



## Extended Abstract

### **TITLE: ASSESSMENT OF MULTI-LAYERED SANDSTONE AQUIFERS IN THE SYDNEY BASIN, BLUE MOUNTAINS**

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#### **Abstract**

Hydrogeological investigations of the Blue Mountains sandstone on the western fringe of the Sydney Basin have shown it to be a complex multi-layered sandstone aquifer. The shallow and intermediate aquifers are critical to spring flow and to stream baseflow in the upper plateau rivers. These aquifers will be typically the ones that support groundwater dependent ecosystems, such as wetlands and hanging swamps. The deep regional aquifer system appears to be flowing towards the deep incised valley rivers and across the Lapstone Monocline with some discharge likely into the Hawkesbury - Nepean River at the base of the plateau. The deep aquifer appears to have a large positive pressure head, which may indicate a significant proportion of the groundwater from the lower Blue Mountains is flowing under the Hawkesbury - Nepean River out further east to the coast.

A regional monitoring bore network was first established in 1997 in the upper Blue Mountains near Katoomba. Over the next 10 years increased demand for groundwater saw entitlements approach the estimated extraction limit for this porous rock aquifer. Concurrently the World Heritage National Park and other nature conservation areas that surround the area have required specific water allocation. Further enhancement of the monitoring network was required in the lower Blue Mountains to manage the competing uses. This paper focuses on a series of additional monitoring bores installed in the lower Blue Mountains for sustainable groundwater management.

#### **Introduction**

Blue Mountains Sandstones forms a plateau that rises up to over 1,000 m above the coastal plain at Katoomba. To the east the sandstone plateau drops down in elevation and it is cut by the north-south trending Hawkesbury – Nepean River floodplain. The lower Blue Mountains is dominated by Triassic Hawkesbury Sandstone porous rock aquifers. The Lapstone Monocline is a major geological structure that cuts the project area and has significant associated faulting. The rainfall varies considerably across the project area because of the diverse range of elevations from high plateau at Katoomba with an annual average rainfall of 1,391 mm/year to less than 780 mm/year at Windsor on the floodplain of the Hawkesbury River. The sandstones which are the main focus of the paper in the Blue Mountains and Richmond areas cover an area of about 3,238 km<sup>2</sup> of which 2,375 km<sup>2</sup> is National Park.

#### **Groundwater management**

The Draft Water Sharing Plan for the Greater Metropolitan Groundwater Sources (NSW Office of Water 2010) was recently released for public exhibition and comment in preparation for the repeal of the *Water Act 1912*.

Only where water sharing plans are in place does the *Water Management Act 2000* apply and replace the *Water Act 1912*. Under both Acts, the rights to the control, use and flow of all water in aquifers are vested in the State. The acts provide the direction to the statutory process to allow individuals and other entities access to the resource by way of licences and approvals. Water sharing plans establish the rules for sharing water between the environment and water users and between competing consumptive water users. The water sharing plan, once finalised and gazetted under the *Water Management Act 2000*, have legal effect for 10 years.

#### **Groundwater monitoring bore investigation**

During 2008 and 2009 the NSW Office of Water organised the installation of 31 monitoring bores at 13 sites in the lower Blue Mountains for groundwater monitoring. These sites fall generally in a triangular area between Springwood, Richmond and Penrith. The bore sites are situated within three groundwater management units (GMU), namely the Blue Mountains Sandstone GMU, the Richmond Sandstone GMU and the Sydney Basin Central GMU (Figure 1). Air lift bore yields up to 32 litres per second (L/s) were encountered during piezometer construction and groundwater samples collected and analysed for major ions (DWE, 2008). The groundwater associated with the Hawkesbury Sandstone was generally low salinity (less than 1,000 mg/L total dissolved solids; TDS) whilst that associated with the shale was saline (over 10,000 mg/L TDS).

During 2009 detailed hydrogeochemical investigations were carried out using groundwater and rock chip samples collected from selected bores in the lower Blue Mountains as part of a joint study with the Australian Nuclear Science and Technology Organisation, the University of NSW and the NSW Office of Water (Luu, 2009). The analysis comprised major and minor



elements, water stable isotopes ( $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ ), dissolved inorganic carbon ( $\delta^{13}\text{C}_{\text{DIC}}$ ) as well as naturally occurring radioisotopes ( $^3\text{H}$  and  $^{14}\text{C}$ ).

Recently electronic groundwater level loggers were installed in order to collect detailed groundwater level data from the new monitoring bore network. The installation of continuous water level loggers and data recorders in the monitoring bores, together with the results of hydrogeochemical work will greatly increase the understanding of the groundwater flow dynamics and allow further detailed assessment of these aquifers.

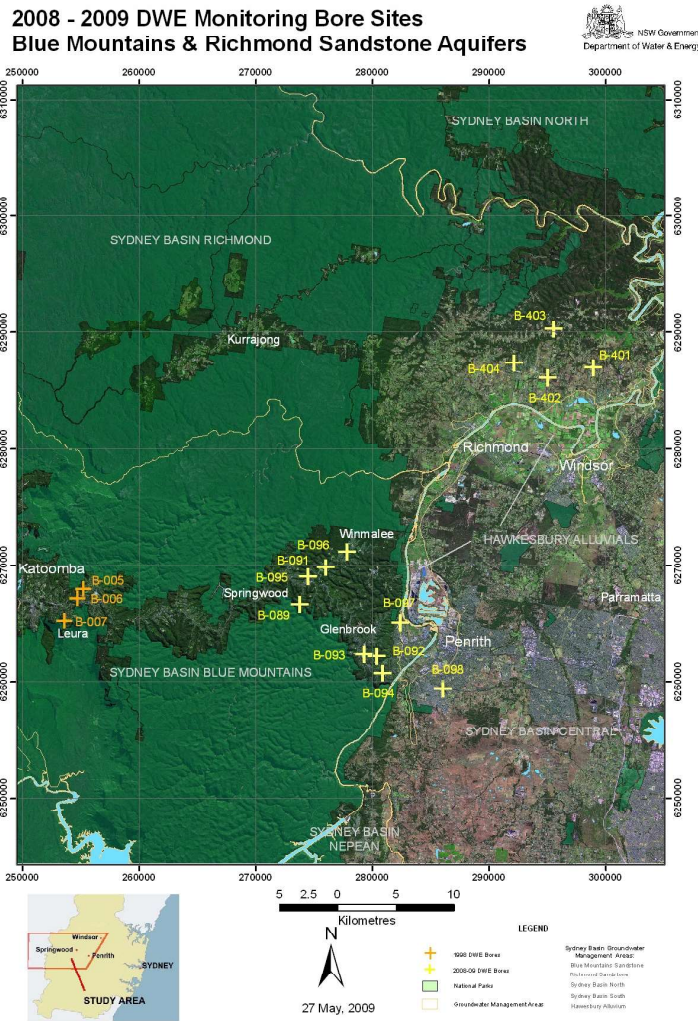


Figure 1 Location of the NSW Office of Water monitoring bore sites in the Blue Mountains Sandstone GMU, Richmond Sandstone GMU and Sydney Basin Central GMU.

### Geology and hydrogeology

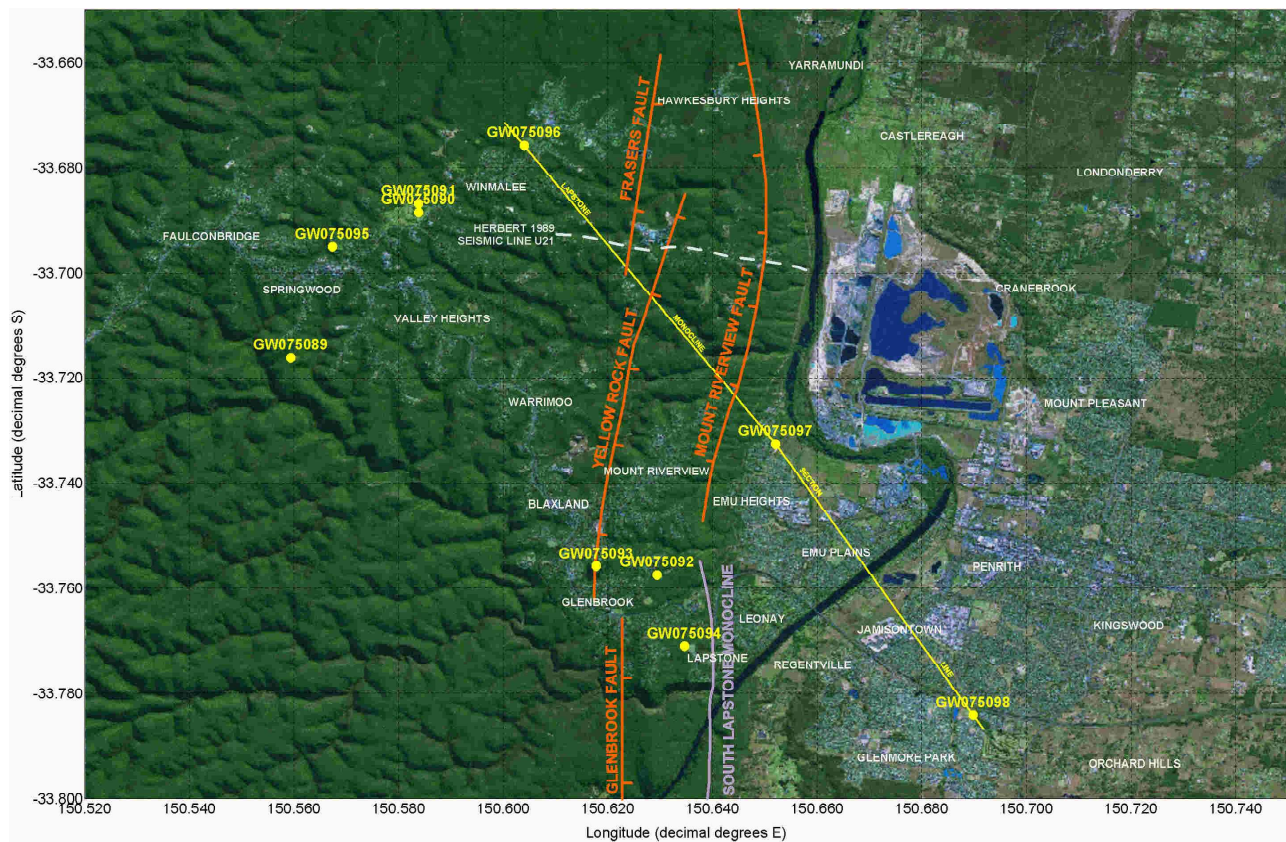
The geology of the study area can be summarised into three main stratigraphic types, being Hawkesbury Sandstone, Wianamatta group rocks which are predominantly shales and the most recent Hawkesbury Alluvium.

The Hawkesbury Sandstone, which is the focus of these groundwater investigations, is dominantly a medium to coarse grained sandstone, but varies from fine to very coarse grained (Herbert 1983). This unit forms the high plateaux and spectacular gorges in the lower Blue Mountains. The formation thickens eastwards with maximum thickness of approximately 230 m. Shale lenses are irregularly spaced throughout the unit. Two contrasting sandstone facies have been distinguished as “sheet sandstone facies” and “massive sandstone facies” (Conaghan 1980). The sheet sandstones consist of crossbeds, usually 0.1 to 5 m in thickness. The “massive sandstones facies” are more friable in weathered exposure, contain large amounts of clay, have generally lower primary porosity and smaller proportions of cementing agents. These massive facies sandstones are up to 15 to 20 m thick and extend over several kilometres. Numerous mudstone units occur within these sandstone units.

The Wianamatta Group rocks consist of a minor sandstone horizon sandwiched between two major shale units. It is generally less than 150 m thick in the study area. The marine origin of these rocks has resulted in the incorporation of a high proportion of soluble salts into the rock matrix, creating a significant connate salt store available for dissolution, leaching and mobilisation. On weathering, the Wianamatta Group produces heavy clays, prone to pipping and water logging. These heavy surficial soils have implications for the generation of urban salinity where the natural drainage is impeded or diverted.

Hawkesbury Alluvium. The alluvium associated with the Hawkesbury River tends to be an admixture of clean quartz sand and cobbles with thin interbeds of yellow clay. The sequence is up to 20 m thick. It is distinguished from the higher level Tertiary alluvium which has a significant clay content.

There has been significant structural movement in the study area with most aquifers exhibiting some secondary porosity characteristics. The Lapstone Monocline is a major geological structure that cuts the project area. The deposition of Permian and Triassic rocks occurred, where the eastern area sank faster than to the west, so that rock units became thicker to the east. The rocks along the hinge lines were progressively bent in a north south direction and preserved as monoclines (Pickett and Alder 1997). There is significant faulting around the monocline, just west of the Lapstone Monocline at Glenbrook where a large vertical fault in the rock occurs with a 50 m displacement to the west. A similar fault is also noted at Kurrajong (Figure 2).



**Figure 2** Overview of the study area, illustrating the orientation of the section line depicted in Figure 3.

Three main groundwater systems have been identified in the sandstone plateau sequence of the lower Blue Mountains (Green *et. al.* 2010):

- A shallow unconfined aquifer in the upper sandstone porous rock aquifer. Local-scale groundwater movement is topographically driven, discharging as hill-slope springs, valley seepages and baseflow to the upper sandstone plateau streams.
- Intermediate low yield aquifers intersected in some monitoring bores are assumed to be perched by less permeable siltstones, mudstones and shale lenses that form part of the Hawkesbury Sandstone sequence. These aquifers are likely to discharge to mid-level valleys within the sandstone plateau. Their responsiveness to rainfall recharge will be assessed following the installation of continuous groundwater level loggers.

- Deeper intermediate-scale aquifers in the interlayered and fractured horizons within the coarser grained porous sandstone aquifer. These aquifers become semi-confined to confined and are considered to discharge at lower levels in the landscape, such as the Glenbrook Creek near Springwood and to the Hawkesbury - Nepean River at Penrith. Artesian groundwater heads have been encountered east of the Blue Mountains Sandstone Plateau at Emu Heights, where the deep bore has a very high yield. The aquifer has a dual porosity and the secondary porosity is likely to be influencing the bore yields at Emu Heights, as it is close to the base of the Monocline which contains fault systems.

An east-west perpendicular section from Winnalee to Glenmore Park near Penrith shown in Figure 3, exhibits the deep aquifer flow from the sandstone plateau down to below the monocline. In addition this shows the shallow unconfined aquifer in the upper aquifer which is topographically driven, discharging at hill slope springs and rivers. The identified relatively thick sequences of massive shales, siltstones and mudstone are likely to be restricting the vertical movement of groundwater to depth, particularly to the intermediate water bearing zones.

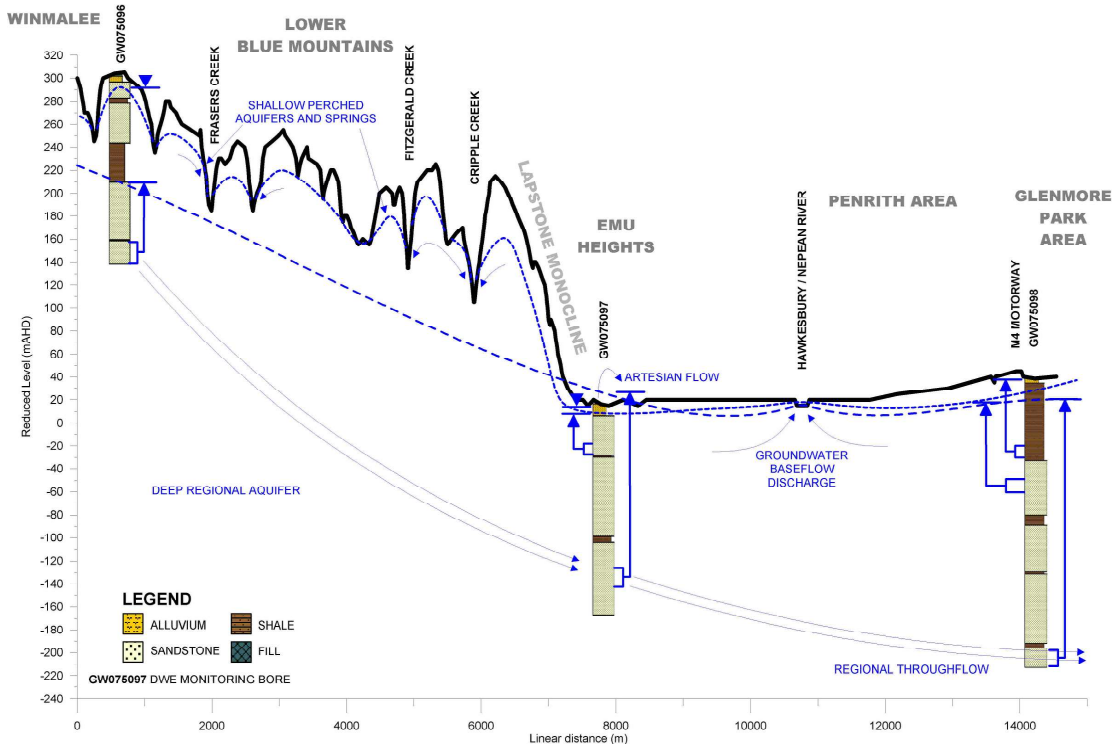


Figure 3 Winnalee to Glenmore Park cross section (NW-SE) showing the shallow and deep groundwater levels that have a large positive pressure head, with artesian flow at Emu Heights.

### Hydrogeochemistry

The elemental and isotopic results can also be broadly subdivided into the shallow, intermediate and deep groundwater systems. In some cases where shale lenses were encountered or relatively different depths sampled, the hydrogeochemical properties exhibited characteristics between shallow-intermediate or deep groundwater.

Shallow groundwaters have a low pH (~4.6) and are generally of the Na-Cl type, with major ions showing their marine-derived source. This groundwater has generally detectable  $^3\text{H}$  activities (>0.8 Tritium Units; TU) and in some cases also their  $^{14}\text{C}$  activities show post-1950 contributions. Both radioisotopes indicate modern recharge occurs. The results of stable isotope analysis indicate a dominantly meteoric origin with most samples adjusting to the local meteoric water line. Carbon stable isotopes show the shallow nature of this groundwater with isotopic values reflecting interaction with soil-derived carbon. The exceptions to this general trend are the results of water samples from near shale lenses, those from where irrigation from groundwater occurs at the land surface, or where leakage beneath surface reservoirs is suspected of taking place.

Intermediate depth groundwater have higher average pH (~5.4) and are also Na-Cl type with increasing  $\text{HCO}_3^-$ , Mg and ferrous iron, indicating increased water-rock interactions. This groundwater generally shows below quantification limit activities for  $^3\text{H}$  and  $^{14}\text{C}$  of ~57 percent Modern Carbon (pMC) with uncorrected residence times of about 4,500 years. Water stable isotopes also show a meteoric origin with dissolved inorganic carbon ratios carbon showing more enriched values consistent with water-rock interaction processes.



Deep groundwater has higher average pH (~5.9) with the major ion chemistry tending towards Ca-HCO<sub>3</sub> type waters. These results also fall below the <sup>3</sup>H quantification limit with <sup>14</sup>C content strongly dependent on the distance from recharge areas. The most easterly sample being as low as 2 pMC with uncorrected residence times of ~30,000 years. Water stable isotopes also show a meteoric origin but generally tend towards more depleted values suggesting potential recharge under cooler conditions. Stable carbon isotopes indicating further water-rock interactions.

### Conclusion

The installation of automated water level loggers in the NSW Office of Water monitoring bore network in the lower Blue Mountains will greatly increase the understanding the groundwater flow dynamics and allow further detailed assessment of these aquifers. This work has more clearly described the aquifer framework, the groundwater flow patterns and will be used to assess the impact of current development on the baseflow of stream and environmental assets of the Blue Mountains and the associated foot hills. This work will also assist government in assessing the potential extraction impacts on groundwater dependent ecosystems for groundwater trading and thus allow an informed decision-making process, in order to maintain important ecosystems into the future.

### Acknowledgments

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