Analysis of mine water origins using geochemistry, Tritium isotopes and algae

William Ziegler[1], Heather Middleton[2]

[1]*Dams Safety Committee, Manager Mining Projects, PO BOX 3720, Parramatta NSW 2124 Australia, bill@damsafety.nsw.gov.au*
[2]*Dams Safety Committee, Mining Regulation Officer, PO BOX 3720, Parramatta NSW 2124 Australia, heather@damsafety.nsw.gov.au*

Abstract In 1979, the New South Wales Dams Safety Committee (DSC) was constituted under the Dams Safety Act 1978, to oversee the safety of the State's dams and to prevent significant uncontrolled loss of their storages. The DSC regulates mining within designated notification areas around the dams that supply drinking water for Sydney Australia. This paper examines one mine operating within a notification area of a major water supply dam and analyses the source of water entering the mine, using Tritium isotopes, water chemistry, algae and water balance. A relationship between rainfall, mine water balance and water chemistry is developed.

Key Words longwall mining, geochemistry, Tritium isotopes, algae, mine water

Introduction

The Dams Safety Committee (DSC) is a New South Wales government body created under the Dams Safety Act 1978, as a consequence of the Reynolds Enquiry (1977) which sought to establish guidelines for regulating the competing demands of mining and safety of water storages. Sydney, the capital of New South Wales, draws its drinking water from dams which are located to the south of the city (Figure 1A). These major water supply dams are underlain by extensive coal deposits, presenting a challenge to the dam safety and security of the water supplies. The DSC regulates mining around the water storages by designating areas around the dams and their storages within which mining cannot occur without prior application and demonstration of safety to the water storages. These regions are referred to as Notification Areas (Figure 1A).

Dendrobium Mine has been longwall mining around Lake Cordeaux since 2005 with extraction of Longwalls 1 to 5 (LW1-LW5) conducted sequentially in Areas 1 and 2 during the period 2005 to 2009 (Figure 1B). Extraction in Area 1 (LWs1—2) commenced in April 2005 with the initiation of LW1 and was completed in March 2007, while extraction in Area 2 (comprising LWs 3—5) commenced March 2007 and ceased in December 2009.

As part of the approval to mine within the Cordeaux Notification Area, the mine is required to monitor the quantity of water entering and leaving the mine, to determine a water balance, along with its chemistry, algae concentrations and

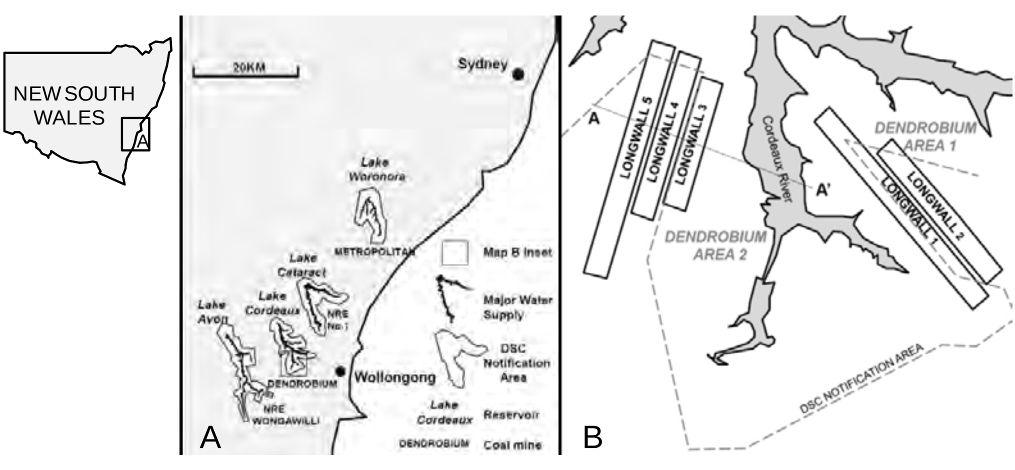

Figure 1 *A - Location of major water supplies South of Sydney; B - Dendrobium Mine illustrating location of longwalls 1—5 (LW1—5) and cross section A-A' Figure 3.*

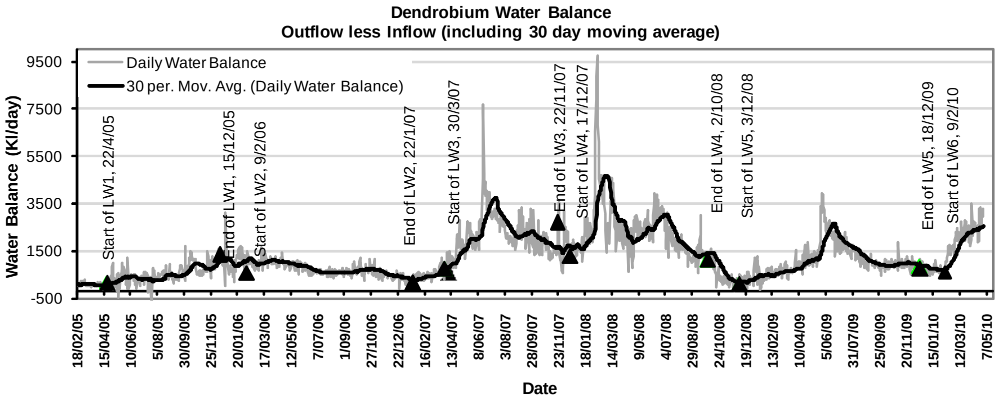

Figure 2 *Dendrobium Water Balance through time showing periods of water inflow to the mine.*

Tritium levels. The aim of this monitoring is to identify the origins of the water, as hydrogeological models for the mine predict that groundwater will drain to the mine workings and eventually reservoir water will make its way into the mine.

The Dams Safety Committee (DSC) has adopted a risk based approach to the safety of the stored waters which has determined that the total loss of water from the reservoir to the mine must not exceed 1ML/day. This limit of 1ML/day for Dendrobium is referred to by the DSC as the 'tolerable limit' for Dendrobium. The extent of conservatism in this limit is apparent when it is compared with the total loss from the reservoir by evaporation which is ≈ 35 ML/day).

Since longwall mining commenced there have been a number of inflow events at Dendrobium, where total water balance in the mine has exceeded 1 ML/day (Figure 2). Approval of future applications for mining within the Cordeaux Notification Area is dependent on the determination of what proportion of inflow waters are potentially from the reservoir.

Hydrogeology

Dendrobium Mine extracts the lower 3.5m of the Late Permian Wongawilli Coal Seam within the Illawarra Coal Measures. Overlying the Coal Measures are the Early Triassic Narabeen Group (which comprises the Coal Cliff Sandstone through to the Baldhill Claystone) and the Middle Triassic Hawkesbury Sandstone (Figure 3). Hydrogeological modelling has identified a potential flow path from the reservoir through the Scarborough Sandstone into the disturbed strata above mine workings in both Areas 1 and 2 with time (Leventhal, 2006), although estimates of loss to the reservoir over the long term are estimated to be in the order of less than 0.5 ML/day.

Water Chemistry

The mine has interpreted mine water chemistry data as consistent with water predominantly sourced from the target Wongawilli Coal Seam and adjacent shales with a contribution from the Scarborough Sandstone during times of inrush. Certainly the bulk of the chemical data does seem

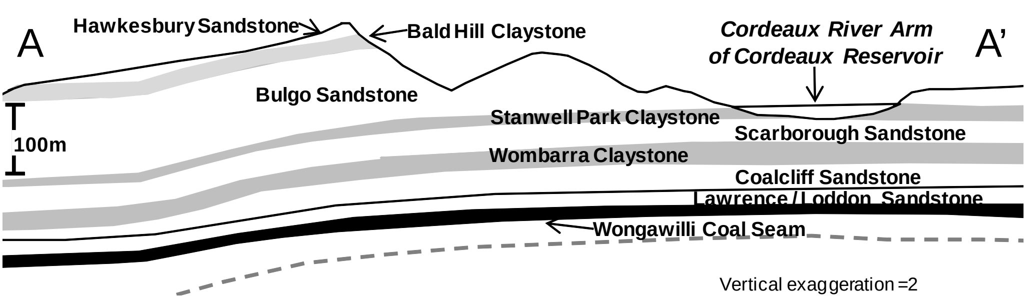

Figure 3 *Cross section through Area 2 and Cordeaux River Arm of Cordeaux Reservoir (see location of cross section on Figure 1B.*

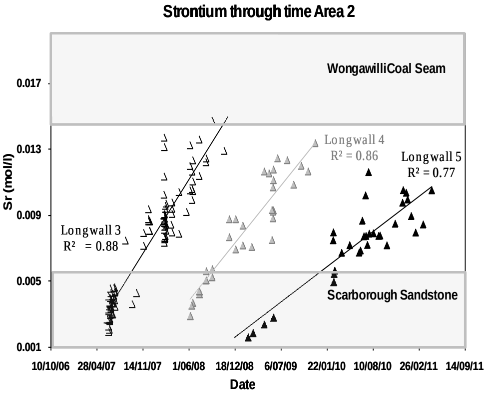

Figure 4 *Variation Sr in goaf waters with time, fields for Scarborough Sandstone and Wongawilli Coal seam are defined by average values ±1Standard deviation.*

consistent with the mine waters being of intermediate composition between these two formation water end members, for example (Figure 4). However not all of the water chemistry concurs with this interpretation.

Analysis of Area 2 mine water salinities indicates that rather than a simple continuous mixing trend between two fluids being observed that three discrete fluid populations seem to be present.

When the changes in the salinity of the mine waters are plotted versus progressive extraction of the longwalls (Figure 5), it becomes apparent that during longwall extraction a low salinity fluid is present. Once extraction has ceased salinity of the mine waters increases, suggestive of increased rock water interaction occurring with increased residence time in the goaf.

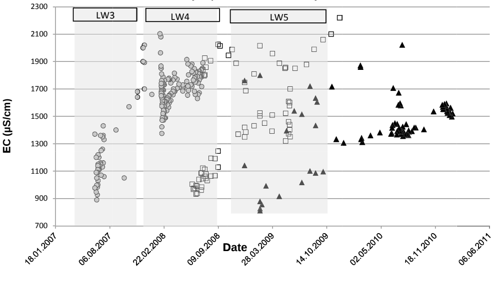

Figure 5 *Evolution of water salinities with extraction of progressive longwalls 3 to 5. Waters present after the cessation of extraction are more saline than those present during longwall extraction.*

Tritium is measured in mine water samples to determine the proportion of modern water present. During periods of increased mine water inflow it is apparent that not only do Tritium levels increase (Figure 6), but that they can increase beyond what is typical for either the Wongawilli Coal Seam (< ≈ 0.1 TU) or the Scarborough Sandstone (0.01—0.3 TU), to levels that are more typical of the overlying Bulgo Sandstone (≈ 0.6—1.2 TU). The overlying Bulgo Sandstone crops out at the surface and is influenced by meteoric recharge (TU ≈ 2.2), it is also known to be impacted by longwall mining in Area 2 (Madden, Merrick, 2009), consequently some input from the Bulgo Sandstone is not only possible but probable. However as the local meteoric tritium signature is ≈ 2.2 TU and Lake Cordeaux (which is predominantly charged by rainfall) has a Tritium signature of ≈ 2 TU, the Tritium water chemistry during times of inflow is also consistent with the mixing of older formation waters with a proportion of modern surface waters (ie reservoir, stream or meteoric waters).

The question for the DSC then becomes, what is the origin of the surface water that is presenting in the mine? This is a question that cannot be definitively addressed with water chemistry alone at this stage.

Significance of Algae

The report by Justice Reynolds on "Coal Mining under Stored Water" (Reynolds, 1977) discussed water inflow at Huntley Colliery. The mine had driven development roadways below an arm of the Avon Reservoir at a depth of 64m. Sections of the roadways experienced heavy dripping. Samples of the water were analysed for the presence of algae. On the study of algae Justice Reynolds states:

"Algae can develop and multiply only in the presence of a strong light source, normally sunlight, and die without it within a certain period. Therefore, any algae which are found in the lightless environment of a colliery must have been introduced from an external source and if they are characteristic of a certain body of standing water then the water must have come from that body."

Whitfield (1988), in discussing water inflow to Blue Panel at Wongawilli Mine, which extracted coal close to the storage of Avon Reservoir, concluded that a coal mining environment was not conducive to the longevity of algae hence *"... the commonality of the algae species between the mine water inflow and the Avon Reservoir ... suggest[ed] a surface to seam connection."*

Presence of Algae

Analysis of algal data from Area 1 and LW3 has indicated the presence of the same species of algae in mine and reservoir waters at the same time as

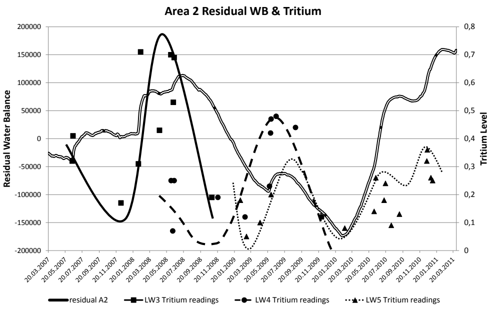

Figure 6 *Residual water balance for Area 2 plotted with Tritium values for the various longwalls– lines have been drawn to elucidate the trends in Tritium levels.*

the mine water balance shows inflows of water (Figure 7).

The Kembla Arm of the Cordeaux Reservoir lies between LW1 and LW3. While LW1 and LW3 goafs were sealed in 2008 (hence the short duration of results from these goafs) water samples from LW2 were able to be sampled through until early 2011. Water samples from LWs 4, 5 & 6 have been collected and analysed for algae. However the results have not yet been fully assessed.

Correlation of mine water balance with rainfall

The possible causes of the cyclic occurrence of inflows to the mine have been the subject of some discussion between the mine and the DSC. Possible causes are; periods of caving in the goafs intersecting discreet bodies of groundwater, or periods of high rainfall driving the increased pressure in the groundwater resulting in groundwater entering the mine, or rainwater entering the mine via a structure. (It is important to note that significant direct connection between the mine and the reservoir can be dismissed on the grounds that the observed inflows would occur continuously as opposed to sporadically).

At an early stage in the investigation of the inflows at Dendrobium it was noticed that they occurred soon after heavy rainfall events, if the water table had been recently recharged by rain. However, no inflows were observed if heavy rainfall followed a relatively dry period. The following two charts (Figures 8 & 9) show the residual values (a “cumulative difference” or “Residual Balance” is determined by plotting the cumulative value of a variable over time, adding a linear trendline and then calculating the difference between the cumulative value and the trendline, resulting in plus values(wet period) and negative values (dry period)). for rainfall and mine water from areas 1 & 2. The “residual balance” depicts the positive and negative values around a long term average. For rainfall, this depicts “wet” and “dry” periods. If mine water inflow is influenced by rainfall then it would be anticipated to relfect excess and deficit rainfall and this is indeed observed.

Correlation functions for rainfall versus mine water inrush were produced using the “correlation” function in Excel (Figures 10 and 11). The best statistically valid correlations were achieved by offsetting rainfall values by various periods. As can be seen Area 2 has a lower correlation than Area 1. However, the response time to inflow following rainfall in Area 2 is a lot shorter than in Area 1, possibly indicative of a different method of recharge. Using this method of correlation the best correlations of rainfall with mine water balance are 79% for a 3 month offset in Area 1, and 62% for a 3 week offset with Area 2. The quick response of Area 2 compared to Area 1 is thought to be indicative of the presence of a geological structure, through which the groundwater is recharged in Area 2, while Area 1 is thought to be more slowly recharged through the stratigraphy.

Discussion

As mine water is a mixture of formation waters,

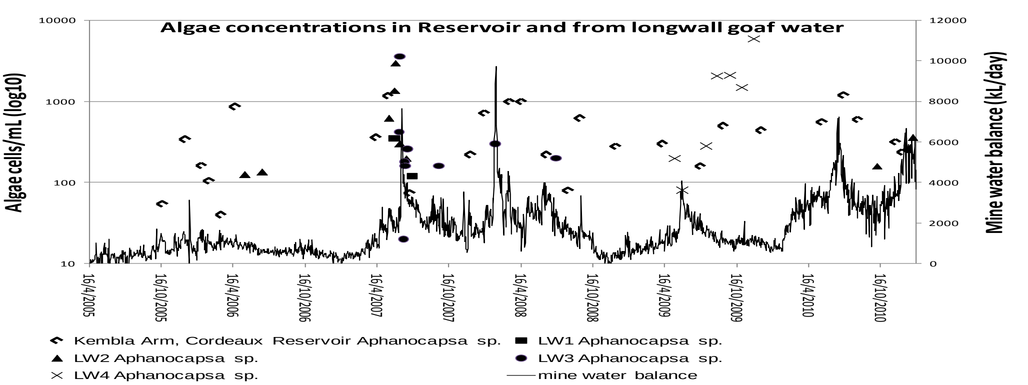

Figure 7 *concentrations of the same species of algae in lake and mine waters.*

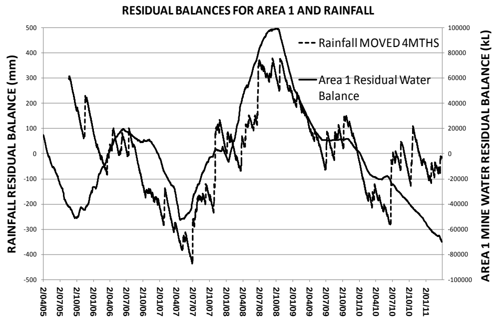

Figure 8 Area 1 rainfall and mine water balance.

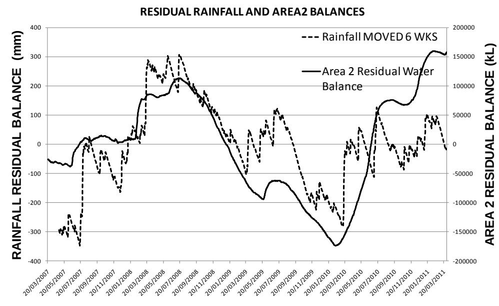

Figure 9 Area 2 rainfall and mine water balance.

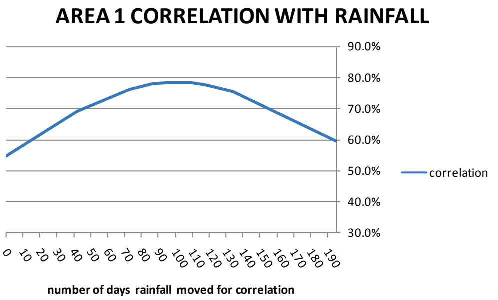

Figure 10 Area 1 correlation of rainfall with mine water balance by moving rainfall forward in time incrementally.

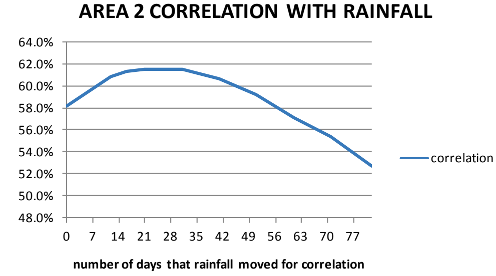

Figure 11 Area 2 correlation of rainfall with mine water balance by moving rainfall forward in time incrementally.

process waters and various contaminants such as lime, salt and hydraulic fluids used underground, it can be difficult to determine the provenance of any modern waters present using water chemistry alone. Tritium values are elevated for mine waters relative to the formations from which they are presumably sourced and are consistent with contributions of around 20% of modern water/surface water to the mine. The Tritium data cannot however distinguish between influxes of rainwater or reservoir water as these are sufficiently similar to each other that they cannot be successfully discriminated between. Furthermore even in conjunction with existing water chemistry data available it is not possible to determine the relative contribution from upper formation waters which have been meteorically recharged in recent times and the contribution from modern surface waters.

While available water chemistry is unable to discriminate between the various potential sources of modern water, the presence of the same algae species in both the reservoir waters and the mine waters does strongly suggest that a proportion of the water presenting in the mine is coming from a surface source (either the reservoir itself or a tributary water body) via fractures (which must be >50µm across to pass algae).

The presence of intact and viable algae in the mine workings has been interpreted in the past by the DSC and others to indicate a flow path of short time duration (less than 100 days) from the surface to mine workings. At this stage no argument can be mounted for a significant connection between the reservoir and the mine, as once such connection was established any inrush would be ongoing rather than rain related. It is however obvious that the presence of algae underground (especially freshwater species in high concentrations) needs to be thoroughly investigated, not only in its role as an indicator of lake water inflow as was undertaken by Whitfield (1988), but also for other potential applications (biofuels?).

The DSC is necessarily conservative and as it cannot be adequately demonstrated what specific component of the modern water presenting in the mine is from the reservoir, the DSC makes the assumption that all of the modern water entering the mine is from the reservoir. The question then becomes if all modern water presenting in the mine is assumed to be derived from the reservoir, how much reservoir water is entering the mine?

Estimates (based on average Tritium levels in mine waters in Area 2) indicate that ≈ 20% of the water presenting in the mine is of 'modern' (ie < 50years old) origin. Consequently once the total mine water imbalance for the three areas being mined at Dendrobium is 5ML/day, then the DSC tolerable level of 1ML/day has been reached.

Acknowledgements

The authors thank BHPBilliton Illawarra Coal for their cooperation with the presentation of this paper. The authors are grateful for discussion and critical review of this paper by Ian Forster and Paul Heinrichs, and Adele Rudd for editing.

References

Leventhal (2006) Dendrobium Area 2 Predicted Hydrogeologic Performance GHD-LongMac Report for BHP Billiton (Doc Ref:21/11716/AZ071.doc).

Madden, Merrick (2009) Extent of Longwall Mining Influence on Deep Groundwater Overlying a Southern Coalfield Mine. IAH Symposium Proceedings (2009) 9pgs.

Reynolds (1977) Coal Mining Under Stored Water. A report of the Commissioner the Honourable Mr. Justice R. G Reynolds to the New South Wales Parliament.

Whitfield, Anderson (1988) The Role of Algae in the Investigation of Water Inflow into a Coal Mine. The Third International Mine Water Congress Melbourne Australia, p251—260.