APPENDIX A

PROGRESS REPORT NO. 1
8 DECEMBER 2010

Pells Consulting

ABN 74 978 620 434
Phone: 02 4381 2125
Fax: 02 4381 2126
49 Lakeside Drive
MacMasters Beach NSW 2251
www.pellsconsulting.com.au

THIRLMERE LAKES

PROGRESS REPORT NO.1

1. INTRODUCTION

This is the first report in respect to a study being undertaken into the water levels in the Thirlmere Lakes and whether the low water levels observed in 2009/2010 were purely the result of natural processes or were, to some extent, associated with physical changes to the environment, including longwall mining.

2. STUDY PROCEDURE

The study is to follow a strict scientific procedure so that any conclusions that may be reached would, hopefully, be reached by any other person or group using the same data and sound, proven, analytical methods.

The building blocks are as set out below.

1. Collect all geological and geomorphological data relevant to the lakes, including the surrounding terrain, the immediate lake floors and the strata down to the level of the Bulli seam.

2. Collect relevant rainfall records.

3. Develop the drought intensity, duration, recurrence interval plot for the site.

4. Collect whatever data are available in respect to the groundwater regime feeding the lakes and historic water levels in the lakes.

5. Develop the water balance hydrological model for the lakes, and use this to simulate the water levels over the past 100 years, calibrate the model, and use it as a means of understanding lake levels since 2000.

6. Collect data in respect to the geometry and timing of longwall mining in the area.

7. Calculate possible changes to the groundwater regime associated with longwall mining in the area.

8. Review preliminary findings and determine further work for the study.

This first progress report gives some background to the lakes and sets out information gathered to data in respect to Items 1, 2, 3 and 6 in the above list.

3. TOGOGRAPHY AND GENESIS OF THE THIRLMERE LAKE SYSTEM

Figure 1 shows the topography around the Thirlmere Lakes and is annotated with the catchment area of the lakes. The total catchment of the five lakes is very close to 5 square kilometres. The lakes are named, from upstream (north) to downstream (west) (see Figure 2):

- Lake Gandangarra
- Lake Werri Berri
- Lake Couridjah
- Lake Baraba
- Lake Nerrigorang

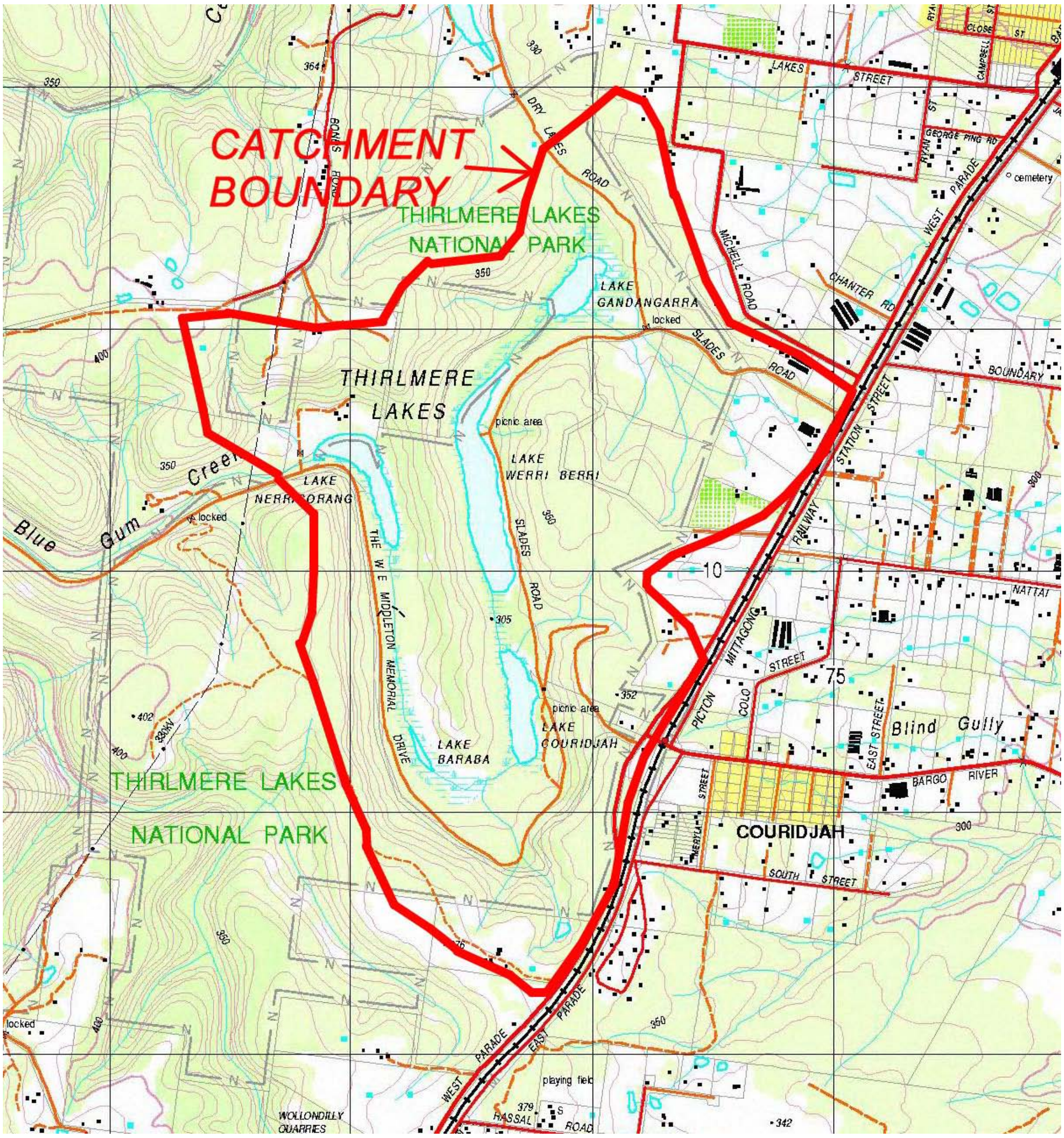

Figure 1: Topography and catchment area.

A 627 hectare area encompassing the lakes was designated Thirlmere Lakes National Park in 1974, because of high conservation value, based on the systems unique origin and ecology.

The lakes are situated within an entrenched valley meander of what was once a well-developed water course. It is interpreted that the drainage pattern of the original river was disrupted when the countryside to the east was lowered by tectonic downwarping, thus elevating the meander relative to the surrounding land surface (Fanning, 1982). Such warping was associated with the formation of the Lapstone Monocline, which extends into the region. Based on the dating of the Lapstone Monocline by Bishop et at. (1982), Fanning suggests the lakes may be at least 15 million years old.

The lake system developed in the elevated basin-like structure of the entrenched meander, which only occasionally overflows to the west down Blue Gum Creek.

The geomorphology and the hydrology of the lake system is surprisingly stable. The limited catchment of the lakes and the nature of the adjacent sandstone have probably been important factors in the low rate of siltation that appears to have taken place in European settlement time.

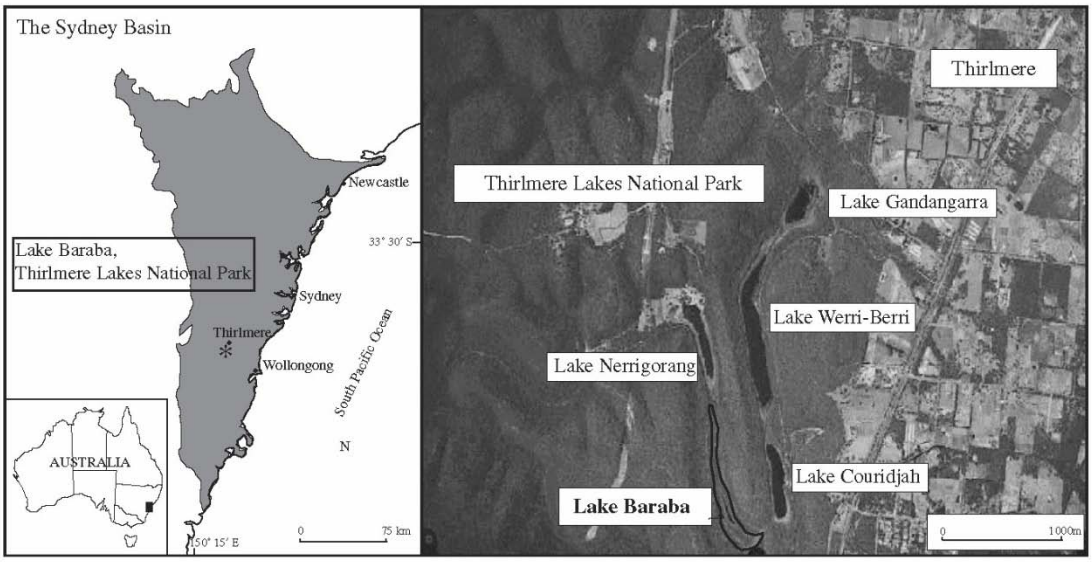

Figure 2: Names of the lakes.

The catchment area consists of rugged sandstone slopes and ridges with associated features of minor cliff lines, colluvial slopes and alluvial fans. Weakly developed soils are found on the debris slopes and fan surfaces whilst residual soils are found on the sandstone ridgetops.

The hydrology of the park includes Blue Gum Creek which drains westward from the lakes into the Little River within Nattai National Park. Fluctuations of water level within Blue Gum Creek and the Thirlmere Lakes themselves correspond to variations in the annual average rainfall. The outlet at Blue Gum Creek limits the height of the lakes.

In May 1974 the outlet was open, recording the highest water levels since 1874. It appears that between these peak periods Thirlmere Lakes is probably a closed basin.

Studies have shown that, on occasions, water levels have dropped by four meters below the maximum. The influence of ground water on the lakes is not well understood. No studies on the flow of water through the lakes have been undertaken.

Fanning, quoting work by Vorst (1974), states that about 50m of unconsolidated sediment underlies the lakes, with “its alternating organic and inorganic nature probably reflecting fluctuations between closed and open lacustrine conditions”.

The explanation give by Fanning for the formation of the lakes, and supported by other workers, is as summarised below.

Tectonic alteration of the margin of the Sydney Basin is reflected in the presence of the Lapstone Monocline and associated faults forming the eastern margin of the Blue Mountains Plateau. Monoclinal folds also occur in the vicinity of Picton, curving around from northwest to southeast and forming the margin of the Illawarra Plateau, extending southwards to the Shoalhaven River. The approximate location of the one of these (the “Thirlmere Monocline” is shown on the Wollongong – Port Hacking 1:100,000 geological map (see Figure 3). Thus it seems that tectonic downwarping of the Triassic rocks has taken place resulting in the subsidence of the Razorback Range area relative to the Thirlmere Lakes area.

The effect of this warping was to truncate the drainage originally flowing southwest through the valley now occupied by Thirlmere lakes.

Thirlmere Lakes, and the alluviated valley to the north and west of them, occupy a position on the axis of the warp (Ollier, 1978), with the accumulation of sediments and formation of the lakes occurring as the former stream lost its catchment that was subsiding to the east. Flow within this subsiding catchment then changed to the west, leaving the lakes with a very small catchment.

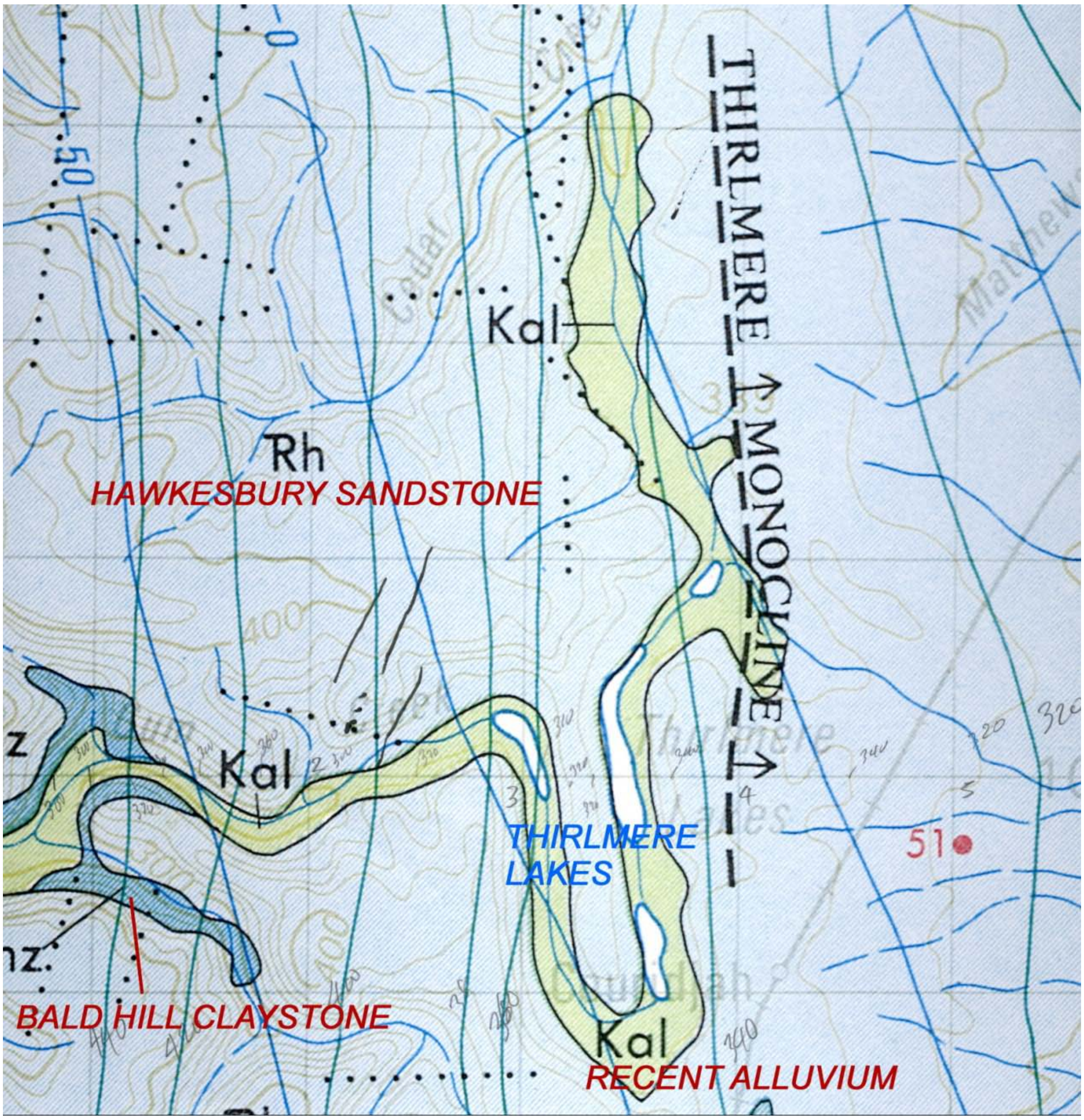

Figure 3: Geological map.

4. PALEO-ARCHAEOLOGY

A paper by Black, Moorey and Martin (2006) describes the results of pollen and charcoal analysis of a 6.35m sediment core extracted from a swampy part of lake Baraba. A summary of the core log is:

Surface to 0.8m	Sandy peat
0.8 to 4.10m	Organic peat, with sandy layer between 0.95m and 1.30m
4.10m to 6.35m	0.5m interbedded grey organic clay and yellow/orange clay.

The dating of the sediments was as follows:

1.5m	4620 ± 180 years before present
2.8m	6720 ± 70 years before present
3.5m	7550 ± 70 years before present
4.6m	23060 ± 340 years before present
6.0m	> 43630 years before present.

The above dates are worth considering in relation to sea level changes along the Australian eastern seaboard (see Figure 4).

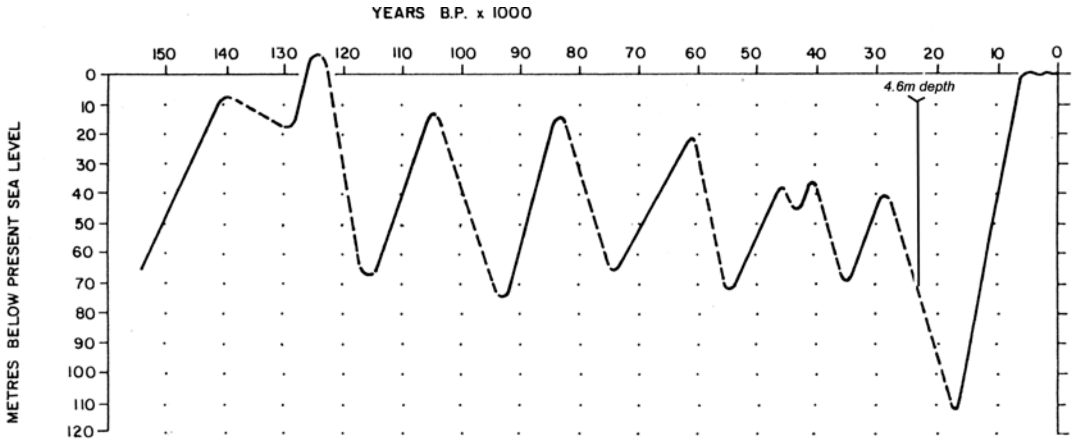

Figure 4: Sea Level Changes – past 150,000 years.

5. GEOLOGICAL SETTING

Figure 3 is part of the Wollongong-Port Hacking geological map. It shows the surface geology. It also provides contours of the base of the Triassic rocks (Hawkesbury Sandstone and Narrabeen Formation). The base of the Triassic is also the surface of the Permian, coal measure, rocks, the top of which is marked by the Bulli coal seam. The published map has been used to produce a West-East geological section as shown in Figure 5.

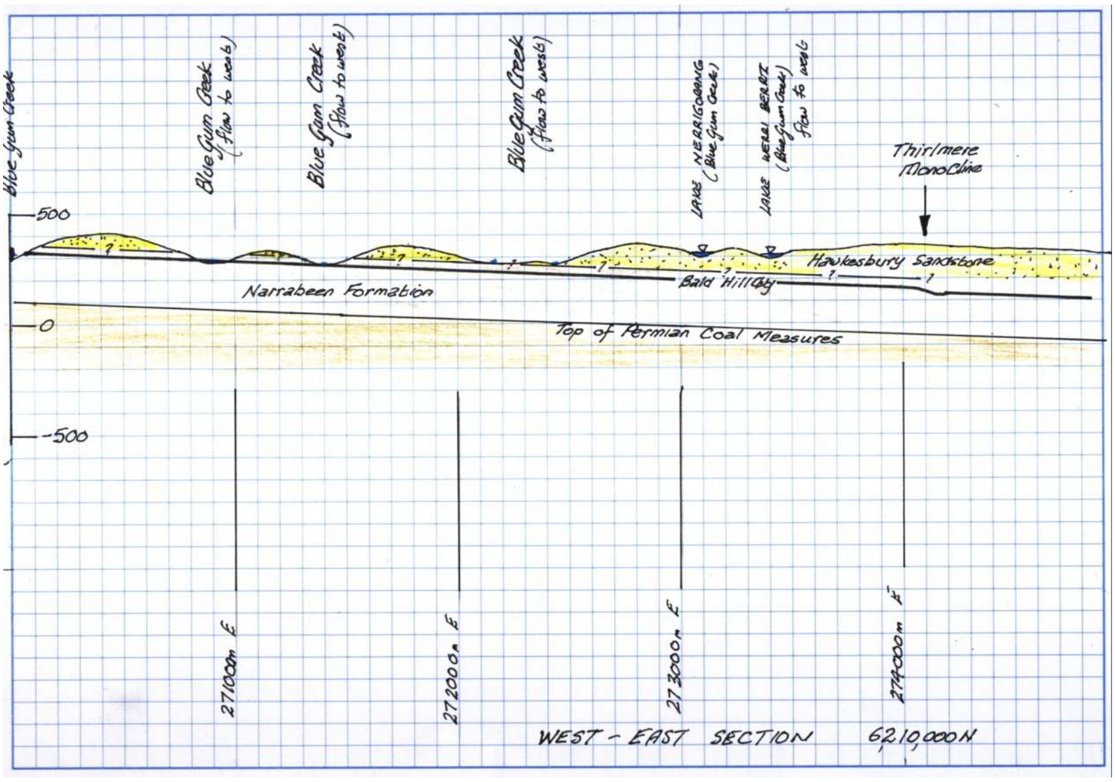

Figure 5: West-East Geological Section.

It is important to note that the Bald Hill Claystone, which forms part of the Narrabeen Formation (beneath the Hawkesbury Sandstone) is a low permeability stratum.

It is typically a massive chocolate brown to red brown kaolinitic claystone with silty and sandy grey and mottled grey-brown zones. It contains minor laminated and thinly bedded siltstones and sandstones ranging in thickness from fractions of a metre to 3m.

Bembrick states that the mineralogy of the Bald Hill Claystone is unique to the red beds of the Sydney Basin. It consists predominately of kaolinite (50% to greater than 75%), with haematite as the principal “contaminant”. Quartz and felspar may be present in minor quantities, but are frequently absent.

Its thickness ranges from:

- 15m at type section at Bald Hill
- 80m at Sutherland
- 80m at Malabar (at shoreline the top surface is 170m below sea level)
- about 100m at Bondi (top surface 120m below sea level)
- 65m at North Head (top surface 140m below sea level)
- 18m at Long Reef Point where the full unit is exposed in the cliff face.

Its thickness beneath the Thirlmere lakes is presently not known to the writer.

As already stated, the geologically-young unconsolidated sediments beneath the lakes are said to be up to 50m thick. However, apart from the limited information given in Section 5, the writer has no information as to the nature of these sediments.

6. EUROPEAN HISTORY

The following relevant information is extracted from NSW National Parks and Wildlife Service, Thirlmere Lakes National Park, New Plan of Management (1997), and from National Parks Association[1] (Ainsley Atkinson, 1998).

The earliest known record of European discovery of the Thirlmere Lakes was an entry in the diary of the second Wilson expedition on 14 March, 1798. The entry reads (sic) "We crosst three deep vallies, with the large ponds of water in each of the vallies. We also crosst one deep gully, we then came to for the night".

John Wilson was an ex-convict and almost certainly the first white man to have visited what is now the Bargo area. Following his release from servitude Wilson chose to wander in the bush with the Aborigines rather than work in the settlement. Wilson was, however, sent on two official expeditions in Sydney's south west during 1798 and it was during the second trip that the Thirlmere Lakes were discovered.

In December 1802 George Caley, who was following the tracks of the explorer Francis Barrallier, became disoriented and headed southward; coming upon the lakes. He believed that he was the first white man to discover them as the diaries of Wilson's expedition had been taken back to England with Governor Hunter. Caley named the largest lake Scirpus Mere (reedy lake) and made reference to the native flora. Caley wrongly concluded that the lakes were the source of the Bargo River.

The area was at this time part of the reserve for the government owned "wild cattle of the cow pastures". The superintendents of the wild cattle may have also been some of the earliest visitors to the lakes.

On 24 September 1867 the Governor, Sir John Young, appointed a Commission to inquire into the best method of supplying Sydney with water. This Commission investigated the potential of the "Couridjah Lagoons" together with a number of other catchments but eventually, in 1869 recommended the Upper Nepean System to the east of Bargo and Appin.

The history of Thirlmere Lakes is tied to the history of railways on the Southern Tablelands during the late nineteenth century and early this century. When the main southern railway line was extended to Mittagong in 1867 a pumping station was established above the third lake and channels were constructed to connect the various lakes. The Couridjah pumphouse located adjacent to Lake Couridjah was constructed at that time to supply water from the lakes to the steam engines which used the southern railway to Mittagong until 1964 (see Photograph 1).

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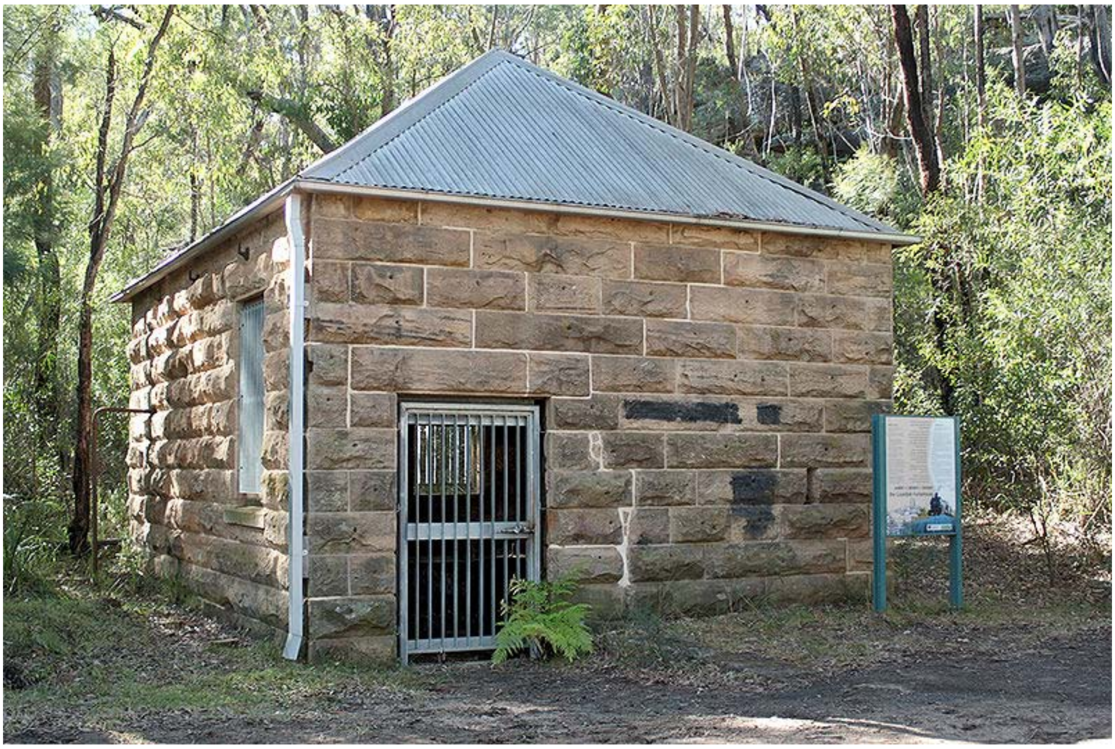
[1] National Parks Journal, Vol 44, No.1, Feb 2000.



Photograph 1: The Couridgjah Pumphouse.

Built from rough rectangular sandstone blocks, the pumphouse forms a structure 6.8 metres long and 4.8 metres wide. It was originally fitted with a slate roof, which has since been replaced with corrugated iron. The original boiler was found to be unsafe in 1875 and replaced with a boiler out of a No. 5 locomotive. In 1934 the engine, pump and boiler were all replaced. By 1975 the boiler and associated machinery had been removed leaving only the pump's mounting block.

The railway station served by the pumphouse was initially named "Couridjah" but later changed to Picton Lakes. This station served the Bargo district until the township of Thirlmere grew large enough to acquire a store, bakery and a hotel of its own. The Railways Department name change from Redbank to Thirlmere Siding was probably influenced by the fact that Thirlmere in England supplies part of the water for Manchester.

At one time there was a proposal that Picton and its extensive railway depot obtain water from Thirlmere Lakes and sufficient 10cm water pipes were accumulated to extend a water line along the railway track to Picton. However the town of Picton was incorporated as a municipality in 1895 and a water supply was brought from a small reservoir on the Bargo river. It was thought that the lakes would not have been a reliable source of supply as it had been reported that they were nearly dry in the 1902 drought.

The lakes were said to again be almost completely dry in the drought of 1928 and evidence from recent research indicates that the lake levels have sometime in the past been at least 4 metres lower than present levels.

Picton Municipal Council persuaded the Railways Department to change the name of Picton Lakes Station back to Couridjah and, in 1960, the name of the lakes changed from Picton Lakes to Thirlmere Lakes.

During the early decades of this century, and after considerable agitation from local residents, Wollondilly Shire Council built an unsealed access road through the park and named it W.E. Middleton Drive

During the mid to late 1950s the aquatic plants around the lake margins and the channels between the lakes were cleared and poisoned to improve conditions for power boating and water skiing.

Power boating and skiing were barred in about 1990. Ainsley Atkinson documents the following additional information.

> *"In the past the lake has been used for high-impact recreational activities such as water skiing. In the 1950s a road was constructed adjacent to the lake to improve access. Arsenic-based herbicides were used to clear natural vegetation from the lake margins, making it more attractive for watersports. At the same time the five lakes were connected by an artificial channel, increasing the effective length of the "lake" for skiers. These "improvements" resulted in accelerated erosion, increased arsenic concentrations in the sediment and sediment disturbance.*
>
> *The study also found that the lake system is relatively stable yet is responsive to natural climatic and associated cycles. For example, fluctuations in water depth are caused by variations in rainfall, which in turn is related to El Niño Southern Oscillation events. During some extreme El Niño events the lake system dried completely. This affects the survival of the rare aquatic species. These effects, however, are limited in duration and frequency and are quickly restored. Therefore, the majority of change that has affected the lake system can be attributed to human activity. Thirlmere Lakes National Park needs to be protected as an area of significant conservation value. Its origin, age, resulting ecology, aesthetics and proximity to Sydney make it attractive to scientists, conservationists, and eco-recreationists alike. This unique environment's very existence is owed to its previously undisturbed nature. While the current management of the park is a reasonable compromise between recreational access and preservation, many of the high-impact recreation activities of the past are not sustainable. Care needs to be taken by those who use and manage the park to ensure that the potential for erosion and disturbance is not increased."*

7. PHOTOGRAPHIC RECORD

The following photographs shown certain of the lakes at certain times.

Photograph 2: 10 January 2002, Jeff Patchett photograph.

Photograph 3: 4 October 1998, Jeff Patchett photograph.
(Same location as Photo 2, pier had been burnt down).

Photograph 4: Werri Berri June 2008, Julie Sheppard photograph.

Photograph 5: Werri Berri 1 January 2010, Julie Sheppard photograph.

8. RAINFALL AND DROUGHT

Figure 6 shows the rain gauge locations within about 20 kilometres of Thirlmere Lakes. Table 1 summaries the closest station to the lakes.

Table 1

Station ID	Station Name	From_	To	Y	X	Approx Distance from Thirlmere Lakes
68010	BUXTON (GIRRAHWEEN)	Jan-35	Dec-53	-34.3	150.5	8.5
68052	PICTON COUNCIL DEPOT	01/1880		-34.1685	150.6145	9.8
68066	WILTON	01/1869	Dec-67	-34.2	150.6	6.6
68133	TAHMOOR POST OFFICE	Jan-62	Dec-74	-34.2167	150.6	9
68135	BALMORAL	01/1889	Dec-20	-34.3	150.55	7.8
68152	PICTON COLLEGE (WARATAH)	Jan-03	Dec-16	-34.2833	150.55	5.8
68158	PICTON RUMPKER STREET	Jan-64	Dec-87	-34.1833	150.6	7.7
68166	BUXTON (AMAROO)	Jan-67		-34.2418	150.5228	1.8
68193	BARGO POST OFFICE	Jan-02	Dec-70	-34.2833	150.5833	7.2

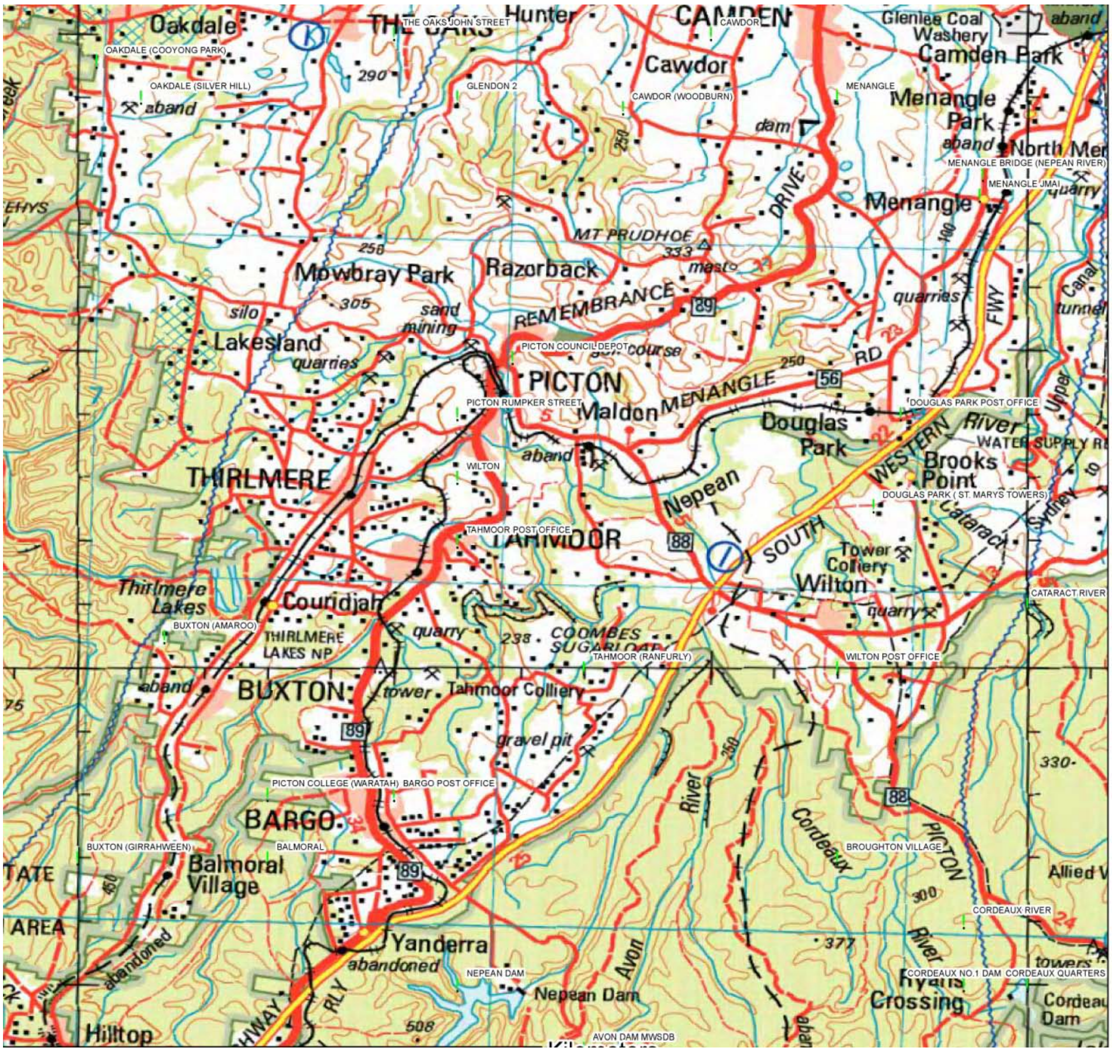


Figure 6: Rainfall station locations.

The two most useful stations are:

- Picton Council Depot (68052) ≈ 10km distance
- Buxton (Amaroo) (68166) ≈ 1.8 km distance.

The Picton Council Depot record is from 1880 to 2010 with some gaps in the 1980's. The Buxton (Amaroo) record is from 1967 to 2010 with very few gaps. The two records have been combined to produce a continuous synthetic record from 1880 to 2010.

Some preliminary analysis has been performed using the rainfall data to generate a drought-reoccurrence plot for drought durations up to 1 year. Further work is to be undertaken to check this work and extend it for durations up to 5 years.

Figure 7 shows the preliminary drought recurrence interval plot, together with the recorded annual rainfalls in 2002, 2006 and 2009.

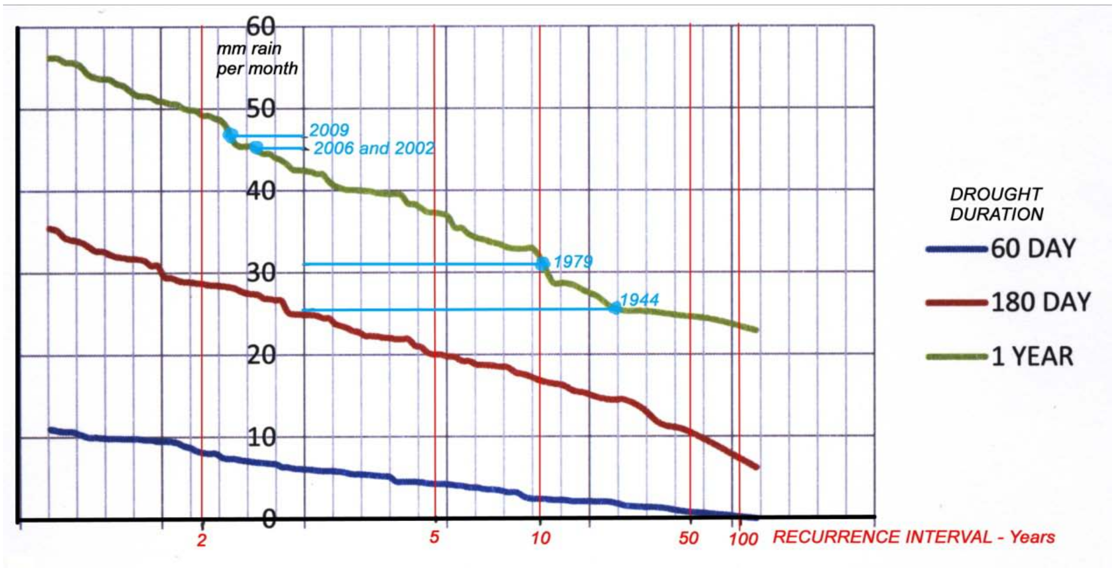


Figure 7: Drought Recurrence Duration Plot.

9. GROUNDWATER

The writer knows little about the groundwater regime at this stage of the project. There is information in the XStrata Annual Environmental Management Report, May 2009 to April 2010, but the writer has not as yet had the time to analyse that data.

The only other observation that has been obtained is a rather garbled response to an article in the Macarthur Chronicle of 25 September 2010. The verbatim response is as follows:

Frank Lauterbach writes:
Posted on 27 Oct 10 at 08:35pm

> *"I grew up at 260 Bargo River Rd Couridjah. We had a bole installed in early 70's to about 420' depth. During the 90's the bole lost its water. My parents put a claim in the Mine Subsidence Boar for mine causing water level to drop. They agreed to truck in water free of charge on going into 2 20,000lt tanks we had till we sold the farm in 2001. If the water level dropped at our place with is about 1 km away from the Thirlmere Lakes, why not then at the lakes."*

10. LONGWALL MINING

Figure 8 shows the completed longwalls of Tahmoor Colliery that are closest to Thirlmere Lakes. These longwall numbers are LW14A/B to LW149. They commenced closet to the lakes and retreated to the SW.

Their commencement dates were:

LW14A	
LW15	21 June 1996
LW16	15 September 1997
LW17	19 February 1999
LW18	21 June 2000
LW19	5 October 2001

Longwalls 20 and 21, that retreated to the NSW were commenced on 20 September 2002 and 12 September 2003 respectively.

Figure 9 shows all the longwalls at Tahmoor as of late 2010 in relation to surface land subdivisions.

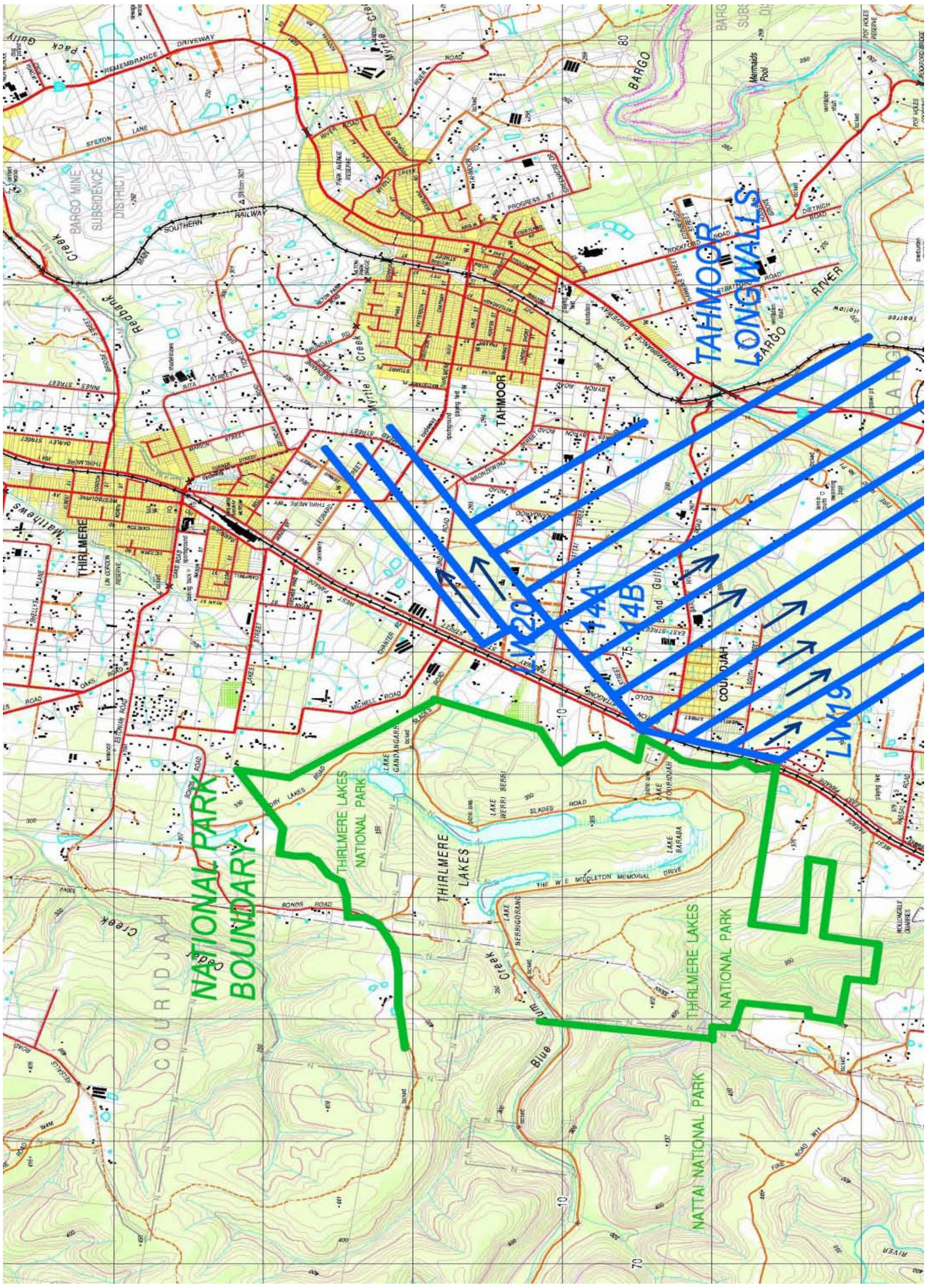


Figure 8: Relevant Tahmoor longwalls

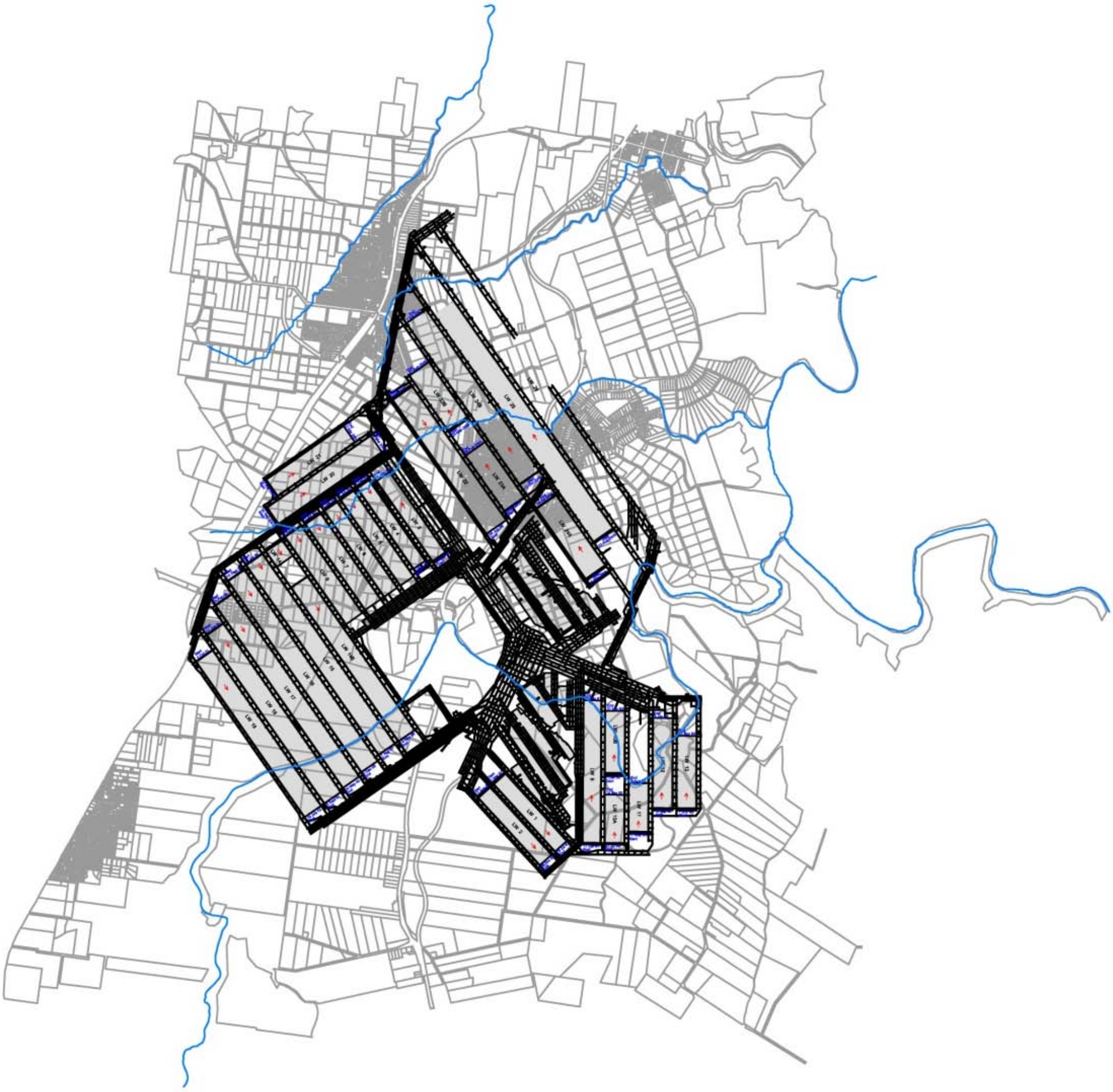


Figure 9: All Tahmoor longwalls

11. ANECDOTAL INFORMATION

The following information has been obtained from the web and from e-mails. Much of this information is relevant but until supported by measurements, photographs or other contemporaneous records, cannot be accepted as scientific fact.

Anecdotal stories from locals tell of walking across the swimming lake during the 1940's; this has been backed up by others but further enquiry reveals that until 1960's the pumphouse on the swimming lakes was used continuously to replenish the tank at Couridjah for the steam trains which continued running (4 trains a day) through until 1960's. A channel had to be dug from the boat lake when the swimming lake ran dry. I've also learned that during this time the dam on Cedar Creek for orchards was replenished by pumping from Thirlmere Lakes across the watershed into that creek (I've tried to contact the orchardist to confirm this but he is away at present).

It seems that the drought times when the lakes were dry was in the period when considerable pumping could have also been a factor.

E-mail David Hunt, 7/12/2010

My concern remains that the issues I've mentioned are not adequately addressed in the AEMR (Annual Environmental Monitoring Report) report.

1. I'd like to draw your attention to a couple of those issues
    1.1 Monitoring of Myrtle Creed – Item 4.7.2.
    I understand monitoring records for Myrtle Creek were not obtained until after completion of Longwalls 22, 23 and 24 when cracking of the creek bed and loss of water in permanent pools occurred, with a resultant loss of creek biodiversity. Therefore the proposed use of these monitoring records as a baseline for future health of this creek (as proposed in the AEMR) would be misleading.
    1.2 Piezometer Records:
    It appears that a study of aquifers and groundwater conditions was not a prerequisite for original mining approvals and without pre-mining records it is not possible to get a comparison for an accurate picture of damage to sub-strata and aquifers. While Xstrata was not involved with the initial investigation the company's experience with mining in similar strata and depths in other locations may assist an interpretation of the more recent studies.
    The AEMR refers to an increased number of piezometers measuring groundwater levels in the future but only piezometers P1 and P2 can give an indication of groundwater movement in the vicinity of completed long walls at the time they were mined.
    2.3 What is the current understanding of the source of the 2.5M1/day flows into the mine workings. If from surrounding aquifers what would be the expected effects on the environment?
    2.4 It is reasonable to assume the early cessation of groundwater flows into Myrtle Ck and loss of permanent pools after rain events is a consequence of the inability of near surface aquifers to retain stormwater due to subsidence cracking? Can the creek ecosystem be recovered and are similar consequences expected for Redbank Creek once it's been undermined?

E-mail David Hunt, 2/12/2010

PHILIP PELLS
FTSE BSc(Eng) MSc DSc(Eng) FIEAust MASCE

REFERENCES

Fanning, Patricia (1982) “The Origin of Thirlmere Lakes, NSW. “Australian Geomorphology Conference, Uni Wollongong, August 1982

Bishop, P, Hunt, P and Schmidt, P. “The Age of Folding of Hawkesbury Sandstone on the Lapstone Monocline”. Australian Geomorphology Conference, Uni Wollongong, August 1982.

Black, M. P, Mooney, S.D. and Martin, H.A. “a > 43,000 – year vegetation and fire history from Lake Baraba, New South Wales, Australia” Quaternany Science Review, 25 (2006) 3003-3016, Elsevier.

APPENDIX B

PROGRESS REPORT NO. 2
11 MAY 2011

ABN 74 978 620 434
Phone: 02 4381 2125
Fax: 02 4381 2126
49 Lakeside Drive
MacMasters Beach NSW 2251
www.pellsconsulting.com.au

THIRLMERE LAKES

PROGRESS REPORT NO.2
11 MAY 2011

1. INTRODUCTION

Our Progress Report No.1 of 8 December 2010 set out the tasks that are being undertaken in this independent study of factors that may have impacted on the water levels in the Thirlmere Lakes between about 2005 and the present time. The work presented in Progress Report No.1, and in this report forms part of the collection of basic data needed to undertake the analytical study of the influences controlling lake water levels.

This report does not repeat any of the information given in Progress Report No.1. The information given in this report comprises:

1. Data regarding historical water levels obtained mainly from old aerial photographs purchased from the Department of Lands, but also some terrestrial photographs taken by members of the public. This information is being summarised in a spreadsheet which will be added to as the study progresses.

2. Data regarding ground water monitoring in the area, this being information contained in the Xstrata Tahmoor Colliery Annual Environmental Management Report covering the period May 2009 and April 2010.

3. Results of preliminary physical modelling and numerical analysis conducted to gain an understanding of the probable impacts of longwall mining on ground water regimes in the Southern Coalfields.

4. Collection of further rainfall data and analysis to categorise the post-2000 drought in relation to early droughts, such as that between 1940 and 1944.

The information obtained in regard to each of the above 4 points is summarised in the following sections of this report.

For ease of reference, Figure 1 shows the layout of the Tahmoor Colliery as of about mid 2010.

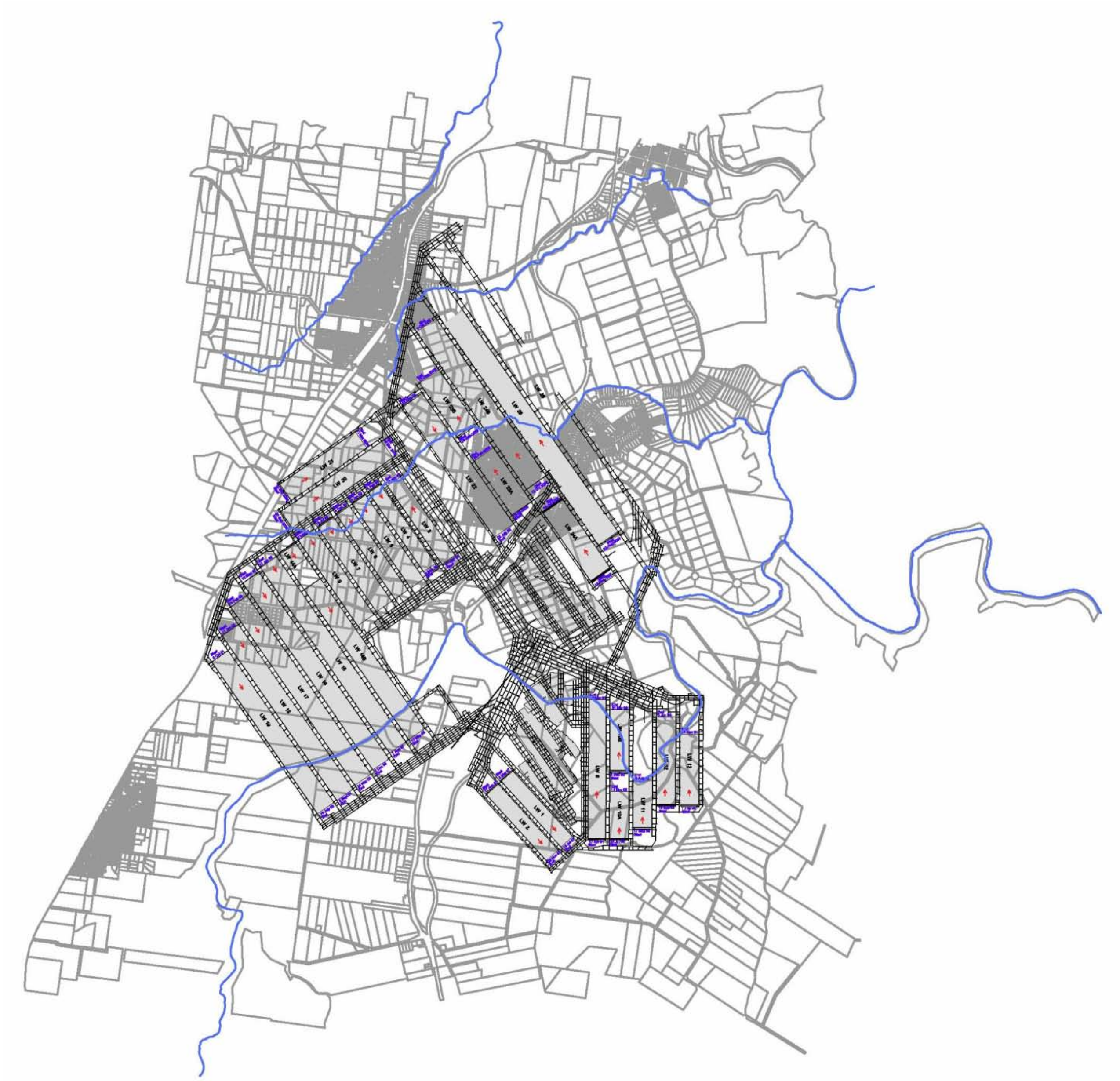


Figure 1: Layout of the Tahmoor Colliery as of about mid 2010.

2. HISTORICAL WATER LEVELS

Aerial photographs were bought from the Department of Lands for the following dates:

- 22 March 1966;
- 2 April 1975;
- 27 October 1983;
- 4 January 1994; and
- 20 December 2005.

In addition, aerial photographs are available on Google Earth for 2009 (partly obscured) and 2010. The relevant portions of these photographs have been extracted and reproduced in Figures 2 – 8 below.

Figure 2: 22 March 1966.

Figure 3: 2 April 1975.

Figure 4: 27 October 1983.

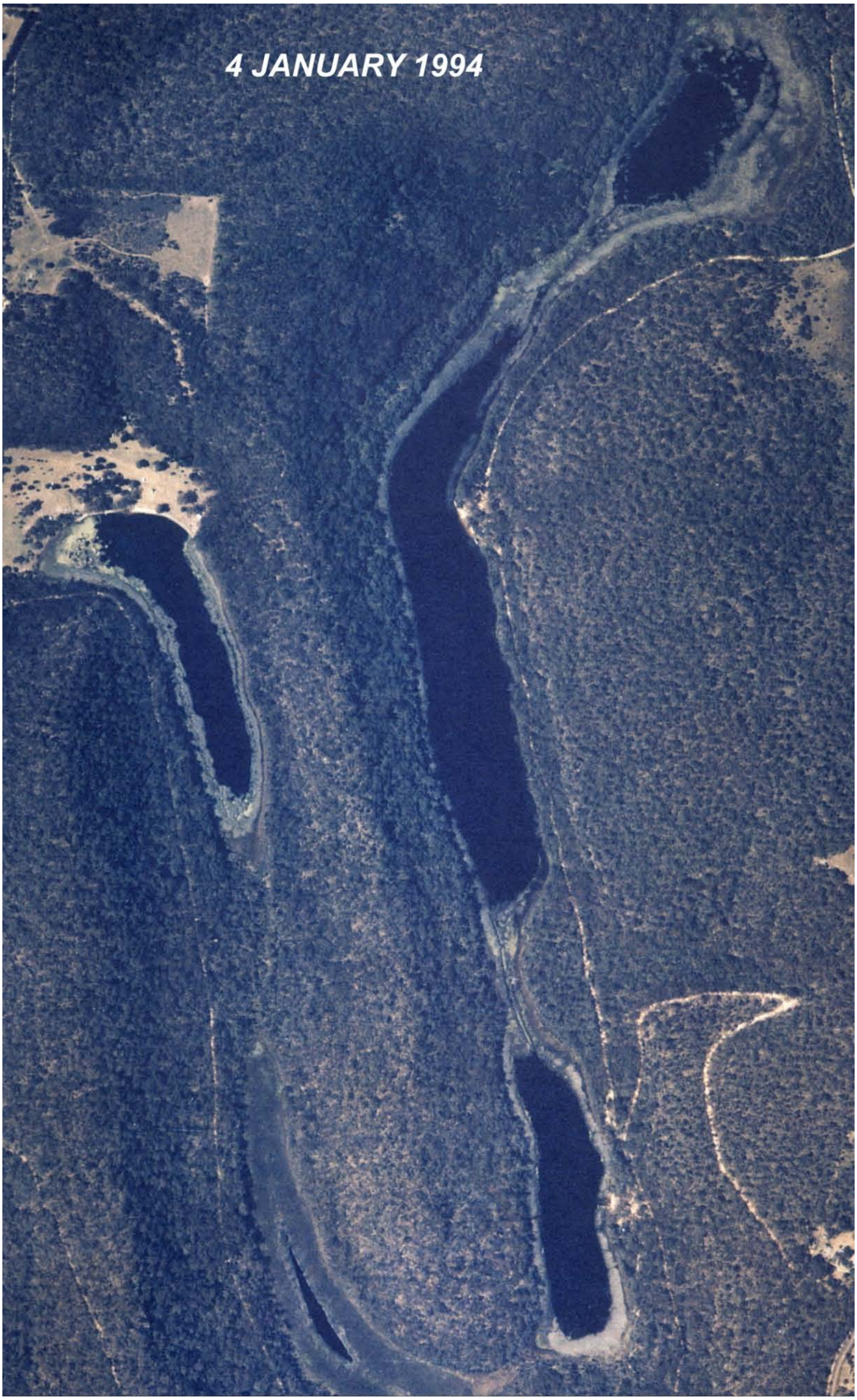


Figure 5: 4 January 1994.

Figure 6: 20 December 2005.

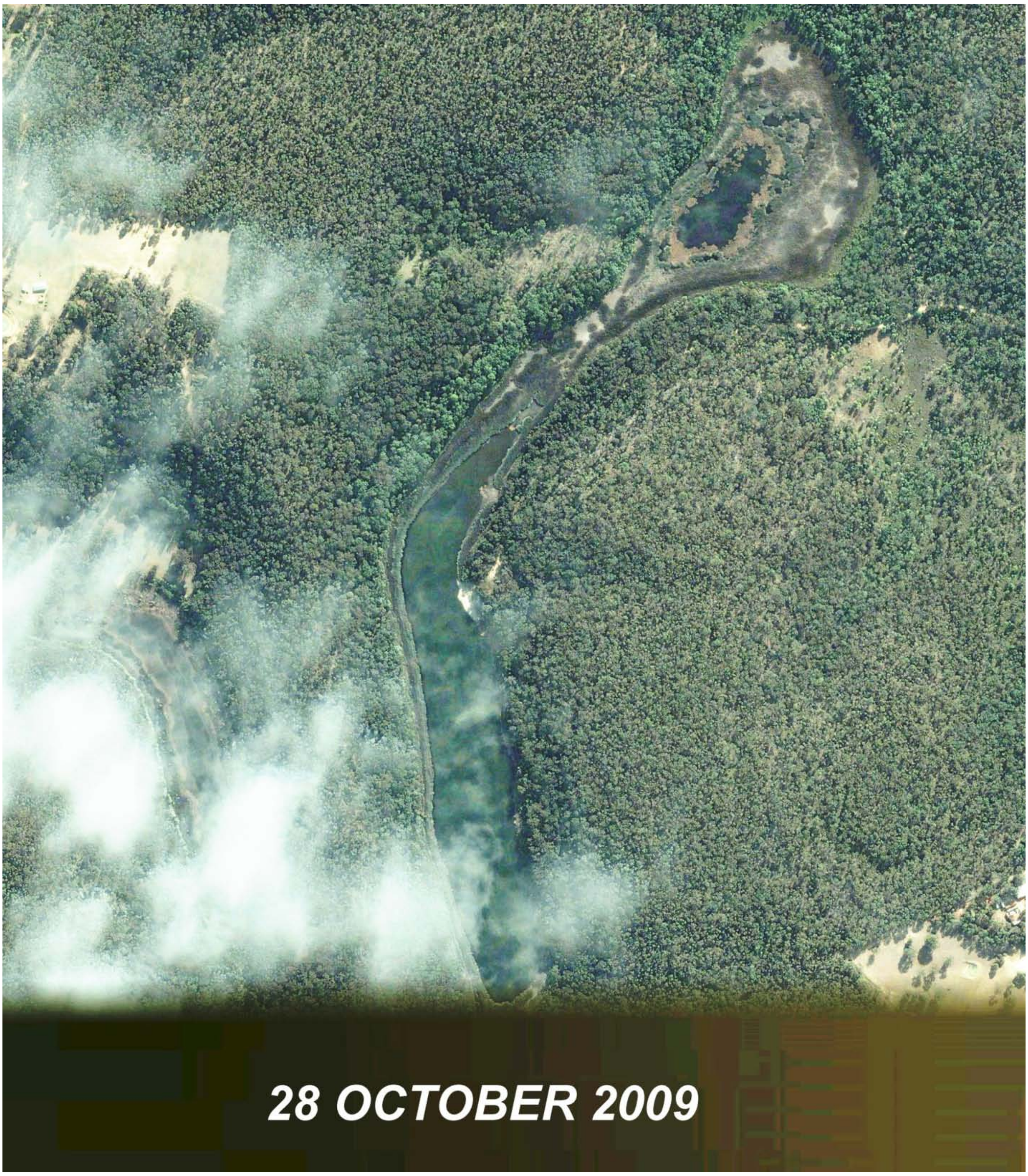


Figure 7: 28 October 2009 (partly obscured).

Figure 8: 13 April 2010.

Some further terrestrial photographs have been received showing lake levels in 1984, 1989 and 2002. These photographs are reproduced in Figures 9 to 13 below.

Figure 12: Lake Couridjah, April 1984, David Hunt photo.

Figure 10: Lake Couridjah, January 1989, David Hunt photo.

Figure 11: Lake Couridjah, January 1989, David Hunt photo.

Figure 9: Lake Couridjah, April 1989, David Hunt photo.

Figure 13: Lake Nerrigorang after fire 2002, Johanessen photo.

It is not possible to determine the volume of water stored in the lakes at different times. So it has been decided to express the amount of water stored in the lakes by comparing the widths of the stored waters with the maximum widths, at the different times. Figures 14 and 15 show the points in Lakes Couridjah and Werri Berri, here the widths have been used to express the amount of water stored at different times.

Figure 14: Lake Couridjah – 13 April 2010

Figure 15: Lake Werri Berri – 13 April 2010

The factual data with respect to the amount of storage at different times is summarised in Table 1, which is a spreadsheet that will be added to as further data becomes available.

TABLE 1
INFORMATION ON LAKE LEVELS

THIRLMERE LAKE LEVEL OBSERVATIONS

DATE	LAKE NAME	OBSERVATION	PERSON OR DATA SOURCE
22/03/66	Werri Berri	Full	Dept Lands Air Photo
22/03/66	Couridjah	Full	Dept Lands Air Photo
2/04/75	Werri Berri	Full	Dept Lands Air Photo
2/04/75	Couridjah	Full	Dept Lands Air Photo
27/10/83	Werri Berri	Full	Dept Lands Air Photo
27/10/83	Couridjah	Full	Dept Lands Air Photo
10/04/89	Couridjah	Full	Hunt photo
30/11/89	Couridjah	>95% Full	Hunt photo
4/01/94	Werri Berri	Full	Dept Lands Air Photo
4/01/94	Couridjah	90% to 95% Full	Dept Lands Air Photo
20/12/05	Werri Berri	Full	Dept Lands Air Photo
20/12/05	Couridjah	>95% Full	Dept Lands Air Photo
13/06/08	Werri Berri	Water level high	Julie Shepard photo of canoe

THIRLMERE LAKE LEVEL OBSERVATIONS			
DATE	LAKE NAME	OBSERVATION	PERSON OR DATA SOURCE
31/10/09	Werri Berri	At 76% of full width at the widest part	Google Earth photo
31/10/09	Couridjah	At 84% of full width at widest part	Google earth photo
13/04/10	Werri Berri	At 50% of full width at widest part	Google Earth photo
14/04/10	Couridjah	At 72% of full width at widest part	Google Earth photo
13/10/10	Couridjah	Level at base of 4th (upper) post of old burnt out jetty	Julie Shepard photo

On 9 May 2011 the writer undertook accurate DGPS survey of water levels and the marker position in Lake Couridjah used by Rivers SOS. The survey used the Omnistar signal, giving an X, Y, Z accuracy of better than 0.1m. The level in Lake Couridjah was measured at RL303.7m and in Lake Werri Berri at RL303.8m.

3. GROUND WATER MONITORING BY XSTRATA

The available data is given in addendum A which is an extract from the Xstrata report dated May 2009 to April 2010.

At this time no analyses have been taken of this data. It is expected that further information on private water bores will be obtained as the study progresses.

4. REPORT BY NSW OFFICE OF WATER

In 2010 a report was produced by the NSW Office of Water titled “Thirlmere Lakes, groundwater assessment”. That report contains some factual information that adds to the currently available body of knowledge.

Figure 16 shows the Department’s documentation of the history of longwall mining at Tahmoor Colliery. Figure 17 shows the Department’s interpreted regional groundwater flow model, which the writer considers to be appropriate.

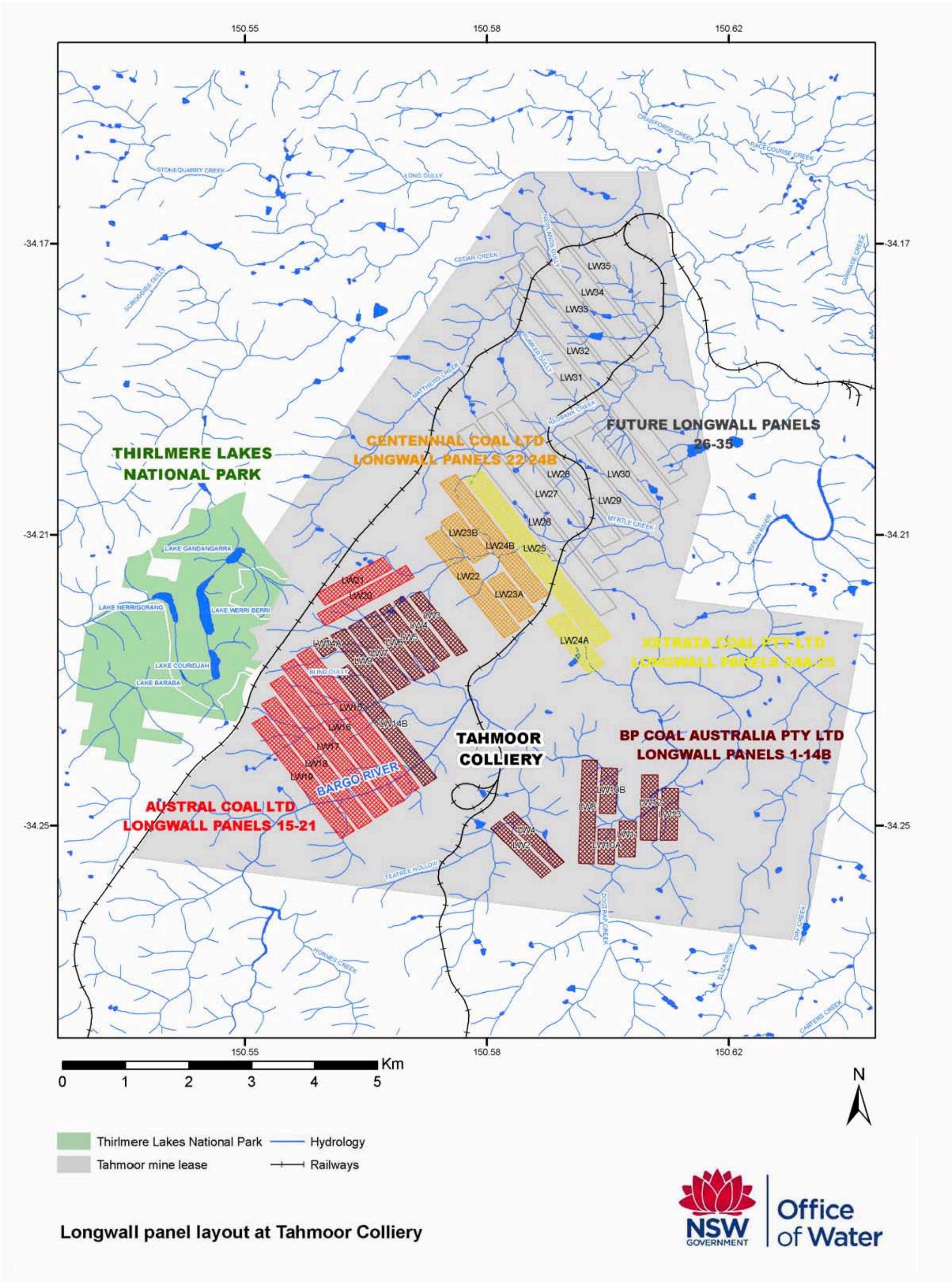


Figure 16: History of longwall mining at Tahmoor.

Figure 22 Conceptual regional groundwater flow systems

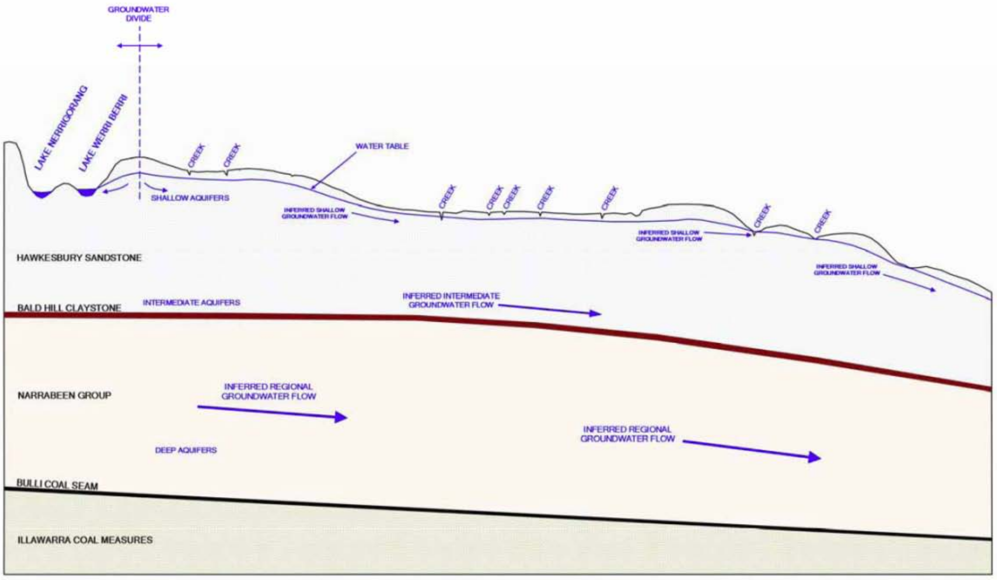


Figure 17: Office of Water regional groundwater flow model.

Figure 18 summarises the Department’s analyses of quantity of water pumped from Tahmoor Colliery between 1995 and 2010. It can be seen that since 2002 the pumping rate has averaged about 1400 million litres per year. This is equivalent to 44 litres per second, which is about equal to 200 garden taps at full flow.

The Department’s analysis of regional groundwater monitoring bores, and its summary of licensed groundwater entitlements in the area is given in Addendum D.

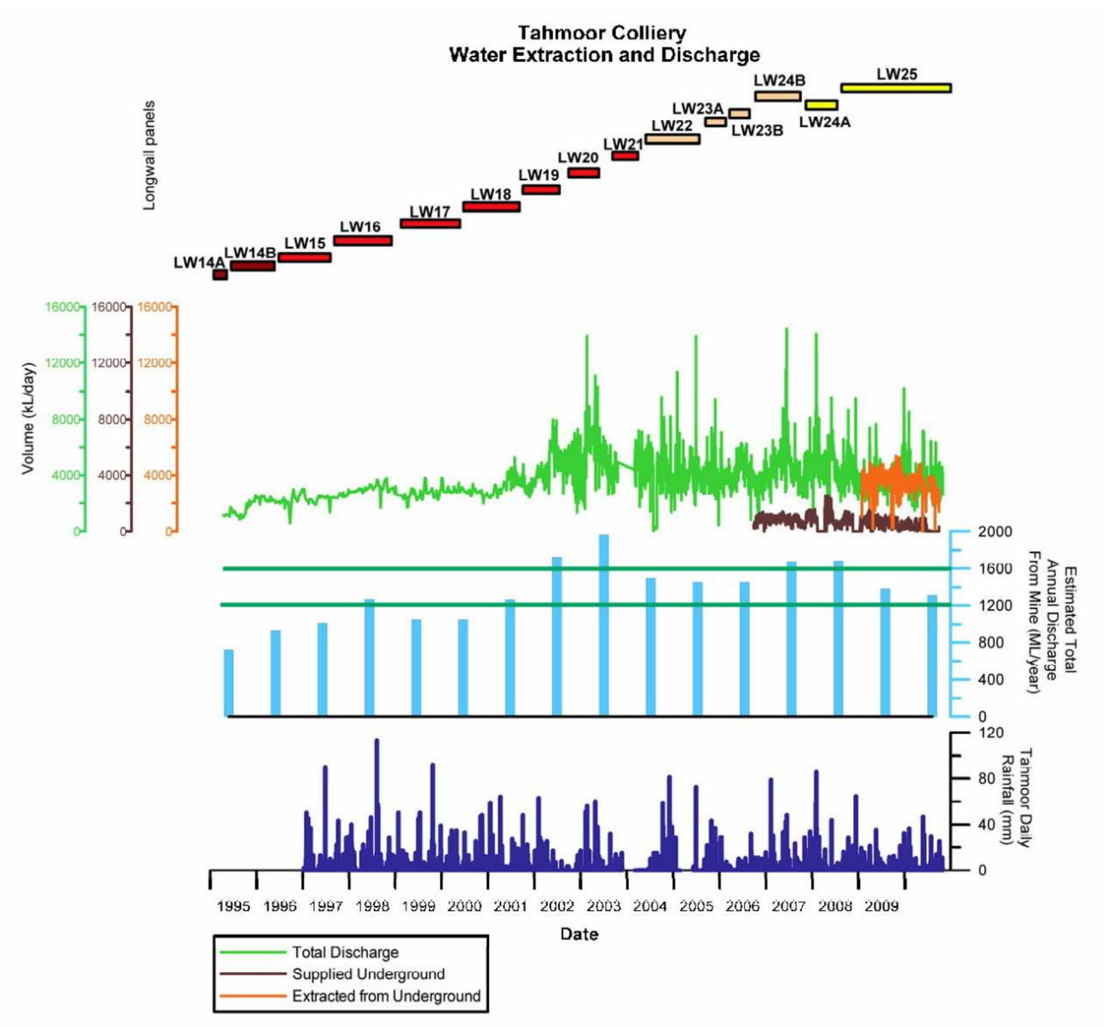


Figure 18: Quantity of water pumped from Tahmoor Colliery.

5. LABORATORY AND NUMERICAL STUDIES

This work is in progress and a draft copy of a report that is being progressive developed is given in Addendum B.

6. DROUGHT ANALYSIS

For the present purpose drought is considered only in terms of rainfall. Other factors, such as temperature, play roles in humans' responses to rainfall deficits.

Rainfall records for the area have been developed from the following primary sources:

- Picton council rainfall record which goes back, with some gaps, to 1889;
- Parramatta rainfall record that commences in 1832 but has gaps until 1858
- Racklyeft family records from Lake Nerrigorang from 1987 to 1997
- Queensland Gov. of Natural Resources Data Drill records created for the Thirlmere Lakes from 1889, based on interpolation from all surrounding records.

The writer has extended the Drill records back to 1858 in order to extend the drought analysis present in Progress Report No. 1. A comparison of the Drill record with the Racklyeft records at Lake Nerrigorang shows good agreement for the period 1987 to 1997. Drought analysis from 1889, using the Drill record, gives the same answers as using the Picton Council records.

Progress Report No.1 discussed the recurrence intervals (frequency) of droughts with durations up to 1 year. It is reasonably obvious (see Office of Water report of December 2010) that the Lakes would be affected by longer duration droughts. At this time we have considered droughts of 3 year and 5 year duration.

Table 1 gives the ranking of independent 5 year duration droughts. By 'independent' is meant drought sequences that were quite separate events. The worst two droughts were the 'Federation Drought' and the 'WW2 Drought'. The 5 year drought ending 2006 is ranked No.6.

TABLE 1
RANKING OF INDEPENDENT 5 YEAR DURATION DROUGHTS AT THE THIRLMERE LAKES

INDEPENDENT 5-YEAR DROUGHT ENDING	TOTAL RAINFALL (mm)
1909	2487
1942	2543
1885	2912
1926	3025
1947	3191
2006	3231
1982	3350
1899	3396
1997	3543
1968	3611
1919	3711
1932	3811
1869	3826
1937	3890
1904	3921
AVERAGE 5 YEAR RAINFALL	4021mm

A good idea of the severity of particular drought periods is gained when one considers 'overlapping' 5 year droughts. This is illustrated in Table 2. This table shows clearly that whilst the period 1905-1909 (Federation Drought) was the worst 5 year drought, the WW2 period generated the next five worst, but overlapping, 5 year drought periods. The drought of 2002 to 2006 only comes in at No.21.

TABLE 2
OVERLAPPING 5 YEAR DROUGHTS

YEAR RANGE (OVERLAPPING DROUGHT YEARS)	CUMULATIVE RAINFALL (mm)
1905-1909	2487.3
1938-1942	2542.5
1940-1944	2543.5
1939-1943	2544.5
1941-1945	2545.5
1937-1941	2546.5
1881-1884	2912.5
1904-1908	2918.7
1936-1940	2942.8
1882-1886	2954.0
1942-1946	2992.8
1922-1926	3024.7
1906-1901	3025.8
1935-1939	3055.5
1880-1884	3056.6
1884-1888	3128.8
1902-1906	3144.4
1907-1911	3164.5
1901-1905	3182.4
1943-1947	3190.7
2002-2006	3231.0
1944-1948	3235.3
1903-1907	3263.6
1920-1924	3271.4
1908-1912	3314.3
1978-1982	3350.3

Table 3 shows the ranking of 3 year duration independent droughts. In this case the three year period ending 1941 was worst, the Federation Drought second, and the three year ending 2004 ranks 8th.

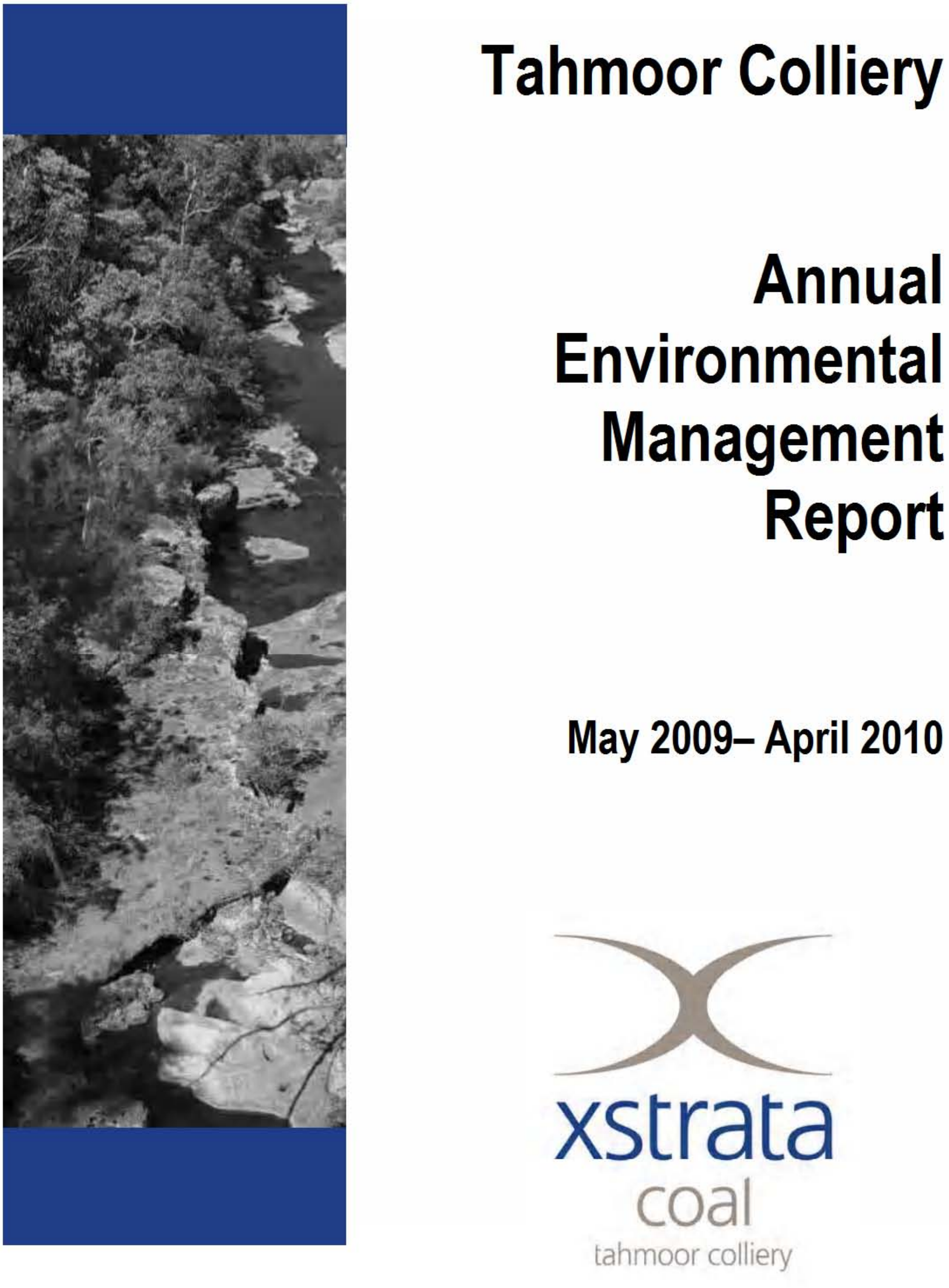
TABLE 3
3 YEAR DURATION INDEPENDENT DROUGHTS

YEAR ENDING 3-YEAR DROUGHT	CUMULATIVE RAINFALL (mm)
1941	1317
1909	1464
1924	1658
1886	1680
1944	1732
1903	1755
1982	1822
2004	1832
1883	1847
1897	1876
1906	1919
1920	1920
1938	1921
1994	1963
1947	2043
2010	2087
1967	2149
1930	2182
1876	2212
1979	2217
1927	2227
1997	2234
1867	2262
1913	2262
1959	2278
1889	2396
2001	2398
1973	2407
AVERAGE 3 YEAR RAINFALL	2412

In due course it is hoped that data on historical lake levels can be related to the drought analysis to gain an understanding of the natural hydrological processes impacting on lake levels.

ADDENDUM A

EXTRACTS RELEVANT TO GROUND WATER FROM THE TAHMOOR COLLIERY ANNUAL ENVIRONMENTAL MANAGEMENT REPORT MAY 2009 – APRIL 2010



Tahmoor Colliery

Annual Environmental Management Report

May 2009– April 2010

xstrata
coal
tahmoor colliery

3.9.9 Groundwater

3.9.9.1 During Reporting Period

To maintain a safe and efficient mine environment, the colliery needs to dewater, or remove, the incidental water make into the mine workings. This activity is required to be licensed and as such, application was made to the Department of Water and Energy (DWE) on 30 November 2007 to licence the colliery mine dewatering activities under Part 5 of the Water Act 1912. A licence was granted for each dewatering line (Licence numbers 10BL60233, 10BL602336 and 10BL602337 on 27 May 2008.

During the reporting period the colliery conducted volume monitoring of the dewatering lines as per the licence conditions.

Three groundwater monitoring sites (piezometers installed) were installed in the lease area during the reporting period to extend the groundwater monitoring network (see **Section 4.16.2**).

A Groundwater Management Plan was submitted to the Office of Water for review and approval (Refer "Tahmoor Colliery Groundwater and Management Plan and Annual Report", Geoterra 2009). The Groundwater Management Plan will assist the colliery in utilizing the monitoring network to better assess the level of impact of mining on local groundwater systems, predict groundwater ingress into the mine and the subsequent impact to the operation, and therefore develop appropriate management actions and mitigation measures.

3.9.9.2 Next 12 Months

As required by the licence conditions an Annual Report is being finalised for submission to the Office of Water. This will occur early in the next reporting period.

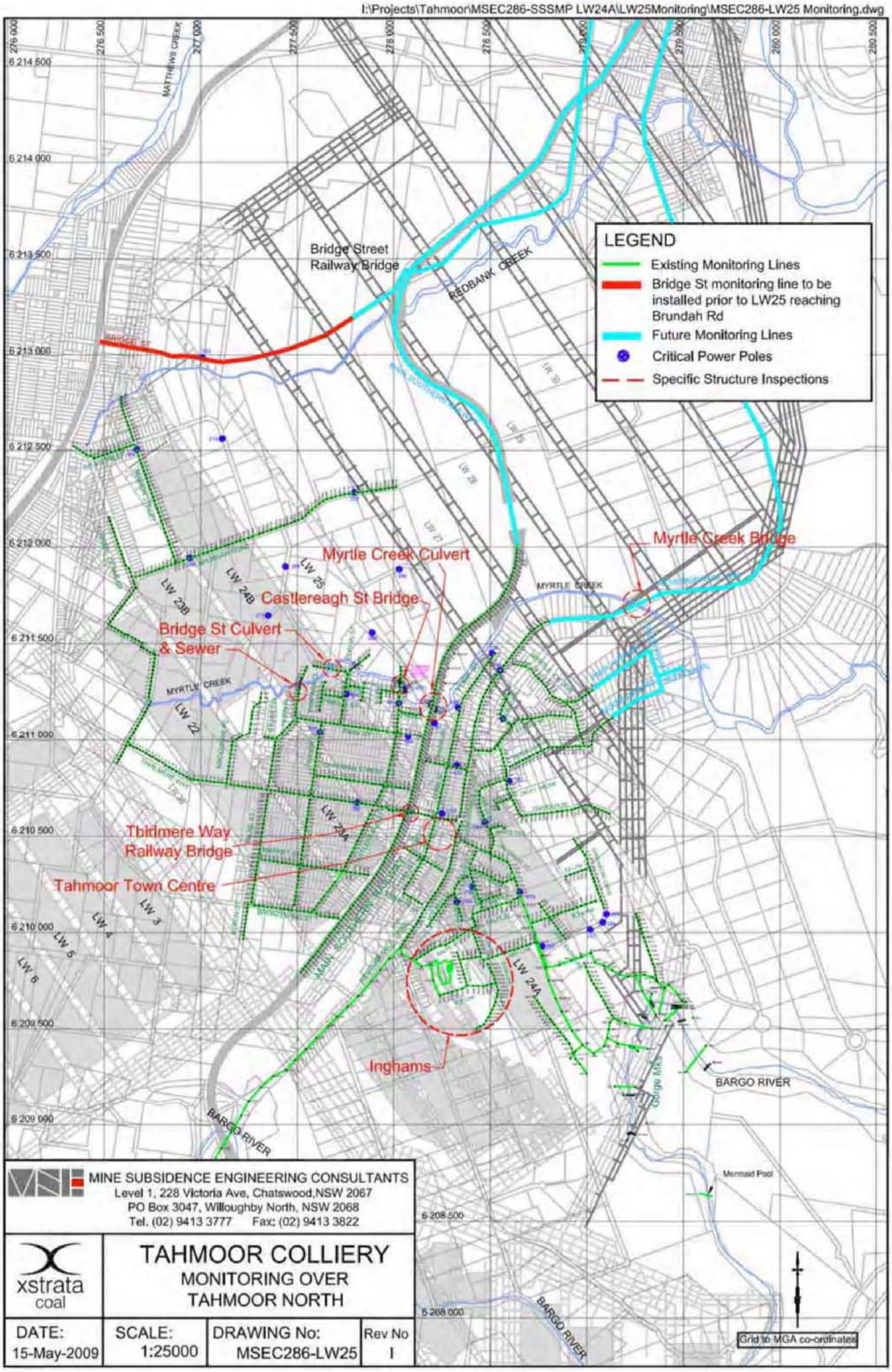


Figure 5 Tahmoor Colliery Subsidence Survey Monitoring Network

Groundwater

Groundwater monitoring over longwall extraction has been undertaken systematically since 2004. The groundwater monitoring network is shown in **Figure 6** below.

Regular manual and data logger based standing water level monitoring in the study area began in June 2004 with the drilling of P1 by the colliery, which is located on the southwest periphery of Panel 22, with water levels monitored every 12 hours.

Piezometers P2 and P3 also have water levels monitored at 12 hourly intervals in remnant coal exploration bores over Panel 23B and the chain pillar between Panels 25 and 26.

Piezometer P4 is a manually monitored bore in an undeveloped, unsecured block of land, 300m northeast of Panel 26.

Piezometer P5 is a disused private bore 950m North West of Panel 26 that was used for general domestic / irrigation water, with water levels logged at twelve hourly intervals.

Piezometer P6 was originally drilled as a water supply bore for the Jay-R-horse stud, 1.1km east of Panel 26, however it was never used as the water was too deep. The standing water levels are manually monitored in P6.

The "Douglas" private bore is located 450m south of Panel 24A over ground that has only been undermined by first working driveages, whilst the "McPhee" private bore is located over Panel 26, which has not yet been mined. Both the private bores do not have suitable access into the bore wellhead, and as a result, standing water levels are not currently monitored. Both bores are used for domestic garden water supply.

Piezometers P7 and P8 are located within the Inghams Turkey property, and lie between the eastern end of Panels 25 and 26 and the Bargo Gorge.

Four further monitoring boreholes (TNC 28, 29, 36, and 43) containing vibrating wire piezometers at various water bearing zones above the target mining seam were established during the reporting period.

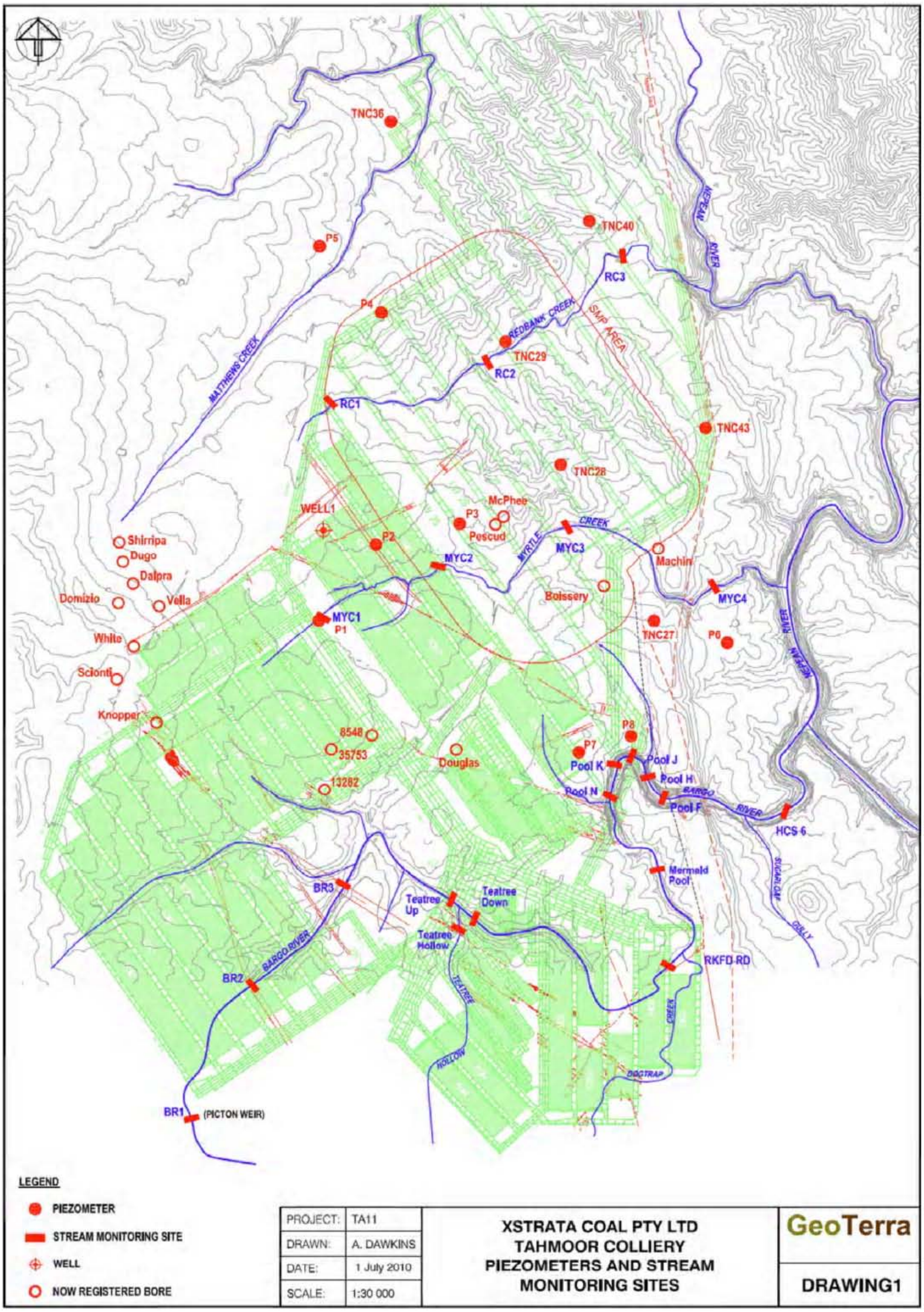


Figure 6 Tahmoor Colliery Groundwater Monitoring Network

Groundwater

Monitoring data from the open standpipe piezometers and private bores (P1 to P8) is shown in **Figure 7**.

Between August 2004 and June 2007, Piezometer P1 depressurised by approximately 5.6m, then recovered by approximately 1.8m up to August 2008 during the extraction of Longwalls 22 to 24. Since Longwall 25 began in late August 2008, P1 has depressurised by approximately 0.9m.

Depressurisation and subsequent recovery occurred over the northern end of Longwall 23B in piezometer P2 in three stages between January 2005 and April 2008, for a total maximum drawdown of approximately 8.4m. The bore recovered to marginally above its original (pre December 2004) water level between April 2008 and July 2009. Since July 2009, P2 has depressurised by approximately 3.8m during the Longwall 25 extraction period.

Between May 2005 and November 2009, P3 rose from approximately 50.8 – 35.8m below surface. Since November 2009, during the Longwall 25 extraction period, P3 depressurised by approximately 5.25m and then recovered to around 36.9m below surface.
During the extraction period of Longwalls 22 to 24, Piezometer P4 had a relatively stable water level up to June 2008. Since June 2008, P4 depressurised by a maximum of approximately 0.75m, with a partial recovery since then of approximately 0.32m.

Since May 2005, P5 has not shown a consistent rise or fall in water levels, although has been wavering between approximately 23 and 26m below surface. Similarly, P6 has been relatively stable at around 94 to 95m below surface.

Since its pre Longwall 25 installation in June 2008, P7 has risen by approximately 7.6m up to late September 2008, then fallen by 5.95m and subsequently recovered by approximately 2.0m up to the end of May 2010. The recovery trend in P7 is still occurring.
Since its June 2008 installation, prior to the start of Longwall 25, P8 has risen by approximately 1.8m.

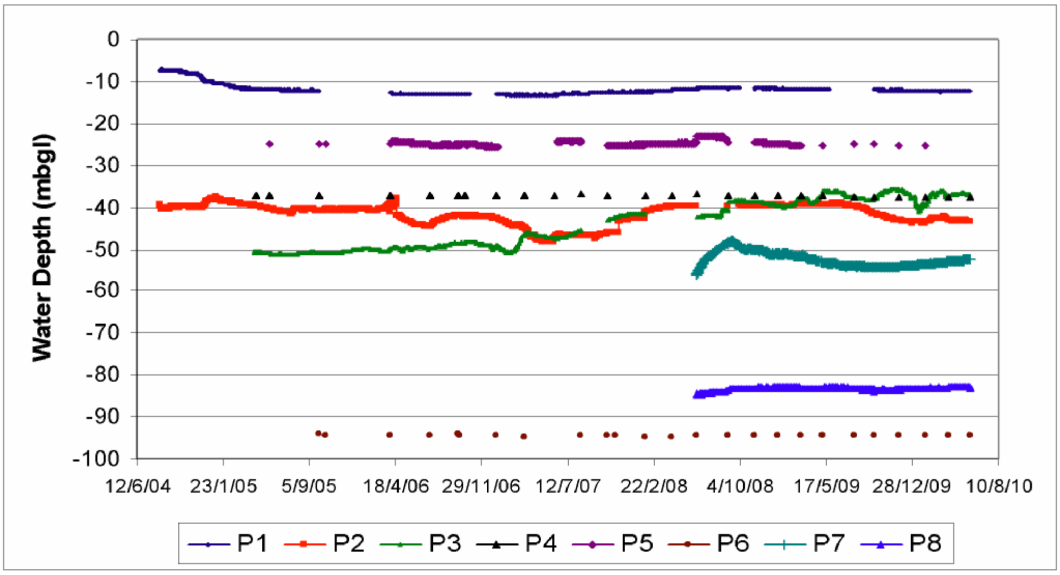


Figure 7 **Standpipe Standing Water Levels, Rainfall and Longwall Advance**

Monitoring data from the vibrating wire piezometers TNC28, 29, 36 and 40 as shown in **Figures 8 to 11** indicate the following; (Note there is no vibrating wire piezometer (VWP) array in TNC27 as the bore collapsed after packer testing and that none of the VWPs have been undermined to date)

TNC28 (since installation on 28/8/08)

- Hawkesbury Sandstone (intake 95mbgl) - relatively static
- Hawkesbury Sandstone (intake 165.1mbgl) – 3.7m rise
- Bald Hill Claystone (intake 245mbgl) – similar trend to lower Hawkesbury Sandstone with a maximum depressurisation of 5.4m and subsequent partial recovery with an overall total fall of 1.2m
- Bulgo Sandstone (intake 270mbgl) – approximately 7m depressurisation
- Scarborough Sandstone (intake 430mbgl) – 28.2m rise to March 2009, then subsequent gradual 3.75m fall
- Bulli Seam (intake 490mbgl) – 4.9m depressurisation since September 2008

TNC29 (since installation on 10/10/08)

- Hawkesbury Sandstone (intake 70.06mbgl) – 1.41m depressurisation
- Hawkesbury Sandstone (intake 195mbgl) – 13.2m depressurisation
- Bald Hill Claystone (intake 182.1mbgl) – similar trend to lower Hawkesbury Sandstone with a maximum depressurisation of 17.7m, although the majority of the fall would be due to the slow equilibration of the piezometer intake as the latter stage of the plot is relatively static to gradually falling
- Bulgo Sandstone (intake 215.1mbgl) – approximately 10.1m depressurisation
- Scarborough Sandstone (intake 382.6mbgl) – 12.12m rise to March 2009, then subsequent gradual 0.95m fall
- Bulli Seam (intake 441.6mbgl) – 5.7m fall up to late March 2009, then rapid recovery over a short 5 day period and subsequently relatively static up to May 2010

TNC36 (since installation on 4/9/09 - data missing between 22/9/09 and 11/4/2010)

- Hawkesbury Sandstone (intake 65mbgl) – relatively static
- Hawkesbury Sandstone (intake 97mbgl) – relatively static
- Bulgo Sandstone (intake 169mbgl) – relatively static
- Bulgo Sandstone (intake 214mbgl) – relatively static
- Bulgo Sandstone (intake 298.5mbgl) – relatively static
- Scarborough Sandstone (intake 412.5mbgl) – overall 4.8m rise
- Bulli Seam (intake 463.5mbgl) – overall 1.5m rise

TNC40 (since installation on 19/12/09)

- Wianamatta Shale (intake 27mbgl) – relatively static
- Hawkesbury Sandstone (intake 65mbgl) – relatively static
- Hawkesbury Sandstone (intake 131mbgl) – relatively static
- Hawkesbury Sandstone (intake 225mbgl) – 8m fall
- Bulgo Sandstone (intake 252mbgl) – 4.5m fall
- Bulgo Sandstone (intake 352mbgl) – 2.9m fall
- Scarborough Sandstone (intake 452mbgl) – 3.45m fall
- Bulli Seam (intake 463.5mbgl) – 2.75m fall

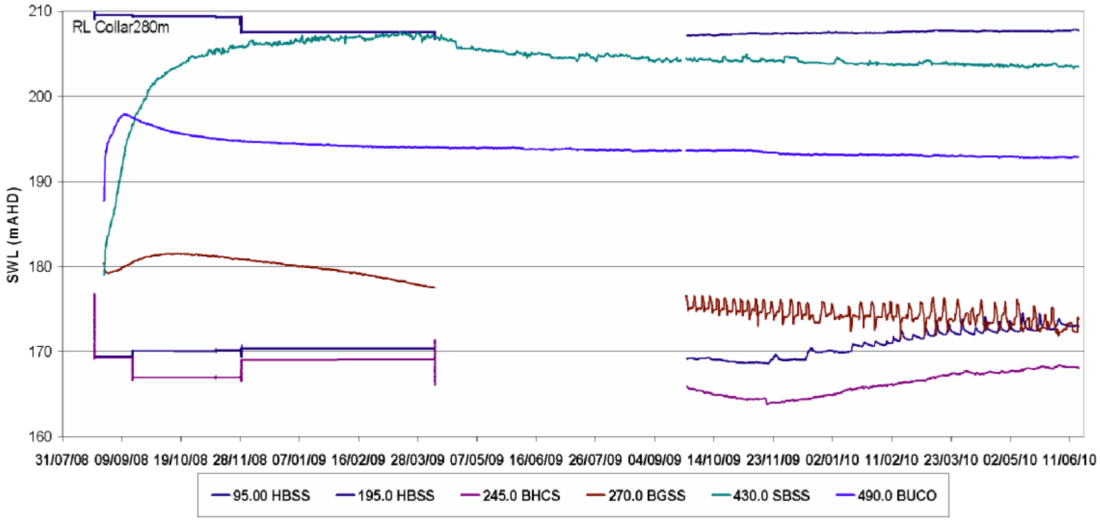


Figure 8 TNC28 Vibrating Wire Piezometer Groundwater Levels

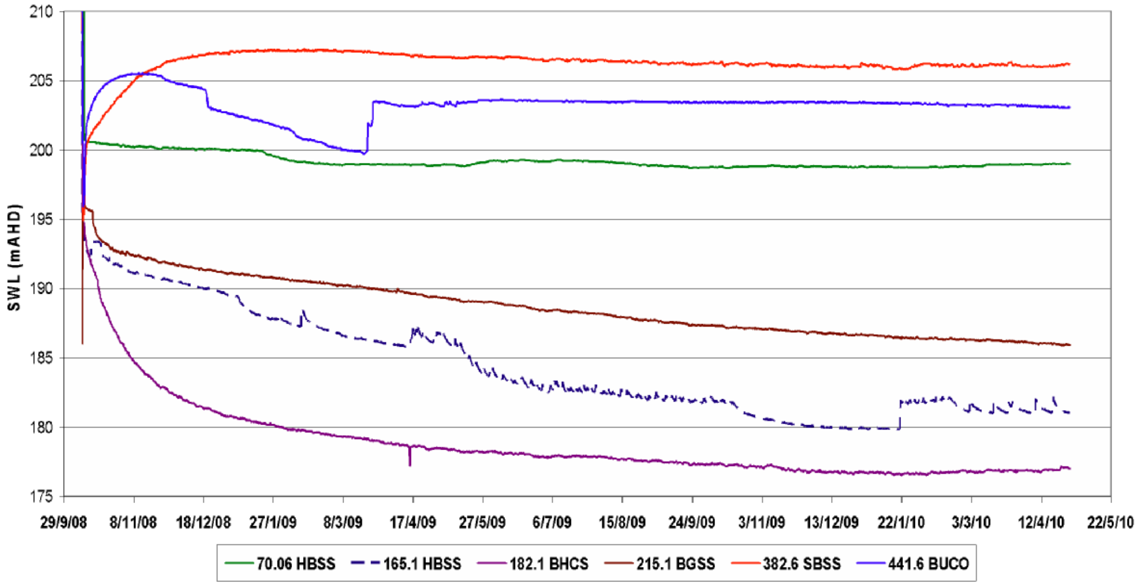


Figure 9 TNC29 Vibrating Wire Piezometer Groundwater Levels

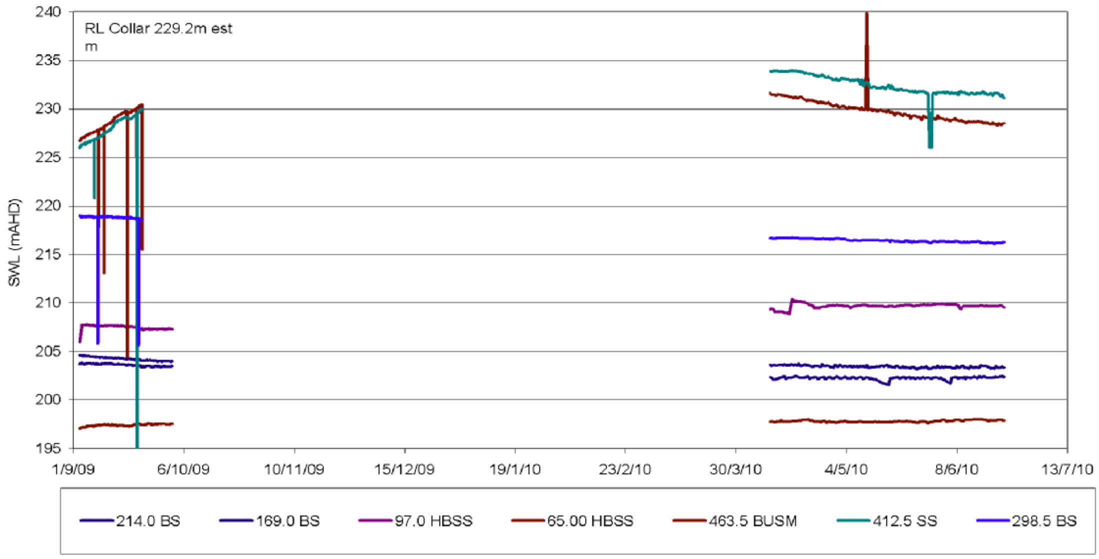


Figure 10 TNC36 Vibrating Wire Piezometer Groundwater Levels

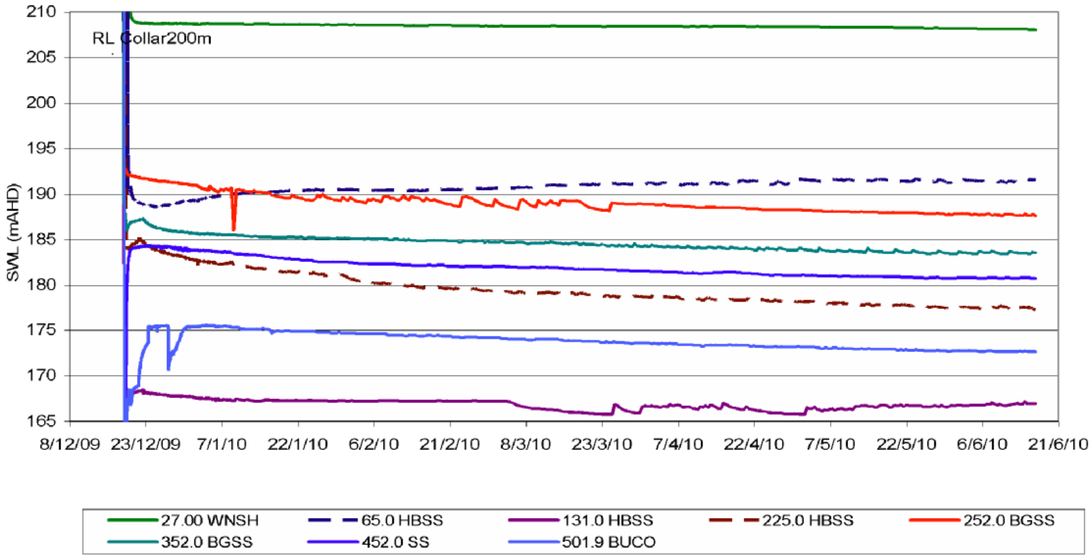


Figure 11 TNC40 Vibrating Wire Piezometer Groundwater Levels

ADDENDUM B

PARAMETRIC STUDY OF THE POSSIBLE IMPACTS OF LONGWALL MINING AREAS IN THE SYDNEY BASIN PROGRESS DOCUMENTATION

This document (in progress) sets out to provide some guidelines as to the possible impacts of longwall mining in the Sydney Basin. The analyses presented here are intended to allow practitioners to understand some of the fundamental factors controlling the impacts on the portion of the groundwater regime that impacts on bore water supplies, base flows to streams and rivers, and surface storages. This paper is not directed at estimating groundwater flows into mines – it is primarily directed at examining the changes in the groundwater pressure regime, i.e. the shapes of the equipotentials.

Figure 1 shows the outlines of completed and planned longwalls in the area around Appin in the Southern Coalfields. Obviously the groundwater regime in that area has been impacted by mining over many many years, and it is not the intention to deal with such a complex geometry. Rather the point of Figure 1 is to illustrate that in a typical set, the longwalls are 2km to 3km long and between 250m and 400m wide. In the Appin area the longwalls are at a typical depth of 450m. At Ulan, NW of Mudgee they are typically between 150m and 250m deep, and proposed longwalls in the Wyong area are about 500m deep.

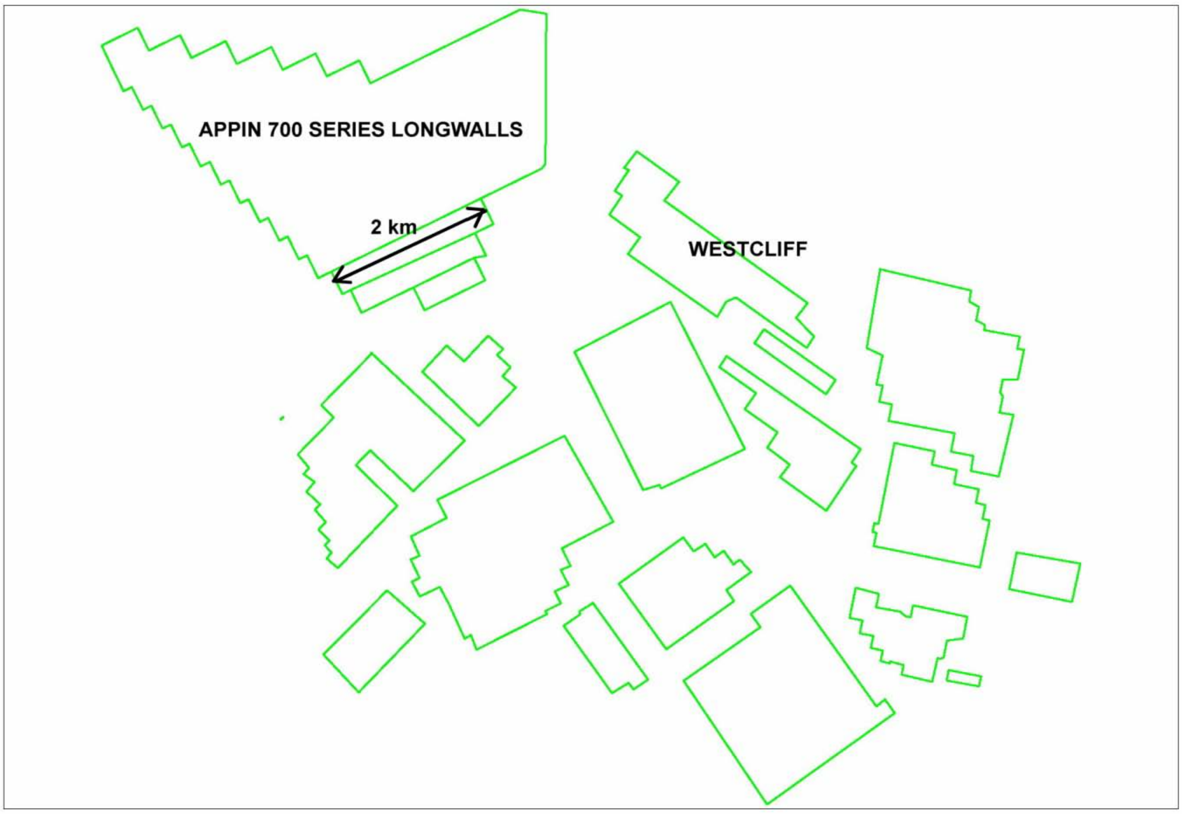


Figure 1: Outline of longwalls in Appin area of NSW Southern Coalfields

In this study we deal with a notional longwall system of 4 completed panels, having a cumulative width of 1200m and length of 3000km. The groundwater flow into such a longwall system is clearly three dimensional. Here we build up to the 3D solution by first exploring the 1D situation in the centre of the system, expanding to 2D across the four completed panels, and then reviewing 3D effects.

The analyses presented in this paper are based a physical model coupled with hand calculations for the 1D problem, the finite element program SLIDE6 for the 2D problem and the programs FEFLOW (3D finite elements) and MODFLOW (finite difference) for the 3D case.

It is generally accepted that the changes to the ground system above longwall system such as those in the Sydney coalfields are as shown in the flowing cartoon taken from a report by Mackie Associates

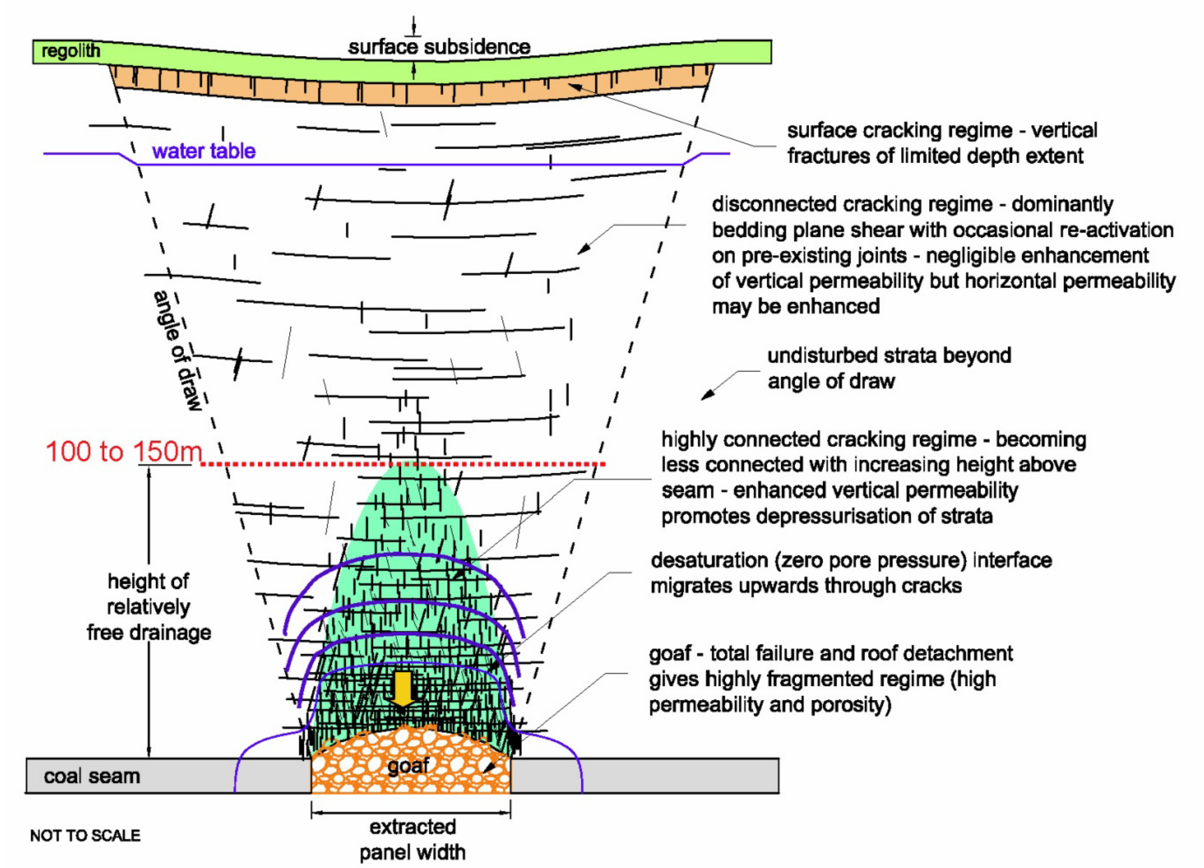


Figure 2: Cartoon of postulated impact of longwall mining

The thicknesses of the different zones do depend on the geology of the Triassic strata that overlie the Permian coal seams. For example, at Ulan, where the Triassic strata are dominantly sandstones, and where there are Jurassic sandstones, the experience is that cracking propagates from the seam to the surface, albeit in a complex pattern of non-continuous cracks. In the Southern Coalfields there are several argillaceous units in the Triassic, including the Bald Hill Claystone. These are less brittle than the sandstones and have a significant influence on the initial vertical permeability, and also the degree of increase in vertical permeability created by the subsidence process. North of the Hawkesbury River the Triassic strata have an even greater proportion of silt and clay rich strata.

I this paper we do not attempt to model the vagaries of reality – that must be left to project specific studies. Rather we have sought to cover the ranges of parameters and geometric changes that cover reality, and thereby explore what factors are of significance to impacts on the near surface groundwater regime.

Conceptually, and in two dimensions, the groundwater flow system above a very simplified version of Figure 2 is as per Figure 3a and Figure 3b.

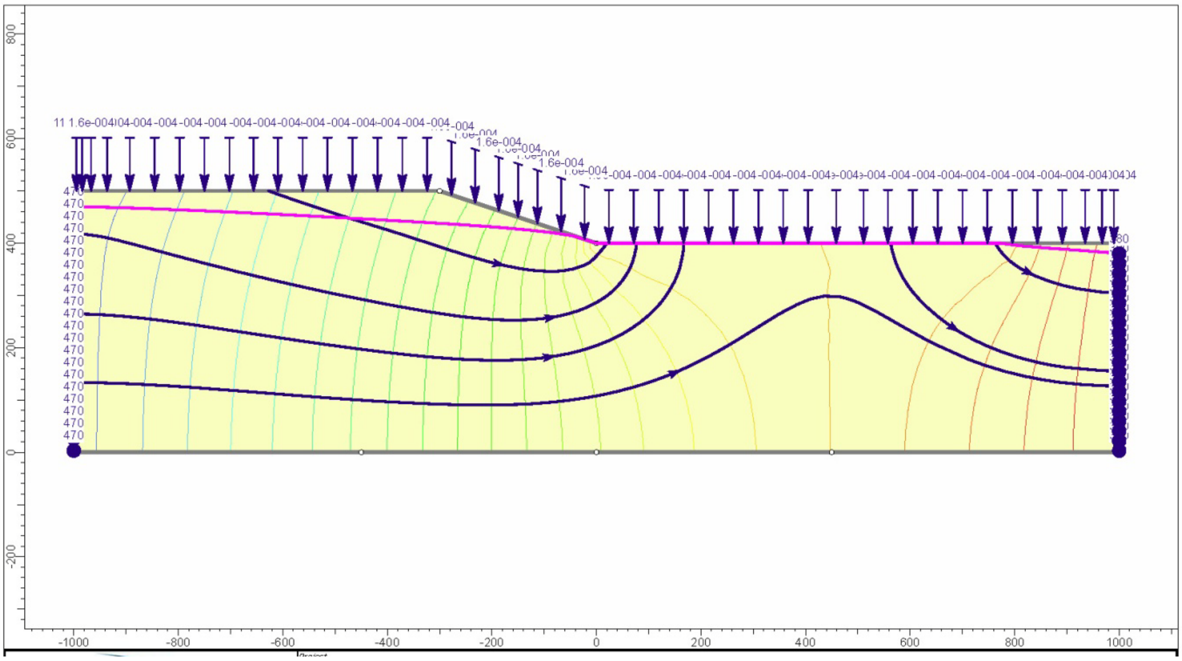


Fig 3a: flow regime prior to mining; 60mm/year infiltration assumed. Homogenous permeability with constant permeability regardless of matric suction

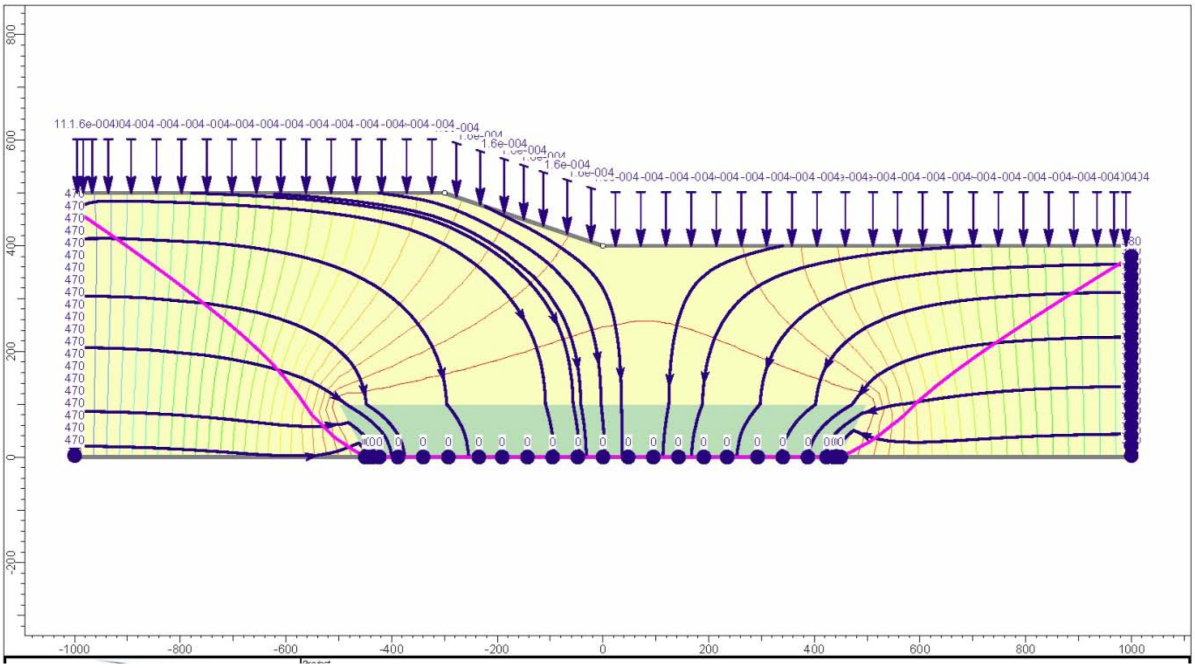


Fig 3b: Flow regime after mining 900m width of longwall panels. Goaf permeability 1000 times that of remainder of overburden, which is taken as being unaffected by mining; Permeability taken as constant regardless of matric suction.

It can be seen that there is a central zone where the flow is close to vertical downwards. Then there is horizontal flow into the sides of the set of longwalls and along the coal seam, which is typically much more permeable that the overlying strata. Finally there is drawdown of the groundwater in the Triassic strata extending outwards from the nominal boundary of the subsidence zone.

ONE DIMENSIONAL FLOW – CENTRAL AREA

We will consider first the apparently trivial, but in reality difficult, one dimensional flow in the central area. In this 1D world we have recharge at the surface, an upper zone (see Fig 2) of increased vertical permeability, a central zone where there may be no substantial change in permeability (but not at Ulan), and the goaf wherein there is a massive increase in permeability. From the base of this column the water cascades into the workings, i.e. the lower boundary is at atmospheric pressure.
What turns this problem from the trivial to the difficult is that the goaf zone is not saturated, and the unsaturated zone may extend, and in the Southern coalfields and at Ulan, does extend well above the goaf. Secondly, the surface recharge may or may not be less than the flow into initial vertical downwards flow.

We constructed an apparatus very similar to that used by Henry Darcy in 1855, which, as can be seen from Fig 4 is not like given in many text books as being Darcy's experiment.

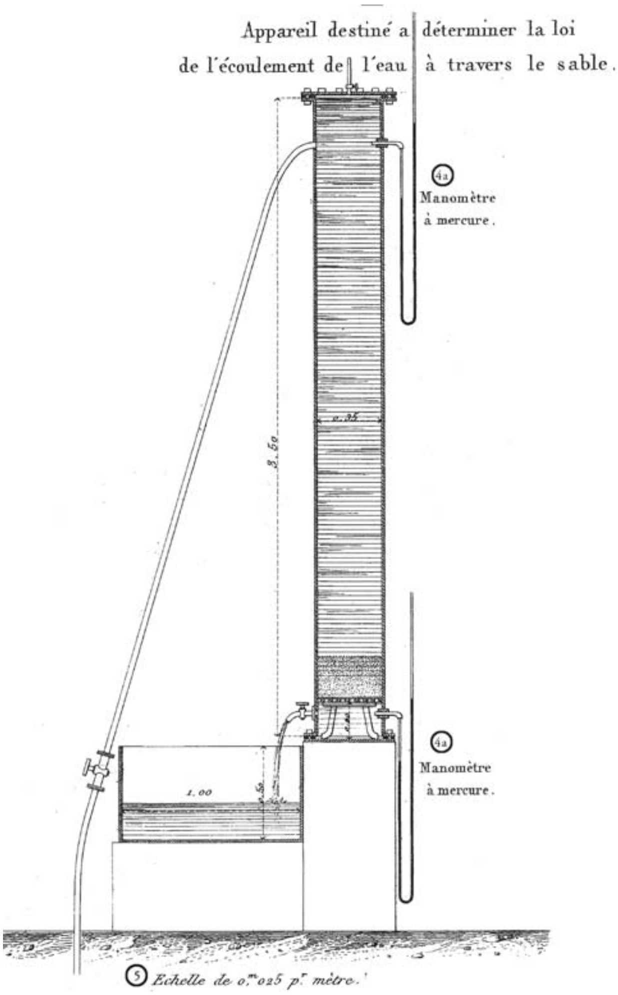


Fig 4: Darcy's experimental setup, 1855

Darcy's column was made of steel, with sealed bolted plates top and bottom.

Darcy used coarse sand quite similar to that we used in our tests and he did his initial tests with pressures at the top of the column of between 1m and 12m excess head, and free flow through a tap at the base. Subsequently his offsider, Ritter, repeated the experiments with excess heads between -3m and + 10m at the base. An important consideration is that there was no means for air to enter the sand column, even when Ritter had negative excess heads at the base.

Our column was made of Perspex, 240mm internal diameter. The sand column was just less than 2m high, and included 3 water monomers, 385mm; 781mm and 2183mm above the base of the sand (see Fig 5)

Fig 5: Apparatus before filling with sand; the Perspex column is full of water. The pipe on the right was to allow filling from the base under controlled conditions.

Figure 6 shows the flow from the column during the final test when flow was allowed to cascade from the base of the sand column.

Fig 6: Final test; water allowed to cascade from base of column. The equilibrium position was that the water level at the outlet flow point (atmospheric pressure) was 35mm above the level into which the water from the column was cascading, presumably flow head converted to static head.

The tests were conducted with a constant head of 215mm above the top of the sand. The initial tests maintained the head at the base equal to that level, therefore giving a head loss of 2.09m over the sand column of 1.875m (i=1.115), or with the outlet throttled so as to decrease the gradient which was then measured using the manometers. These measurements gave an average permeability of 2.0 to 2.1e-4 m/sec. Using the manometer measurements with throttled outlet indicated that the upper part of the column was slightly less permeable than the lower (2.36 versus 1.84 e-4 m/sec)

The interesting, and initially unexpected part of the experiment was when, with constant upper head level, the conditions at the base of the column were changed to cascading flow. (See Fig 5). Three things happened:

1. The total flow decreased by about 3% - consistently and repeatable
2. The pressures in the upper two manometers increased a small amount; about 5mm of water
3. The lowermost manometer, 385mm above the base, sucked in air and it could be seen through the Perspex that most of the lower part of the sand column contained void air.

This result, although counter-intuitive, can be explained, and had important implications when considering the problem of flow into a system of longwall panels. It arises out of the fact that the permeability to water flow of a soil drops dramatically as the soil contains more and more air, i.e.as the matric suction increases.

Our test can be reproduced by finite element analysis, as set out below.

Figure 7 shows the numerical model of the test, assuming a constant permeability of 2e-4 m/sec and a head at the base of the column equal to the elevation head.

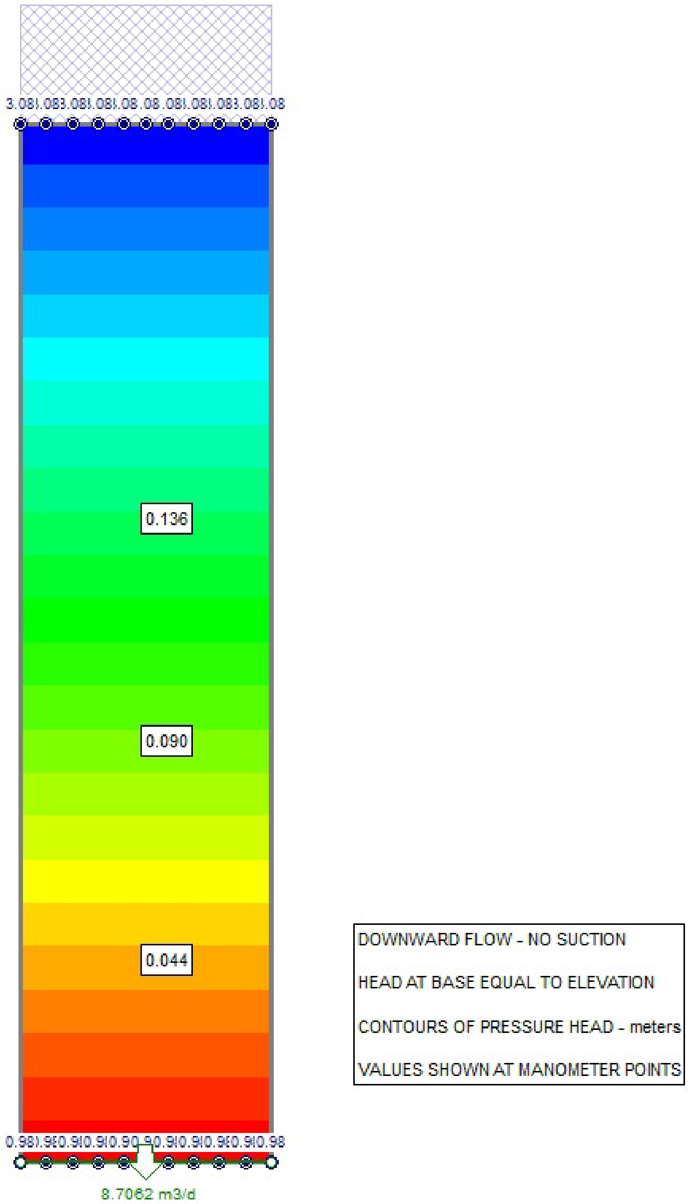


Fig 7: Constant permeability; head at base equal to elevation.

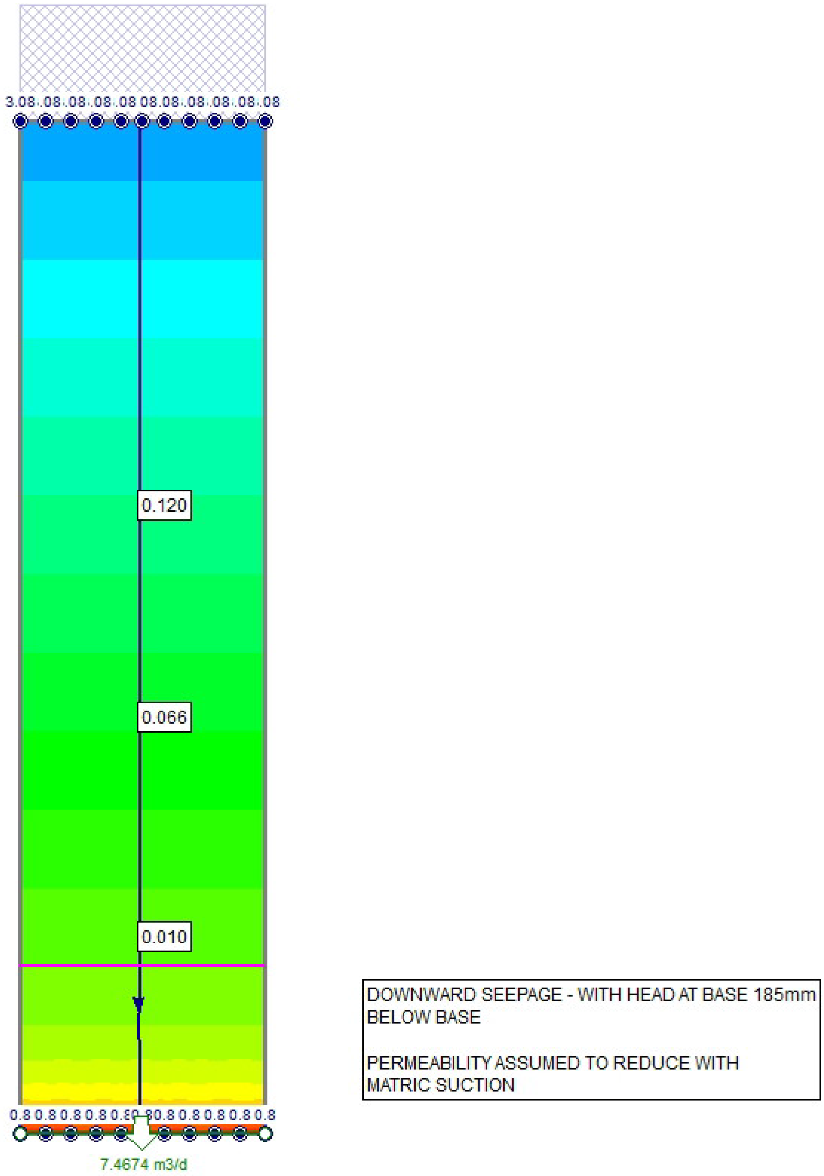
Figure 8 shows the same numerical model, but with the head at the base 185mm below the elevation of the base, and with a postulated permeability suction pattern as per Figure 8. It can be seen that there is a reduction of 15% in the total flow, even though there has been a small increase in the hydraulic gradient. This is what happened in the physical test, except there was only a 3% reduction. A match could be achieved simply by manipulating the permeability- suction function shown in Fig 9. The following points are made from the above counter-intuitive finding:

1. In the longwall mining situation there is no doubt that the goaf area is partly saturated, with cascading downward flow.

2. Above the shattered goaf the fractured rock, up to some unknown height, is also partly saturated, being impacted not just by air in the mine but from coal gasses. What the permeability characteristics of this zone are, nobody

knows; but it is probably true that the permeability is less than the equivalent saturated rock mass.

3. How the above impacts on the vertical downward flow into the set of longwall panels is clearly a very difficult question, made more difficult by considering the matter of surface recharge versus downward flow.



DOWNWARD SEEPAGE - WITH HEAD AT BASE 185mm BELOW BASE

PERMEABILITY ASSUMED TO REDUCE WITH MATRIC SUCTION

Figure 8

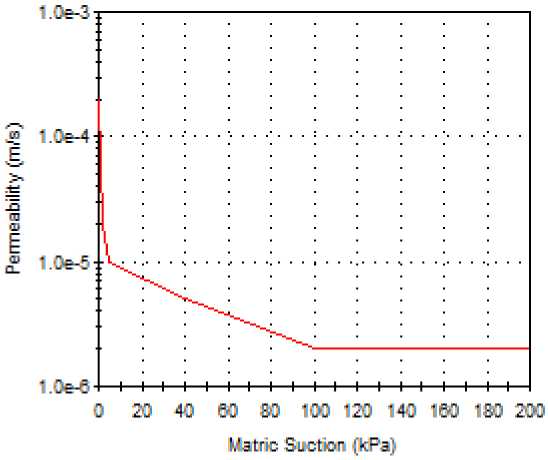


Fig 9 Assumed permeability matric suction relationship.

APPENDIX C

PROGRESS REPORT NO. 3
1 JUNE 2011

Pells Consulting

ABN 74 978 620 434
Phone: 02 4381 2125
Fax: 02 4381 2126
49 Lakeside Drive
MacMasters Beach NSW 2251
www.pellsconsulting.com.au

THIRLMERE LAKES

PROGRESS REPORT NO.3
1 JUNE 2011

1. INTRODUCTION

The following progress reports have been issued to date:

- No.1 dated 8 December 2010:
  - lists tasks for the study;
  - provides initial evaluation of rainfall data,
  - summarises site history and geological context; and
  - shows Tahmoor longwall layout near the lakes.

- No.2 dated 11 May 2011:
  - historical aerial photographs, 1966, 1975, 1983, 1994, 2005, 2009, 2010;
  - tabulated information on historical water levels;
  - data from groundwater monitoring from Xstrata AEM report;
  - additional rainfall data;
  - extracts from NSW Office of Water Report of 2010; and
  - analysis of 3 year and 5 year duration droughts.

This third progress report provides a substantially extended tabulation of information germane to historical lake storage levels. This information has been obtained from:

(i) a search through newspaper records using the Trove system of the National Library of Australia;

(ii) interviews with long term residents of the area, particularly the Rackleyft family; and

(iii) data from the files of NSW Parks and Wildlife (NPWS).

In addition this report includes:

- photographs taken at Lake Nerrigorang during discussions with the Rackleyft family on 9 May 2011;

- a contour map of the lakes area (work in progress);

- coordinates and levels of key points surveyed by GPS (RTK)[1] on 9 May 2011;
- an updated plot of rainfall records that have been checked against the local records kept by the Rackleyfts, presented as annual rainfall above or below the average, and so-called residual mass curve; and
- additional information on the geology of the area, and geological structures (faults, folds) that may impact on the groundwater behaviour in the area.

2. INFORMATION RELEVANT TO LAKE WATER LEVELS

Table 1 is an updated history of factual information that provides data on historical lake water levels. This table will be updated further as the study progresses.

TABLE 1

THIRLMERE LAKE LEVEL OBSERVATIONS

YEAR	DATE	LAKE NAME	OBSERVATION	PERSON OR DATA SOURCE
1798	14/3/1798	All	Wilson, Collins and a third young man find three deep valleys with large ponds of water . This is the first recorded discovery of the lakes by Europeans.	RAHS Volume 6 Part 7
1802	?/?/1802	Uncertain	Caley finds one of the lagoons- plenty of water.	RAHS Volume 25 Part 6 of 1939
1860	?/?/1860	Uncertain	Major floods in Picton, bridge over the stone quarry river swept away.	RAHS
1865	?/?/1865	Uncertain	Record of the water in the lakes being very pure	SMH 14/3/1865
1867	?/?/1867	All	Lakes considered to be a large water supply comprising "vast reservoirs"	SMH 30/9/1867
1881	?/?/1881	All	Consideration being given to bring water from the Picton lakes to Picton	SMH 27/8/1881
1902	?/?/1902	Werri Berri, Couridjah	Nearly dry, a local farmer, Mr Pfeiffer cut rushes to feed his stock so as to keep them alive	FB Knox, local historian of Picton

---

[1] RTK is the acronym for Real Time Kinematic, a system that gives centimetre accuracy to GPS survey.

THIRLMERE LAKE LEVEL OBSERVATIONS				
YEAR	**DATE**	**LAKE NAME**	**OBSERVATION**	**PERSON OR DATA SOURCE**
1902	?/?/1902	All	Visit by MWS & DB to consider the possibility of tapping the Picton lakes for Sydney water supply	SMH 6/10/1902
1910	?/?/1910	All	"Desolation no rain for months, water is scarce and mostly purid with dead fish"	SMH 15/1/1910
1928	?/?/1928	Werri Berri, Couridjah	Water level low	FB Knox, local historian of Picton
1944	?/?/1940	Werri Berri, Couridjah	Lakes reported to be dry to the extent that Mr Robert Rackleyft could walk across to reach Nerrigorang	Verbal information from Helen Squires (nee Rackleyft)
1966	22/03/66	Werri Berri	Full	Dept Lands Air Photo
1966	22/03/66	Couridjah	Full	Dept Lands Air Photo
1974	?/?/1974	All	Overflowing, fire brigade memo records that the access roads around the lakes was underwater in several places.	NPWS record from the fire department of 1974
1975	2/04/75	Werri Berri	Full	Dept Lands Air Photo
1975	2/04/75	Couridjah	Full	Dept Lands Air Photo
1980	?/?/80	Nerrigorang	Full	Olive Johanessen photo (c/o Caroline Graham)
1983	27/10/83	Werri Berri	Full	Dept Lands Air Photo
1983	27/10/83	Couridjah	Full	Dept Lands Air Photo
1984	?/4/84	Couridjah	Water level about 1.5m below end of jetty	David Hunt photo
1989	10/04/89	Couridjah	Full	Hunt photo
1989	30/11/89	Couridjah	>95% Full	Hunt photo
1989	?/1/89	Couridjah	Water level about 1m below jetty end.	David Hunt photo
1989	?/4/89	Couridjah	Water level about 30cm below end of jetty.	David Hunt photo
1994	4/01/94	Werri Berri	Full	Dept Lands Air Photo
1994	4/01/94	Couridjah	90% to 95% Full	Dept Lands Air Photo

THIRLMERE LAKE LEVEL OBSERVATIONS				
YEAR	DATE	LAKE NAME	OBSERVATION	PERSON OR DATA SOURCE
1998	4/10/98	Werri Berri	Water level about 1m below end of jetty.	Jeff Pratchett (Tahmoor local).
2002	10/01/02	Werri Berri	After fire. Jeff comment: "Taken in the same post after the water level dropped, jetty burnt, which by this time was well out of water. I stand at 6ft and the water was well over my head, back in 1998 when you climbed up the ladder. At least a 7ft fall in the four years."	Jeff Pratchett (Tahmoor local).
2002	?/?/02	Nerrigorang	Lake appears to be lower (but hard to tell due to burnt reeds)	Olive Johanessen photo x 4 (c/o Caroline Graham)
2005	20/12/05	Werri Berri	Full	Dept Lands Air Photo
2005	20/12/05	Couridjah	>95% Full	Dept Lands Air Photo
2008	13/06/08	Werri Berri	Water level high	Julie Shepard photo of canoe
2009	31/10/09	Werri Berri	At 76% of full width at the widest part	Google Earth photo
2009	31/10/09	Couridjah	At 84% of full width at widest part	Google earth photo
2010	13/04/10	Werri Berri	At 50% of full width at widest part	Google Earth photo
2010	14/04/10	Couridjah	At 72% of full width at widest part	Google Earth photo
2010	13/10/10	Couridjah	Level at base of 4th (upper) post of old burnt out jetty	Julie Shepard photo
2010	13/10/10	Nerrigorang	Dry	Caroline Graham photo
2010	6/09/10	Baraba	Dry	Caroline Graham photo
2010	8/10/10	Werri Berri	Very low water level	Caroline Graham photo
2010	6/09/10	Werri Berri	Dry	Caroline Graham photo
2010	17/11/10	Gunangarra	Water appears low	NPWS photo
2010	12/12/10	Gunangarra	Water appears low (and remains the same level)	NPWS photo
2010	17/11/10	Werri Berri	Water appears very low	NPWS photo
2010	12/12/10	Werri Berri	Water appears very low	NPWS photo
2010	17/11/10	Couridjah	Water level low	NPWS photo

THIRLMERE LAKE LEVEL OBSERVATIONS				
YEAR	**DATE**	**LAKE NAME**	**OBSERVATION**	**PERSON OR DATA SOURCE**
2010	12/12/10	Couridjah	Water appears low (and remains the same level)	NPWS photo
2010	17/11/10	Nerrigorang	Dry	NPWS photo
2010	12/12/10	Nerrigorang	Dry	NPWS photo
2011	11/04/11	Gunangarra	Water appears low (and remains the same level)	NPWS photo
2011	11/04/11	Werri Berri	Water appears extremely low (dry)	NPWS photo
2011	11/04/11	Couridjah	Water appears low (and remains the same level)	NPWS photo
2011	11/04/11	Nerrigorang	Dry	NPWS photo

The history of water extraction from the lakes is also of relevance. The following is what has been recorded from Mr Ron Silm (who started Cedar Creek Orchards).

- *He arrived in the area in 1937and remembers visiting the pumphouse at the swimming lake after that time. When they stopped pumping water for the steam trains they continued pumping for some years for water for Picton Lakes Village in Couridjah which was a Dept of Health enterprise I think connected with the Sanitarium at QV Hospital.*
- *When water was too low in the swimming lake for pumping they dug a deep channel to connect with the boating lake; it was so deep evidently 2 boys were drowned in this channel.*
- *He remembers times when the lakes were dry sometime in the 40's and 50's. During some of the dry times in the 50's Ron obtained a permit to pump out of the N extension to the swimming lake, which is currently full of reeds, across the watershed into the Cedar Creek catchment which then flowed down to his orchard beside Cedar Creek.*
- *He remembers 3 separate times they were pumping each time continuing for several weeks with the pumps running 24 hrs a day at 1000gallons per minute. He believed it had minimal impact on the level in the lakes; I guess it would have been drawing water from the swimming lake also since it was connected at that time. Ron will look through his records since he says he had full details of dates quantities etc.*
- *Ron also mentioned he had a friend Jimmy Roche who's since left the neighbourhood. Jimmy had an orchard in Nattai St Couridjah and he and a number of other orchardists in Couridjah all had bores which ran dry when the mining began nearby. It was quite an issue at the time he remembers because the mining company was having great difficulty coping with massive quantities of groundwater entering their workings.*

3. PHOTOGRAPHS AT LAKE NERRIGORANG – HISTORICAL AND MAY 2011

Aerial photo of Lake Nerrigorang marked to show where Photographs 1 to 7 were taken during site visit on 9 May 2011.

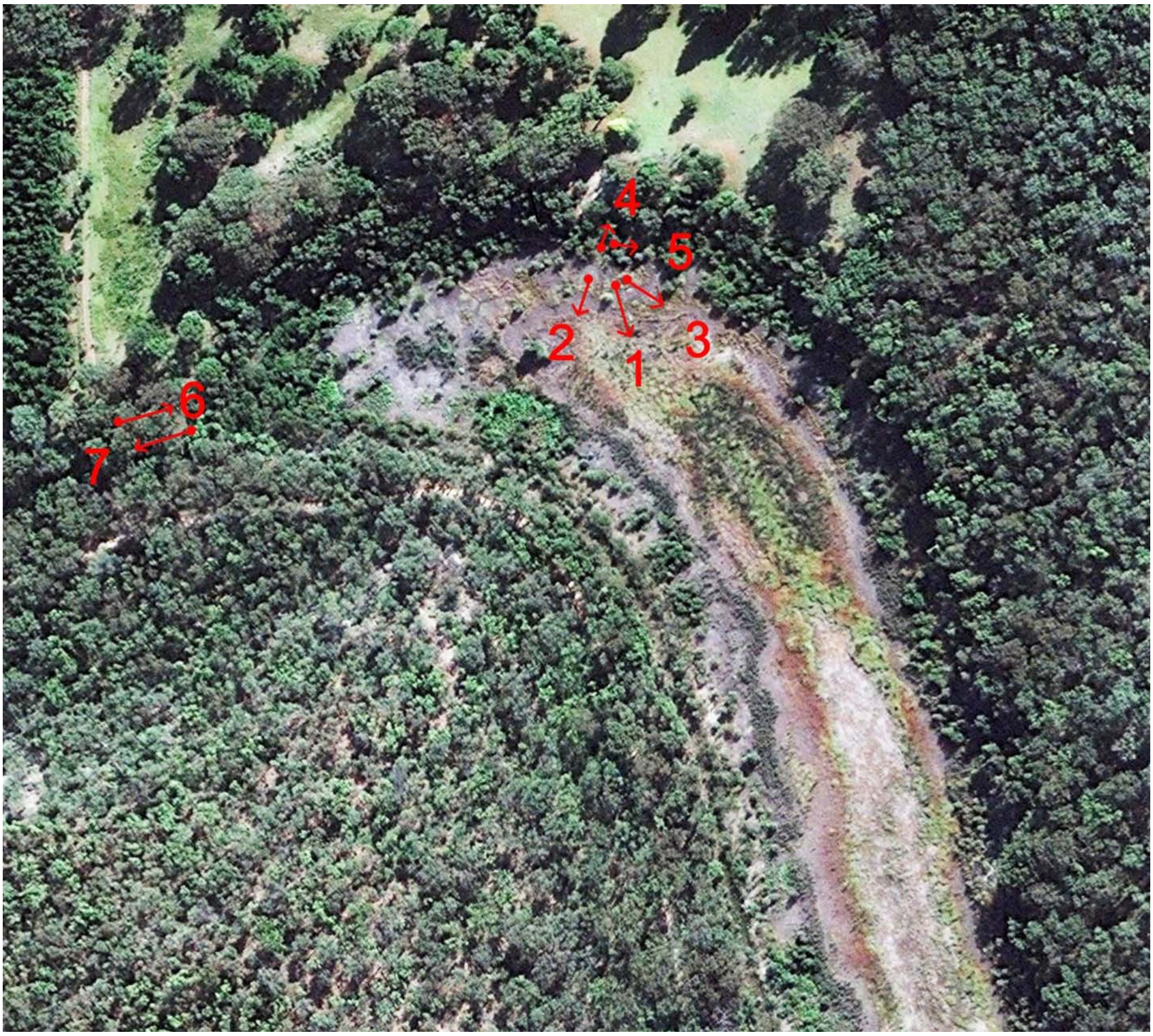


Photo 1: Lake Nerrigorang

Photo 2: Lake Nerrigorang – Paul Rackleyft recalls depth of about 14ft deep in about 1985/1986.

Photo 3: Lake Nerrigorang - Peat at forefront of picture (very spongy under foot).

Photo 4: Lake Nerrigorang – Helen Squires and Paul Rackleyft stated the lake level in 1985 was at Helen's feet and in 1989 level with Helen's neck (full and equal to overflow pipe in Blue Gum Creek).

Photo 5: Lake Nerrigorang - Indicates vegetation growth of trees in last 15 years since water has receeded (the white sand was put there by Win Racklyeft to create a beach).

Photo 6: Lake Nerrigorang - Little Blue Creek (took overflow from Lake Nerrigorang).

Photo 7 Lake Nerrigorang - Standing in Little Blue Creek looking out the access road to the old Rackleyft camp.

At a meeting held at the lakes on 9 May 2011 (see Appendix A) we were given photographs taken by Olive Johanessen and the Rackleyfts. Some of these are reproduced below.

Lake Nerrigorang 1980s, Olive Johanessen photograph.

Lake Nerrigorang, 2002 after bushfire, Olive Johanessen photograph.

Lake Nerrigorang, 2002 after bushfire, Olive Johanessen photograph.

Canoe on Lake Nerrigorang, late 1950s.

4. CONTOUR MAP

Figure 1 is portion of a contour map of the area that is currently a work-in-progress. It will be improved and extended to include detailed survey, and groundwater and geological information.

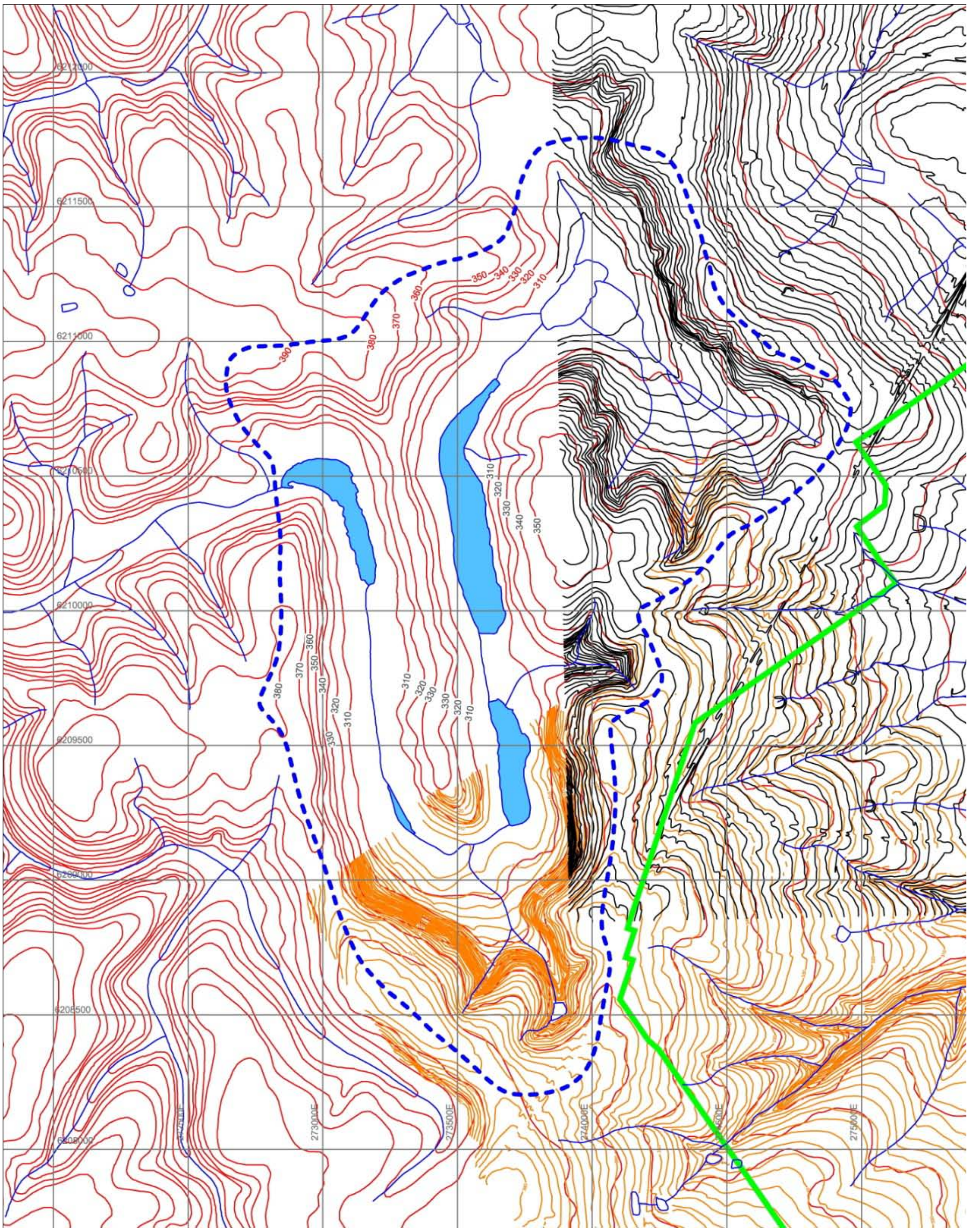


Figure 1: Contour map.

Table 2 sets out details of survey points recorded on 9 May 2011.

TABLE 2

SURVEY 9 May 2011				
POINT	**CONTROL**	**EASTING**	**NORTHING**	**RL**
COURIDJAH EDGE	DGPS	273737.14	6209425.61	306.21
COURIDJAH EDGE	DGPS	273737.45	6209426.03	302.47
CoURIDJAH Post 1	DGPS	273749.62	6209494.46	303.05
COURIDJAH POST 2	DGPS	273749.62	6209493.07	303.71
PIPE END	DGPS	273753.34	6209491.41	303.25
COURIDJAH EDGE	RTKFloat	273737.31	6209425.69	303.69
COURIDJAH EDGE	RTKFloat	273737.41	6209425.72	303.66
TREE LINE	RTKFloat	273752.58	6209423.52	305.5
STAIRS bottom	RTKFloat	273772.29	6209426	306.76
STAIRS top	RTKFloat	273773.8	6209425.9	308.07
WERRI BERRI Edge	DGPS	273512.48	6210513.31	303.84
Werri Berri Steps top	DGPS	273553.74	6210549.45	312.98
Werri Berri Steps bottom	DGPS	273553.34	6210548.8	312.23
Werri Berri edge	DGPS	273509.6	6210518.04	302.83

5. RAINFALL AND DROUGHT

Section 6 of Progress Report 2 discusses the calibration and drought analysis of rainfall records from 1858 to 2010.

Figure 2 shows another form of presentation of those records. It shows the annual excess and deficit rainfalls relative to the 150 year average. It also shows the cumulative line for these excess and deficit values. This cumulative line is what is called the ‘residual mass curve’ in the 2010 report by NSW Water. Where this line slopes upwards indicates a period of wetter-than-average weather. Where it slopes downwards indicates drought (i.e. less than average rainfall). The steeper the slope the more extreme is the drought intensity, and the longer the downward trend the longer is the drought duration. This curve shows usually the information given in the tables in Progress Report 2, namely that the recent drought (2000-2006) is swamped in severity and duration by the drought ending 1909, 1942/7, 1885 and 1923.

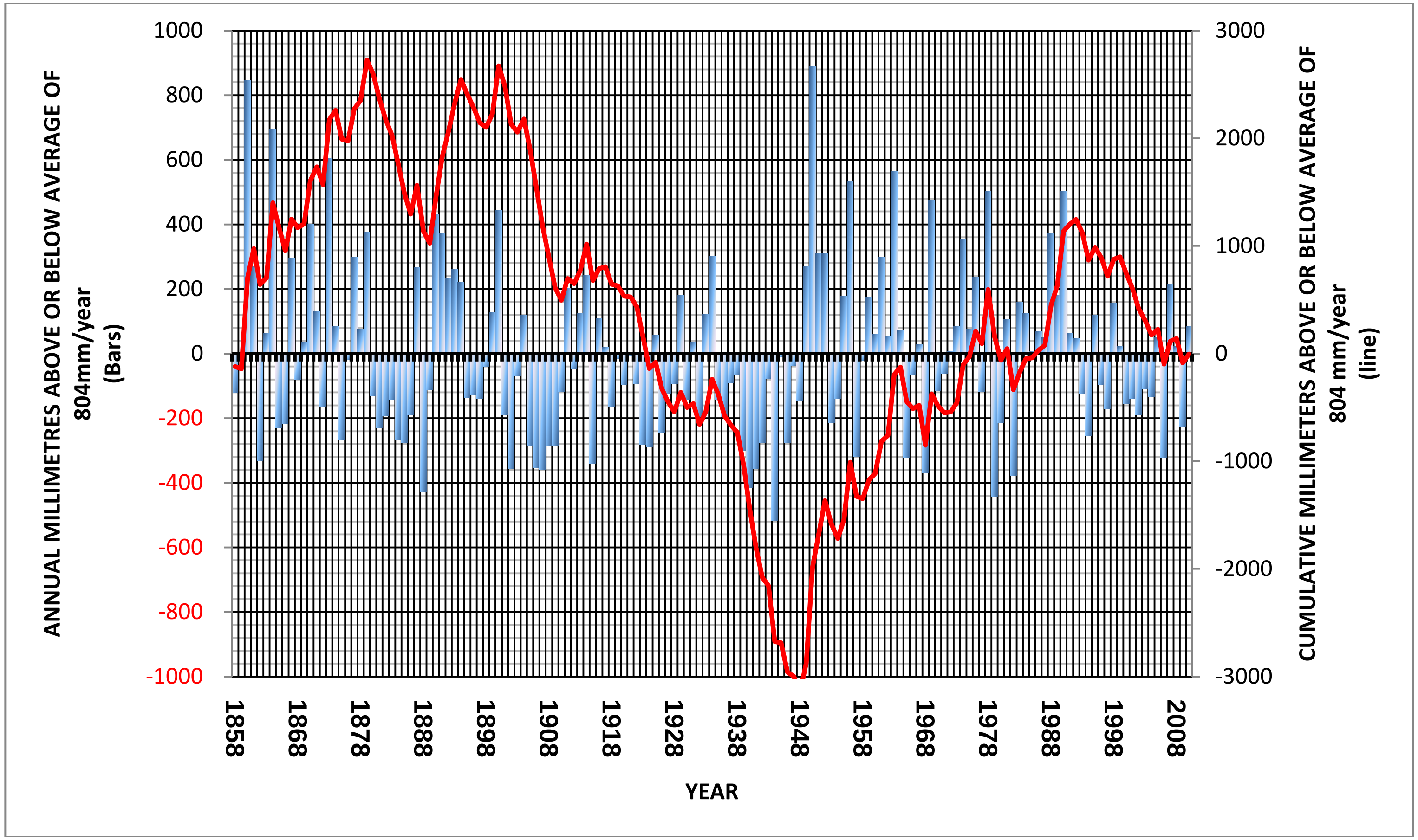


Figure 2: Calibration and drought analysis of rainfall records from 1858 to 2010.

6. GEOLOGICAL DATA

A significant effort is being directed to understanding the geology and hydrology of the area. The following information has been obtained from two publications:

- Branagan & Packham, Field Geology of NSW, 2000.
- Geology of the Wollongong and Port Hacking 1:100,000 Sheet (1986).

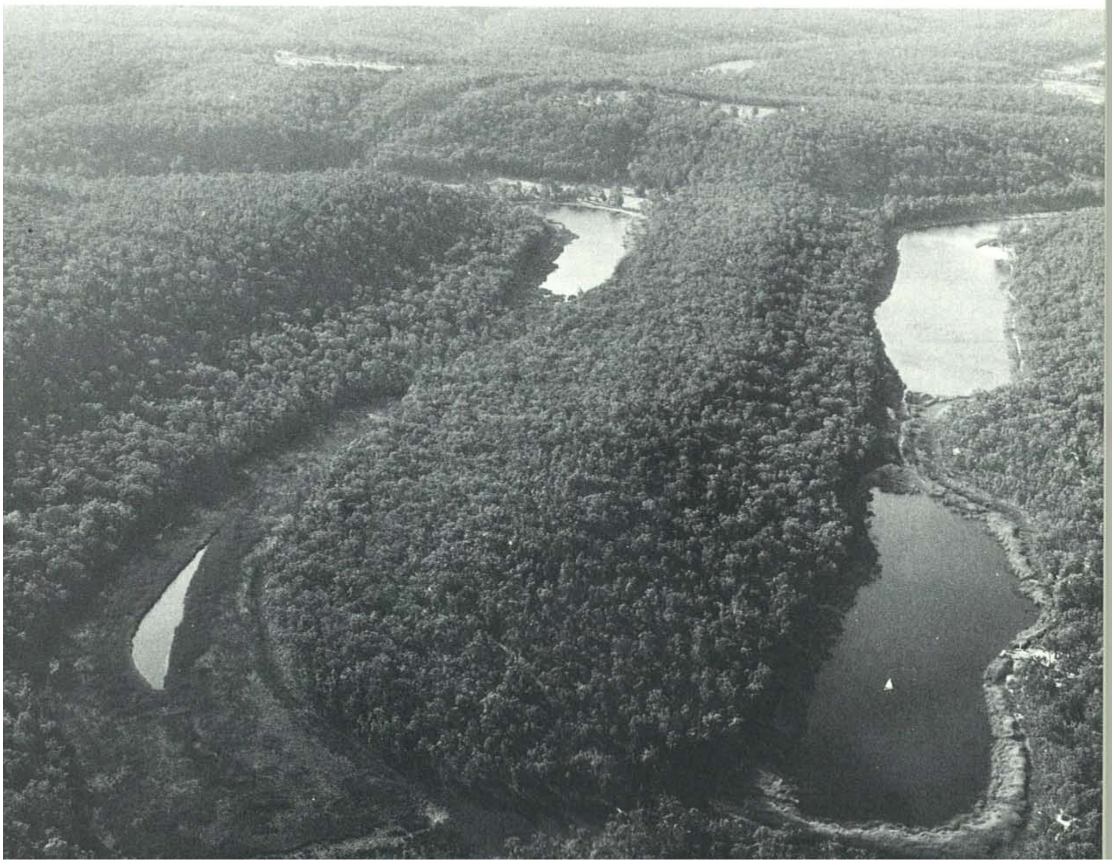
> *“What was for many years named the ‘Lapstone Monocline’ marking the eastern edge of the Blue Mountains is best referred to as the Lapstone Structural Complex, which includes the monocline and a number of associated faults and folds. The complex extends for more than 100km from near Picton in the south to beyond the Colo River. The eastern front, although monoclinal at Lapstone and Kurrajong Heights, is faulted on the Richmond-Springwood Road, and at Bents Basin near Wallacia. On the west side, from near Cut Rock (see Hartley excursion), south to beyond Glenbrook Creek, there are numerous en-echelon fold-faults, all probably developed during the same overall movement (figure 36). High level river gravels occur at various places along the structure, and are believed to represent one or more ancient courses of the proto Hawkesbury River, displaced as folding occurred. The present Nepean-Hawkesbury River system follows a course from Wallacia to Windsor that cuts through the complex, suggesting that this course was in existence prior to the folding.*
>
> *There is disagreement amongst geologists and geomorphologists about the history of deformation. For many years it was believed that the folding forming the monocline and uplifting the Blue Mountains Plateau occurred late in Tertiary time (Pliocene). This was called the ‘Kosciusko Uplift’.*
>
> *Evidence today suggests that the structures formed earlier. We think that the Blue Mountains Plateau was quite high from Mesozoic time, and that the monoclinal structure was formed by downdragging late in the Cretaceous or early in the Tertiary when the Tasman Seas formed by seafloor spreading. Other geologists believe that the structures at the edge of the Blue Mountains existed since the Triassic, and are exhumed. There is still fruitful research to be done on this intriguing problem.”*

Field Geology of New South Wales 2000,
Branagan & Packham (p.119)

?CRETACEOUS ALLUVIUM (Kal)

Sandy alluvium fills much of a dry valley west of Thirlmere, as well as forming a low watershed (GR 737115) between Blue Gum Creek and an unnamed, north-flowing tributary of Cedar Creek. Hollows within this alluvium, which extends the full length of Blue Gum Creek in the map area, are occupied by the Thirlmere Lakes (see photo 7). During this present study several auger holes were sunk in a sandpit at the watershed. They penetrated 2 m of stiff, clayey sand without reaching bedrock. At a depth of about 0.5 m the sand is progressively more mottled, being generally light greyish brown with friable, reddish brown, ferruginous nodules. The sand consists of medium to coarse, subangular quartz.

Photo 7. Thirlmere Lakes. These occupy depressions in the ?Cretaceous alluvium which chokes the headwaters of the valley of Blue Gum Creek.



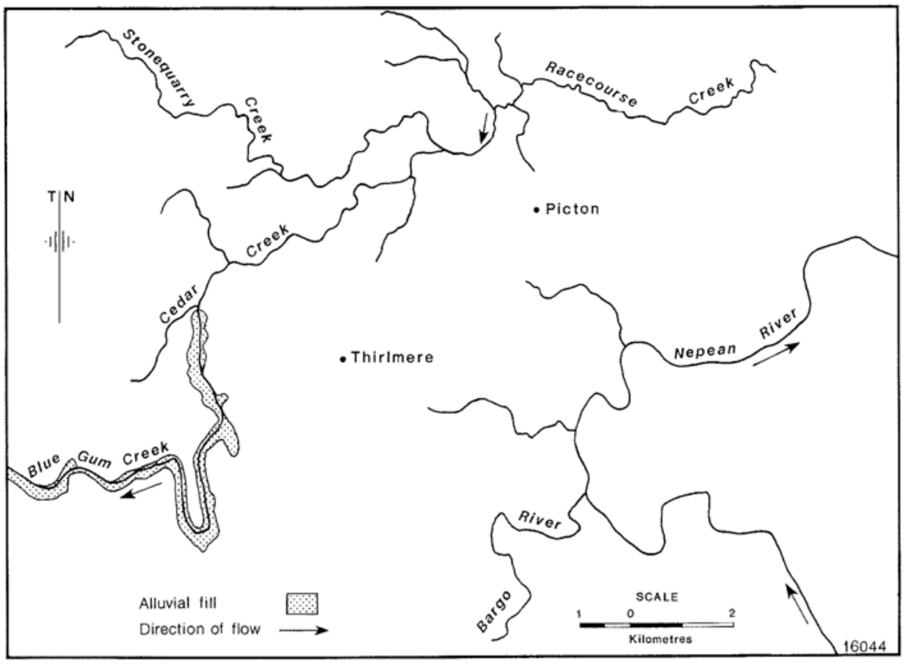


Figure 9. Reconstruction of drainage in the Thirlmere-Picton area in Late Cretaceous time, obtained by restoring the contours on the base of the Wianamatta Group to a common level. Relict alluvial fill in Blue Gum Creek is indicated by stippling.

The location of this alluvium on a watershed, though still within a valley, is difficult to explain considering the present drainage system. The nearness of the alluvium to a series of monoclinal flexures indicates an interrupted drainage — Cedar Creek and its tributaries are likely to have been the headwaters of Blue Gum Creek rather than part of the Nepean River system as they are now. Branagan (1975) related these flexures to slumping of the coastal region, following rifting between 80 million to 60 million years ago which produced the Tasman Sea (Hayes and Ringis 1973). If the topography which existed before the monoclines and faulting in the region is reconstructed by restoring the structure contours on the base of the Wianamatta Group to a common level, then Cedar Creek would have a distinct west-flowing gradient. Furthermore, it would have had as tributaries Racecourse Creek and Stonequarry Creek (see figure 9). As the west-flowing headwaters of the old Blue Gum Creek were changing into an east-flowing tributary of the Nepean River, the stream gradient would have been progressively lowered. This lowering of the stream gradient would have affected the ability of the stream to shift sediment for any great distance. Ultimately the stream would have been unable to move anything at all as the gradient reached zero. Once the headwaters reversed direction to form the modern east-flowing Cedar Creek, the alluvium in this section would have been

subject to erosion because of the comparatively steeper stream gradient to the east.

Assuming such an origin for the alluvium at this locality, its likely age is within the interval associated with the Tasman rifting, namely, late Cretaceous-early Tertiary.

A preliminary sketch has been prepared showing geological structures (see Figure 3). This is based on publicly available data on structures encountered in Tahmoor Colliery and from 2010 publications by Chris Ferguson and Andrew Bray on the geological structures associated with the Kurrajong structural zone.

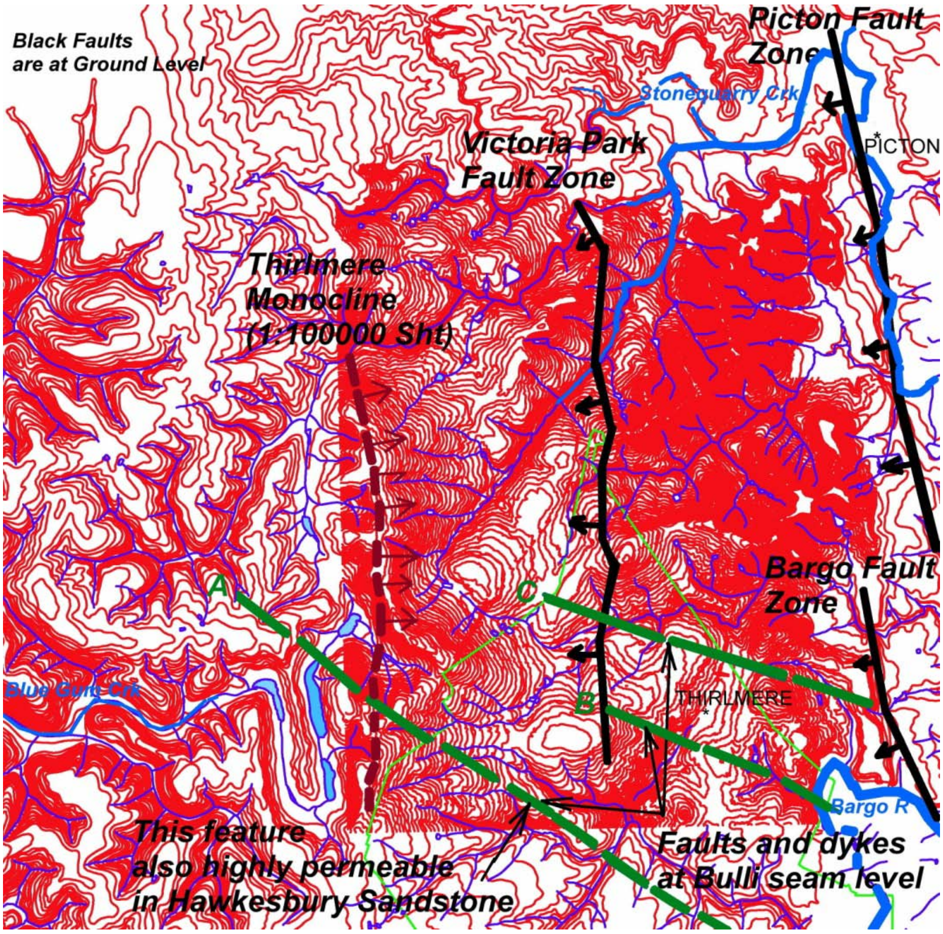


Figure 3: Preliminary sketch showing geological structures.

APPENDIX A

MEETING AT THIRLMERE LAKES ON 9 MAY 2011

Attendees:	Philip Pells
	Marita Campbell
	Caroline Graham (Rivers SOS)
	Julie Sheppard
	David Hunt
	Alistair Henchman, NPWS (Director, Southern Branch)
	Adrian Johnstone, NPWS (Area Manager, Nattai Area)
	Ben Owers, NPWS (Ranger, Nattai Area)
	Denis Wilson, Australian Water Campaigners Inc
	June Rackleyft (June's husband Win ran a camp for decades at Thirlmere Lakes)
	Paul Rackleyft
	Helen Squires (ne Rackleyft)

Information/Photos/Records Received at Meeting

Photos given to Caroline Graham (from Jeff Pratchett (Tahmoor resident), Olive & Bjorn Johanessen (visitors to the camp run by Win Rackleyft).

Photos and information regarding Cedar Creek Orchards from David Hunt.

Rainfall records from Michael Cronan (Thirlmere resident who used to work at the Tahmoor Colliery as a contracts manager).

NPWS photographic records for 7 points around the Lakes (First record: 17/11/2010, Second record: 12/12/2010 and Third record: 11/4/2011).

Information received from Rackleyft family

Helen Squires (nee Rackleyft)
Email: brayline@bigpond.net.au
Ph: 46 83 0241

Helen and Paul's father Win Rackleyft had a private holiday camp on Lake Nerrigorang from about 1920.

Helen and Paul recall their Uncle Robert (Win's brother) talking about Werri Berri and Couridjah drying up during the 1940's, having picnics on the lake and that their neighbour's (name: Dougite?) cows escaping as this property owner had used Werri Berri as a lake as a fence line. They had to put up fence posts through the lake and had to get the fence posts out before the lake went back up. Got a few out but not all of them.

Helen's father was away at war during the 1940's.

Lake Nerrigorang did not dry up during this drought (went down to half).

Helen is going to source photos from her aunty (her father's sister), who may possibly have photos of the Lakes during the 1940/1950.

Helen recalls fires sweeping through on 2001 Christmas Day. Paul and Helen confirm Nerrigorang did not recover. Paul describes the decline in the water level like “pulling a plug”.

Helen and Paul will search further through their records for any useful photos/information and scan and send to Marita.

Information regarding Boreholes

David Hunt confirmed the Office of Water produced a report last year using local borehole records (Caroline has seen the report and will forward to Marita the link).

David thought there were two issues to be addressed:

1. Details of borehole locations
2. Details of the negotiations between the mining company and property owners to tie in with the longwalls (re Couridjah).

APPENDIX D

PROGRESS REPORT NO. 4
15 JUNE 2011

Pells Consulting

ABN 74 978 620 434
Phone: 02 4381 2125
Fax: 02 4381 2126
49 Lakeside Drive
MacMasters Beach NSW 2251
www.pellsconsulting.com.au

THIRLMERE LAKES

PROGRESS REPORT NO.4
15 JUNE 2011

EXTRACT FROM THESIS BY PATRICIA FANNING (NEE VORST).

In 1974, Patricia Fanning (nee Vorst) wrote a thesis titled “Thirlmere Lakes, N.S.W.: geomorphic environment and evolution” for her honours degree. Patricia Fanning is now a lecturer at Macquarie University.

In 1974 the lakes were full. Nerrigorang was overflowing into Blue Gum Creek, probably for the first time since the late 1800s. Fanning noted that after torrential rainfall on 25 May 1974 the level of the lakes was observed to have risen approximately 200mm in one week, but the pre-wet period level was restored in a matter of weeks.

The thesis contains a large amount of factual information relevant to the present study. Extracts from the thesis are reproduced in the following subsections.

Topographical and hydrographic information

Fanning under took depth measurements across what she called Lakes 1,2 and 4; the present names being Werri Berri, Couridjah and Nerrigorang. Her hydrographic contours are reproduced in Figure 1 (Figure 3.1 of the Thesis).

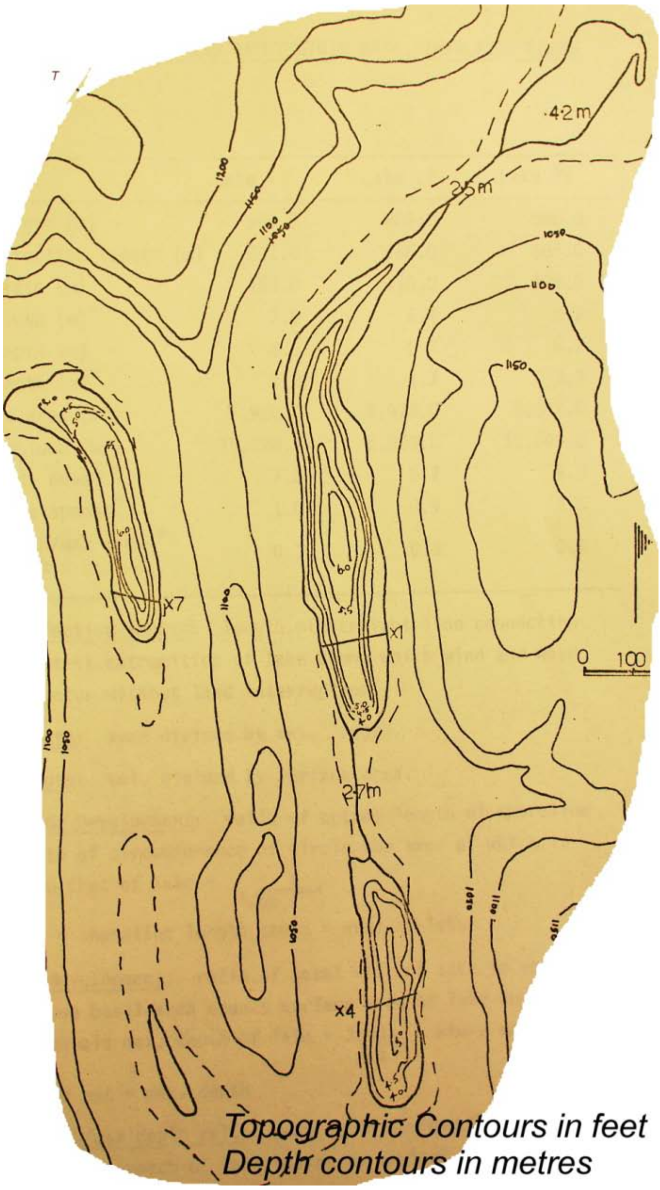


Figure 1

Figure 1 shows the locations of three cross sections. Her profiles for these three sections are given in Figure 2. It can be seen from Figure 2 that, in 1974, all three lakes had maximum depths of about 6 metres.

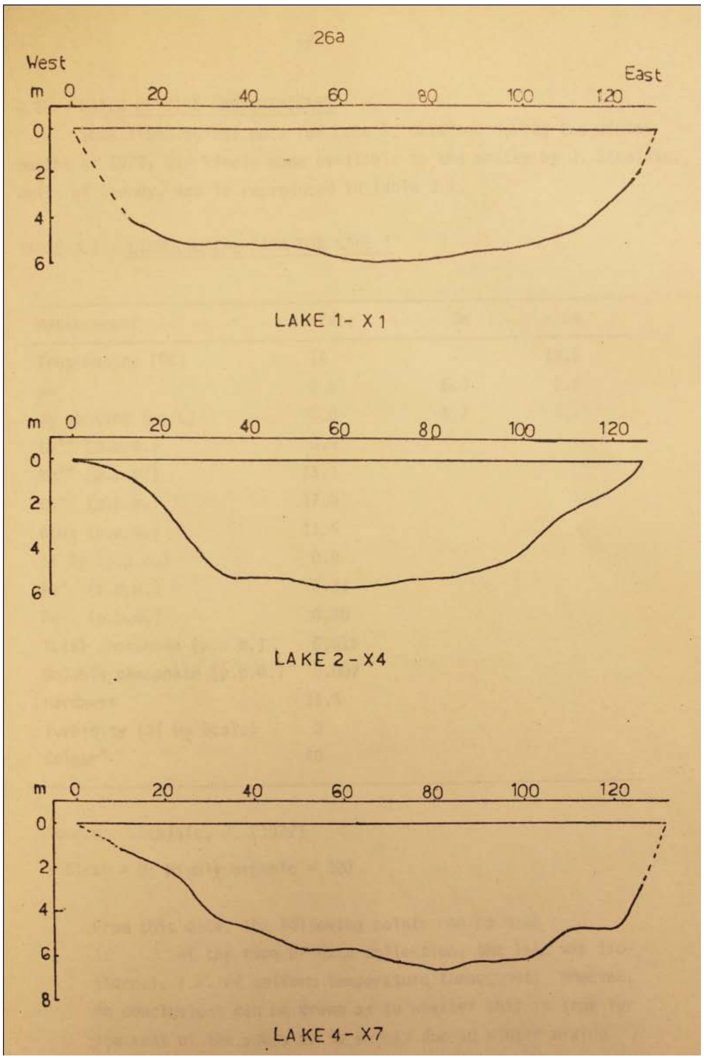


Figure 2

Table 1 summarises the depths, areas and storage volumes as measured by Fanning.

TABLE 1
Depths, Area and Storage Volumes

Parameter	Werri Berri	Couridjah	Nerrigorang
Max. length (m)	989.0	466.0	586.0
Max. width (m)	158.0	110.0	125.0
Max. depth (m)	6.6	5.2	6.7
Surface area (m^2)	6,922.0	2,978.0	3,347.0
Total volume (m^3)	15,228.0	5,063.0	11,045.0

Alluvium beneath the lakes

Fanning made use of three procedures in an attempt to determine the depth and nature of the alluvium beneath the lakes. Firstly, boreholes were drilled using augers on a Gemco drilling rig which had a maximum penetration depth of just over 30m. Secondly, an attempt was made to use seismic methods to determine the profile of the underlying Hawkesbury Sandstone. Thirdly, an estimate of the shape of the underlying sandstone profile was made using geomorphic methods.

The locations of the boreholes are shown in Figure 3. Summary logs of the boreholes are given in Table 2 and shown diagrammatically in Figure 4.

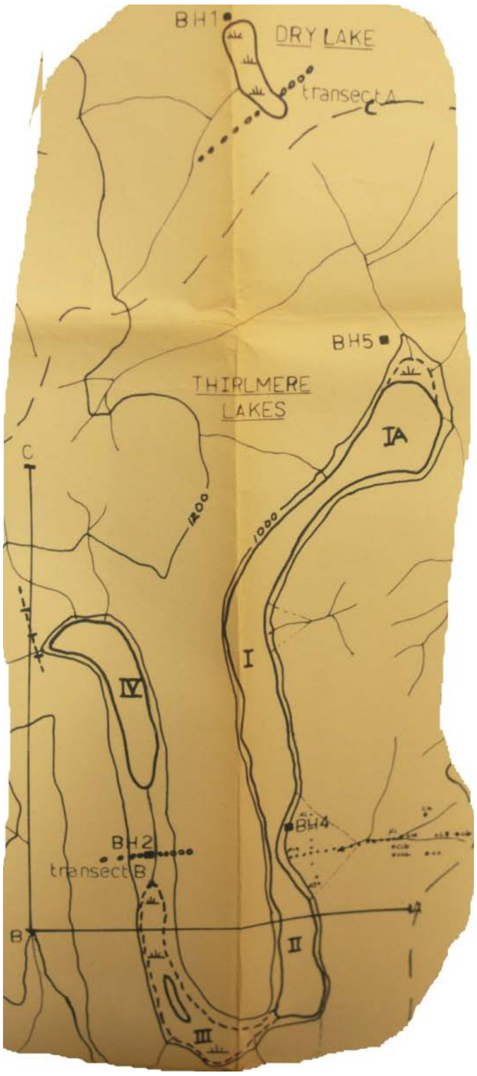


Figure 3

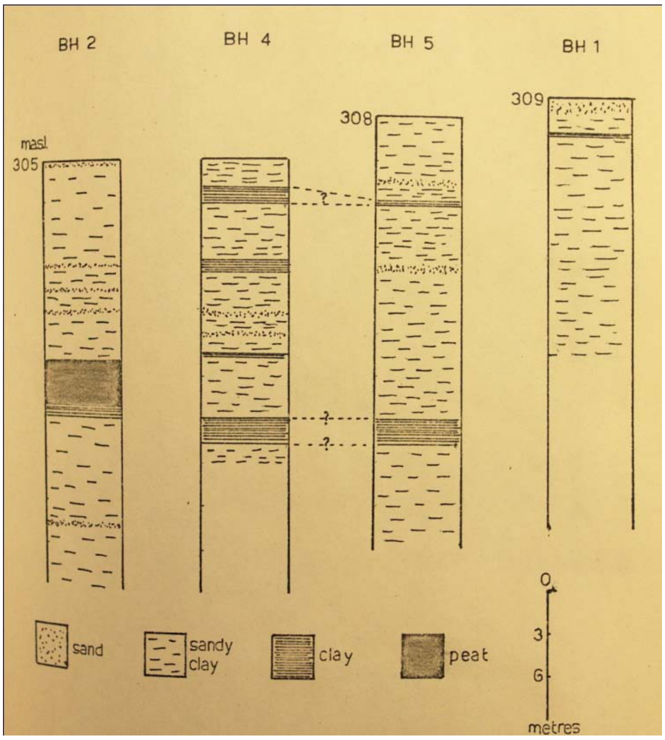


Figure 4

TABLE 2
Summary of logs of the boreholes

HOLE NUMBER	DEPTH (M)	TEXTURE
BH1	1.0	Medium sand
	1.5	Sandy clay
	3.6	Sandy clay
	4.2	Clay
	5.1	Sandy clay
	18.0	Sandy clay
BH2	1.0	Medium sand
	3.0	Sandy clay
	7.5	Sandy clay
	7.8	Medium sand
	9.0	Sandy clay
	9.3	Medium sand
	11.3	Sandy clay
	12.0	Medium sand
	12.8	Clay
	14.3	Sandy clay
	17.3	Peat
	18.0	gl(??) clay
	25.5	Sandy clay
	26.0	No sample
	29.5	Sandy clay

HOLE NUMBER	DEPTH (M)	TEXTURE
BH4	0.5	Medium sand
	1.8	Fine sandy clay
	3.0	Clay
	3.6	Clayey sand
	6.0	Clayey sand
	6.9	Sandy clay
	8.4	Clay
	11.0	Sandy clay
	11.3	Clayey sand
	13.0	Sandy clay
	13.3	Clayey sand
	16.0	Clay
	18.3	Sandy clay
	20.0	Sandy clay
	21.0	Clay
	22.0	Sandy clay
BH5	1.6	Clayey sand
	3.3	Sandy clay
	5.0	Sandy clay
	6.6	Clay
	7.6	Sandy clay
	8.5	Sandy clay
	10.0	Sandy clay
	11.6	Sandy clay
	13.3	Sandy clay
	15.0	Sandy clay
	16.6	Sandy clay
	18.3	Sandy clay

Fanning's description of the seismic survey is as follows:

> "*A seismic survey was conducted under the direction of Mr. J. W. Tayton, School of Earth Sciences, Macquarie University, in order to determine, firstly, the depth of sediment in the valley and, secondly, the location(s) of sediment layers as revealed by changes in the velocity of the sound waves as they travelled through layers of different densities. The location of the survey transect is shown in Fig. 1.2.*
>
> *The bedrock cliffs on either side of the valley were found to continue at approximately the same angle beneath the overlying valley fill. However, interference with the sound waves because of the narrowness of the valley resulted in the bedrock base remaining undetected; its depth was calculated to be beyond 50 to 60 metres. Changes in velocity occurred at 2 to 3 metres, from 300 metres/sec. to 1,100 – 1,200 metres/sec., with a subsequent progressive increase with depth to about 2,000 – 2,100 metres/sec; the former reflects the change from unsaturated to saturated sediment (the velocity of sound waves in water is 1,400 metres/sec.), while the latter probably reflects increasing compaction of the sediments. Velocity changes were at approximately the same depth across the valley, which lead Mr. Tayton to believe (pers. comm.) that the zone of bedrock weathering had not been encountered; its profile would follow the outline of the bedrock valley sides,*

which would be reflected in a non-uniform depth of velocity change across the valley.

Thus, the bedrock valley is, as suspected, very deep and is filled with unconsolidated sediment which may be the products of a variety of depositional processes."

Analyses of the deep clay layers were not undertaken because of the inability to remove all of the organic matter by treatment with hydrogen peroxide. However, their textural appearance strongly resembled that of clay layers encountered in cores extracted from the present lakes.

There is a strong textural resemblance between the sandy clays in the boreholes and the surface material of the alluvial fans and debris slopes; one possible mode of deposition of this material is therefore via sheetwash form the adjacent hillslopes."

Aquatic Vegetation

Fanning classified four different zones of vegetation that could be distinguished at all of the lakes. The characteristic species with their corresponding water depths are given in Table 3 (her Table 3.4), and illustrated in Figure 5.

TABLE 3
AQUATIC VEGETATION ZONATION, WITH CORRESPONDING WATER DEPTHS

ZONE	PLANT SPECIES	APPROX. WATERDEPTH[1] RANGE (M)
A	*Brasenia schreberi*	4.0
B	*Lepironia articulata* *Eleochaeris sphacelata*	2.0 – 4.0 1.0 – 3.0
C	*Lepidosperma longitudinale*	0 – 2.0
D	*Melaleuca linariifolia* *Lepyrodia muelleri*	0 – 0.3 0 – 0.1

[1] Water depths as at May, 1974; note that zone boundaries are diffuse in terms of water depth, but are clearly distinguished in the field.

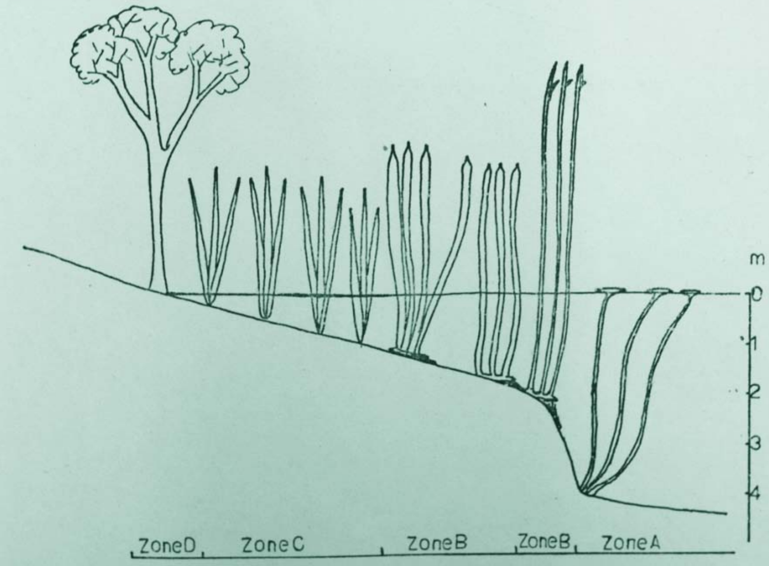


Fig. 3.4 : SCHEMATIC PROFILE OF AQUATIC VEGETATION ZONATION AT THIRLMERE LAKES

Figure 5: Schematic profile of aquatic vegetation zonation at Thirlmere Lakes

Climate and Lake Levels

The following is extracted from this portion of her thesis:

> *"A comparison of a graph of rainfall over Lake George, N.S.W., since 1886 with that of monitored lake levels for the same period shows that there is a very strong correlation between years of above average rainfall and higher water levels; similarly, low lake levels correspond to years of below average rainfall. Since there is an almost one-to-one correspondence in the direction of change in rainfall from year to year at Lake George and at Picton, the situation which appears to have existed at Lake George may also have existed at Thirlmere Lakes. Thus, since rainfall records began in 1880, higher lake levels may have been experienced in and around 1890, 1900, 1915, 1930, and from 1950 to 1965; lower lake levels may have occurred in and around 1908 to 1910, 1920 and 1927, and 1938 to 1945. This latter period corresponds with that reported by a local resident, Mr. W. Racklyeft (see Section 3.4 above).*
>
> *Thirlmere Lakes may not have been as high as the present time for about 100 years, i.e. since 1874, and before that, since 1822; in both of these years, Lake George reached its highest historical level. Thus, Thirlmere Lakes may have been a closed basin for part or all of this time."*

APPENDIX E

PROGRESS REPORT NO. 5
31 AUGUST 2011

Pells Consulting

ABN 74 978 620 434
Phone: 02 4381 2125
Fax: 02 4381 2126
The Old Post Office
49 Lakeside Drive
MacMasters Beach NSW 2251
www.pellsconsulting.com.au

THIRLMERE LAKES

PROGRESS REPORT NO.5
31 AUGUST 2011

1.0 INTRODUCTION

This is the fifth and final progress report representing the collection and collation of factual information germane to assessing the factors that have played a role in the loss of water from the Thirlmere Lakes between about 1992 and 2010.

In early 1992, Lake Nerrigorang was full. Its level then fell steadily, until by late 2010 it was empty. Lakes Werri Berri and Couridjah were full through to about 1996 and then their water levels fell to the point that in August 2011 Lake Werri Berri was empty, and Lake Couridjah's water depth was less than 0.5m.

It is our view that with the completion of this progress report there is sufficient factual information, collated in the five progress reports, to allow the requisite analyses to be completed to facilitate scientific assessment of the factors that have impacted on the decreases in water levels in the lakes.

The additional factual information in this report comprises:

- site survey undertaken on 22 August 2011,
- additional historical photographs of the lakes provided by various persons from the Picton-Thirlmere area, and anecdotal information, all being relevant to assessing historical lake levels,
- monthly rainfall data for three relevant periods; 1938 to 1950, 1974, and 1998 to 2011,
- data on major bushfires that could have impacted on catchment runoff characteristics,
- data on faults and dykes that could impact on seepage from the lakes,
- borehole water level data from NSW Water, and
- rock mass permeability data.

2.0 SITE SURVEY AUGUST 2011

On 22 August 2011 survey work was completed by Pells Consulting using differential GPS with RTK correction[1], and terrestrial survey by optical levelling. The objective of this work was to measure:

- the floor levels of each lake,
- the outlet level from Lake Nerrigorang to Blue Gum Creek and
- to provide absolute values to use in conjunction with Patricia Fanning's bathymetric data for development of depth-versus-storage curves for each lake.

At the time of the work Lake Nerrigorang was empty (see Photograph 1), Lake Werri Berri was effectively empty (see Photographs 2 and 3), Lake Couridjah had a maximum water depth of about 0.5m, and "Dry Lake" (Gandangarra) was dry.

At our request, Mr Paul Rackleyft inspected the bed of Blue Gum Creek downstream of the overflow point from Lake Nerrigorang. There was no water in the creek bed for about least 700m downstream of the overflow point.

Photograph 1: Lake Nerrigorang, August 2011, P. Pells photo.

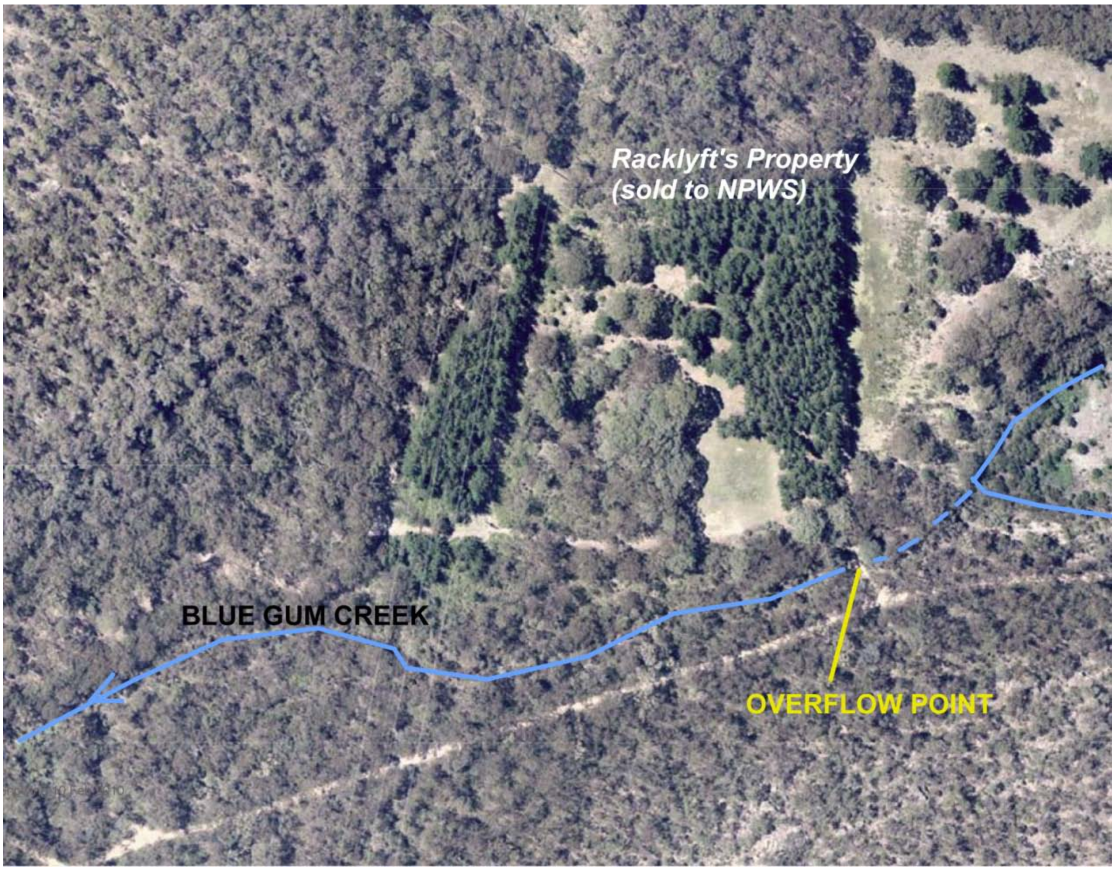
---

[1] This gives plan positions with an absolute accuracy of about 0.1m, absolute vertical level to about 0.5m, and relative vertical level, in any 10 minute period, to about 0.1m.

Photograph 2: Lake Werri Berri, August 2011, P. Pells photo.

Photograph 3: The last reflection in Lake Werri Berri, August 2011, P. Pells photo.

Photograph 4 shows the position of the overflow point between Lake Nerrigorang and Blue Gum Creek.



Photograph 4: Overflow point between Lake Nerrigorang and Blue Gum Creek.

Figure 1 shows the locations of the survey points and Figure 2 gives a summary, in long section, and three cross-sections, of the levels that have been assessed from the survey.

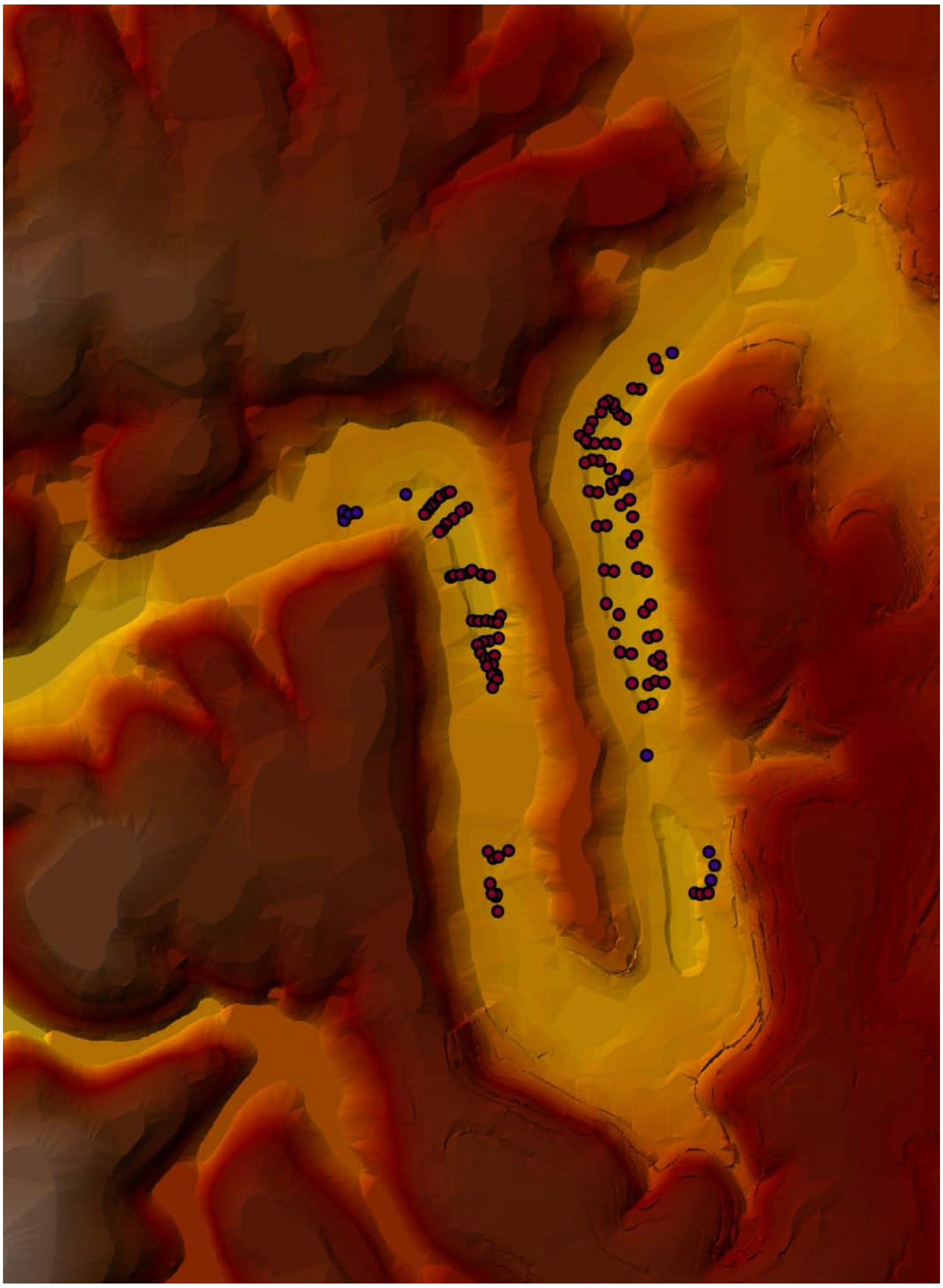


Figure 1: Thirlmere Survey.

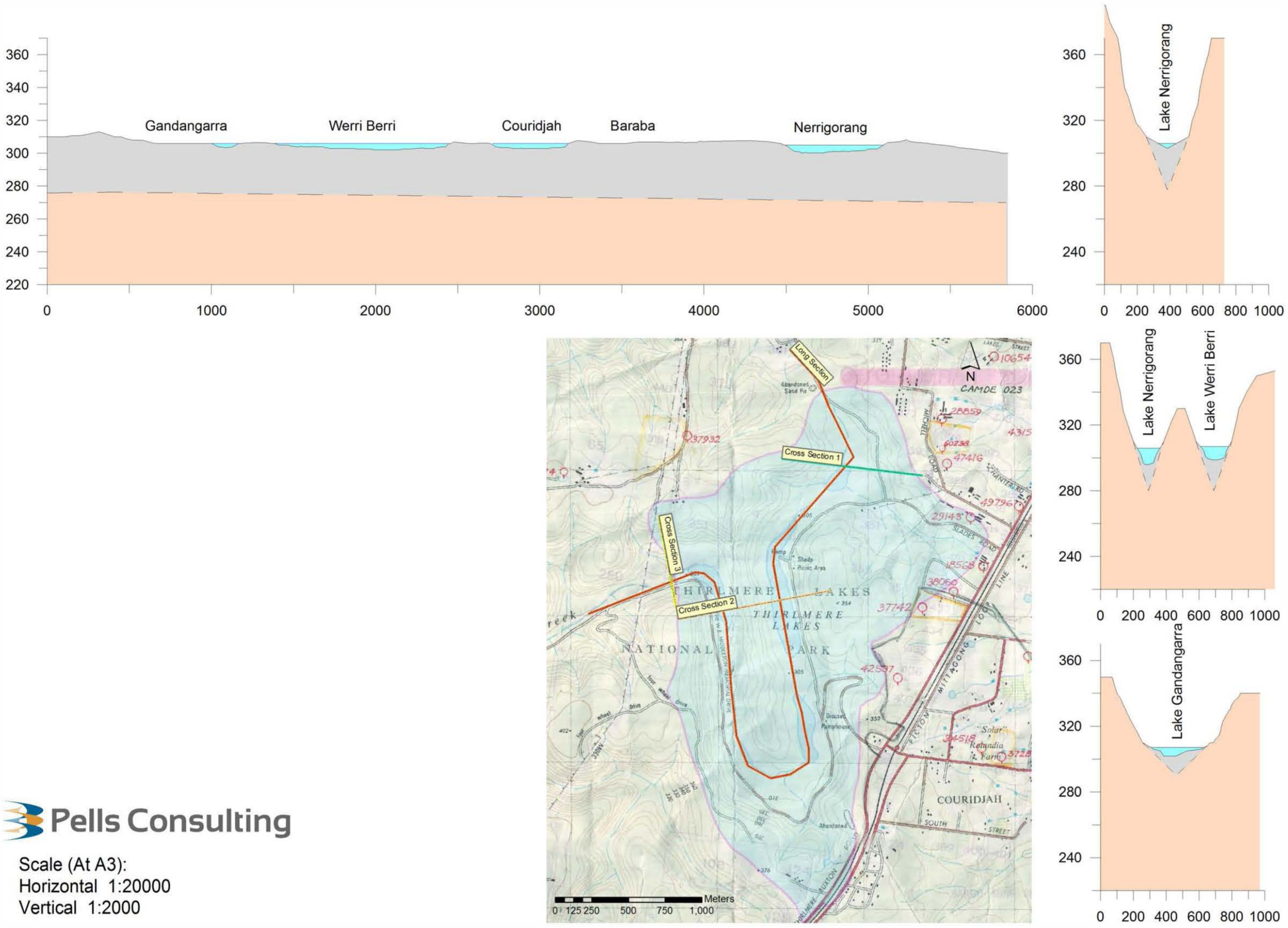


Figure 2: Longitudinal and cross sections.

Details of the computed depth-versus-storage, and depth-versus-surface area curves, for each lake, will be given in our final interpretative report.

All the survey information and all borehole and geological structural data is being accumulated in GIS format.

The survey solved one puzzle, namely: why does Lake Baraba never fill up?

It transpires that the level of the peat in Lake Baraba (see Photograph 5) is at or above the full water levels of the other lakes. In fact, the peat level in Lake Baraba is about 7m above the floor level of Lake Nerrigorang. Lake Baraba is, actually, a valley fill swamp and is discussed further in Section 9.

Photograph 5: Lake Baraba, 22 August 2011 (P. Pells photo).

3.0 ADDITIONAL HISTORICAL PHOTOGRAPHS

The previous four progress reports have included various photographs provided by members of the public. Further photographs have been received that are valuable proxy data in establishing historical changes in lake levels. These are reproduced in Photographs 6 to 18, below.

Photograph 6: Lake Nerrigorang, mid 1950s (Rackleyft photo).

Photograph 7: Lake Nerrigorang, 1988 (Rackleyft photo).

Photograph 8: Lake Nerrigorang, 1990 (Rackleyft photo).

Photograph 9: Lake Nerrigorang, 1994 (Rackleyft photo).

Photograph 10: Lake Couridjah, 1990 (Mall Juske photo).

Photograph 11: Lake Werri Berri, 1990 (Mall Juske photo).

Photograph 12: Lake Nerrigorang, March 1987 (Rackleyft photo).

Photograph 13: Lake Werri Berri, Summer 1958/1959 (Mall Juske photo).

Photograph 14: Lake Couridjah,
3 June 2011 (Julie Sheppard photo).

Photograph 15: Lake Couridjah,
4 August 2011 (Julie Sheppard photo).

Photograph 16: Gundangarra, 1954 (Mall Juske photo).

Photograph 17: Lake Werri Berri, 1993 (Angela Jansz photo).

Photograph 18: Lake Nerrigorang after bushfire, 2002 (Johanessen photo).

On 22 August 2011, we were informed on site by an NPWS officer that in late 1995 the water edge of Lake Werri Berri was about 2.5m from the stone wall.

4.0 RELEVANT MONTHLY RAINFALL DATA

Our previous progress reports have documented annual rainfall figures for the area of the Thirlmere Lakes.

It has been suggested in the media that the lakes should have refilled to some extent in 2011 because of good rainfall in 2010 and 2011. To assist in considering this matter we have extracted data from the Bureau of Meteorology, giving monthly data for:

(i) the severe drought of 1938 to 1948 which terminated in very heavy rain in 1949 and 1950,

(ii) 1974 where, during the period of study by Patricia Fanning, the lakes were overflowing, and the NSW Bushfire organisation was concerned that access to the National Park had been cut off by the road around the lakes being under water in places, and

(iii) the dry period of 1998 to 2006 followed by fluctuating rainfalls of 2007 to 2011.

The relevant data were given in Appendix A.

5.0 BUSHFIRES

The relevant major bushfires are set out in Table 1. We are seeking further information as to which of these fires affected the Thirlmere Lakes area.

TABLE 1

MAJOR BUSHFIRES – BLUE MOUNTAINS AND SYDNEY REGIONS

Year	Location	Comments
1910	Warragamba	Recorded as burning Blue Gum Creek (SMH 15/1/1910)
1912	Sydney, Blue Mountains	(SMH 25/1/1912)
1939	Blue Mountains, Sydney Southern NSW, Canberra	
1953	Mittagong, Bowral Belanglo Forest	
1957	Blue Mountains and Sydney Region	Bushfires in the Blue Mountains area drive by gale force winds destroyed 25 homes, shops, schools, churches and a hospital. See evidence of previous bushfire in Photographs 13.
1964/ 1965	Southern Tablelands	Major fires occurred in the Snowy Mountains, Southern Tablelands and outer metropolitan area. The Chatsbury/Bungonia fire covered 250,000ha and destroyed the village of Wingello. Three lives were lost. In March the Tumut Valley fire burnt 80,000ha.
1968/ 1969	Sydney, Blue Mountains and Illawarra, 1 million hectares burnt	Widespread damage occurred over much of the eastern part of the State. Major fires at Wollongong burnt rainforest, destroyed 33 homes and 5 other buildings. Fires in the lower Blue Mountains were fanned by 100km/h westerly winds and destroyed 123 buildings. Three lives were lost.

Year	Location	Comments
1974/ 1975	Widespread fires	The severest season for perhaps 30 years in the far west with 3,755,000ha burnt, 50,000 stock lost and 10,170km of fencing destroyed. 1.5 million ha were burnt in the Cobar Shire in mid-December and 340,000ha in the Balranald fire. The Moolah-Corinya fire burnt 1,117,000ha and was the largest fire put out by bush fire fighters. Its perimeter was over 1,000km.
1976/ 1977	Blue Mountains and Northern Sydney	In early December, 9,000ha were burnt and three homes destroyed in Hornsby Shire, and 65,000ha were burnt in the Blue Mountains.
1977/ 1978	Blue Mountains	In the Blue Mountains area 49 buildings were destroyed and 54,000ha burnt. Sydney suburbs up to 60km away were showered with fallout of blackened leaves.
1978/ 1979	Blue Mountains and Sydney	Serious fires occurred in the Southern Highlands and South West Slopes regions. Over 50,000ha were burnt, give houses were destroyed and heavy stock losses were inflicted.
1979/ 1980	Widespread	Following severe drought conditions over most of the State, major fires were widespread. In Mudgee Shire, 55,400ha were burnt and one life was lost. 9,000ha were burnt in Warringah Shire and 14 houses lost. Fires occurred in the majority of council areas within the State burning at total of over 1 million ha.
1982/ 1983	Eastern seaboard, widespread	$12 million worth of pine plantation was destroyed in southern NSW in a fire, which burnt 25,000ha in only two and a half hours. The Grose Valley fire burnt 35,000ah.
1993/ 1994	Widespread	In late December 1993, a series of fires began on the north coast and in the Hunter Region. As weather conditions continued to deteriorate, fire occurrence spread from the Queensland border to Batemans Bay. In excess of 800 fires started between December 27, 1993 and January 16, 1994. Over 800,000ha were burnt.
Dec 2001 to Jan 2002	Widespread throughout Sydney region (said to be worst on record)	The second spate of 5 “Bushfire Emergencies” commenced at 1500 hours on 3 December 2001 with the declaration of the Blue Mountains Rural Fire District. The fires generally started as a result of a severe dry thunderstorm with many lightning strikes on the Great Dividing Range and to the west. See Photograph 18 of Lake Nerrigorang after this bushfire.

6.0 FAULTS AND DYKES

Figure 3 in Progress Report No. 3 gives information on major faults in the Thirlmere-Tahmoor area. We have now concentrated on two particular sets of dyke/fault structures that have been encountered in the Tahmoor Colliery and which influence groundwater movement in the area of the lakes and the south western portion of Tahmoor Colliery.

Figure 3 of this report shows faults and dykes mapped in the Tahmoor Colliery and published on the internet by Xstrata Coal. There is clearly a major NW-SE fault/dyke zone that cuts across the mine. For the purpose of communication we have termed this Tahmoor NW-SE strike-slip fault and intrusion zone, as “T1 fault” in shorthand. It appears that the T1 fault played a role in the significant inflows that occurred during excavation of the Tahmoor decline (Ref1). A splay of the T1 fault was associated with overbreak in the No.3 shaft (Ref 2). It is interpreted that this fault zone dips to the NE.

A second fault that is considered to be of relevance is the NW boundary fault (termed here the T2 fault), encountered in some drives, and postulated by Xstrata as extending to the SW (see Figure 3).

The information in Figure 3 regarding the T1 and T2 faults is transcribed onto Figure 4 in relation to the positions of the Thirlmere Lakes. If these structures extend to the lake area they could influence groundwater movement around and beneath the lakes.

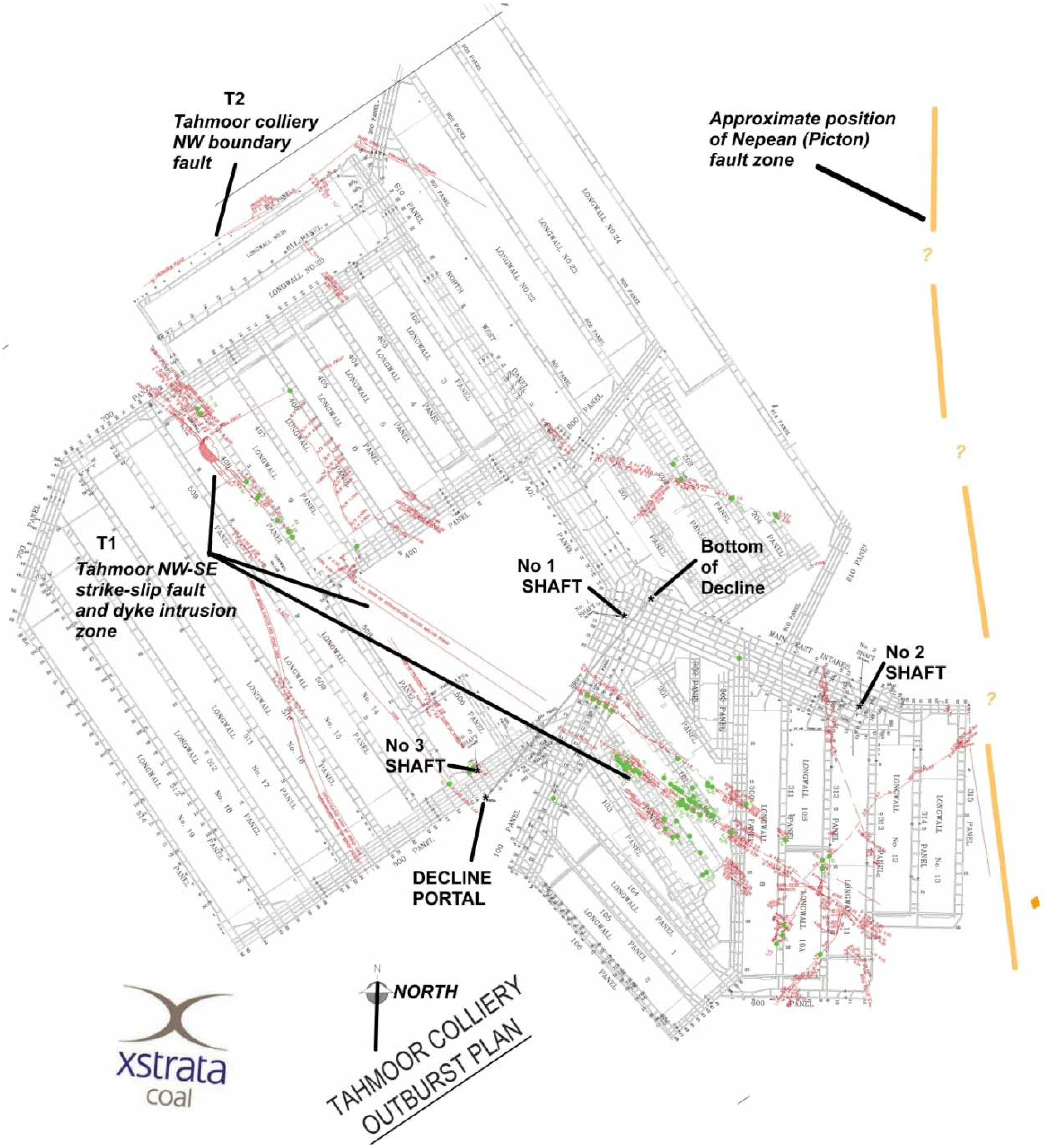
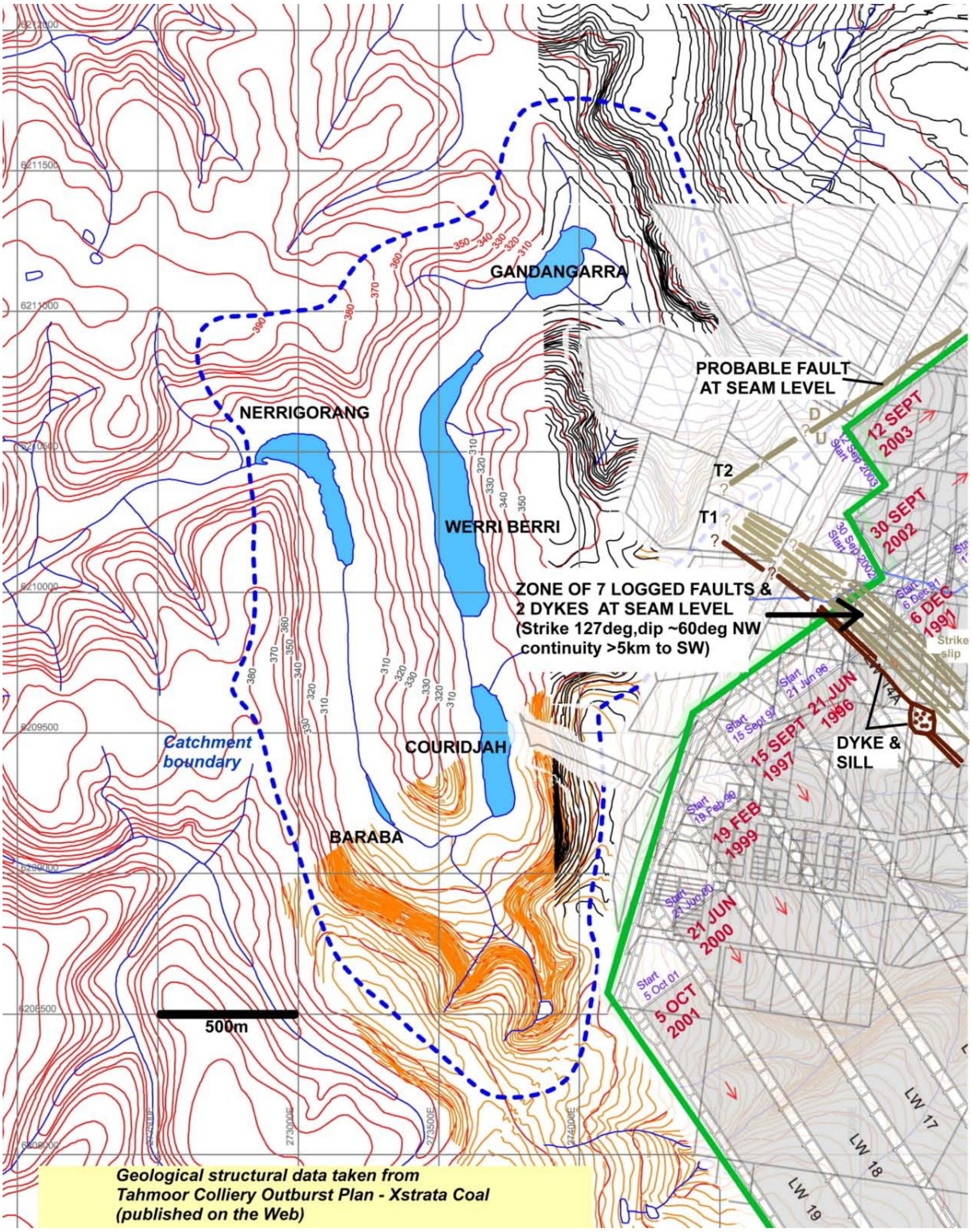


Figure 3: Tahmoor structures.



Geological structural data taken from Tahmoor Colliery Outburst Plan - Xstrata Coal (published on the Web)

Figure 4: Structural geology.

7.0 BOREHOLE DATA

Table 2 summarises bore data in the area east of the Thirlmere Lakes. The bores are shown in Figure 2.

TABLE 2

BOREHOLE NO.	LATITUDE	LONGITUDE	DATE INSTALLED	DEPTH OF BORE	STANDING WATER LEVEL (DURING DRILLING)	HOW MUCH WATER PRODUCED
34518	34 13' 59"	150 33' 20"	1/7/1970	76.2	24.30	0.47
37289	34 14' 1"	150 33' 26"	1/7/1973	137.10	32.90	4.55
42537	34 13' 43"	150 32' 59"	1/9/1975	121.9	45.7	2.27
102439	34 13' 34"	150 33' 6"	30/7/1998	115	72	0.5
37742	34 13' 28"	150 33' 6"	1/1/1972	112.80	53.30	1.52
38060	34 13' 24"	150 33' 14"	1/1/1974	122.5	45.7	3.03
18568	34 13' 18"	150 33' 22"	1/11/1961	63.4	32.6	1.14
29143	34 13' 8"	150 33' 19"	1/10/1968	73.2	41.1	0.76
49796	34 13' 5"	150 33' 32"	1/2/1980	61.0	24.6	0.8
47416	34 12' 56"	150 33' 13"	1/11/1979	64.0	24.4	0.7
60238	34 12' 58"	150 33' 8"	1/2/2004	48.0	27.0	1.70
28859	34 12' 46"	150 33' 12"	1/10/1968	45.7	13.7	1.14
104720	34 12' 34"	150 33' 7"	6/3/2003	91	54	1.7
10654	34 12' 32"	150 33' 26"	1/6/1954	39.6	8.6	0.63
70979	34 12' 42"	150 33' 40"	Unknown	48.0	10	1.7
43154	34 12' 50"	150 33' 39"	1/10/1968	48.8	No details	2.27
37860	34 13' 39"	150 33' 33"	1/3/1969	137.1	32.9	2.27
10584	34 13' 51"	150 33' 39"	1/5/1954	50	29.9	0.99
12612	34 13' 26"	150 33' 42"	Unknown	57.9	No details	No details
11200	34 13' 13"	150 33' 51"	15/2/2008	61	30	3
11299	34 13' 54"	150 33' 37"	1/11/1955	61	22.8	0.76

In mid-2011, NSW Water installed four groundwater level monitoring boreholes (piezometers) in the lakes area, one at the north end of Lake Nerrigorang, two near the old Lake Couridjah pump station, and one within the area of Lake Gandangarra.

Figure 5 shows the locations of the piezometers and Table 3 and 4 give relevant data as supplied by NSW Water. Ground level at the two piezometers at Lake Couridjah was measured on 22 August 2011, using a combination of GPS (RTK mode) and optical levelling, as 309.1m.

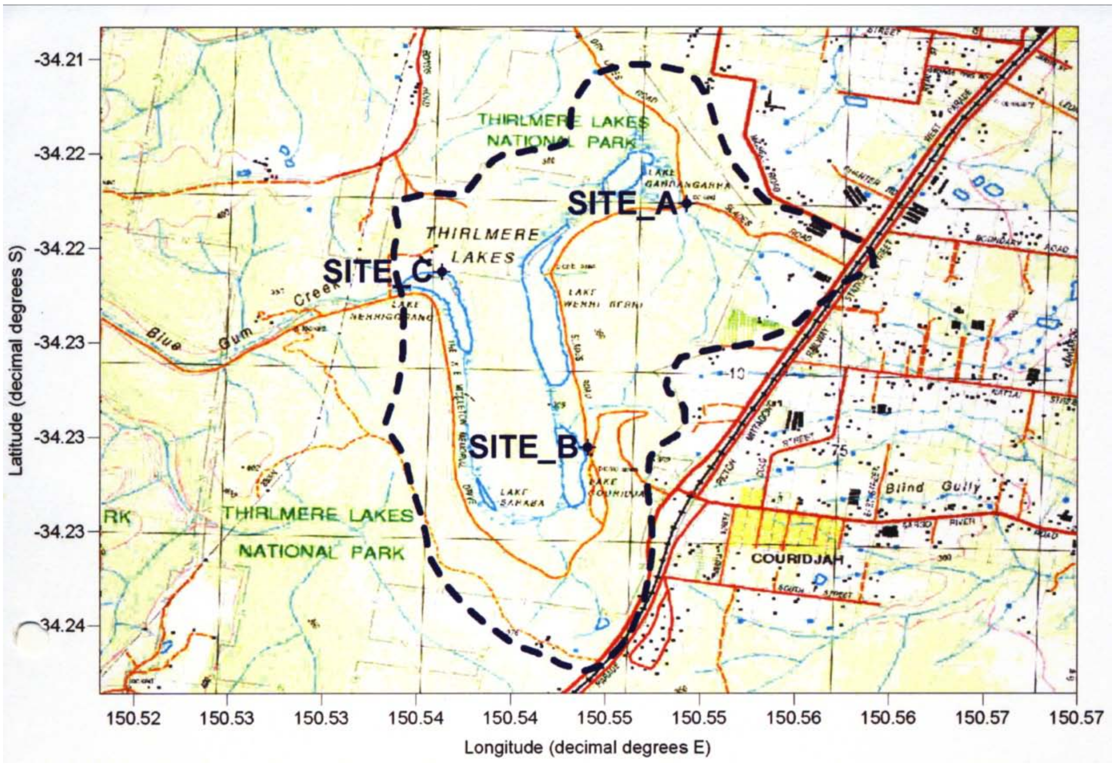


Figure 5: Locations of piezometers.

TABLE 3

Summary Drilling Details for Thirlmere Lakes National Park Monitoring Bores

Site	Site identifier	Hole identifier	Depth drilled (m)	Method	Depth completed (m)
Lake Gandangarra	A	GW075411	28	HQ core/ Rotary mud	28
Lake Couridjah	B	GW075409/2 GW075409/1	100 24	TUBEX/ Rotary air HQ core/ Rotary mud	100 15
Lake Nerrigorang	C	GW075410	18	HQ core/ Rotary mud	17.5

TABLE 4

Summary Standing Water Levels for Thirlmere Lakes National Park Monitoring Bores

Site	Site identifier	Hole identifier	Standing water level (m)	Time	Date
Lake Gandangarra	A	GW075411	12.74	1246	28 June 2011
Lake Couridjah	B	GW075409/2 GW075409/1	16.99 8.35	1313 1309	28 June 2011 28 June 2011
Lake Nerrigorang	C	GW075410	9.19	1332	28 June 2011

Further readings were taken by NSW Water on 17 August 2011 as:

GW075409/1	8.45m below ground level
GW075409/2	17.12m below ground level
GW075411	12.82m below ground level

8.0 ROCK MASS PERMEABILITY DATA

8.1 Stratigraphy

A stratigraphy cross-section beneath the lakes is presented in Progress Report No. 4. The relevant strata in respect to groundwater movement to, or from, the lakes are:

- the Recent alluvium forming valley infill within the paleovalley containing the lakes,
- Hawkesbury Sandstone,
- Bald Hill Claystone,
- Narrabeen Formation, including Bulgo Sandstone and siltstone horizons,
- Bulli Seam,
- Permian strata beneath the Bulli Seam, including other coal seams.

A report by the NSW Department of Water of December 2010, titled “Thirlmere Lakes, groundwater assessment”, states as follows:

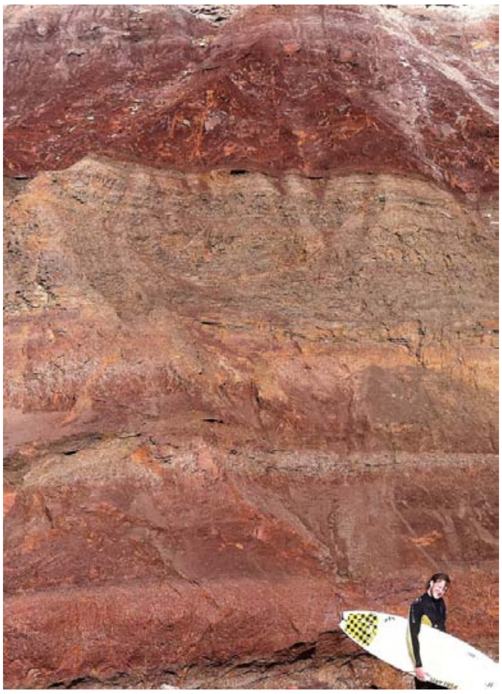
> ”*Significant regional aquifers within the Sydney Basin are hosted by Triassic strata (Hawkesbury Sandstone and Narrabeen Group sandstones). Groundwater accumulates in porous zones (‘sheet sandstone’ units, refer to previous sections) within the sandstone rock mass, and generally flows down the prevailing dip of the strata. That is, the direction of groundwater movement is generally toward the central basin area. Overprinting by faulting, fracturing and fissuring enhances the permeability of these rock units on various scales and is significant in improving the transmissivity of the*

> *strata generally. The Bald Hill Claystone forms a regionally significant aquitard, separating the Hawkesbury Sandstone from the underlying Bulgo Sandstone. Under normal circumstances, this unit forms a barrier to vertical groundwater movement between the two aquifers."*

The concept that the Bald Hill Claystone "forms a barrier to vertical groundwater between the two aquifers" needs to be viewed in relation to available facts.

8.2 Structure of the Bald Hill Claystone

The Bald Hill Claystone is an approximately 20m thick layer of interbedded, siltstone, claystone and fine sandstone comprising mainly kaolinite and haematite. It contains as many as eight soil profiles[2] (ie. eight superimposed palaeosols), is fissured and jointed, and is transgressed (in places) by faults and igneous intrusions (see Photographs 19 to 21).



Photograph 19: Bald Hill Claystone at Long Reef, Sydney

Photograph 20: Joints in Bald Hill Claystone at Bald Hill

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[2] Herbert (1980) Chapter 2 *A Guide to The Sydney Basin.*

Photograph 21: Through going joint in the type section at Bald Hill, just north of Stanwell Park.

8.3 In-situ permeability data for undisturbed Bald Hill Claystone

Figure 6 summarises in situ measurements, predominantly from borehole packer (Lugeon) tests, in the Southern Coalfields and off the coast of Sydney. Figure 7 shows the field measurements plotted versus depth.

It can be seen that the measured packer test permeability values for the Bald Hill Claystone fall within the ranges measured in the Hawkesbury Sandstone and the Narrabeen Formation. In assessing these results cognisance must be taken of the fact that where boreholes do not intercept joints, permeability is largely controlled by the near horizontal bedding planes. However, in assessing vertical permeability consideration must be given to the evidence (see Section 8.2) that the Bald Hill Claystone is closely jointed.

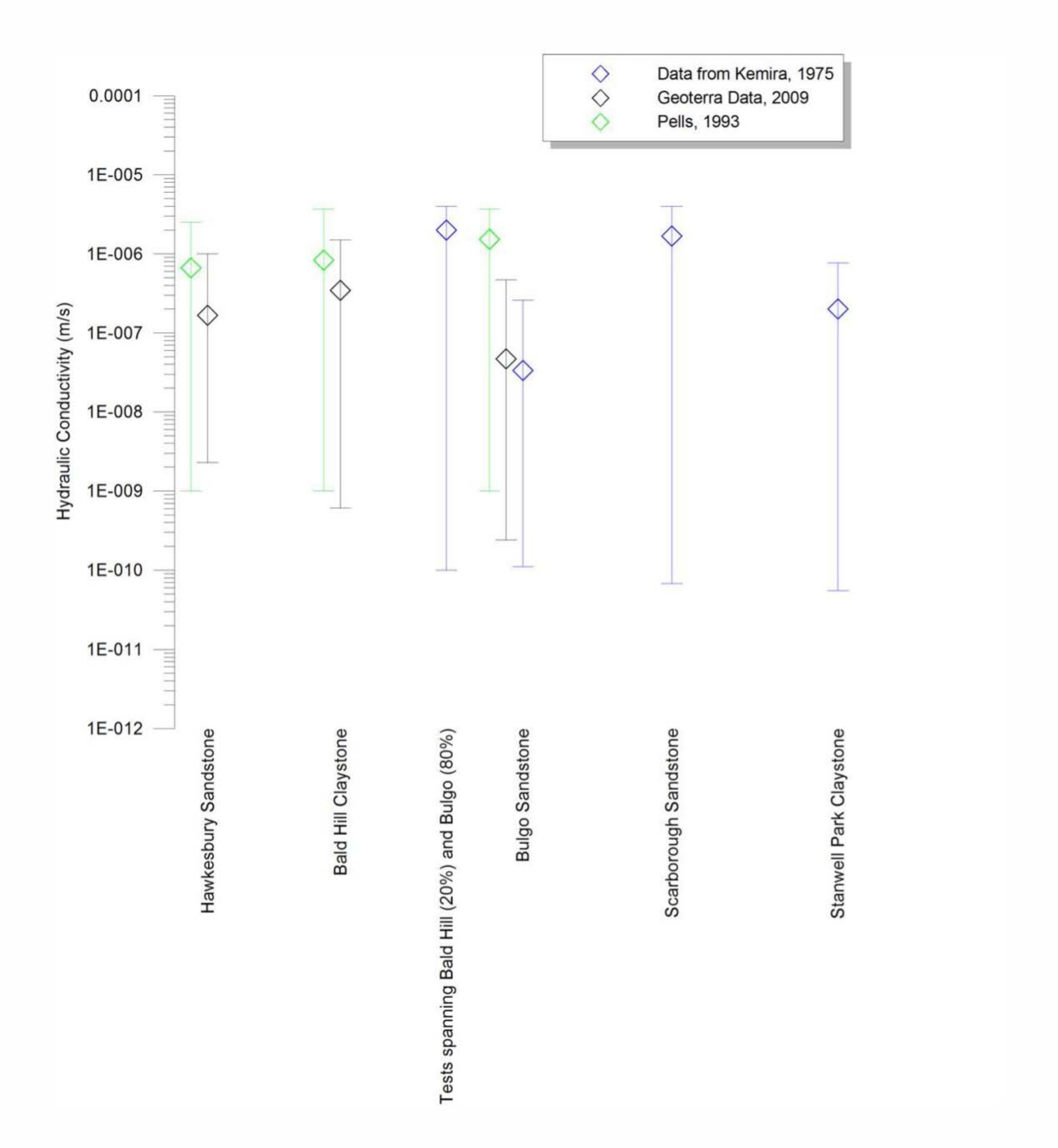


Figure 6: Packer test data from the Narrabeen and Hawkesbury.

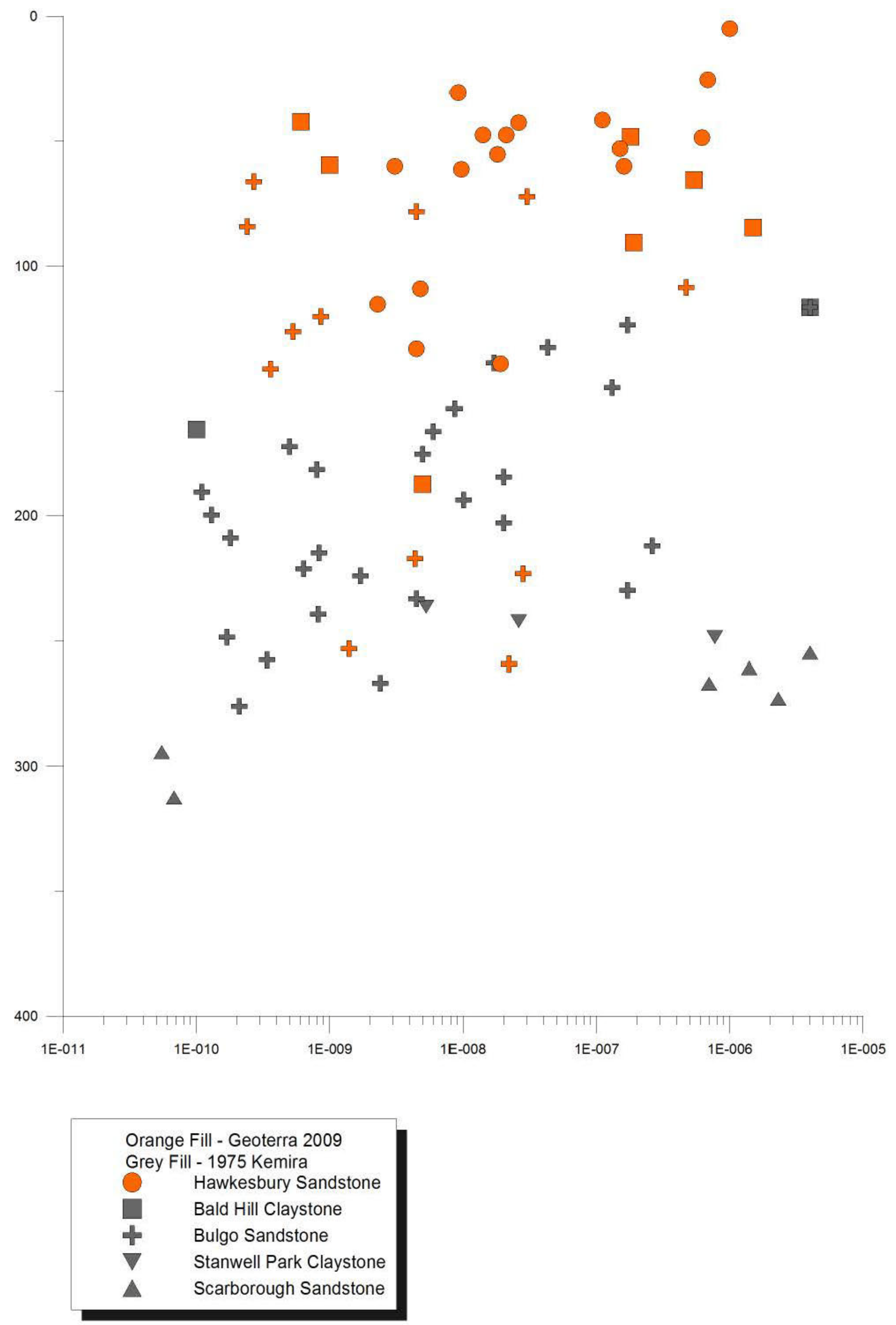


Figure 7: Permeability data plotted versus depth

8.3 Impact of Longwall Mining on Permeability of the Overlying Rock

The extent to which longwall mining causes rock fracturing, and hence permeability increase, is discussed in detail in Chapter 4 of the Bulli Seam Operations PAC report of July 2010. That report discusses the great uncertainty in respect to the height above longwalls panels in which new fractures will result in a substantial increase in vertical permeability. The Panel concluded, “for the purpose of progressing its assessment that”:

“1. When the MSEC model (see Figure 8) is applied to conditions similar to the calibration data, it could produce reasonable predictions of the height of fracturing even though it has mechanistic shortcomings for that purpose, with the maximum height being 1.37 times panel width;

2. Based on other studies including Gale (2008), a potentially worst case outcome appears to be fracturing extending up to a height of 1.5 times panel width but with increasing disconnection of fracturing;

3. It is unlikely that the highly connected and freely drainable fractured zone will extend upwards into and beyond the Bald Hill Claystone for longwall panel widths up to 310m. This is suggested by a range of field measurements and observations, the most recent being extensometer measurements conducted over LW32 (310m width) at West Cliff Area 5 where more than 90% of fracture displacements seem to have occurred at or below the claystone.”

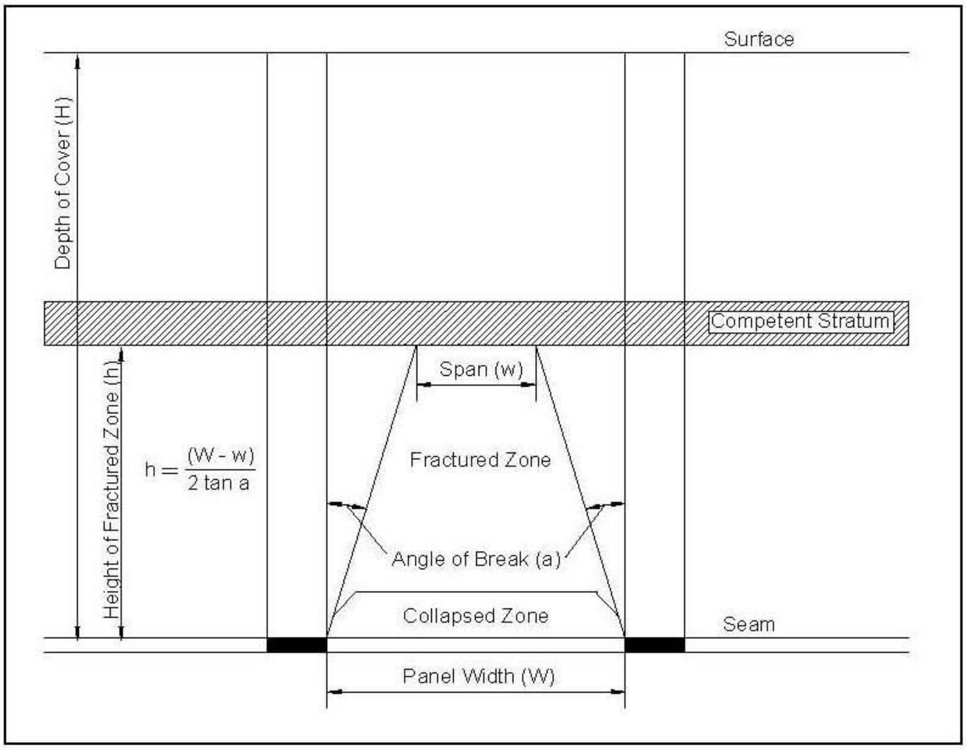


Figure 8: MSEC model for extent of fracture zone.

9.0 LAKE BARABA

Whilst Lake Baraba is of least concern to most of the community, because it is neither pretty nor useful, it is probably the most important of the lakes from the scientific viewpoint (Ref 3). It is one of only 33 sites in the Australian, South East Asian and Pacific regions that have a record of vegetation during the last glacial maximum (ice age), 18,000 to 25,000 years ago. It provides a detailed source of information of plant and tree types, and fire records, to beyond 43,000 years ago. This information is important in understanding the impact of humans (Aboriginals and European) on the flora of SE Australia (Ref 4).

A detailed analysis of a 6.35m long continuous core from the lake bed (Ref 3) shows a major change in the stratigraphy at a depth of about 0.4m, where peat (60% to 90% organics), changes to black and yellow clays (< 20% organics). This change has been dated at about 8,000 years ago (see Figure 9, taken from Ref 3).

M.P. Black et al. / Quaternary Science Reviews 25 (2006) 3003–3016

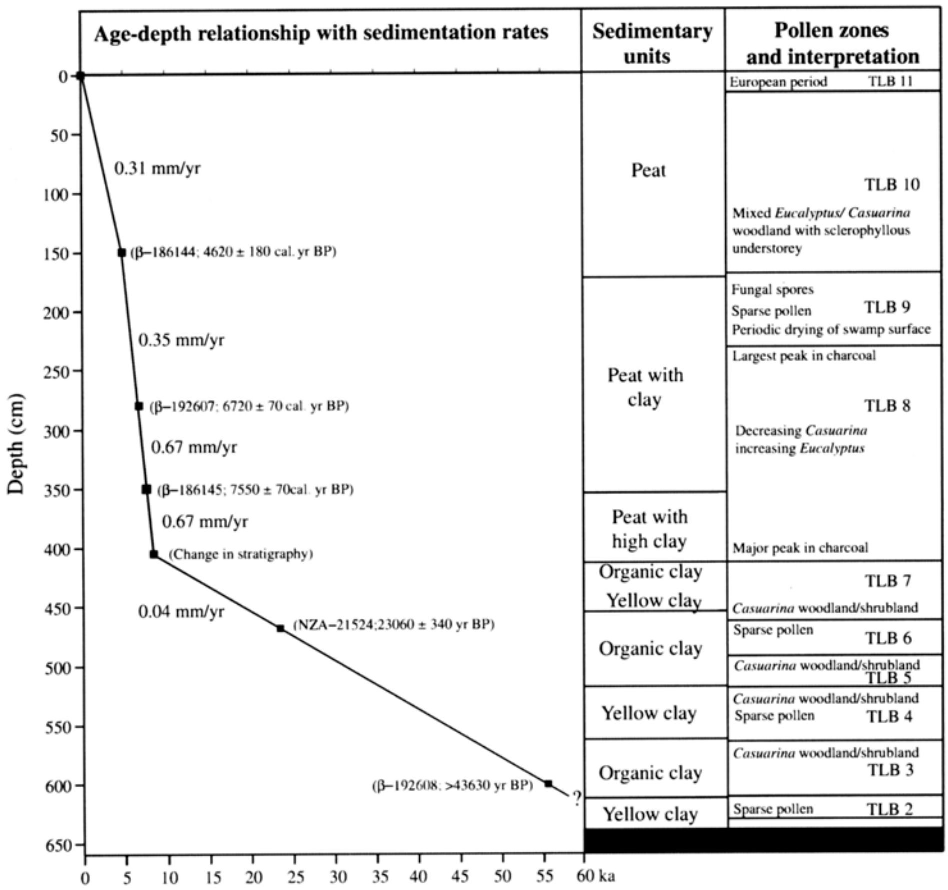


Figure 9

Quite remarkably, analyses of pollen from the core clearly showed the presence of *Pinus* species to a depth of about 100mm, showing the starting point of European influence.

We do not understand why Lake Baraba became a valley infill swamp some 8,000 years ago, and has remained so, with a level some 7m above the floor of Lake Nerrigorang and 6m above the floor of Lake Couridjah.

Photographs 22 to 27 show the plant types that currently dominate Lake Baraba.

Photograph 22: *Lepidosperma longitudinal* Sward sedge

Photograph 23: *Lepyromdia muelleri* Scale rush

Photograph 24: *Schoenus brevifolius* Zig zag bog rush

Photograph 25: *Lepironia articulate* Tall Sedge

Photograph 26: *Eleocharis-sphacelata* Tall Spike Rush

Photograph 27: *Philydrum lanuginosum* Woolly frogmouth

Photograph 28: *Brasenia schrebi* Watershield lily – endangered species.

10.0 CONCLUSIONS

We are of the opinion that sufficient factual information has been collected and collated to allow scientific calculations to be undertaken as an aid in assessing important factors controlling the substantial decreases in the lake water levels over the past decade. There is sufficient proxy data to develop a reasonable plot of lake water levels from prior to the WWII drought through to September 2011 (~ 70 years). Hydrological and hydrogeological calculations should allow an objective assessment to be made as to whether the decade-long drop in levels has, or has not, been a phenomenon independent of mining activities.

REFERENCES

1. Black, M. P., Mooney, S. D. And Haberle, S. G. "*The fire, human and climate nexus in the Sydney Basin, eastern Australia*". The Holocene, Vol 17, No. 4.

2. Black, M. P., Mooney, S. D. And Martin, H. A. "*A > 43,000 – year vegetation history from Lake Baraba, New South Wales, Australia*". Quaternary Science Reviews, Vol 25, 2006.

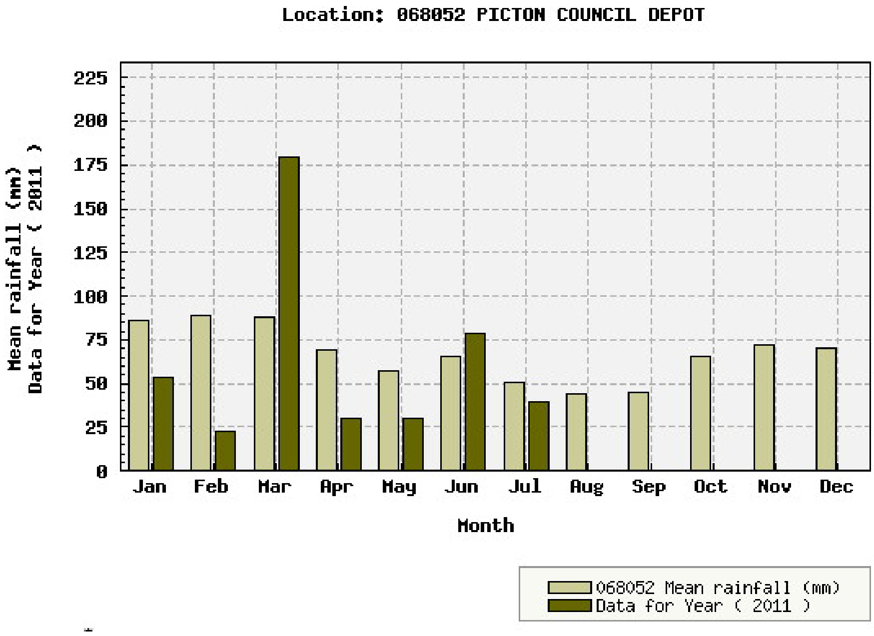
3. Fawcett, D. H. And Rose, J. A. F. "*Groundwater problems encountered whilst sinking at Tahmoor Colliery*". 3rd Australian Tunnelling Conference, 1978.

4. Pells Sullivan Meynick Pty Ltd, Report PSM16.R1, December 1993.

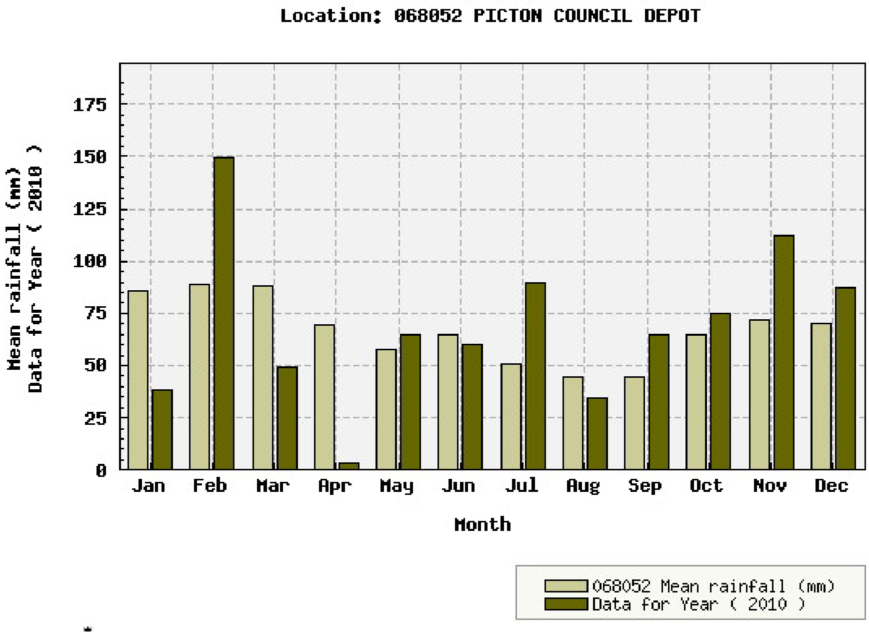
APPENDIX A

MONTHLY RAINFALL AT PICTON COUNCIL DEPOT

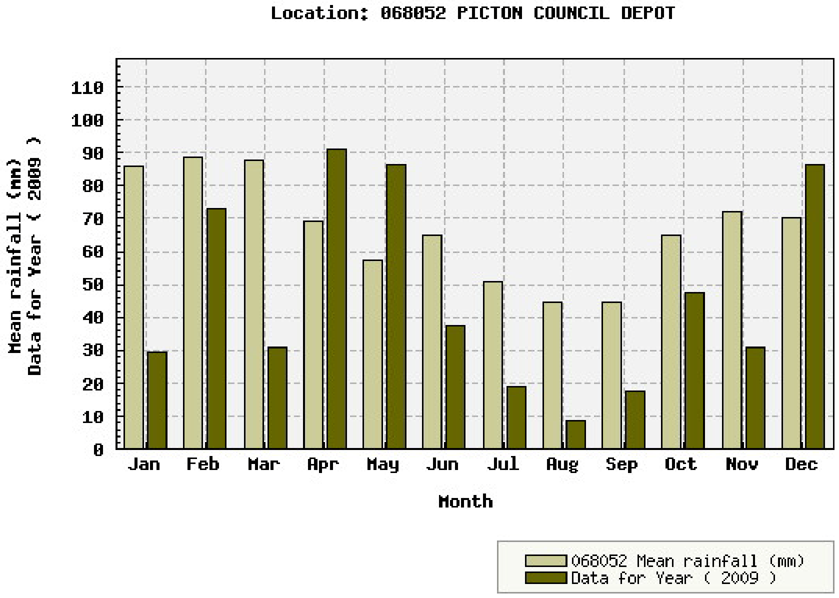
Note: the annual average is 801mm.



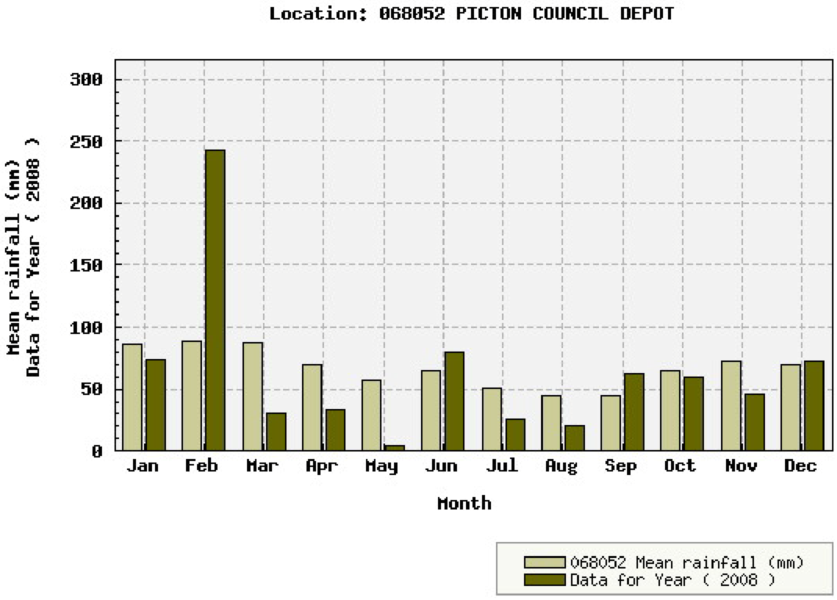
2011



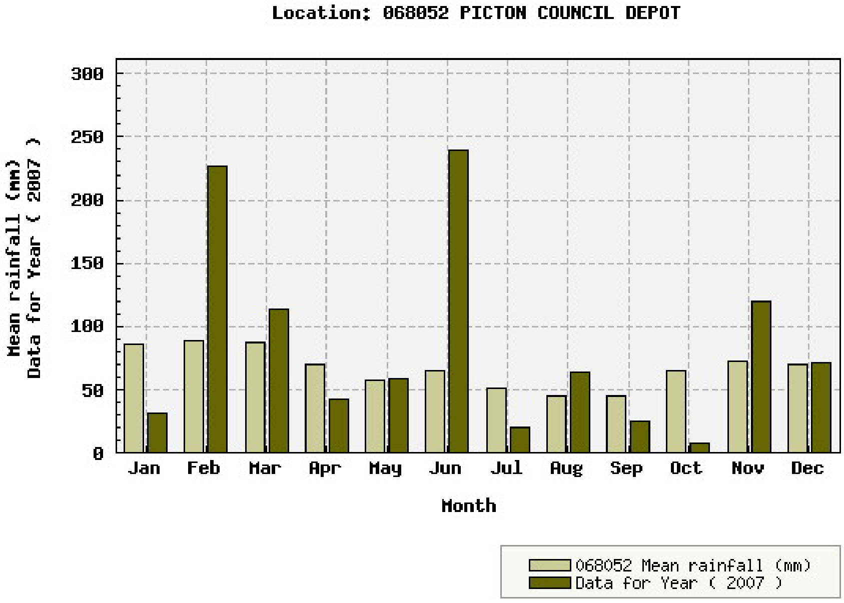
2010
Total Rainfall: 829.1



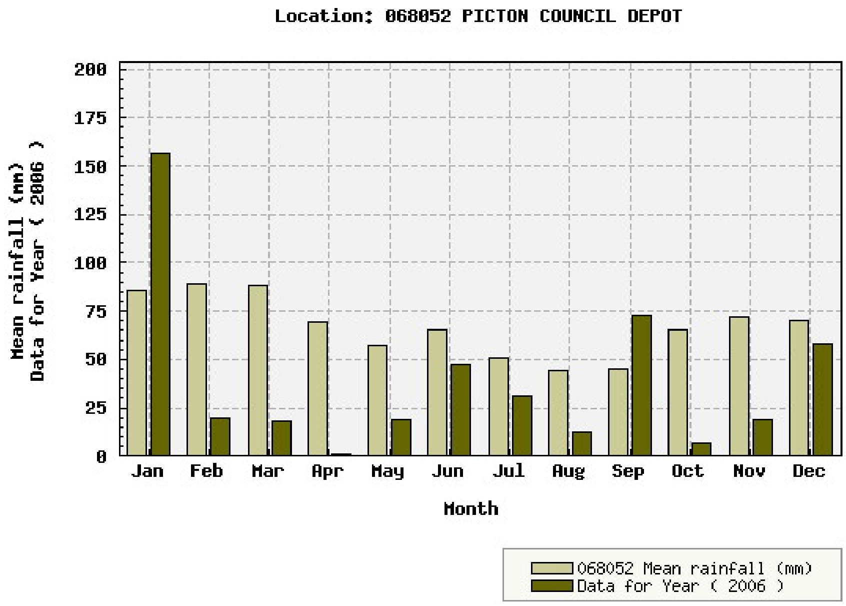
2009
Total rainfall: 559.1



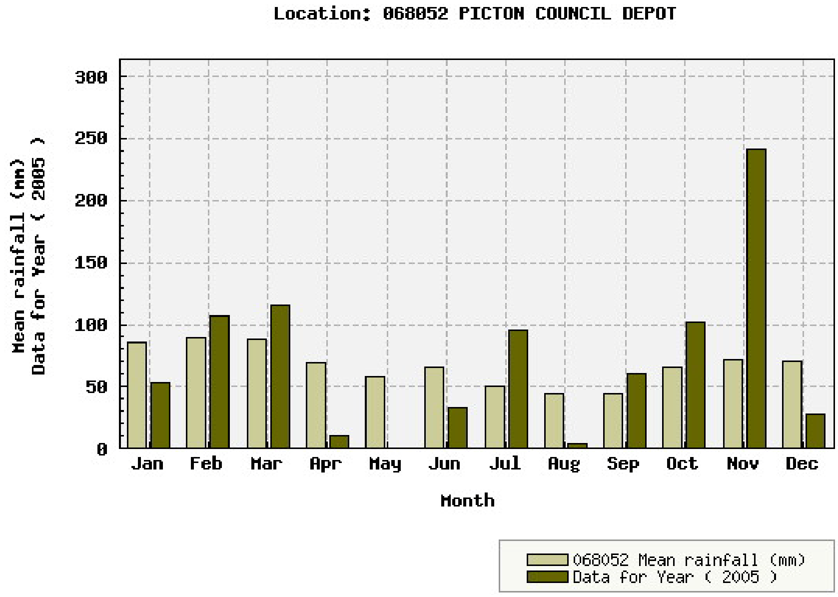
2008
Total rainfall: 750.8



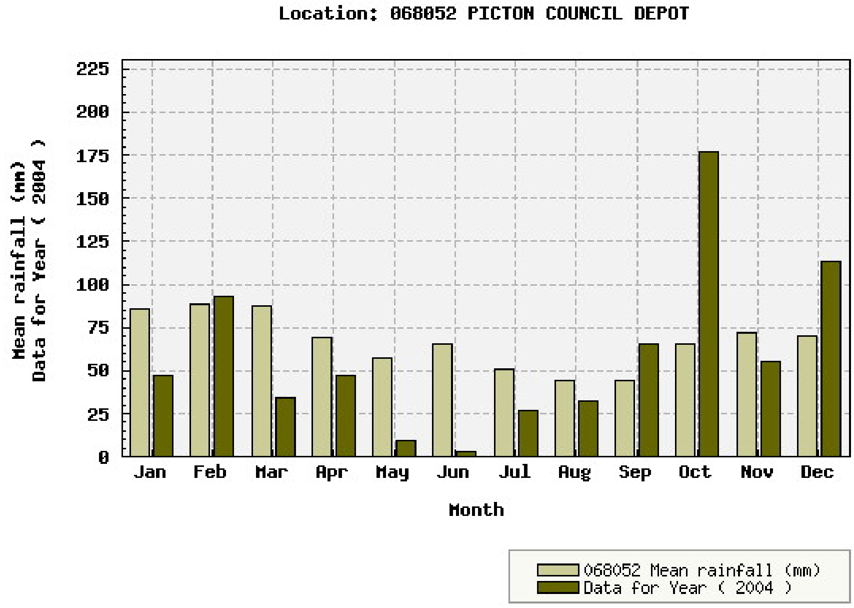
2007
Total rainfall: 1,019.0



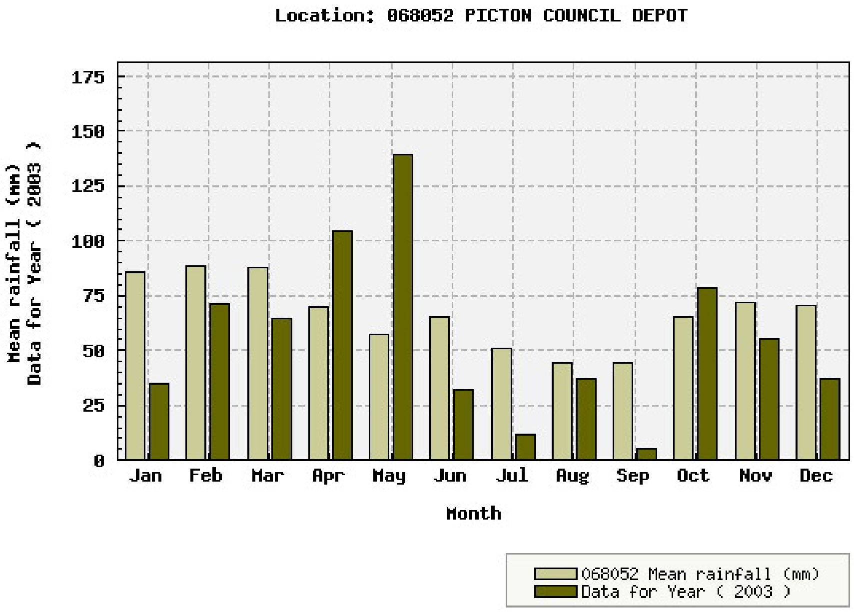
2006
Total rainfall: 461.5



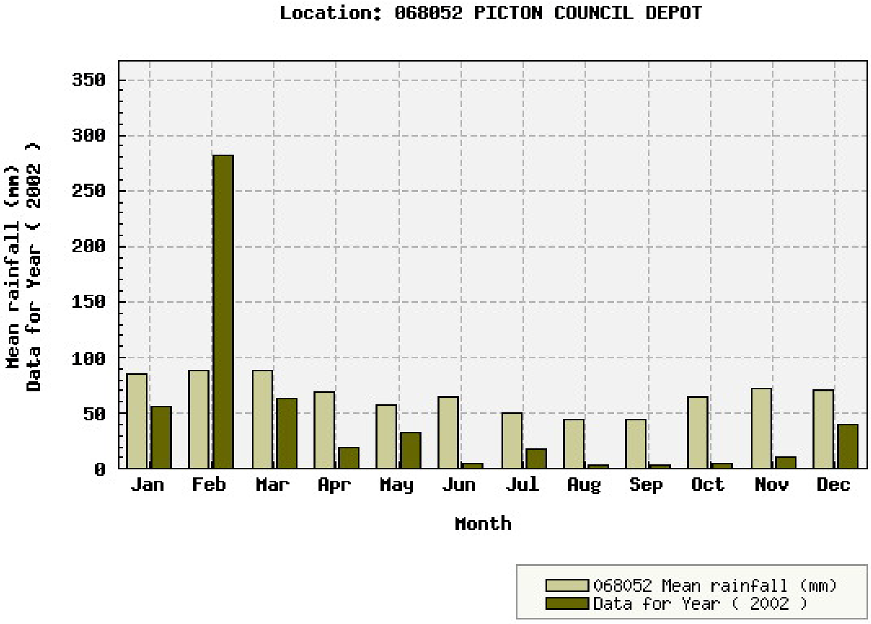
2005
Total rainfall: 851.9



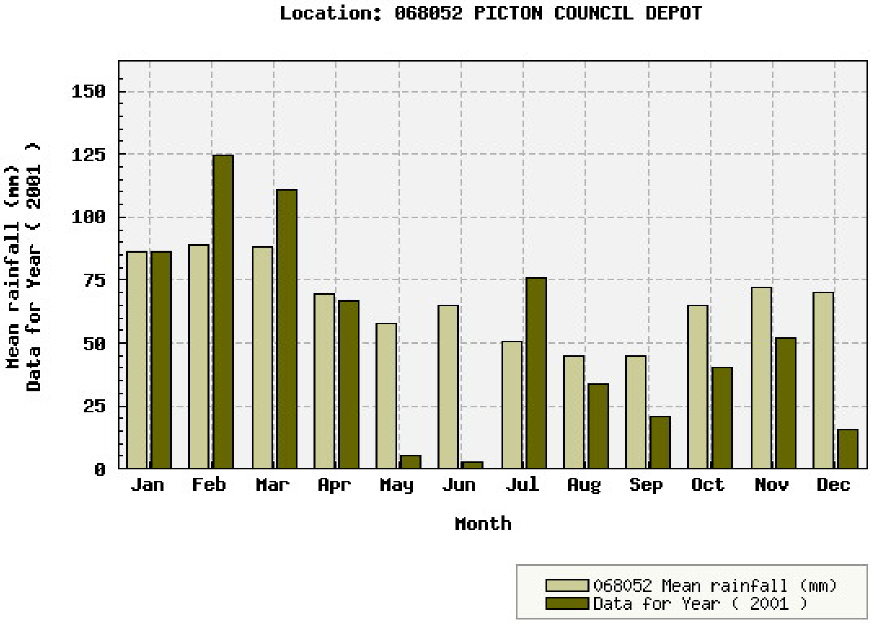
2004
Total rainfall: 702.9



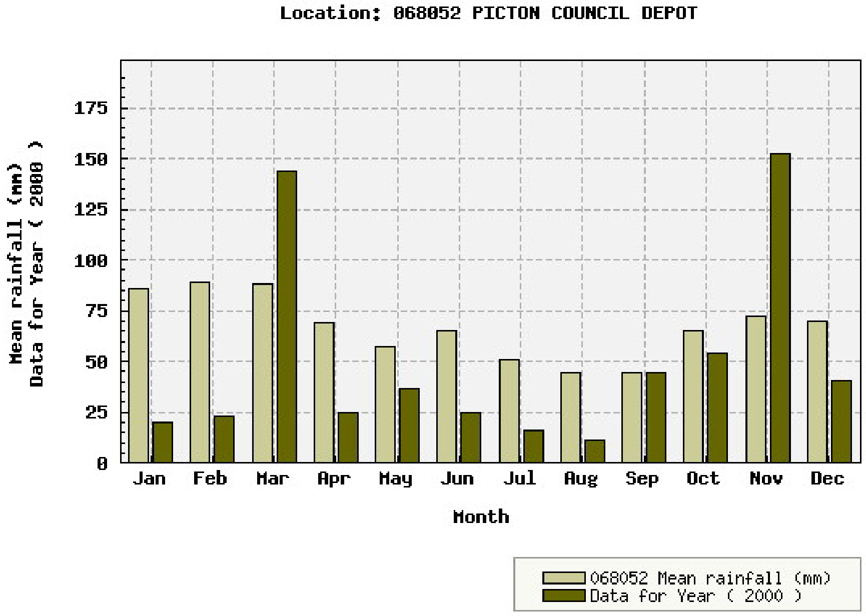
2003
Total rainfall: 671.6



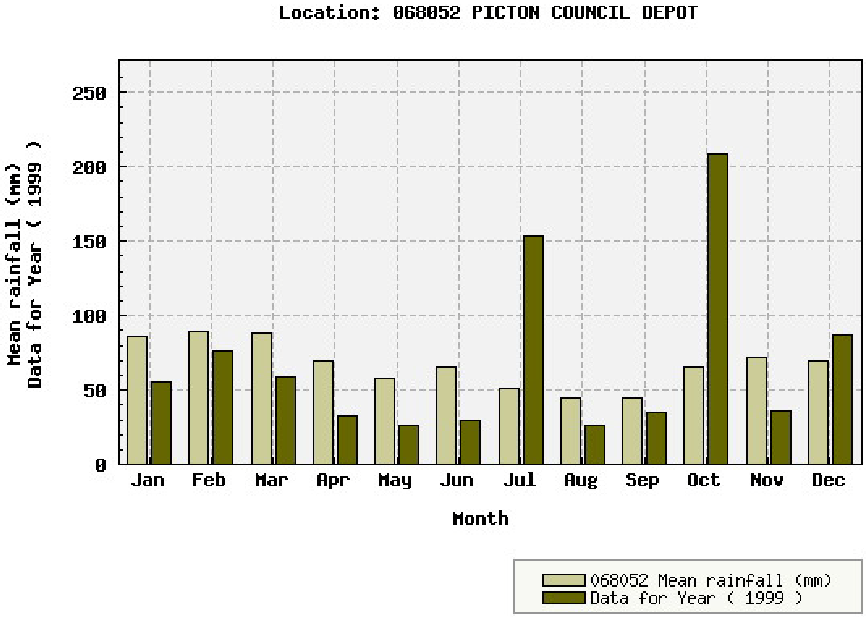
2002
Total rainfall: 538.6



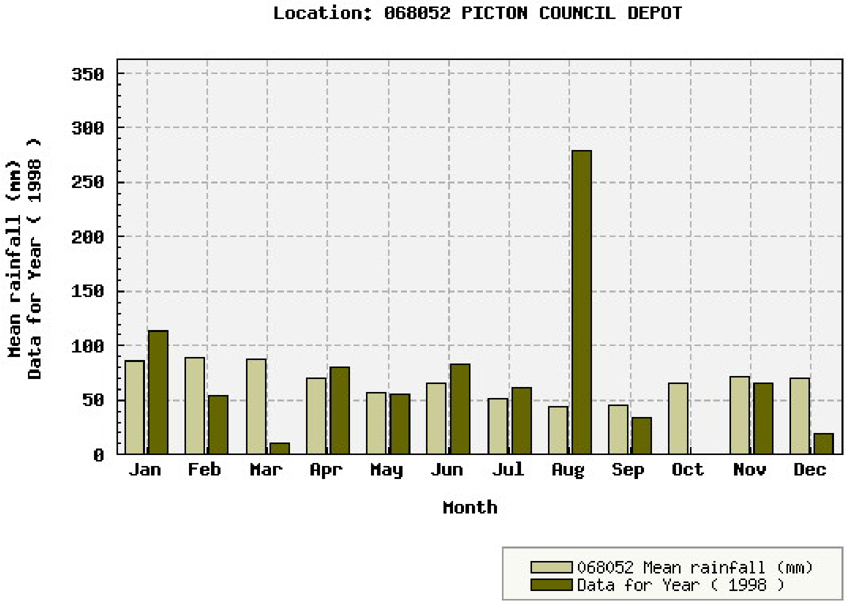
2001
Total rainfall: 636.0



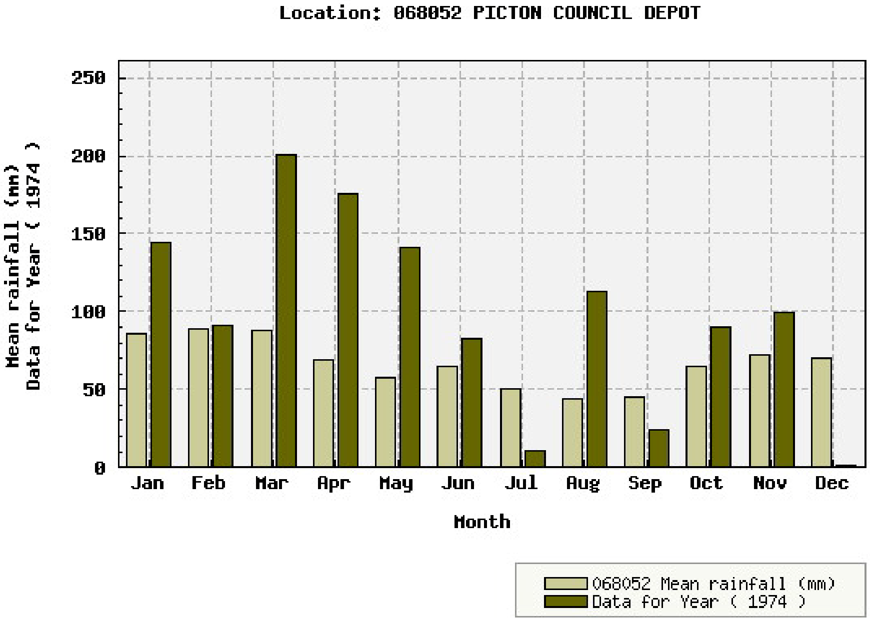
2000
Total rainfall: 592.0



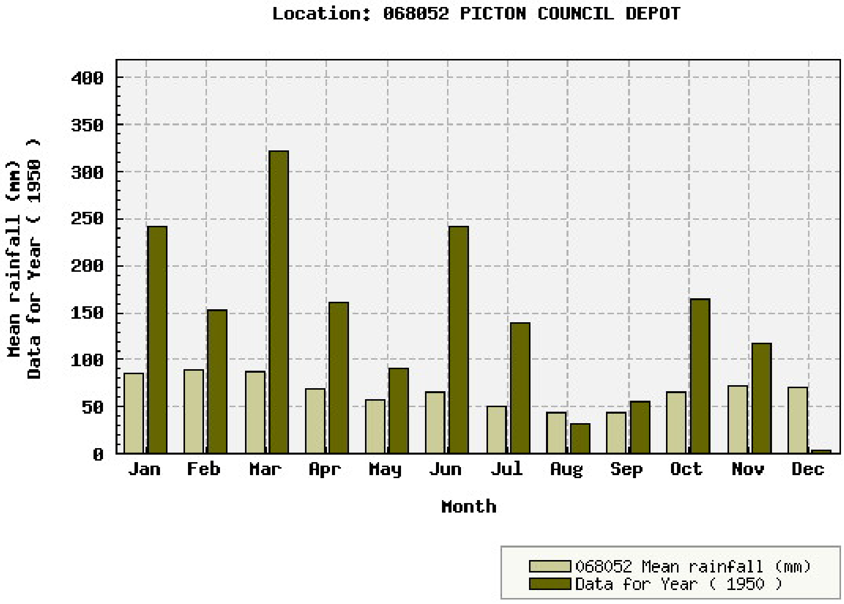
1999
Total rainfall: 825.0



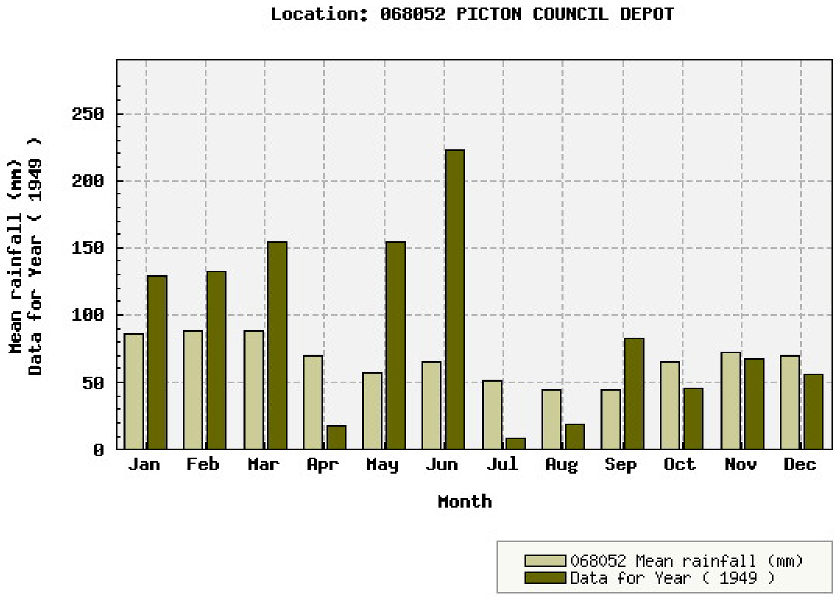
1998
Total rainfall: 857.0



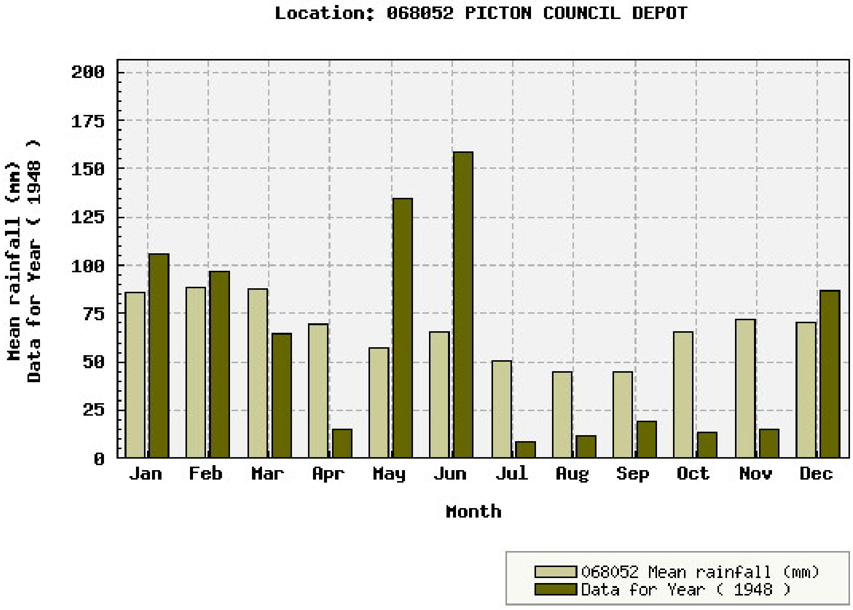
1974
Total rainfall: 1,174.5



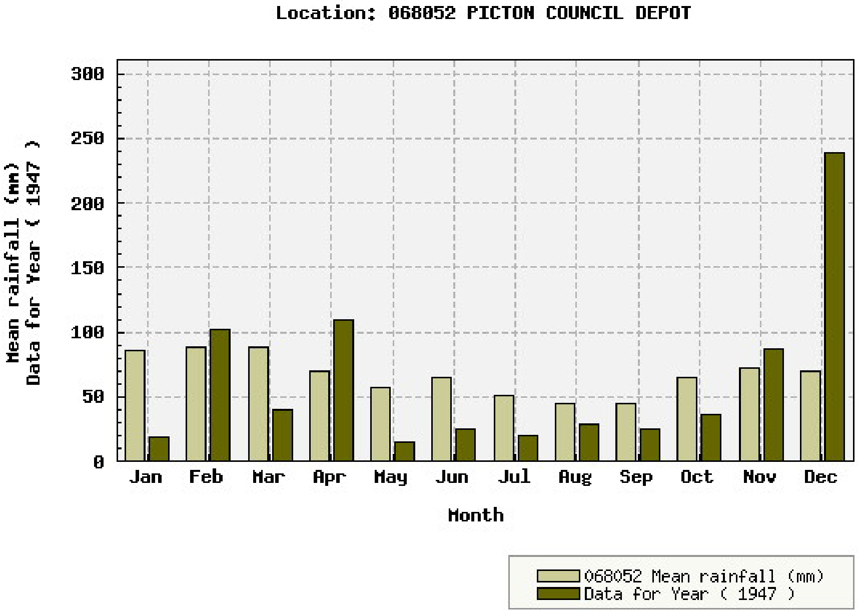
1950
Total rainfall: 1,723.2



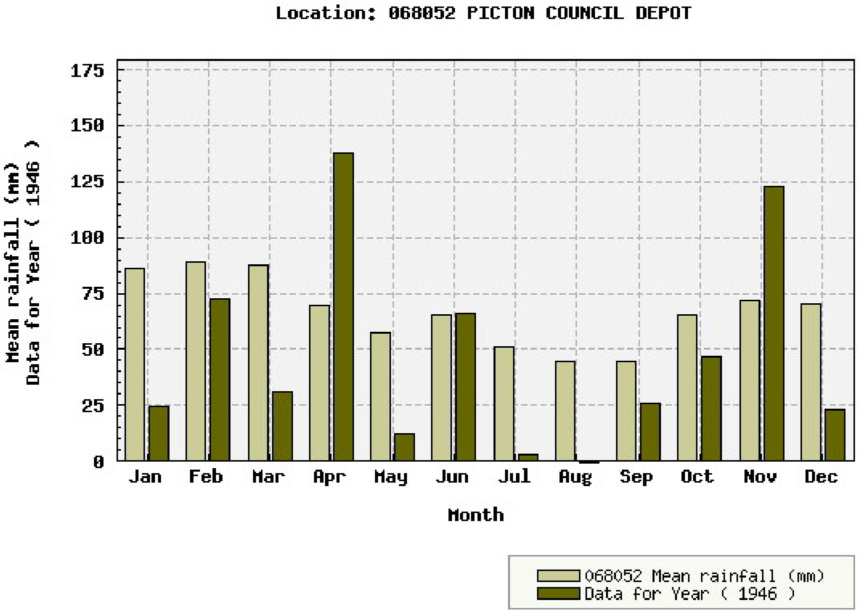
1949
Total rainfall: 1,089.6



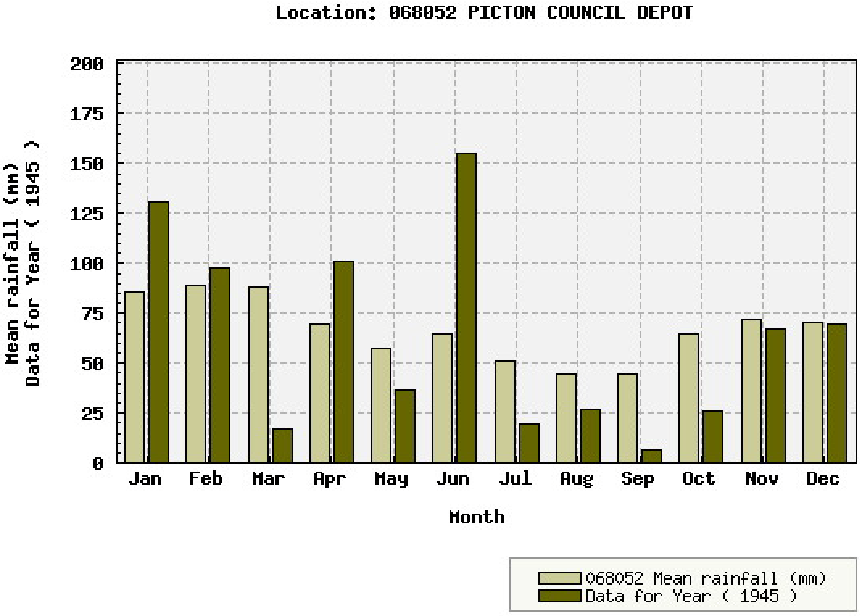
1948
Total rainfall: 732.0



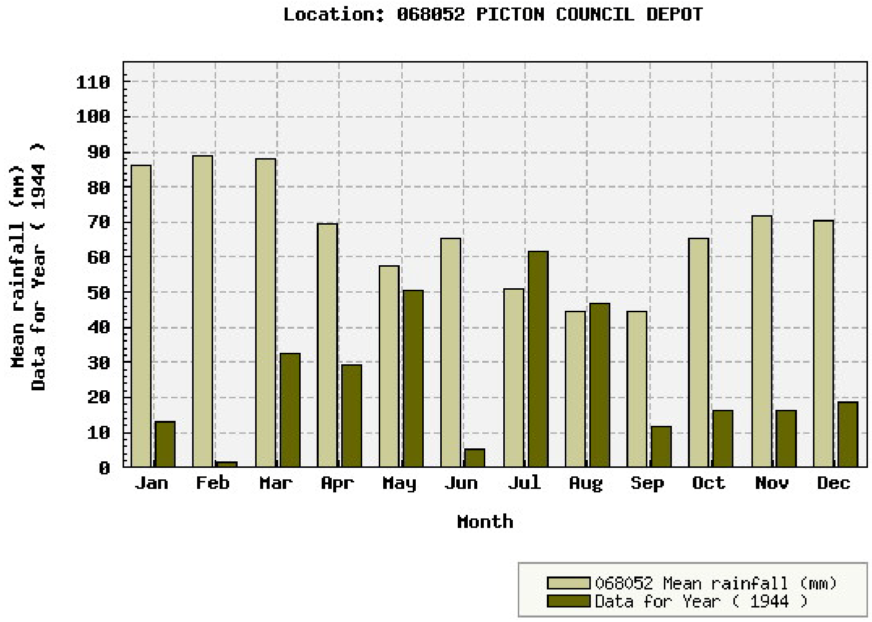
1947
Total rainfall: 746.5



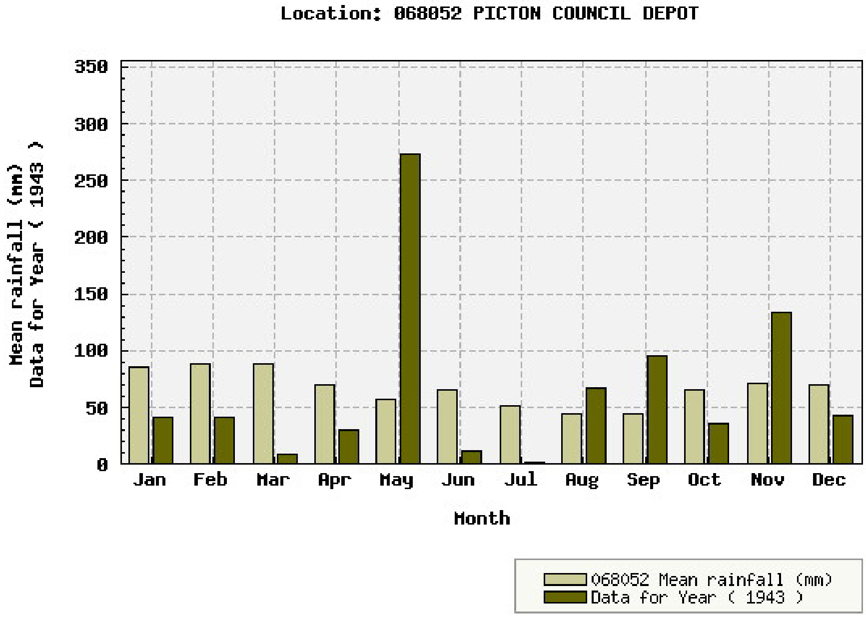
1946
Total rainfall: 565.7



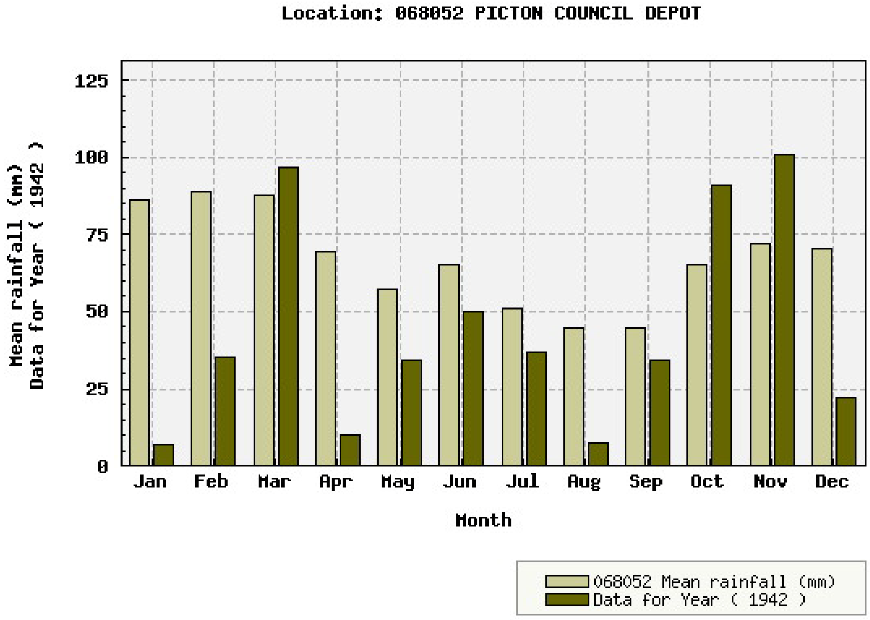
1945
Total rainfall: 753.3



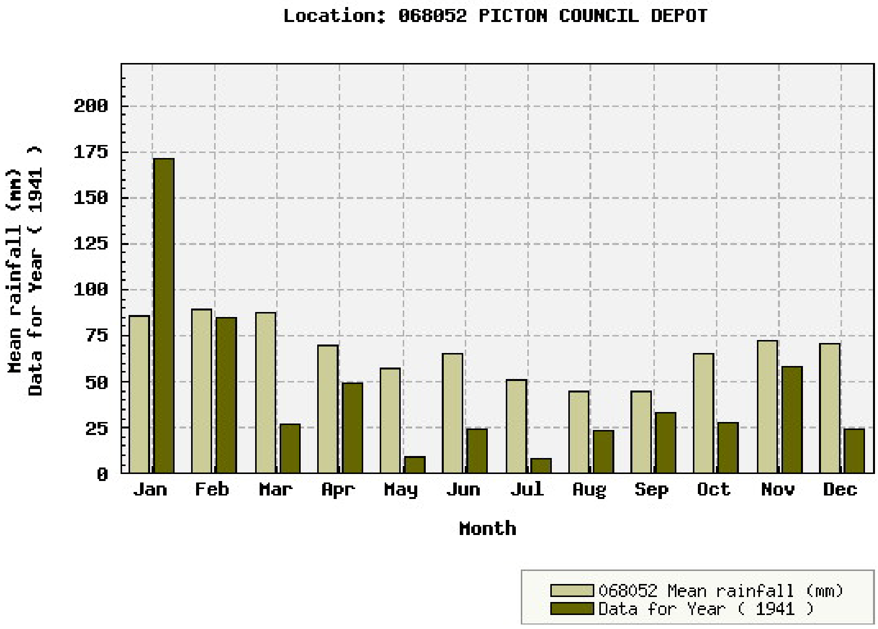
1944
Total rainfall: 303.2



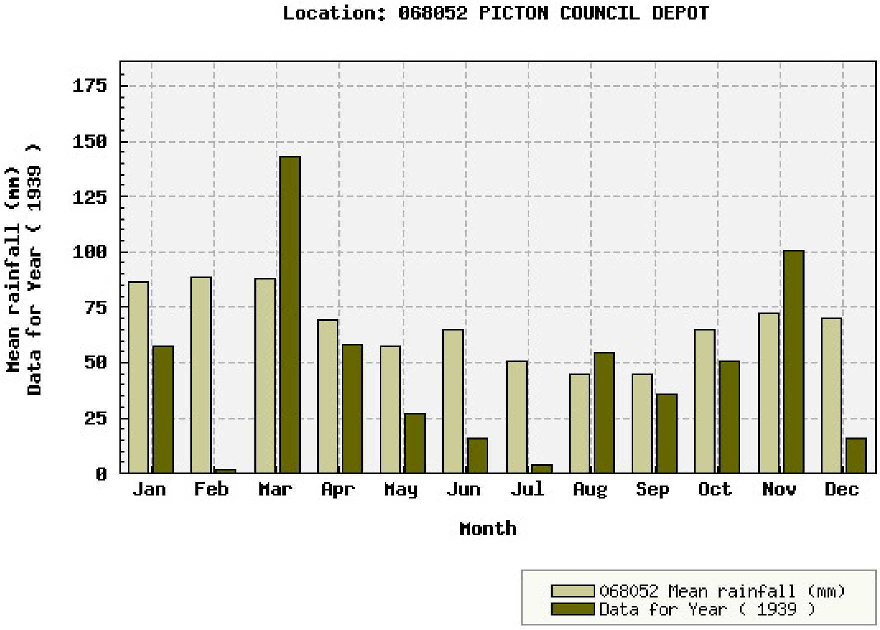
1943
Total rainfall: 783.8



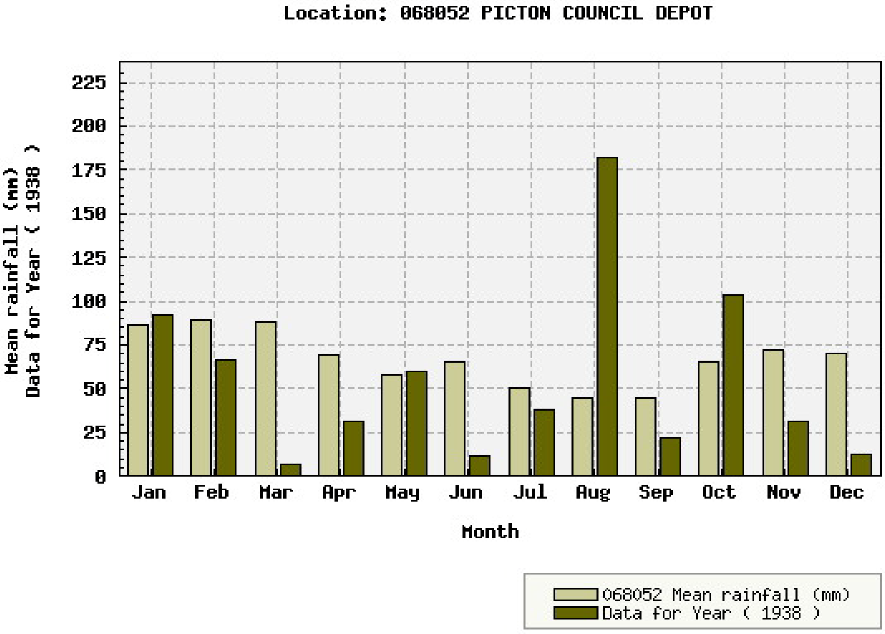
1942
Total rainfall: 525.7



1941
Total rainfall: 541.0



1939
Total rainfall: 562.7



1938
Total rainfall: 657.7