The Old River Mooki Drainage System and its impact on the hydrogeology of the Breeza Area

Introduction

Groundwater modelling of the possible impact of opencast coal mining at Watermark (Shenhua) and Caroona (BHP) has used a very simplified conceptual model of the hydrogeology in the area. In broad terms, it is assumed that a layer of low hydraulic conductivity clay rich material (Narrabri Formation) overlies a much higher hydraulic conductivity layer of sand and gravel (Gunnedah Formation) that sits on top of gently westward dipping, Permian age (250 to 300 Mya), coal measures. It has been assumed that the major aquifer in the region is represented by the Gunnedah Formation sands and gravels. Significant groundwater resources have been developed from the Gunnedah Formation and used to irrigate highly productive black vertisol soils developed on the Narrabri Formation. The location of an extensive groundwater resource immediately beneath highly productive soils has made this region (The Liverpool Plains) one of the most valuable agricultural resources in Australia. It is noted that the Guinness Book of Records listed an abstraction bore close to Breeza as the largest producer of water worldwide for a while in the past. It is a considerable societal challenge that: immediately beneath this agricultural resource lies an extensive and thick (>10 m) resource of coal that contains coal seam gas that can be extracted (CSG) or mined by either long-wall underground mining or by extensive opencast mining. In fact, the coal seam is so thick that it is not possible to remove all the coal by long-wall methods so that, where possible, opencast methods are preferred. This has led to large mines being developed (Werris Creek, Maules Creek etc) or proposed (Watermark, Vickery or Caroona) on the Liverpool Plains. The co-location of agricultural and mining resources has led to extensive conflict where the short-term benefit to the economy by mining is pitted against the longer-term benefit of agricultural production.

Groundwater models

Drilling for groundwater investigation of the alluvial aquifer was extensive in the 1970s as government organisations moved to promote agriculture on the Liverpool Plains. This occurred as irrigation water also became available from Keepit Dam and later, Split Rock Dam. The majority of the long-term groundwater observations on the Liverpool Plains begin in the 1970s. Bore locations close to the study area are shown on the map in Figure 1. Note that the 3 pits proposed by Shenhua are indicated by a light pink tone in Figure 1.

As is often the case with targeted drilling of a groundwater resource, exploration drilling was stopped as soon as bed rock (solid rock) was proven underneath the unconsolidated sands, clays and gravels. At some locations, the bedrock was proven by taking a core from the base of the borehole. The fact that this approach was developed highlights the apparent difficulty in determining the base of the alluvials and the top of the bedrock. This was the result of extensive weathering of the bedrock (often sandstone) before deposition of the alluvial material.

The extensive data set of depths to bedrock that was developed during this phase of investigation has been incorporated into the data sets used for groundwater modelling. As the Liverpool Plains represent a large area (approximately 5,000 km^2), there had to be major simplifications to the assumed geology to achieve a model of a size that could be accommodated by available computer technology. These assumptions were that the unconsolidated formations could be subdivided into an upper layer of clay and a lower layer of sand/gravel that sat on top of material through which water could not flow (the bedrock). These were perfectly sensible assumptions for a regional model but fail when the groundwater movements associated with mining from the Permian coal measures is included.

The problem is exacerbated by a lack of communication between the mining and agricultural communities, already sharpened by perceived threats and differences between each other. From a science perspective, mining companies have little interest in the unconsolidated and geologically recent (alluvial) deposits to the extent that detail of these deposits is seldom recorded when boreholes are drilled to investigate the coal reserves.

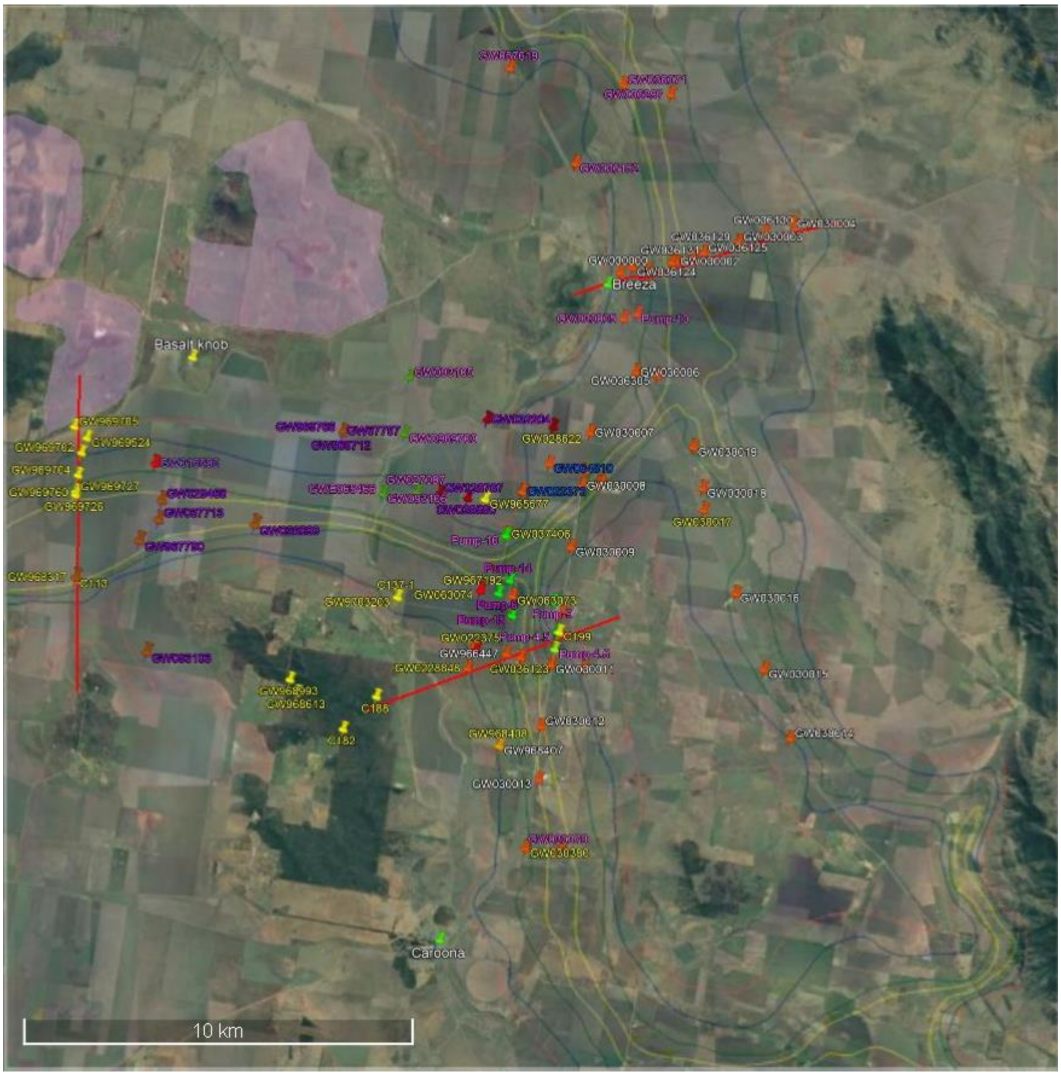

Figure 1. Location map

The possibility of groundwater flow between the unconsolidated deposits and the older rocks has been ignored by both communities until it became a required feature of the EIS process to guarantee that lowering the hydraulic head in the coal measures, as is required for CSG, underground or opencast coal mining will not impact the agricultural resource beyond a set distance from a mine. The NSW Aquifer Interference Policy was established in 2012 and identified that a cumulative impact of more than 2 m in the groundwater head would not be acceptable. The various EIS studies have therefore stressed that their groundwater modelling indicated that drawdown will be less than the 2 m threshold outside of the mining lease.

The requirement to consider both the overlying unconsolidated deposits and the underlying coal measures requires a change to the simple conceptual model, viz:

- It is necessary to understand possible linkages between the unconsolidated deposits and the coal measures and
- It is necessary to identify in greater detail the distribution of clay – as this will impede the movement of water.

Despite these requirements being explained at a number of meetings with various Government Departments and the submission of reports that have never been acknowledged, it is apparent that there remains little appreciation of this serious, if a little inconvenient, problem.

Groundwater Resources

Various Government Departments have had carriage of the responsibility to monitor the water levels beneath the ground so that groundwater management can be effectively promoted. Currently, it is the WaterNSW agency that has responsibility for monitoring all groundwater levels in NSW. This responsibility appears to be secondary to that of monitoring surface water resources.

WaterNSW publishes monitoring data on its web pages and also acts as an invaluable repository for longer term groundwater monitoring and the details of drilling works. It is also noted however, that there is little data available for boreholes drilled for mining purposes. This data is the responsibility of Resources and Geoscience in NSW and that organisation has a prime responsibility to support mining. Data is not always freely available – leading to further lack of communication as noted before.

Eight locations along Mystery Road between Breeza and Caroona detailing the reduction in groundwater levels since the onset of irrigated agriculture are shown in Figure 2. It is clear from this data that groundwater levels are declining throughout. They show little response to possible groundwater recharge that should have occurred through the wetter years (1970 to 2000) and increased rates of drawdown since 2012. This data calls into question the recharge rates assumed in the groundwater models. It is also significant that there is frequently little difference between the levels at different depths in the aquifer. The piezometers are always numbered from the shallowest (No 1) to the deepest (2 or 3, typically). Groundwater levels are falling in response to the large number of abstraction bores installed in the last 50 years. The rate of abstraction is significant with many bores exceeding 10 ML/day (115 L/s) where abstraction is frequently constant (24 hours per day) during dry periods throughout the growing season. One small area at the top of Mystery Road has a group of 7 bores with an abstraction capacity of 63 ML/day (730 L/s). The locations of these bores are shown on Figure 1. It would appear that this level of abstraction is mining the groundwater resource.

The Old Mooki River Channel

It is clear that the boundary between the base of the Gunnedah Formation and the Coal Measures is not planar – as indicated by the groundwater models. At some time in the past 66 Mya of the Cenozoic Age and probably commencing in the Late Eocene, there may have been regional uplift that rejuvenated the drainage systems causing increased erosion and down cutting. The Liverpool Range volcanicity occurred between 32 and 35 Mya (Late Eocene). This accumulation of lava may have interrupted and blocked former drainage channels. In any case, from the beginning of the Oligocene (33 Mya) drainage channels began to flow north and the Old River Mooki Channel was deepened. This is significant as the Old River Mooki cuts down into the coal measures and is later filled with clay, sand

and gravel. The channel and the disposition of sands and gravels is shown in 3 geological sections in Figures 3, 4 and 5.

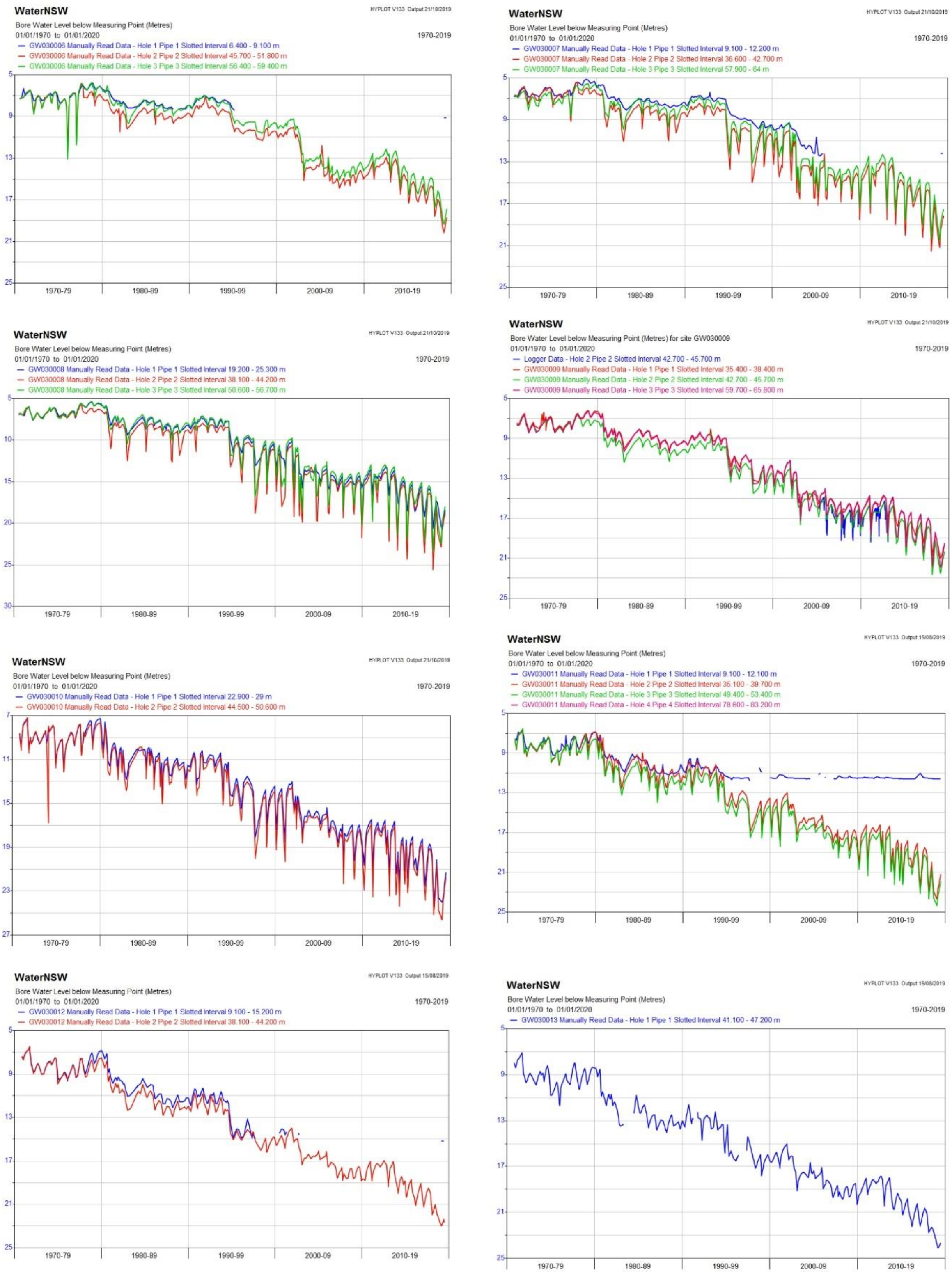

Figure 2. Change n groundwater levels along Mystery Road – 1970 to 2020

The Mystery Road section

In Figure 3, a cross section between bores completed by BHP as a part of their Caroona investigation is shown. The section crosses the Mooki River and Mystery Road (southern most section shown by a red line on Figure 1).

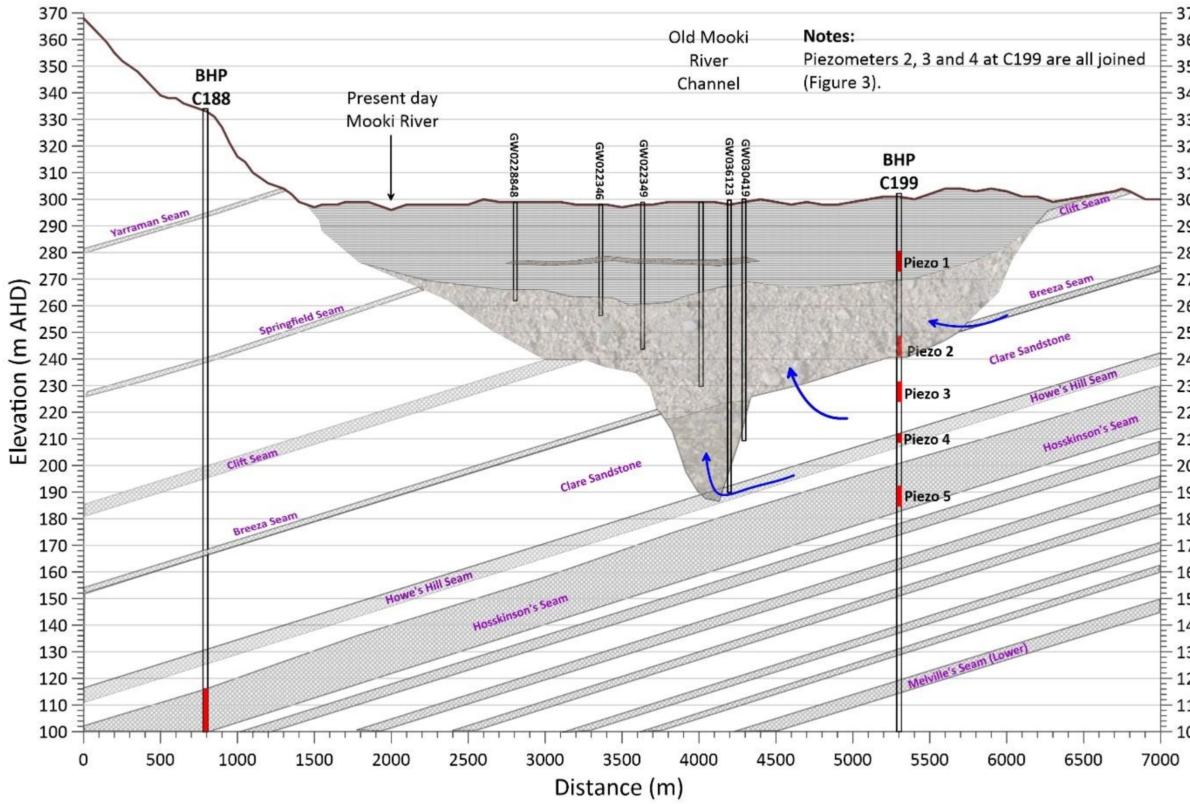

Figure 3: Geological cross-section between Bores C188 and C199 drilled by BHP

The piezometers shown are at the Group of 5 boreholes at site C199 on Mystery Road (between Bores GW030010 and GW030011 seen on Figure 1). The lithology with respect to the Permian coal measures is derived from the geophysical logging carried out by BHP. It can be seen that the Old Mooki River channel is broad and has been eroded out to an elevation of approximately 230 m AHD but that a deeper channel with steep sides is also cut down to an elevation of 190 m AHD. The presence of this old river channel has no linkage to the current slow flowing river that sits on top of the Clays of the Narrabri Formation. In this section, the approximation of two alluvial layers appears justified, although the presence of the deep central channel is overlooked.

The Breeza cross section

The Breeza cross section (Figure 4) has been constructed running east west across the narrowed neck of the Mooki River Valley at Breeza. The left-hand side depicts the volcanic deposits of Breeza Hill. These may be Triassic age Garrawilla Volcanic (193 Mya) or later Tertiary (perhaps Oligocene). The age and form of the intrusion is unknown and should be clear from the exploration drilling carried out by Shenhua but not yet released. The unconsolidated deposits show a marked variability with alternations between clay and sand and gravel deposits that are at odds with the simple arrangement used in the groundwater models. The inclined units to the right of the section represent the older Carboniferous thrusted formations to the east of the Mooki Thrust. The location of this has been based upon the Geological Map of the Gunnedah Coalfields Southern) produced by NSW Geology and Resources.

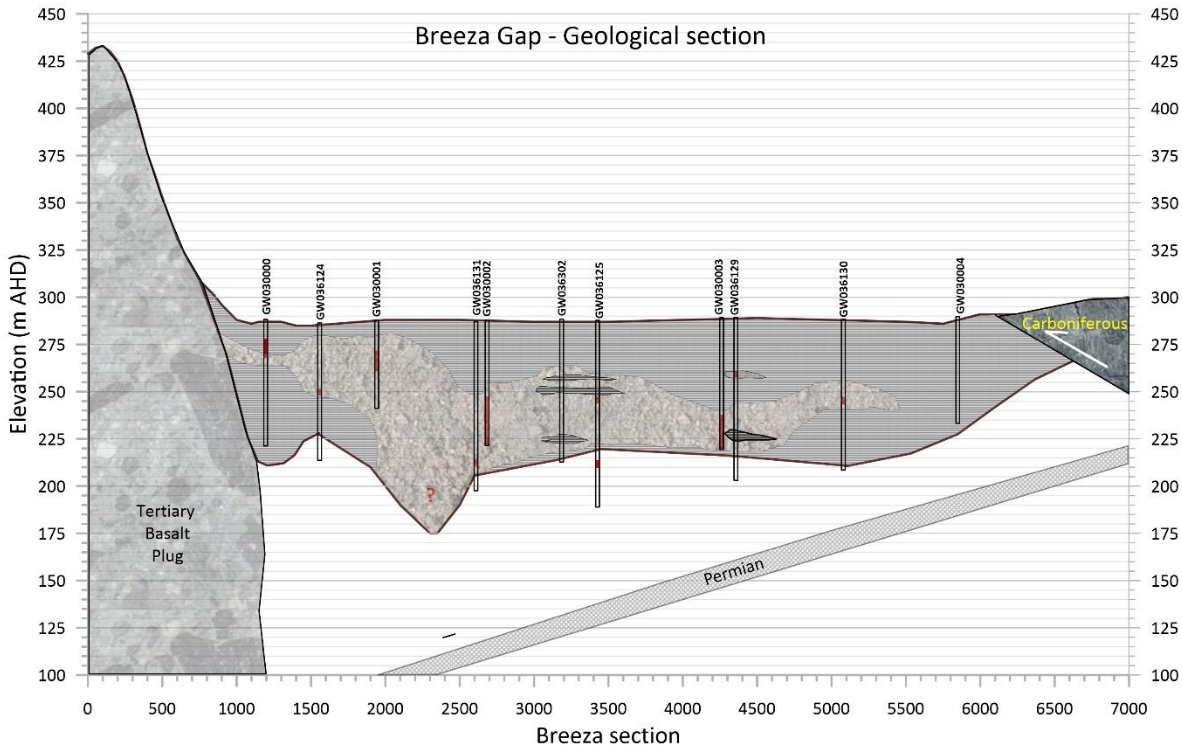

Figure 4: Breeza cross section

The presence of the Permian coal seam is shown schematically as there is no deep drilling data available.

The Clift Road cross section

This section (Figure 5) is drawn from the south to the north terminating inside the proposed southern pit at Watermark. The amount of geological detail is less than that available at the previous 2 cross sections. No additional drilling along this profile is apparent since April 2011, despite the proximity of the old Mooki River channel to the southern pit boundary. To assist with visualisation, an image taken from the roadside at Wollar showing opencast mining of a thick seam is shown.

The geological control is poor along Clift Road as, although there is a deep bore to 462 m (drilled by mines - GW969760) and a second to 233 m (drilled by BHP - GW968317), both records are unavailable. In the case of GW969760 (cored to 462 m in March 2011), data has not been released to WaterNSW for the cored section. In the case of GW968317 (also given the name C113 by BHP), although data is held by Mines, release of the data has been refused and the hole was backfilled by BHP when they completed their investigations.

DPIE NSW took over a limited number of boreholes at 4 sites from BHP. It is unclear why C113, which is the closest to the proposed Watermark mine proposed to be developed by Shenhua, was not included. The remaining bores shown to the north of C113 are secured and locked. They have no identification marks – in contrast to the normally clear identification markings on all WaterNSW bores – despite the fact that they have some records on the WaterNSW data base. Note the locations of the open sections on the piezometers on Clift Road. These have been determined from the borehole completion records on the WaterNSW database.

It is noted on several of the logs reported for the Clift Road sequence that the bedrock is extremely weathered. This is of particular significance noting the close distance to the proposed pit wall.

Furthermore, the fluid EC of the waters recovered at the time of drilling or from the piezometers report high salt levels – in excess of twice sea water in the area between the Old Mooki Channel and the proposed pit.

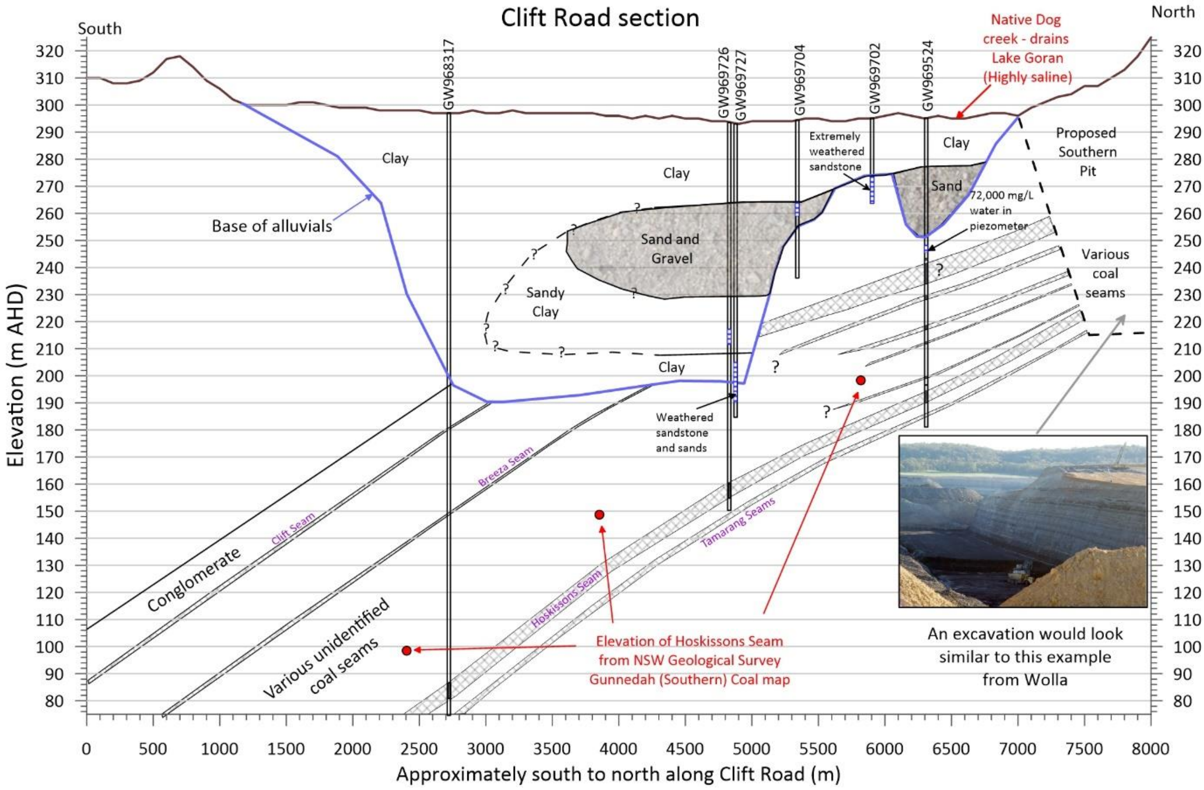

Figure 5: Cross section south to north along Clift Road (marked as a red line on Figure 1).

It is clear from the sections shown in Figures 3 to 5 that the lithology in the unconsolidated materials is very far from the uniform 2 layers used in the groundwater modelling conceptualization. It is also clear that the Old Mooki River channel is a significant feature, not least because it has eroded down to the base level of the proposed pits and will have exposed the Hoskissons Coal seam between Mystery Road and Breeza – giving rise to a major concern regarding linkage between the coal seams and the alluvials. Contours showing the depth to the base of the channel are shown in Figure 1. The yellow line signifies a channel depth of 100m; 80 m shown by the green line; 60 m by the blue line and 40 m by the red line. These contours are drawn based upon the geological data for each of the bores on the WaterNSW data base.

Linkage between the Gunnedah Formation and the Coal Seams

Partly out of luck, the BHP Site C199, which consists of 5 piezometers completed in separate boreholes but shown together for convenience in Figure 3, was opened in 2019 and the loggers recovered. Two of the 5 loggers had failed but the three remaining contained valuable data. The data since the boreholes were completed in 2015 are shown in Figure 6. There is a farm abstraction borehole approximately 50 m distant with an abstraction of 4.5 ML/day from the base of the Gunnedah Formation

The loggers in the Clare Sandstone and the Hoskissons seam had failed. The groundwater levels in the Narrabri Formation (Peizo 1) show approximately only a metre of water in the base of the hole at

275.1 m AHD. This water is drawn down during the irrigation pumping season but begins to recover 2 to 3 months after abstraction from the Gunnedah Formation stops. The drought during 2018 and 2019 caused the water level to drop below the base of Piezo 1 – indicating that the Narrabri Formation had become dry.

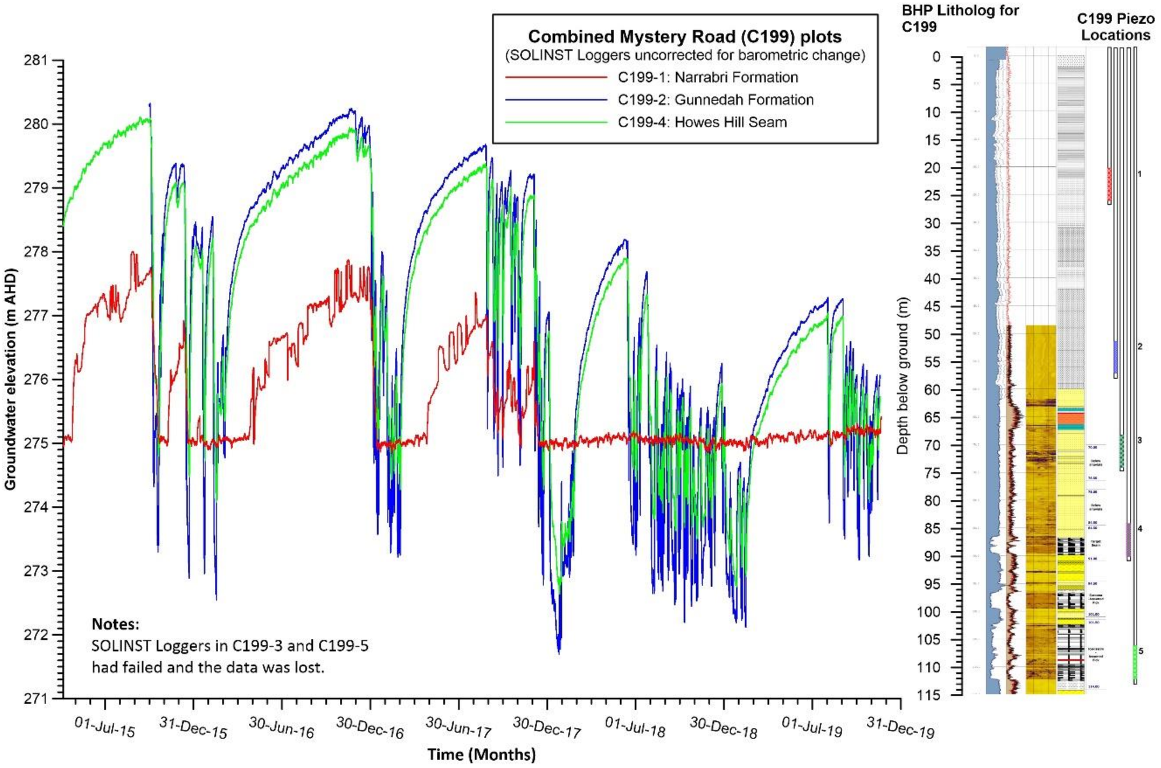

Figure 6: Groundwater levels in C199 with the geophysical log data and the depths to the piezometers also shown.

Significantly, the groundwater level in the Gunnedah Formation and the Howes Head coal seam react to the abstraction from the Gunnedah (50 m distant) almost identically. This signifies very good connection between the Gunnedah and the coal seam.

As the logger in Piezo 3 into the Clare Sandstone and in Piezo 5 into the major Hoskissons coal seam had failed, some doubt lingered over the data interpretation. Also, the loggers installed by BHP were SOLINST absolute gauge loggers that did not take account of atmospheric pressure variation.

In December 2019, In-Situ vented loggers were installed in Piezos 2, 3 4 and 5 and an atmospheric logger was installed in Piezo 1. The data for the 40-week period (mid November 2019 to end August, 2020) is shown in Figure 7. Note that the Clare Sandstone and the Howes Head coal seam water levels are practically identical – indicating no vertical flow between these two units. The Hoskissons seam responds typically to pumping with slightly higher levels before the pumps were turned on at the end of November 2019 and lower levels while the pump is active. The Howes Head logger record is shown starting later and ending earlier so that the close match between the Clare Sandstone and the Coal seam can be observed. There is clearly no doubt that pumping from the Gunnedah Formation is impacting the Permian Clare Sandstone and the Howes Head coal seam almost as much as it impacts the Gunnedah formation at the same distance. This indicates very good interconnection across the base of the alluvials and into the coal measures and is a critical observation that undermines the conceptualisation used in building the groundwater models.

The water level in the Hoskissons seam (Piezo C199-5 in Figure 7) is scaled differently to the shallower piezos. It should not be ignored however, that this deeper piezometer also shows a response to the groundwater abstraction in the Gunnedah Formation, albeit with a phase lag of approximately 10 weeks in the recovery although the response to the drawdown at the end of November 2019 is only slightly lagged.

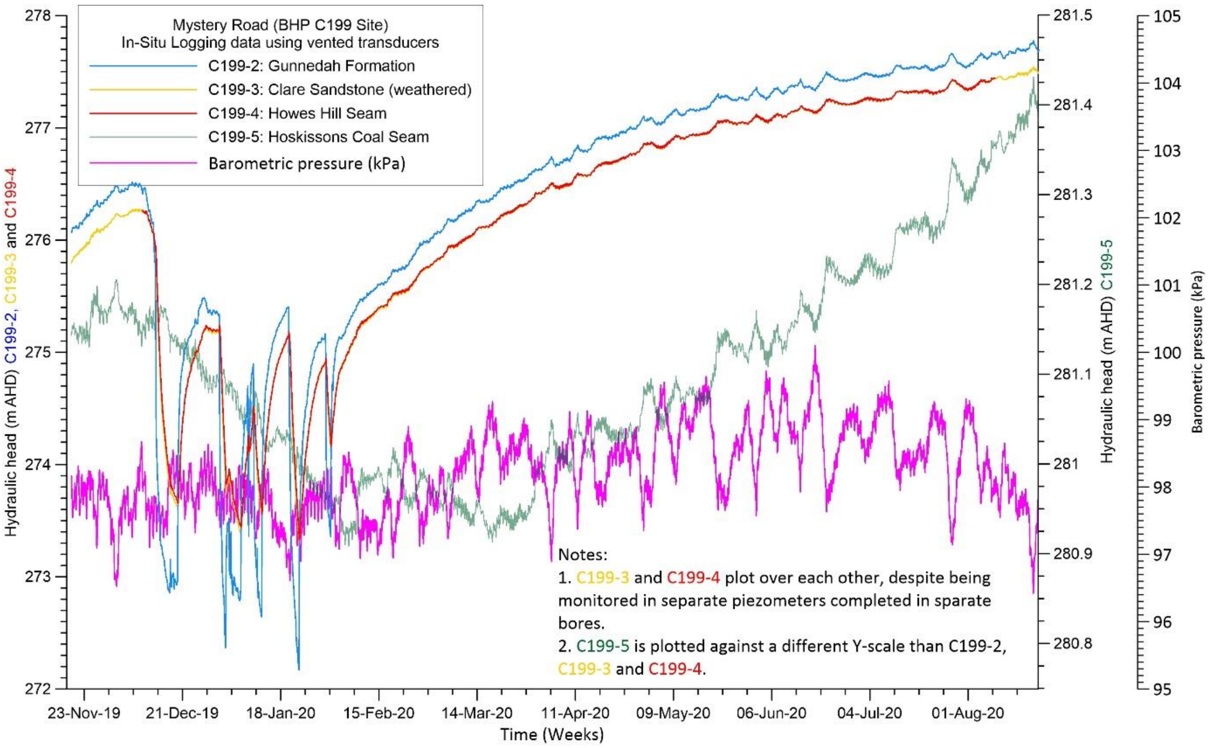

Figure 7: Groundwater levels (measured using In-Situ Level Troll 700H) in C199 piezometers with the atmospheric pressure variation.

The detailed response to pumping is shown over a shorter time frame in Figure 8. The periods when the abstraction bores were turned on are shown by the grey boxes derived from data obtained from the farmers. There is no record of exactly which bore pumps what abstraction rate and if the bores were all turned on at the same time. However, close agreement between the drawdown in the aquifer and the pumping period is so exact as to leave little doubt that the aquifer levels are responding to groundwater abstraction.

It has been suggested by some that the response of the Howes Head piezometer and the Clare sandstone piezometer occur as a result of decreasing the overburden pressure by dropping the water level in the alluvials. This hypothesis can be rejected when the slightly different responses are considered. This is particularly clear during the second period of abstraction. In addition, the fluid EC and temperature data from the 5 bores that were measured on 8 August 2020 demonstrate uniformity. The data are presented in Table 1.

Table 1: Fluid properties at C199 in August 2020

Piezometer	Formation	Depth to water (m)	Fluid temperature (Degrees C)	Fluid conductivity (μ S/cm)
C199-1	Narrabri	21.47	19.6	527
C199-2	Gunnedah	21.51	19.6	643
C199-3	Clare Sandstone	21.65	19.6	522
C199-4	Howes Hill Seam	21.65	10.3	473
C199-5	Hoskissons Seam	17.78	19.3	807

Other points of note include: the observation that the 68 mm rainfall event that started to break the drought in the autumn of 2020 did not cause a response in the groundwater levels; and that Piezo 199-5 shows a very clear confined response with an out-of-phase relationship when compared to change in atmospheric pressure.

The data for C199 show beyond doubt that the top of the sandstone, the coal seam and the Gunnedah Formation are acting as a single aquifer. Pumping from one directly impacts the other and vice versa.

This may explain the exceptionally large groundwater yields from this small part of the aquifer. Note however, that overall levels are declining comparatively rapidly as shown in Figure 2.

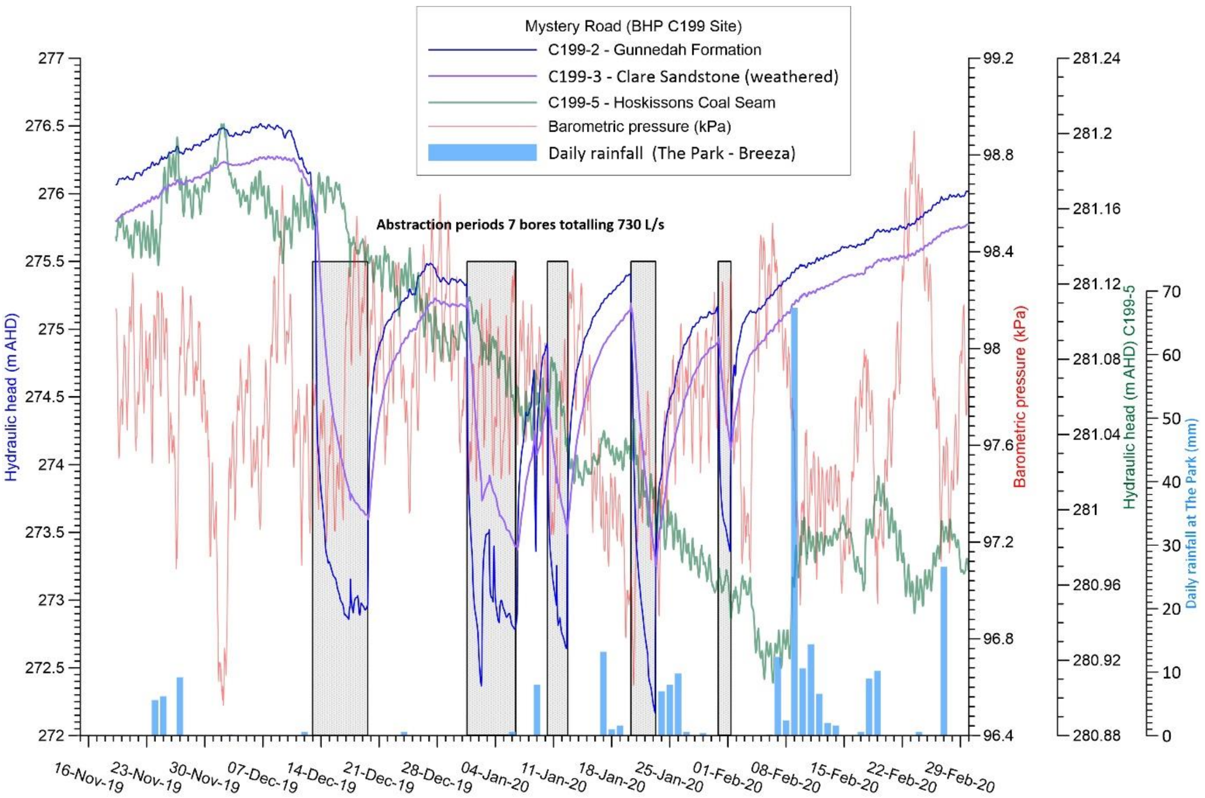

Figure 8: Groundwater levels (measured using In-Situ Level Troll 700H) in C199 piezometers with the atmospheric pressure variation – limited time period.

The data from C199 Site demonstrate what can be achieved by careful monitoring in a well constructed set of piezometers. It is also noted that similar responses to abstraction were noted at another site reported in the BHP Gateway Report. The Site at C102, further south down Mystery Road (Figure 1) recorded similar linkage between the coal measures and the Gunnedah Formation.

Unfortunately, the offer by BHP to add this site to the list of sites handed over by BHP to NSW DPIE Water was, for some reason, rejected and the holes were filled with cement slurry when BHP completed their work. This was the fate of boreholes at 9 of the sites offered by BHP, comprising 50 boreholes in total.

Identification of Lithology along Clift Road (Figure 5)

There are only 9 boreholes drilled along Clift Road and there is only limited data available on the WaterNSW web site. C113 (GW968317 – drilled in August 2007) was drilled as part of the detailed investigation by BHP of the Caroona coal deposit that lay directly to the south of the Shenhua Watermark investigation. Details of the lithology and geophysical logs of the bores were submitted to NSW Geological Survey. A request by NSW DPI Water for access to the data for this site has been refused. Data for the deep bore (GW969760) is also not available.

The depth to the main coal seam (The Hoskisson Seam – regionally extensive and often >10 m in thickness) at C113 was identified in the BHP Gateway report and this is indicated in Figure 5. There is limited information concerning the alluvial deposits at C113 but the depth to solid rock (Permian) is recorded. The possible depths of the Clift and Breeza seams has been extrapolated from a site (C137) close to C188 (Figure 1). The red dots in Figure 2 give the estimated elevations of the top of the Hoskisson seam from the NSW Geological Survey Gunnedah Coalfields Map (Southern). It is noted that the location of the Hoskisson seam in C113 was approximately 25 m lower than the geological map estimates, however the general dip and extent are confirmed and extrapolation to the north from C113 is therefore warranted.

Two bores (GW969276 – drilled in June 2010 and GW969277 – drilled in March 2011) have been drilled close to each other on Clift Road. They show broadly similar geology and both indicate a thick succession of gravel between elevations of 230 and 265 m AHD. There are no existing water bores into this deposit, which it is noted, lies on the predicted path of the Old Mooki River Channe (Figure 1)l. Bore GW969276 recorded very weathered sandstone at the base of the channel (198 m AHD). Considerable difficulty was recorded during drilling at GW969277 where there was significant core loss in the alluvial section. Both bores had piezometer sections installed as indicated by the horizontal blue lines in Figure 2. It is noted that neither piezometer allows monitoring of the gravel aquifer.

Bore GW969702 (Drilled in April 2011) recorded extremely weathered material at the base. The shallow depth to bedrock indicates considerable buried topography between the main channel to the south and the edge of the proposed southern pit. Bore GW969524 (drilled in April 2010) recorded bedrock at an elevation of approximately 250 m AHD with a succession of coal seams at depth in the solid rock beneath. It is not clear what correlation exists between these seams and other seams recorded in the area. The lowest seam is assumed to be the Hoskissons seam but this is much thinner than in other locations and this assumption may be incorrect.

Bore GW969704 was completed using a sonic coring method and gives good detail of the unconsolidated materials.

The Southern Pit boundary is taken from Shenhua publications. It is noted that the water sampled from the piezometer completed in sandstone at GW969524 indicated a salinity of 72, 000 mg/L (about twice sea water salinity).

We note that Shenhua's monthly monitoring of groundwater conditions appears to be from 3 of these bores along Clift Road – completed before Shenhua's investigation and drilling commenced in 2012.

There is no indication of any new groundwater monitoring bores installed by Shenhua to investigate conditions within 2 km of the southern boundary.

Risk to the alluvial aquifer associated with developing the Southern Pit at Watermark

The gravel-filled channel under the black soils along Clift Road (Figure 5) is a part of the old Mooki River drainage system that was cut down to an elevation of approximately 190 m AHD during Miocene times (23.3 to 5.3 Mya). It has already been demonstrated that there is good connectivity between the Clare Sandstone and the gravel channel at Site C199 on Mystery Road. It is then clearly probable that the same interconnectivity exists along Clift Road and particularly to the north where the Permian sediments have been noted to be very highly weathered.

Groundwater abstraction from the Southern Pit is therefore highly likely to impact the gravel groundwater resource below Clift Road. Head losses in this channel will then likely propagate eastwards into the high yielding aquifer resource at the top of Mystery Road. Noting that the NSW Aquifer Interference Policy requires minimum impact at distances of 2 km from a coal excavation, it is inexplicable that no groundwater monitoring is being undertaken either in the gravel channel or between the gravel channel and the southern pit boundary. The gravel channel is only 2 km from the southern boundary and may well be closer.

Furthermore, early investigations by Shenhua and their subcontractors revealed the presence of faults running between the southern pit and out onto the black soil plains at Clift Road. Faulting of this type will exacerbate the risk of leakage between the gravel deposits and the pit as the pit level is reduced to an elevation approximately equal the base of the gravel channel.

In addition to these concerns is the observation that water quality in the bores that have been installed along Clift Road indicate that the groundwater at some depths is highly saline (twice sea water salt concentrations). The presence of this saline water is probably related to drying periods of Lake Goran to the west and the formation of lunettes. Lunettes have been mapped in the deposits immediately to the north east of Lake Goran. The removal of this water will require very careful management.

Summary

In summary, my hydrogeological analysis is that there is a very high risk of connectivity between the gravel channel deposits and the sediments that are proposed to be removed to form the Southern Pit. As such, control of groundwater inflow is likely to pose very significant problems, with aquifer drawdown occurring beneath the black soil plains. Prevention of this will require extensive and expensive remedial measures to seal the pit from the aquifer. In the light of this observation, which could have been made at any time during the evaluation process, it is, as I have noted above, inexplicable that no appropriate monitoring is occurring. Not one of the three points where groundwater levels are being monitored monthly, is actually designed to determine aquifer impacts. The piezometers are not completed at the correct depths. What is necessary before any permission is granted to commence mining, is the installation of at least 3 nests of piezometers along Clift Road and the monitoring at least 3-hourly for a minimum of six months to determine the actual groundwater conditions. A design based upon C199 by BHP is required.

I would note that the extensive groundwater modelling that has been carried out as a part of the project EIS etc. is actually of no value at the necessary local scale as the model of the geology upon which the models have been based is simply wrong. This may be unfortunate, but the detailed results from C199 and a careful consideration of the lithology – as provided in Figures 3, 4 and 5, leave little room for doubt. It is accepted that considerable work of a high quality, with respect to groundwater modelling, has been carried out and presented. However, if the conceptual model that forms the basis for constructing the groundwater model is incorrect, then no amount or number of computer runs or optimisations can fix this problem. As noted by an international leader in the field of groundwater modelling, ‘All groundwater models are wrong. What can we learn from the modelling?’ It appears that nothing has been learnt from this modelling as very little hydrogeological field work has occurred to check the model conclusions.

I can therefore have no confidence in the actual predictions of the groundwater modelling provided to date. No confidence as to whether the NSW Aquifer Interference Policy can be satisfied.

Ian Acworth

12 October 2020

Biography: Ian Acworth is an Emeritus Professor (UNSW) and has 45 years of experience in hydrogeology. His has completed a BSc in Earth Sciences (Leeds, UK); an MSc in Hydrogeology (Birmingham University) and a PhD in Groundwater from the Geology Department at Birmingham University. He has 10 years consulting experience in various parts of the world and has taught and researched groundwater at UNSW for 27 years before retiring in 2015. Since then he has published many papers in the international literature and has written a book (600 pages) entitled “Investigating Groundwater” that was published by the International Association of Hydrogeologists in 2019.