.1 Agriculture

There is no evidence that agriculture has substantially changed the surface configuration of the catchment. Land clearing outside of the National Park, particularly in the east, is obvious on aerial photos and space imagery (Fig. 8-1). There are nuclear settlements in the east, but outside of the catchment.

Road density is low, and it is highest in the eastern section of the catchment. Inspection of roads did not identify any major water diversions within the catchment, nor does the Picton to Mittagong Loop Line appear to have impacted on the catchment.

There are reports of water extraction from the lakes for agriculture, but there has been no significant water extraction for agricultural purposes for more than 30 years (Pells, 2011, p. 11; discussed in Chapter 5).

There are reports of grazing on the lake floors during dry periods, before they were declared part of Thirlmere Lakes National Park. "Poaching[10]" would have impacted on the lake floors and the micro-climate of the lakes in the past. It has been over four decades since grazing was allowed on the lake floors, so it is highly likely that any impacts have been ameliorated by bioturbation, inundation, and plant growth.

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[10] "Poaching" is a term which means, in this context, trampling or cutting up turf with hooves.

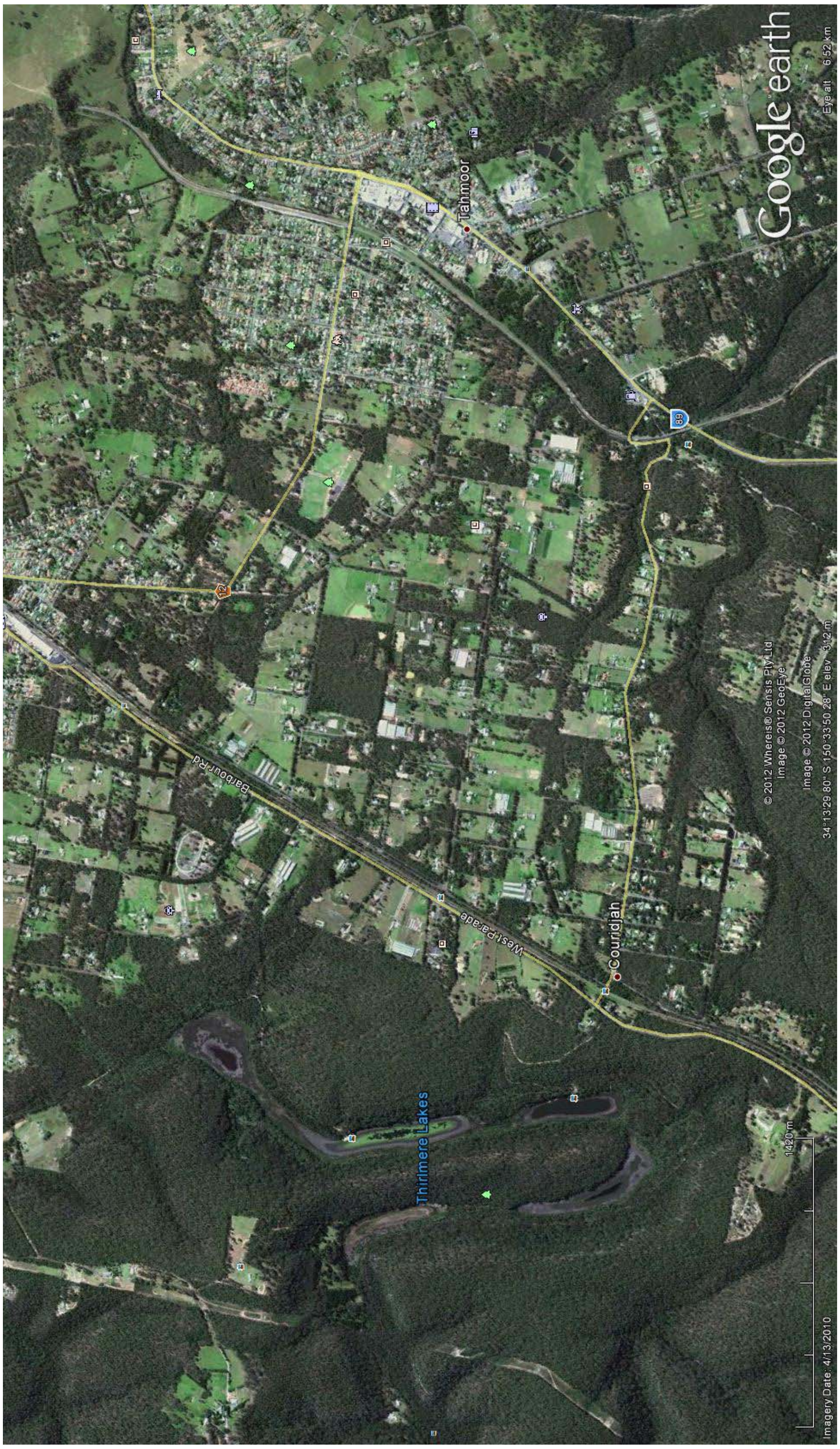


Figure 8-1. Satellite imagery (13/4/2010) of Thirlmere Lakes region and area to east (copyright Google Earth: ©2012 Whereis®Sensis Pty Ltd; Image ©2012Geoeye; Image©2012 DigitalGlobe).

8.1.2 Industrial

Water was extracted for the railways from 1867 to 1964 but water for this or any other industrial purpose has not been extracted for over 30 years to the best of the Committee’s knowledge. The connection between the lakes was enhanced by excavation of the cols separating Lake Gandangarra from Lake Werri Berri and Lake Couridjah from Lake Werri Berri. This excavation may have increased the area of lake surface exposed to evaporation at times of lower lake levels, but it is not thought to be significant to the water budget for the lakes.

8.1.3 Residential and Commercial

Water from the lakes was used to supply residences and a hospital for a number of years but not for the last 30 years, except for some minor extraction with the recreational area at Lake Nerrigorang. There are several references to proposals to use the water in Thirlmere Lakes to augment water supplies for Picton and other areas, but these proposals, which would have resulted in substantial works, were not realised.

8.1.4 Recreational water use

The lakes have been used for swimming and boating. The Committee has sighted photographs from 1902 showing picnics on the shores of the lake and there are a number of photographs and statements from locals of the recreational use of the lakes from the 1950’s onwards. One of the triggers for this inquiry was the inability of residents to enjoy the recreational opportunities of the lakes because they were either dry or very low.

Despite intense recreational use there is unlikely to have been any significant impact on the surface hydrology of the lakes, except for indirect impacts related to roads and car parks.

8.1.5 Conclusions concerning surface water use

There is no evidence to suggest that landuse practices of any kind have significantly influenced the surface hydrology or the volume of water in the lakes for the last three to four decades. Prior to the 1960's, the impact would have been marginal and the Committee was unable to see any link between surface water extraction in the past and present low lake levels.

8.2 IMPACTS ON EVAPOTRANSPIRATION, RAINFALL AND RUNOFF

8.2.1 Anthropogenic climate change

While there are a number of studies for the Sydney region identifying the potential impact of anthropogenic climate change (Sydney Catchment Authority, 2010), there is no direct evidence from the lakes. As discussed previously, the flood- and drought-dominated regimes are natural phenomena, although a case has been made that anthropogenic factors may have intensified them (Warner, 2009). While there is uncertainty about the magnitude of anthropogenic climate change in the area, there is substantial evidence of increased temperatures over the last two decades (Office of Water, 2010; State of the Environment, 2011). Whether rainfall has increased or decreased is open to debate although the consensus again predicts increased dry spells with possible changes in the winter and summer rainfall regimes.

Increased temperatures will increase evapotranspiration, which is further enhanced as shallow waters “heat up”, particular with the black, radiation absorbent, beds. If there is a change towards increased dry spells then increased evapotranspiration will lead to lowering the level of the lakes in the long-term.

8.2.2 Vegetation removal

Most of the catchment remains vegetated although the extent of regrowth following earlier clearing is uncertain. The present vegetation cover appears to be a mature community. There is unlikely to have been a change in evapotranspiration as a result of changes in vegetation.

8.2.3 Bushfires

There is a debate about the extent to which European settlement has changed the fire regime. Black (2006) established that, in the long-term, changes in fire regime were more related to climate change than to Traditional Custodian landuse practices.

Fires change the rainfall-runoff regime, and the impact may last for several years after a fire (Marcar et al., 2006; Smith et al., 2011; Willgoose, 2011). There were significant bushfires in the catchment in 2001 and 2006. It is not possible with the data available to the Committee to identify whether or not the fires have influenced runoff and hence lake levels. As both fires occurred during a period of drought it is highly likely that the drought regime dominated any potential effect of fires on runoff (Collings and Ball, 2003). Chafer (2006) used Thirlmere as one of his two target sites for estimating the severity of the 2006 fires. He noted the loss of water repellent behaviour of the soil during burning but was unable to say exactly how this affects runoff, suggesting that small depths of rainfall would be absorbed but large rainfalls would fill soil stores that would rapidly overflow.

NPWS have a fire management plan for the park. Once again, it is not possible to assess the impact of this management policy on the rainfall-runoff regime of the catchment, and hence lake levels.

It is unlikely that recent bushfires have had a significant impact on the hydrology of the lakes. While regeneration of forests following fires may result in higher evapotranspiration many years after the fire, there are no data by which to judge the impact of fires in the long-term.

8.2.4 Rainfall

Apart from regional evidence of temporal changes in rainfall, there is nothing to suggest that the rainfall has been impacted by landuse in the area. Gero and Pitman (2006) suggest an impact on storms in the Sydney Basin as a result of land clearing in the southwest, but the results of their study are not sufficiently detailed to link their work directly to fluctuations in Thirlmere lake levels.

8.2.5 Conclusion

While there is some uncertainty about the impact of bushfires on the hydrology of the Thirlmere Lakes catchment, there is nothing to suggest that any other land management practices within the catchment would have changed the rainfall-runoff regime of the catchment.

8.3 IMPACTS OF GROUNDWATER EXTRACTION

The review of groundwater in Chapter 6 identified a large number of bores that were extracting groundwater from the catchment, but only four or five bores that were extracting water directly from the topographic catchment.

None of the bores are monitored for either water level changes or volumes of water pumped from them. The suggestion has been made by some members of the community that there may be a number of unlicensed bores, but the Committee has no independent evidence of this.

There are a large number of bores to the east of the catchment, in the down-dip direction, which is the direction of groundwater flow from the lakes. Without knowing the volumes of water pumped from these bores or the variation in groundwater levels over time the Committee cannot assess the impact of the bores on the water table and hence any consequent impact on groundwater flows from Thirlmere Lakes. It is highly likely that pumping rates increased during the droughts.

On the basis of anecdotal evidence submitted by the community about the lowering of water levels and the rates of pumping, there is reason to suggest that groundwater extraction may exceed the rate of recharge, but there is no proof of this, nor what is causing the lowering.

8.4 MINING

Longwall mining recovers some 80% of the coal resource. As the face advances and the chocks are moved forward the roof behind collapses into the goaf. The collapse of the roof of the excavated area creates instability in the rocks above, to the ground surface, which is called mine subsidence. Chapter 6 contains a discussion about mining and groundwater. The following will examine this relationship for the area in more detail.

8.4.1 A primer on mine subsidence

Several reviews have been conducted on mine subsidence in the Southern Coalfields, and there are a number of research and technical studies (Holla and Barclay, 2000; Sydney Catchment Authority, 2007; NSW Dept of Planning, 2008; Russell et al., 2010). The following draws from these reviews.

Subsidence is deformation of the ground surface caused by mining. When the roof of a longwall collapses this triggers a collapse of material above until the material that falls fills the void and chokes off the collapse (Fig. 8-2). The height of this caved zone is called the caving height. Sagging in the rock strata above the collapsed zone causes the rocks to “stretch” or be put into tension, which opens joints, delaminates bedding planes, and causes movement along joints and bedding planes, and even the formation of new fractures. The sagging propagates upwards and outwards, but with decreasing curvature of the sag, with a consequent decrease in shear and tensile stresses. The point at which the stresses are too low to open structural planes of weakness in a continuous block marks the transition between the fractured zone and the constrained zone. At the surface a trough develops which is aligned with the long-wall axis (Figs 8-3 and 8-4). Successive longwalls result in the enlargement of this trough, in both depth and area (Fig. 8-5). The NSW Office of Planning (2008) suggests that this model is not universally applicable, as it was developed for areas with flat topography and horizontal beds. Holla (1997) has some detail on the effect of high relief areas.

The propagation of the subsidence outward from the mine section is defined as the angle of draw, the angle between two lines drawn from the edge of the mine workings, one vertical and the other to the limit of vertical displacement on the surface, usually defined by a minimum vertical displacement of 20 mm (Fig. 8-3).

The angle of draw defines the width of the trough at the surface formed by mine subsidence. On the margins of the trough the rocks and soil material are in tension as they are being stretched. In the centre of the trough the rocks are in compression as they are being forced together (Fig. 8-4). The compression can force strata to delaminate and rise slightly and as a consequence opens joints and bedding planes, if not establish new fractures. “*As mining approaches a site, the site will begin to tilt towards the excavation. Maximum tilt occurs at the point of inflection between concave and convex curvature. If the zone of concave curvature then passes beneath the site, the site will start to tilt back in the opposite direction and, if the mining area is sufficiently large, it will in theory ultimately return to its original vertical inclination*” (NSW Dept. Planning, 2008, p. 49).

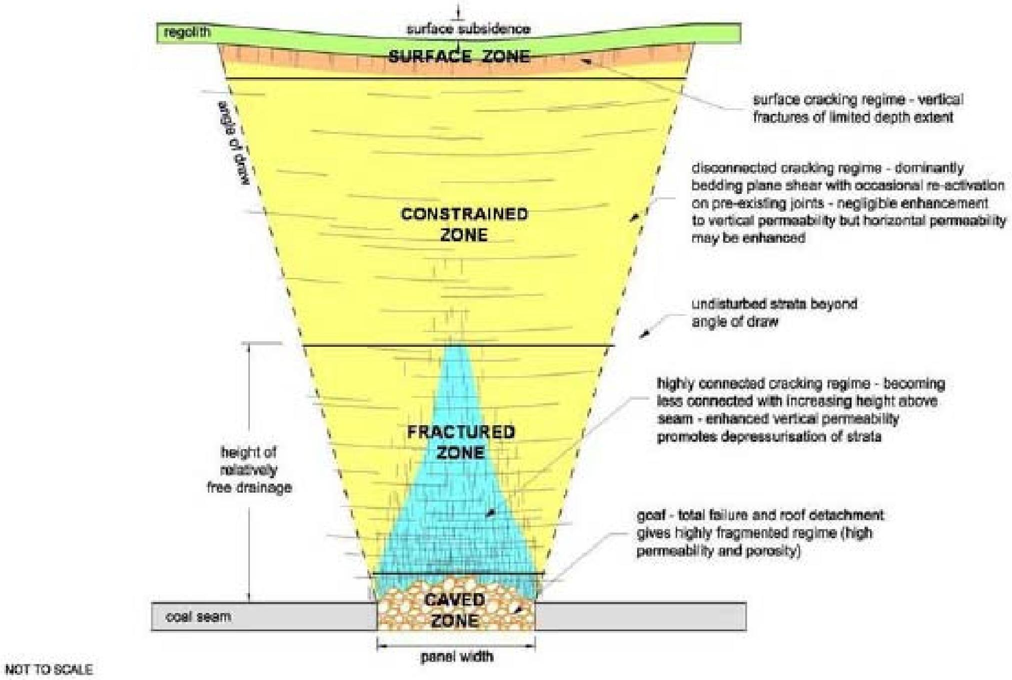


Figure 12: Conceptual Model of Caving and the Nature of Fracturing above a Mine Excavation

Source: Adapted from Wyong Areas Coal Joint Venture

Figure 8-2. Conceptual model of mine subsidence (From NSW Dept. of Planning, 2008, p. 46). With permission ©State of NSW through Department of Planning.

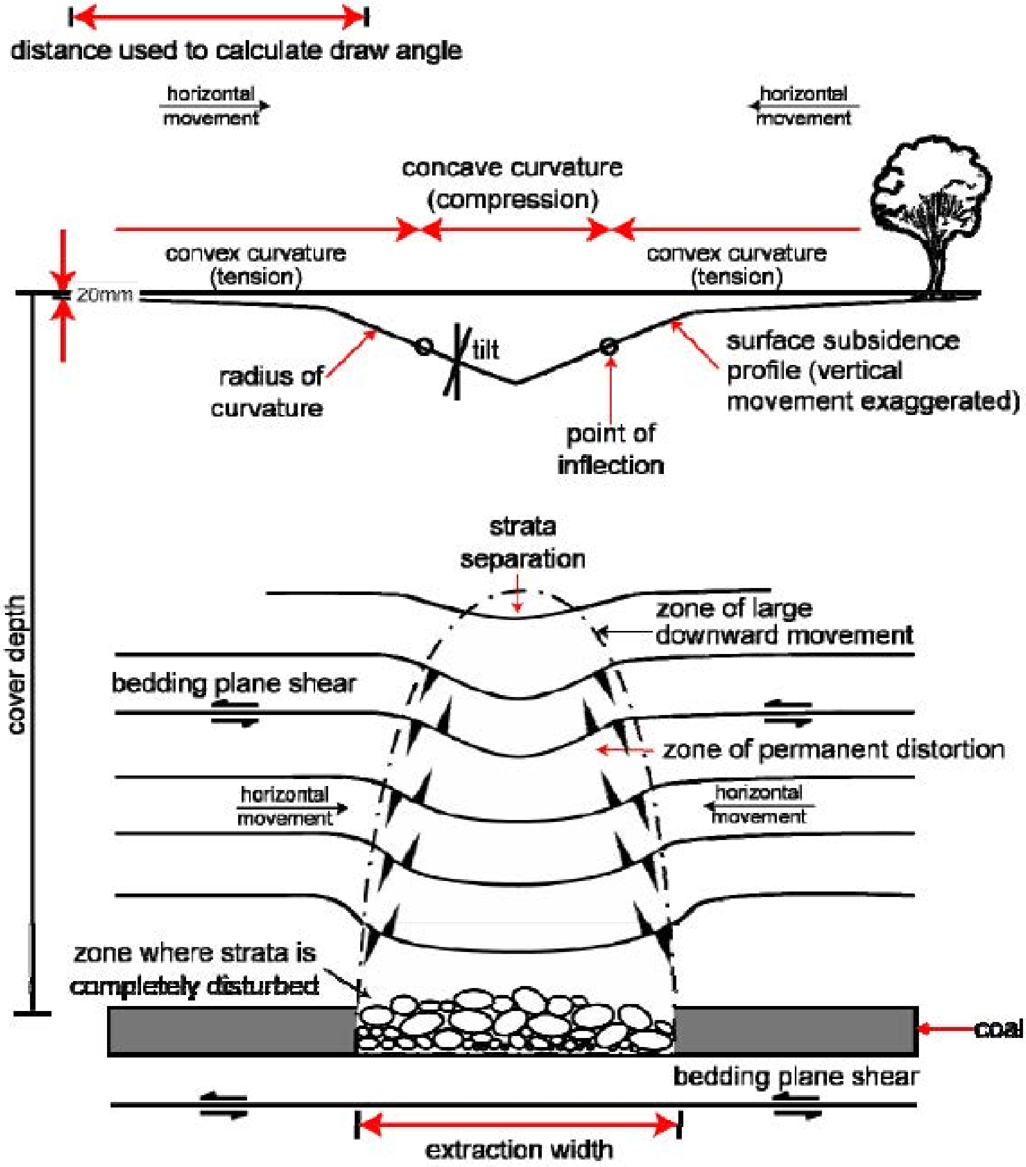


Figure 2-1 Formation of a subsidence trough (Holla and Barclay, 2000)

Figure 8-3. Description of forces and terminology for subsidence trough (from Sydney Catchment Authority 2007). With permission.

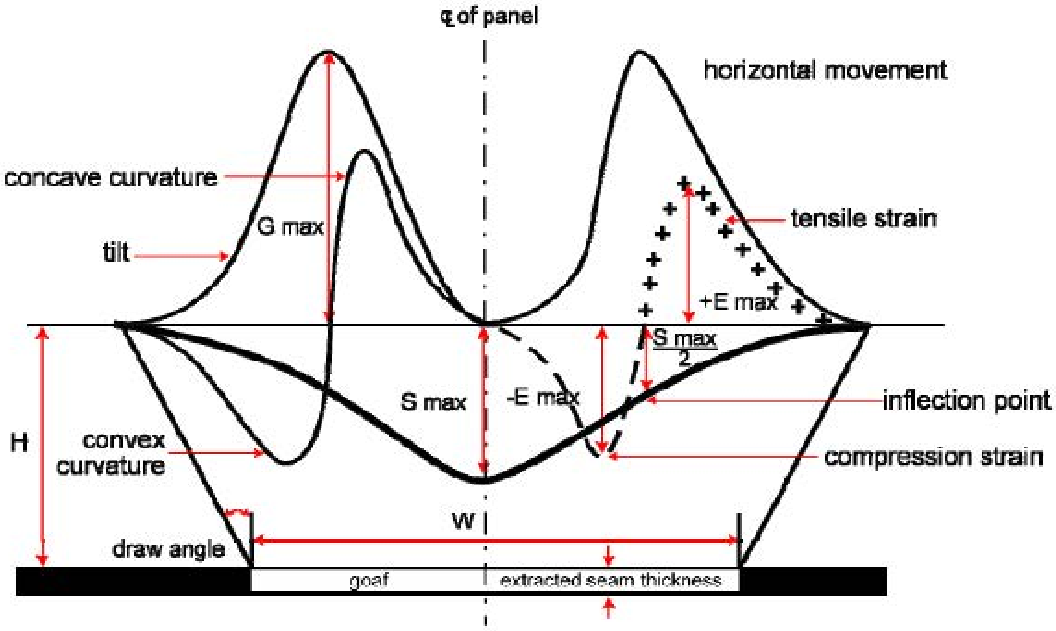
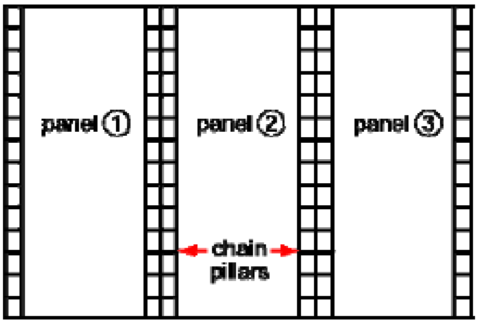


Figure 2-2 Characteristics of trough-like subsidence: left half vertical components, right half horizontal components (Holla and Barclay, 2000)

Figure 8-4. Description of forces and characteristics of trough subsidence (from Sydney Catchment Authority 2007).

The reviews suggest that the effect of longwall mining may not be fully seen at the surface until several adjacent longwall panels are excavated. As more coal is excavated more load is placed on the remaining pillars or panel abutments and they are subject to increasing compression force. Subsidence may continue for several years after the mining has finished. The surface impact of mine subsidence is often seen in displacement of fences, tilt in houses, posts, and cracking in roads, houses, bridges, and water and sewerage lines (Fig. 8-6). There are documented cases of deleterious effects of mining on surface hydrology elsewhere in the Hawkesbury Sandstone terrain, for example on the Newnes Plateau, near Lithgow, NSW, which led to fines being applied by the Commonwealth (DSEWPaC, 2012).



(a) Plan of longwall layout

(b) Subsidence profile - shallow and smooth

(c) Subsidence profile - deep and smooth

(d) Subsidence profile - deep and wavy

Figure 2-3 Profiles over a series of longwall panels (Holla and Barclay, 2000)

Figure 8-5. Impact on surface subsidence trough of several adjacent longwall panels (From Sydney Catchment Authority 2007). With permission.

Figure 8-6. Result of mine subsidence in Tahmoor. The vertical offset is >500 mm on either side of the patch in the road.

Further complicating the impact of mining is the interaction with the natural stresses that exist in the rock material which result from topographic loading (hills and valleys) and tectonic forces. The effect of the mining is to permit rock material to move towards the excavation, which then translates into a closure of valley walls and uplift, or upsidence, of the valley floor (Fig. 8-7).

A schematic diagram of the impact of upsidence is presented in Fig. 8-8, which is based on a case study of Waratah Rivulet, located over the longwalls of the Metropolitan Colliery. There are a number of studies that have identified the impact of mine subsidence on water flow in streams, including the impact of Tahmoor Colliery on the Bargo River (NSW Dept of Planning, 2008). There are also studies which suggest that this impact is minor or temporary (Geoterra, 2008).

The issue with river valleys is whether the structural deformation is significant enough to allow the water to escape to deep aquifers. Some argue that the delamination and cracking is surficial and does not represent a substantial loss of water from the river system. It was noted by the NSW Dept. Planning (2008, p. 70) that "*Centennial Tahmoor reported that it has experienced upsidence of some 400 mm, resulting in sporadic cracking of the river bed and the drying out of some ponds at the time of mining. Subsequently, the fracture network in the Upper Bargo River appears to have largely* *self healed, surface water levels have returned to their pre-mining steady state, and there are no obvious impacts on ecology*".

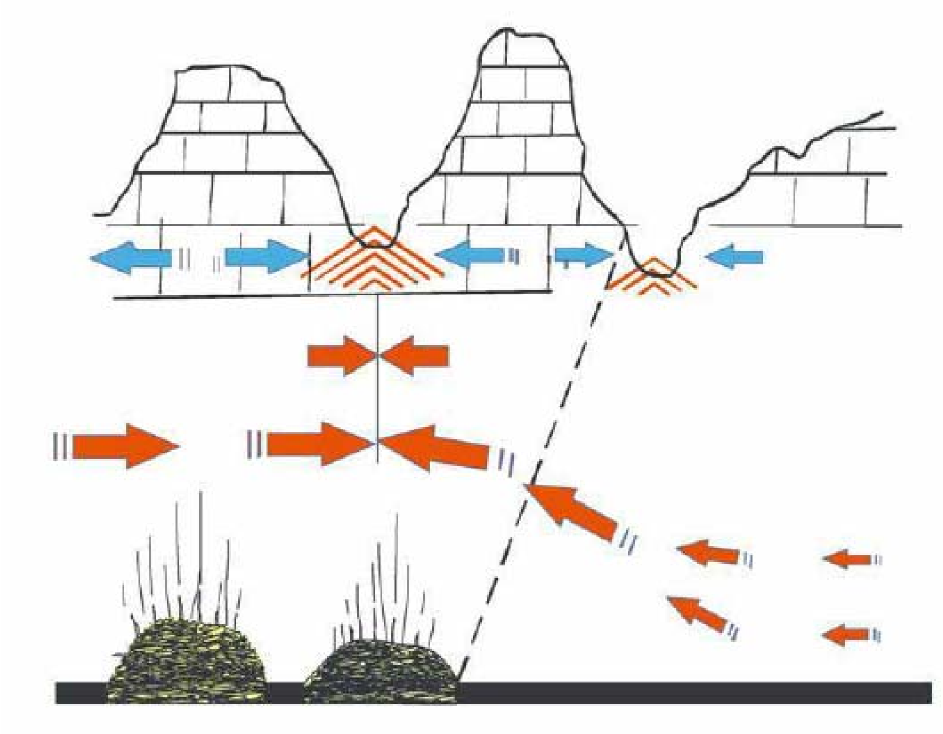


Figure 18: Conceptual Distribution of Horizontal Stress above Mine Workings in Deeply Incised Topography

Note: Natural, regional stress shown in blue; mining induced stress shown in red.
Source: Adapted from Galvin, 2005

Figure 8-7. Stresses in uneven topography (From NSW Dept. Planning 2008, p. 54). With permission ©State of NSW through Department of Planning.

The Sydney Catchment Authority (2007, p. 19) noted that "*Cracks at the ground surface occur as either faceline or ribline cracks. Faceline cracks develop as a longwall advances and the overburden behind the working area subsides in a dynamic wave, they run parallel to the longwall face, and generally close up as the longwall advances and the ground subsides to its maximum depth at greater distances back from the face (Dawkins, 1999). Ribside cracks develop along the axis of the extracted panel, as the overburden falls in towards the subsidence trough. Generally these cracks do not close up, although they may be reduced as adjacent panels are extracted (Dawkins, 1999). When these types of cracks occur in the surface layers the rate of channel water drainage to the groundwater table can increase.*

Generally, it is thought that such fractures are contained within a shallow zone close to the surface (Booth, 2002; Judall, Plat, Thomas and Associates, 1984), however if they extend to a sufficient depth they are able to provide a connection between surface water and deeper permeability zones (Parkin, 2002). Connection with permeable regional aquifers could lead to a net loss of water to the local catchment if the regional aquifer has discharge locations outside the catchment of flow origin".

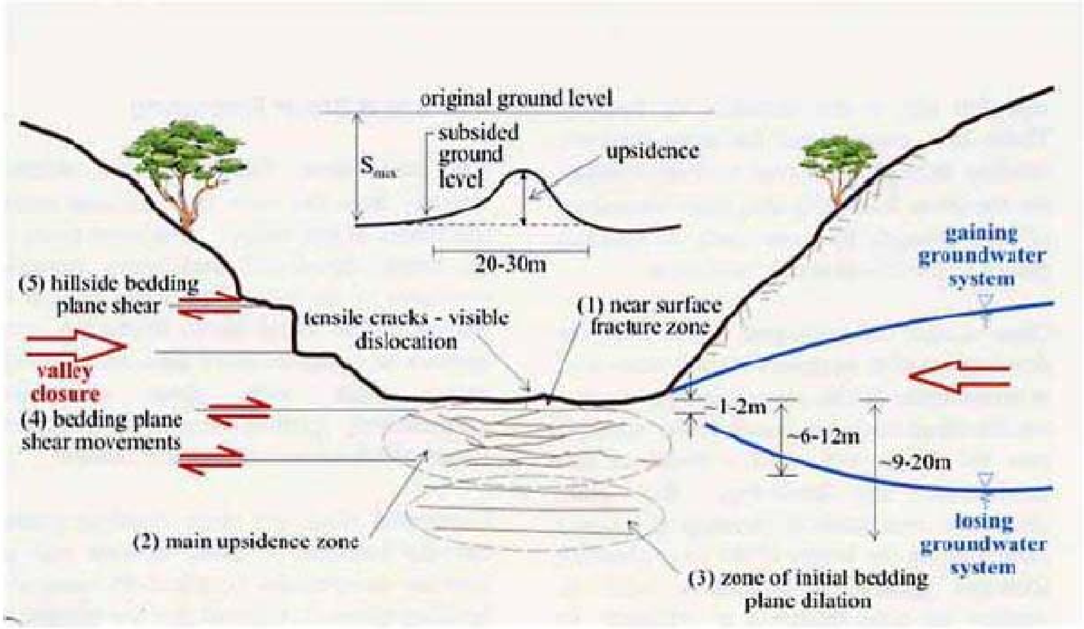


Figure 21: Upsidence Fracture Network Determined from Surface and Subsurface Monitoring, Waratah Rivulet at Metropolitan Colliery

Source Mills, 2008

Figure 8-8. Impacts of mine subsidence on Waratah Rivulet (NSW Dept. of Planning, 2008, p. 57). With permission ©State of NSW through Department of Planning.

The NSW Dept of Planning (2008) review of the impact of mining on swamps was inconclusive, although they suggested that there was a strong possibility that mining caused drainage and watertable drops, degrading the swamps. Their evidence was based largely on the work of Tomkins and Humphreys (2006).

A number of submissions to this inquiry reported the loss of water from streams and swamps and the failure of the flow to return over time. What is uncertain is whether the deformation seen at the surface translated to enhanced groundwater flow from the surface to the mine.

What is undeniable is that there is structural deformation and this does, whether permanently or temporally, either to depth or to a shallow extent, impact on surface and groundwater hydrology and the connection between them.

Mine subsidence can result in far-field displacement, which is horizontal surface displacement of tens of millimetres some kilometres from the limits of mining. "*Hebblewhite et al (2000) reported horizontal displacements in excess of 65 mm towards mine workings that were 680 m away (where mining was at a depth of approximately 450 m)*" (NSW Dept. Planning, 2008, p. 59). However, no direct evidence exists of adverse impacts of this far-field displacement (NSW Dept. Planning, 2008, p. 60).

Faults, folds, joints and dykes can all induce changes in the stress patterns and because of their effect on the transmission of stresses through the rocks. The changes are not always predictable.

The NSW Dept. of Planning (2008) has summarised the impacts of subsidence in their Table 9 (p. 64), reproduced below (Table 8-1).

Table 8-1. Subsidence impacts (Source: NSW Dept Planning, 2008, p.64).

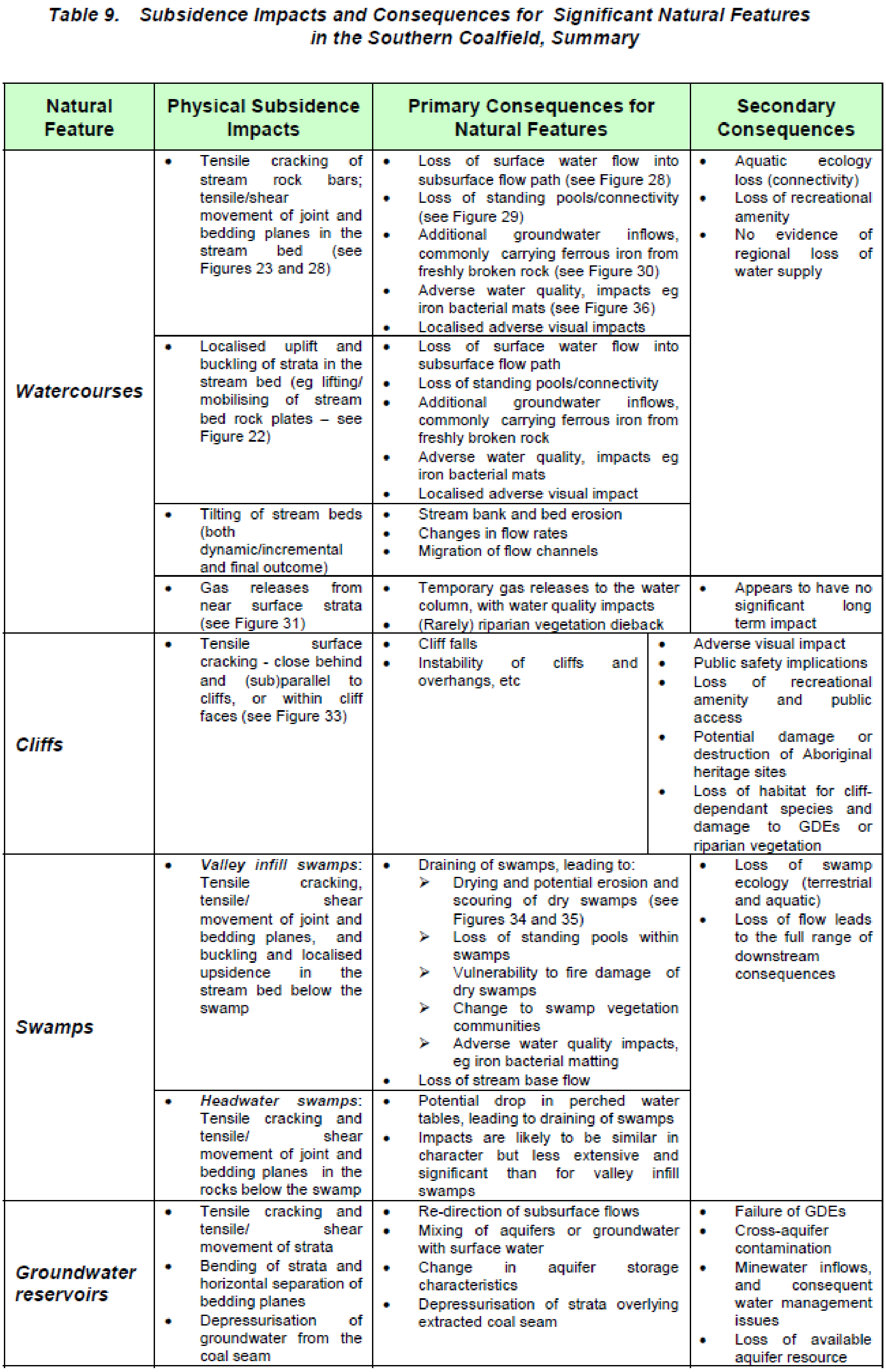


Table 9. Subsidence Impacts and Consequences for Significant Natural Features in the Southern Coalfield, Summary

Natural Feature	Physical Subsidence Impacts	Primary Consequences for Natural Features	Secondary Consequences
Watercourses	• Tensile cracking of stream rock bars; tensile/shear movement of joint and bedding planes in the stream bed (see Figures 23 and 28)	• Loss of surface water flow into subsurface flow path (see Figure 28) • Loss of standing pools/connectivity (see Figure 29) • Additional groundwater inflows, commonly carrying ferrous iron from freshly broken rock (see Figure 30) • Adverse water quality, impacts eg iron bacterial mats (see Figure 36) • Localised adverse visual impacts	• Aquatic ecology loss (connectivity) • Loss of recreational amenity • No evidence of regional loss of water supply
	• Localised uplift and buckling of strata in the stream bed (eg lifting/ mobilising of stream bed rock plates – see Figure 22)	• Loss of surface water flow into subsurface flow path • Loss of standing pools/connectivity • Additional groundwater inflows, commonly carrying ferrous iron from freshly broken rock • Adverse water quality, impacts eg iron bacterial mats • Localised adverse visual impact	
	• Tilting of stream beds (both dynamic/incremental and final outcome)	• Stream bank and bed erosion • Changes in flow rates • Migration of flow channels	
	• Gas releases from near surface strata (see Figure 31)	• Temporary gas releases to the water column, with water quality impacts • (Rarely) riparian vegetation dieback	• Appears to have no significant long term impact
Cliffs	• Tensile surface cracking - close behind and (sub)parallel to cliffs, or within cliff faces (see Figure 33)	• Cliff falls • Instability of cliffs and overhangs, etc	• Adverse visual impact • Public safety implications • Loss of recreational amenity and public access • Potential damage or destruction of Aboriginal heritage sites • Loss of habitat for cliff-dependant species and damage to GDEs or riparian vegetation
Swamps	• *Valley infill swamps*: Tensile cracking, tensile/ shear movement of joint and bedding planes, and buckling and localised upsidence in the stream bed below the swamp	• Draining of swamps, leading to: ➢ Drying and potential erosion and scouring of dry swamps (see Figures 34 and 35) ➢ Loss of standing pools within swamps ➢ Vulnerability to fire damage of dry swamps ➢ Change to swamp vegetation communities ➢ Adverse water quality impacts, eg iron bacterial matting • Loss of stream base flow	• Loss of swamp ecology (terrestrial and aquatic) • Loss of flow leads to the full range of downstream consequences
	• *Headwater swamps*: Tensile cracking and tensile/ shear movement of joint and bedding planes in the rocks below the swamp	• Potential drop in perched water tables, leading to draining of swamps • Impacts are likely to be similar in character but less extensive and significant than for valley infill swamps	
Groundwater reservoirs	• Tensile cracking and tensile/ shear movement of strata • Bending of strata and horizontal separation of bedding planes • Depressurisation of groundwater from the coal seam	• Re-direction of subsurface flows • Mixing of aquifers or groundwater with surface water • Change in aquifer storage characteristics • Depressurisation of strata overlying extracted coal seam	• Failure of GDEs • Cross-aquifer contamination • Minewater inflows, and consequent water management issues • Loss of available aquifer resource

In the Tahmoor area, which is within the Bargo Mine Subsidence District, 495 claims were received by the Mine Subsidence Board for the period 2004-2011, with 116 refused, and seven homes were demolished during this period (2010-2011 Mine Subsidence Board Annual Report, 2011, p. 19). The Mine Subsidence Board searched for claims east of Thirlmere Lakes for the Committee. The Board report that, to the east of the lakes and within the zone bounded by northings 6208000 and 6212000 (MGA), there were no claims within 1 km of the Lakes and 24 claims in the 1 km to 2 km zone. Of these 24 claims, 20 were lodged in the period 1995-2000 and 4 were lodged in the period 2001 to 2004. The Mine Subsidence Board pointed out that property damage is not a suitable measure to establish geotechnical impacts that may result from coal extraction. Wollondilly Shire Council has a number of records of repairs to mine subsidence damaged infrastructure, including roads and bridges.

Mine subsidence surveys conducted by Waddington and Associates (2002) along the Loop Line at Couridjah on seven occasions, relating to mining Longwalls 17 to 19, reached peak values of 33 mm and 35 mm at two pegs. The majority of the 59 pegs had subsidence less than 25 mm. The residual subsidence was predicted to be less than 3 to 4 mm. The subsidence due to Longwall 20 was expected to be no greater than for Longwalls 17 to 19.

8.4.2 Mining, mine subsidence and groundwater

The model for the relation between mine subsidence and groundwater identifies three zones (Fig. 8-9), the fracture zone immediately above the goaf, the aquiclude zone (really an aquitard) in which it is assumed that stresses have not significantly affected the hydraulic properties of the rocks, and the surface zone where cracking may change both surface and subsurface hydrology. Under this model water pumped from the mine comes from the coal seam and there is unlikely to be any impact on the aquifers above. But, the Sydney Catchment Authority (2007) states that "*there are reports of* *depressurisation of aquifers overlying the coal seams, but the impact on aquifers and further up in the stratigraphic column and surface water-aquifer relationships is more problematic*". The variations in hydraulic gradients are attributed to changes in the porosity and permeability of fractured rocks.

Merrick (2010, p. 2060) states that the "*constrained zone in the overburden is likely to have competent sandstone/claystone lithologies that sag coherently rather than fracture extensively. This zone, by mediating the hydraulic connection between shallow and deep aquifers, will mitigate potential impacts at land surface*". Waring and Peterson (2008) outline a number of techniques that could be used to assess the connection between the surface and deep aquifers, including isotopic geochemical dating, geochemical signatures, and in the case of the Bulgo Sandstone, dissolved gas signatures.

Under this model only bores that penetrate into the fractured zone would be affected by mine drainage. It is undeniable that there are many places in the world where mining extends below significant water bodies (e.g. mining under Lake Macquarie) and there has been no significant leakage of water from those water bodies into the mines during workings. But all mines in wet areas leak and eventually they fill with water if the water is not pumped out. The source of this water is another question. However, it cannot be denied that there are instances where there has been significant flow of water into mines from water bodies above them, sometimes catastrophic. The NSW Dept. of Planning (2008, p. 81) reports: "*Byrnes (1999) reported on detailed investigations into groundwater hydrology undertaken in the Southern Coalfield for longwall mining under Cataract Reservoir. His report included case studies from around the world of successful and unsuccessful experiences in mining under water bodies. Byrnes concluded that higher than 185 m above the seam (equivalent to 1.7 times panel width) there was no evidence that there was any change in the hydraulic connectivity of water from reservoirs to mine workings. A number of other measurements and studies have produced outcomes consistent with this conclusion. However, the studies also highlight that mine design recommendations should not be applied blindly and that careful consideration must always be given to site specific geology and geological features.*" "*the accuracy of any subsidence prediction technique should not be taken for granted*".

Contradicting the accepted model is the work of Jankowski and Knights (2010). They analysed hydrologic data from upstream and downstream of longwall panels. They concluded for the Southern Coalfields that "*longwall mining-induced subsidence has enhanced the surface water-groundwater interaction, both laterally and longitudinally; vertical and horizontal extension and enlargement of fractures and bedding planes resulting from the longwall mining activity could explain the loss of flow due to a more intensified surface water-groundwater interaction, and to a greater depth, than would have occurred prior to mining; the flow system is both connected-gaining and disconnected–losing over various segments of the main stream; streamflow losses due to mining dominate during very low to low flow conditions, whereas streamflow losses during medium to high flows are masked by the large volume of streamflow; surface flow which has been redirected to the subsurface may reappear further downstream or be permanently lost from the drainage basin*"

Sydney Catchment Authority (2007, p. 24) provide a model of the impact on groundwater of the advance of a longwall (Fig. 8-10). The model illustrates the fall in groundwater levels in bores in the surface zone, above the aquitard, the recovery that may or may not take place as the mining progresses.

There is considerable debate about whether the water levels recover, the mining companies arguing that the piezometer data shows recovery. The question that arises is whether the piezometers have been installed soon enough. As Dr Marshall stated in his presentation to the Committee, the observed changes may not identify earlier unmonitored changes. Tahmoor Colliery has been operating since 1974-6. The question of whether there is a true picture of groundwater changes from bores installed in 2000+ is open to debate.

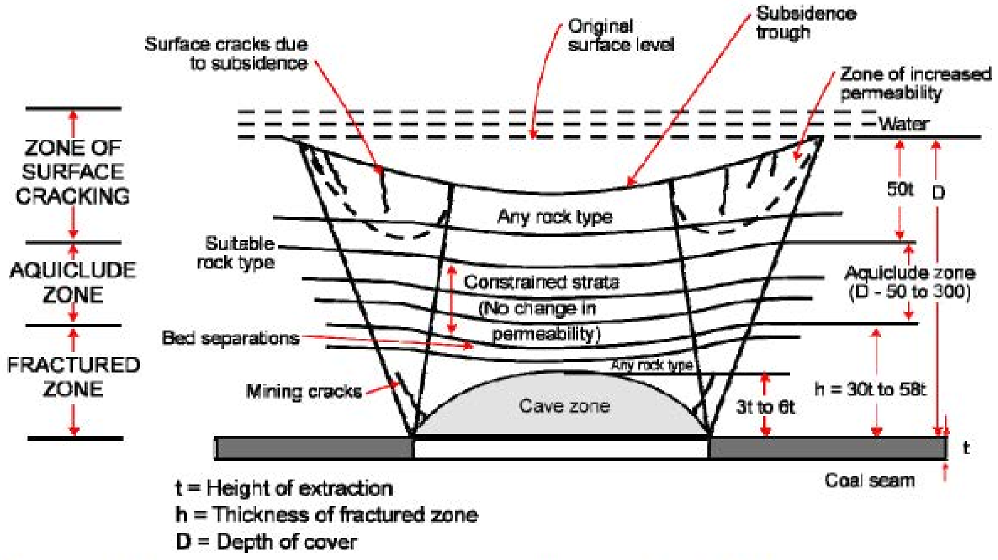


Figure 4-1 Schematic of areas above a longwall mine (Booth, 2003)

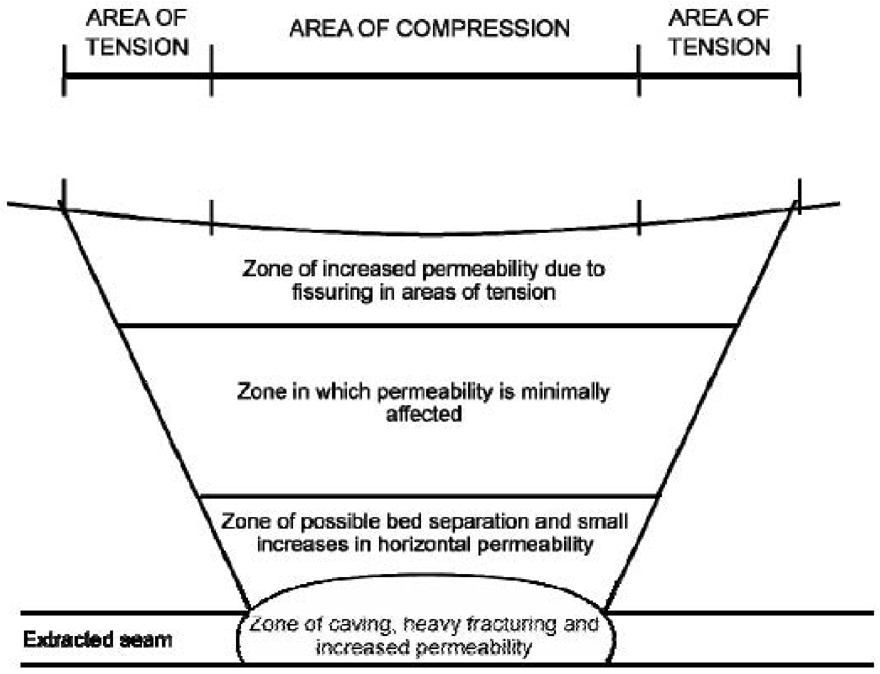
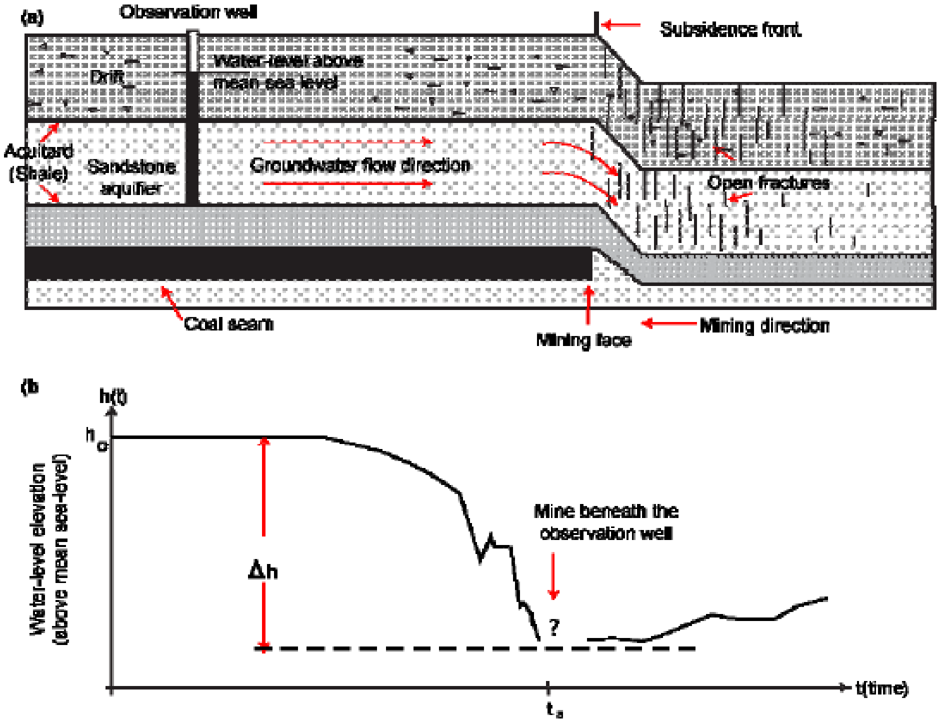


Figure 4-2 Typical overburden zones above a longwall mine (Judall, Platt, Thomas and Associates, 1984)

Figure 8-9. Model for groundwater – mine subsidence interaction (Sydney Catchment Authority, 2007, p. 23). With permission.



A schematic cross section of (a) a longwall mine and (b) the resulting water-level drop. Measurements usually become impossible when the mining face reaches the well at time t_S.

Figure 4-3 Cross section of a longwall mine and the corresponding water level drop (Karaman et al., 1999)

Figure 8-10. Model for impact on groundwater of a progressing longwall (Sydney Catchment Authority 2007, p. 24). With permission.

Krogh (2007) reviews a number of longwall hydrology studies from around the world, as well as in the Southern Coalfields. He argues that subsidence and fracturing of the overburden has caused significant changes in groundwater systems in many areas in the United States, citing a number of authors. In some cases water levels recover, in others there are clear and unambiguous records of no recovery of water levels in bores, drying of swamps, lakes and streams. He points out that most assessments in the Southern Coalfields of "*no net loss*" have been based on "*conditions existing once* *mining has damaged the system*” with a significant gap of groundwater systems prior to mining.

In the summary of the impacts of mine subsidence the Sydney Catchment Authority (2007, Ch. 7) review identifies that:

1. There is limited information on the upper fracture level.
2. There are few papers discussing surface water impacts.
3. Lack of independent published material on the changes to the surface-groundwater interactions and what existed focused on the mine and ignored losses that did not impact on the mine.
4. The site specific relevance of data makes it difficult to transfer assessments of impacts.
5. Much of the research/literature focuses on fracturing in the immediate mine roof.
6. Subsidence is likely to be between 1 to 2 m with 80% occurring within 2 months of completion of the longwall panel.
7. Recovery of groundwater and surface water systems may take years and in some cases is not guaranteed.

Summarising the data available from the Tahmoor area, both the mine data and hydrocensus information reviewed in Section 6.8, the following conclusions can be drawn:

- there was significant lowering of the groundwater table within the Hawkesbury Sandstone in 1975-1978 in the vicinity of the construction of the drift and shafts.
- the encountered flows during the shaft and drift construction were significantly greater than reported yields in other private bores in the area (typically).
- there is eastward flowing groundwater through the Hawkesbury Sandstone.

- the Bald Hill Claystone is a significant aquitard, although most recent data show partial depressurisation but this may be due to equilibration issues of the VWP.

- partial depressurisation of the Hawkesbury Sandstone has occurred due to longwall mining.

- the change in groundwater conditions is not uniform, with a sporadic distribution of private bore owners who have reported loss of yields/decline in water levels. This suggests that not only proximity to longwalls is a factor, but also probably geological structures.

- depressurisation of the Hawkesbury Sandstone has steepened the hydraulic gradient to the east, although whether this steepening is temporary or permanent is not known.

- private bores located approximately 0.6 km from Lake Gandangarra and Lake Couridjah reported decline in yields/water levels when mining came within 1 km of their properties.

The Committee reviewed the groundwater modelling presented by both Pells (2011) and Heritage Computing (2012). The former uses a 2 dimensional approach while the latter uses a 3 dimensional model. Both models concentrate initially on the dewatering and associated depressurisation in the Permian rocks, below the Bald Hill Claystone. Neither appears to consider the recharge to the west where these formations intersect the groundsurface nor the complexity of groundwater flow in the Hawkesbury Sandstone. It is not possible to judge exactly where the water discharge from the mine is coming from within the mine and the committee was not made aware of any detailed quantitative records of within-mine water transfers and it is unlikely that they exist. The Committee is of the view that it would be more efficient to first investigate and monitor the aquifers within the Hawkesbury Sandstone. Any impacts of groundwater loss into the Permian rocks (Narrabeen Group and Illawarra Coal Measures) should become evident through this monitoring and modelling. Groundwater movement in the Hawkesbury Sandstone appears to be the key to understanding the groundwater losses from Thirlmere Lakes. The Committee is also of the view that there would be value in dating the groundwater as part of an investigation of the groundwater hydrology in the region.

8.5 CONCLUSIONS

1. There are no substantive surface landuse changes or activities that could account for a change in the hydrologic behaviour of Thirlmere Lakes Catchment (Section 8.1).

2. Bushfires may have played a role in desiccation of the catchment but the evidence is not available to make a firm assessment (Section 8.2).

3. Anthropogenic climate change is likely to have increased evaporation through increased temperatures over the last two decades, but it is not possible to assess the significance of the impact from available data (Section 8.2).

4. There is evidence that mine subsidence has affected the surface-groundwater link in the area above the mining but the evidence also suggests that there has been no impact of mine subsidence on bedrock to the west of the Loop Line (Section 8.4).

5. Bores show a variety of responses to mining in their vicinity and there is no consistent pattern of response to mining (Section 8.4).

6. There is no debate that mining depressurises the bedrock in the vicinity of the mining cavity resulting in a pressure force towards the cavity in three dimensions (Section 8.4).

7. There is no evidence water extracted from the mine is water drawn from the Hawkesbury Sandstone aquifers rather than the aquifers immediately above the Bulli Coal Seam (Section 8.4).

8. There are localised areas within the mine where flow has increased, but the extent, location and duration of the change in flow is unknown as the only monitored flow of water is at the sumps from which water is pumped to the surface (Section 8.4).

9. Changes in water levels in bores are not necessarily evidence of a direct connection between the water in those bores and the groundwater discharging into the mine (Section 8.4).

10. Groundwater modelling undertaken by Pells Consulting and Heritage Computing has come to different conclusions. These differences are based on the differences in the models and the data and assumptions they employ (Section 8.4).

11. The data are not available within the vicinity of Thirlmere Lakes to be conclusive about the impact of the mining on groundwater, and any study at this time would be looking at post-mining impacts, if any (Section 8.4).

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 FINDINGS

There are three possible explanations for the changing levels in Thirlmere Lakes and their present low level:

1. The low levels are a response to natural processes.
2. The low levels are result of human activity.
3. The low levels result from a combination of natural and human activity.

Each of these options is reviewed in the following.

9.1.1 Natural processes

Thirlmere Lakes occupies a topographic high. Its primary source of water is rainfall, and water in the lakes and adjacent groundwater stores either evaporates/transpires, is discharged in overflows to Blue Gum Creek, or percolates into groundwater and flows out of the catchment.

There is ample evidence that lake levels have fluctuated in the historic and geologic past:

a. Historical records and local citizen accounts attest to lake levels fluctuating and one or more of the lakes being dry in the last 200 years.

b. Traditional Custodians have accounts of the lakes drying out, which covers the period for the last 40,000 years.

c. Photographs, aerial imagery, and satellite imagery show one or more of the lakes being dry in the last 100 years.

d. Geomorphic evidence in the form of peat islands, which can only be explained by lake levels lowering sufficiently to expose peat beds and then rising again.

e. Sequences of old lake shores evident in the geomorphology of the lake margins.

The only explanation for the fluctuations prior to 1800 is climatic, changes in rainfall amount and intensity and/or changes in evapotranspiration. There is no evidence of significant tectonic movement sufficient to disrupt the hydrologic cycle, although it always remains a possible influence.

The fluctuations in lake levels in the last 200 years appear to parallel the flood and drought-dominated regimes evident in streams in the Hawkesbury-Nepean catchment and elsewhere, in Lake George water levels, which is a closed basin with a lake floor-catchment area ratio similar to Thirlmere Lakes, and as seen in the rainfall records for the last 150 years.

There is clear evidence of fluctuations in the levels of the lakes of the order of 2 to 3 m in less than a year and prior to mining. The reductions in levels suggest significant natural groundwater loss from the lakes.

There is no evidence of any natural process that would have changed local groundwater flows over the last 200 years.

The outlet of the four lakes, Gandangarra, Werri Berri, Couridjah and Baraba, is the col between Baraba and Nerrigorang, which is thought to be sufficiently stable to preclude, through a mechanism of periodic breaching and damming, fluctuations in lake levels in historic times. The outlet of Lake Nerrigorang is less stable, but does not appear to have been significantly breached in the last 50 years.

There is no direct measurement of evapotranspiration in the catchment over either short or long periods, but indicators from cores suggest vegetation changes that may reflect long-term (geologic time frames) changes in evapotranspiration, rainfall and temperature.

The drought from 1992 to 2007/9 (the Millennium Drought) was one of the three most severe on record and several studies suggest it was the most severe. Irrespective of its ranking, it appears to have had sufficient rainfall deficiency to result in the lakes becoming dry.

The first three lakes in the Thirlmere Lakes system, Gandangarra, Werri Berri and Couridjah, appear to be highly interdependent in terms of water level. Lake Nerrigorang appears to be more hydrologically independent and may be more transient than the four upstream lakes.

There are errors and variations in estimates of former lake levels, suggesting that hydrology models optimised on these levels will have significant errors.

Modelling of the hydrology of the Thirlmere Lake catchment, optimised on variations in lake levels, suggest in the studies of Pells Consulting (June, 2012) and Gilbert and Associates (April, 2012) a strong relation between rainfall and lake levels, although Pells Consulting's (2012) study suggests that not all of the lake level fluctuations can be explained by rainfall changes.

Based on the Committee's review of an annual hydrologic model, it is apparent that the Thirlmere lake levels are sensitive to small changes in water loss.

There is not sufficiently accurate data to dismiss or accept the recent drought as the sole cause of the lakes going dry. None of the modelling of lake levels is sufficiently accurate to make confident assertions of the impact of factors other than drought.

The conclusion:

> fluctuations in rainfall appear to account for a substantial component of the variation in lake levels, but there is some doubt about changes in the last 40 years, some of which may be related to changes in sub-catchment geometry of lakes Baraba and Couridjah, possible increases in evapotranspiration brought about by higher temperatures, possible impacts of fire on the hydrologic regime, and possibly changes in the groundwater losses.

9.1.2 Human activity

Prior to Thirlmere Lakes being declared a National Park, direct pumping of water for railways, water supply and agriculture may have accounted for some of the variations in lake levels. For the last 30 years pumping has been a minor component and can be dismissed as a cause for recent fluctuations.

There is insufficient human disturbance of the catchment to explain fluctuations in lake levels by flow diversion, devegetation, and hardening of catchment surfaces. Those changes that have occurred do not explain periodic rises and falls in the lake levels in such a small catchment.

There are a large number of bores to the east of Thirlmere Lakes. No detailed records have been kept of the extraction of water from these bores or their water levels over time. There is a suggestion that a number of unlicensed bores exist. If groundwater flow is towards the east, these bores may have extracted sufficient water to increase the east-sloping hydraulic gradient and lowered the water table. Accounts of bore use during the last drought (1995-2007/9) suggest that pumping rates may have increased during this period, but there is no direct evidence. An increase in groundwater extraction would partly explain recent fluctuations in lake levels, but is unlikely to explain the fluctuations prior to 1940, the earliest date for most of the bores.

There is substantial evidence that coal mining to the east has extracted water from the local groundwater system since 1974 when the drift and shafts 1 and 2 were built. Early records of mine water discharge are poor, and are a reflection of the technology of the time that relied on estimates of the capacity of pumps, time of pumping and, in some cases, levels of flows in discharge channels that did not have controls and that may have received surface water discharge. More recent technology, including flow meters with data loggers, gives a more accurate picture of water discharge. However, because of the nature of underground water management, it is not possible to relate the discharge from the mine (mine water make) to a particular source of water within the mine. Most of the groundwater extracted from Shaft 3 sump comes from groundwater reservoirs that extend towards Thirlmere Lakes, albeit, at depth. At the time of inspection in September 2012 Panel 500 was relatively dry with no significant groundwater flow from the walls, roof, floor, or flow along the floor.

There is no evidence that the Bald Hill Claystone beneath Thirlmere Lakes has been breached or “punctured” in any way. The stratigraphic evidence suggests that it is some distance below the supposed maximum depth of the valley of Thirlmere Lakes of 50 m (245-250 mAHD). In addition, the sediment filling the lakes, to the depth that it has been drilled, to approximately 30 m (270 mAHD), textures as clays, and there may be beds of thick clay throughout the valley fill. Such clayey material would act as aquitards and would be flexible to small distortions in the strata. There is no evidence of subsidence in the immediate vicinity of Thirlmere Lakes, although it is obvious and reported to the east of the Picton-Mittagong Loop Line.

The estimated depth of 50 m of valley fill is open to question and cannot be affirmed from recent work. There is substantive evidence of a depth of valley fill of 30 m in places along the thalweg of Thirlmere Lakes valley.

There is evidence that the Bald Hill Claystone has maintained its hydraulic integrity above the mines. However, it is possible that mine subsidence, which clearly transmits its effects to the ground surface, has opened joints and bedding planes in the substantive sandstone beds above the Bald Hill Claystone, over the longwalls. Equally, there is the possibility of structural changes in the aquitards above the longwalls, including the Bald Hill Claystone. It is highly likely that transmissivity has been increased in the Hawkesbury Sandstone aquifers. An associated increase in the hydraulic gradient towards the east resulting from groundwater lowering over the longwalls would result in more rapid discharge of water through the sandstones. No apparent increase in groundwater discharge might be seen in the mine, but groundwater discharge towards the east would increase.

While there is evidence of the impact of the mining on groundwater levels in the Hawkesbury Sandstone, including reports of “catastrophic” falls in water levels in the bores, there is conflicting evidence from mine operated piezometers which show groundwater recovery. These more recent groundwater monitoring bores may have missed changes in groundwater levels and surface slopes that occurred prior to their installation.

There appears to be no substantive hydraulic conductivity measurements in the area to the east of Thirlmere Lakes although there is a substantial body of data available from packer tests elsewhere in the Tahmoor area.

There is evidence that the aquifer below Lake Nerrigorang, extending into the valley of Blue Gum Creek, has not been depressurised.

The Committee could find only one date for the age of the groundwater, taken in 1974 at the time of construction of the drift. This date was obtained from groundwater above the Bald Hill Claystone. The committee is of the opinion that is worthwhile to re-try tritium dating or ^{14}C dating in order to determine the age of the water discharging into the mine.

There is one additional human impact. If the temperature of the region has increased over the last 2 decades, evapotranspiration will probably have increased. It is not easy to quantify anthropogenic climate change. There are no direct measurements in Thirlmere Lakes catchment of temperature or evaporation parameters, and advection changes due to changes in wind regime, and the complications of bushfire on rainfall-runoff regime and evapotranspiration can only be surmised using data from elsewhere and regional scale modelling. For the time being anthropogenic climate change is recognised as a possible contributor to recent fluctuations in lake levels, but is not sufficiently quantifiable for a definite conclusion to be drawn.

The conclusion:

> Groundwater pumping from bores to the east of Thirlmere Lakes may have increased the hydraulic gradient towards the east and mine subsidence may have increased hydraulic conductivities and the hydraulic gradient towards the east without breaching the integrity of the Bald Hill Claystone. The combination of groundwater extraction, lowering of the groundwater table, increased gradient towards the east, and increased hydraulic conductivities

> would have resulted in increased loss of groundwater from Thirlmere Lakes and tipped the delicate hydrologic balance of the lakes towards increased loss and lower lake levels. Anthropogenic climate change and bushfires may also have contributed to recent low lake levels.

9.1.3 A combination of natural and human influence

Disentangling the impact on lake levels of natural changes in rainfall, possible changes in evapotranspiration, and the impact of anthropogenic-related increased groundwater flow towards the east is not easy. The next section proposes studies to assess the relative significance of each.

It is clear that the veracity of data on previous lake levels is open to debate. Hydrology models built around these estimates of lake levels are not as robust as they may seem. Using hydrology models to support arguments about the cause of fluctuations in lake levels is, at this time, fraught with difficulty. It will not be possible to develop robust hydrology models until more data are available on the hydrologic regime of the Thirlmere Lakes catchment

Flooding rains and drought, whether natural or influenced by human activity, account for a large proportion (if not all) of the variation in lake levels, which have clearly fluctuated in the past due to natural process.

There is no evidence that the integrity of the containment structure that directly underlies Thirlmere Lakes has been breached. However, there is substantive evidence that groundwater in the Hawkesbury Sandstone to the east of the lakes has been significantly affected by human activity, by both groundwater extraction for domestic and agricultural purposes, and possibly mine water extraction and/or mine subsidence, The Committee cannot disentangle the significance of each without additional data.

The conclusion:

> The majority of the fluctuation in lake levels can be accounted for by variations in rainfall (drought and flooding rains), but there is evidence that recent fluctuations and consequent low lake levels may have been influenced by groundwater extraction to the east by bores and mining, combined with reduced recharge from lower rainfalls. All three would have contributed to the change in the groundwater regime to the east.

The Committee accepts that this last conclusion requires additional work to test it. For the time being it considers it to be a viable working hypothesis. There are insufficient data at present to be certain that drought is the sole factor accounting for the majority of the loss of water in Thirlmere Lakes. The minor effect of changes in catchment geometry, catchment response to rainfall, groundwater extraction, reduced natural rainfall recharge of Hawkesbury Sandstone aquifers, mine subsidence, and the impact of water extraction in the Tahmoor Mine are difficult to disentangle and not possible to quantify at this time without additional research.

9.1.4 Biodiversity

Effective management of the values that have been identified for the Lakes is constrained by limited knowledge of the ecological requirements of species and communities, and best practice management. The extent of information that is available is inadequate to ascertain if the ecological character of the Lakes has changed in response to anthropogenic pressures, or possibly even to describe the ecological character using accepted protocols.

As the Plan of Management for the Lakes was developed some 15 years ago it should be reviewed and the explicit incorporation of an adaptive and participatory management process, including relevant monitoring, incorporated as a basis for addressing the management and research that will be required to overcome the information gaps and uncertainties identified.

The Lakes are not listed under the Ramsar Convention on Wetlands as a Wetland of International Importance (known as a Ramsar site). Available information suggests that the Lakes meet the criteria for listing as a Ramsar site.

Listing as a Ramsar site would explicitly commit Australia to maintain the ecological character of the Lakes and to formally report to the Convention any likely or actual (adverse) change in ecological character, as required under the Convention. The Lakes are already subject to the wise use provision within the Convention which, since 2005, has been defined as ensuring the ecological character of all wetlands are maintained, although not with the same reporting requirements as those associated with a formally listed Ramsar site.

Specific ecological investigations should be undertaken to address the gaps in information about the Lakes and the cause/effect of change associated with the wetting/drying patterns. Details of the distribution and age structure of the terrestrial vegetation are required, as are details of the recent fire history as a way of determining the effect of the vegetation on the runoff from the catchment to the Lakes. Additionally, the effects of past grazing by ungulates on the Lakes and fringing vegetation should be investigated. A specific investigation of the processes controlling the formation and desiccation of the peat within the lakes is required, as is an analysis of the seeds and other propagules in the sediment of the lakes.

The current management approaches, including the dearth of information, derived from hypothesis-based monitoring, for decision making, is at odds with the obligations and recommended practices outlined through Australia’s participation in the World Heritage, Biological Diversity and Wetland Conventions. A review of the existing management approaches and advisory structures should be conducted and placed within the context of whether or not the current management structures should be adjusted, or even replaced.

9.2 RECOMMENDATIONS

Arising from the Committee's studies and uncertainties in some of the data the following recommendations are made. The committee has indicated possible funding sources to realise these recommendations.

9.2.1 Community values

There is a wealth of information on the Traditional Custodian and European settlement history of Thirlmere Lakes that needs to be assembled and put into a narrative. There were a variety of opinions on the social, cultural and economic value of the lakes expressed to the Committee, but none of these opinions had been studied in such a way that the Committee could establish the consensus view. Nobody seemed to be thinking about the values of the lakes if their low water levels were natural, or how they could be valued if they were indeed highly variable systems. Finally, there were clear economic benefits from the lakes that appeared not to be realised, such as linking the Railway museum to the lakes through re-creation of 19th century train trips to the lakes with picnics using vintage cars or horse drawn carriages from Couridjah Station.

Recommendation:

> that a socio-economic-historical study of the lakes be commissioned, aimed to assess community values and community opportunities as well as improve the anecdotal evidence on lake levels.

Realisation:

1. Community surveys should be stratified on the basis of period of residence, age, occupation and so forth.
2. The study would take no more than 1 to 2 years to complete.
3. Funding should be provided by the State Government.

9.2.2 Geomorphology

As one academic put it, the environmental history derived from deep and well-obtained cores in Thirlmere Lakes could be as important as the Lake George cores, having significance in understanding the climate history in Eastern Australia. Much about the geomorphic history of Thirlmere Lakes is unknown, speculative, or based on very old data and assumptions that need to be retested. The Lakes are a part of the Greater Blue Mountains World Heritage Area, are reputed to be of value because of their geomorphic history and setting, as much as for their ecology, and yet little known about their geomorphic history.

Recommendation:

> that a consortium of suitably qualified researchers be invited to investigate the geomorphic history of Thirlmere Lakes, with a focus on understanding the variation in lake levels

Realisation:

1. Any geomorphic investigation should be commenced with a detailed geophysical survey using, amongst other techniques, resistivity, refraction, ground penetrating radar, magnetics, and gravity. No drilling should be attempted until this geophysical survey is completed, and it should extend from Dry Lake through Thirlmere Lakes and at least 2 km downstream in Blue Gum Creek.

2. A detailed topographic survey needs to be undertaken, possibly using lidar.

3. Drilling in sensitive areas requires modern techniques of emplacement of drilling equipment, including construction of weight-dispersing platforms and helicopter delivery of drill rigs. It would be possible to undertake the necessary drilling (to approximately 100 m) from a platform of less than 100 m^2 in area accessed by a single track. Disturbance would be minimised and rehabilitation of sensitive areas simplified. This approach to drilling would enable a large number of sites to be accessed that are presently inaccessible because of environmental sensitivity. Although the Committee can see the need for no more than two cores, possibly three will be needed.

4. The drilling team needs an established reputation in recovery rates in soft and hard sediments.

5. The possibility of using the core holes for deep and shallow groundwater measurements needs to be assessed. If possible they should be used to supplement the NSW Office of Water Thirlmere Lakes Groundwater Study program with its four piezometers.

6. The management of the cores needs to be firmly established prior to drilling, especially as special storage conditions may be required and allocation of samples will have to be managed to ensure no future studies are compromised.

7. The cores should be examined for, amongst other things, palynological, paleontological, geochemical, micro-mineralogy, and absolute dating trends. It would be worthwhile undertaking detailed mineralogical analysis to establish if the fallout from eastern Australia dust incursion and volcanic activity occur in the cores.

8. There should be a detailed study of the geomorphology and soils of the slopes and establishment of photo-monitoring sites to record changes not only in the lakes but also in the slopes.

9. The Committee expects the project to involve a suitable consortium.

10. The Committee recommends that any study should link with local residents and organisations.

11. As the project would be of national importance we expect it to be funded by the Commonwealth Government, through existing grant schemes or a one-off grant, from the following departments: Climate Change and Energy Efficiency; Industry, Innovation, Science, Research and Tertiary Education; Resources, Energy and Tourism; Sustainability, Environment, Water, Population and Communities.

12. An independent management team needs to be appointed to oversee the project and ensure accountability.

9.2.3 Hydrology

The surface water hydrology of the lakes is unknown, other than the intermittent data on water levels and the more complete records of daily rainfall. If hydrology models are to be appropriately tested an accredited meteorology station needs to be installed, within the catchment boundary, which meets Bureau of Meteorology standards for equipment installation, maintenance, and quality control. Equipment for monitoring, in real time, lake levels, groundwater, and soil moisture regimes needs to be installed. It is considered too expensive to install the equipment required for direct transpiration measurements, but it may be possible for this to be done in collaboration with another research project. A gauging station should be established on Blue Gum Creek. The concrete causeway on Blue Gum Creek provides the best location for this and guarantees some security.

Recommendation:

> that a hydro-meteorology network be installed in Thirlmere Lakes and maintained for a minimum of 5 years.

Realisation:

1. The network would consist of an automatic (and web-linked) tipping bucket raingauge, anemometer, radiometers, soil moisture meters, shallow groundwater and lake level recorders, gauging station.
2. We expect the project to involve a suitable consortium.
3. We expect the project to be funded as a joint project between the NSW Government and Federal Government.
4. A management team needs to be appointed to oversee the project, probably the same as for the geomorphology study.

9.2.4 Groundwater

Groundwater is a key issue in this inquiry. It is worthwhile establishing a real-time monitoring network using existing bores. The information will not only inform this study but be of importance in future mining proposals. There is a real opportunity to research the connection between longwall mining with near-surface and surface hydrology. The results from this study would probably be of value to other areas of underground mining. In addition, some detailed hydraulic conductivity tests should be conducted in a number of specially drilled bores and, following the tests, these bores should be monitored with piezometers to a depth of at least 400 m, with emphasis on the first 200 m. Four or five bores would be sufficient.

Recommendation:

> that existing bores be monitored for water levels and pumping rates, a number of deep bores be drilled and monitored, and that a number of hydraulic conductivity (packer) tests be conducted in order to establish aquifer properties in the Hawkesbury Sandstone to the east of Thirlmere Lakes.

Realisation:

1. At least 3 bores in the vicinity of Thirlmere Lakes (within the catchment if possible) and two west-east lines consisting of 5 bores each from Thirlmere Lakes to the Southern railway be monitored for water level and pumping rates.
2. Where feasible all the bores in the monitoring program and where funding allows, other suitable bores be tested for hydraulic characteristics of the aquifers.
3. Five deep bores need to be drilled, tested and monitored.
4. That the data be used to construct a regional geohydrology model.
5. That a consortium be appointed to conduct the study.
6. That the study proceeds for 3 years.
7. We expect the project to be funded by the NSW Government and Coal Industry (as a possible ACARP project).

9.2.5 Biodiversity

A review of the existing management approaches and advisory structures should be conducted and placed within the context of whether or not the current management structures should be adjusted, or even replaced. As a component of this, the Plan of Management for the Lakes should be reviewed and updated to ensure it can support the management, monitoring and research that is required to further investigate the cause and impact of the wetting/drying cycles in the Lakes.

Steps should be taken to List the Lakes as Internationally Important under the Ramsar Convention on Wetlands. This should include a formal description of the ecological character of the Lakes.

Specific ecological investigations should be undertaken to address the gaps in information about the Lakes and the cause/effect of change associated with the wetting/drying patterns, including, but not confined to: the distribution and age structure of the terrestrial vegetation; the recent fire history; the effect of past grazing by ungulates on the Lakes and fringing vegetation; the processes controlling the formation and desiccation of the peat within the Lakes; an analysis of the seeds and other propagules in the sediment of the Lake; and changes in the vegetation distribution in the Lakes.

Realisation:

1. The existing management approaches and advisory structures for the GBMWHA and the Thirlmere Lakes National Park should be reviewed by an independent panel, including representation from the local community, and recommendations provided on suitable advisory, monitoring and research investigations into the Thirlmere Lakes.
2. The NSW National Parks and Wildlife Service should review the Plan of Management and through a participatory management approach develop suitable monitoring of and research into the ecological features of Thirlmere Lakes.
3. The NSW National Parks and Wildlife Service should undertake an ecological characterisation of Thirlmere Lakes and assess whether or not the Lakes meet the criteria for listing as a Ramsar site.
4. The above activities should be completed and publicly tabled within a 12 month period.

9.3 MODERATING GROUNDWATER LOSS

Considerable interest was expressed by the community in the opportunity for restoring lake levels. It is not possible to remediate the natural component of the factors causing variations in lake levels. If the Committee's primary hypothesis is correct, then it may be possible to reduce the groundwater loss to the east, at a minimum of cost. However, this action will not address evapotranspiration losses from the catchment or groundwater losses to the west and to depth.

9.3.1 A water mound

There is a body of literature that addresses the management of contaminated groundwater using reactive barriers (e.g. Blowes et al., 1997, Benner et al., 1999). The Committee is not implying that there is any contaminated water in the area, but it is possible to use this technology as a guide to a management strategy for Thirlmere Lakes. If groundwater flow to the east, within the Hawkesbury Sandstone aquifers, is a factor in loss of water from Thirlmere Lake, an attempt to reduce this groundwater flow is warranted. The Committee envisages a groundwater mound, artificially inserted into an aquifer, retarding the flow of groundwater towards the east.

The concept is relatively simple. Inject the already treated mine water, presently discharged into the Bargo River, into the Hawkesbury Sandstone aquifer, along a line approximately defined by the Loop Line (Picton to Mittagong railway line), building groundwater to a height of approximately 302-305 mAHD. This would result in a groundwater gradient back towards the lake, thus reducing groundwater loss from the lakes (Fig. 9.1). This injected water would not impact on the ecology of the lakes as it is unlikely that any of it would reach the lakes if injection is well managed.

Well injection technology to recover aquifers, or Managed Aquifer Recharge, is a well-established technology (Dillon et al., 2009) although the literature emphasises waste water recharge. It is part of Aquifer Storage and Recovery programs which are now used in many places in Australia.

Clearly, research into the properties of the Hawkesbury Sandstone aquifers to the east of Thirlmere Lakes would be required before the "water mound" concept could be implemented. This research was outlined in the previous section.

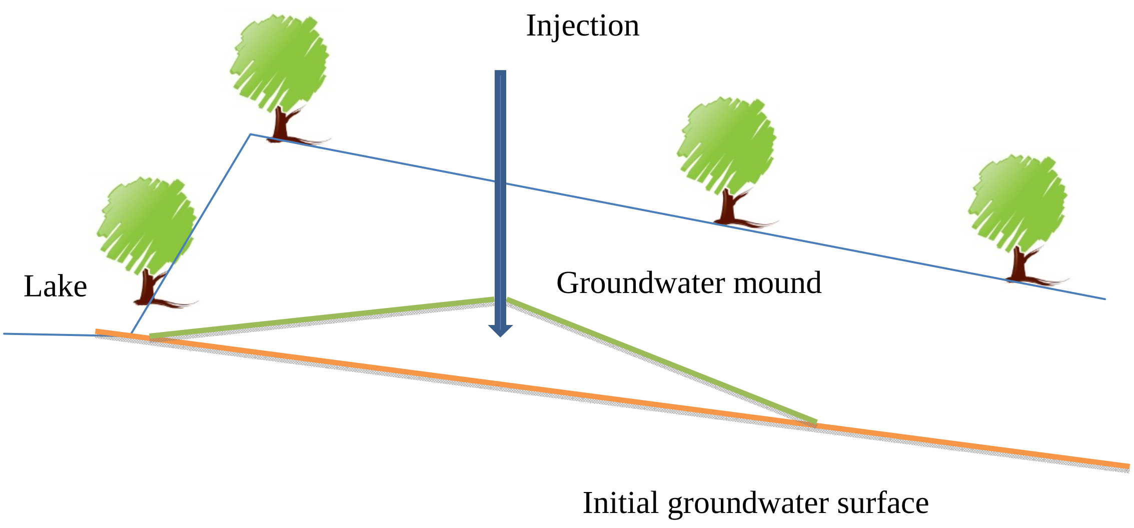


Figure 9-1. Schematic of water mound and reverse groundwater flow.

9.3.2 Realisation

If there is any value in the “water mound” idea of reducing groundwater loss it would have to be preceded with significant research into the groundwater hydrology of the area to the east of Thirlmere Lakes and detailed modelling on its feasibility. In order to develop the groundwater mound concept it would be necessary to undertake some groundwater studies to establish:

a. The aquifer properties

b. The quantity of water required to establish and maintain the mound

c. The effectiveness of the mound in restricting groundwater flow to the east from the lakes.

The Committee envisages this research is complementary with the groundwater research listed in 9.2.4 above. Once it was confirmed that the scheme could work, a simple SCADA (Supervisory Control and Data Acquisition) system could be designed to control pumping the treated mine water 3 to 4 km from the mine treatment site to injection points and controlling injection rates and groundwater mound elevation.

At this time the Committee knows of no other mine water injection system designed to control groundwater flow, although groundwater injection by mines in the Southern Coalfields has been used as a means of mine water disposal in the past.

9.4 SUPERVISION OF PROJECTS AND THEIR PRIORITY

The Committee sees value in appointing a Scientific Supervisory Team to assist in the realisation and management of the recommendations presented above. This team would not overlap with any Management groups appointed by NPWS for Thirlmere Lakes National Park. Rather, its role is to provide the necessary independence in the process and evaluation of information collected when the studies are undertaken. Such a Supervisory Team would address community concerns, often expressed to the Committee, about the linkage between the mining company and researchers, irrespective of whether or not this was true. There should be a transparent process in its activities.

A Supervisory Team need not be a financial or administrative burden for Government. Its role is to have oversight of the implementation and progress of the proposed projects.

The priority of the projects, in relation to understanding fluctuations in the Levels of Thirlmere Lakes is:

1. Hydro-meteorology monitoring station
2. Monitoring and assessment of existing bores
3. Topographic mapping of Thirlmere Lakes
4. Groundwater investigation and modelling
5. Ecological study

6. Community values study as it relates to lake levels
7. Geomorphic study of catchment
8. Geomorphic study of lake sediments
9. Assessment of the ‘water mound” concept.

9.5 A NOTE ON THE PRECAUTIONARY PRINCIPLE

A number of submissions to the Inquiry tried to invoke the Precautionary Principle as something that should guide the investigations and conclusions of the Committee.

Responsiveness to the international and national nature conservation and resource management policies that apply to the Thirlmere Lakes National Park raises the spectre of adopting a ‘Precautionary Principle’ to ensure that where there is a threat of serious or irreversible damage, uncertainty should not be used to justify postponing cost-effective measures to prevent damage. The application of this principle has been hotly debated since being included in the 1992 United Nations Conference on Environment and Development and included within the Convention for Biological Diversity. Weier and Loke (2007) comment that “There are many ways to exercise precaution, ranging from research through to regulation and outright bans of activities.” and recommend an approach “… of taking action to respond to new information is part of the spectrum of precautionary measures.” In this respect the calling of this inquiry can be seen as a step in implementing the Precautionary Principle with an expectation that after the outcomes of the inquiry have been tabled that further decisions will be made to ensure that the threats to the environment of the Thirlmere Lakes from anthropogenic activities is minimised; this is in line with the expectations of the Thirlmere Lakes Inquiry Committee, and could include a precautionary approach to implement a policy to limit the proximity of longwall mining to national park boundaries, and to reassess current practices in relation to the proximity of mining.

However, the Precautionary Principle, which is primarily a Regulatory and Legal Tool, is not of relevance in this scientific investigation. The Independent Committee’s work as an investigation does not pose a risk to the environment or humans. The Precautionary Principle in this instance comes into operation when the results of scientific investigation are to be applied. There is much discussion about the Precautionary Principle (Sunstein, 2003; Peterson, 2006). In scientific research it is the issue of safety related to the investigation and the ethics of the research that are paramount. Furthermore, the Committee has not undertaken any research that would be relevant in establishing the mechanics of the application of the Precautionary Principle, such as proximity of mining to specific features.

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11. GLOSSARY

Acidity	Base neutralising capacity.
AHD	Australian Height Datum. The geodetic datum for altitude in Australia, essentially an agreed mean sea level for Australia. 980930
Alkalinity	Acid neutralising capacity.
Anion	An ion with a negative charge – usually non-metal ions when disassociated and dissolved in water.
Anthropogenic	Occurring because of, or influenced by, human activity.
Alluvium	Unconsolidated sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on river beds, floodplains, and alluvial fans.
Aquatic ecosystem	The stream channel, lake or estuary bed, water, and (or) biotic communities and the habitat features that occur therein.
Aquiclude	A low-permeability unit that forms either the upper or lower boundary of a groundwater flow system.
Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.
Aquifer properties	The characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Aquifer, confined	An aquifer that is overlain by low permeability strata. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Aquifer, semi-confined	An aquifer overlain by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the confining layer – also known as a leaky artesian or leaky confined aquifer.
Aquifer, unconfined	Also known as a water table or phreatic aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of an unconfined aquifer.
Aquitard	A low-permeability unit that can store groundwater and also transmit it slowly from one aquifer to another. Aquitards retard but do not prevent the movement of water to or from an adjacent aquifer.
Australian Height Datum	See AHD.
Background concentration	A natural concentration of a substance in a particular environment that is indicative of minimal influence by human (anthropogenic) sources.
Bacterial mats	Microbial mat. A layer or aggregate of microorganisms in which cells adhere to each other and/or to a surface.

Baseflow	The part of stream discharge that originates from groundwater seeping into the stream.
Baseline sampling	A period of regular water quality and water level measurements that are carried out over a period long enough to determine the natural variability in groundwater conditions.
Bedding plane	In sedimentary or stratified rocks, the division plane which separates the individual layers, beds or strata.
bgl	Below ground level.
Bore	A structure drilled below the surface to obtain water from an aquifer or series of aquifers.
Boundary	A lateral discontinuity or change in the aquifer resulting in a significant change in hydraulic conductivity, storativity or recharge.
Calcite	The mineral calcite is a common calcium carbonate corresponding to the formula $CaCO_3$ and is one of the most widely distributed minerals on the Earth's surface. It is a common constituent of sedimentary rocks, limestone in particular.
Carbon-13 (^{13}C)	A natural, stable isotope of carbon and one of the environmental isotopes. It makes up about 1.109% of all naturally occurring carbon on Earth.
Carbon-14 (^{14}C)	Or radiocarbon is a radioactive isotope of carbon. Its nucleus contains six (6) protons and eight (8) neutrons. Its presence in organic materials is used in radiocarbon dating. It occurs naturally and has a relative abundance up to one part per trillion (0.0000000001%) of all naturally-occurring carbon on Earth. Carbon-14 is one of the most important nuclides in groundwater studies because its half life of 5,730 years covers a critical time scale of ~500 to 40,000 years, which is ideal for dating regional and intermediate flow systems
Carbon dioxide (CO_2)	An atmospheric gas comprised of one carbon and two oxygen atoms.
Cation	An ion with a positive charge – usually metal ions when disassociated and dissolved in water.
Chlorine-36 (^{36}Cl)	A naturally occurring radioisotope of chlorine. It has a half life of 301,000±2,000 years and is suitable for age dating groundwaters up to 1 million years old.
Claystone	A non-fissile rock of sedimentary origin composed primarily of clay-sized particles (less than 0.004 mm).
Closure	Is the reduction in horizontal distance between the valley sides, and is expressed in units of millimetres (mm). Closure also results from the redistribution of, and increase in the horizontal stresses in the strata as mining occurs.
Coal	A sedimentary rock derived from the compaction and consolidation of vegetation or swamp deposits to form a fossilised carbonaceous rock.
Coal seam	A layer of coal within a sedimentary rock sequence
Compression	A system of forces or stresses that tends to decrease the volume or shorten a substance, or the change of volume produced by such a system of forces.

Compressive strain	A strain that tends to push together the material on opposite sides of a real or imaginary plane.
Concentration	The amount or mass of a substance present in a given volume or mass of sample, usually expressed as microgram per litre (water sample) or milligrams per kilogram (sediment sample).
Confining layer	A body of relatively impermeable material that is stratigraphically adjacent to one or more aquifers – it may lie above or below the aquifer.
Curvature	Is the second derivative of subsidence, or the rate of the change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the Radius of Curvature with units of 1/kilometre (1/km), but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres (km).
Detection limit	The concentration below which a particular analytical method cannot determine, with a high degree of certainty, a concentration.
Deuterium (^2H)	Also called heavy hydrogen, a stable isotope of hydrogen with a natural abundance of one atom in 6,500 of hydrogen. The nucleus of deuterium, called a deuteron, contains one proton and one neutron, where a normal hydrogen nucleus has just one proton.
DGPS	Differential GPS, use of Global Positioning Systems and a base station to improve the accuracy of positions measurements (see Appendix 3-3).
Dilation	Deformation that is change in volume, but not shape.
Discharge	The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.
Discharge area	An area in which there are upward or lateral components of flow in an aquifer.
Dissolution	Process of dissolving a substance into a liquid. If the saturation index is less than zero, the mineral is undersaturated with respect to the solution and the mineral might dissolve.
Drawdown	Lowering the water table in an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping groundwater from bores and wells.
Dyke	A tabular body of igneous rock that cuts across the structure of adjacent rocks. Most dykes result from the intrusion of magma.
Electrical conductivity (EC)	A measure of a fluid’s ability to conduct an electrical current and is an estimation of the total ions dissolved. It is often used as a measure of water salinity.
Environmental indicators	A measurable feature or features that provide managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality.
Environmental isotopes	Also known as stable isotopes, they act as ‘groundwater signatures’ and can be used as natural groundwater tracers.

Equilibrium	A balance between the thermodynamic forces of precipitation and dissolution. A saturation index (SI) of zero indicates apparent equilibrium
Erosion	The group of processes whereby soil or rock material is loosened and removed from any part of the earth's surface. It includes the processes of weathering, solution, corrosion, and transportation. The mechanical wear and transportation are affected by running water, waves, moving ice, or winds, which use rock fragments to grind other rocks.
Evaporation	the loss of water by evaporation processes, which may also include the evaporation of water through the action of plants, although the latter is commonly called evapotranspiration.
Evapotranspiration	This can mean loss of water from plants by transpiration process, or all the evaporation and transpiration losses of water from a unit of land surface.
Fault	A fracture in rock along which there has been an observable amount of displacement. Faults are rarely single planar units; normally they occur as parallel to sub-parallel sets of planes along which movement has taken place to a greater or lesser extent. Such sets are called fault or fracture zones.
Fissility	The property of rocks to split down planes of weakness.
Flow path	The path of two dimensional flow through porous media.
Fracture	Breakage in a rock or mineral along a direction or directions that are not cleavage or fissility directions.
Fractured rock aquifer	These occur in sedimentary, igneous and metamorphosed rocks which have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding planes, fractures and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary aquifers.
Geohydrology	the study of water, its quantity, quality and movement, in the soil and rocks of the earth.
Geomorphology	The science that studies the general configuration of the Earth's surface; the description of landforms and the processes that formed them.
GL	giga litres = 10^9 L = 10^6 m^3, a million cubic metres
Goaf	That part of a mine from which the mineral has been partially or wholly removed; the waste left in the old workings; also called gob.
Global Meteoric Water Line (GMWL)	A line that defines the relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation from a number of global reference sites.
Groundwater	The water contained in interconnected pores located below the water table in an unconfined aquifer or located at depth in a confined aquifer.
Groundwater Dependent Ecosystems (GDEs)	Groundwater dependent ecosystems are communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater.

Groundwater flow	The movement of water through openings in sediment and rock within the zone of saturation.
Groundwater flow system	A regional aquifer or aquifers within the same geological unit that are likely to have similar recharge, flow, yield and water quality attributes.
Hardness	Sum of the ions which can precipitate as “hard particles” from water. Often the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}), and sometimes iron (Fe^{2+}) carbonates.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).
Hydraulic gradient	The change in total hydraulic head with a change in distance in a given direction.
Hydraulic head	Is a specific measurement of water pressure or total energy per unit weight above a datum. It is usually measured as a water surface elevation, expressed in units of length. In an aquifer, it can be calculated from the depth to water in a monitoring bore. The hydraulic head can be used to determine a hydraulic gradient between two or more points.
Hydrochemistry	Chemical characterisation of water (both surface water and groundwater).
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater. See Geohydrology
Hydrology	The study of water at and near the surface of the earth.
Hydrolysis	Decomposition of a chemical compound by reaction with water, such as the dissociation of a dissolved salt or the catalytic conversion of starch to glucose.
Infiltration	Flow of water downward from the land surface into and through the upper soil layers.
Interfluves	The region of higher land between two rivers that are in the same drainage system.
Ion	An ion is an atom or molecule where the total number of electrons is not equal to the total number of protons, giving it a net positive or negative electrical charge.
Isotope	One of multiple forms of an element that has a different number of neutrons than other atoms of that element. Some elements have isotopes that are unstable or radioactive, while others have ’stable isotopes’.
Isotropic	Having hydraulic properties that are the same in all directions.
Jurassic	A geological period extending from 199 million years ago to 145 million years ago.
Lithology	The study of rocks and their depositional or formational environment on a large specimen or outcrop scale.
Lineament	Large-scale linear feature that expresses itself in terms of topography, which is itself an expression of the underlying structural features.

Local Meteoric Water Line (LMWL)	A line that defines the local relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation. In this report the LMWL used is for coastal Sydney.
Longwall mining	An underground process of mining coal whereby the coal is excavated from its seam and the overburden material is allowed to fall back in its place.
L/s	litres per sec (also written as l/s, Ls^{-1})
Major ions	Constituents commonly present in concentrations exceeding 10 milligrams per litre. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulphate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.
Methane (CH_4)	An odourless, colourless, flammable gas, which is the major constituent of natural gas. It is used as a fuel and is an important source of hydrogen and a wide variety of organic compounds.
Methanogenesis	Methanogenesis is the formation of methane by microbes known as methanogens. This occurs in reduced environments.
Microsiemens per centimetre (µS/cm)	A measure of water salinity commonly referred to as EC (see also Electrical Conductivity). Most commonly measured in the field with calibrated field meters.
ML	mega litres = 10^6 L = 10^3 m^3, a thousand cubic metres.
Monitoring bore	A non-pumping bore, is generally of small diameter that is used to measure the elevation of the water table and/or water quality. Bores generally have a short well screen against a single aquifer through which water can enter.
Monocline	Is a step-like fold consisting of a zone of steeper dip within an otherwise horizontal or gently-dipping sequence
Normal faulting	Where the fault plane is vertical or dips towards the downthrow side of a fault.
Overburden	Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal especially those deposits that are mined from the surface by open cuts.
Oxidising conditions	Conditions in which a species loses electrons and is present in oxidised form.
Oxygen-18 (^{18}O)	A natural, stable isotope of oxygen and one of the environmental isotopes. It makes up about 0.2 % of all naturally-occurring oxygen on Earth.
Pan correction factor	a factor applied to the pan evaporation reading to equate it with evaporation from an open water body such as a lake. It is always <1.
Pan evaporation	the measurement of potential evaporation at meteorological sites using a four-foot diameter class A evaporation pan.
Panel	A coal mining block that generally comprises one operating unit.

Percent modern carbon (pMC)	The activity of ^{14}C is expressed as percent modern carbon (pMC) where 100 pMC corresponds to 95 % of the ^{14}C concentration of NBS oxalic acid standard (close to the activity of wood grown in 1890).
Perched water	Unconfined groundwater located near surface separated from an underlying body of groundwater by an unsaturated zone and supported by an aquitard or aquiclude.
Permeability	The property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. It is a measure of the relative ease of fluid flow under unequal pressure. The hydraulic conductivity is the permeability of a material for water at the prevailing temperature.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Permian	The last period of the Palaeozoic era, finished approximately 230 million years before present.
pH	Potential of Hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).
Piezometer	See monitoring bore.
Pillar	A column of rock remaining after solution of the surrounding rock.
Porosity	the volume of voids, or empty spaces, in a given volume of rock or soil.
Porosity, primary	The porosity that represents the original pore openings when a rock or sediment formed.
Porosity, secondary	The porosity caused by fractures or weathering in a rock or sediment after it has been formed.
Potential evaporation	the maximum evaporation possible under the prevailing meteorologic conditions. Sometimes equated with pan evaporation.
Potentiometric surface	Surface to which water in a confined aquifer would rise by hydrostatic pressure.
Permeability	the rate of flow of water through rock or soil under given pressure conditions (see hydraulic conductivity and transmissivity)
Precipitation	1) in meteorology and hydrology, rain, snow and other forms of water falling from the sky (2) the formation of a suspension of an insoluble compound by mixing two solutions. Positive values of saturation index (SI) indicate supersaturation and the tendency of the water to precipitate that mineral.
Pumping test	Test made by pumping a bore for a period of time and observing the change in hydraulic head in the aquifer. It may be used to determine the bore's capacity and the aquifer's hydraulic characteristics.
Pyrite	Also known as iron pyrite, and is iron disulfide, FeS_2.
Quaternary	The most recent geological period extending from approximately 2.5 million years ago to the present day.

Quality assurance	Evaluation of quality-control data to allow quantitative determination of the quality of chemical data collected during a study. Techniques used to collect, process, and analyse water samples are evaluated.
Radioisotope	Radioisotopes undergo radioactive decay allowing for determination of residence times in aquifers and groundwater renewability.
Recharge	The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water reaching the water table or exposed aquifers. The addition of water to an aquifer.
Recharge area	A geographic area that directly receives infiltrated water from surface and in which there are downward components of hydraulic head in the aquifer. Recharge generally moves downward from the water table into the deeper parts of an aquifer then moves laterally and vertically to recharge other parts of the aquifer or deeper aquifer zones.
Redox potential (ORP or Eh)	The redox potential is a measure (in volts) of the affinity of a substance for electrons – its electronegativity – compared with hydrogen (which is set at 0). Substances more strongly electronegative than (i.e. capable of oxidising) hydrogen have positive redox potentials. Substances less electronegative than (i.e. capable of reducing) hydrogen have negative redox potentials. Also known as oxidation-reduction potential and Eh.
Redox reaction	Redox reactions, or oxidation-reduction reactions, are a family of reactions that are concerned with the transfer of electrons between species, and are mediated by bacterial catalysis. Reduction and oxidation processes exert an important control on the distribution of species like O_2, Fe^{2+}, H_2S and CH_4 etc in groundwater.
Reducing conditions	Conditions in which a species gains electrons and is present in reduced form.
Residence time	The time that groundwater spends in storage before moving to a different part of the hydrological cycle (i.e. it could be argued it is a rate of replenishment).
Reverse faulting	A moderately angled planar fracture line that extends through layers of rock. A reverse fault occurs when older (deeper) rock layers are pushed upwards with respect to younger rocks on either side of the fracture line.
Riparian	Of, on, or relating to the banks of a natural course of water.
RL	Reduced level or height, usually in metres above or below an arbitrary or standard datum.
Salinity	The concentration of dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS). The conversion factor of 0.6 mg/L TDS = 1 EC unit is commonly used as an approximation of salinity.

Saturated zone	The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric pressure. The water table is the top of the saturated zone in an unconfined aquifer.
Sedimentary aquifers	These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest volumes of groundwater.
Sedimentation	That portion of the metamorphic cycle from the separation of the particles from the parent rock, no matter what its origin or constitution to and including their consolidation into another rock.
Seismology	The geophysical science of earthquakes and the mechanical properties of the earth.
Siderite	A mineral composed of iron carbonate $FeCO_3$.
Siltstone	A fine-grained rock of sedimentary origin composed mainly of silt-sized particles (0.004 to 0.06 mm).
Spring	Location where groundwater emerges on to the ground surface. Water may be free flowing or slowly seeping.
Stable isotope	Stable isotopes are not radioactive, and do not decay over time. For example, most nitrogen atoms have 14 neutrons, while a very small percentage of naturally-occurring nitrogen atoms have 15 neutrons. The ^{15}N atoms are referred to as stable isotopes.
Standing water level (SWL)	The height to which groundwater rises in a bore after it is drilled and completed, and after a period of pumping when levels return to natural atmospheric or confined pressure levels.
Stratigraphy	The depositional order of sedimentary rocks in layers.
Subsidence	Usually refers to vertical displacement of a point, but the subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where subsidence is small, can be greater than the vertical subsidence. Subsidence is usually expressed in units in millimetres (mm).
Surface water-groundwater interaction	This occurs in two ways: (1) streams gain water from groundwater through the streambed when the elevation of the water table adjacent to the streambed is greater than the water level in the stream; and (2) streams lose water to groundwater through streambeds when the elevation of the water table is lower than the water level in the stream.
Tensile strains	A normal strain that tends to pull apart the material on opposite sides of a real or imaginary plane.

Tension	A system of forces tending to draw asunder the parts of a body, especially of a line, cord or sheet, combined with an equal and opposite system of resisting forces of cohesion holding the parts of the body together; stress caused by pulling. Opposed to compression, and distinguished from torsion.
Tertiary	Geologic time at the beginning of the Cainozoic era, 65 to 2 million years ago, after the Cretaceous and before the Quaternary.
Tilt	is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of millimetres per metre (mm/m). A tilt of 1 mm/m is equivalent to a change in grade of 0.1%.
Throw	1. The amount of vertical displacement occasioned by a fault. 2. More generally, used for the vertical component of the net slip.
Total Dissolved Solids (TDS)	A measure of the salinity of water, usually expressed in milligrams per litre (mg/L). See also EC.
Trace element	An element found in only minor amounts (concentrations less than 10 milligram per litre) in water or sediment; includes the metalloid arsenic and heavy metals cadmium, chromium, copper, lead, mercury, nickel, and zinc.
Tracer	A stable, easily detected substance or a radioisotope added to a material to follow the location of the substance in the environment or to detect any physical or chemical changes it undergoes.
Transmissivity	The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Triassic	The earliest of the three periods that constitute the Mesozoic Era, approximately between 230 and 180 million years before present.
Tritium (^3H)	A short-lived isotope of hydrogen with a half-life of 12.43 years. It is directly incorporated into the water molecule ($^1H^3HO$ or 1HTO) and so is the only radioisotope that actually dates groundwater. It is commonly used to identify the presence of modern recharge. Tritium is produced naturally in small amounts owing to the interaction of cosmic radiation with atmospheric oxygen and nitrogen in the troposphere, and is also produced by thermonuclear explosions.
Turbidity	Reduced clarity of surface water because of suspended particles, usually sediment.
Unconfined aquifer	Where the groundwater surface (water table) is at atmospheric pressure and the aquifer is recharged by direct rainfall infiltration from the ground surface.

Unsaturated zone	That part of an aquifer between the land surface and water table. It includes the root zone, intermediate zone and capillary fringe.
Upsidence	Is the reduced subsidence, or the net vertical movement within the base of a valley. Upsidence results from the buckling of near surface strata in the base of the valley which results from the redistribution of, and increase in the horizontal stresses in the strata immediately below the base of the valley as mining occurs.
Valley closure	Is the reduction in horizontal distance between the valley sides, and is expressed in units of millimetres (mm). Closure also results from the redistribution of, and increase in the horizontal stresses in the strata as mining occurs.
Water quality	Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Water quality data	Chemical, biological, and physical measurements or observations of the characteristics of surface and groundwaters, atmospheric deposition, potable water, treated effluents, and waste water and of the immediate environment in which the water exists.
Water table	The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow bores extending a few metres into the zone of saturation and then measuring the water level in those bores.
Well	Any structure bored, drilled driven or dug into the ground, (which is deeper than it is wide), with the purpose of accessing groundwater.

12. LIST OF APPENDICES

1.0 CHAPTER 2

Appendix 2-1 Terms of Reference

Appendix 2-2 Curriculum Vitae of Committee Members

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1.1.1 Appendix 2.1 TERMS OF REFERENCE

Thirlmere Lakes Inquiry

An inquiry into recent variations in water level in Thirlmere Lakes.

Under the authority of the Minister for the Environment, the Thirlmere Lakes Inquiry Committee is authorised to inquire into and report on the following matters concerning recent variations in water level in Thirlmere Lakes:

1. Historical, paleo-climatogical, and other scientific records regarding lake levels, rainfall events and other natural or land management data related to the condition and circumstances of the Thirlmere Lakes

2. Identification of patterns in the relationship between water levels in the Thirlmere Lakes and known rainfall events, land management practices or other factors

3. An assessment of current water levels in Thirlmere Lakes against identified patterns

4. Recommendations for management actions to address the factors identified as likely to have a direct or indirect effect on lake levels and/or on the natural and cultural values of Thirlmere Lakes National Park.

5. Recommendations for future studies to better understand the hydrology of the Thirlmere Lakes and provide better information for future management.

6. Any other matters the Inquiry Committee considers relevant to the reasons for or responses to water levels in the Thirlmere Lakes.

In preparing its recommendations the Thirlmere Lakes Inquiry Committee may have reference to a wide range of information sources including, but not limited to: scientific data and studies including paleo-climatological studies; expert opinion; climate or other modelling; comparative information across the region; data from similar water bodies; historical information; private records (such as family photos or private data collections); and submissions from the public.

The Thirlmere Lakes Inquiry Committee will consist of the following members:

- A chairperson with senior qualifications and expertise in hydrology, geology, geomorphology, climatology, paleogeography and/or related natural processes relevant to the inquiry
- Two members with qualifications and expertise in hydrology, geology, geomorphology, climatology, paleogeography and/or related natural processes relevant to the inquiry
- One member with qualifications and expertise in freshwater ecology, ecological management or natural sciences relevant to the inquiry
- One member with expertise related to mining practices and techniques including short and long term environmental effects.

The Thirlmere Lakes Inquiry Committee will as expeditiously as possible, but in any case on or before 30 June 2012, deliver a final report on the results of the inquiry to the Minister for the Environment.

1.1.2 Appendix 2.2 Curriculum Vitae of Committee Members

Dr Steven Riley is a fellow of Engineers Australia and a Fellow of the Royal Geographic Society, with training, research, professional experience and more than 200 published papers in the areas of Geomorphology, Hydrology, Mining, Modelling and Sustainable systems. He has worked in Africa, India, Philippines, South America, and Australia. He has published a number of papers and facilitated several conferences on the Hawkesbury Nepean Catchment system. Dr Riley recently retired as head of Engineering at the University of Western Sydney after a 33 year career in Universities and the Commonwealth Public Service. He continues to work in the area of environmental engineering, primarily on appropriate energy, water and sewage systems for people at the bottom of the pyramid in SE Asia, India and Africa.

Max Finlayson is the Director of the Institute for Land, Water and Society at Charles Sturt University. He has spent 30 years in wetland research and conservation in temperate and tropical regions, and has over 200 publications on the ecology, assessment, conservation and wise use of coastal and inland wetlands, the ecology of aquatic plants, and water pollution. He has been involved in many international projects in Asia, Africa, Europe and South America, as well as global assessments covering environmental change, water management, biodiversity and ecosystem services, and climate change. He is an advocate of the transfer of environmental science into policy, and the involvement of local people in science, and has a distinguished record in the governance of conservation and science-based organisations

Dr Wendy McLean is a Principal Hydrogeologist with an international consulting firm and member of the International Association of Hydrogeologists. She has a background in Earth Science and over 10 years' experience in Hydrogeology, with a particular focus on the use of hydrogeochemical, environmental isotope and applied tracer techniques in hydrogeology. Dr McLean has undertaken groundwater and surface water investigations in a range of hydrogeological environments throughout Australia and has extensive experience in the Sydney Basin investigating groundwater contamination, salinity, coal seam gas development, longwall mining, and water resource supply. She is currently involved in an ARC Linkage Project, trialling novel isotopic methods for assessing aquifer and surface water linkages. Dr Mclean is also currently involved in a number of projects investigating groundwater and surface systems, and groundwater dependent ecosystems in catchments in the Southern Coalfields where longwall mining is occurring

Dr Damian Gore is Associate Professor in Environmental Science at Macquarie University, Sydney. He is a geologist and geomorphologist with initial research in soil erosion, hydrology and sedimentology followed by extensive experience in the management of contaminants and remediation of mine sites or landfills, from Antarctica to the Arctic. He manages the "Environmental Quality laboratory", an analytical facility specialising in X-ray techniques, based at Macquarie University. A career highlight has been the initiation of a $5M remediation of a contaminated site at Australia's Casey Station in Antarctica. Recent mine-related research encompasses sites in NSW near Braidwood, Broken Hill, Gloucester, Inverell and Sunny Corner.

Kevin Thomas has lived and worked in the local area for over 30 years. As a geography teacher he has a background in physical, human and environmental geography. He has extensive travel experience both in Australia and around the world. He has received awards from the Department of Education and the New South Wales Teachers Federation for his work with students, staff and community members. His work as a teacher saw him initiate, develop and attend school trips to Japan and Bali. He also organised reciprocal visits to his school, by students from Japan and South Korea. As a Head Teacher he was responsible for running the Social Science Department at his local high school. He lives within 200 metres of Thirlmere Lakes National Park and is a regular visitor to it. He has watched with dismay as the lakes have gradually disappeared. So, it is not surprising that when he was asked to be the community's representative on the committee investigating the disappearance of the Lakes, he was quick to accept the position.

1.1.3 Appendix 2.3 Summaries of meetings of the committee as published on the web

Meeting update: 23 November 2011

The Thirlmere Lakes Inquiry committee held its first meeting on 23 November 2011. The meeting was held at Tahmoor, with a trip to Thirlmere Lakes. Dr Steven Riley, Dr Wendy McLean and Associate Professor Damian Gore attended the meeting. Professor Max Finlayson was unable to attend.

The committee agreed on a timetable for its work and discussed how the community would be given an opportunity for input into the inquiry. The committee will gather and analyse information from a range of sources, before providing a report to the Minister for the Environment.

The committee undertook a field trip to Thirlmere Lakes, which was short due to the rain on the day.

The committee will be meeting at least once a month until June 2012.

The community will be provided with an opportunity to provide input and information during December and January. An opportunity for community members to meet with the committee and discuss their submission will be provided in March 2012.

The final report will be delivered to the Minister for the Environment in June 2012.

Meeting update- 16th of December 2011

The Thirlmere Lakes Inquiry committee held its second meeting on the 16th of December 2011. The meeting was held in Sydney. Dr Steven Riley, Dr Wendy McLean, Associate Professor Damian Gore and Professor Max Finlayson attended the meeting.

The committee was given an update on the inquiry webpage and progress for calling for submissions, as well as the storage of information collected by the committee. The inquiry website will be updated regularly with information on the progress of the inquiry. Scientific information from a number of sources has already been obtained by the committee.

A detailed discussion on the hydrology, geomorphology, geology and ecology of the lakes was undertaken by the committee. The committee developed several conceptual hydrological models for the fluctuations in water level, as hypotheses to guide us in evaluating data, reports and other sources of information The committee will undertake a field trip to Thirlmere Lakes in January to study the lakes more closely.

20th of January field trip.

The Thirlmere Lakes Inquiry committee undertook a field trip to Thirlmere Lakes. Dr Steven Riley, Associate Professor Damian Gore and Professor Max Finlayson attended the field trip.

The committee examined the geology, geomorphology, water levels, and flora of Bluegum Creek, Lake Nerrigorang and Lake Baraba, and visited some of the sites of previous research. A number of field observations were made that will assist the committee in their deliberations. A second field trip to examine Lakes Couridjah, Werri Berri and Gandangarra will take place in February.

27th of January meeting.

The Thirlmere Lakes Inquiry committee held its third meeting on the 27th of January 2012. The meeting was held in Sydney. Dr Steven Riley, Dr Wendy McLean, Associate Professor Damian Gore and Professor Max Finlayson attended the meeting.

The committee discussed the submissions received through the call for submissions, and reviewed ways of involving the community in the inquiry and ensuring maximum transparency of process.

The committee reviewed progress in the collection of information on the hydrology, geomorphology, geology and ecology of the lakes and identified further information that needs to be collected.

February field trips.

Field trips to Thirlmere Lakes were undertaken on the 8th, 10th and 12th of February by various members of the committee

The committee installed a number of temporary piezometers, and observed the response of the lakes to recent rainfall events, including shallow ground water flows and the significant spatial variability in runoff into the lakes. The committee also observed the catchment geomorphology and soils.

24th of February meeting.

The Thirlmere Lakes Inquiry committee held its fourth meeting on the 24th of February 2012. The meeting was held in Sydney. Dr Steven Riley, Dr Wendy McLean, Associate Professor Damian Gore and Professor Max Finlayson attended the meeting. Kevin Thomas, recently appointed as the community representative also attended.

The committee reviewed submissions , identified additional information to be requested, and started planning for the upcoming public meetings. Progress made by committee in on catchment hydrology, geo- hydrology, geology, geomorphology and ecology was reviewed. The committee also identified further information that needed to be collected to progress the committee’s understanding of the hydrology of Thirlmere Lakes.

March field trips.

Field trips to Thirlmere Lakes were undertaken on the 7th, 9th 14th and 15th of March.

The committee completed installation of Piezometers, took readings on the water levels, undertook a GPS survey of each of the lakes, and collected a number of other observations and readings.

The committee also undertook measurements of ground water levels in a number of local bores, and obtained rainfall information from local residents.

16th of March meeting.

The Thirlmere Lakes Inquiry committee held its fifth meeting on the 16th of March 2012. The meeting was held in Sydney. Dr Steven Riley, Dr Wendy McLean, Associate Professor Damian Gore, Professor Max Finlayson and Kevin Thomas attended.

The committee finalised the venues and other arrangements for the two public meetings on the 30th and 31st of March, reviewed progress on data collection, reviewed possible hypotheses, and discussed future studies.

Web address http://www.environment.nsw.gov.au/water/ThirlmereLakesInquiry.htm

19th of March field work

Committee members undertook surveying and read piezometers at Thirlmere Lakes.

30th and 31st of March

Community meetings held at Tahmoor and Sydney, for presentation of submissions a short presentation by the Committee, and opportunity of questions to be asked of the Committee and for the Committee to ask questions of those who made submissions

4th of April field work

Surveying and reading of piezometers

11th April Council Meeting and field work

Meeting with members of Wollondilly Shire Council and observations at Thirlmere Lakes

20th of April Meeting

The Committee reviewed their draft report.

23rd of April Meeting with Pells Consulting

Meeting to exchange information

22nd May Meeting at Wollondilly Shire Council Chambers

Dr Riley presented some of the work leading up to the Draft Report

14th of June field work

Surveying and monitoring of water levels

6th July Community consultation

Open forum at Thirlmere Primary School to receive comments on the Draft Report and answer questions related to the report. Minutes available on the web. http://www.environment.nsw.gov.au/resources/water/060712ThirlmereLakesCttee.pdf

2nd, 13th, 17th 27th July meetings

Briefings of Ministers Office, Local Member and media

17th of August Meeting

Committee reviewed submissions on Draft Report and field work of the last two months.

18th August and 5,6th September Field work

Additional surveying and water level monitoring

7th of September Meeting

Committee reviewed draft of Report

17th September Field work

Committee undertook with students from Macquarie University geomorphic studies of the Baraba-Nerrigorang col.

21st September Meeting at Tahmoor Colliery

Committee inspected above and below-ground operation, pumps, water management and condition of Panels at Tahmoor Colliery

1.1.4 Appendix 2.4 Call for submission: contacts and web pages

Thirlmere Lakes Inquiry call for submissions

Public input into the inquiry

The involvement of the community in the inquiry is encouraged. The committee welcomes anyone with relevant information to provide it at any time during the inquiry. Submissions may take the form of data (including, but not limited to hydrologic, geotechnical, climatic, visual, ecological) and/or analysis of the data. All information must be verifiable, in-line with standard scientific practice. All conclusions must be backed by evidence.
Submissions can be made by

- online submission form
- mail to Thirlmere Lakes Inquiry, PO Box 99, PICTON, NSW 2571
- email to thirlmere.lakes@environment.nsw.gov.au

The Committee prefers that submissions and associated evidence are submitted in electronic form, if possible. All submissions will be available on the Inquiry web site, subject to the permission of those who make the submissions.
All submissions received by the inquiry are a matter of public record and are available for public inspection upon request. Your submission may contain information that is defined as personal information under the NSW Privacy and Personal Information Protection Act 1998. The submission of personal information with your submission is voluntary, however as the committee may need to contact you about your submission, it is encouraged.
Should the need arise, the inquiry committee may contact you to seek clarification on your submission.

Comments on the draft report

A draft report will be released for public comment in April 2012.
Procedures for making a comment on the draft report will be provided in the future.

Web address http://www.environment.nsw.gov.au/water/Thirlmeresubmissions.htm

Organisations and individuals contacted

Park neighbours and other interested stakeholders;

Rivers SOS;

NPWS Metro South West Regional Advisory Committee;

Greater Blue Mountains World Heritage Area Advisory Committee;

Sydney Catchment Authority;

Department of Sustainability, Environment, Water, Population and Communities;

NSW Office of Water;

NSW Minerals Council;

Blue Mountains World Heritage Institute;

Australian Coal Association;

UNESCO Australia;

Wollondilly Shire Council;

University of Wollongong;

Xstrata/ Tahmoor Colliery;

Nature Conservation Council;

Hawkesbury Nepean Catchment Management Authority;

Mines Subsidence Board;

NSW Department of Primary Industries;

1.1.5 Appendix 2.5 Submissions to the Inquiry

Note: Personal submissions have been altered to remove all personal information to ensure compliance with the requirements of the *Privacy and Personal Information Protection Act 1998.*

See attached File “Submissions” on DVD.

Number	**Personal or Organisation**	**Organisation**
1	Caroline Graham	Rivers SOS
2	Ian Sheppard	Tahmoor Colliery
3	Personal	
4	Personal	
5	Dr Brian Marshall	Blue Mountains Conservation Society
6	Personal	
7	Personal	
8	Personal	
9	Gary Schoer	NPA- Southern Sydney Branch
10	Personal	
11	Personal	
12	Personal	
13	Personal	
14	Personal	
15	Personal	
16	Personal	
17	Personal	

18	Julie Sheppard	Rivers SOS
19	Personal	
20	Luke Johnson	Wollondilly Council
21	Personal	
22	Personal	
23	Personal	
24	Sharyn Cullis	Georges River Environment Alliance
25	Personal	
26	Personal	
27	Personal	
28	Personal	
29	David Harris	NSW Office Of Water
30	Personal	
33	Keith Muir	Colong Foundation for Wilderness
34	Philip Pells	Pells Consulting
35	Personal	
36	Personal	
37	Personal	
38	Personal	
		Submissions on Draft Report
39	Personal	
40	Personal	
41	Personal	
42	Personal	
43	Personal	

44	Personal	
45	Personal	
46	Personal	
47	Ian Sheppard	Xstrata
48	Personal	
49	Julie Sheppard	Rivers SOS
50	Luke Johnson	Wollondilly Shire Council
51	Personal	
52	Dr Brian Marshall	Blue Mountains Conservation Society

1.1.6 Appendix 2.6 Agenda for public meetings of 30th and 31st March 2012

Chair: Mr Robert Wynne

Agenda - Thirlmere Lakes Inquiry public hearings.
10am - 1pm, 30th March 2012, Tahmoor Community Centre

Time	Item
1 - 1:15pm	Arrival, coffee and tea provided
1:15 - 2 pm	Introduction and overview of inquiry. Steven Riley
2 - 2:30 pm	John Smyth submission
2:30 - 3 pm	Julie Sheppard submission
3 - 3:30 pm	Caroline Graham submission
3:30 - 4pm	Tea break
4pm – 4:30pm	Wollondilly Council submission Brad Staggs
4:30pm - 5pm	Cita Murphy submission
5 - 5:30 pm	Overview of inquiry (repeat for late arrivals) Steven Riley
5:30 - 6:30 pm	Open questions from audience- All committee
7pm	Meeting close

Agenda - Thirlmere Lakes Inquiry public hearings.
10am - 4pm, 31st March 2012, Rydges World Square

Time	Item
10am - 10:30 am	Arrival tea & Coffee
10:30am - 1pm	Open discussion and our presentation
1:pm - 1:30 pm	Lunch
1:30pm - 2pm	Martin Chessell submission
2pm - 2:30pm	Trish Fanning submission
2:30pm -3pm	Scott Mooney submission
3pm - 4pm	Open discussion

(see attached video files on DVD for video clips of meetings)

1.2 Chapter 3

1.2.1 Appendix 3.1 Logs of exploration bores around Thirlmere Lakes

See attached files for TNC26, PMX3, DDH6, TNC25

TNC26

PMX3

DDH6 (CPN6)

TNC25

1.2.2 Appendix 3.2 List of earthquakes in the Picton region

Source: Australian Geosciences

Magnitude	Canberra Sydney Melbourne	Latitude	Longitude	Approximate location	Depth (km)	ML
1.9	27 November 2011 @ 00:40:49	-34.204	150.857	E of Appin, NSW.	15	1.91
2	02 November 2011 @ 03:22:12	-34.413	150.755	NW of Mount Kembla, NSW.	0	1.97
2.2	01 February 2011 @ 19:15:47	-34.416	150.402	NW of Bowral, NSW.	10	2.15
1.9	26 March 2010 @ 04:37:42	-34.158	150.774	Appin area NSW.	0	1.93
3.4	29 August 2009 @ 08:20:06	-34.217	150.338	West of Picton NSW.	3	3.4
2.9	19 April 2009 @ 01:35:07	-34.532	150.486	SE of Bowral NSW. Nearest station CNB.	11	2.9
1.8	19 January 2009 @ 02:57:09	-34.065	150.488	W of Camden NSW. Nearest station RIV.	10	1.8
2.3	23 May 2008 @ 14:44:57	-34.534	150.671	SE of Bowral NSW. Nearest station CNB.	0	2.3
3.2	18 August 2007 @ 13:57:39	-34.379	150.376	NW of Mittagong NSW. Nearest station RIV.	18	3.2
2.6	18 August 2007 @ 13:44:44	-34.372	150.37	NW of Mittagong NSW. Nearest station RIV.	9	2.6
3.1	11 April 2007 @ 10:58:51	-34.253	151.01	NE of Wollongong NSW. Nearest station RIV.	20	3.1
2	29 July 2006 @ 15:25:55	-34.34	150.788	NW of Wollongong NSW. Nearest station RIV.	0	2
3	19 June 2006 @ 01:49:34	-34.069	150.424	W of Camden NSW. Nearest station RIV.	12	3

1.6	04 March 2006 @ 23:40:14	-33.916	150.665	S of Penrith NSW. Nearest station RIV.	2	1.6
1.9	19 May 2005 @ 23:30:29	-33.923	150.693	N of Camden NSW. Nearest station RIV.	6	1.9
2.5	29 December 2004 @ 16:48:24	-33.933	150.73	Narellan, NSW. Nearest station MGCD.	10	2.5
1.8	29 December 2004 @ 14:52:14	-33.913	150.692	Narellan, NSW. Nearest station RIV.	5	1.8
2	29 December 2004 @ 14:44:43	-33.928	150.707	Narellan, NSW. Nearest station RIV.	6	2
1.7	29 December 2004 @ 14:25:50	-33.935	150.726	Narellan, NSW. Nearest station RIV.	10	1.7
2.4	11 December 2003 @ 21:24:35	-34.422	150.435	Bowral NSW. Nearest station RIV.	0	2.4
4.2	11 December 2003 @ 21:19:20	-34.485	150.444	Bowral NSW. Nearest station RIV. Felt in Canberra and Sydney.	5	4.2
3.9	15 February 2002 @ 00:27:20	-34.524	150.744	Lake Avon NSW. Nearest station RIV. Felt by many people in the Sydney and Wollongong areas.	5	3.9
2.2	08 October 2000 @ 14:52:30	-33.914	150.937	Sydney NSW.	18	2.2
2.6	29 September 1999 @ 10:42:06	-34.528	150.476	Bowral NSW. Felt	2	2.6
4.8	17 March 1999 @ 12:58:10	-34.234	150.77	Appin NSW. Felt	8	4.8
3.2	10 December 1996 @ 23:58:35	-34.141	150.503	Near Picton N.S.W. 9kms NW Thirlmere	6	3.2
3.3	10 December 1996 @ 23:54:26	-34.158	150.53	Damage was reported from 'The Oaks' and Picton and the shaking was widely felt.	5	3.3
2	01 May 1995 @ 20:58:56	-34.5	150.5	-	15	2
2.7	04 January 1995 @ 00:51:59	-34.523	150.507	-	15	2.7
2.8	07 October 1994 @ 10:49:10	-34.423	150.691	ELOUERA	2	2.8
2	31 October 1992 @ 19:34:42	-33.911	150.467	LAKE BURRAGORANG	19	2

2.2	15 August 1992 @ 20:06:32	-34.29	150.87	-	6	-
2.2	19 August 1990 @ 04:19:00	-34.54	150.51	ROBERTSON	0	-
3	30 March 1990 @ 21:33:00	-34.25	150.83	CATARACT DAM	0	-
1.6	18 October 1987 @ 05:10:36	-34.07	150.41	-	6	-
2.7	02 April 1987 @ 15:12:38	-34.16	150.37	-	22	-
1.9	13 January 1987 @ 11:11:21	-34.28	150.44	-	16	-
2	21 October 1986 @ 21:43:54	-34.46	150.71	-	18	2
2.7	30 August 1986 @ 20:59:31	-34.44	150.97	-	18	2.7
1.7	16 February 1986 @ 04:53:52	-34.17	150.32	-	24	1.7
2.1	15 February 1986 @ 02:28:28	-33.91	150.44	-	9	2.1
2.3	15 April 1984 @ 03:52:38	-34.03	150.99	-	17	2.3
3.5	18 May 1983 @ 18:42:52	-33.98	150.65	-	22	3.5
3.5	22 March 1983 @ 23:39:35	-34.35	150.4	-	19	3.5
2.2	18 January 1983 @ 11:50:47	-34.46	150.52	-	0	2.2
2	31 December 1982 @ 13:10:10	-34.17	150.34	-	19	2
1.9	28 December 1982 @ 20:38:29	-34.4	150.88	-	10	1.9
1.8	06 November 1982 @ 22:49:51	-34.41	150.87	-	12	1.8
2.5	20 September 1982 @ 09:52:05	-34.26	150.41	-	19	2.5

1.9	10 September 1982 @ 21:17:28	-34.41	150.89	-	11	1.9
2	20 July 1982 @ 20:34:18	-34.33	150.95	-	16	2
1.6	30 June 1982 @ 00:09:14	-34.43	150.78	-	12	1.6
1.6	11 June 1982 @ 23:57:11	-33.97	150.55	-	17	1.6
2	25 May 1982 @ 03:06:37	-33.98	150.55	-	15	2
2.1	25 May 1982 @ 00:24:21	-33.96	150.55	-	12	2.1
1.8	25 May 1982 @ 00:14:31	-33.98	150.53	-	12	1.8
1.9	24 May 1982 @ 23:59:42	-33.97	150.53	-	14	1.9
1.9	24 May 1982 @ 23:53:16	-33.97	150.53	-	15	1.9
2.2	16 March 1982 @ 23:02:13	-34.16	150.34	-	23	2.2
1.7	03 March 1982 @ 02:21:05	-34	150.54	-	0	1.7
3.3	19 November 1981 @ 23:18:52	-34.227	150.886	Appin aftershock	12	3.3
4.6	16 November 1981 @ 03:58:10	-34.249	150.897	-	14	4.6
3.3	07 September 1980 @ 19:55:39	-34.155	150.698	-	18	3.3
2.2	08 April 1980 @ 05:36:45	-34.05	151	-	0	2.2
2	27 March 1980 @ 05:09:47	-34.04	150.44	-	22	2
1.8	05 March 1980 @ 15:58:40	-34.46	150.49	-	18	1.8
2.3	30 January 1980 @ 17:18:20	-34.38	150.53	-	17	2.3

2.1	30 January 1980 @ 16:34:03	-34.37	150.55	-	18	2.1
2.1	19 May 1979 @ 00:44:14	-34.05	150.54	-	18	2.1
2	20 April 1979 @ 05:04:08	-34.15	150.34	-	20	2
3	16 April 1979 @ 11:34:16	-33.94	150.53	-	18	3
2	14 April 1979 @ 12:07:29	-33.93	150.49	-	16	2
2.2	10 April 1979 @ 20:05:26	-34.01	150.51	-	18	2.2
2.2	05 April 1979 @ 13:04:38	-34.48	150.41	-	20	2.2
1.7	16 March 1979 @ 22:33:00	-33.99	150.54	-	19	1.7
2.8	16 January 1979 @ 03:31:34	-34.14	150.34	-	24	2.8
2.2	21 November 1978 @ 15:09:23	-34.11	150.83	-	10	2.2
2.2	09 November 1978 @ 15:19:52	-34.12	150.85	-	24	2.2
2.2	30 October 1978 @ 16:21:51	-34.12	150.89	-	27	2.2
2.2	23 October 1978 @ 15:35:29	-34.13	150.83	-	13	2.2
2	07 September 1978 @ 20:47:01	-34.01	150.49	-	12	2
1.9	18 August 1978 @ 15:30:57	-33.95	150.8	-	15	1.9
2.2	03 August 1978 @ 15:43:23	-34.08	150.92	-	0	2.2
2	19 July 1978 @ 15:28:57	-34.13	150.92	-	0	2
1.7	28 May 1978 @ 02:16:32	-34.17	150.88	-	0	1.7

2.3	23 May 1978 @ 15:11:58	-34.13	150.87	-	0	2.3
2.1	02 May 1978 @ 15:09:24	-34.14	150.86	-	15	2.1
2.5	06 April 1978 @ 14:54:58	-34.07	150.65	-	13	2.5
1.6	25 March 1978 @ 20:33:11	-34.11	150.7	-	0	1.6
1.8	25 March 1978 @ 13:29:55	-34.12	150.75	-	0	1.8
2.2	14 March 1978 @ 14:12:12	-34.05	150.7	-	16	2.2
2.1	04 March 1978 @ 12:16:03	-34.01	150.63	-	14	2.1
1.8	10 February 1978 @ 10:25:27	-34.5	150.33	-	0	1.8
2.3	26 January 1978 @ 16:44:58	-34.17	150.39	-	17	2.3
1.9	23 June 1977 @ 10:11:29	-34.35	150.37	-	0	1.9
2.6	20 June 1977 @ 16:09:20	-34.12	150.92	-	10	2.6
1.7	23 May 1977 @ 16:35:22	-34.16	150.84	-	8	1.7
1.9	15 May 1977 @ 04:08:39	-34.33	150.82	-	7	1.9
2.3	27 April 1977 @ 16:01:57	-34.18	150.85	-	0	2.3
1.8	19 April 1977 @ 11:37:26	-34.5	150.43	-	0	1.8
2.5	30 December 1976 @ 19:42:30	-34.03	150.78	-	0	-
1.9	22 September 1976 @ 21:20:45	-34.05	150.45	-	0	1.9
2.4	19 August 1976 @ 01:16:59	-34.2	150.35	-	16	2.4

3	09 January 1976 @ 15:30:28	-34.21	150.63	-	7	-
1.7	14 March 1975 @ 08:46:10	-34.3	150.63	-	0	1.7
1.5	07 March 1975 @ 02:54:20	-34.18	150.35	-	0	1.5
1.1	26 February 1975 @ 19:24:58	-34.12	150.55	-	5	1.1
1.8	05 February 1975 @ 17:00:25	-34.45	150.52	-	0	1.8
1.4	15 January 1975 @ 13:47:53	-34.13	150.47	-	16	1.4
1.2	17 December 1974 @ 21:11:34	-34.3	150.83	-	0	1.2
1.4	21 November 1974 @ 20:56:54	-34.53	150.79	-	6	1.4
0.7	19 November 1974 @ 17:26:17	-34.47	150.65	-	0	0.7
1.2	16 November 1974 @ 13:44:07	-34.13	150.4	-	0	1.2
2	16 November 1974 @ 11:34:37	-34.12	150.85	-	0	2
1.4	10 November 1974 @ 19:13:58	-34.08	150.42	-	0	1.4
1.6	16 October 1974 @ 15:18:52	-34.53	150.4	-	0	1.6
1.6	10 October 1974 @ 08:11:04	-34.45	150.79	-	33	1.6
1.4	09 October 1974 @ 22:53:08	-33.92	150.4	-	7	1.4
1.7	03 October 1974 @ 15:43:25	-34.11	150.9	-	31	1.7
2.8	23 July 1973 @ 13:34:49	-34.19	150.33	-	16	2.8
1.9	10 July 1973 @ 03:08:58	-34.18	150.3	-	0	1.9

2.1	09 July 1973 @ 20:51:34	-34.19	150.36	-	14	2.1
2.2	02 July 1973 @ 19:12:02	-34.15	150.33	-	0	2.2
1.4	26 June 1973 @ 15:48:27	-34.17	150.37	-	0	1.4
1.4	22 June 1973 @ 22:49:04	-34.18	150.34	-	0	1.4
2.1	11 June 1973 @ 19:48:14	-34.19	150.32	-	0	2.1
2.7	21 May 1973 @ 17:30:11	-34.15	150.32	-	0	2.7
2	18 May 1973 @ 15:17:09	-34.27	150.32	-	0	2
2.1	18 May 1973 @ 15:16:01	-34.17	150.35	-	0	2.1
2.3	15 May 1973 @ 05:41:26	-34.18	150.33	-	0	2.3
2.5	14 May 1973 @ 15:19:14	-34.2	150.35	-	0	2.5
2.3	14 May 1973 @ 15:10:18	-34.2	150.32	-	0	2.3
2	13 May 1973 @ 10:07:42	-34.18	150.3	-	0	2
2.2	08 May 1973 @ 08:06:22	-34.2	150.37	-	0	2.2
3	07 May 1973 @ 21:57:53	-34.17	150.4	-	0	3
2.3	01 May 1973 @ 12:30:35	-34.17	150.38	-	0	2.3
2.8	15 April 1973 @ 21:21:07	-34.17	150.32	-	11	2.8
2.4	15 April 1973 @ 21:15:13	-34.18	150.31	-	11	2.4
1.8	15 April 1973 @ 08:41:26	-34.17	150.33	-	14	1.8

3.4	15 April 1973 @ 07:06:02	-34.18	150.31	-	12	3.4
2.3	14 April 1973 @ 12:33:47	-34.13	150.33	-	29	2.3
2.8	13 April 1973 @ 16:52:23	-34.17	150.35	-	34	2.8
1.8	11 April 1973 @ 23:23:21	-34.15	150.38	-	31	1.8
2.1	06 April 1973 @ 06:30:09	-34.18	150.36	-	31	2.1
2.7	04 April 1973 @ 20:08:36	-34.16	150.35	-	24	2.7
2	04 April 1973 @ 17:05:46	-34.18	150.36	-	23	2
1.8	03 April 1973 @ 18:20:20	-34.18	150.32	-	20	1.8
2.5	03 April 1973 @ 06:50:10	-34.14	150.34	-	26	2.5
2.6	01 April 1973 @ 08:06:05	-34.19	150.35	-	6	2.6
1.7	01 April 1973 @ 04:26:00	-34.12	150.39	-	28	1.7
2.2	31 March 1973 @ 19:36:26	-34.16	150.35	-	25	2.2
2.3	31 March 1973 @ 17:29:17	-34.17	150.38	-	28	2.3
2.2	31 March 1973 @ 13:18:41	-34.17	150.33	-	0	2.2
2.6	31 March 1973 @ 07:21:40	-34.2	150.34	-	0	2.6
1.9	31 March 1973 @ 05:44:01	-34.14	150.39	-	33	1.9
2	30 March 1973 @ 23:20:26	-34.17	150.34	-	16	2
1.9	30 March 1973 @ 11:01:48	-34.16	150.38	-	17	1.9

2.2	29 March 1973 @ 22:42:21	-34.17	150.35	-	18	2.2
1.9	29 March 1973 @ 22:25:50	-34.2	150.39	-	1	1.9
2.6	29 March 1973 @ 19:41:48	-34.16	150.34	-	13	2.6
3	29 March 1973 @ 02:59:13	-34.17	150.32	-	17	3
2.8	28 March 1973 @ 11:09:45	-34.14	150.31	-	21	2.8
1.4	28 March 1973 @ 07:44:04	-34.19	150.38	-	22	1.4
3	27 March 1973 @ 20:52:10	-34.18	150.35	-	15	3
1.9	27 March 1973 @ 20:25:02	-34.14	150.38	-	24	1.9
1.4	27 March 1973 @ 10:34:35	-34.17	150.36	-	28	1.4
2.2	27 March 1973 @ 08:44:28	-34.18	150.35	-	15	2.2
1.8	27 March 1973 @ 08:42:47	-34.17	150.39	-	28	1.8
1.7	26 March 1973 @ 15:27:45	-34.13	150.38	-	30	1.7
1.6	25 March 1973 @ 21:59:46	-34.16	150.39	-	34	1.6
3.2	25 March 1973 @ 11:25:46	-34.18	150.34	-	14	3.2
2.1	25 March 1973 @ 11:08:35	-34.18	150.33	-	14	2.1
2	24 March 1973 @ 03:06:03	-34.19	150.33	-	14	2
2.2	24 March 1973 @ 00:26:33	-34.17	150.36	-	19	2.2
1.7	23 March 1973 @ 21:52:20	-34.16	150.36	-	20	1.7

1.8	23 March 1973 @ 08:12:06	-34.17	150.34	-	25	1.8
2.2	22 March 1973 @ 16:39:26	-34.2	150.41	-	27	2.2
1.7	22 March 1973 @ 12:22:26	-34.16	150.37	-	28	1.7
2.2	22 March 1973 @ 09:05:07	-34.18	150.35	-	14	2.2
2.7	22 March 1973 @ 07:04:28	-34.19	150.34	-	12	2.7
1.4	22 March 1973 @ 06:56:23	-34.2	150.41	-	25	1.4
1.8	22 March 1973 @ 06:10:33	-34.14	150.42	-	32	1.8
2.3	22 March 1973 @ 00:55:52	-34.15	150.37	-	27	2.3
3.4	22 March 1973 @ 00:39:59	-34.18	150.33	-	12	3.4
2.7	21 March 1973 @ 16:51:19	-34.16	150.32	-	19	2.7
2.2	21 March 1973 @ 04:49:08	-34.18	150.35	-	15	2.2
1.7	20 March 1973 @ 22:56:56	-34.16	150.32	-	0	1.7
1.4	20 March 1973 @ 13:38:30	-34.21	150.32	-	0	1.4
2.1	20 March 1973 @ 12:52:09	-34.14	150.39	-	33	2.1
2.1	20 March 1973 @ 12:10:17	-34.16	150.36	-	25	2.1
2.1	20 March 1973 @ 02:46:30	-34.19	150.34	-	27	2.1
2.2	20 March 1973 @ 01:52:32	-34.16	150.38	-	27	2.2
2.1	19 March 1973 @ 19:39:43	-34.17	150.36	-	28	2.1

3.5	19 March 1973 @ 12:56:10	-34.19	150.33	-	16	3.5
1.6	19 March 1973 @ 11:48:13	-34.25	150.46	-	33	1.6
2	19 March 1973 @ 00:48:19	-34.17	150.37	-	28	2
1.7	18 March 1973 @ 19:30:01	-34.14	150.41	-	27	1.7
2.5	18 March 1973 @ 18:55:07	-34.17	150.37	-	21	2.5
2.2	18 March 1973 @ 11:48:56	-34.15	150.37	-	31	2.2
2.2	18 March 1973 @ 08:52:18	-34.15	150.34	-	21	2.2
1.9	18 March 1973 @ 07:29:57	-34.18	150.36	-	27	1.9
3.4	18 March 1973 @ 03:05:29	-34.16	150.36	-	24	3.4
1.8	18 March 1973 @ 02:33:56	-34.15	150.39	-	31	1.8
1.4	17 March 1973 @ 07:09:58	-34.15	150.37	-	17	1.4
2.7	17 March 1973 @ 02:05:40	-34.18	150.32	-	12	2.7
1.4	16 March 1973 @ 13:20:24	-34.15	150.37	-	30	1.4
2.1	16 March 1973 @ 12:44:27	-34.14	150.41	-	36	2.1
1.6	16 March 1973 @ 12:29:12	-34.16	150.37	-	30	1.6
1.6	16 March 1973 @ 12:12:35	-34.16	150.38	-	30	1.6
3.7	16 March 1973 @ 11:48:02	-34.17	150.34	-	27	3.7
1.4	16 March 1973 @ 11:19:59	-34.16	150.4	-	33	1.4

1.7	16 March 1973 @ 08:30:47	-34.13	150.29	-	34	1.7
2.6	16 March 1973 @ 08:04:04	-34.16	150.33	-	21	2.6
3	16 March 1973 @ 07:48:49	-34.17	150.34	-	18	3
2.7	16 March 1973 @ 04:09:04	-34.19	150.34	-	13	2.7
2.4	16 March 1973 @ 02:38:56	-34.16	150.35	-	26	2.4
1.9	15 March 1973 @ 23:03:18	-34.16	150.4	-	27	1.9
1.6	15 March 1973 @ 21:34:00	-34.18	150.42	-	20	1.6
2.7	15 March 1973 @ 21:30:02	-34.15	150.32	-	15	2.7
1.4	15 March 1973 @ 20:21:26	-34.12	150.41	-	33	1.4
1.6	15 March 1973 @ 20:18:18	-34.2	150.37	-	14	1.6
2.2	15 March 1973 @ 19:37:21	-34.18	150.36	-	26	2.2
1.7	15 March 1973 @ 04:49:08	-34.17	150.36	-	20	1.7
2.4	15 March 1973 @ 03:50:58	-34.17	150.37	-	19	2.4
1.4	15 March 1973 @ 01:18:43	-34.15	150.32	-	28	1.4
1.4	14 March 1973 @ 20:41:26	-34.16	150.37	-	29	1.4
3.2	14 March 1973 @ 19:55:34	-34.18	150.32	-	21	3.2
2.2	14 March 1973 @ 18:56:54	-34.18	150.37	-	18	2.2
3.9	14 March 1973 @ 16:06:02	-34.2	150.33	-	22	3.9

1.9	14 March 1973 @ 13:16:49	-34.16	150.35	-	23	1.9
2.4	14 March 1973 @ 11:57:12	-34.16	150.34	-	19	2.4
2.3	14 March 1973 @ 09:04:36	-34.16	150.37	-	24	2.3
2.2	14 March 1973 @ 05:30:12	-34.17	150.36	-	23	2.2
1.8	14 March 1973 @ 02:49:19	-34.17	150.32	-	20	1.8
2.1	14 March 1973 @ 02:01:18	-34.16	150.34	-	8	2.1
3.5	13 March 1973 @ 16:14:45	-34.16	150.34	-	24	3.5
2.3	13 March 1973 @ 16:13:56	-34.17	150.33	-	9	2.3
2.4	13 March 1973 @ 11:49:18	-34.16	150.36	-	22	2.4
2.7	13 March 1973 @ 09:07:02	-34.16	150.36	-	20	2.7
1.7	13 March 1973 @ 07:04:45	-34.16	150.36	-	7	1.7
2.1	13 March 1973 @ 06:26:39	-34.2	150.34	-	12	2.1
1.7	13 March 1973 @ 05:52:34	-34.17	150.39	-	23	1.7
2.7	13 March 1973 @ 03:03:42	-34.19	150.35	-	11	2.7
1.8	13 March 1973 @ 01:02:21	-34.18	150.33	-	14	1.8
1.8	13 March 1973 @ 00:45:46	-34.17	150.32	-	19	1.8
3.1	13 March 1973 @ 00:42:02	-34.18	150.35	-	12	3.1
1.7	12 March 1973 @ 23:16:56	-34.13	150.38	-	29	1.7

1.9	12 March 1973 @ 22:07:00	-34.17	150.32	-	15	1.9
1.8	12 March 1973 @ 18:25:22	-34.15	150.36	-	25	1.8
2.1	12 March 1973 @ 18:19:05	-34.16	150.37	-	28	2.1
2.9	12 March 1973 @ 17:14:31	-34.17	150.33	-	20	2.9
2.2	12 March 1973 @ 14:23:02	-34.16	150.37	-	23	2.2
2.9	12 March 1973 @ 13:36:17	-34.18	150.33	-	11	2.9
1.9	12 March 1973 @ 12:01:12	-34.17	150.37	-	22	1.9
2.5	12 March 1973 @ 11:51:09	-34.17	150.35	-	13	2.5
2.8	12 March 1973 @ 11:37:38	-34.17	150.33	-	10	2.8
1.6	12 March 1973 @ 11:21:13	-34.17	150.33	-	14	1.6
2.2	12 March 1973 @ 11:11:40	-34.16	150.32	-	17	2.2
1.7	12 March 1973 @ 09:43:09	-34.18	150.35	-	17	1.7
1.8	12 March 1973 @ 09:21:52	-34.21	150.31	-	11	1.8
1.9	12 March 1973 @ 07:09:39	-34.17	150.4	-	31	1.9
1.9	12 March 1973 @ 03:44:55	-34.16	150.35	-	16	1.9
1.9	12 March 1973 @ 02:45:21	-34.14	150.36	-	29	1.9
1.7	12 March 1973 @ 01:20:46	-34.16	150.36	-	27	1.7
2.2	12 March 1973 @ 00:50:29	-34.17	150.38	-	28	2.2

1.6	11 March 1973 @ 22:14:07	-34.18	150.35	-	23	1.6
2.7	11 March 1973 @ 21:56:59	-34.18	150.33	-	13	2.7
1.9	11 March 1973 @ 20:52:44	-34.18	150.35	-	11	1.9
2.3	11 March 1973 @ 20:42:37	-34.17	150.35	-	22	2.3
2	11 March 1973 @ 20:24:18	-34.18	150.35	-	18	2
2.1	11 March 1973 @ 19:25:00	-34.16	150.44	-	19	2.1
1.7	11 March 1973 @ 18:38:38	-34.17	150.34	-	24	1.7
2.1	11 March 1973 @ 16:24:59	-34.17	150.37	-	28	2.1
2	11 March 1973 @ 16:07:38	-34.18	150.36	-	23	2
2.9	11 March 1973 @ 15:36:13	-34.17	150.33	-	24	2.9
2.4	11 March 1973 @ 15:27:21	-34.17	150.35	-	13	2.4
3.1	11 March 1973 @ 13:09:22	-34.18	150.37	-	13	3.1
2.4	11 March 1973 @ 12:13:40	-34.18	150.34	-	21	2.4
2.3	11 March 1973 @ 11:16:25	-34.17	150.32	-	16	2.3
2.1	11 March 1973 @ 10:50:22	-34.18	150.35	-	21	2.1
2.4	11 March 1973 @ 09:26:12	-34.19	150.33	-	13	2.4
2.5	11 March 1973 @ 09:20:33	-34.15	150.37	-	29	2.5
2.2	11 March 1973 @ 08:25:59	-34.17	150.33	-	9	2.2

2.8	11 March 1973 @ 06:14:01	-34.16	150.35	-	12	2.8
2.2	11 March 1973 @ 04:43:21	-34.15	150.33	-	24	2.2
2.5	11 March 1973 @ 04:35:43	-34.18	150.33	-	13	2.5
3.1	11 March 1973 @ 04:04:12	-34.18	150.35	-	24	3.1
1.9	11 March 1973 @ 03:58:57	-34.17	150.36	-	24	1.9
2.6	11 March 1973 @ 03:56:02	-34.16	150.34	-	20	2.6
1.6	11 March 1973 @ 03:28:45	-34.12	150.39	-	22	1.6
1.6	11 March 1973 @ 03:24:38	-34.17	150.36	-	25	1.6
1.7	11 March 1973 @ 03:20:02	-34.15	150.36	-	25	1.7
2.1	11 March 1973 @ 02:39:19	-34.17	150.37	-	23	2.1
2.4	11 March 1973 @ 02:16:56	-34.17	150.32	-	17	2.4
2.5	11 March 1973 @ 02:01:43	-34.15	150.35	-	10	2.5
2.5	11 March 1973 @ 01:53:42	-34.17	150.34	-	14	2.5
2.1	11 March 1973 @ 00:57:13	-34.17	150.32	-	19	2.1
1.9	11 March 1973 @ 00:23:03	-34.16	150.34	-	16	1.9
3.1	10 March 1973 @ 23:29:47	-34.18	150.34	-	22	3.1
3.6	10 March 1973 @ 22:53:54	-34.16	150.34	-	26	3.6
3.3	10 March 1973 @ 22:53:10	-34.17	150.35	-	25	3.3

3.2	10 March 1973 @ 22:47:05	-34.17	150.35	-	26	3.2
1.7	10 March 1973 @ 22:09:02	-34.18	150.36	-	22	1.7
1.4	10 March 1973 @ 21:14:23	-34.19	150.34	-	14	1.4
2.7	10 March 1973 @ 20:58:54	-34.18	150.32	-	17	2.7
1.6	10 March 1973 @ 20:39:05	-34.18	150.32	-	12	1.6
1.6	10 March 1973 @ 20:32:47	-34.19	150.34	-	15	1.6
2.7	10 March 1973 @ 20:22:33	-34.19	150.33	-	12	2.7
2.2	10 March 1973 @ 20:18:11	-34.18	150.33	-	18	2.2
2.2	10 March 1973 @ 20:10:22	-34.18	150.38	-	26	2.2
1.4	10 March 1973 @ 20:07:45	-34.17	150.31	-	29	1.4
2.6	10 March 1973 @ 19:08:26	-34.18	150.33	-	17	2.6
2.9	10 March 1973 @ 18:20:21	-34.17	150.33	-	17	2.9
3	10 March 1973 @ 18:14:50	-34.19	150.34	-	20	3
2.2	10 March 1973 @ 18:02:10	-34.16	150.34	-	27	2.2
1.8	10 March 1973 @ 17:57:42	-34.16	150.36	-	28	1.8
1.8	10 March 1973 @ 17:42:44	-34.18	150.37	-	26	1.8
1.9	10 March 1973 @ 17:10:50	-34.17	150.35	-	22	1.9
1.7	10 March 1973 @ 17:10:06	-34.16	150.35	-	27	1.7

1.9	10 March 1973 @ 16:30:35	-34.16	150.37	-	24	1.9
1.9	10 March 1973 @ 16:08:55	-34.19	150.35	-	21	1.9
1.6	10 March 1973 @ 16:07:05	-34.21	150.38	-	13	1.6
2.5	10 March 1973 @ 15:20:44	-34.16	150.34	-	25	2.5
2.5	10 March 1973 @ 15:18:15	-34.17	150.32	-	19	2.5
1.8	10 March 1973 @ 15:17:14	-34.18	150.35	-	21	-
2	10 March 1973 @ 14:19:52	-34.18	150.32	-	13	2
3.5	10 March 1973 @ 14:11:37	-34.18	150.34	-	26	3.5
1.9	10 March 1973 @ 14:11:01	-34.16	150.38	-	26	1.9
1.9	10 March 1973 @ 14:06:18	-34.14	150.36	-	26	1.9
2.5	10 March 1973 @ 13:23:54	-34.17	150.34	-	13	2.5
1.8	10 March 1973 @ 13:18:50	-34.18	150.33	-	15	1.8
1.9	10 March 1973 @ 13:15:45	-34.17	150.34	-	24	1.9
1.4	10 March 1973 @ 13:09:46	-34.19	150.35	-	14	1.4
1.6	10 March 1973 @ 13:06:55	-34.19	150.33	-	8	1.6
2.4	10 March 1973 @ 12:56:41	-34.16	150.33	-	19	2.4
1.4	10 March 1973 @ 12:54:34	-34.16	150.37	-	27	1.4
1.7	10 March 1973 @ 12:50:43	-34.16	150.39	-	28	1.7

1.9	10 March 1973 @ 12:46:29	-34.17	150.36	-	23	1.9
2	10 March 1973 @ 12:20:40	-34.17	150.34	-	24	2
1.9	10 March 1973 @ 12:19:42	-34.15	150.35	-	25	1.9
1.8	10 March 1973 @ 12:16:09	-34.18	150.34	-	16	1.8
2.5	10 March 1973 @ 11:57:53	-34.17	150.34	-	16	2.5
1.7	10 March 1973 @ 11:54:41	-34.14	150.37	-	31	1.7
2.4	10 March 1973 @ 11:48:51	-34.17	150.33	-	19	2.4
2.4	10 March 1973 @ 11:21:49	-34.18	150.33	-	19	2.4
1.6	10 March 1973 @ 11:12:30	-34.19	150.34	-	11	1.6
1.6	10 March 1973 @ 11:10:03	-34.15	150.37	-	30	1.6
1.9	10 March 1973 @ 11:03:22	-34.17	150.35	-	23	1.9
2	10 March 1973 @ 11:01:10	-34.17	150.35	-	21	2
2.4	10 March 1973 @ 10:48:10	-34.17	150.35	-	22	2.4
1.7	10 March 1973 @ 10:39:19	-34.15	150.36	-	24	1.7
2	10 March 1973 @ 10:31:58	-34.17	150.35	-	14	2
1.9	10 March 1973 @ 10:30:41	-34.19	150.33	-	11	1.9
1.6	10 March 1973 @ 10:23:12	-34.17	150.33	-	13	1.6
2.4	10 March 1973 @ 10:16:04	-34.18	150.35	-	20	2.4

1.7	10 March 1973 @ 09:56:29	-34.16	150.37	-	18	1.7
1.6	10 March 1973 @ 09:54:58	-34.16	150.34	-	20	1.6
2.4	10 March 1973 @ 09:46:50	-34.17	150.34	-	20	2.4
2.6	10 March 1973 @ 09:36:28	-34.17	150.33	-	19	2.6
2	10 March 1973 @ 09:11:45	-34.2	150.33	-	8	2
1.8	10 March 1973 @ 09:02:48	-34.17	150.35	-	22	1.8
1.7	10 March 1973 @ 08:59:12	-34.14	150.36	-	22	1.7
1.9	10 March 1973 @ 08:54:36	-34.16	150.37	-	27	1.9
1.9	10 March 1973 @ 08:45:17	-34.19	150.33	-	14	1.9
2.8	10 March 1973 @ 08:32:22	-34.11	150.34	-	20	2.8
2	10 March 1973 @ 08:27:55	-34.14	150.33	-	12	2
1.8	10 March 1973 @ 08:20:37	-34.19	150.31	-	16	1.8
1.6	10 March 1973 @ 08:10:33	-34.14	150.38	-	27	1.6
2	10 March 1973 @ 08:06:12	-34.18	150.3	-	14	2
2.5	10 March 1973 @ 08:02:26	-34.18	150.32	-	15	2.5
1.6	10 March 1973 @ 07:57:17	-34.18	150.32	-	19	1.6
1.7	10 March 1973 @ 07:55:35	-34.18	150.34	-	17	1.7
2.1	10 March 1973 @ 07:50:10	-34.17	150.35	-	24	2.1

2	10 March 1973 @ 07:40:11	-34.18	150.34	-	16	2
2	10 March 1973 @ 07:29:43	-34.16	150.35	-	25	2
2.4	10 March 1973 @ 07:24:43	-34.16	150.33	-	25	2.4
2.6	10 March 1973 @ 07:17:05	-34.18	150.32	-	25	2.6
2.1	10 March 1973 @ 07:15:47	-34.16	150.34	-	25	2.1
3.4	10 March 1973 @ 07:01:10	-34.19	150.37	-	25	3.4
3.3	10 March 1973 @ 06:54:18	-34.17	150.36	-	4	3.3
2.6	10 March 1973 @ 06:45:12	-34.18	150.35	-	12	2.6
3.5	10 March 1973 @ 06:41:46	-34.16	150.32	-	12	3.5
2.2	10 March 1973 @ 06:29:55	-34.17	150.34	-	15	2.2
2.1	10 March 1973 @ 06:23:36	-34.17	150.32	-	12	2.1
1.7	10 March 1973 @ 06:19:59	-34.1	150.32	-	9	1.7
2.3	10 March 1973 @ 06:14:48	-34.18	150.34	-	14	2.3
3.2	10 March 1973 @ 06:12:12	-34.13	150.35	-	9	3.2
1.6	10 March 1973 @ 06:12:04	-34.17	150.35	-	23	1.6
3	10 March 1973 @ 06:06:28	-34.15	150.32	-	12	3
2.2	10 March 1973 @ 06:05:20	-34.15	150.32	-	10	2.2
2.1	10 March 1973 @ 06:02:53	-34.16	150.34	-	18	2.1

2.3	10 March 1973 @ 05:55:04	-34.2	150.35	-	22	2.3
3	10 March 1973 @ 05:53:47	-34.17	150.33	-	13	3
1.6	10 March 1973 @ 05:52:43	-34.19	150.38	-	21	1.6
2.7	10 March 1973 @ 05:50:59	-34.17	150.34	-	20	2.7
2.4	10 March 1973 @ 05:49:17	-34.16	150.32	-	12	2.4
1.6	10 March 1973 @ 05:47:10	-34.16	150.33	-	16	1.6
2.8	10 March 1973 @ 05:43:03	-34.16	150.34	-	25	2.8
2.3	10 March 1973 @ 05:41:35	-34.16	150.33	-	16	2.3
2.1	10 March 1973 @ 05:39:05	-34.18	150.37	-	2	2.1
1.8	10 March 1973 @ 05:36:43	-34.17	150.3	-	34	1.8
1.8	10 March 1973 @ 05:35:53	-34.15	150.35	-	24	1.8
2.1	10 March 1973 @ 05:35:19	-34.17	150.33	-	16	2.1
3.4	10 March 1973 @ 05:32:21	-34.18	150.35	-	15	3.4
2.5	10 March 1973 @ 05:31:30	-34.17	150.34	-	31	2.5
3.2	10 March 1973 @ 05:27:50	-34.18	150.34	-	16	3.2
3.7	10 March 1973 @ 05:21:59	-34.15	150.37	-	38	3.7
5.5	10 March 1973 @ 05:09:14	-34.17	150.32	Picton NSW	21	5.5
1.5	07 March 1973 @ 01:32:33	-33.91	150.35	-	0	1.5

1.8	16 February 1973 @ 15:16:37	-34.47	150.37	-	1	1.8
1.8	15 January 1973 @ 10:48:23	-34.49	150.37	-	5	1.8
1.9	15 August 1972 @ 17:10:00	-34.33	150.98	-	0	1.9
1.8	09 August 1972 @ 13:09:24	-34.3	151	-	0	1.8
1.8	03 August 1972 @ 15:08:30	-34.27	150.97	-	0	1.8
1.8	16 May 1972 @ 15:15:50	-34.38	150.88	-	0	1.8
2.1	13 May 1972 @ 15:40:46	-34.15	150.88	-	0	2.1
2.4	08 January 1971 @ 15:10:30	-34.15	150.83	-	0	2.4
3.1	19 October 1968 @ 03:51:12	-34.52	150.45	-	13	-
1.3	24 August 1963 @ 20:13:34	-34.54	150.65	-	0	1.3
1.8	29 March 1963 @ 16:30:00	-34.25	151	-	0	1.8
2.3	28 March 1963 @ 12:32:09	-34.25	151	-	0	2.3
2	27 March 1963 @ 19:36:20	-34.25	151	-	0	2
2	17 January 1963 @ 04:26:54	-34.54	150.45	-	0	2
3.2	10 July 1962 @ 16:44:05	-34.2	150.43	-	8	3.2
1.9	23 June 1962 @ 22:55:02	-34.12	150.42	-	0	1.9
2.3	27 April 1962 @ 11:31:57	-34.54	150.51	-	25	2.3
1.7	02 September 1960 @ 10:02:03	-34.17	150.3	-	10	1.7

1.2.3 Appendix 3.2 DGPS Survey Thirlmere Lakes

As part of the Committee's investigations it was necessary to obtain some topographic information on the lakes and their catchment, as a means of independently verifying data and to address some obvious data gaps.

A GPS[1] survey was the obvious solution to obtain the necessary data in a cost effective manner. The Committee had access to the necessary resources, although it is grateful for assistance from Macquarie University (Dr Arianna Traviglia of the Department of Ancient History, Faculty of Arts) and Ultimate Positioning (Scott Barling). NPWS provided access to CORSnet[2]© for post processing of the data.

Equipment and data collection

A Trimble 6000 series GeoXH© 3.5G GPS receiver was used, together with a Tornado© antenna, in most cases mounted 2m above ground level on a pole (for point readings). TerraSync© 6.2 was the software running on the GeoXH. Post-processing was undertaken with Pathfinder© 6.1. The narrowness of the valley of Blue Gum Creek prevented real-time correction because of lack of signal from the base station. The Cordeaux and Menangle CORSnet base stations were used during the survey period.

A data dictionary was developed for the project.

The configuration of the GPS for point collection was:

Co-ordinate System: UTM[3] Zone 56 South, Australian Height Datum (m). Datum GDA94

Accuracy setting for points: 10cm Horizontal

Satellite data was collected using GPS and GLOSNASS[4] as the base stations manage both satellite systems.

Point logging proceeded for 20-30 minutes, sufficiently long enough to collect several hundred readings for averaging to give a reasonable accuracy on location and height.

The HAE was corrected to AHD[5] using the AUSGeoid09 conversion within the GeoXH Terrasync software.

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[1] GPS is the US Global Positioning System. GNSS – Global Navigation satellite Systems includes GPS

[2] CORSnet – NSW network of Continuously Operating Reference Stations or base stations established to correct GNSS data

[3] UTM – Universal Transverse Mercator projection.
HAE is Height Above Ellipsoid.
GDA94 – Geocentric Datum of Australia 1994.

[4] GLOSNASS – GLObal Navigation Satellite System (managed by Russian Federation Government http://www.spaceandtech.com/spacedata/constellations/glonass_consum.shtml

A check on accuracy was undertaken by using as bench marks the elevation of piezometers from the piezometer survey of the Office of Water and comparing estimates of height obtained by the GeoXH (AHD). Comparisons are in the following table.

Errors were encountered with the DGPS survey in the heavily treed areas, particularly in the vicinity of the outlet piezometer on Nerrigorang and in Blue Gum Creek. These sites need to be resurveyed with a combination of optical and GPS. Insufficient time was available to recheck the readings.

Office of Water Piezometers	**GeoXH** **(m AHD)**	**Office of Water** **(m AHD)**	**Absolute Difference** **(m)**
Nerrigorang (concrete collar height)	307.905	307.81	0.095
Couridjah 100m	307.557	307.6	0.043
Ganangarra	307.428	307.34	0.088

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[5] AHD – Australian Height Datum. The AHD elevation does not correspond to the Ellipsoid height and, for those that like a bit of confusion, it does not exactly correspond to mean sea level around Australia.

Table All Lakes survey information (corrected)

Gandangarra					Easting	Northing	Ht (m AHD)	
Piezometer	OW piezo 075411	03/15/12	grd		274223.54	6211003.42	307.43	
Piezometer	col small	03/15/12	grd		273735.12	6210955.27	302.76	
Piezometer	piezo	03/15/12	grd		273824.23	6211083.37	301.67	
lake level	lake	near piezo	03/15/12		273814.78	6211080.44	302.35	
Werri Berri								
Point_generic	concrete top retain wall steps				273554.79	6210547.87	306.95	
Point_generic	on sand fan				273531.46	6210531.72	302.11	
lake level	weriberri	near boat area	03/15/12	grd	273520.87	6210519.23	300.48	
lake level	werriberri	in grass	03/15/12	grd	273542.69	6210488.80	300.57	
Piezometer	werriberripiezo	03/14/12	grd		273590.66	6209961.26	300.66	

lake level	werriberri	near piezo	03/14/12	grd	273591.87	6209967.22	300.46	
lake level	werrtiberri	west shore	03/14/12	grd	273544.36	6210095.87	300.45	
lake level	werriberri	east shore opp piezo	03/14/12	grd	273635.89	6209980.62	300.44	
lake level	werriberri	east shore	03/14/12	grd	273628.39	6210092.83	300.66	
Couridjah								
Piezometer	OW piezo 100m	03/14/12	grd		273768.98	6209568.51	307.56	
Piezometer	Couridjah piezo	03/14/12	grd at base		273685.47	6209272.79	301.31	
Point_generic	bmconc top step				273775.18	6209422.76	306.47	
Point_generic	top pells peg				273743.85	6209433.59	301.45	
lake level	water	near pells peg	03/14/12	grd	273743.32	6209434.41	301.14	
lake level	couridjah	west bank opp sand spit	03/14/12	grd	273668.91	6209385.34	301.32	
lake level	couridjah	south	03/14/12	grd	273719.50	6209225.65	301.23	
lake level	couridjah	east side opp piezo	03/14/12	grd	273756.05	6209291.92	301.24	
Baraba								
Bore hole	Gore's auger	2m		on track	273207.44	6209825.34	305.46	
lake level	baraba	nth edge	03/14/12	grd	273203.27	6209671.39	304.30	
Piezometer	baraba	03/14/12	grd		273205.49	6209640.10	304.00	
Nerrigorang								
lake level	nerrigorang	near piezo	03/14/12	grd	273038.95	6210499.65	298.79	
lake level	nerrigorang	east shore	03/14/12	grd	273099.15	6210448.29	298.86	
lake level	nerrigorang	west shore	03/14/12	grd	273011.90	6210464.01	298.83	
Piezometer	OW piezo 75410	03/14/12	concrete slab		273034.08	6210587.14	307.03	

Piezometer	nerrigorang	03/14/12	grd		273037.53	6210507.92	298.97	
Point_generic	nerrig outlet channel				272857.45	6210461.07	303.61	
Piezometer	outlet piezo	03/19/12	grd		272840.73	6210455.87	306.67 Optical survey – 304.2 to 304.4	Error?
Point_generic	centre crossing blue gum ck				272796.54	6210434.31	305.2 Optical survey corrected	Error?
lake level	pool u/s causeway	ck bed	03/19/12	grd	272810.93	6210433.65	304.13	Error?
Blue Gum Ck								
Piezometer	**Jurassic fence**	**03/14/12**	**grd**		**271128.79**	**6210307.49**	**291.15**	**Error?**
Piezometer	Jurassic piezo	03/19/12	grd		271128.54	6210309.03	291.84	Error?

1.3 Chapter 4

1.3.1 Appendix 4.1 Maidla rainfall data

There are some missing data in the file. Refer to Buxton.

Year	Day	Month												
1989		1	2	3	4	5	6	7	8	9	10	11	12	
	1	25	0	0	62	0	0	0	1	0	0	0	0	
	2	20	0	0	55	0.5	1	0	0	0	0	0	0	
	3	15	0	4.5	30	0.5	22	0	0	0	0	0.5	4	
	4	0	11	0	0	0	27	0	0	0	0	0	8	
	5	0	0	0	0	2	2.5	0	0	0	0	5.5	36	
	6	5	0	0	2.5	2.5	0	0	0	0	0	16	3	
	7	0	0	0	0	8.5	0	0	0	0	0	7	3.5	
	8	0	0	0	1	2.5	0	3.5	0	0	0	0	0	
	9	0	0	2.5	21	6	0	0	0	0	0	1.5	4.5	
	10	0	0	5.5	0.5	0.75	0	0	0	0	0	3	1.5	
	11	0	0	5	0.5	0	5	0	1	0	0	9.5	11	
	12	0	2.75	15	24	5	0	0	0	0	0	0	0	
	13	0	0	12	1.5	1.5	0	0	0	0	0	0	3.5	
	14	3	0	34	0	0	0.5	0	0	0	0	0	0	
	15	0	0	3	0	3	0	0	0	0	0	0.5	0	
	16	0	0	1	0.5	21	1	6	4.5	0	0	3.5	0	
	17	0	0	0.5	0	0	0.5	1.5	0	0	0	3.5	0	
	18	18	0	2	0	0	0	0	0	0	0	1	0	
	19	6	13	2	0	0	20	0	0	0	1.25	9	0	

	20	0	13	5	0	0	4.5	0	1	0	1	0	0	
	21	0	0	0	0	0	1.5	0	0	0	0	0	0	
	22	2	0	0	8.5	5.5	0.5	0	0	1.25	0.75	0	0	
	23	2.5	0	0	10	0	7	5.5	0	0	0	0	0	
	24	0	0	0.5	8	0	0	1.5	0	0	4.5	0	0	
	25	0	3	4	3	0	5	1	0	0	1	6	0	
	26	0	3.5	0	8	0	0	0	2	0	0	0	0	
	27	0	0	7	40	0.5	3	0	0	0	0	0	0	
	28	0	0	0	4	0	2.5	0	0	0	0	0	0	
	29	0		0	3.5	0	0	0	0	0	0	0	1.5	
	30	0		17	0	0	0	0	0	0	0	0	0	
	31	0		70		0		0	0		0		0	
Monthly total		96.5	46.25	190.5	283.5	59.75	103.5	19	9.5	1.25	8.5	66.5	76.5	961.25
Year	Day	Month												
1990		1	2	3	4	5	6	7	8	9	10	11	12	
	1	0	1	1	0	0	0	3	103	0	0	0	1	
	2	0	132	0	0	0	0	0	16	0	0	0	1	
	3	0	97	0	4	0	0	0	13	3.5	0	0	12	
	4	0	13	0	41	0	0	0	1	0	0	0	3.5	
	5	0	5	0	12	0	0	0	6.5	0	0	0	0	
	6	0	4	35	1	0	0	0	0	0	3	0	0	
	7	15	1	0	0	2	3	0	0	0	0	0	0	
	8	27	4	0.75	26	0	0	0	0	6.5	3	0	17	
	9	17	18	0	11	0	0	0	0.5	0	0	9	2	
	10	1	12	0	32	0	0	0	0	0	2.5	0	8.5	

	11	1	1	2	1.5	0	0	1	0	0	0	0	0	
	12	2.5	8	0	18	0	0	1	0	9	0	0	0	
	13	0.75	0	0.5	0.75	0	0	0.5	0	26	0	0	0	
	14	0	0	0	0	0	0	0	0	15	0	0	0	
	15	0	0	10	1	0	0	0	0	0	0	5	0	
	16	0	0	0.75	1.25	0	0	0	0	1.5	0	0	0	
	17	0	19	0	1	11	8	0	0	0	0	0	0	
	18	0	0.5	7.5	44	1	0	13	0	0	0	0	0	
	19	5	0	0	41	0	0	0	1.5	0	5	0	0	
	20	1.5	0	0.75	15	0	0	0	0	0	0	0	0	
	21	1.5	5	0	0	0	0	0	0.5	0	4	0	0	
	22	0	8	0	0	26	0	0	0	0	0.5	0	0	
	23	0	3	1.5	0	18	0	2.5	0	0	3	0	0	
	24	0	0.5	0	0	31	0	2.5	0	0	0	0	0	
	25	0	0	1.5	0	1	0	0	0	0	0	0	0	
	26	0	0.75	4	0.5	0	0	0	0	0	0	0	0	
	27	0	0	1.25	0	0	1	11	0	0	0	0	0	
	28	0	0	3	0	0.5	0	0	0	0	0	0	0	
	29	0		16	0	0.75	0	0	0	5	0	0	0	
	30	0		0	0	15	1.25	1	0	0	0	0	0	
	31	0		1.5		1		71	1		0		0	
Monthly total		72.25	332.75	87	251	107.25	13.25	106.5	143	66.5	21	14	45	1259.5
Year	Day	Month												
1991		1	2	3	4	5	6	7	8	9	10	11	12	
	1	0	0	0	0	0	0	0	0	0	0	0	0	

2	0	0	0	0	0	0	0.5	0	0	0	0	0	
3	0	0	0	0	0	0	2	0	0	0	8.5	4.5	
4	4	0	0	0	0	0	0	0	0	0	0	4	
5	0	5	0	0	0	1	3	3.5	0	4	0	0	
6	0	21	0	0	0	25	0	0	0	5	0	0	
7	0	0	0	0	0	26	0	0	0	0	0	0	
8	0	0	0	0	0	9	12	1.5	0	0	0	0	
9	0	0	0	0	0	110	7	0	0	0	0	0	
10	14	5.5	0	0	3	165	17	0	7.5	0	0	3	
11	4	5	0	25	0	0	0.5	0	2	0	0	3.5	
12	27	0	0	0	0	0	1	0	0.5	0	0	55	
13	0	0	0	0	0	0	1.5	0	0	0	0	73	
14	0	0	0	12	0	0	0	0	0	0	0	3.5	
15	0	17	0	0	0	0	0	0	0	0	0	0	
16	0	0	0	0	0	0	0	0	0	0	17	0	
17	2	0	0	0	0	0	0	0	0	0	0	0	
18	40	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	2	0	0	0	0	0	0	0	
20	0	1	1	0	11	0	0	1	0	0	0	0	
21	27	0	0	0	12	0	0	0	0	0	1	37	
22	4	12	0	0	0	0	10	0	0	0	0	4	
23	17	11	0	0	0	0	1	3.5	0	0	0	0	
24	0	0	0	0	0	0	0	0	0	0	0	0	
25	0	0	0	2.5	0	0	0	0	2	0	0	0	
26	0	1	0	0	0	0	0	0	3	4.5	1.25	0	
27	0	5	0	0	0	0	0	0	0	0	0	2	
28	0	0.5	0	0	0	0	0	0	0	0	0	0	

29	0		4.5	0	0	0	0	0	0	0	0	12	
30	0		6.5	0	2.5	0	0.5	0.5	0	0	0	0	
31	0		0		0		0	0		9		24	
Monthly total	139	84	12	39.5	30.5	336	56	10	15	22.5	27.75	225.5	997.75
Year Day	Month												
1992	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	0	0	0	0	0	0	0	0	0	2	0	
2	0	8	0	0	0	2.5	0	0	0	0	0	0	
3	5	0	3	3.5	1	0	0	0	3	0	0	2	
4	5	11	9	0	0	0	2	0	0	4	2.5	63	
5	0	1.5	0	0	0	0	0	2.5	0	0	12	3.5	
6	0	15	0	0	0	0	0	0	0	0	0.5	12	
7	0	6	0	5	1	0	0	0	0	0	0	4	
8	11	31	0	0	0	0	0	0	0	1	0	0	
9	9	96	0	0	0	0	0	0	2.5	0	1	0	
10	18	20	0	0	0	0	0	0.5	0	0	0	0	
11	0	0	0	0	1	0	0	0	4.5	0	0	0	
12	0	1.5	0	0	4	0	0	0.5	0	0	0	0	
13	1	0	0	0	0	0	0	0	0	0	0	18	
14	0	0	0	0	0	0	0	0	0	0	0	0	
15	0.5	0	0	0	0	0	0	0	0	0	0	0	
16	0	0	0	0	0	0	0	0	1	6.5	3.5	17	
17	0	0	0	1	23	1	4.5	0	0	4.5	8	0	
18	0	0	0	0	0	2	0	0	0	5	5.5	22	
19	0	0	0	0	0	0	1	0	0	0	2.5	0	

20	0	0	0	7	0	0	0.5	0	0	0	0	0	
21	0	0	9	0	10	0	0	0	0	0	11	5	
22	0	0	1.5	0	2.5	0	0	0	0	0	0	37	
23	16	45	0	0	0	0	0	0	0	0	0	20	
24	8	6.5	0	0	0	0	0	2	8	0	1	0	
25	0	0	1.5	0	0	8	0	0	0	7	0	1	
26	0	0	0	0	0	5	0	0	0	0.5	0	0	
27	0	0	0	20	0	0	0	0	0	0.5	0	0	
28	0	0	0	0	1.5	0	0	0	0	6.5	0	0	
29	0	0	5	0	0	1	0	4	1	3	9	0	
30	0		0	0	0	0	0	2.5	0	1.5	2	0	
31	0		0		0		0	0		15		0	
Monthly total	73.5	241.5	29	36.5	44	19.5	8	12	20	55	60.5	204.5	804
Year Day	Month												
1993	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	0	0	0	0	0	0	0	5	2.5	0	0	
2	0	2	0	0	0	0	0	0	0	1	19	1.5	
3	15	0	0	0	0	0	0	0	0	0	0	10	
4	0	0	0	0	0	0	0	0	0	0	0	15	
5	0	0	0	0	0	0	0	0	0	0	0	0.5	
6	1	2	7	0	0	0	0	0	0	0	0	0	
7	2	0	43	0	0	0	0	0	0	0	0	9	
8	0	0	32	0	0	0	0	0	2	0	0	0	
9	0	20	14	0	0	0	0	0	4.5	0	0	0	
10	0	0	1.5	0	0	0	0	0	0	0	0	0	

	11	0	13	11	0	0	0	0	0	0	0	0	0	
	12	1.5	3	10	0	0	0	0	0	2.5	0	4	0	
	13	0	2	2	0	0	0	0	0	50	0	10	27	
	14	0	0	0	0	0	0	0	0	3	0	0	0	
	15	0	0	0	0	0	0	0	0	2	19	0	0	
	16	0	17	3	1.5	0	0	0	0	0	15	0	0	
	17	0	2	12	0	0	0	0	0	0	0	19	0	
	18	18	0	9.5	0	0	0	0	0	0	4	0	0	
	19	0	0	0	0	0	0	0	0	1	0	18	0	
	20	0	8	0.5	0	0	0	0	0	0	0	12	1	
	21	16	18	4	0	0	0	0	0	0	0	0	6	
	22	0	0	0	0	0	0	0	0	0	0	0	0.5	
	23	16	0	0.5	0	0	0	0	0	0	0	0	0	
	24	2	0	0.5	0	0	0	0	0	0	3.5	55	0	
	25	0.5	0	23	0	0	0	0	0	0	0	0	0	
	26	1	0	1	0	0	0	0	0	0	0	0	0	
	27	2	0	0	0	0	0	0	0	0	0	0	0	
	28	0.5	0	0	7	0	0	0	0	0	0	1	0	
	29	0		0	0	0	0	0	0	0	0	0	0	
	30	0		0	0	0	0	0	0	0	0	0	0	
	31	0		0		0		0	0		0		0	
Monthly total		75.5	87	174.5	8.5	0	0	0	0	70	45	138	70.5	669
Year	Day	Month												
1994		1	2	3	4	5	6	7	8	9	10	11	12	
	1	0	8.5	1.5	9	0	0	0	0	0	0	18	0	

2	0	2.5	0	0	0	0	0	0	0	0	4	0	
3	0	0	0	0	0	0	0.5	0	0	0	0	0	
4	0	4.5	0	0	0	0	0	0	0	0	22	0	
5	0	1	0	0	0	0	0	0	0.5	0	0	0	
6	0	0	13	0	0	0	0	0	0	0	0	0	
7	0	23	4	0	0	45	0	0	0	2.5	0	0	
8	0	0	30	0	0	1	0	0	0	0	0	0	
9	0	1.5	13	0	0	1	0	0	0	0	0	26	
10	0	1	0	0	0	0	0	0	0	0	0	0	
11	0	110	20	0	30	0	0	0	0	0	0	0	
12	0	14	0	39	0	0	4	0	0	0	0	0	
13	2.5	3	0	12	0	0	0	0	0	0	1	0	
14	2.5	0	0	0.5	0	0	0	0	0	0	0	0	
15	1	12	0	0	0	0	0	0	0	0	0	0	
16	0	0	0	0	0	0	0	0	0	0	0	0	
17	9	0	0	0	0	0	0	0	0	0	2	0	
18	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	7	0	7	1	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	
22	6	0	0	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	0	0	0	0	0	0	0	2	
24	0	0	0	0	0	0	0	0	0	0	4	9	
25	0	0	0	0	0	0	0	0	0	0	10	12	
26	0	0	6	0	0	3.5	0	0	0	0	0	3.5	
27	0	24	0	0	0	1.5	0	0	0	0	0	0	
28	0	0	7	0	0	0	0	0	0	5	15	0	

	29	0		3	0	0	0	0	0	0	0	0	0	
	30	2		0	0	0	0	0	0	0	0	0	0	
	31	0		0		1.5		0	0		0		0	
Monthly total		23	205	97.5	60.5	31.5	52	4.5	7	0.5	14.5	77	52.5	625.5
Year	Day	Month												
1995		1	2	3	4	5	6	7	8	9	10	11	12	
	1	0	0	1	0	10	0	0	0	0	2	0	12	
	2	8.5	0	14	0	7.5	0	0	0	25	7	0	0	
	3	20	0	3	0	0	2	0	0	0	2	6	0	
	4	3.5	0	24	0	2	1	0	0	0	2	1.5	2.5	
	5	7	1.5	44	0	3.5	0	0	0	0	0	6.5	40	
	6	9	0	10	0	1	0	0	0	0	0	0	0	
	7	2	0	2	0	3	0	0	0	0	0	0	0	
	8	0.5	0	2	0	0	0	0	0	0	0	0	0	
	9	0	0	0	0	0	0	0	0	0	0	0	3	
	10	0	0	0	0	0	6	0	0	0	0	0	24	
	11	0	30	0	0	6.5	0	0	0	0	0	2.5	0	
	12	0	10	4	0	0	0	0	0	0	4	0	0	
	13	0	2.5	0	0	33	0	0	0	0	0	0	0	
	14	0	4	0	8.5	13	0	0	0	0	0	0	0	
	15	0	5	0	3.5	85	4.5	0	0	1	0	0	0	
	16	0	6	0	0	12	0	0.5	0	8	0	3.5	1	
	17	2	0	0	0	0	0	0	0	5	0	1	4.5	
	18	5.5	0	0	0	0	0	0	0	0.5	0	0	0	
	19	55	0	0	0	0	0	0	0	0	0	30	0	

20	57	0	0	0	0	0	0	0	10	13	12	0	
21	0	0	0	0	0	0	0	0	0	8	22	0	
22	2	12	0	0	0	0.5	0	0	0	0	16	0	
23	0	0	0	0	0	0	0	0	0	0	0	0.5	
24	0	0	0	0	0	0	0	0	115	0	0	0	
25	0	0	0	0	8	0	0	0	17	0	0	0	
26	0	0	0	0	0	0	0	0	0.5	0	15	9.5	
27	1	0	0	0	0	1	0	0	0	0	0	4	
28	5	4	5	0	0	0	0	0	0	3	0	1.5	
29	0		0	0	0	0	0	0	0	0	5.5	0	
30	0		0	0	0	0	0	0	0	0	11	3.5	
31	0		0		0		0	0		0		0	
Monthly total	178	75	109	12	184.5	15	0.5	0	182	41	132.5	106	1035.5
Year Day	Month												
1996	1	2	3	4	5	6	7	8	9	10	11	12	
1	3.5	0	0	0	5	6	0	0	0	4	0	0.5	
2	0	0	0	0	10	0	0	0	0	0	0	0	
3	4	1	1	0	25	0	0	0	0	0	0	0	
4	0	0	4	0	64	0	0	0	0	0	32	0	
5	25	0	0	0	58	0	7.5	0	0	0	0	0	
6	10	0	0	0	0	0	0	0	0	2.5	0.5	10	
7	1	0	16	0	0	0	0	0	0	12	0.5	1	
8	0	7	0	0	0	0	0	0	0	0	0	0	
9	0	0	0	0.5	0	0	0	0	0	0	0	0	
10	0	2	0	8.5	0	0	0	0	0	0	4	2.5	

	11	0	0	0	20	0	0	0	0	2	0	0	0	
	12	0	0	0	0	0.5	0	0	0	2	6.5	0	0	
	13	1.5	0	0	0	0	0.5	0	0	0	0	0	0	
	14	0	0	4	0	0	0	0	0	0	0	9	0	
	15	1.5	0	0	0	0	3	0	0	0	0	13	0	
	16	0	0	0	0	0	5	0	0	0	0	1	2.5	
	17	0	0	0	0	0	0	0	0	0	31	0	1	
	18	0	0	0	0	0	0	0	0	0	0	0	0	
	19	0	0	0	0	0	0	4.5	1	0	0	0	0	
	20	12	1	0	0	0	0	0	0	1	0	0	0	
	21	0	0	0	0	0	0	0	0	1	0	4	0	
	22	4	0	0	0	0	0	0	0	0	0	0	0	
	23	8	0	0	0	0	13	0	0	0	0	14	19	
	24	8	0	0	0	0	3	0	0	0	0	0	0	
	25	6	0	0	0	0	0	0	0	0	0	0	2	
	26	0	4	0	0	0	0	6	0	0	3.5	0	0	
	27	0	4	0	0	0	0	28.5	1	0	3.5	0	0	
	28	0	12	0	0	0	0	3.5	0	0	0	1.5	5.5	
	29	0	0	0	0	0	0	0	0	36	0	0	0	
	30	0		0	5.5	0	0	0	50	7	0	0	0	
	31	0		0.5		0		0	4		0		0	
Monthly total		84.5	31	25.5	34.5	162.5	30.5	50	56	49	63	79.5	44	710
Year	Day	Month												
1997		1	2	3	4	5	6	7	8	9	10	11	12	
	1	0	1	0	0	0	0	0	0	10	0	0	0	

2	1	0	53	0	0	0	0	0	6	0	0	0	
3	0	0	0	0	1.5	0	0	0	0	0	0	0	
4	0	0	1.5	0	0	0	0	4	0	0	6	0	
5	0	0	1	0	0.5	0	0	3	0	0	0	0	
6	3	0	7	0	0	0	0	0	0	3	0	0	
7	0	0	4	0	5	0	0	2	0	47	3	0	
8	0	0	1	0	0	0	0	0	0	0	0	9	
9	0	0	0	0	0	0	0	0	0	0	0	20	
10	0	5	0	0	0	0	0	0	0	0	0	0	
11	0	54	0	0	0	0	0	0	0	0	5.5	0	
12	0	17	0	0	0	0	0	0	0	0	2	0	
13	0	1.5	0	0	0	0	6	0	0	0	0	0	
14	0	2.5	0	0	0	0	0	0	0	0	7.5	0	
15	1	0	0	0	0	0	0	0	0	0	15	0	
16	0	0	3.5	0	30	0	0	0	1.5	0	0	0	
17	1.5	0	0	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	12	0	0	0	0	0	0	2	
19	0	0	0	0	2	0	0	0	12.5	0	0	0	
20	0	0	0	0	12	0	0	1.5	11	0	0	0	
21	0	0	0	0	2	0	0	0	3	0	0	0	
22	0	0	0	0	2	0	0	0	6	0	0	0	
23	11.5	0	7	0	6	0	0	0	25	0	0	0	
24	1	8	0	1.5	0	1.5	0	0	3.5	0	0	0	
25	11.5	1	0	0	0	87.5	0	0	3	0	0	0	
26	7.5	0	0	0	0	0	4.5	0	7	0	0	0	
27	0	0	0	0	0	5	0	0	0	4	0	0	
28	38	0	0	0	0	0	0	0	2.5	1	0	0	

	29	52		0	0	0	0	0	0	0	0	0	0	
	30	0		0	0	0	0	0	0	0	0	0	0	
	31	0		2.5		0		0	4.5		3		1	
Monthly total		128	90	80.5	1.5	73	94	10.5	15	91	58	39	32	712.5
Year	Day	Month												
1998		1	2	3	4	5	6	7	8	9	10	11	12	
	1	1.5	0	0	1	0	14.5	0	0	0	0	0	0	
	2	1	0	0	0	17	5	0	0	0	0	0	0	
	3	18	0	0	0	1.5	32	0	0	0	0	0	1	
	4	6	8	0	0	3.5	3	0	8	9	0	0	0	
	5	1	0	1	0	15	0	3.5	8	13	0	0	0	
	6	1.5	22	0	0	0	0.5	0	20	0	3	0	0	
	7	1.5	13	0	0	0	0	0	87	0	0	9.5	0	
	8	5	1	0	0	0	0	0	1	0	0	21.5	0	
	9	1	0	0	23	0	0	1.5	0	0	0	0	0	
	10	0	19	10.5	7	0	0	0	0	0	0	0	0	
	11	0	0	0	0	0.5	0	0	0	6.5	0	1	0	
	12	0	0	0	1	1	0	0	0	11	0	9	2	
	13	2.5	0	0	0	1	0	0	0	0	0	15	0	
	14	0	0	0	0	3.5	0	0	0	0	0	0	11.5	
	15	0	0	0	0	1	0	0	44	4	0	0	12	
	16	0	0	0	1.5	0	0	0	51	0	0	1	4	
	17	28	0	0	0	4	0	0	38	0	0	1.5	1	
	18	11	0	0	0	12	0	6.5	5	0	4.5	2	1	
	19	12	0	0	0	0	0	0	11	0	0	3	0	

20	0	1	0	9	0	0	21	2	0	0	0	0	
21	0	0	0	20	0	0	0	1.5	0	0	0	0	
22	0	1	0	13.5	0	53	0	0	0	0	0	0	
23	0	0	0	0	0	2	0	0	0	0	2	0	
24	0	0	2.5	0	0	0	4	2.5	1.5	0	5	0	
25	22	0	0	0	0	0	11	0	0	0	2.5	0	
26	9	0	0	0	0	0	10	0	0	0	14	0	
27	0	2	0	0	0	0	1	0	0	0	1	0	
28	0	0	0	0	0	0	0	0	0	0	0	0	
29	0		0	0	0	0	0	0	0	0	0	0	
30	0		0	0	0	2.5	0	0	0	0	0	0	
31	0		0		0		0	0		0		0	
Monthly total	121	67	14	76	60	112.5	58.5	279	45	7.5	88	32.5	961
Year Day	Month												
1999	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	30	0	2.5	7	0	42.5	0	0	6	0	0	
2	0	0	0	0.5	0	0	0	0	0	6	0	0	
3	0	2	0	0	0	0	0	0	0	18	0	0	
4	0	5	1.5	0	0	0	0	0	0	1	0	0	
5	0	0	0	0	0	0	0	0	0	0	0	0	
6	0	0	0	0	3.5	6.5	0	0	0	0	20	1.5	
7	0	0.5	5	0	3.5	0	0	0	0	0	1	0	
8	2.5	11	0	0	0	0	0	0	0	0	0	7.5	
9	0	0	0	0	0	5	0	2	0	0	0	12	
10	0	11	0	2	0	15	0	0	0	1	0	0	

11	0	3	0	0	0	0	7	0	0	1	5	0	
12	0	1	0	1	0	0	46	7	0	0	0	0	
13	0	0	0	0	0	0	48	0	0	0	0	0	
14	0	0	0	0	0	0	2.5	2	0	2	0	0	
15	0	0	0	0	0	0	4.5	0	0	0	1	0	
16	0	0	0	0	0	0	0	0	8	2	1	3	
17	0	0	2	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	0	0	1.5	0	0	28	0	3.5	
19	5	0	10	0	0	0	0	0	1.5	8.5	0	0	
20	0	0	1	0	0	0	2	0	2	0	0	0	
21	18	0	2.5	0	2.5	0	0	0	0	0	0	0	
22	8	5	0	2	8	2	0	0	6.5	0	5	0	
23	6.5	0	0.5	0	2	0	0	0	0	0	0	3	
24	0	0	0	0	0	0	0	0	1	109	0	48	
25	0.5	0	0	0	0	0	0	0	2	21	0	12	
26	0	0	0	0	0	2.5	0	6	21	0	0	6	
27	1	0	16	0	0	0	0	0.5	0	0	0	13.5	
28	7	0	0	0.5	0	0	0	8	0	0	0	5.5	
29	6		0	0	1	0.5	0	0	0	0	0	0	
30	1		0	2	0	5	0	0	0	30	0	0	
31	10		1		0		0	0		3		0	
Monthly total	65.5	68.5	39.5	10.5	27.5	36.5	154	25.5	42	236.5	33	115.5	854.5
Year Day	Month												
2000	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	0	0	6	3	0	0	0	6	0	8	1	

2	0	0	0	0	8.5	0	2.5	0	0	0	4	0	
3	0	0	0	0	5.5	0	6.5	0	0	0	6	0	
4	0	0	0	4.5	7.5	0	0	0	0	0	1	1.5	
5	0	0	0	0	0	0	0	0	0	0	0	4	
6	0	0	0	0	0	0	3	0	0	0	0	5.5	
7	0	0	22	0	0	0	0	1.5	0	0	0	0	
8	0	0	29	0	0	0	0	0	3	0	1	0	
9	0	0	7	0	0	0	0	0	1	20.5	0	0	
10	0	0	0	0	1.5	0	0	0	0	0	0	0	
11	0	0	0	0	0	0	0	0	0	0	0	17	
12	0	0	0	0	0	0	0	0	0	0	13.5	15	
13	0	10.5	2	0	0	0	0	5	0	9.5	22.5	0	
14	0	0	0	1.5	0	0	0	0	0	0	57	0	
15	0	0	7	0	0	0	0	0	0	0	31	0	
16	0	0	1	11	0	0	0	0	0	0	12.5	0	
17	0	0	0	0	0	0	1	0	0	0	9	0	
18	0	0	0	0	0	9	1	0	0	9.5	10	5.5	
19	0	0	13	0	0	2.5	0	0	0	0	1	0	
20	0	0	34	0	0	0	0	0	0	1	2	0	
21	0	0	13	0	0	2	0	0	0	0	0.5	0	
22	0	1.5	17	0	0	0	0	1	0	0	0	0	
23	0	0	10.5	0.5	0	0	0	0.5	0	0	1.5	0	
24	0	0	0	4	4.5	0	0	0	0	4	0	0	
25	0	0	0	1	0	0	2	0	3.5	0	0	0	
26	5.5	12.5	0	0	0	0	0	0.5	1	0	0	0	
27	4	0.5	0	0	0	2.5	3	0	22.5	0	0	0	
28	0	0	0	0	0	0	0	0	5.5	0	1.5	0	

29	0	1	0	0	0	26	0	0.5	0	0	0	0	
30	0		0	0	0	0	0	1	0	0	10.5	1	
31	12.5		0		0		0	0		4		2	
Monthly total	22	26	155.5	28.5	30.5	42	19	10	42.5	48.5	192.5	52.5	669.5
Year Day	Month												
2001	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	3.5	6.5	0	0.5	0	0	0	0	3	0	0	
2	0	8.5	3.5	1	0	0	3.5	0	5.5	47	0	0	
3	1	0	0	0	0	0	0	0	0	0	0	7	
4	0	45	1.5	0	0	0	0	0	0	0	0	0	
5	2.5	38	3.5	0	0	0	6	0	0	0	0	2	
6	0	8	7.5	0	0	0	0	0	0	0	27	0	
7	2	0	13.5	0	2	0	0	0	0	0	8	5	
8	0	0	3	0	1.5	0	0	0	3	0	0	0	
9	0	0	5	33	0	0	3	0	0	0	0	0	
10	0	2	0	0	0	3	20	0	15	12.5	0	0	
11	0	1	4.5	0	0	0	2	0	1	0	15.5	0	
12	0	0	13	0	0	0	6	0	0	0	0	0	
13	0	0	3	0	0	0	0	0	0	3	2.5	0	
14	0	0	0	0	0	0	0	2	0	0	2	0	
15	0	0	0	0	0	0	0	0	0	0	2	0	
16	0	0	6	0	0	0	0	0	0	0	0	0	
17	48.5	0	0	0	0	0	0	0	4.5	0	4.5	1	
18	3	0	0	0	0	0	0	0	0	0	5.5	0	
19	0	0	0	4.5	1	0	0	1.5	0	0	0	0	

20	0	13	0	19	0	0	0	0	9	0	0	0	
21	0	0	2.5	15	0	0	0	0	1.5	2	0	0	
22	0	0	0	5	5	0	0	0	0	0	0	0	
23	0	0	0	0	4	0	1.5	0	0	0	0	0	
24	0	0	0	0	0	0	3	0	0	0	0	1.5	
25	3	0	0	0	0	0	11	0	0	1	0	0	
26	4.5	0	0.5	0	0	0	18	21	0	0	0	0	
27	23	1.5	0	0	0	0	3.5	12	0	0	0	0	
28	2.5	6	0	0	2.5	0	0	3	0	0	0	0	
29	0		4.5	1.5	0	0	0	0	0	0	0	0	
30	4		0	1	0	0	0	0	0	0	0	0	
31	22		0		0		0	0		0		0	
Monthly total	116	126.5	78	80	16.5	3	77.5	39.5	39.5	68.5	67	16.5	728.5
Year Day	Month												
2002	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	13.5	0	0	0	0	0	0	0	0.5	0.5	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	26	4	0	0	0	0	14.5	2.5	0	0	0	
4	0	70	0	0	0	0	0	0	0	0	0	0	
5	0	29	0	0	1	0	0	0	0	0	0	0	
6	22.5	26	2	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	4	0	0	0	0	0	0	
8	0	0	0	0	0	0	0	0	0	0	0	0	
9	0	0	0	0	0	0	0	0	0	2.5	0	20	
10	0	2	0	10	0	0	0	0	0	0	1	0	

11	0	0	2	0	0	0	0	0	0	0	0.5	0	
12	0	0	0	0	0	0	0	1.5	0	0	1	0	
13	0	0	0	0	0	0	0	0	0	0	1	0	
14	0	0	0	8	1.5	0	0	0	0	0	0	0	
15	16	0	0	0	0	0	0	0	2	0	0	0	
16	1.5	6	0	0	2.5	0	0	0	5	0	0	0	
17	0	7.5	0	10	0	0	0	0	0	0	0	1.5	
18	0	30	0	0	0	7.5	10	0	0	0	0	0	
19	0	0	0	0	0	1	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	
21	1	0	0	5.5	0	0	0	0	0	0	1	0	
22	0	0	0.5	3	0	0	0	0	0	0	0	0	
23	0	0	0	0	1	0	0	1	0	0	0	1	
24	3	0	0	0	6	0	2.5	1	0	0	0	0	
25	1.5	25	0	0	0	0	0	0	0	0	0	1	
26	0	2	17.5	0	0	0	0	0	0	0	0	3.5	
27	0	0	17	0	4	0	0	0	0	0	1	3.5	
28	0	0	0	0	18	0	0	0	0	0	0	0	
29	1.5		23.5	0	0	0	0	2	0	0	7	0	
30	0		0.5	0	0	0	0	0	3.5	0	5	0	
31	2.5		0.5		0		0	0		0		10	
Monthly total	49.5	237	67.5	36.5	34	12.5	12.5	20	13	3	18	40.5	544
Year Day	Month												
2003	1	2	3	4	5	6	7	8	9	10	11	12	
1	17.5	1	0	0	0	13.5	0	0	0	10.5	0	2.5	

2	0	1	0	0	0	2	2	0	0	9	1.5	4	
3	0	3	1.5	0	0	0	0	0	0	0.5	0	16	
4	4	0	0	0	0	0	0	0	0	0	0	0.5	
5	0	0	0	0	0	0	0	4	0	19	0	0	
6	0	0	1.5	0	0	0	0	0	0	6.5	0	0	
7	0	0	0	0	0	0	0	0	0	5	0	0	
8	0	0	0	0	0	0	0	0	0	0	0	0	
9	0	0	3.5	0	0	0	2.5	0	0	0	0	0	
10	4	23	3.5	0	2	0	0	1	0	0	0	0	
11	3.5	0	24	2	0	0	0	1	3	0	0	0	
12	0	3.5	6	0	6	8.5	0	0	4.5	0	3	15.5	
13	0	0	0	4	30	0	0	1.5	0	0	1	0	
14	0	0	0	0	19	0	0	0	1.5	0	0	0	
15	0	0	5	0	46	0	2	0	0	0	0	0	
16	0	3	1	0	16	0	0	0	0	2	3.5	0	
17	0	0.5	0	0	2.5	0	1	0	0	0	1	0	
18	0	6	0	0	0	0	0	0	0	23	0	0	
19	0	1	0	0	0	0	0	0	0	7	0	0	
20	0	14.5	0	0	0	3.5	0	0	0	0	12.5	4	
21	0	35	0	0	0	0	0	0	0	0	16	0	
22	0	21	0	0	0	0	0	1	0	0	14.5	0	
23	0	12.5	0	0	0	0	3	29	0	0	2.5	0	
24	0	0	0	1.5	21	0	0	0	0	0	2.5	0	
25	0	1	0	7	5	7	0	0	0	12	0.5	0	
26	0	0	0	8.5	2	0	0	0	0	0	0	0	
27	0	1	0	67	1.5	0	0	0	0	0	0	0	
28	0.5	0	5	0	0	3	0	0	0	1	0	0	

	29	0		1	0	0	0	0	0	0	0.5	0	0	
	30	0		0	0	0	0	0	0	0	0	0	0	
	31	0		2		0		0	0		1.5		0	
Monthly total		29.5	127	54	90	151	37.5	10.5	37.5	9	97.5	58.5	42.5	744.5
Year	Day	Month												
2004		1	2	3	4	5	6	7	8	9	10	11	12	
	1	0	0	0	0	0	0	0	1	0	34	0.5	0	
	2	0	0	0	0	0	0	0	2	0	0	7.5	0	
	3	1.5	0	0	0	0	0	0	0	0	0	1.5	1	
	4	4	0	0	39	0	3	0	0	8.5	0	12	0	
	5	0	0	0	6.5	0	0	0	0	11.5	0	9	1	
	6	0	4	16	0	0	0	0	0	0	0	0	7	
	7	0	0	8	0	0	0	0	0	6.5	0	5	6	
	8	0	4	0	0	0	0	0	0	0	0	0	5	
	9	0	1	0	0	0	0	0	0	0	0	2	0	
	10	0	0	0	0	0	1	0	0	0	0	10.5	60	
	11	0	8.5	0	0	0	0	30.5	0	0	0	0	2.5	
	12	6	0	4	0	0	0	3	0	0	0	0	24	
	13	2	0	0	0	0	0	0	1	0	0	0	0	
	14	0	0	0	0	0	0	0	0	0	2	0	0	
	15	0	0	0	0	0	0	0	0	0	0	0	0	
	16	13	0	0	0	0	0	0	3	0	0	0	0	
	17	0	0	0	0	0	0	5	13	0	6	0	0	
	18	0	0	0	0	0	0	0	0	0	10	0	0	
	19	0	0	0	0	0	0	0	0	17	3	0	0	

20	0	0	0	0	0	0	0	0	0	39	5	0	
21	2	2	18	0	0	0	0	0	0	23	0	0	
22	10	4	0	0	0	0	0	0	0	5	0	3	
23	14	0	0	0	0	0	0	0	0	0	0	8	
24	0	0	0	0	0	0	0	0	0	20	0	5	
25	0	2	0	0	11	0	1.5	0	0	0	0	0	
26	0	10	0	0	0	0	0	0	0	0	0	0	
27	0	0	0	4	0	0	0	0	2.5	0	0	0	
28	0	0	0	1	0	0	0	0	1	0	0	0	
29	0	0	0	15	0	0	0	6	9.5	0	0	0	
30	0		0	0	0	0	0	2	23	0	0	0	
31	2		0		0		0	0		0		0	
Monthly total	54.5	35.5	46	65.5	11	4	40	28	79.5	142	53	122.5	681.5
Year Day	Month												
2005	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	90	3	0	0	0	0	0	0	0	10	3	
2	3	20	1	0	0	0	0	0	0	0	0	29	
3	5	0	9.5	0	0	0	0	0	11	0	0	0	
4	0	0	0	7.5	0	0	0	1.5	1	0	8	0	
5	0	0	0	1	0	0	0	0	0	0	1.5	0	
6	0	0	0	0	0	0	0	0	0	0	0	5	
7	0	0	0	0	0	0	0	0	0	10	30	0	
8	0	0	0	0	0	0	7	0	0	0	0	0	
9	0	6	0	0	0	0	2.5	0	0	0	0	0	
10	0	3	0	2	0	3	0	1	7.5	0	4	0	

	11	0	0	0	1.5	0	2	0	0	0	0	0	0	
	12	0	0	0	1	1.5	0	3	0	0	0	0	0	
	13	0	0	0	0	0	2.5	0	0	0	2.5	0	0	
	14	2	0	0	0	0	0	0	0	0	0	0	0	
	15	2.5	1	0	0	0	0	0	0	0	0	4.5	0	
	16	0	0	8.5	0	0.5	0	0	0	6.5	12.5	0	2	
	17	9	1	1	0	0	0	0	0	2.5	0	0	0	
	18	0	0	0	0	0	0	0	0	0	2	0	0	
	19	0	8.5	0	0	0	1	0	0	0	8	0	0	
	20	0	35	0	0	0	0	0	1.5	1	6.5	3	0	
	21	25	2	0	0	0	0	0	0	1	7.5	0	0	
	22	0	0	0	0	0	0	0	0	0	7.5	4	0	
	23	18	0	0	0	0	3.5	0	0	0	0	0.5	0	
	24	2	0	0	0	1	1.5	0	0	0	15	4.5	0	
	25	0	0	0	0	0	2.5	0	0	17	0	16.5	0	
	26	2	1	0	0	0	2	0	0	12	0	12	0	
	27	1	0	0	0	0	4	0	0	0	0	11.5	0	
	28	2	0	0	0	0	2	0	0	0	0	39	0	
	29	0		34	0	0	30	0	0	0	0	32	0	
	30	3.5		0	0	0	80	0	0	0	41	9	0	
	31	0		0		0		0	0		64		0	
Monthly total		75	167.5	57	13	3	134	12.5	4	59.5	176.5	190	39	931
Year	Day	Month												
2006		1	2	3	4	5	6	7	8	9	10	11	12	
	1	0	5	1.5	0	1	1	0	0	0	0	0	1	

2	7	0	0	0	0	10	0	0	0	0	9	17	
3	0	0	0	0	0	0	4	0	0	0	6	0	
4	4	0	0	0	0	0	4.5	4	0	0	2.5	0	
5	6	0	0	0	0	5	0	4.5	0	0	8	0	
6	4.5	0	0	0	0	0	0	0	35	0	1	0	
7	2.5	0	0	0	1.5	0	0	0	1	0	1.5	0	
8	0	0	0	0	0	0	0	0	0	0	0	0	
9	0	0	0	0	0	2	0	0	13.5	0	0	0	
10	0	0	0	0	0	23	0	0	6	0	2	0	
11	26	0	0	0	0	0	0	0	3.5	0	0	5	
12	0	1	0	0	0	0	0	0	0	0	0	0	
13	0	0.5	0	0	0	0	0	0	0	0	2	0	
14	3	2	1.5	0	0	0	2	0	0	0	0	0	
15	4	6.5	1	0	1	0	9	3	0	0	0	11	
16	41	0	0	0	0	0	0	0	0	0	0	0	
17	46	0	0	0	0	0	4	0	0	6	0	0	
18	13	2.5	0	0	0	0	2	0	0	0	0	0	
19	9.5	0	0	0	0	0	0	0	0	0	0	7	
20	0	0	0	0	0	3	0	0	0	0	0	0	
21	0	0	1	0	0	5	0	0	0	0	0	0	
22	0	0	2.5	0	0	0	1	0	0	0	0	0	
23	0	0	3.5	0	1	3	2	0	0	0	1	7	
24	0	0	1.5	0	0	0	9.5	0	0	0	0	6.5	
25	0	0	0	0	0	0	1.5	3	0	0	0	0	
26	0	8	0	0	0	0	0	0	0	0	0	0	
27	0	0	0	0	0	0	0	0	0	0	0	0	
28	0	0	0	0	0	0	0	0	0	0	0	0	

29	0		0	0	0	0	0	0	0	0	0	4	
30	0		5	0	7.5	2	0	3.5	0	0	0	0	
31	0		0		0		0	0		0		0	
Monthly total	166.5	25.5	17.5	0	12	54	39.5	18	59	6	33	58.5	489.5
Year Day	Month												
2007	1	2	3	4	5	6	7	8	9	10	11	12	
1	18	0	4	0	0	0	0	0	0	0	0	0	
2	2	3	0	0	0	0	0	0	0	0	0	0	
3	2	0	0	0	0	0	0	0	0	0	35	24	
4	0	0	6	0	0	0	0	0	0	0	0	0	
5	0	0	16	0	0	0	0	0	10	0	0	0	
6	0	0	8	0	0	0	0	0	5	0	0	0	
7	0	5	0	4	0	0	0	0	0	0	10	0	
8	0	0	0	0	1	0	0	0	14	0	16	0	
9	0	0	18	0	0	64	10	0	2	0	12	0	
10	0	106	0	0	0	0	0	0	14	0	5	0	
11	0	70	0	0	0	6	0	0	0	0	0	12	
12	0	21	2	0	0	0	0	0	0	0	0	6	
13	0	1	0	0	0	46	0	0	0	0	0	0	
14	0	0	0	0	0	48	0	0	0	0	0	0	
15	0	0	0	0	0	18	0	0	0	0	0	0	
16	0	0	0	0	0	4	0	0	0	0	0	30	
17	0	0	0	0	0	0	0	0	0	0	0	1	
18	0	0	0	0	36	24	0	0	0	0	0	0	
19	0	52	0	0	2	0	0	45	0	0	0	0	

20	0	0	0	0	0	0	0	8	0	0	0	7	
21	0	0	0	0	0	0	0	3	0	0	12	6	
22	0	5	0	10	0	0	0	5	0	0	6	0	
23	0	0	0	2	0	0	0	4	0	0	2	0	
24	8	14	0	5	0	6	0	3	0	0	2	0	
25	0	1	2	3	0	0	0	0	0	0	0	0	
26	0	7	16	7	0	0	0	0	0	0	10	0	
27	0	2	0	3	0	20	0	0	0	0	0	0	
28	0	13	0	1	0	0	0	0	0	0	0	0	
29	0		0	0	0	0	0	0	0	0	0	0	
30	0		0	0	0	0	0	0	0	0	2	0	
31	0		0		0		0	0		0		0	
Monthly total	30	300	72	35	39	236	10	68	45	0	112	86	1033
Year Day	Month												
2008	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	0	0	0	0	6	0	2	0	0	0	0	
2	0	0	0	0	0	11	0	0	8	0	0	0	
3	4.5	0	0	0	0	42	0	0	8	5	0	0	
4	1	30	0	0	0	9	0	0	1.5	13	0	0	
5	0	94	0	0	0	0	0	2	33.5	0	0	0	
6	0	33	0	3	0	0	0	0	1.5	0	0	0	
7	0	17	7	3	0	1.5	4.5	1	0	0	0	0	
8	0	23	0	0	0	0	1.5	0	0	0	0	0	
9	0	4	0	0	0	0	0	0	0	0	0	0	
10	0	0	0	0	0	5	0	0	0	0	0	4.5	

11	0	0	0	0	0	3.5	0	0	0	1.5	0	8.5	
12	0	0	0	0	0	1	0	0	0	0	0	64	
13	0	0	0	0	0	0	3	0	0	13	0	0	
14	0	0	0	3	3	0	0	0	0	0	13	0	
15	14.5	0	0	3	0	0	0	0	0	0	0	0	
16	13.5	0	0	1	3	0	0	0	0	0	0	0	
17	0	2	0	4	0	0	0	0	0	0	0	0	
18	30	0.5	0	3.5	0	0	0	1	0	0	8	1	
19	12	0.5	0	4	2	3.5	0	0	0	0	17.5	0	
20	0	0	3.5	4	0	0	7	0	0	4	0	0	
21	3	10	2.5	0.5	0	0	0	0	2	0	0	0	
22	0	0	4	5	0	0	0	6	0	8	3	0	
23	0	0	1	2	0	0	0	0	0	0	0	0	
24	0	0	8.5	6	0	0	0	0	0	0	0	1	
25	0	0	9	0	0	0	0	0	0	0	2.5	1	
26	0	35	0	0	0	0	0	0	4	0	2	0	
27	0	10	0	2	0	0	3.5	0	0	0	0	11	
28	0	0	0	2.5	0	0	1	0	0	6	0	0	
29	0	0	0	1	0	0	0	0	0	1.5	0	1	
30	0		0	0	0	0	0	8.5	0	1	0	0	
31	26		0		0		0	1.5		0		0	
Monthly total	104.5	259	35.5	47.5	8	82.5	20.5	22	58.5	53	46	92	829
Year Day	Month												
2009	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	0	1	33	0	0	0	0	0	0	0	0	

2	0	0	0	10	0	2	0	0	0	12	4		
3	0	0	0	11	0	9.5	0	0	7.5	4	1.5		
4	0	0	0	0	0	0	0	0	0	4	2		
5	0	0	0	0	0	0.5	0	0	0	9.5	5		
6	0	0	0	0	0	3	0	0	0	3	8		
7	0	0	0	0	0	0.5	0.5	0	3	0	2		
8	0	0	1.5	0	0	0.5	7	0	0	0	1		
9	0	0	2	0	0	0	4.5	0	0	0	0		
10	0	1.5	0	0	0	0	0.5	0	0	3	0		
11	4.5	1.5	0	5	0	0	0	4	0	0	0		
12	0	1	7.5	0	0	0	0	0	0	0	0		
13	0	8.5	1.5	9	0	0	0	0	0	0	0		
14	0	0	1.5	0	0	0	0	0	0	0	0		
15	1.5	25	0	0	0	1	0	0	0	2	0		
16	0	17	0	0	0	0	0	0	0	0	0		
17	0	7	0	0	0	1	0	0	0	0	0		
18	0	11	0	0	3	3.5	0	0	0	0	0		
19	0	1.5	0	0	24	0.5	0	0	0	0	0		
20	0	2	0	2	23	5	0	0	0	0	0		
21	2	1	0	4.5	10	7.5	0	0	0	0	3.5		
22	0	1.5	5	2	30	0	0	2.5	6.5	0	0		
23	19	0	2	0	0	0	0	0	1	0	0		
24	0	1.5	0	2	0	1.5	0	0	0	0	0		
25	0	0	15	0	0	0	0	0	0	10.5	0		
26	4	0	0	0	0.5	0	9.5	0	1	0	0		
27	0	0	0	0	5.5	0	0	0	0	1	0		
28	0	5	0	0	0	1	0	0	0	9	0		

29	0		0	0	0	0	0	0	0	0	0		
30	0		8	0	1	0	0	2	0	0	18		
31	0		24		0		0	0		0			
Monthly total	31	85	69	78.5	97	37	22	8.5	19	58	45	0	550
Year Day	Month												
2010	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	2	0	0	0	0	0	2	0	20	44	16	
2	0	10.5	0	0	0	20	2.5	5	4	20	0	1	
3	10.5	23	0	0	0	17.5	0	0	14	19	4	3	
4	0	25	1	0	1	1	0	0	7	0	0	10	
5	1	39	1.5	0	2	0	4.5	0	0	0	3	12	
6	0	6.5	0	2.5	0	0	0	0	0	0	0	11	
7	0	21	0	1	0	0	0	0	0	0	0	1	
8	0	4	0	0	0	0	0	0	0	0	30	4	
9	0	0	0	0	0	0	1	0	1	0	0	0	
10	0	0	0	0	0	0	1	12	2	0	12	3	
11	0	3	0	0	0	0	0	9	0	6.5	4	0	
12	0	22.5	0	0	0	0	0	0	0	0	0	0	
13	0	14.5	0	0	0	0	5	0	0	0	0	0	
14	3	15	0	0	0	0	0	0	25	0	7	0	
15	1	1	0	0	0	0	0	1	0	0	11	0	
16	5.5	0.5	0	0	0	0	0	0	0	1	0	13	
17	0	0	0	0	0	0	0	0	0	3	0	0	
18	0	0	0	0	0	0	0	11	0	0	0	1	
19	0	0	0	0	0	0	0	0	0	0	0	6	

20	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	3	0	0	0	0	0	0	0	
22	2	0	0	0	0	0	0	0	1	0	0	0	
23	0	0	0	0	0	2	0	0	0	18	0	0	
24	0	0	0	0	4	6	8	0	0	6	0	0	
25	0	0	0	6	1	0	12	0	0	0	0	8	
26	0	0	0	1	40	0	0	0	0	0	0	5	
27	2	0	0	0	8	0	0	0	0	0	0	0	
28	6.5	9.5	0	0	3	0	39	0	0	0	23	0	
29	0		13.5	0	9	0	0	0	0	0	17	0	
30	1		22.5	0	7	0	0	0	0	0	35	0	
31	2.5		0		6		5	0		0		0	
Monthly total	35	197	38.5	10.5	84	46.5	78	40	54	93.5	190	94	961
Year Day	Month												
2011	1	2	3	4	5	6	7	8	9	10	11	12	
1	2.5	0	1	1	0	1	1	0	0	7	0	0	
2	6	0	0	0	4	0	0	0	0	0	5.5	0	
3	0	8	2	0	0	0	0	0	0	0	1.5	2.5	
4	0	1	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	2	0	0	0	0	0	0	0	0	
6	0	0	0	0	0	0	0	4	4	4.5	0	0	
7	17	0	0	0	0	0	0	0	0	1	18	17.5	
8	5	0	0	0	0	0	0	0	0	10	3.5	12	
9	11	0	0	0	0	0	0	0	2	0	1.5	0	
10	8	0	1	4	0	0	0	0	1.5	0	0	0	

11	28	9	4	0	0	0	0	1	0	0	0	14	
12	0	6	0	0	0	0	0	0	0	0	0	8	
13	0	0	4.5	0	0	5	0	0	0	0	0	0	
14	4	1	0	0	0	8	0	0	0	3	0	0	
15	0	2	3.5	0	0	9	6	0	0	0	0	0	
16	0	6	15	0	0	0	1	0	0	0	14	0	
17	0	0	0	0	0	0	0	17	0	0	0	0	
18	0	0	2	0	0	1	1	3	0	0	0	1.5	
19	0	0	37	0	0	0	9	10	0	0	0	15.5	
20	0	0	38	3	0	0	1	1	0	0	3	0	
21	0	0	41	0	0	0	8	0	0	0	1.5	5	
22	0	0	1	0	6.5	0	3	0	0	0	30	0	
23	3	0	0	0	0	0	0	0	1	0	8	0	
24	0	0	0	1	2.5	0	1	0	15	0	24	0	
25	0	0	0	9	0	0	0	0	3.5	3	77	0	
26	0	2	0	0	0	0	0	0	0	8	1	1	
27	0	5	2	0	0	0	0	0	0	2	0	0	
28	0	1	0	3	0	0	0	0	0	1	0	0	
29	0		0	4.5	4	3	0	0	10	1	0	0	
30	0		0	1	21	0	0	0	0	0	2.5	0	
31	0		2		17.5		0	0		0		0	
Monthly total	84.5	41	154	28.5	55.5	27	31	36	37	40.5	191	77	803
Year Day	Month												
2012	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	6.5	8	21.5		1							

2	0	30	12.5			1							
3	0	11	12			29							
4	0	0	7.5			1							
5	0	0	1			10							
6	0	0	1			0.5	2						
7	3.5	7.5	30										
8	0	1	7										
9	5	36											
10	0	9				3.5	12.5						
11	2	17				17							
12	0	1				1	2.5						
13	2.5	13				1.5							
14	5	0											
15	0	5											
16	2	13	40.5			16.5							
17	2	0	1	26.5									
18	0.5	0	2	73									
19	0.5	30	0.5	1				1					
20	2.5	5						10					
21	2	0		6.5			2.5						
22	4	8	3	2.5									
23	1	0	0.5	3									
24	0	0		3.5	15								
25	35	0	0.5										
26	20	3	2.5				5						
27	0	0	6				1						
28	1	4.7	1										

29	2	43	1										
30	1												
31	1.5												
Monthly total	93	243.7	137.5	137.5	15	82	25.5	11	0	0	0	0	745.2

1.3.2 Appendix 4.2 Picton rainfall data analysis

Reliability of Picton Rainfall Data

Meteorological station Picton (station 068052, Bureau of Meteorology) has the longest period of rainfall data in the vicinity of Thirlmere Lakes. The station has rainfall records extending from 1/1/1880 to the present day. However, the record is not complete. Approximately 9% of the daily rainfall data for the period are missing, with a large gap in recordings in the 1980's and 1990's.

The missing data for Picton can be estimated using the SILO Patched Data Set for the Picton rainfall station (http://www.longpaddock.qld.gov.au/silo/). However, the SILO data only begins from 1/1/1889.

A comparison of the measured monthly rainfall for Picton and estimated SILO patched rainfall data shows some differences. The positive values indicate the SILO estimate of rainfall for a particular month is larger than the Picton station measurement of rainfall for the same month (Fig 1).

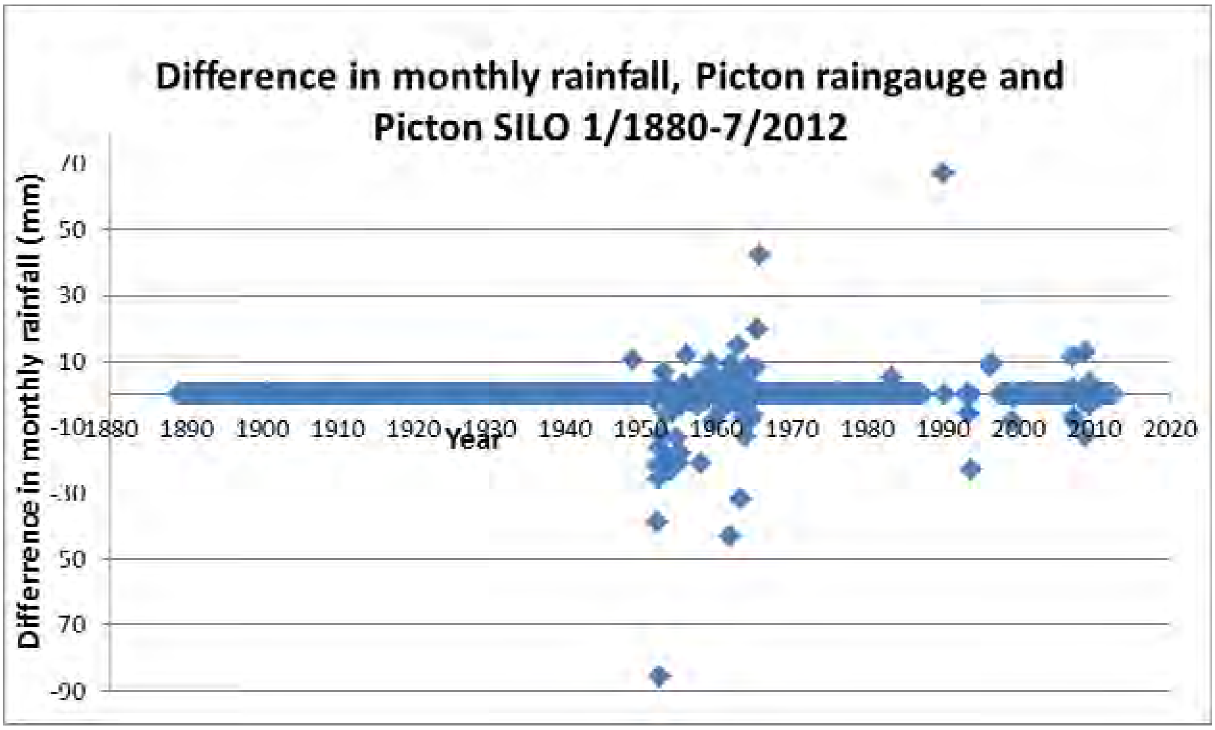

Figure 1. Difference between measured monthly rainfall at Picton (raingauge) and estimated monthly rainfall Picton (SILO) for period 1/1/1880 to 31/7/2012. The SILO data start at 1889 and the missing data are shown as spaces along the horizontal axis. Positive values indicate the SILO values are larger than the measured values.

There is common agreement between the two data sets except for some months in the periods 1949-1965 and 1983-2009. More detailed graphical analysis (Fig 2) shows that the differences are less than 10 mm for the majority of the months. There are only two months where the SILO data are greater than the measured Picton data by more than 20 mm, and four months when the SILO data are smaller than the measured Picton data by more than 30mm. The few number of months with any large difference in monthly rainfall suggests that the SILO data, which are a complete data set for the period 1889 to 2012 (replacing more than 50 missing monthly values) are worth using, at least for general trends in rainfall over the last 130 years.

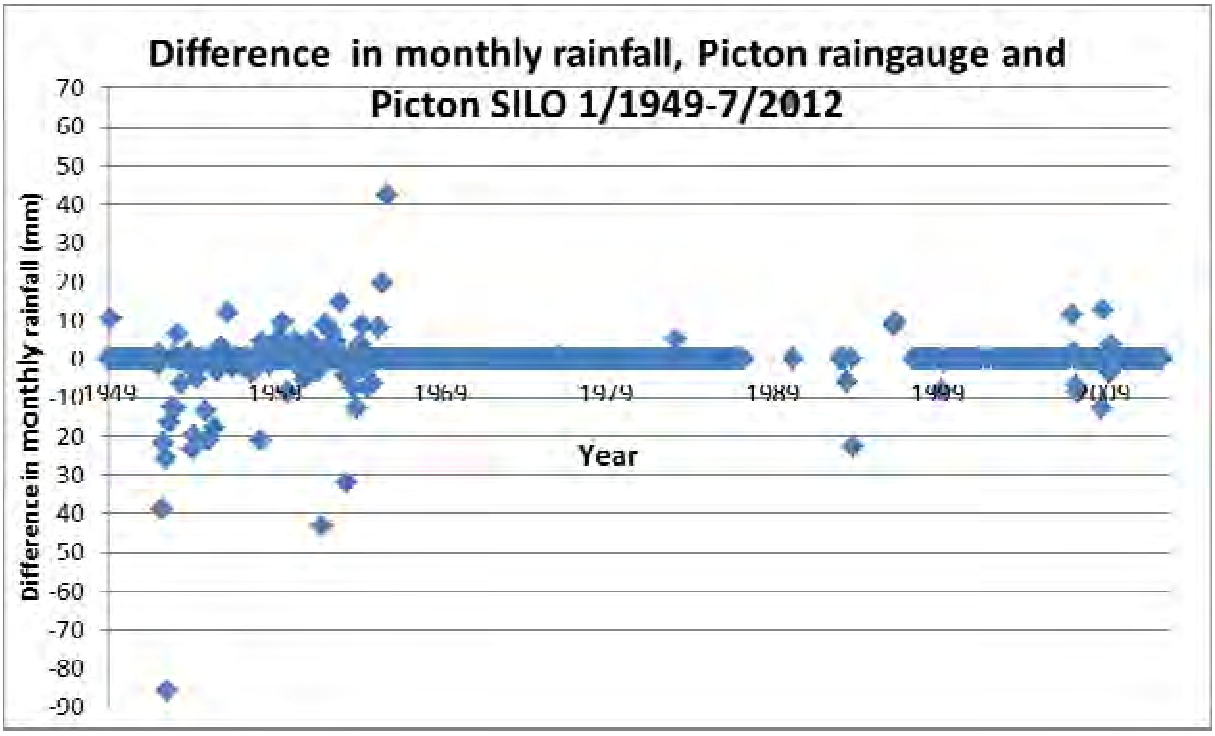

Figure 2. Difference between measured monthly rainfall at Picton (raingauge) and estimated monthly rainfall Picton (SILO) for period 1/1/1949 to 31/7/2012.Missing data are shown as spaces along the horizontal axis. Positive values indicate the SILO values are larger than the measured values.

No reason is given in the Picton meteorological station records for the missing data. The reliability of the rainfall readings in the periods when the measured Picton and SILO Picton differ is not clear, and would require further detailed analysis. The Picton raingauge was moved on 9/9/2002 from the Bowling Club to the Council Depot (latitude changed from -34.16642 to -34.16848 and longitude changed from 150.61094 to 150.61450). This change would not account for the missing data or the differences in the measured and estimated monthly rainfalls.

SILO uses geostatistical spatial interpolation techniques to estimate missing data (Jeffrey et al., 2001). There are some uncertainties in the SILO estimates (Beesley et al., 2009), as the comparison undertaken herein shows, which is not uncommon with interpolation techniques. These differences can have implications for hydrologic modelling (Tozer et al., 2011)

Comparison of the average monthly rainfalls and annual rainfall for the Picton recorded and SILO Picton data (Table 1) shows that there is no significant difference in the means.

Table 1. Comparison of mean monthly and average annual rainfall for Picton Bureau of Meteorology and Picton SILO data.

Month	BOM 1880-2012	SILO 1889-2012
Jan	86.0	88.0
Feb	90.4	92.6
Mar	88.5	88.6
Apr	69.9	69.6
May	57.1	59.2
June	65.1	65.9
July	50.6	50.0
Aug	44.4	44.7
Sept	44.7	45.1
Oct	65.0	62.9
Nov	72.4	74.5
Dec	70.1	69.5
Annual	803.6	810

Differences in monthly rainfalls

There is a seasonal difference evident in the average monthly rainfall for Picton SILO data (Fig 3).

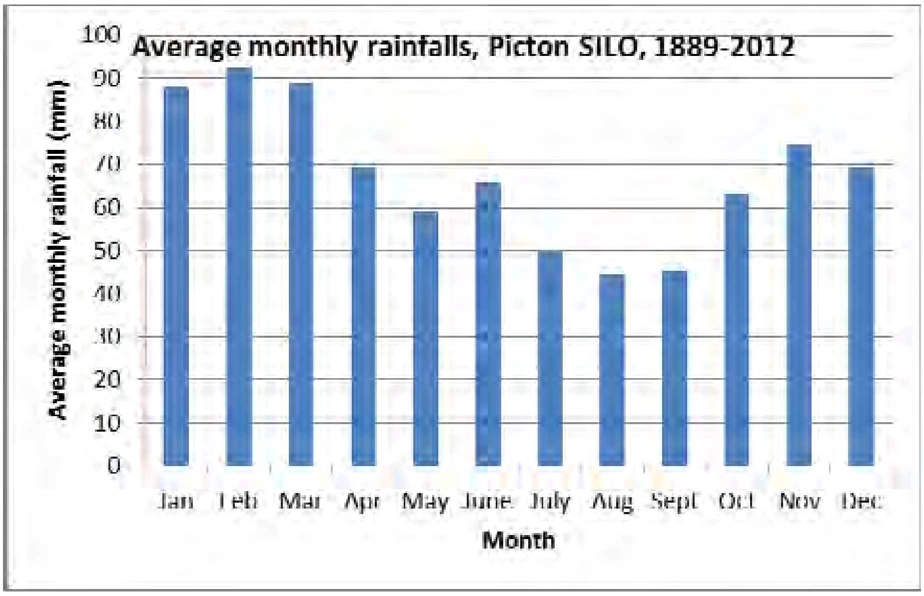

Figure 3. Average onthly rainfall data for Picton SILO, 1889-2012

One way analysis of variance shows that there is a statistically significant difference in the monthly rainfalls.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Jan	123	10821.2	87.97724	5156.29
Feb	123	11384.9	92.56016	7391.987
Mar	123	10902.1	88.63496	5743.228
Apr	123	8561.6	69.6065	4390.507
May	123	7279.4	59.18211	4369.978
June	123	8108.9	65.92602	5736.238
July	123	6144	49.95122	3170.914
Aug	123	5501	44.72358	3132.681
Sept	123	5552.3	45.14065	1147.501
Oct	123	7733.4	62.87317	3443.775
Nov	123	9168	74.53659	4303.226
Dec	123	8551.5	69.52439	2675.322

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	365527.5	11	33229.78	7.87099	2.09E-13	1.795177
Within Groups	6180721	1464	4221.804			
Total	6546248	1475				

Clearly winter is drier than the summer period, and months with the highest average monthly rainfall are in mid to late summer.

Cumulative deviation from the mean monthly rainfall

The cumulative deviation from the mean for the period 1889 to 2012 (Fig 4) shows the same pattern as demonstrated for a number of stations in the Hawkesbury-Nepean catchment, and elsewhere, as discussed in Section 4.3

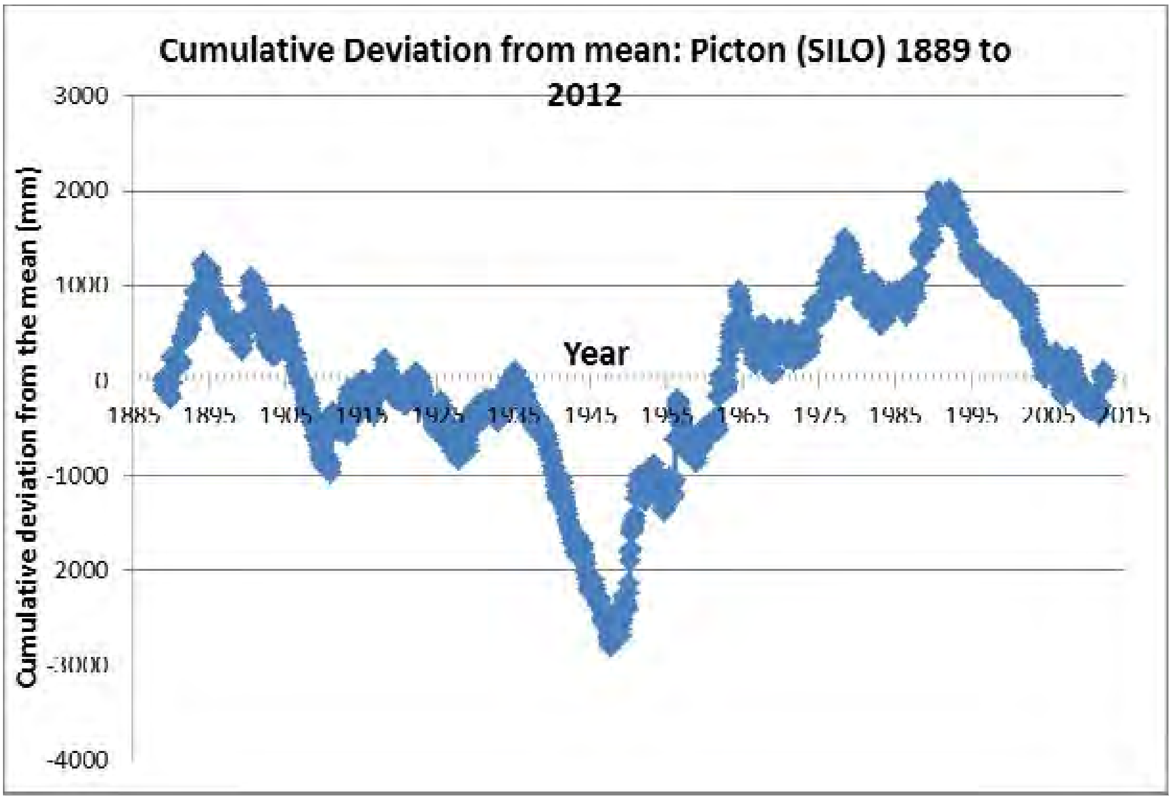

Figure 4. Cumulative deviation from the mean monthly rainfall for Picton SILO for the period 1889-2012.

Comparative analysis for periods 1889-1947 and 1948-2012

To ensure that there is no inhomogeneity in the rainfall data the data set was split into two periods.

The analysis of cumulative deviation from the means for the Hawkesbury-Nepean catchment (Section 4.3) and the SPI analysis of rainfall excess and deficits (Section 4.4) suggest that the rainfall data for Picton can be split into two periods, 1889-1947 and 1948-2011, each encompassing a flood- and drought-dominated regime.

The means for the each of the months in these two periods were compared using a two sample t-test, assuming unequal variances, with the hypothesis being that there is no significant difference in the means for the two periods.

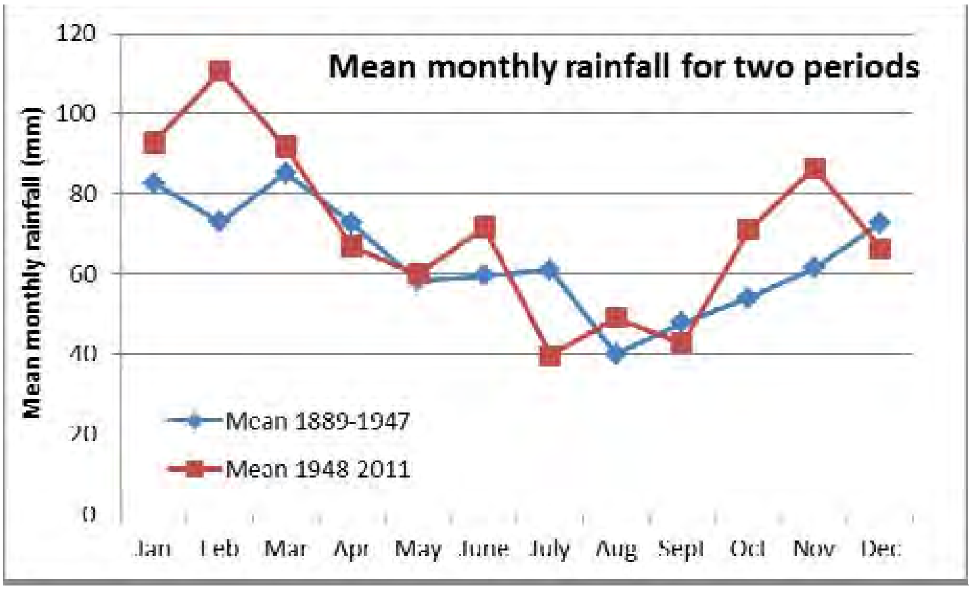

Figure 5. Mean month rainfalls for Picton for the periods 1889 to 1947 and 1948 to 2011.

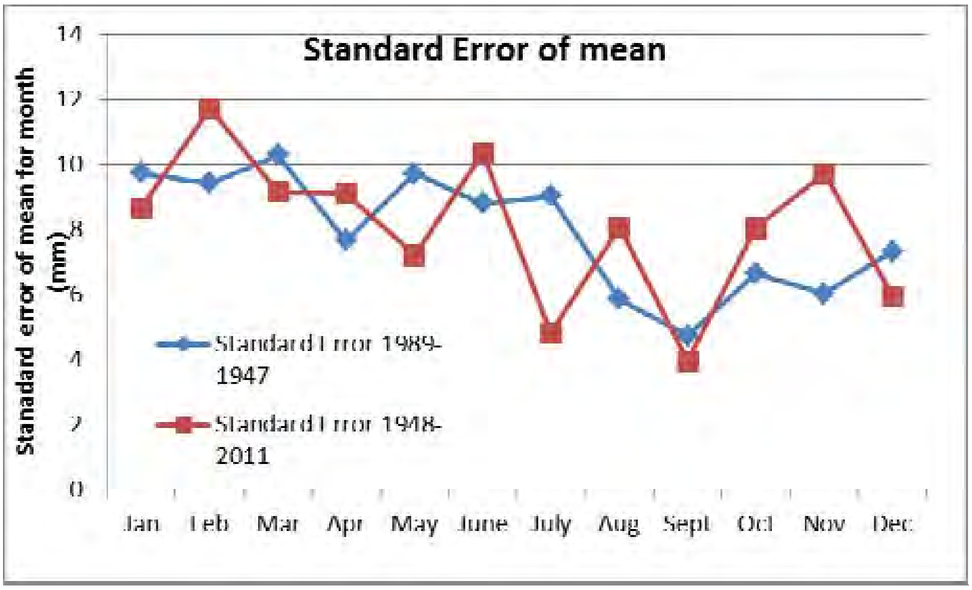

Figure 6. Standard error of the mean for monthly rainfalls for the periods 1889 to 1947 and 1948 to 2011.

The three months with statistically significant differences in mean monthly rainfall (significance level set at P<=0.05) for the two periods are February, July, and November.

The mean monthly rainfall for the two periods 1889-1947 and 1948-2011 is 64 and 71 mm respectively. The means are significantly different at P=0.04. The significant differences in the mean monthly rainfall suggest that the 1948-2011 period is slightly wetter than the 1889-1947 period.

On the two-tail t-test for unequal variances there is no statistically significant difference (P=0.07) between the means of the annual rainfall for the periods 1889-1947 (769 mm) and 1948-2012 (849 mm), although the more recent period is slightly wetter than the earlier. The lower rainfall in the period 1889 to 1947 may be partly attributed to the two significant droughts in the period.

There is clearly a difference in the significance of the differences between the monthly rainfall means and the annual rainfalls for the two periods. This is attributed to the seasonality in the rainfall data, which is obviously not evident in the annual data. The difference may also be a statistical aberration, as the monthly data have twelve times as many sample points as the yearly data.

1.4 Chapter 5

1.4.1 Appendix 5.1 Water level data

Date	**Werri Berri**					**Couridjah**					**Nerrigorang**					
	Pells Depth	Pells Predicted	Gilbert Depth WB	Gilbert Predicted WB	Committee Depth	Pells Depth	Pells Predicted	Gilbert Depth	Gilbert Predicted	Committee Depth	Pells Depth	Pells Predicted	Gilbert Depth N	Gilbert Predicted N	Committee Depth	
1/7/1867	305					305					305					
1/10./1884	305					305										
20/10/1884	305					305										
1/12/1902	301	303				301	300.4									
24/12/1902	305	302.8				305	300.4									
1/08/1906	303.5	303.1				303.5	300.4									
4/04/1913	302	304.7				302	303.1									
4/06/1916											303	303.8				
1/07/1925	304	304				304	304				304	303.1				
3/11/1926	303	303.3				303	303									
1/03/1933	303	303.7				303	303.3				303	303.5				
1/07/1944	300	301.9				300.5	300.4				300	299.9				
31/03/1949	300.5	302.8				300.5	301.8				300.5	300.5				
10/12/1953											305	304.3			304.2	Pells. May 2012, p.18. Fig 21 Committee assumed full lake and date is as specified by Pells Consulting
5/07/1955	304.5	304.3	304.1	304.5		304.5	304.1	304.3	304.1		304	304	301.4	301.7		
15/12/1955	305.5	304.1														
20/12/1955	304	304.3				304	304.1				302	304.8				

mid 1950's														304.2	Pells Consulting Oct 2011, Appendix E (August 2011 progress report 5), Photo 6,p.7. Assume lake full
1/01/1959	304.5	303.9													
1965,1										303.9	303.2				
22/03/1966	303	303.2	301.7	303.2	303.5	303.4	301.4	303.2		304		300.2	301.3		
29/06/1969			302.5	303.5			302.9	303.5				299.9	300.5		
10/12/1971	303.5	303.8													
x/5/1974									306						Vorst, Fig 5.5 this report
1/11/1974					304.8	304.8									
2/04/1975	303.5	304.5	302.7	303.6	303.5	304.3	302.5	303.6		303	304.4	299.9	300		
26/06/1979			302.6	304.6			302.6	304.6				300.1	302.6		
27/10/1983	303	304.9	302.7	300.6	302.5	304.7	302.6	302.3		303.5	303.6	299.8	298.6		
1/04/1984									304.5						Pells Consulting, Oct 2011, Appendix B (Aug 2011 progress report), Fig 12, p.10
1/03/1987										303.5	304.3				
21/03/1988			302.9	300.1			301.5	301.9				300.4	297.8		
1/04/1988										305	304.9			304.2	Pells Consulting, Oct 2011, Appendix E (Aug 2011 Progress Report),Photo 7, p.8. Assumed lake

																full
1/01/1989										306						Pells Consulting, Oct 2011, Appendix B (May 2011 Progress Report), Fig 10,,p.10
1/04/1989						305	304.5			306						Pells Consulting, Oct 2011, Appendix B (May 2011 Progress Report), Fig 9, p.11
1/07/1989											305	304.9				
1/12/1989						305	304.5									
1/01/1990											304.5	304.3				
1/02/1990	304	304.7														
Early 1990's															303.5	Pells Consulting, Oct 2011, Appendix E (August2011 Progress Report) Photo 8, p.8
25/09/1990			303.4	305.9				303.8	305.9				301.2	304.3		
1/12/1990						305.5	305									
sometime 1990					305.7											Pells Consulting (Oct 2011), Appendix E (Aug 2011 Progress Report), Photo 11,p.9

10/01/1993	304	304.4			306											Pells Consulting (Oct 2011), Appendix E (Aug 2011 Progress Report), Photo 17, p.12
4/01/1994	303.5		303.1	303.4		303.5	303.3	303.3	303.4		302	303.2	299.9	300.9		
1/04/1994	304	303.7														
sometime 1994															299.8	Pells Consulting, Oct 2011, Appendix E (Aug 2011 Progress Report), Photo 9, p.8
late 1997					304					304						NPWS photos Fig 5.7 and 5.8
4/10/1998						304				303						Pells Consulting, Oct 2011, Appendix A (Dec 2010 Progress Report) Photo 3, p.12
14/10/1998	304	304	302.6	303		304	303.9	302.4	303		303.5	302.9	300.3	300.1		
10/12/1998	303.5	303.4				304.5	304.3									
late 1998															301.2	Photo supplied by Ratcliffs
10/01/2002										305						Pells Consulting, Appendix A, p.10
22/02/2002	302	303	302.3	300.8		302.5	302.9	302.3	302.5		301	301	298.7	299		
1/03/2002											300.5	301			299.6	Pells Consulting, Oct 2011,

													Appendix B (May 2011 Progress Report), Fig 13, p.12
20/12/2005	302.5	302.9	302	298.9	302.5	302.9	301.9	300.6	300.5	300.4	298.8	297.6	
29/07/2006									299	300			
13/06/2008	304												
1/11/2008	303.5												
31/10/2009	303	303.4	300.3	300.9	303	303	301.3	301	298	299.9	297.8	296.9	
1/01/2010	301.5	302.9											
13/04/2010	301.5	302.5	300.1	300.3	301.5	302.1	301	300.8	298		297.8	297.2	
1/01/2011	300.7	301.9			300.4	302.8							
10/02/2011	300	303.1	300.1	299.3	300	303	301.2	300.9	298	299.3	297.8	297.1	
9/05/2011	300.5				300.5				298				
22/08/2011	300				300.2				298				
1/10/2011	300				299.9	303							
19/01/2012	300				300				298				
25/03/2012	300.5				300.5				298				
18/05/2012	301				301.5				298.3				

305.86 - Couridjah overflows into Baraba (305 Pells)

302.82 - Nerrigorang overflows into Werri Berri (305 Pells)

302.86 - Werri Berri and Couridjah connected (304 Pells)

305.73 - Baraba overflows into Nerrigorang (305 Pells)

<301 (300)? Bed of Nerrigorang (302.9 Pells)

299.5? Bed of Werri Berri

300? Bed of Couridjah

303.2 Bed of Baraba

304.29 -Nerrigorang overflows into Blue Gum Creek (?) (305 Pells) Gilbert and Assoc, 2012,p58, Table 8.2. All their height data Pells Consulting, Letter 13 July 2012, p.16. Height data for 1949 to 2005 (aerial photos) Heights sent to Committee by Pells Consulting 4/9/12 Committee's interpretation of Pells Consulting predictions or estimate of depth	297.8 Bed of Nerrigorang		

Gilbert and Associates estimated and predicted lake levels

Lake Level derived from Aerial photography (m AHD)							Modelled Lake Water Level (m AHD) - 1m ET Depth Limit				
Date	Date	Gandangarra	Werri Berri	Couridjah	Baraba	Nerrigorang	Gandangarra	Werri Berri	Couridjah	Baraba	Nerrigorang
5/07/1955	1955.51	304.06	304.06	304.06	303.53	301.39	304.05	304.05	304.05	304.53	301.68
22/03/1966	1966.22	302.00	301.66	301.44	303.52	300.21	303.15	303.16	303.16	302.76	301.33
29/06/1969	1969.49	301.83	302.49	302.85	303.53	299.95	303.52	303.52	303.52	304.98	300.51
2/04/1975	1975.25	302.38	302.73	302.51	303.54	299.89	303.63	303.63	303.63	304.91	300.02
26/06/1979	1979.48	302.25	302.65	302.57	303.53	300.13	304.57	304.56	304.56	304.66	302.56
27/10/1983	1983.82	302.08	302.74	302.58	303.53	299.78	302.59	300.59	302.30	305.55	298.56
21/03/1988	1988.22	301.55	302.90	301.47	303.53	300.41	301.88	300.10	301.92	302.65	297.31
25/09/1990	1990.73	302.16	303.36	303.77	303.53	301.19	305.85	305.85	305.85	305.72	304.28
4/01/1994	1994.01	302.36	303.07	303.31	303.53	299.86	303.41	303.42	303.41	303.97	300.90
14/10/1998	1998.78	301.90	302.62	302.41	303.53	300.31	303.00	303.00	303.00	305.18	300.06
22/02/2002	2002.14	301.71	302.27	302.16	303.52	298.74	302.82	300.83	302.49	305.33	299.02
20/12/2005	2005.97	302.59	302.01	301.87	303.53	298.78	301.48	298.90	300.62	303.09	297.60
29/07/2006	2006.58	301.34					300.36				
31/10/2009	2009.83	301.25	300.34	301.29	303.53	297.75	300.52	300.93	301.00	302.79	296.93
13/04/2010	2010.28	301.24	300.10	300.99	303.53	297.75	300.99	300.30	300.79	302.84	297.23
10/02/2011	2011.11	301.13	300.07	301.20	303.53	297.75	301.32	299.32	300.89	302.69	297.25
17/01/2012	2012.04	301.00	299.50	300.50	303.25	297.75	301.03	298.70	300.55	302.82	297.08

1.5 Chapter 6

1.5.1 Appendix 6.1 Water bore information

Bore	Completed Depth	Easting	Northing	Year	SWL	Yield	Aquifer
GW008537	65.5	277,989	6,211,214	1/01/1947	34	0.467	
GW008548	65.5	277,099	6,209,867	31/01/1947	28	0.53	
GW010459	64	274,240	6,213,745		24.9		Hawkesbury SS
GW010496	40.6	276,413	6,211,793		28.6		Hawkesbury SS
GW010584	50	275,340	6,209,548		29.9		Hawkesbury SS
GW010604	76.2	276,637	6,214,234		28.3		Hawkesbury SS
GW010654	39.6	274,949	6,211,974		8.6		Hawkesbury SS
GW011200	60.9	275,596	6,210,633	1/09/1955	22.8	1.136	Hawkesbury SS
GW011234	52.4	275,883	6,209,314	1/10/1955	27.4	1.136	Hawkesbury SS
GW011299	60.9	275,291	6,209,454	1/11/1955	22.8	0.757	Hawkesbury SS
GW012611	50.2	275,711	6,210,081	1/10/1945	18.2	0.113	
GW012612	57.9	275,398	6,210,320	28/02/1983	27.4	0.113	
GW013282		276,627	6,209,270				
GW018568	63.3	274,881	6,210,554		32.6		Hawkesbury SS
GW022245	146.3	273,516	6,207,685	1/10/1943	54.8	0.252	Hawkesbury SS
GW028859	45.7	274,601	6,211,534	1/10/1968	13.7	1.136	Hawkesbury SS
GW029143	73.1	274,796	6,210,860	1/10/1968	41.1	0.757	Hawkesbury SS
GW034518	76.2	274,860	6,209,289	1/07/1970	24.3	0.473	Hawkesbury SS
GW034687		278,221	6,209,000				
GW035753	142	276,668	6,209,703		24.5		Hawkesbury SS
GW037289	137.1	275,015	6,209,232				Hawkesbury SS
GW037294	152.7	272,114	6,213,755	3/12/1971	75.2	2.273	

GW037742	112.7	274,479	6,210,236	1/01/1972	53.3	1.515	Hawkesbury SS
GW037860	137.1	275,178	6,209,914	25/06/1976	36.5	2.273	Hawkesbury SS
GW037932	95	272,853	6,211,419		34.1		Hawkesbury SS
GW038060	122.5	274,680	6,210,364	13/01/1974	45.7	3.031	Hawkesbury SS
GW038074	60.9	278,216	6,209,215	11/03/1983	18.2		
GW042537	121.9	274,310	6,209,770	1/09/1975	45.7	2.273	Hawkesbury SS
GW042788 (P6)	148	280,417	62`10315				
GW042825	114.6	273,088	6,207,366		83.2		Hawkesbury SS
GW043154	48.7	275,295	6,211,427	2/06/1977	5.7	2.273	Hawkesbury SS
GW047037	90.8	272,445	6,213,856	1/01/1947	61		
GW047416	64	274,634	6,211,226	9/11/1979	24.4	1.5	Hawkesbury SS
GW047903	92.3	275,698	6,213,496	14/09/1981	18.3	6.69	Hawkesbury SS
GW049796	61	275,127	6,210,961		24.6		Hawkesbury SS
GW057274	115	272,074	6,211,164				
GW059311	51.8	273,294	6,212,643	24/03/1982		0.63	Hawkesbury SS
GW060205	50	275,109	6,212,779	31/10/1985	8	1	Hawkesbury SS
GW060238	48	274,508	6,211,159	8/05/1985	31.2	1.5	Hawkesbury SS
GW062068	150	276,493	6,209,514	21/02/1987	36	0.938	Hawkesbury SS - Bald Hill Claystone 177 to 189 m
GW063525 (P5)	76 (1954) 91 (1990)	276,635	6,214,326				
GW067570 (P4)	85	277,164	6,213,708	28/06/1988	10	0.22	
GW070979		275,315	6,211,674		25.6		
GW072432	76	273,364	6,212,851				Hawkesbury SS
GW073406	63	275,272	6,209,445	1/01/1952		0.68	
GW102630	43	273,332	6,211,914	29/10/1999	21		Hawkesbury SS
GW102706	150	271,245	6,213,073	20/10/1998	94	0.15	Hawkesbury SS
GW104077	48	275,333	6,211,928	27/11/2001	22		Hawkesbury SS
GW104659	132	276,617	6,207,391	14/02/2003	51	0.8	Hawkesbury SS
GW104720	91	274,451	6,211,918	6/03/2003	54	1.7	Hawkesbury SS
GW105145	67	275,872	6,210,499	1/01/1952			
GW105148	120	278,006	6,209,733	21/09/1995	33	0.3	
GW105246	120	274,934	6,211,237	3/10/2003	71	0.2	Hawkesbury SS
GW105254	163	278,246	6,211,856	2/10/2003		0.67	Hawkesbury SS
GW105813		279,408	6,213,106	26/04/2005			
GW106281 (P1)	48	277,018	6,210,748	27/04/2005	11		Hawkesbury SS

GW107525	145	274,856	6,211,080	1/01/1950		0.5	
GW107918		279,629	6,211,559	9/03/2007			
GW108981	175	276,641	6,210,801	27/06/2008	48	0.5	Hawkesbury SS/ Bald Hill Claystone 156-174 m
GW109010	169	278,173	6,211,781	10/07/2008		0.8	
GW109153	60	272,074	6,207,558	5/08/2008			
GW109203	91	274,797	6,212,250	12/08/2008	30	0.2	Hawkesbury SS
GW109224	132	279,140	6,211,222	18/08/2008		1	
GW110435 (P7)	100	279215	6209715		55		
GW110436 (P8)	105	279363	6209869		85		
Excluding NSW Office Monitoring Bores							

Table. Hydrocensus data

Bore number	Elevation top of bore	Easting	Northing	Depth of Bore	Date of installation	Water depth at installation	Water depth survey date	Water depth at survey	Casing height	Geology
	m AHD	m	m	m		m		mbtoc	m	
GW0104720	331.3	274441.7	6211954.8	91	6/03/2003	54	9/03/2012	43.6	0.38	HS
GW047416	329.8	274627.1	6211249.2	64	1/11/1979	24.4	9/03/2012	35.7	0.11	HS
GW029143	337.8	274802.8	6210874.3	73.1	1/10/1968	41.1	9/03/2012	46.95	0.27	HS
GW0101247	309.2	272151.5	6210332.9	42	31/01/1998	7	9/03/2012	8.24	0.32	HS
GW075409/1	307.6	273771.0	6209571.0	15	28/06/2011	8.35	9/03/2012	8.22	-0.18	HS
GW075409/2	307.6	273772.0	6209569.0	100	28/06/2011	16.99	9/03/2012	16.7	-0.22	HS
GW075411	307.3	274232.0	6210996.0	28	28/06/2011	12.74	9/03/2012	12.22	-0.38	HS
GW075410	307.8	273034.0	6210587.0	18	28/06/2011	9.19			1	HS
GW035753	298.8	276610.6	6209674.6	142	1/10/1972		6/09/2012	32.61	0.31	HS
GW034518	325.3	274925.6	6209246.8	76.2	1/07/1970	24.3	6/09/2012	29.29	0.11	HS
GW018568	329.8	274899.1	6210554.7	63.4	1/11/1961	32.6	6/09/2012	37.9	0.38	HS
GW062068/1	294.9	276579.3	6209579.5	150	21/12/1987	36	6/09/2012	28.86	0.15	HS
GW062068/2	294.8	276580.5	6209579.6		21/12/1987	36	6/09/2012	28.71	0	HS
GW057274	404.0	272104.0	6211098.7	115	1/01/1982		1/11/2007	47	0.3	HS
GW037742	341.0	274483.0	6210209.8	112.8	1/01/1972	53.3	6/09/2012	38.02	0.17	HS
GW102439	340.9	274477.2	6210080.2	115	30/07/1998	72	6/09/2012	51.97	0.37	HS