A multidisciplinary study of groundwater conditions in sedimentary strata at Thirlmere Lakes (NSW)

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SUMMARY

The Thirlmere Lakes include five natural wetlands within a Blue Mountains World Heritage listed national park, where there are concerns over an apparent possibility of a long term decline in water levels. Lake levels correlate with rainfall variability and are historically known to have dried several times during prolonged droughts. However, the effects of long term hydrological changes on the Lakes are unclear, as are uncertainties associated with extraction of water for local uses and the possible effects of nearby longwall coal mining.

This study is part of a large multi-disciplinary research program, of which this part focuses on groundwater conditions insedimentary strata, and the possibilities of interactions with sediments below the Lakes. Surface geophysical techniques and mapping of geological structures will be combined with deep drilling, wireline logging, geological and hydrogeological investigations. Characterisation of sedimentary strata include permeability, bulk density, moisture content, porewater stable water isotopes and XRD mineral identification. New deep drillholes are planned to obtain information on hydraulic properties of formations. A staged geophysical survey program is designed to complement the geological investigation. Resistivity imaging, time-domain electromagnetics and ground penetrating radar (GPR) will be employed to define sedimentary structure within the unconsolidated alluvium (sand, clay and peat layers) and depth estimates to the underlying rock. A combination of these geophysical methods and contextural geological information, will be used to identify structural and sedimentological anomalies and their hydrogeological properties such as permeability and connection to deeper strata. The results of this work provide new data on groundwater conditions in structured rock that underlie the sediments of Thirlmere Lakes.

Key words: Thirlmere Lakes, groundwater, geophysics, hydrogeology, geology

INTRODUCTION

There are concerns over the possibility of long term decline in water levels at Thirlmere Lakes situated within the Blue Mountains World Heritage listed national park due to their high recreational and ecological value. Although some studies have been undertaken, there is considerable uncertainty about the geological and hydrological mechanisms controlling recharge and discharge of the lake system, and in particular the degree of hydraulic connectivity between surface water, shallow and deep groundwater.

To assist in addressing these knowledge gaps, this study will focus on the field application of geophysical and groundwater methods to improve understanding of groundwater conditions in rock strata below lake sediments. The study is part of a large study involving a multidisciplinary team to combine this newly collected field information with surface hydrology studies, paleo-hydrology studies and sediment hydrogeological studies. Thus, the main aim of the geophysical part of the geology study was to estimate the depth of sediments below the Lakes and identify possible geological lineaments within rock strata near the Lakes.

Background and previous investigations

The Lakes are located around 8 km southwest of Picton, NSW in a valley with surface elevation of around 305m AHD, while the ridges to the west, east and north rise up to 410m AHD. The ridges are relatively steep at between 45° and 70° incline. The lake system although possibly related to former river valley is now considered as a closed system (Vorst, 1974). The current outlet from the system is Blue Gum Creek, flowing towards the west to Lake Burragorang (Figure 1).

The area is underlain by Triassic Hawkesbury sandstone which consists of quartz rich interbedded massive and cross bedded sandstones and associated fluvial overbank deposits. This area was structurally altered in the later mid-cenozoic by an east-west contraction and uplift of around 160m (The Lapstone block, Andrews (1910); Fergusson et al. 2011). The sedimentary strata now dip to the east and north east (DOEH, 2012). Soils and sediments are developed as residual soils and colluvial material from slope debris and alluvial fans (from the mouth of the creeks to the east and south of the Lakes) (Vorst, 1974). Each of the Lakes are separated by several sedimentary sills which in the past 40-50 years have been cut through to allow the water flow between the Lakes.

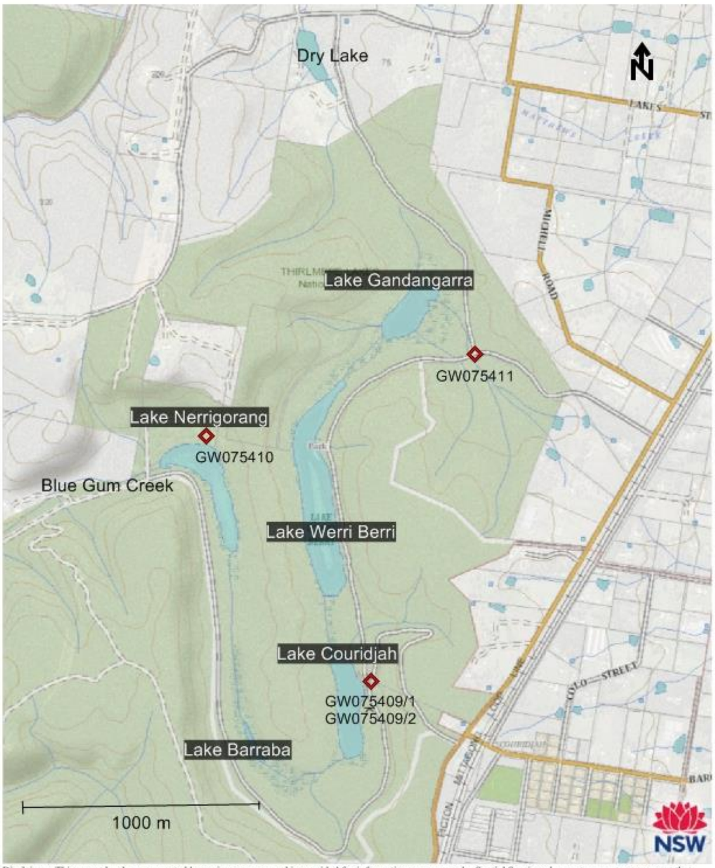

Figure 1 Thirlmere Lakes and location of existing monitoring bores

Bathymetry of Lakes Werri Berri, Couradja and Nerrigorang indicates the maximum depth of Lakes at 6.6m, 5.2m and 6.7m, respectively (Vorst (1974) and Schadler and Kingsford, 2016). Limited coring of lake sediments found it to consist from top to bottom of medium sand overlying sandy clay, changing to coarse detrital organic material classified as peat (3-4m depth). Significant change in depositional environment between peat and sand/clay sediments is due to vegetation growth at the base of the lake (Vorst, 1974). Peat and lacustrine clays were intersected in Lake Barraba and Lake Couridjah, respectively (Black, 2006 and Gergis, 2000). The peat thickness was found to be up to 3 m (between 14.3m and 17.3m below ground) while the overall thickness of the sediments in the Lakes was found to be around 20 m.

A seismic survey by Vorst (1974) tried to identify the depth of the valley and it indicated that the angle of the cliffs continued at the same angle below the lake sediments. However, the refraction survey interference due to the narrow valley and highly weathered bedrock did not allow the depth to bedrock to be estimated accurately. The depth based on the seismic survey velocity data was estimated to be approximately 50-60m.

There are several theories of the development and deposition of the lake system. Although none of the theories has been confirmed, the tectonic movements in the Sydney Basin in Tertiary have affected the drainage system resulting in a change in drainage direction in some parts of the basin (Stroud et al, 1985) . The basement of the Lakes system is locally inclined to the east with the whole sedimentary sequence dipping to the east (Heritage Computing, 2002). This understanding was based on drillholes and lower elevation of the base of Hawkesbury Sandstone in the east (<207m AHD), and higher elevation at the Blue Gum Creek (235 to 260 mAHD) in the west (DOEH, 2012). The Dry Lake (which is now the part of the catchment draining to the north) (Figure 1) may have been part of the Thirlmere Lakes system (Rose and Martin, 2007). The formation of the Lakes then may have occurred as a combination of tectonic events and development of alluvial fans blocking surface flow. The alternative theory (DOEH, 2012) is that the Lakes are headwaters of the Blue Gum Creek and Hawkesbury sandstone controls the geometry of the catchment.

Based on the measurements of lake water levels (Pells, 2016) their relative levels decrease in the following order: Lake Barraba, Lake Gandagarra, Lake Couridjah, Lake Werri Berri and Lake Nerrigorang (Figure 2). These measurements (2012-2014) and historical data (as reconstructed by Pells (2016)) indicate two possibilities: the water flow is not in the direction from Dry Creek to Blue Gum Creek, or the Lakes are disconnected from each other ie flow only occurs when the Lakes overflow and groundwater flow is insufficient to maintain the flow from Dry Lake to Blue Gum Creek. The DOEH (2012) suggest that the Lakes Gandangarra, Werri Berri and Couridjah are interconnected when the water saturation in the Lakes is between 2-3 m (302.8 m AHD). The elevation of the col between Lake Barraba and Lake Nerrigorang is much higher (305.5 mAHD) and effectively separates it from other four Lakes until it is overtopped. Based on the interpreted water levels in Lakes Werri Berri, Couridjah and Nerrigorang, and rainfall data in the period from 1925 to 2016 (Pells, 2016), it appears that although the rainfall historically had an important influence on the lake levels, there were time periods where the lake level rise occurred despite limited rainfall. Although it is difficult to evaluate subsurface water fluxes because of inconsistency in elevation measurements between different surveys (DOEH, 2012) it appears that groundwater contributes to the Lakes system. The extent of this contribution is not known (Riley, 2012 and Russell, 2010)

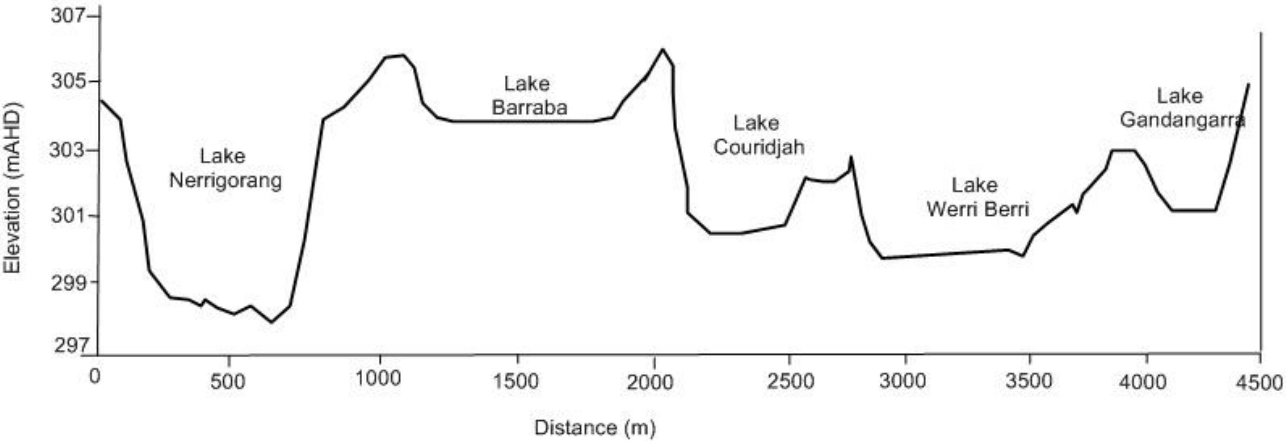

Figure 2 Long section of Thirlmere Lakes with lake elevations and their interpreted depths (redrawn from Gilbert and Associates, 2012)

Tahmoor Colliery which is located to the east of the lake system, mined Bulli coal seam at a depth of approximately 420 m. The mine has pumped 800 ML/year (ML = megaliters) of water from the seam in 1995 with an increase to 1200-2000 ML/year from 2002 onwards (Pells, 2016). The water was sourced from sedimentary strata however there is inconclusive evidence as to the possible impact on the shallow unconsolidated strata comprising lake sediments. As a comparison, the water pumped from the lake in the period from late 1880s to 1960s decreased from 110 ML/year to <10 ML/year and a number of groundwater bores increased from 1960s to 2010 from 20 ML/year to >400 ML/year (Schadler and Kingsford, 2016). Studies by Pells (2016) and Schadler and Kingsford (2014) indicate that the mine groundwater extraction after 1995 may have impacted the levels in the Lakes, however the study by Pells attributes the influence to drying of the Lakes to the natural climate conditions in addition to other factors. Schadler and Kingsford (2014) indicate that the lake level decline may have occurred at the same time as the groundwater development started. On the other hand, Russell et al (2010) found that the declining water levels were due to climatic variability. Banerjee et al (2016) used Landsat time series data to establish the changes in Lakes water area and found that the rainfall variability was the dominant factor associated with these changes.

Regional groundwater mapping by Heritage Computing (2012) and DOEH (2012) indicates that regional groundwater flow in the Hawkesbury Sandstone is to the east and northeast. To improve knowledge on groundwater levels, four bores were drilled next to Lakes Gandangarra, Couridjah and Nerrigorang (Russell, 2012) (Figure 1). The bores were installed down through shallow unconsolidated sediments and consolidated sandstone. The groundwater levels measured following installation indicate that shallow groundwater flow (within the top 25 m below surface) is in the north-northwesterly direction with a downward gradient at Lake Couridjah. A similar downward gradient is noted by Geoterra (2011) at the Tahmoor Colliery.

METHOD

To improve knowledge of the geological conditions and groundwater interactions between lake sediments and rock strata, this study will apply selected geophysical methods. Geophysical survey data will be complemented by new drilling and data. The geophysical approach was initially aimed at using resistivity and ground penetrating radar. These methods were based on the recommendations by Inter-agency working group (2017) and further expanded on.

Field scale ground penetrating radar (GPR) survey is aimed at:

- Thickness of unconsolidated sediments
- Moisture content estimation
- Characterisation of aquifer geometry, water table depth and soil properties

Resistivity survey was recommended with the aim of:

- Defining the depth to bedrock
- Estimating the volume of sediments

The applications and use of GPR method is not favourable where the subsurface comprises moist clays as the penetration may be very limited. However, the dry sandy formations are expected to be resistive enabling depth of penetration to 15 m. The effectiveness of GPR will also be reduced in heterogeneous conditions. The method has been used successfully in the past to develop stratigraphic and hydrogeologic models of the hyporeic zone (Conant et al , 2004). This survey was therefore proposed for the edges of the lake where the soil is unsaturated and the top couple of meters were expected to comprise mainly sand layers. The survey lines were proposed to be located at some distance from the Lakes edge.

Resistivity surveys are typically undertaken to determine the resistivity distribution of the subsurface (Samouelian et al, 2006). Based on the anticipated resistivity contrasts between sand, clay and peat, the surveys were proposed to obtain information about the relative distribution of lithology beyond the sparse location of boreholes. The limitation of this method is that sensitivity of the measurement decreases as the depth of investigation increases and the quality of the data is strongly dependent on the size of the contrast of the resistivity between the strata (Demanet et al., 2001). In this project the applications were planned to include the determination of strata horizons, moisture content and thickness of the sediments and possibly the depth to bedrock. The borehole information was planned to be used to calibrate the distribution of hydrogeological properties of shallow sediment.

RESULTS AND CONCLUSIONS

The results of this study complemented with drilling at strategic locations along the geophysical survey lines are expected to allow determination of shallow aquifer stratigraphy and thicknesses of shallow sediment lithology. Such results will contribute to improving conceptual models of the Lakes and reduce uncertainties regarding the possibility of hydraulic connection between the sediments below the lake, and groundwater in rock strata. Preliminary results would be available following the initial survey to understand the best technique for mapping narrow valley with sufficient contrast in shallow sediments to understand the stratigraphy and groundwater conditions.

ACKNOWLEDGMENTS

This Project has been assisted by the New South Wales Government through the Office of Environment & Heritage.

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