Vertical hydraulic head gradients were also assessed by analysing the vertical pressure head distribution at each piezometer nest for late 2013 / early 2014 (Figure 6.2). The distributions support the hydraulic head cross-section, with the majority of sites indicating negligible vertical hydraulic head gradients. These are located in and around the mine lease, underneath WG. Strong vertical gradients due to depressurisation from the Berrima mine can be identified at piezometer nests B62 and B63. The lateral position of GW075032 suggests the vertical gradient at that location has been created by the existing mines. Drawdown from mining is not conspicuously observable in hydrographs for piezometers at H43X, the nearest Hume site to the existing mines; this site shows a negligible gradient in sandstone, probably due to insulation from the mined area via incision by drainage courses. H77 shows a moderate gradient at shallow depths, highly typical for outcropping Hawkesbury Sandstone in the Southern Highlands. The results suggest the drawdown from the Berrima mine has migrated mainly northwards and eastwards.

Sites H136 and H35 are interpreted to have potential unsaturated zones (of unknown vertical thickness) below the base of the basalt and WG respectively.

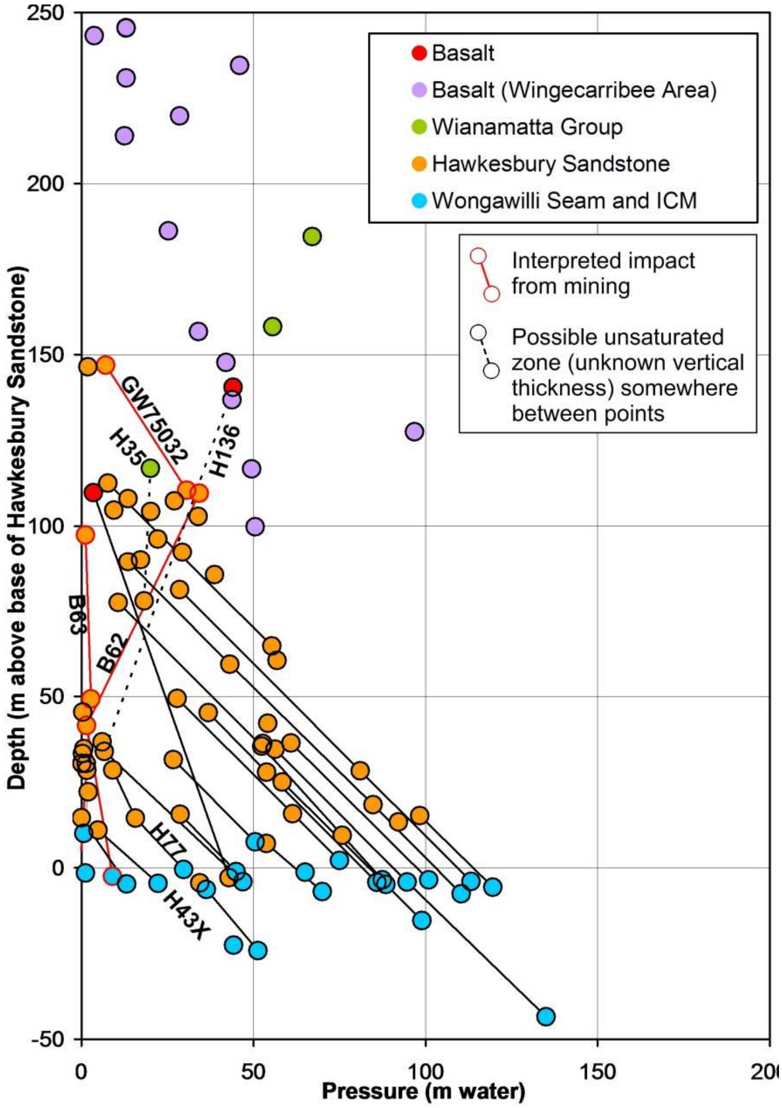



**Figure 6.2. Vertical pressure head distributions for late 2013 / early 2014.**

# 6.3. Hydraulic head surfaces for late 2013 / early 2014

Where vertical hydraulic head gradients are present, it is necessary to consider the vertical position of a piezometer in the profile when assessing hydraulic head surfaces. Surfaces are usually only useful if observations for a surface are located at the same stratigraphic horizon, since the K field is controlled by the structure of the medium. Horizons that are a given distance above or below an important depositional marker (such as the base of the Hawkesbury Sandstone) are generally required, however an element of variability from changing overburden thickness is present.

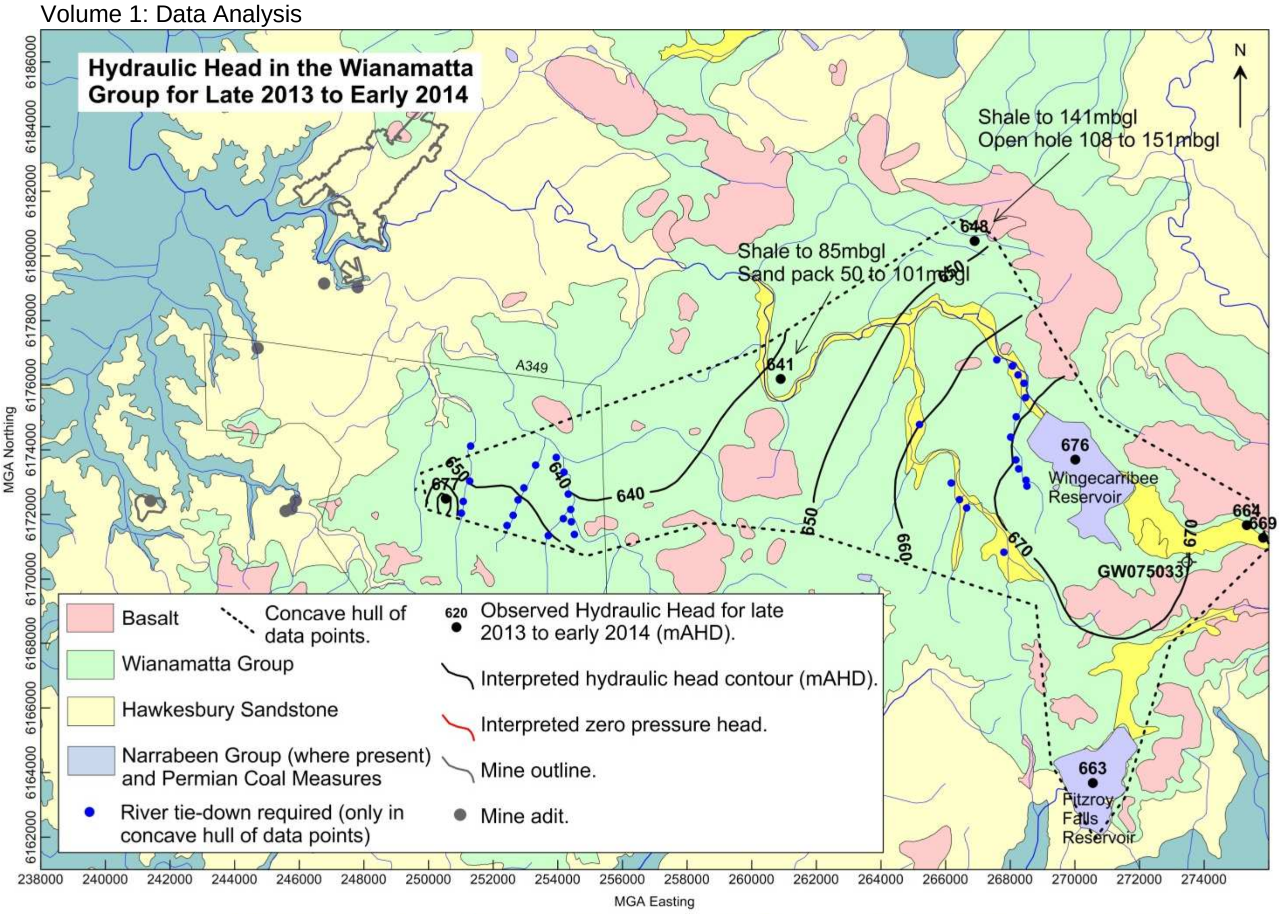
Hydraulic head surfaces for late 2013 / early 2014 (the period with the greatest overall lateral coverage in observations at the time of reporting) were compiled for the following horizons, to achieve a reasonable representation of the three-dimensional variation of hydraulic head over the area and at the same time using horizons where a sufficient number of observations were available to provide a meaningful surface:

- WG (7 observations, of which two are long-term elevations of water levels in Wingecarribee and Fitzroy Falls Rservoirs).
- Shallow Hawkesbury Sandstone (19 observations between 77 m and 108 m above the base of the Hawkesbury Sandstone, and application of zero pressure head at appropriate locations on the Berrima and Loch Catherine mine boundaries).
- Deep Hawkesbury Sandstone (23 observations between 22 m and 45 m above the base of the Hawkesbury Sandstone, and application of zero pressure head at appropriate locations on the Berrima and Loch Catherine mine boundaries).
- Wongawilli Seam and ICM (21 observations between 0 m and -24 m above the base of the Hawkesbury Sandstone, and application of zero pressure head at appropriate locations on the Berrima and Loch Catherine mine boundaries).

Figure 6.3 shows the hydraulic head surfaces for the WG and shallow Hawkesbury Sandstone. Appendix E has hydraulic head surfaces for deep Hawkesbury Sandstone and the Wongawilli Seam / ICM. The combination of highland topography and contrasting outcrop lithologies produces a hydraulic head field which is elevated along the western Hawkesbury Sandstone outcrop and at Wingecarribee Reservoir to the southeast, and decreases towards the south and northeast. Wingecarribee Reservoir and rainfall recharge at sandstone outcrop areas form the main upper hydraulic controls in the subsurface, for the hydraulic head field.

Surfaces obtained from initial contouring of data were tied down with ground elevations wherever these initial surfaces intersected ground surface (mainly at drainage channels). Points where tie-down was undertaken are shown, and provide an approximation for the areas where baseflow to drainage channels occurs (recognising that the extent of tie-down zones are a function of data density, and that the actual hydraulic head in these zones, for the particular horizon, is not necessarily at ground surface).

The water table is difficult to locate, especially where vertical hydraulic head gradients are present. An approximation can be made by extrapolating the pressure head distributions in Figure 6.2 to obtain the y axis intercept (the depth where pressure head is zero) and taking the elevation of that point. However this is not possible where hydraulic head gradients are greater than 1, such as for B62.



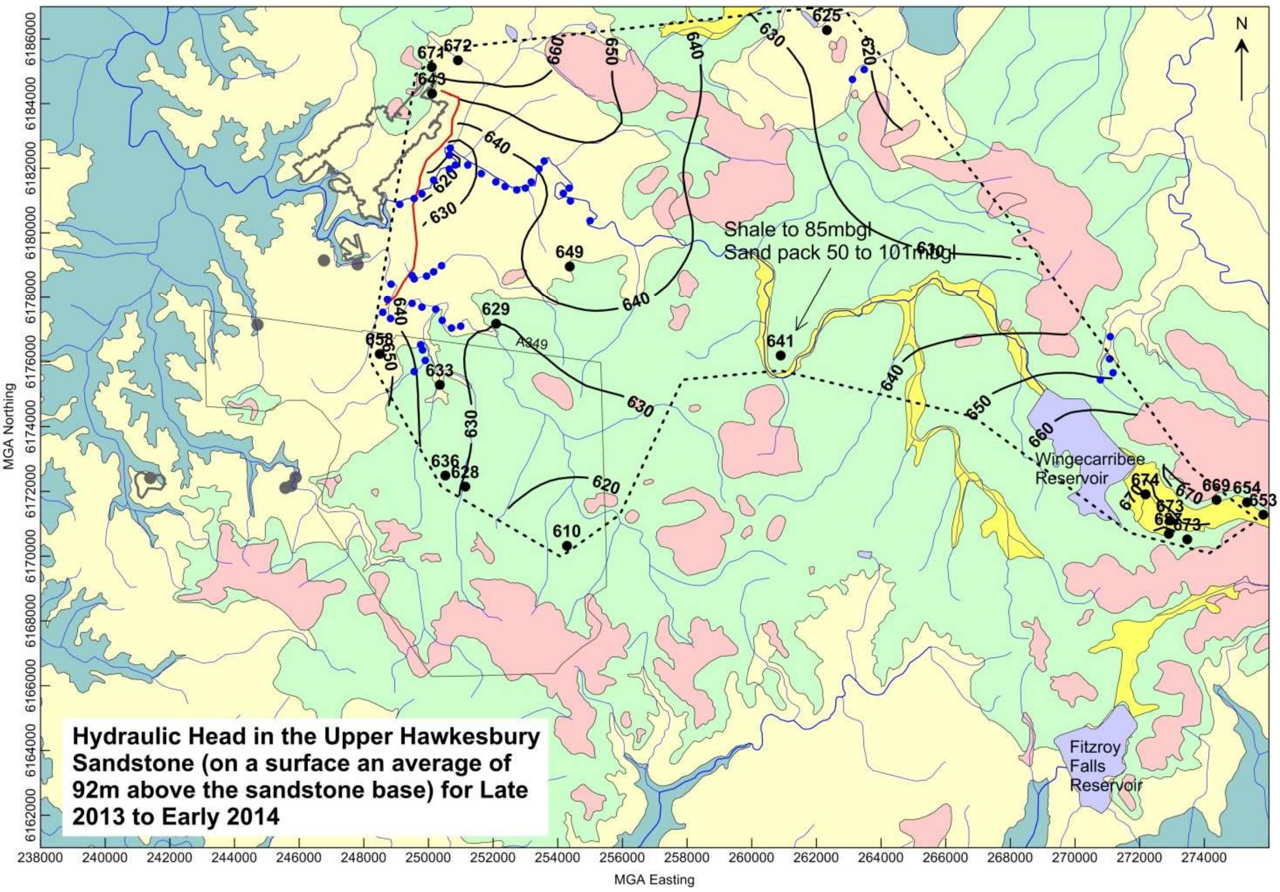




**Figure 6.3. Interpreted hydraulic head surfaces for late 2013 / early 2014.**

## 6.4. Hydraulic heads in basalt

The interpreted unsaturated zone below the Wianamatta Group (WG) over a large part of the study area (Figure 6.1) prompted a detailed assessment of the hydraulic relationship between basalt and underlying strata. This comprised assessment of the hydraulic head field present in the southeastern basalt body (see Figure 6.4), and underlying WG. The purpose of the assessment was to characterise the probable behaviour of hydraulic heads in the basalt groundwater system due to drawdown in underlying media, given the large number of private bores utilising the basalt groundwater system.

The southeastern basalt body is as shown in Figure 6.4. Most other basalt bodies in proximity to the proposed mine footprint are very small. Another large body is located just west of the southeastern basalt body however it likely hosts a smaller groundwater system, and also hosts fewer private bores.

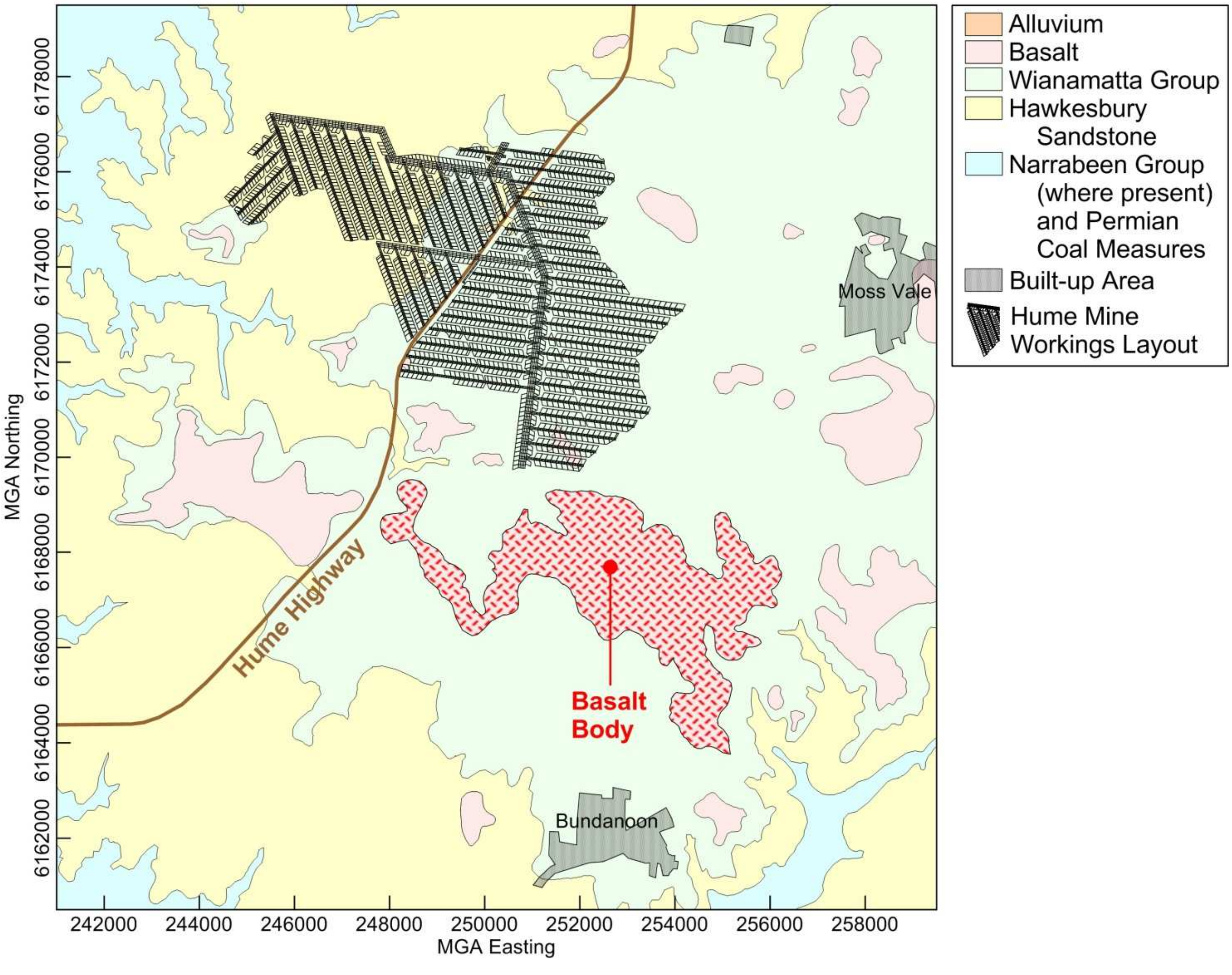



**Figure 6.4. The southeastern basalt body.**

A database of hydraulic head measurements, specifically for the basalt body and underlying media, was compiled from registered private bores penetrating this subsurface volume (DPI Water database extraction 2015). The analysis is more three-dimensional in nature than is possible using observations from monitoring networks alone.

Bore completions and measured water levels were obtained for 40 water bores, in hydraulic communication with the following media in and around the basalt body (see Figure 6.5):

- 30 in basalt only.
- 7 in Hawkesbury Sandstone (HAW) underlying basalt.
- 3 in HAW on the fringes of the basalt body.

Figure 6.5 shows private bores present in the area, and the 40 private bores for which the hydraulic connection has been interpreted from construction records and measured water levels. Data are provided in Appendix F. Lithologies recorded in bore logs may not agree with published geology maps. No measurements of hydraulic head for the WG were available for this volume. Measured water levels cover a period mainly between 1990 and 2010. Hydraulic heads were calculated for each bore. Observations from monitoring piezometer nests H136 (three piezometers in basalt, HAW, and ICM) and H42 (two piezometers in HAW and ICM), located at the basalt body, were added to the observation dataset to create a database of 45 hydraulic head observations in the subsurface volume.

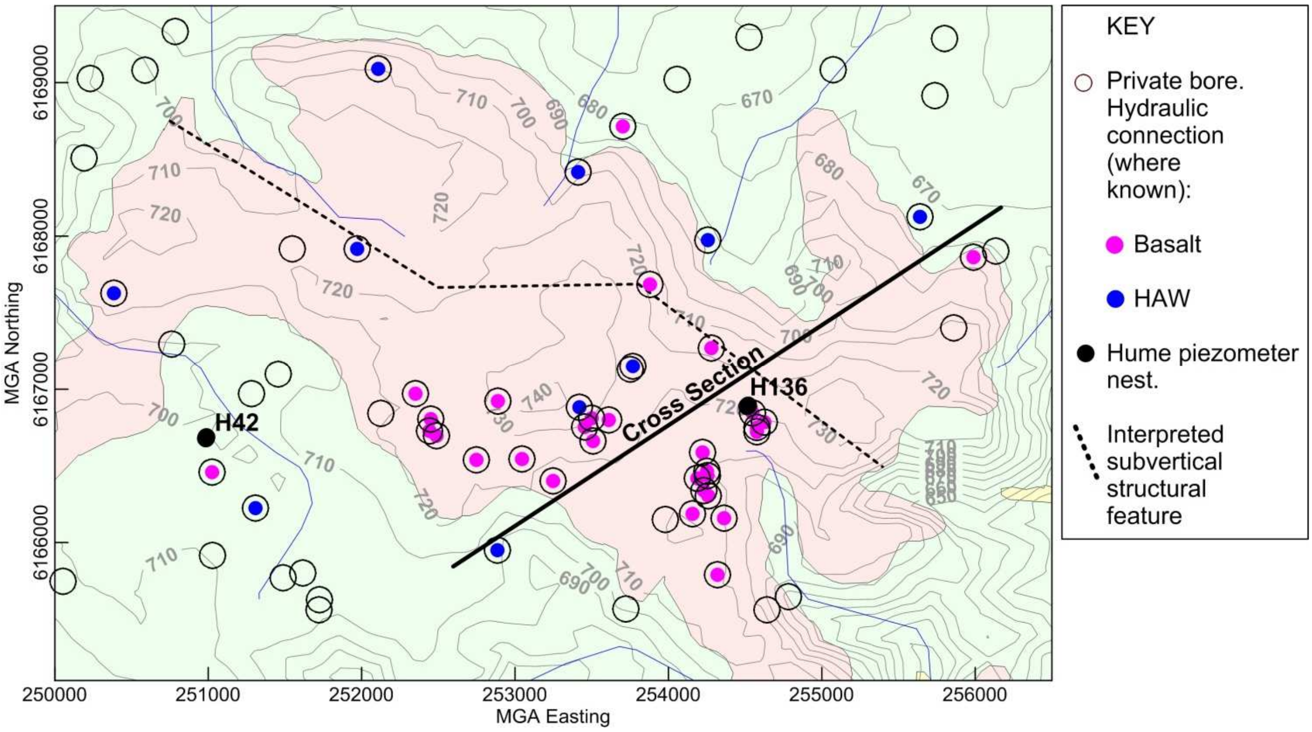



**Figure 6.5. Private bores located in and around the southeastern basalt body. Those used for analysis are coloured (identified hydraulic connection).**

The database was initially used to assess vertical pressure head gradients. This distribution is shown in Figure 6.6, and includes observations from piezometers in the wider lease area to assist with assessing gradients. Only one observation was available for the WG (H35B, in the centre of the Hume lease).

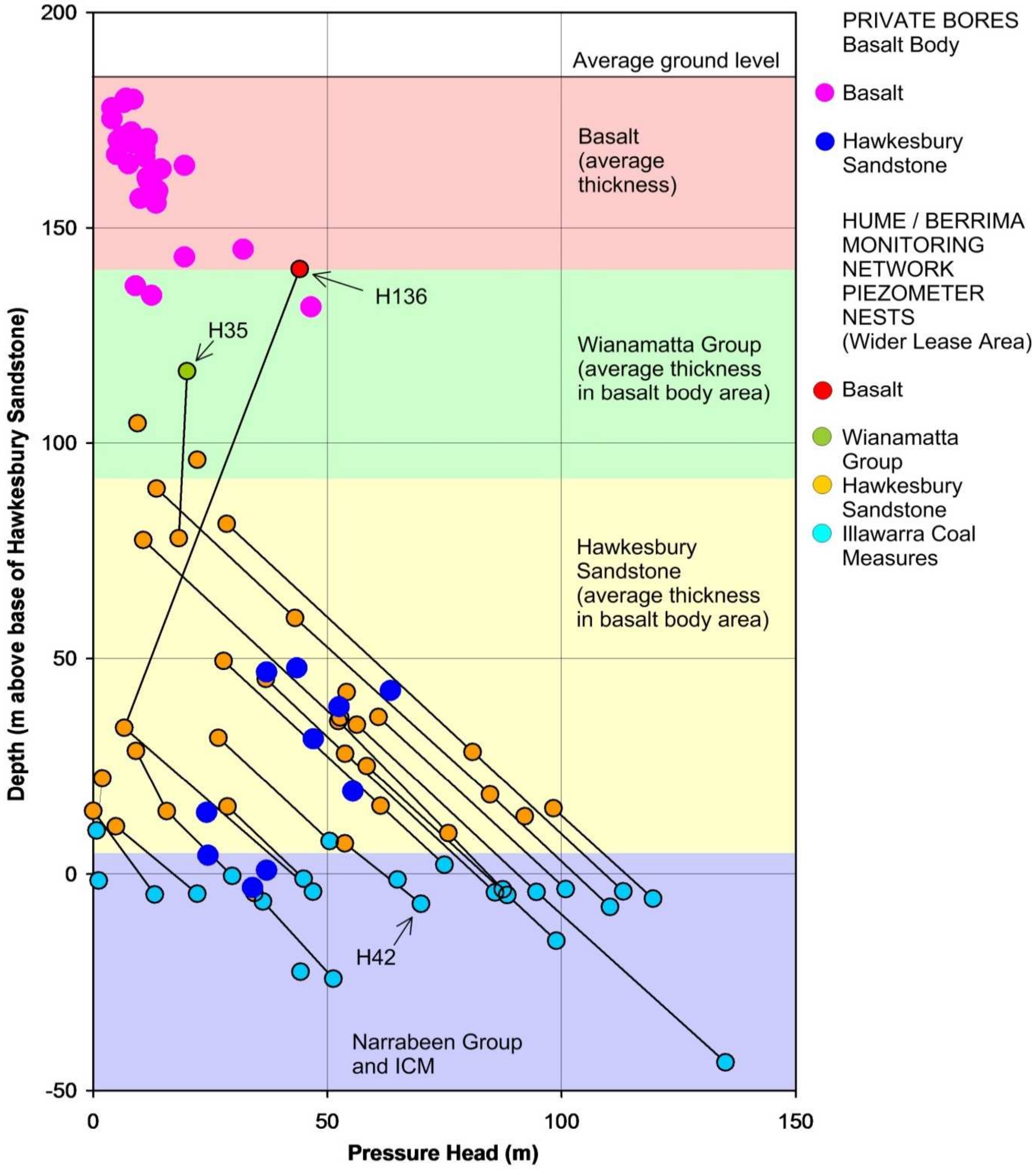



**Figure 6.6. Pressure head versus depth distribution for the basalt body volume (mainly from private bores), and for the wider lease area (from monitoring piezometer networks).**

Figure 6.6 (and Figure 6.7, see below) indicates that vertical hydraulic head gradients are small in the basalt and HAW, but likely to be significant (and downward) in the intervening WG. The pattern emerging from the large number of observations strongly indicates a largely unsaturated zone below the WG, in the basalt area. This was further investigated by compiling a hydraulic head cross section for the basalt body (see Figure 6.5 for section location). Observations made in basalt within 500 m (laterally) of the cross section were included for plotting.

Figure 6.7 shows the interpreted hydraulic head cross section. An unsaturated zone occurs below the WG south of the subvertical structural feature. North of the structural feature, the hydraulic head difference between the top of the HAW and the base of the basalt is about 80 m. The overall hydraulic gradient is about -1 downward. North of the structural feature, the pressure head at the top of the sandstone is an average of about 10 m.

The analysis indicates the following:

- Drawdown in the HAW south of the structural feature will not cause any change to the saturated flow regime in the basalt in the same area. The majority of private bores in the basalt are located here.
- North of the structural feature, the top of the sandstone can undergo a drawdown of about 10 m before desaturation occurs between the sandstone and WG, at which point any further drawdown will not impact the saturated flow regime in the overlying basalt. This is an increase in the magnitude of the vertical hydraulic head gradient of about 13%. This assumes saturation is maintained from the base of the WG (moving upwards); this is considered reasonable given the strong vertical anisotropy exhibited by the WG.
- It is estimated that of the recharge to the basalt, less than 10% drains vertically into the WG, with the remainder consumed by surface processes and baseflow. The realisation of drawdown greater than 10 m at the top of the HAW is therefore likely to increase the vertical drainage from the basalt by about 1% of the recharge to the basalt, or less.
- If maximum drawdown were to occur at the top of the HAW, drawdown in the basalt would initially be non-zero but negligible, as drainage from storage occurs. With time, drainage from storage ceases and water levels would re-establish (during mining), with the increased vertical drainage satisfied by decreased baseflow to streams.

No direct evidence (from bores) is available for the structural feature. Its presence is interpreted from hydraulic heads, regional lineaments, and structure contour surfaces considered in unison. The feature is considered major, running approximately ENE-WSW, underneath the basalt body. The structure was likely an access gallery for the basalt extrusion, and appears to exhibit the classical behaviour of increased K along its plane, but decreased K in a direction normal to its plane.

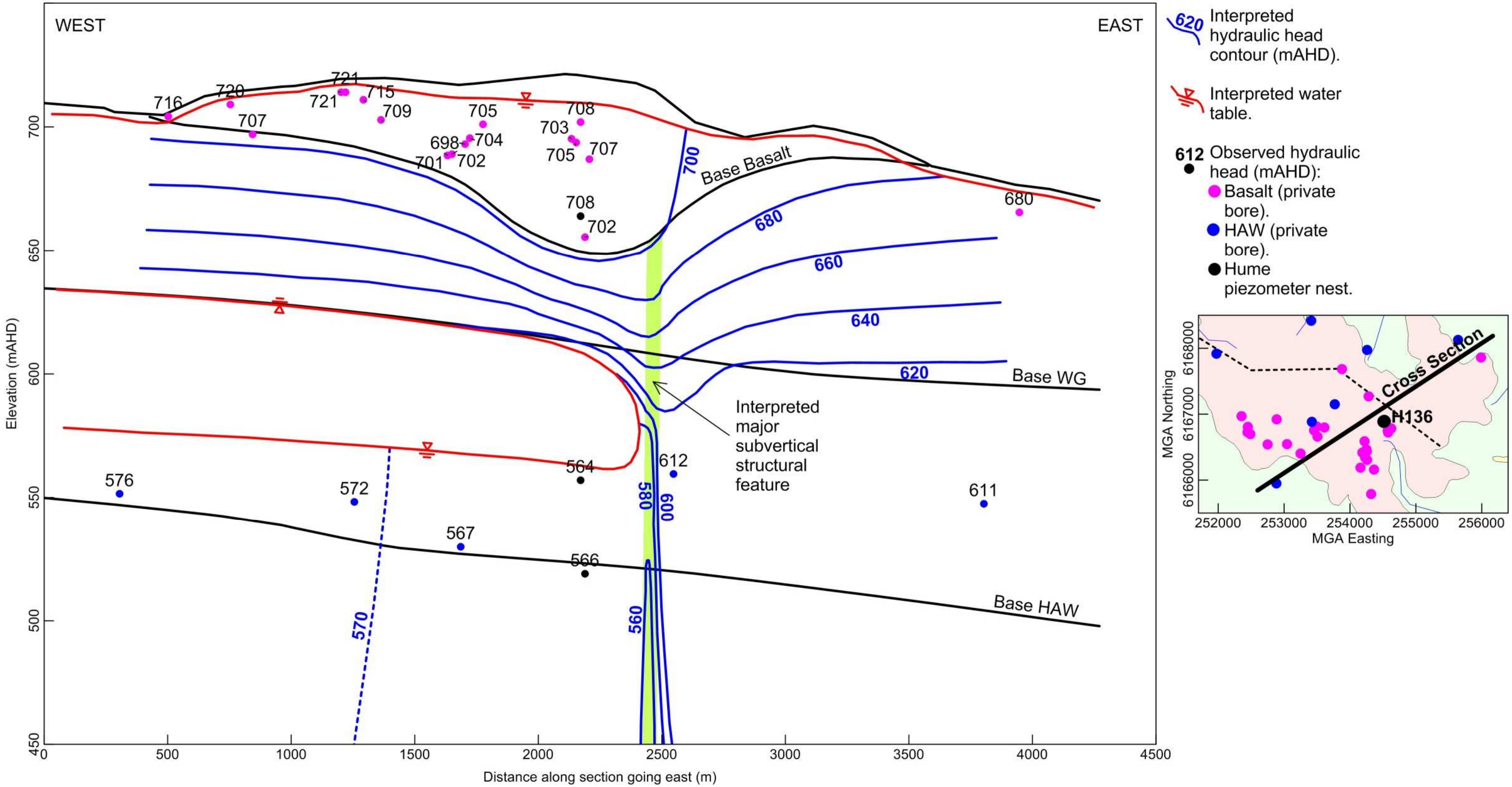



**Figure 6.7. Hydraulic head cross section along the basalt body.**

## 6.5. Reliability of Hydraulic Head Measurements

The reliability of a hydraulic head measurement is a necessary consideration for model calibration. Standpipe piezometers (SPs) provide the most reliable hydraulic head observations, however practical considerations limit the number of piezometers in the vertical profile at a single location. Vibrating wire piezometers (VWPs) provide hydraulic head measurements of lower accuracy than SPs, but practical considerations allow significantly greater coverage of the vertical profile with VWPs at a single location (up to five in the Hume network) than is possible with SPs. The Hume monitoring network contains a combination of SPs, VWPs, and private water bores for acquisition of hydraulic head observations and provides a substantial database for characterisation of the groundwater system in the Hume area.

An estimate of the resolution of VWPs was previously made for another project in the Southern Coalfield using measurements from VWPs located at two sites on a mine lease. It was found that simultaneous water level measurements from coincident VWPs varied. Results indicated that, 50% of the time, a VWP measurement at that site would have been within 7.8 m of the measurement from a coincident VWP. The ability of a VWP to provide the true hydraulic head adds an additional uncertainty to the measurement. This accuracy is considered not better than ±10 m most of the time. This accuracy may be acceptable in areas with a high vertical hydraulic head gradient (for example, for depressurisation due to underground mining, as at B62 and B63), but may be less suitable in areas with smaller vertical hydraulic head gradients.

The lower accuracy of VWP measurements has been taken into consideration when comparing model output to hydraulic head observations. The hydraulic head calibration dataset includes observations from VWPs at locations B62 and B63 in the Berrima monitoring network.

# 7. Groundwater inflows to the Berrima mine void

Measured discharge from the Berrima mine void provides an invaluable calibration aid for numerical modelling. When used in conjunction with hydraulic heads, the mine inflows are able to significantly reduce the uncertainty associated with the correlation between rainfall and K. Coupled with reliable a-priori estimates of rainfall recharge and the Kh distribution, deep discharges (mine inflows in this case) provide vital information in estimating the Kv distribution between the surface and the mining zone.

Mine operators have monitored discharge from the Berrima workings for several years, with discharge measurements available from 2005. Water is pumped from various points within the workings to the main sump where it flows through an old roadway to the Wingecarribee River where it is discharged through an adit under EPA Licence conditions (EMGA 2011). Water was previously pumped from the workings to storage tanks in the northern corner of the Berrima pit top, from where it was used for dust suppression, equipment washdown, bathhouse and ablutions, and piped under gravity to the township of Medway for non-potable water use (EMGA 2011). During the recent active mine life (2012/2013) these consumptions (plus an estimate for ventilation loss) are estimated to have been about 0.05 ML/day. At present, the consumption is estimated to be about 0.02 ML/day. These consumptions were or are taken from void inflow, with the remainder discharged to the Wingecarribee River.

Existing groundwater removed in coal moisture (during mining) is conservatively estimated to have been about 0.1 ML/day (about 2% existing groundwater, at 0.25 Mt/y). Coal removal is assumed to have ceased on 31 March 2013.

When the mine was active, mine workers observed that the void inflow rate appeared to be approximately proportional to the area of seam roof exposed, with no obvious lateral inflow from the Wongawilli seam. Anecdotal information indicates the following:

- Panels driven beneath basalt experienced higher inflows.
- Wet weather sometimes resulted in large volumes of water flowing down along the contact zones of dykes. There appeared to be a strong correlation between the occurrence (and distribution) of subvertical dykes and increases in inflow during 2008.

Monitoring of void discharge at the licensed discharge point up to October 2012 was undertaken using a v-notch weir. In October 2012 a more accurate cut throat weir outfitted with an automatic recorder was installed. Void discharge observations have the following limitations:

- Prior to 2009, it is understood that measurements may only have been made when discharge pumps were active, with resulting measurements excluding periods of no pumping. If pump on/off times were available, averages over periods larger than the pumping frequency would be useful, since void inflow during pump off times would report to void storages for future pumping. However, it is not clear if observations published prior to 2009 were averaged over large periods (compared to the pumping frequency). The data points present in published information would suggest this was not the case.
- It is understood that the original v-notch weir had a lower accuracy than the cut throat weir installed in 2012.
- The coincident installation of an automatic recorder with the cut throat weir suggests observations between 2009 and 2012 may also have suffered from biased sampling.

These limitations mean observation reliability is reasonable only after October 2012. Prior observations may be overestimates. Figure 7.1 shows the recorded discharge. Also shown is the monthly cumulative rainfall residual for the period 2000 to the present (incorporating an entire southern oscillation cycle with the major drought in the middle of last decade).

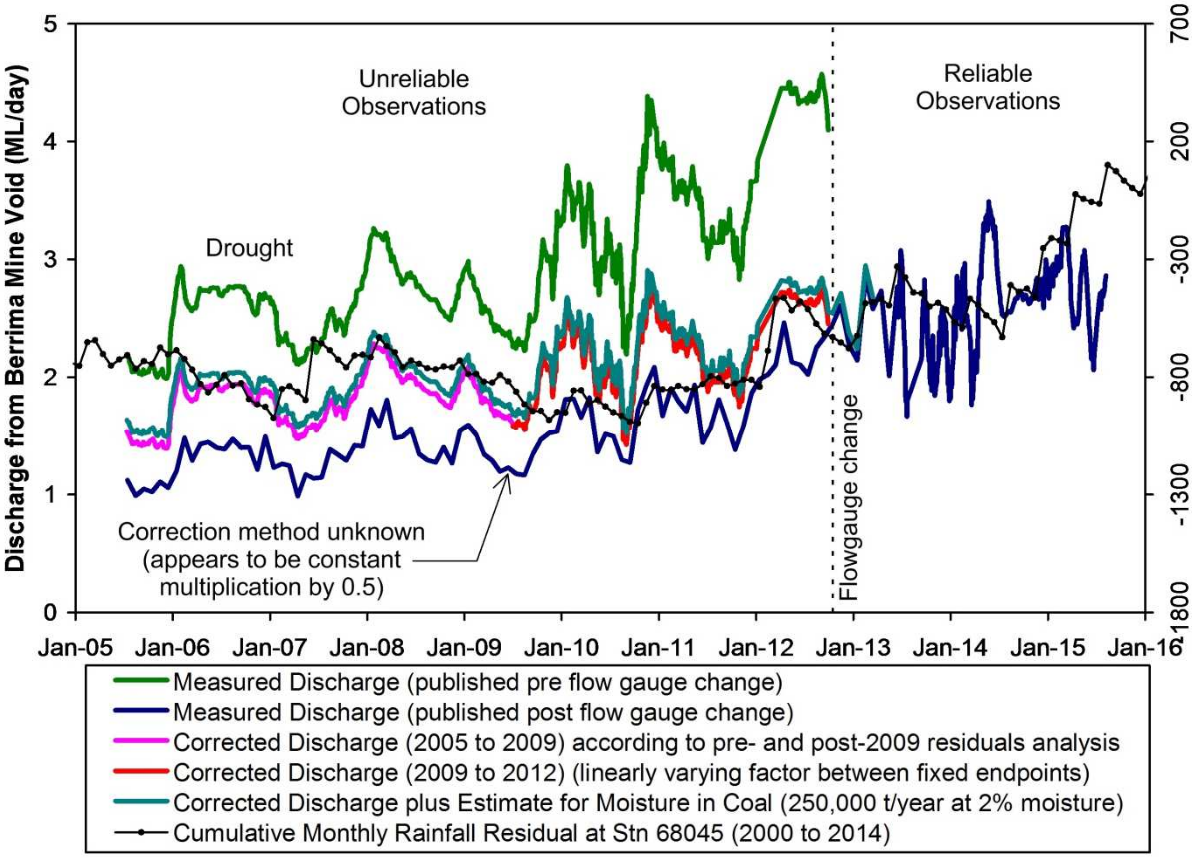



**Figure 7.1. Measured discharge from the Berrima mine.**

Observations take no account of changes in void storage or evaporation, however it is understood that in the last few years the void was kept virtually empty, and changes in the small underground sump storages are considered to negligibly affect average monthly flow volumes. Also, the void is not known to be artificially ventilated. The majority of the inflow to the void is discharged to the river, with the consumptions listed above accounting for about 2% (during mining) or 1% (post mining) of the total inflow.

Observations are considered reliable following the flow gauge change in October 2012. Observations prior to the change do not appear reliable. Pre-gauge-change observations published in 2014 appear to have been multiplied by 0.5 to obtain corrected observations. Uncorrected pre-gauge-change observations appear to begin increasing from 2009. Pre-gauge-change observations may also have been affected by drought conditions between 2005 and 2009.

Published corrected observations were assessed for any relationship with rainfall by correlating the departure of the rainfall and inflow patterns from their respective long-term trends. These departures are known as residuals and were calculated by first plotting the cumulative value of these variables over time, then fitting a polynomial trend line to the cumulative curves and finding the residuals via the difference between observations and the fitted polynomials.

Figure 7.2 shows discharge and rainfall residuals, and indicates the clear relationship between rainfall and inflow. The highest degree of correlation was for a 12-month lag between rainfall and inflow. The ratio of inflow to rainfall residuals prior to 2009 suggests the potentially applied reduction factor (50%), to obtain corrected observations, might be too large.

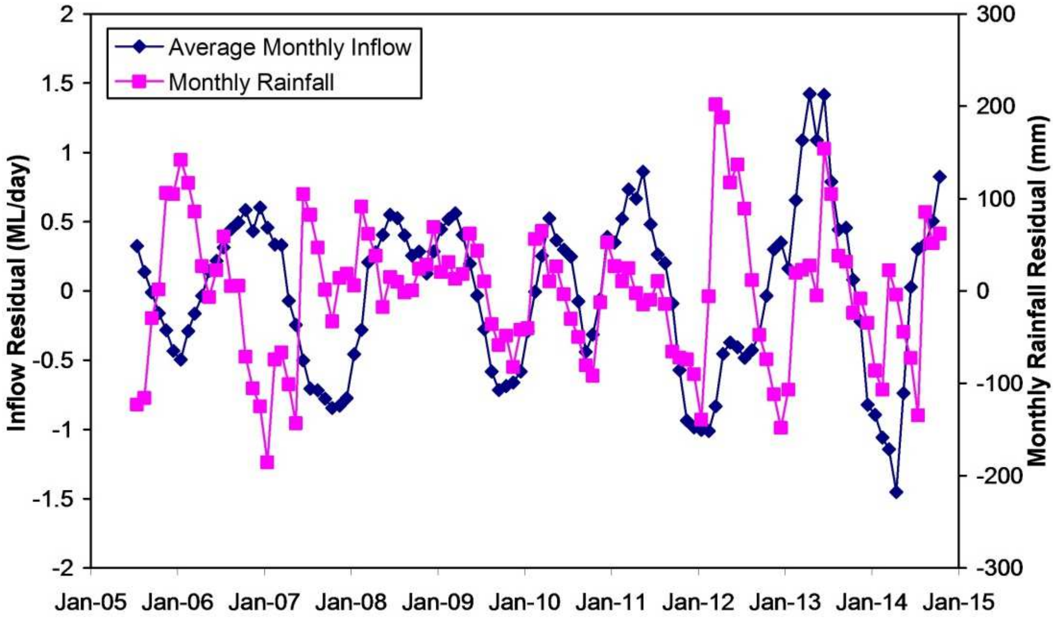



**Figure 7.2. Departures of rainfall and Berrima mine discharge from their long-term trends.**

Comparing pre- and post-2009 residuals ratios, the reduction to obtain corrected discharge is calculated to be a maximum of about 30%. This correction is based on residuals only, not magnitudes. Corrected discharge using a 30% reduction, for the period 2005 to 2009, is shown in Figure 7.1. Observations obtained after the gauge change are considered to be reliable. For observations made between 2009 and the gauge change, a correction has been applied comprising a linearly varying correction factor of 30% at 2009 to 41% at the gauge change (to obtain compliance in observations at that point); this dataset is also shown in Figure 7.1. The adopted observation dataset used for calibration therefore comprises the following three components:

- 2005 to mid-2009: Uncorrected observations reduced by 30%.
- Mid-2009 to October 2012: Reduction by 30% at mid-2009, increasing linearly to reduction by 41% at October 2012 (to obtain compliance in observations at that point).
- Post October 2012: Observations as published.

A nominal consumption of 0.1 ML/day is added to account for groundwater removed in mined coal (assumed to have ceased on 31 March 2013). The adopted dataset appears to accord more reasonably with the cumulative annual rainfall deficit than other datasets.

# 8. Groundwater character

Water quality monitoring has been undertaken at the Hume groundwater monitoring network (Parsons Brinckerhoff 2015). These data have been subjected to statistical analysis to assess groundwater character in the various hydrostratigraphic units. Table 4 lists statistics for these units, for electrical conductivity (EC) and sulphate.

**Table 4. Electrical conductivity and sulphate of groundwater from the Hume monitoring network.**

| Analyte | Hydrostratigraphic Unit | | | |
|---|---|---|---|---|
| | Basalt | Wianamatta Group | Hawkesbury Sandstone | Wongawilli Seam and Illawarra Coal Measures |
| Electrical Conductivity | | | | |
| Average (uS/cm) | 748 | 2477 | 295 | 392 |
| Standard Dev. (uS/cm) | 13 | 158 | 243 | 261 |
| Sulphate | | | | |
| Average (mg/L) | 64 | 80 | 7 | 17 |
| Standard Dev. (mg/L) | 27 | 9 | 9 | 26 |
| Sample Information | | | | |
| Number of Samples | 2 | 2 | 69 | 56 |
| Sampling Date Interval | Average interval 17 October 2011 to 23 May 2014 | | | |

In the Hume lease area, the Hawkesbury Sandstone (HAW) has the lowest average EC of the units, comparable to the Illawarra Coal Measures. EC of the Wianamatta group is more than 8 times larger than the HAW. This is also observed in the Sydney metropolitan area. Sulphate concentrations for the units follow similar proportions.

## 8.1. Stream flow and electrical conductivity

Concurrent streamflow and stream EC measurements are useful as an independent indicator of the flow range where groundwater seepage to the stream is a large proportion of the total flow.

Intermittent EC measurements for WaterNSW station E332 and concurrent daily flow measurements for the adjacent flow gauge (212272: Wingecarribee River at Berrima Weir) for the period 1991 to 2014 were correlated. Multiple EC readings taken on the same day were volume-averaged (where more frequent flow measurements were available), or time-averaged.

A strong inverse correlation is apparent when viewing flow and EC time series (see Figure 8.1). Figure 8.1 shows daily flow and EC correlated for two periods:

- 1991 to 2001 inclusive (weak regulation).
- 2002 to 2014 inclusive (strong regulation).

Stream regulation is conspicuous in the latter dataset, resulting mainly from the severe drought of the 2000s. Reservoir water has a large component of surface runoff and its EC will be lower than groundwater EC. Artificial discharges wash away high EC water at prevailing low flow, and replace it with lower EC water at moderate flows. In extreme cases, where streamflow ceases, a small artificial discharge reaching the gauge will have significantly lower EC than would be expected naturally.

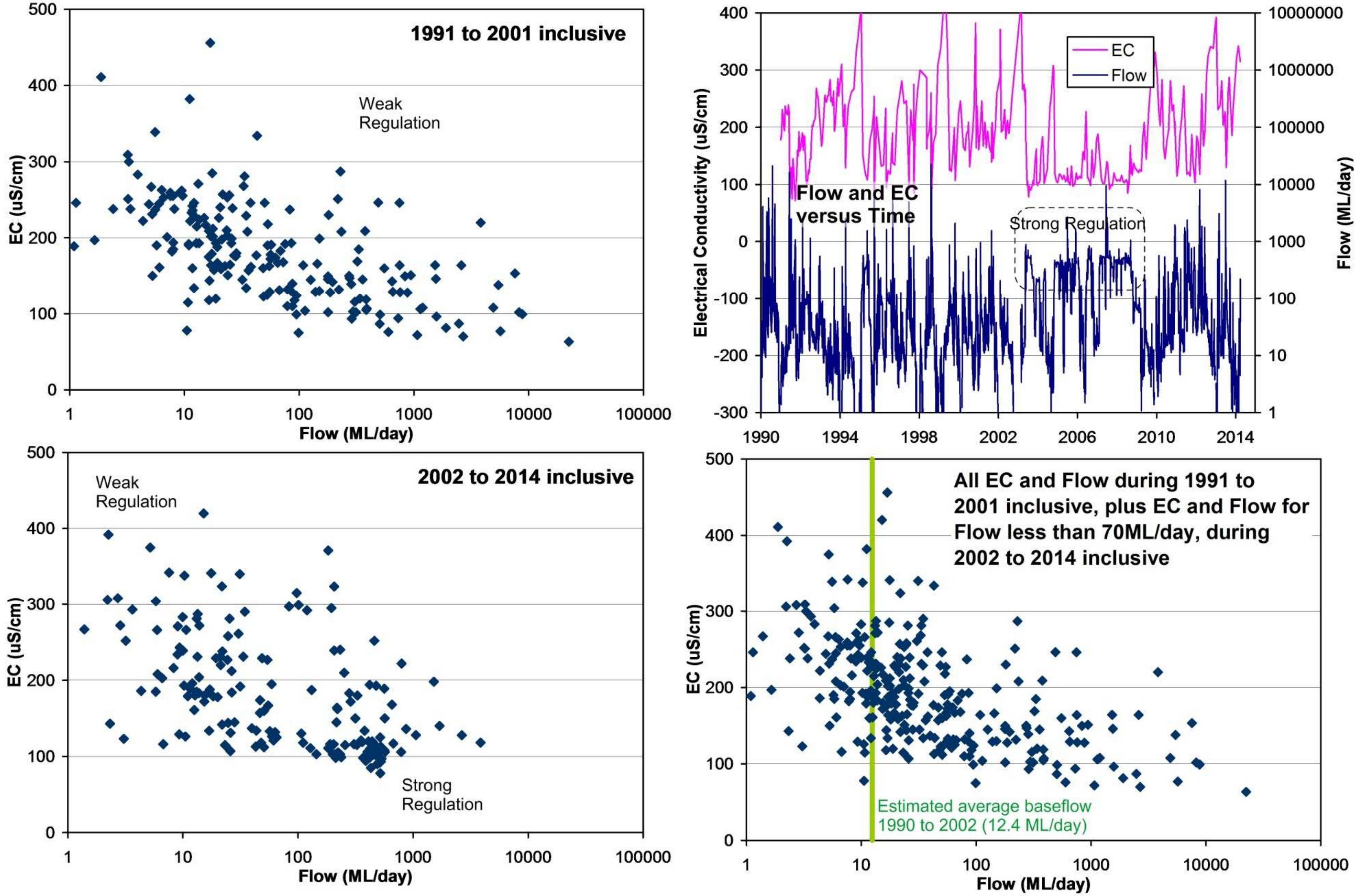



**Figure 8.1. Flow at stream gauge 212272 and measured stream EC. Anticlockwise from top right: comparison of time series; correlation for 1991 to 2001; correlation for 2002 to 2014; selected dataset estimated to have reduced impact from regulation.**

Considering only measurements occurring during weakly regulated times, a reasonable hyperbolic relationship is apparent between log[flow] and EC.

The baseflow at gauge 212272 calculated using the local minimum method (see above) is in reasonable agreement with the flow versus EC distribution, being located in the likely zone of major change of the distribution.

# 9. Groundwater use

## 9.1. Private bore use

Registered private water supply bores from the NSW State Government database are shown in Figure 9.1. A drawdown impact assessment for private water bores in the Hume area is reported in Volume 2. Over the mine lease, the majority of bores are reportedly deeper than 100 m, in an attempt to harness water supplies in the Hawkesbury Sandstone underneath reasonable thicknesses of WG. This trend continues north-eastwards, along the WG body (see Figure 9.1 and Drawing 1).

A search of private water bore access licences within 9 km of the Hume mine area centroid returned 83 known water access licences with a combined level of entitlement of 14.5 ML/day (5300 ML/year). It is understood that a significant number of unregistered bores also exists. No metering of usage is undertaken by regulatory agencies for the area, therefore actual usage from registered bores is not known.

The vast majority of private bores extract groundwater from the Hawkesbury Sandstone. A number of basic rights bores (registered for stock and domestic use) also exist; there is no volumetric entitlement associated with these bores. The total usage of basic rights bores within 9 km of the mine centroid is estimated to be about 2.6 ML/day. The total level of entitlement for the model area is likely to be in excess of 20 ML/day. Basic rights bores are estimated to have a combined usage of up to approximately 5 ML/day.

A search of surface water access licences in the regional area returned 173 licences with a combined entitlement of 26 ML/day (9495 ML/year). Table 5 lists the total entitlement by management area. Actual usage is estimated using published information for the catchment of gauge 212238 as a corollary, based on land use (and assuming 10% of intensive urban use areas are irrigated with water to maintain grass).

**Table 5. Surface water entitlement by management zone.**

| Management Zone | Total Entitlement (ML/year) |
|---|---|
| Bundanoon Creek | 1108 |
| Lower Wingecarribee River | 1135 |
| Lower Wollondilly River | 5411 |
| Medway Rivulet | 1027 |
| Nattai River | 124 |
| Upper Wingecarribee River | 690 |
| Total | 9495 |

Figure 9.2 shows the following:

- Monitoring piezometers where drawdown from pumping at proximal private bores is evident.
- Irrigation and intensive urban land uses according to government databases.

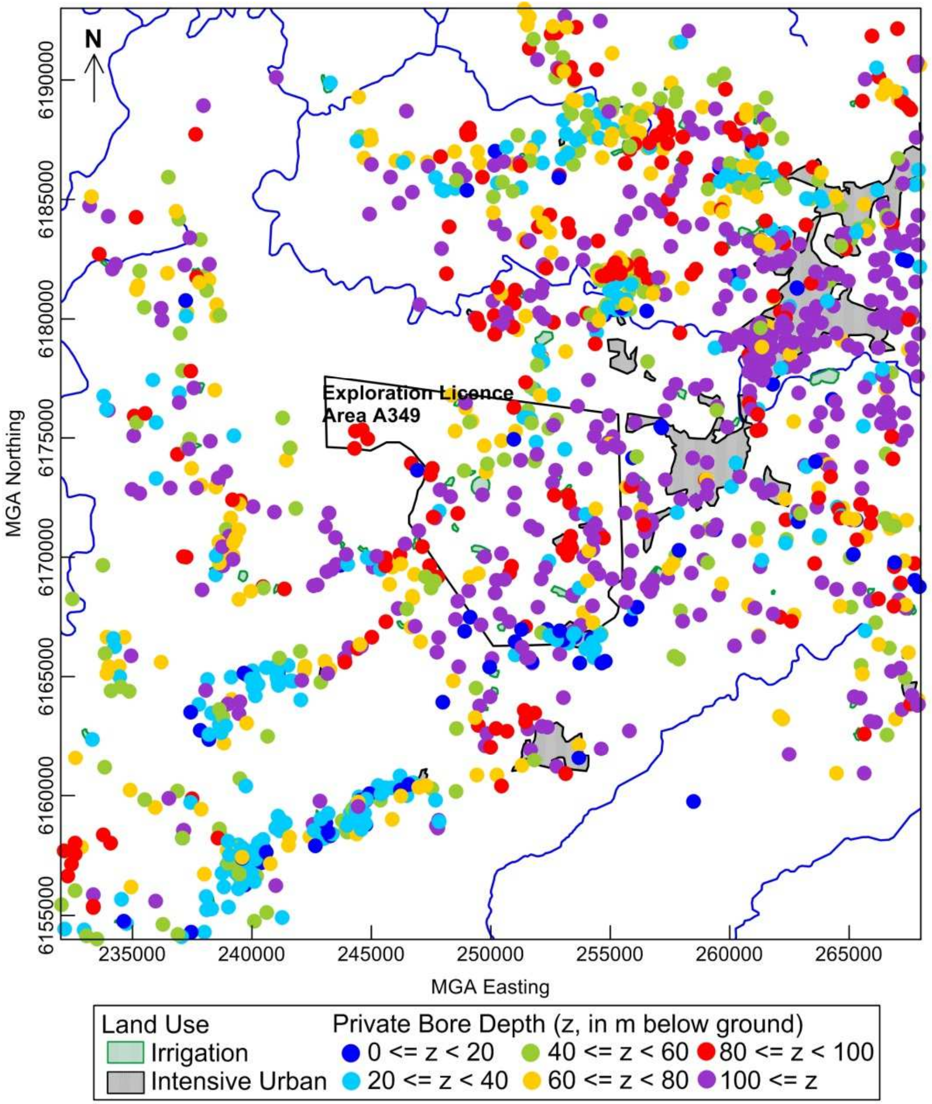



**Figure 9.1. Registered private water bore locations, according to completed depth.**

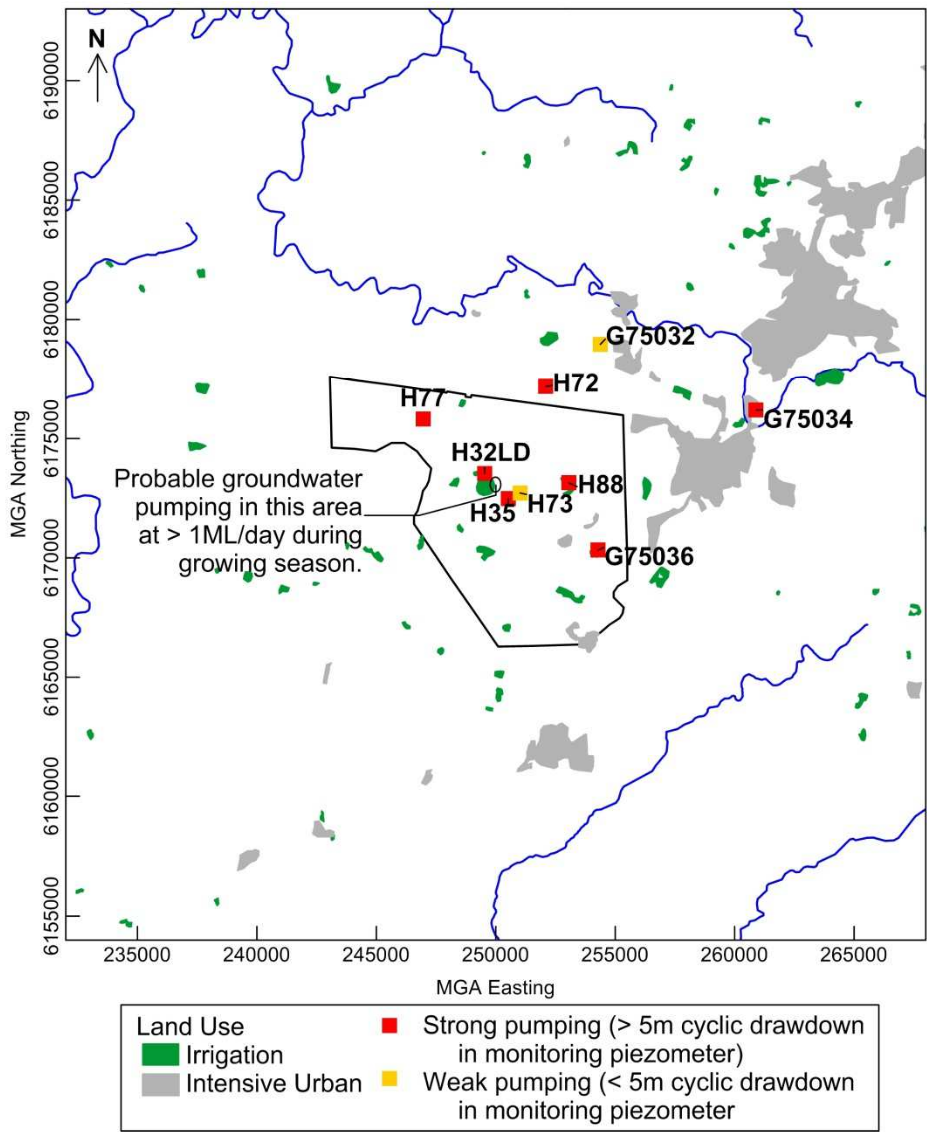



**Figure 9.2. Land use and interpreted private pumping effects in monitoring hydrographs.**

Drawdown seen at Hume monitoring piezometer locations H32, H35, and H73 between October 2013 and January 2014 is potentially related to pumping from the same private bore. At that location there is what appears to be an irrigated circular agricultural field of about 700 m diameter. Depending on the crop, and southern oscillation cycles, the additional water required (above rainfall) over the growing season, for this field, may be in excess of 1.0 ML/day. An approximate calculation using observed maximum drawdowns at the monitoring piezometers, an assumed transmissivity of 100 $m^2$/day, and a bore located on the northeast perimeter of the field, was undertaken using the Jacob equation, with results indicating a pumping rate in excess of 1.5 ML/day over the period October 2013 to January 2014.

# 10. Hydrogeological conceptual model

A hydrogeological conceptual model has been developed based on the data analysis conducted in the preceding sections. A large database of observations for Kh, hydraulic head, and fluxes provides a reliable platform for development of a numerical groundwater flow model for numerical simulation of the proposed Hume mining operations. In conjunction with a large number of baseflow estimates (shallow discharge of groundwater from the system), observed discharge from the Berrima mine (deep discharge of groundwater from the system) provides a vital observation dataset for large-scale reliable estimation of Kv down the media profile, an important parameter for simulation of deep discharges such as mine inflows, and vertical propagation of drawdown. Pumping tests undertaken by Hume at HU0098 and GW108194 provide useful independent estimates of large-scale Kv for sandstone, providing additional calibration targets.

## 10.1.Recharge

Recharge to the groundwater system occurs mainly by rainfall infiltration. Recharge may also occur from drainage channels wherever the stream stage is higher than the water table. Annual recharge to the water table is estimated to be about 2% of annual rainfall for the Hume area. Annual baseflow to drainage channels is estimated to be about 1.5% of rainfall from baseflow analysis.

## 10.2.Key hydraulic properties

Hydraulic conductivity and storativity decrease with depth. The K field for the Hume area has greater magnitudes than seen elsewhere in the Southern Coalfield, and is believed to result from significant tectonic disturbance and associated intrusive activity. For Kh measurements in the same depth interval, the Kh distribution is log-normal, with a standard deviation of between 0.5 and 0.8 decades around the geometric mean.

Vertical anisotropy is also believed to decrease with depth, given the greater proportion of matrix flow at depth. Kv/Kh is estimated to be around 0.01 at the depths monitored during the pumping tests.

## 10.3.Discharge

Groundwater discharge or consumption occurs as follows:

- Baseflow discharge to drainage channels.
- Evapotranspiration in the unsaturated zone, in zones with shallow water tables, at escarpments, and at forested areas.
- Groundwater pumping or discharge to mined voids.

Discharge to the Berrima and Loch Catherine mine voids ultimately reports to drainage channels so that this term forms part of the baseflow to drainage channels.

## 10.4.Approximate water balance

Table 6 lists an approximate water balance for the model area (say 800 $km^2$), to the nearest 5 ML/day, for average rainfall conditions. The estimate for reservoir leakage considers only the proportion that would be surface runoff into the reservoir. Baseflow to streams includes discharge from mine voids in the area.

**Table 6. Approximate water balance for the model area for average rainfall conditions.**

| IN (ML/day) | | OUT (ML/day) | |
|---|---|---|---|
| Rainfall Recharge (just over 2% of annual rainfall) | 45 | Baseflow to streams (about 1.5% of annual rainfall) | 30 |
| Leakage from Reservoirs and release from groundwater storage. | 5 | Groundwater pumping | 10 |
| | | Surface water pumping | 5 |
| | | Evapotranspiration | 5 |
| TOTAL | 50 | TOTAL | 50 |

# 10.5.Ground deformation

Hume will use the PF mining method which comprises a non-caving system where ground response is similar to conventional 1st workings mining methods. These methods were extensively practised prior to the advent of mechanisation but are rarely undertaken now. The PF method is the preferred mining method for the Hume project as it significantly minimises groundwater impacts compared to full extraction mining. Deformation (dilation) from 1st workings is limited to minor movement in the roof above roadways, extending upwards a maximum of about 3 m, depending on road width, horizontal stress magnitudes, roof rock strength, and rock bolting (or other support) strategy. Dilation typically extends about 2 m into the roof for common 1st workings mine plans. Extensional strains in the overburden are significantly smaller, and extend a shorter vertical distance, than for full extraction mining. Deformation in the dilated zone comprises enlargement of defect apertures and minor cracking. The dilated zone undergoes a marked increase in K, and is usually completely drained. Above the dilated zone, negligible deformation occurs and saturation is maintained.

Anecdotal information from the Berrima mine indicates the roof was extremely competent except in areas mined towards the end of the mine life (to the north), where a significant structural zone was encountered.

For the Hume project, intervening pillars are designed to remain intact and receive the overburden weight shed from over the roadways.

The dilated zone and coal seam are surrounded by a compressional zone (the pressure arch and abutments) (Booth 1986) within which K decreases. In numerical simulation, the compressional zone is described using a drain conductance. In a 1st workings operation where the workings are a network of headings, rooms, and pillars, a multicellular hydraulic head pattern will be induced in the lower strata around the mine openings (Booth 1986). Higher in the profile, the cellularity diminishes and hydraulic head contours flatten (Booth 1986), inducing more diffuse effects in the hydraulic head field. Figure 10.1 presents a typical hydraulic head field generated around square mine openings for a 1st workings operation (after Figure 3 of Booth 1986).

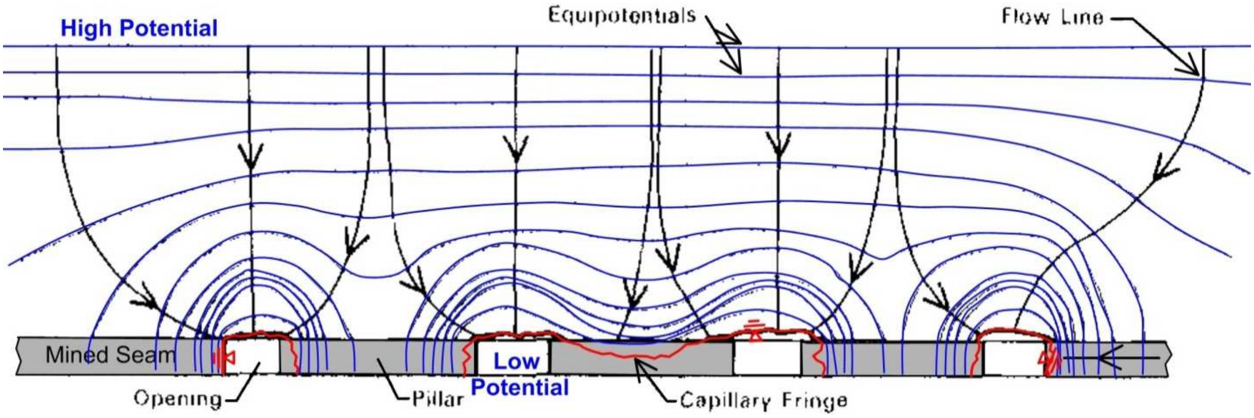



**Figure 10.1. A typical hydraulic head field generated around a 1st workings network of openings (after Booth 1986).**

## 10.5.1. Full extraction

Full extraction (longwalls or pillar removal) is not proposed at Hume, but was practiced at the Berrima mine (as pillar extraction). This method creates deformation which extends significantly higher into the overburden than for non-caving methods. Caving from full extraction results in the creation of two distinct zones above a panel (Tammetta 2013): the Collapsed Zone and the Disturbed Zone (Figure 10.2, after Tammetta 2016). The Collapsed Zone is severely disturbed and is completely drained of groundwater during caving, and is subsequently unable to maintain a positive pressure head. Groundwater flow is not laminar and Darcy's law is unlikely to be obeyed. The Disturbed Zone overlies the Collapsed Zone, and maintains positive groundwater pressure heads. Mine-induced desaturation in the Disturbed Zone occurs above the chain pillars. Results from Tammetta (2013) indicate the height of desaturation (H) for pillar extraction panels is between 50% and 60% of their longwall counterparts. This is caused by the differing patterns of caving between these types.

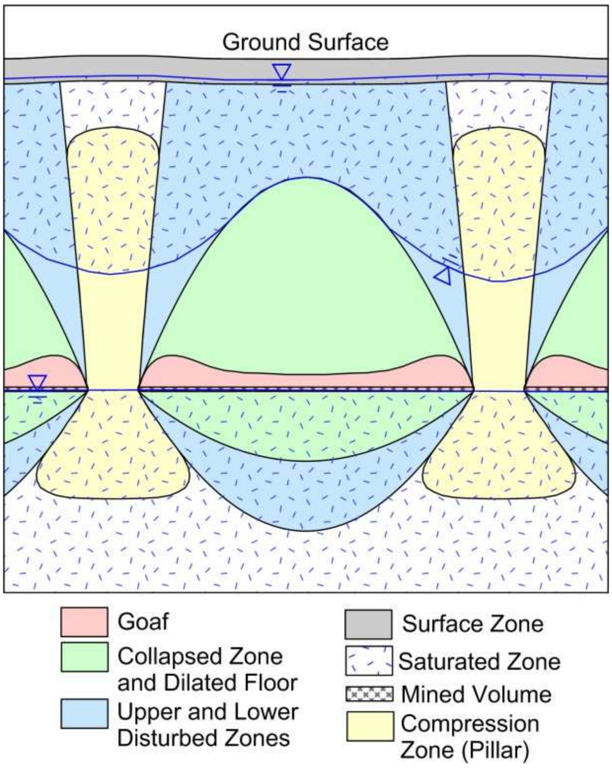



**Figure 10.2. Adopted conceptual model for desaturation above full extraction workings (after Tammetta 2016). The subsurface is shown as a cross-section normal to the panel long dimension.**

In the study area, the Berrima mine practiced full extraction (pillar extraction). H for mined pillar extraction panels is calculated using the equation in Tammetta (2013) for longwall panels, with pillar extraction H taken as 60% of longwall H for the same panel geometry.

# 10.6.Conceptual model

The elements of the conceptual model discussed above are presented pictorially in Figure 10.3, based on the hydraulic head cross section of Figure 6.1. It shows a schematic representation of the hydraulic head field that will be created by the PF mining method of the Hume Mine.

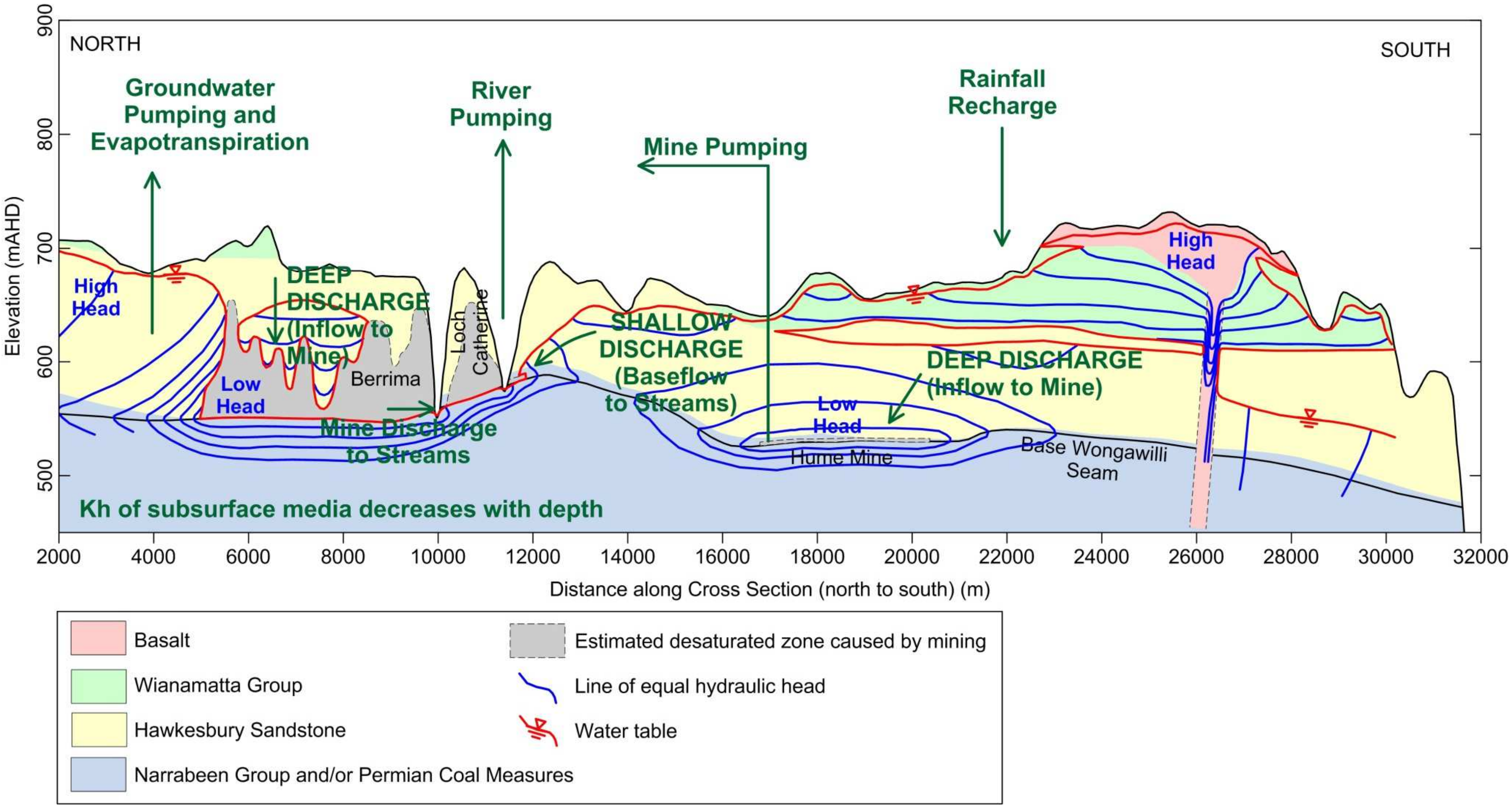



**Figure 10.3. Hydrogeological conceptual model.**

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# Important information about your **Coffey** Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

## Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

## Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

## Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

## Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

## Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

## Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they incorporate the report findings.

# Important information about your **Coffey** Report

### Data should not be separated from the report*

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

### Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment. Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

### Rely on Coffey for additional assistance

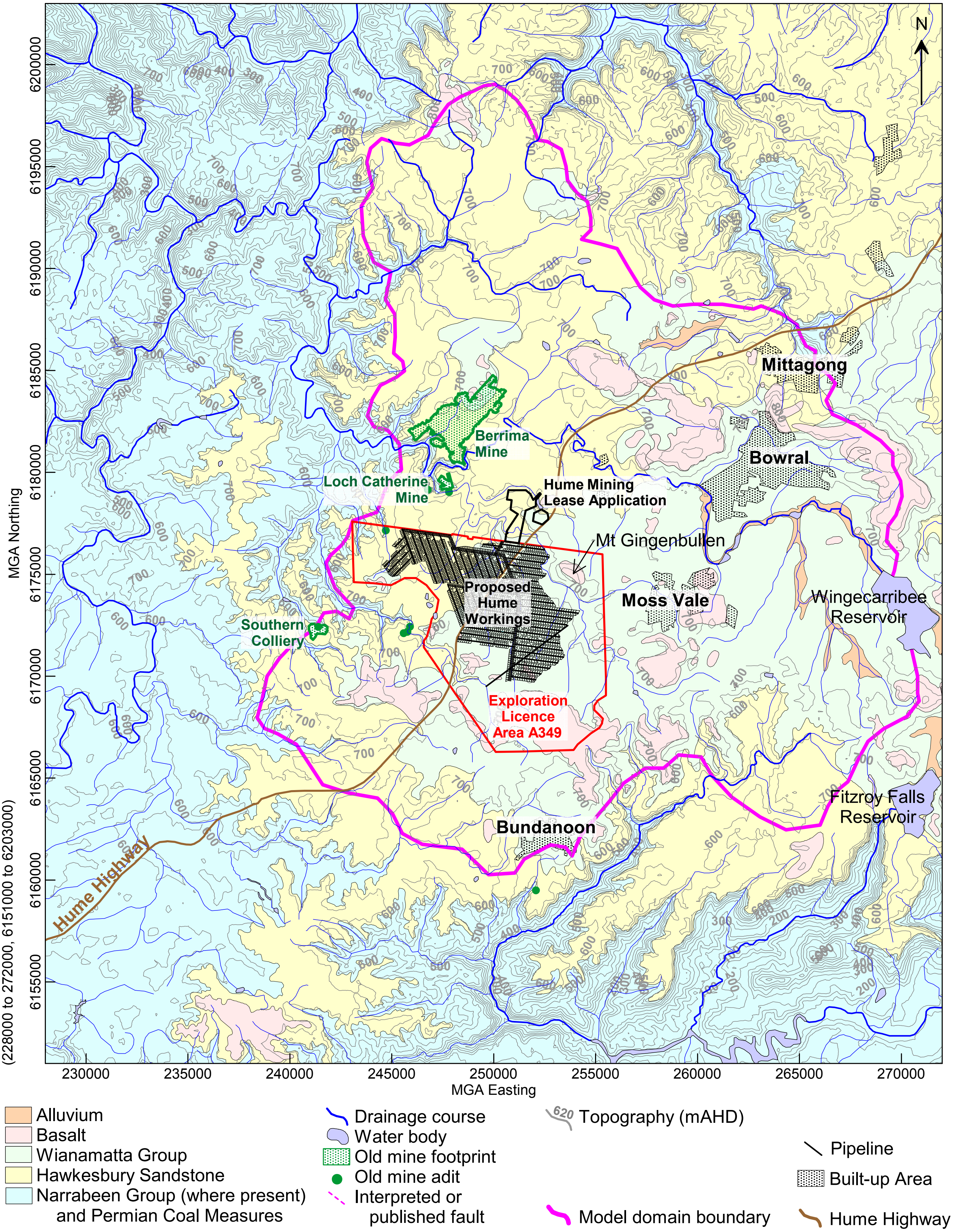
Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design towards construction,
speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

### Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.

# Drawings

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| drawn | PT | client: | Hume Coal Pty Limited |
| approved | RJB | project: | Hume Coal Project Groundwater Assessment |
| date | 30 Jun 2016 | | |
| scale | 1:250,000 | title: | **Regional Locality Plan** |
| original size | A4 | project no: GEOTLCOV25281AB | figure no: **Drawing 1** |

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# Appendix A - Baseflow Analysis

# 1. Baseflow Analysis

The aim of baseflow separation for a streamflow record is to distinguish the following two streamflow components (Eckhardt 2012):

- Baseflow (groundwater discharging into the stream).
- Quick flow (surface runoff and interflow).

The term “runoff” refers to quick flow, or the higher frequency component of the two components extracted from a streamflow series.

Two commonly used methods for baseflow separation are filtering and local minimum searches. For the Hume Coal project the local minimum search is adopted. Both methods are discussed below.

## 1.1. Filtering method

Eckhardt (2012) provides a useful summary of filtering techniques for baseflow separation. The following text is a summary from that paper.

In the past, many baseflow separation methods have been proposed, amongst them the two parameter recursive digital filter of Eckhardt (2005), which has since been applied in numerous studies, sometimes under the name of “Eckhardt filter”. The equation for the Eckhardt Filter defines a low-pass filter, and represents a whole class of filter algorithms which are based on the widely accepted linear storage model (Eckhardt 2005).

Examples are the algorithms of Chapman and Maxwell (1996) and Boughton (1993). The filter of Chapman and Maxwell (1996) is derived from the Eckhardt Filter by fixing one of the filtering parameters (BFImax) to 0.5 (where BFImax is the maximum value of the baseflow index [the long-term ratio of baseflow to total streamflow] that can be modelled by the algorithm). These methods use only a time-series of streamflow as the observational input.

Filter algorithms which rely more on physics have been presented by Furey and Gupta (2001) and Huyck et al. (2005). In the algorithm of Furey and Gupta (2001), time series of streamflow and precipitation are required, and the following four parameters have to be specified:

- d (the time delay between precipitation and groundwater recharge).
- c1 (the ratio of overland flow to precipitation).
- c3 (the ratio of groundwater recharge to precipitation).
- a (the recession constant).

In the algorithm of Huyck et al. (2005) bk is a function of bk−1, bk−d , bk−d−1, yk−d , and yk−d−1. Twelve parameters have to be specified: d, c1, c3, and nine other parameters describing hydraulic characteristics and the shape of the hydrostratigraphic unit. Required are not only time series of streamflow and precipitation, but also a digital elevation model and information on the drainable porosity of the soil.

Filtering methods are prone to the error where calculated baseflow can be greater than streamflow. This is because a single recession constant is (usually) used, which may perform poorly when confronted with several accumulated recession pulses. When trimming is employed (ensuring baseflow is never larger than total flow), they are useful for analysis of the annual variation in baseflow, when magnitudes are constrained by results from the local minimum method.

## 1.2. Local minimum method

In the local minimum method, baseflow is estimated by analysing the minima in streamflow time series when partitioned into N-day periods. Unlike filtering methods, the local minimum method cannot calculate baseflows that are greater than streamflow, and makes no assumptions about recession character. Based on experience, and the preferred use of the method by overseas agencies, this method is considered superior to filtering for extraction of baseflow magnitudes. This method was therefore adopted for the current work.

For the Hume Coal Project, the local minimum method is implemented using the program BFI and the procedure of Wahl and Wahl (1995). The BFI program (Wahl and Wahl 1995) is based on a set of procedures developed by the Institute of Hydrology (1980a, b) in which the streamflow record is partitioned into intervals of length N-days.

In the standard method (the one used in the current work), the minimum streamflow during each N-day interval is then identified and compared to adjacent minimums to determine turning points. If 90% of a given minimum (the turning point test factor, f) is less than both adjacent minimums, then that minimum is a turning point. The baseflow hydrograph is completed by connecting the turning points. The current version allows the user to vary the values of N and f to permit tuning the algorithm for different catchments or to match other baseflow separation methods (Wahl and Wahl 1995). In the USGS Toolbox implementation (Barlow et al 2015) (the one used in the current work), turning points are identified continuously throughout the entire period of record, which avoids the creation of artificial turning points at the end of each year. This modification also changes how the daily values are partitioned after a year is completed in which the number of days in the year is not an even multiple of N.

In the modified approach, parameter f is replaced by a daily recession index K′, and the turning-point test considers the exact number of days between turning-point candidates. Results obtained using the modified approach will usually be very similar to those obtained by the standard approach if $K' = f^{1/N}$.

For each year of data, the flow record is analysed for varying values of N. The output is then visually examined on a graph to find the inflection point in the baseflow response. Figure 1 shows the interpretation graph for Gauge 212272 (Wingecarribee River at Berrima). Excluding dam release years, the inflection point is taken as 6 days. 1995 is a conspicuous dam release year. The apparent baseflow versus N function for these years has a more significant convex-up form, at large N.

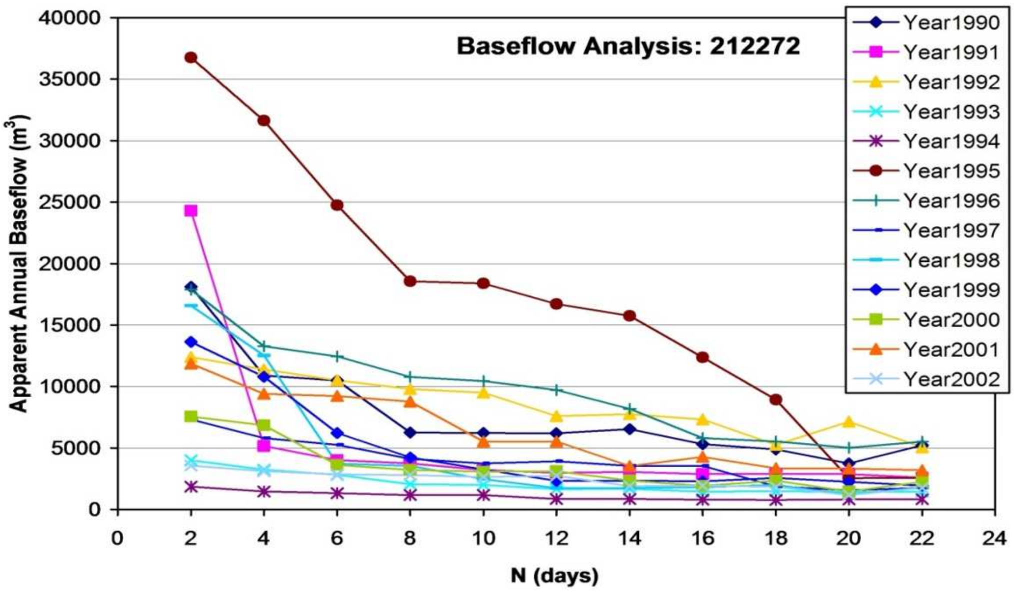



**Figure 1. Baseflow analysis for gauge 212272.**

The Nepean and Wingecarribee Rivers are regulated. Figure 2 shows the effect of controlled release from Wingecarribee Reservoir on the three Wingecarribee River Gauges (years with conspicuous dam releases are circled). Controlled dam releases do not affect the overall water balance of a drainage channel on a regional basis, except to afford increased consumption by evaporation from the increased surface area of a dam (which would otherwise not exist). However, over small periods and in proximity to such a dam (and depending on the release discharge versus time function), controlled releases can cause a component of surface runoff to masquerade as baseflow. The dam storage acts as a weak to moderate low-pass filter on the response of the drainage channel. However, this effect is attenuated with increasing distance downstream from the dam. Because of the complicating factors associated with dam releases, years with dam releases are removed from the analysis.

The baseflow analysis also incorporates removal of river flow through licensed river extraction, using the catchment for gauge 212238 as a guide, in conjunction with licensing information for the Hume area. The northern part of the 212238 catchment is similar to the central parts of the Wingecarribee River catchment, where Wianamatta Group soils are exploited for horticultural use (with a similar concentration of such enterprises). The analysis also accounts for evaporation from major dams (Wingecarribee Reservoir for gauges 212009, 212031, and 212272), and changes in dam storage.

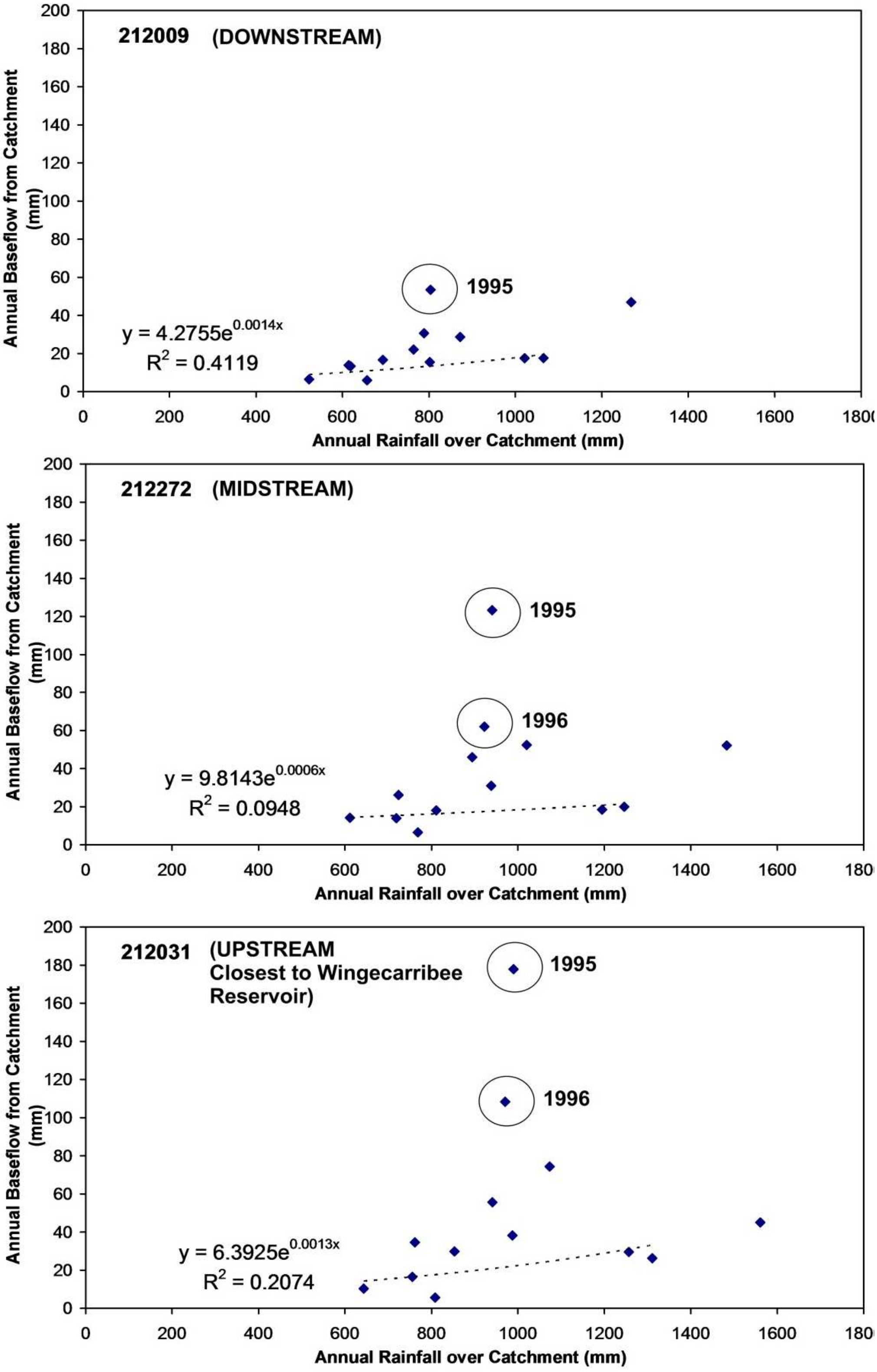
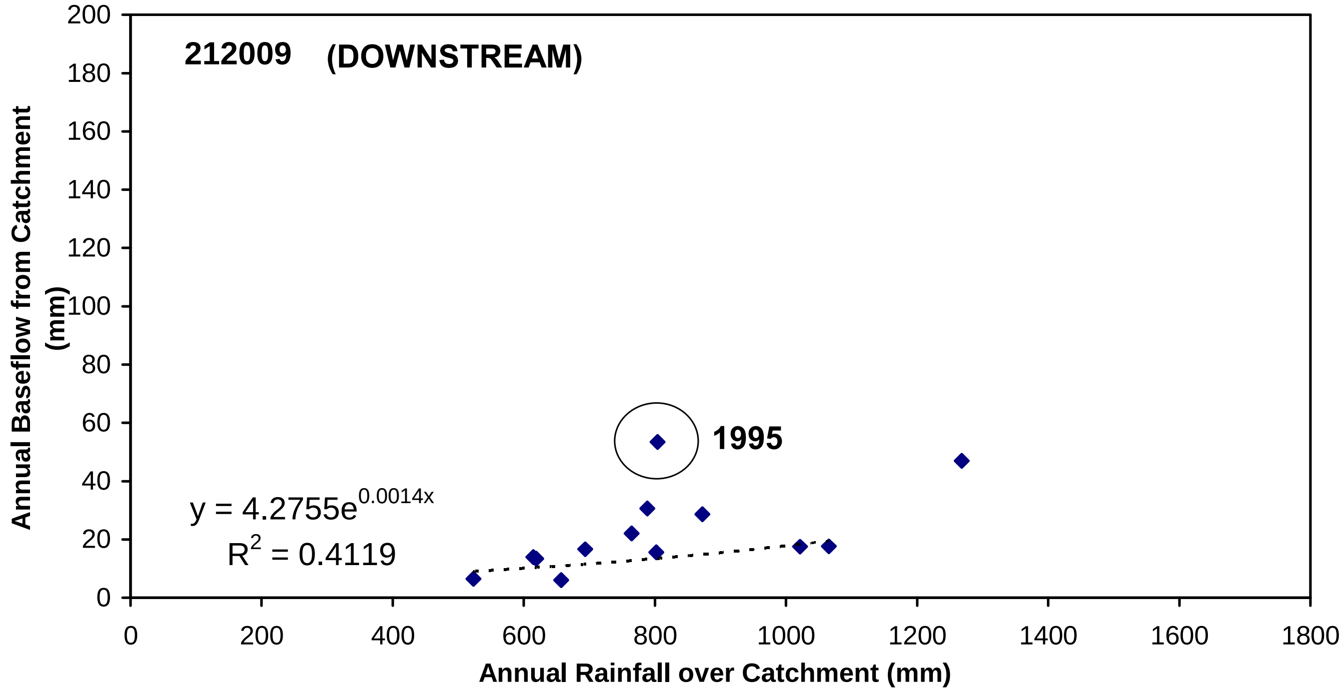
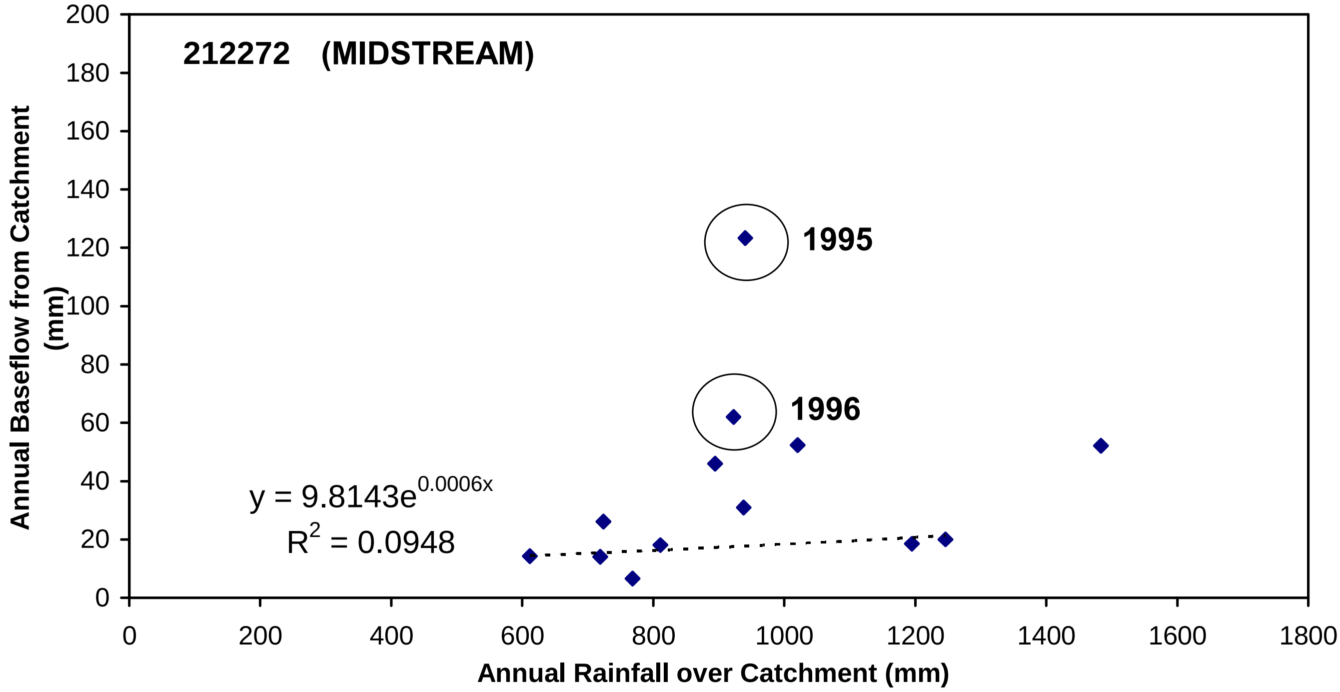


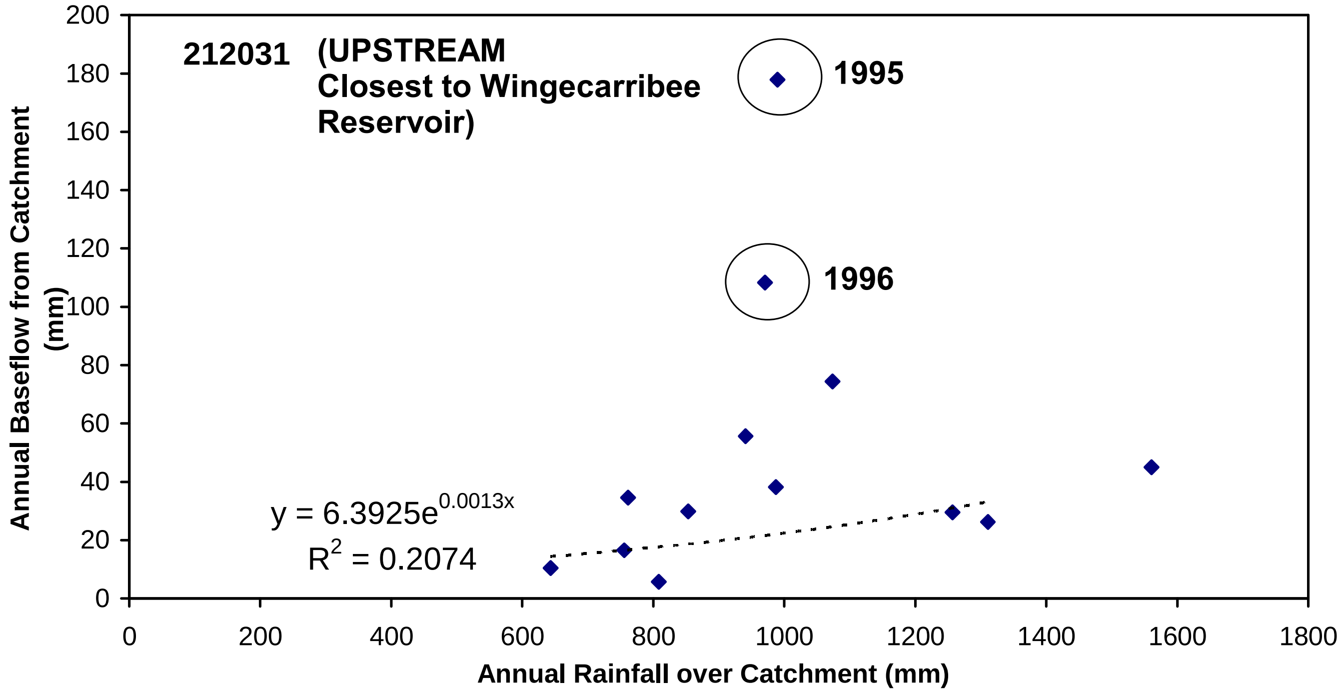

**Figure 2. Estimated annual baseflow for the three Wingecarribee River gauges.**

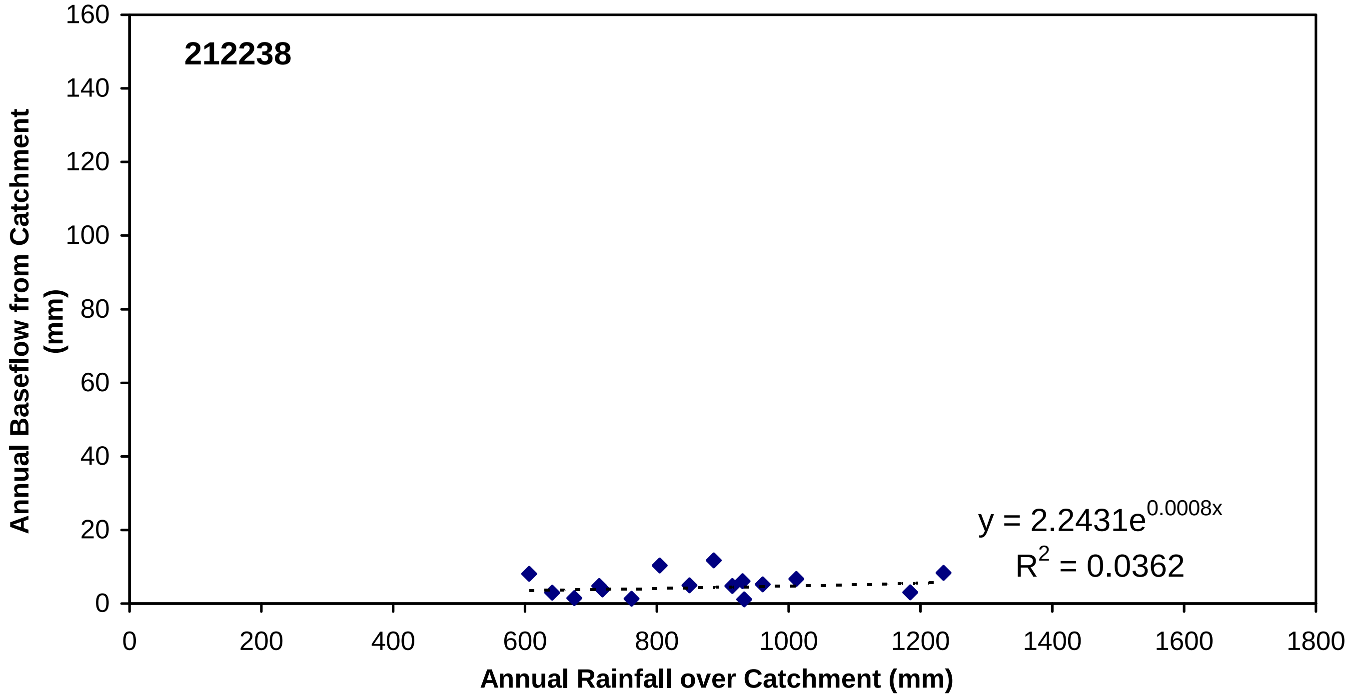
## 1.3. Results

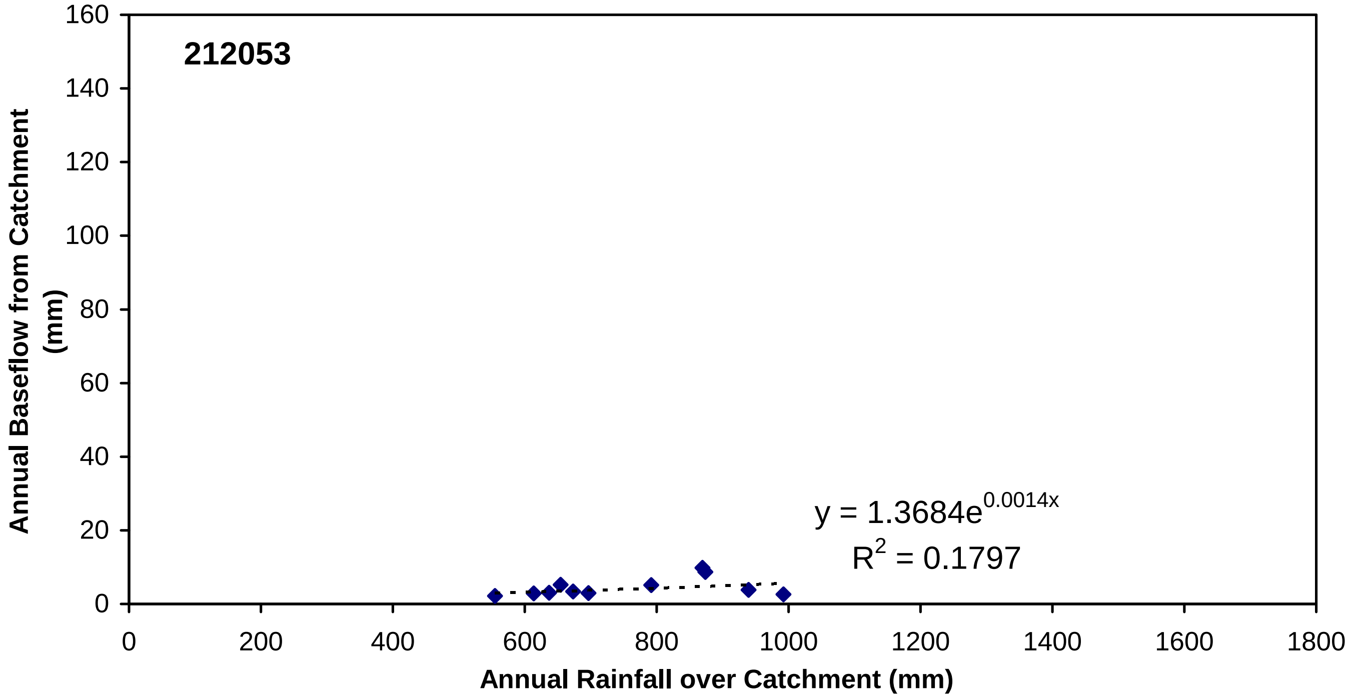
The following pages present additional results of the baseflow analysis undertaken for the Hume project, as charts of baseflow and surface runoff depths over the catchments. See the main report for a summary of the results.

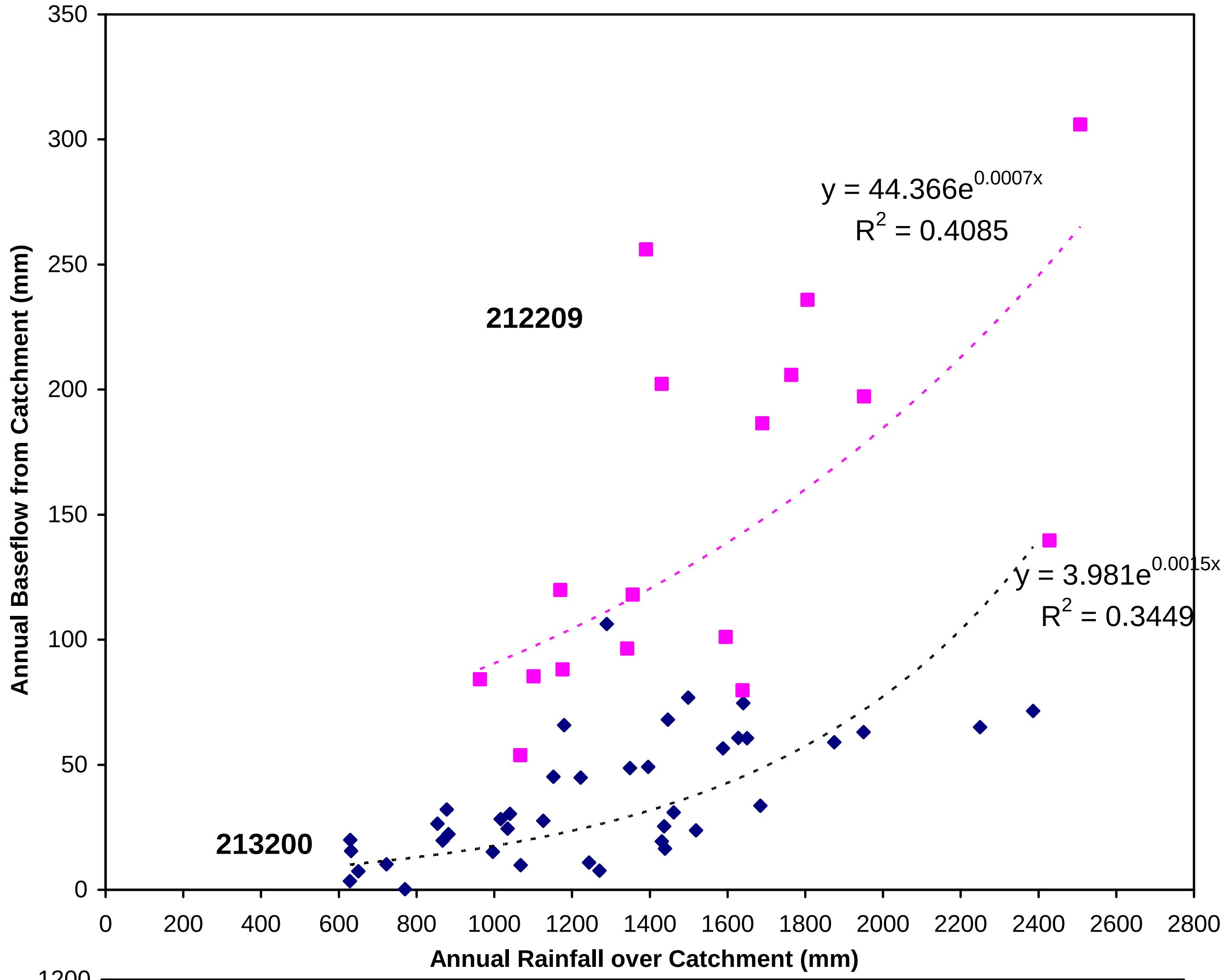

212009 (DOWNSTREAM)
1995
y = 4.2755e0.0014x
R2 = 0.4119
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400
1600
1800


212272 (MIDSTREAM)
1995
1996
y = 9.8143e0.0006x
R2 = 0.0948
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400
1600
1800

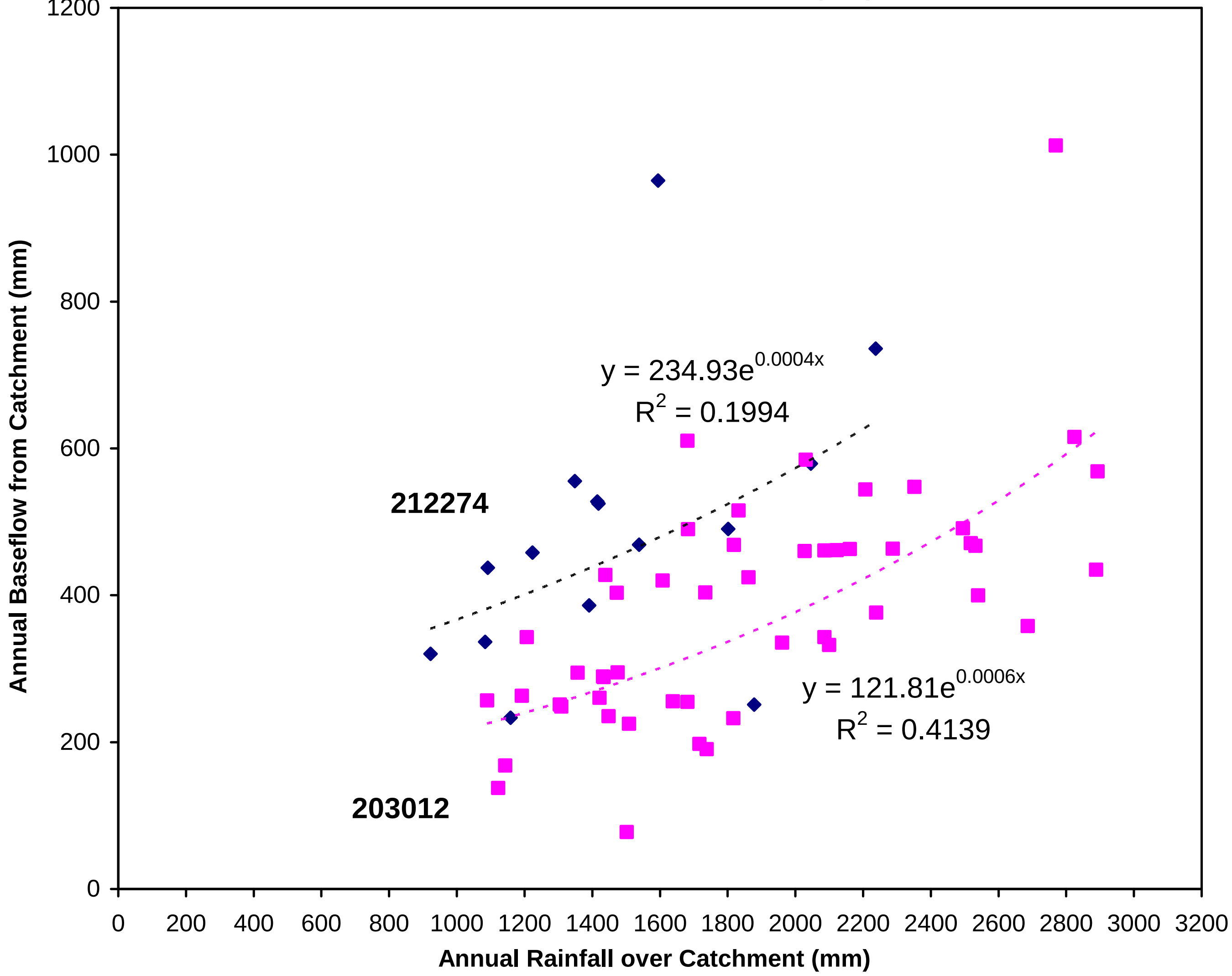

212031 (UPSTREAM Closest to Wingecarribee Reservoir)
1995
1996
y = 6.3925e0.0013x
R2 = 0.2074
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400
1600
1800


212238
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
y = 2.2431e^0.0008x
R2 = 0.0362
0
20
40
60
80
100
120
140
160
0
200
400
600
800
1000
1200
1400
1600
1800

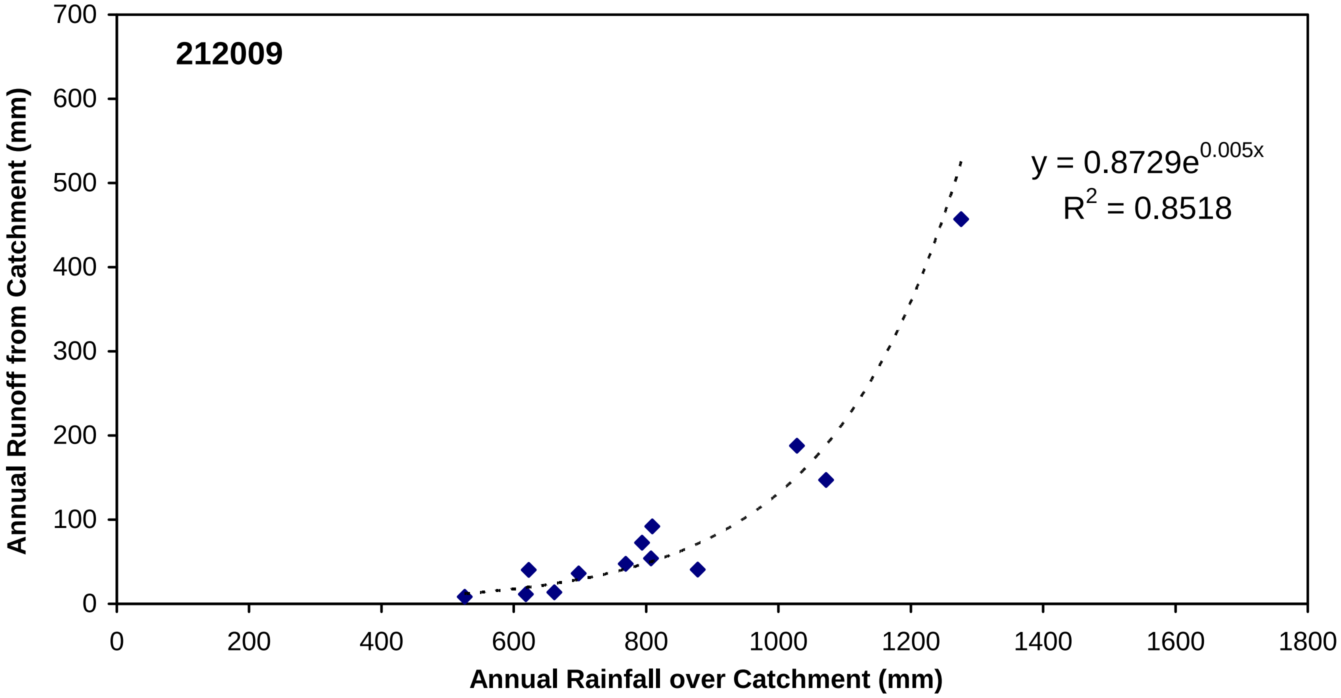

212053
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
y = 1.3684e^0.0014x
R2 = 0.1797
0
20
40
60
80
100
120
140
160
0
200
400
600
800
1000
1200
1400
1600
1800

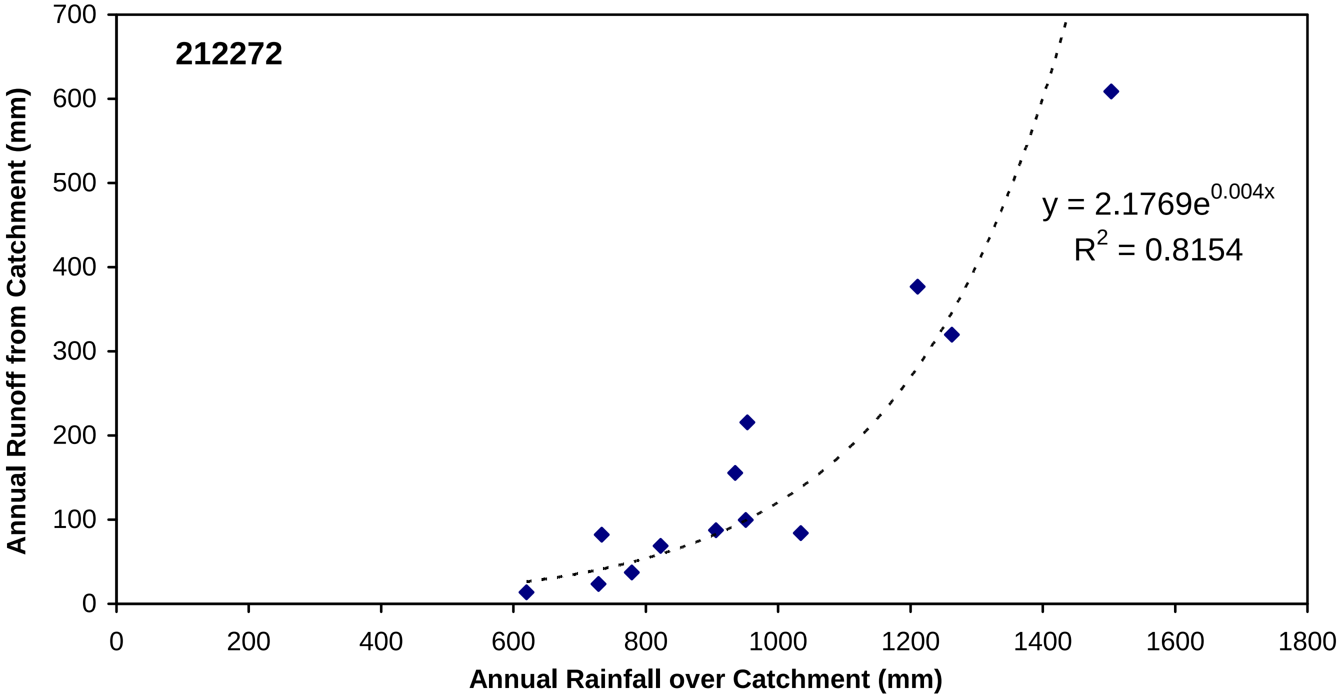


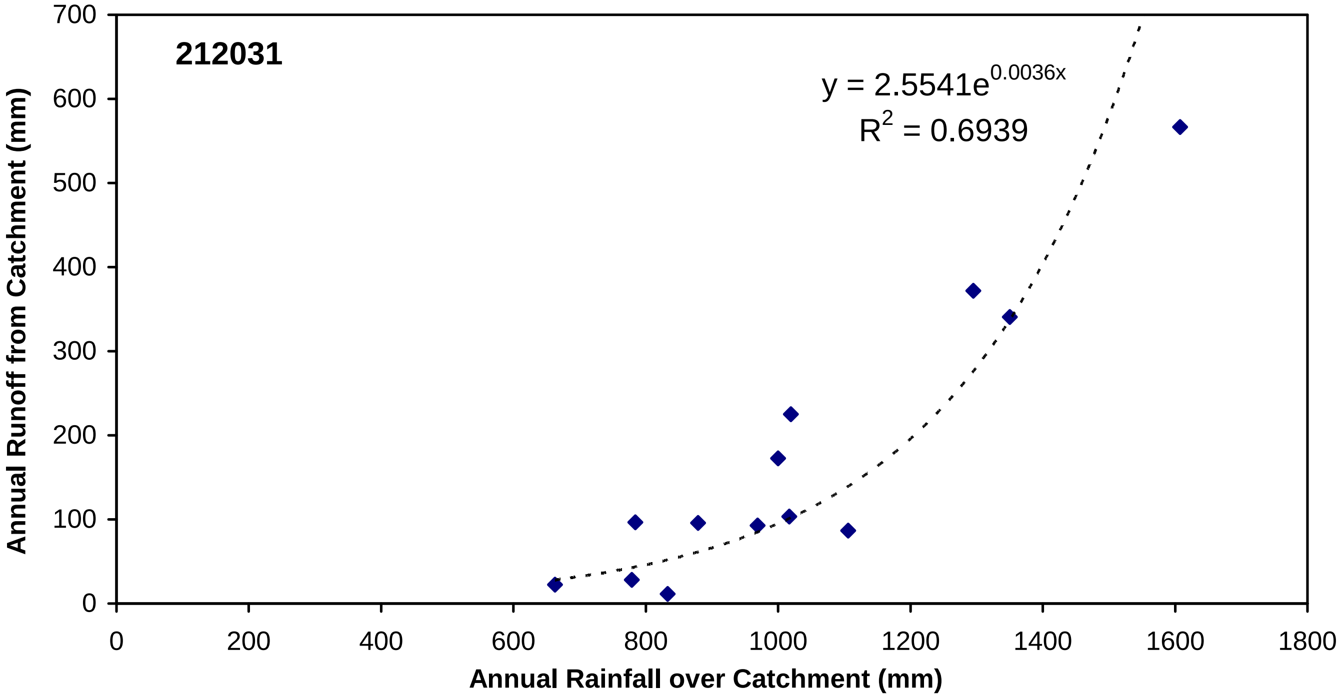
y = 44.366e^0.0007x
R2 = 0.4085
212209
y = 3.981e^0.0015x
R2 = 0.3449
213200
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
50
100
150
200
250
300
350
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800

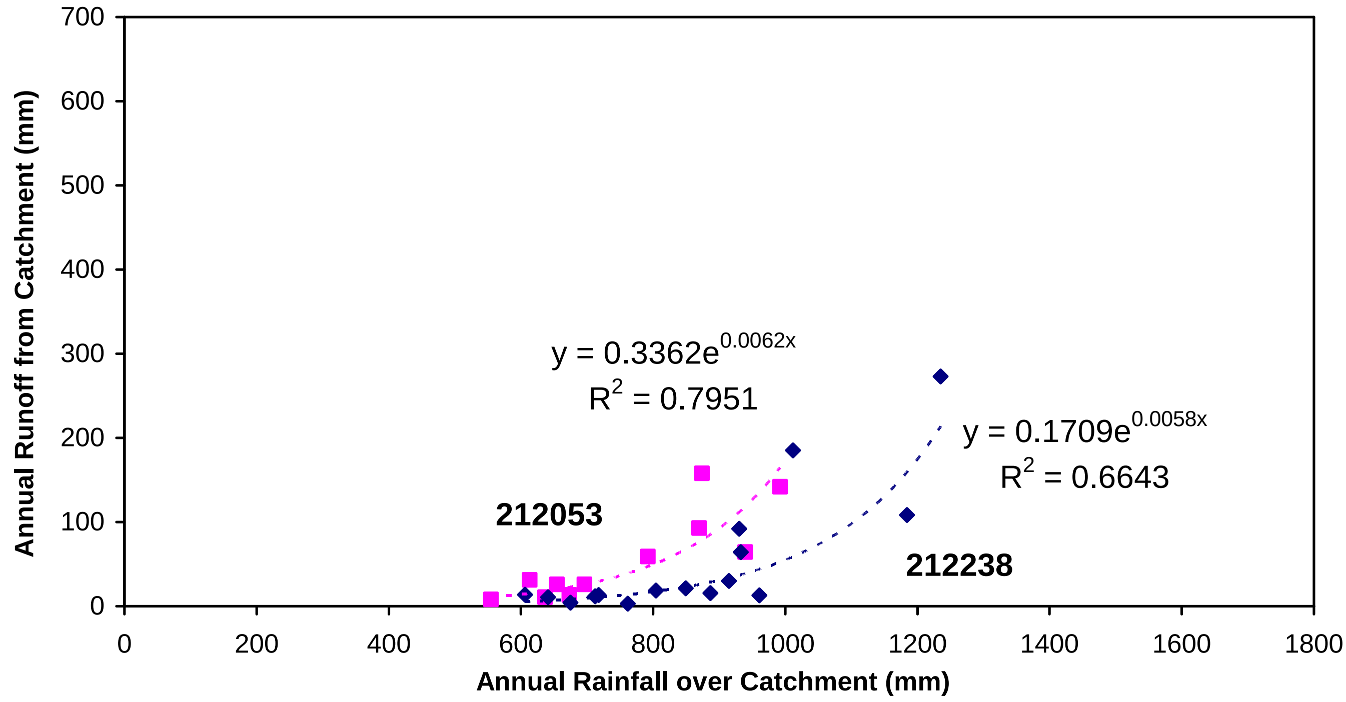



y = 234.93e^0.0004x
R2 = 0.1994
212274
y = 121.81e^0.0006x
R2 = 0.4139
203012
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
200
400
600
800
1000
1200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200

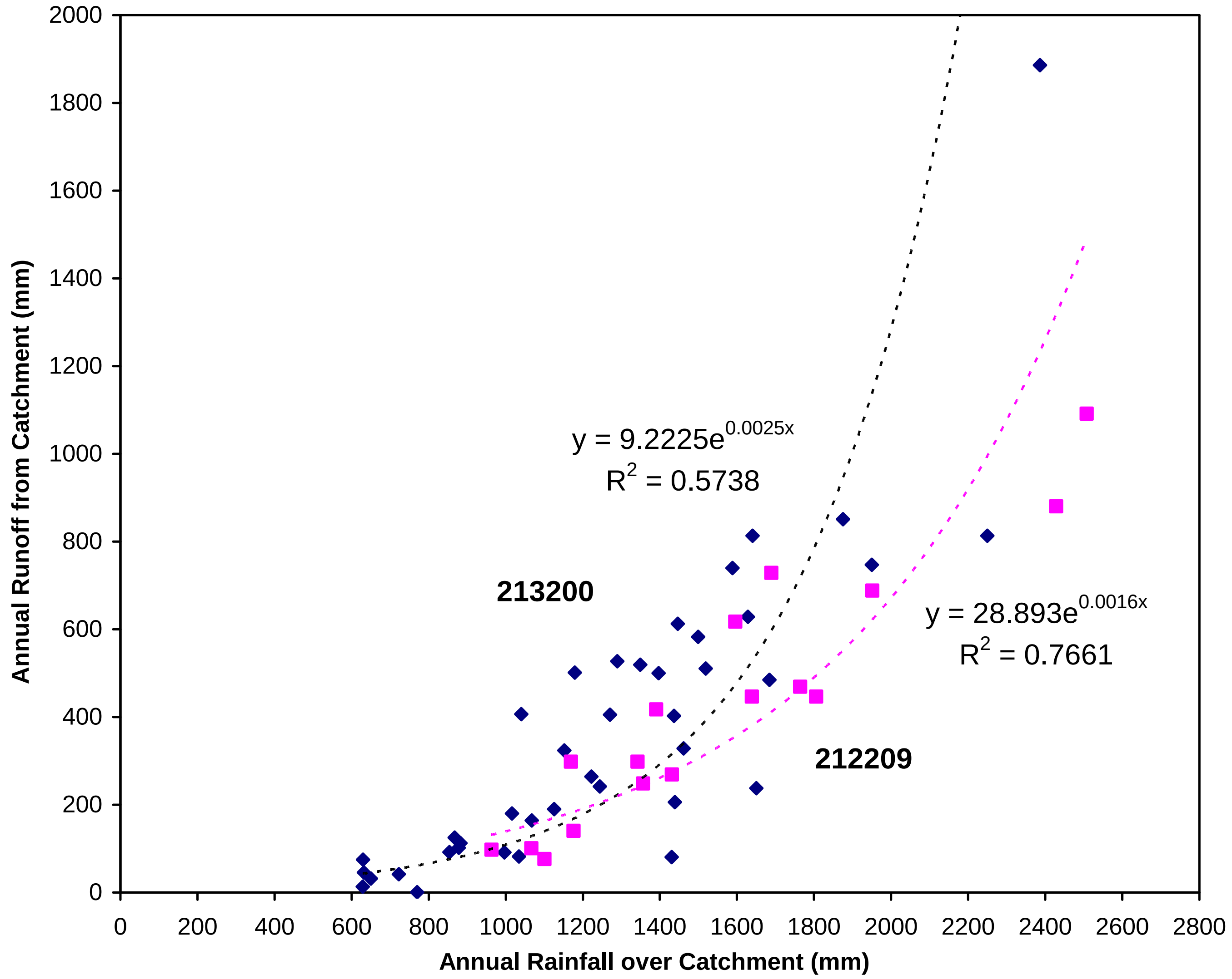

212009
y = 0.8729e^0.005x
R^2 = 0.8518
Annual Runoff from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600
1800


212272
y = 2.1769e^0.004x
R^2 = 0.8154
Annual Runoff from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600
1800

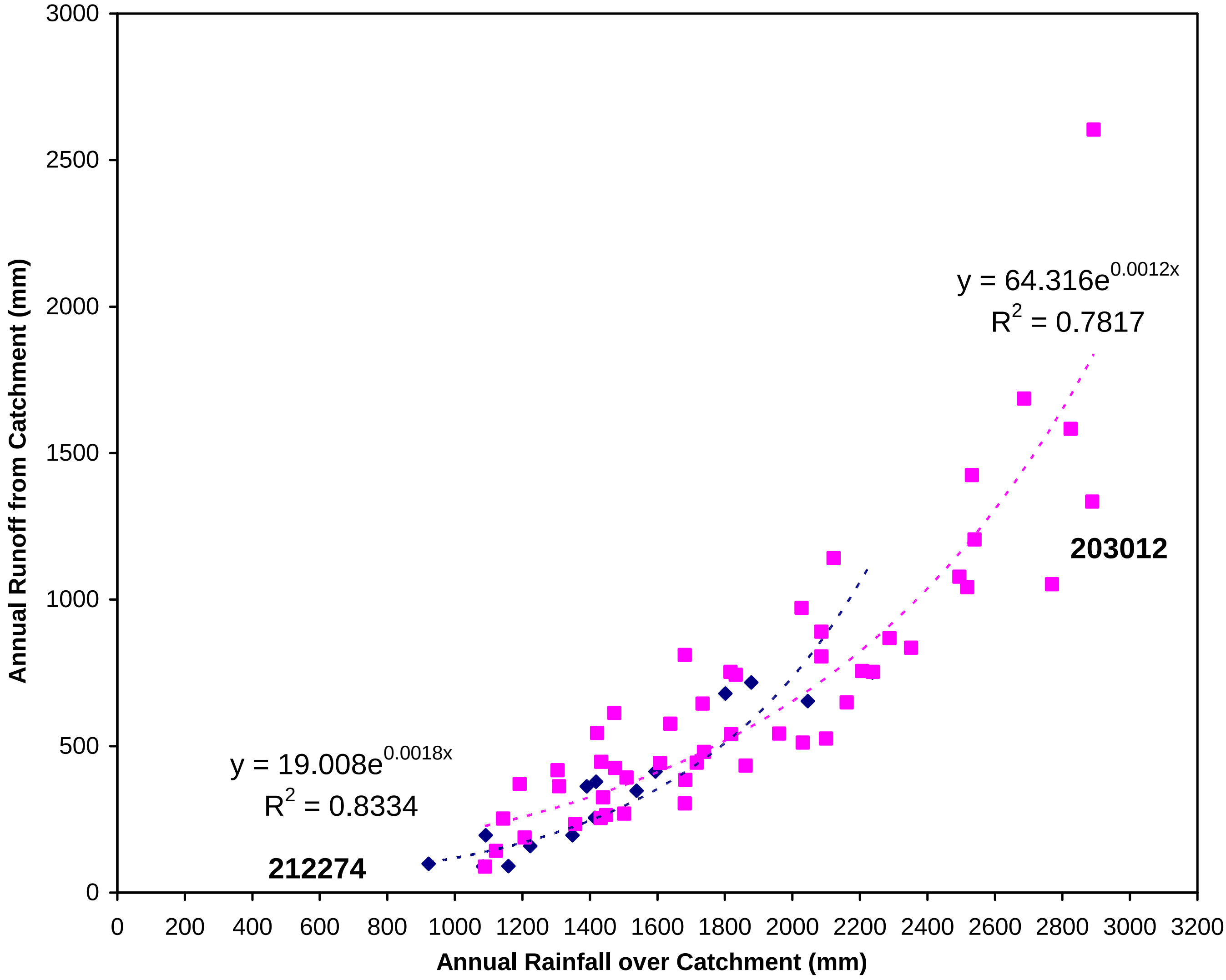

212031
y = 2.5541e^0.0036x
R^2 = 0.6939
Annual Runoff from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600
1800



Annual Runoff from Catchment (mm)
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
1600
1800
Annual Rainfall over Catchment (mm)
y = 0.3362e^0.0062x
R^2 = 0.7951
y = 0.1709e^0.0058x
R^2 = 0.6643
212053
212238

Annual Runoff from Catchment (mm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Annual Rainfall over Catchment (mm)
y = 9.2225e^0.0025x
R^2 = 0.5738
y = 28.893e^0.0016x
R^2 = 0.7661
213200
212209



Annual Runoff from Catchment (mm)
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
Annual Rainfall over Catchment (mm)
y = 64.316e^0.0012x
R^2 = 0.7817
203012
y = 19.008e^0.0018x
R^2 = 0.8334
212274

# Appendix B - Specific Capacity Analysis

Specific capacity (Sc) is the pumping rate divided by the drawdown in the pumped bore at a specified time. Most tests in the database were of 1 day duration, so the drawdown at 1 day is selected or estimated.

An analysis is undertaken using tests where temporal drawdown data are available. For each test, Sc is calculated at 1 day. Transmissivity is interpreted from temporal drawdown at the pumped bore using the Jacob method for confined conditions (Tj). The quantity (Tj – Sc)/Tj is then plotted against pumping rate and the relationship approximated with a trendline. This relationship is then used to convert Sc for tests where temporal drawdown is unavailable (the majority of government records).

The method assumes the bores in the database are approximately similar in hydraulic behaviour (well loss component), reasonable for the current database. It also assumes that dissimilarities in screened lithology are minor.

Table B1 lists the eight bores used to find a relationship, and Figure B1 shows the resulting relationship.

**Table B1. Bore tests used for specific capacity analysis.**

| Bore | Registration Number | Hole diameter (mm) | Casing diameter (mm) | Pumping Rate (L/s) | Test Duration (days) | Tj* (m2/day) | Interpretation | Specific Capacity for Pumping Time = 1 day | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Pumping Rate (m3 | Drawdow (m) | Sc (m2/day) | (Tj - Sc)/Tj |
| Belbin | GW106150 | 165 | 160 | 0.8 | 1 | 14 | AGE 2010 | 69 | 7.4 | 9 | 0.33 |
| Culpepper M | GW066593 | | | 0.3 | 0.07 | 56 | AGE 2010 | 26 | 0.58^ | 45 | 0.20 |
| H98 | | 165 | 160 | 5.2 | 1 | 103 | This study | 449 | 8.0 | 56 | 0.45 |
| Wongonbra | GW108194 | 200 | N/A | 20 | 7 | 243 | This study | 1728 | 34.8 | 50 | 0.80 |
| Summer Dell | GW105950 | 200 | N/A | 11.4 | 2 | 180 | This study (dat | 985 | 16.0 | 62 | 0.66 |
| Ravenswood | GW110236 | 200 | N/A | 9.2 | 1 | 56 | This study (dat | 795 | 20.5 | 39 | 0.31 |
| Wongonbra | GW108194 | 200 | N/A | 17.8 | 2 | 176 | This study (dat | 1538 | 14.6 | 105 | 0.40 |
| Wongonbra 2 | GW108195 | 200 | N/A | 8.3 | 1.2 | 20 | This study (dat | 717 | 47.0 | 15 | 0.24 |

* Tj = Jacob T

^ Estimated for pumping time of 1 day

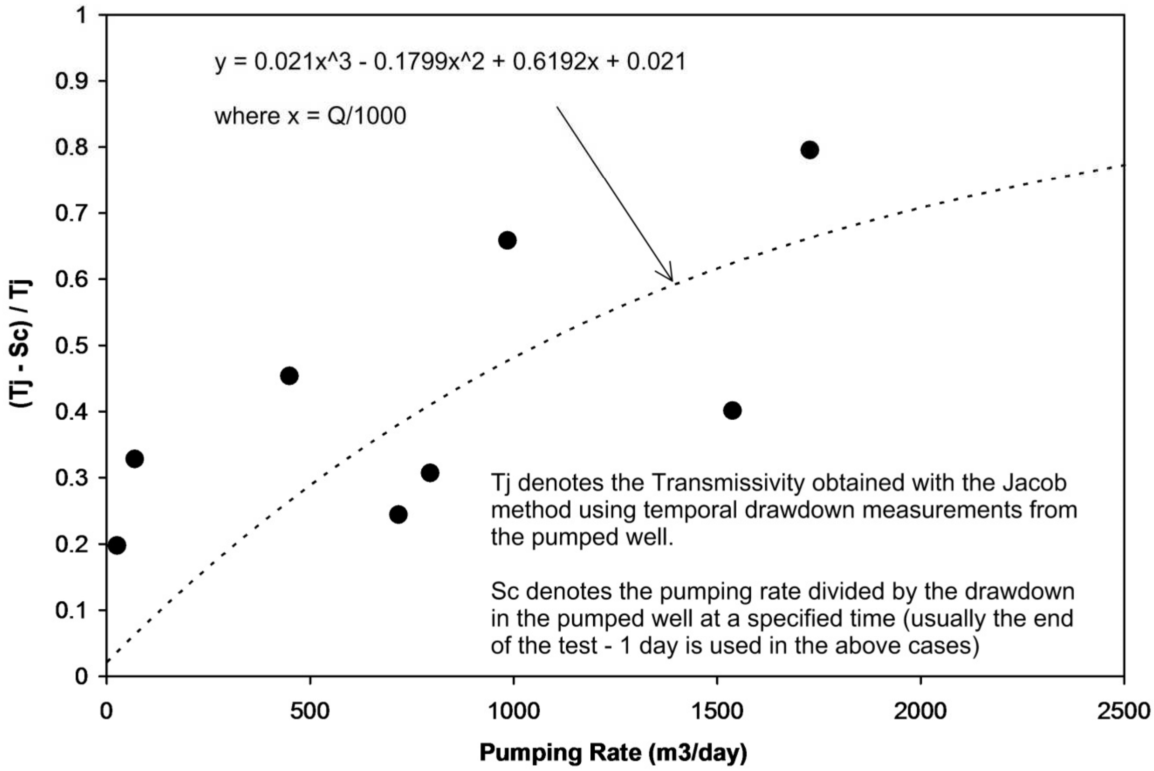



**Figure B1. Results of specific capacity analysis for tests in Table B1.**

# Appendix C - Additional Hydraulic Conductivity Analysis

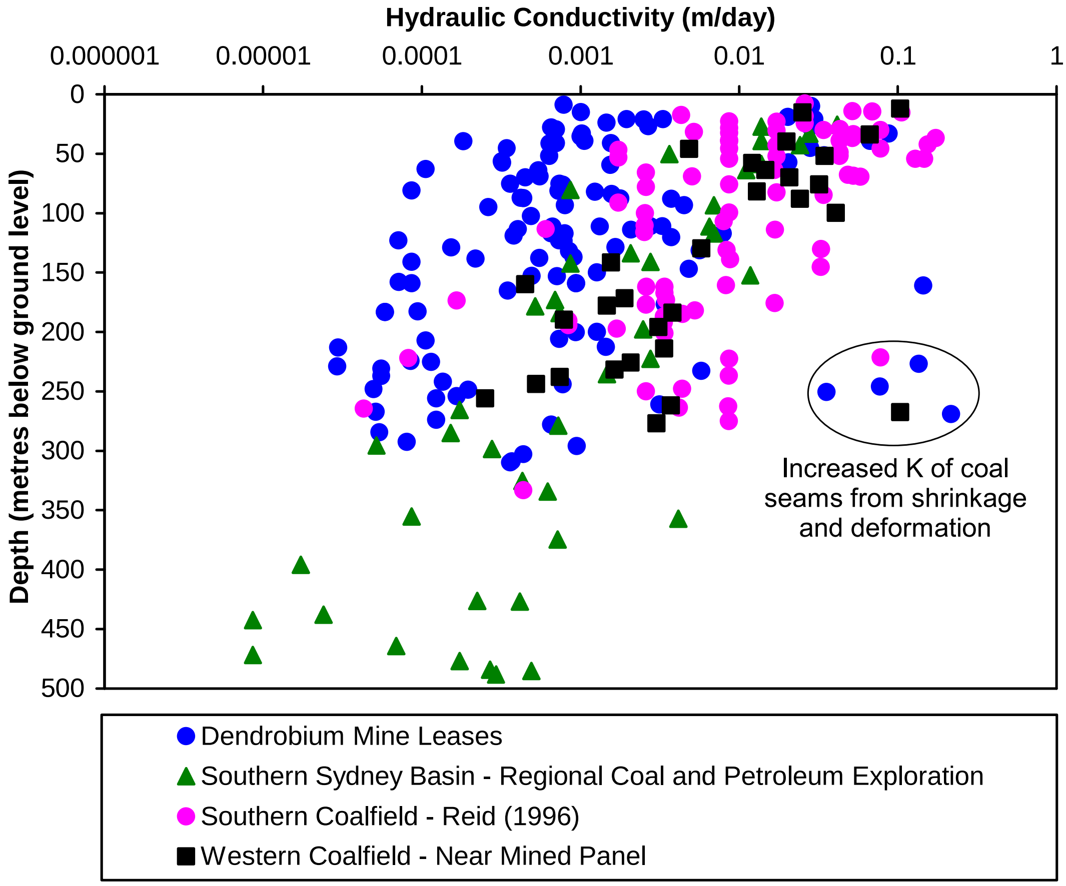
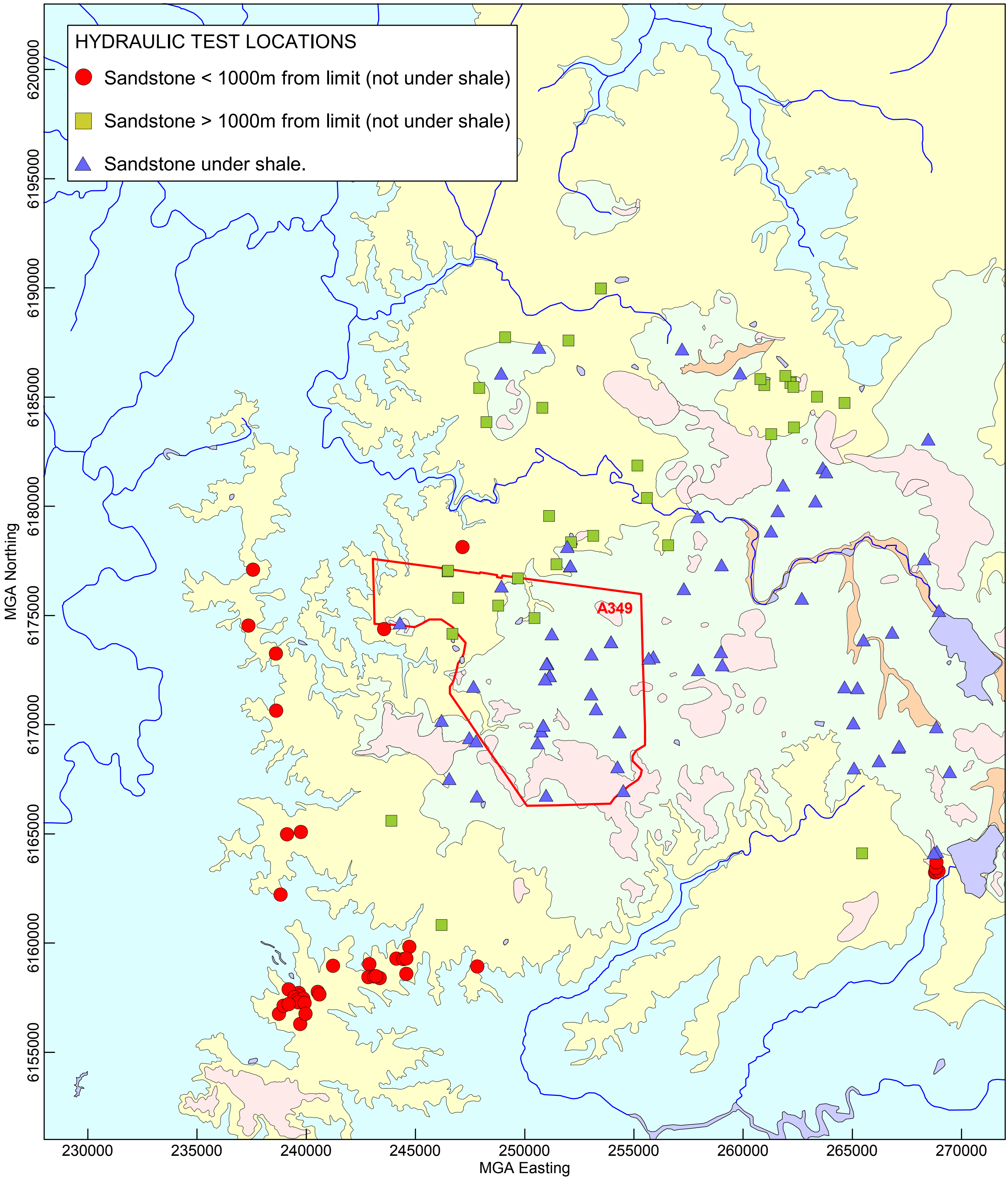
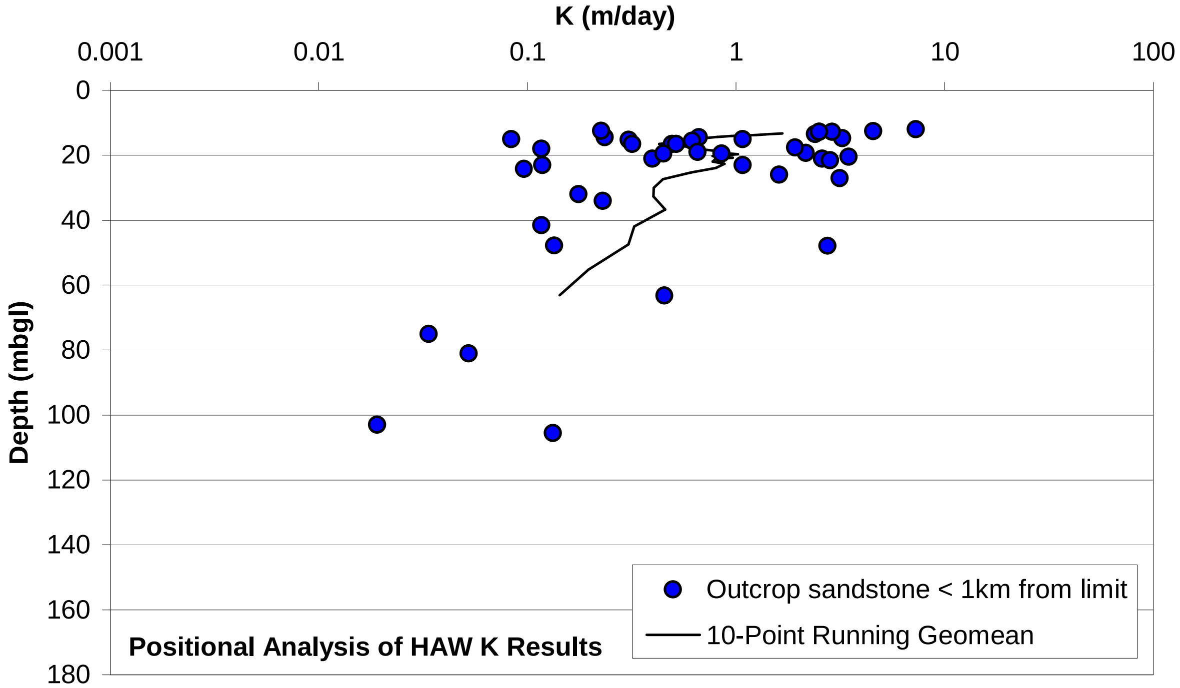
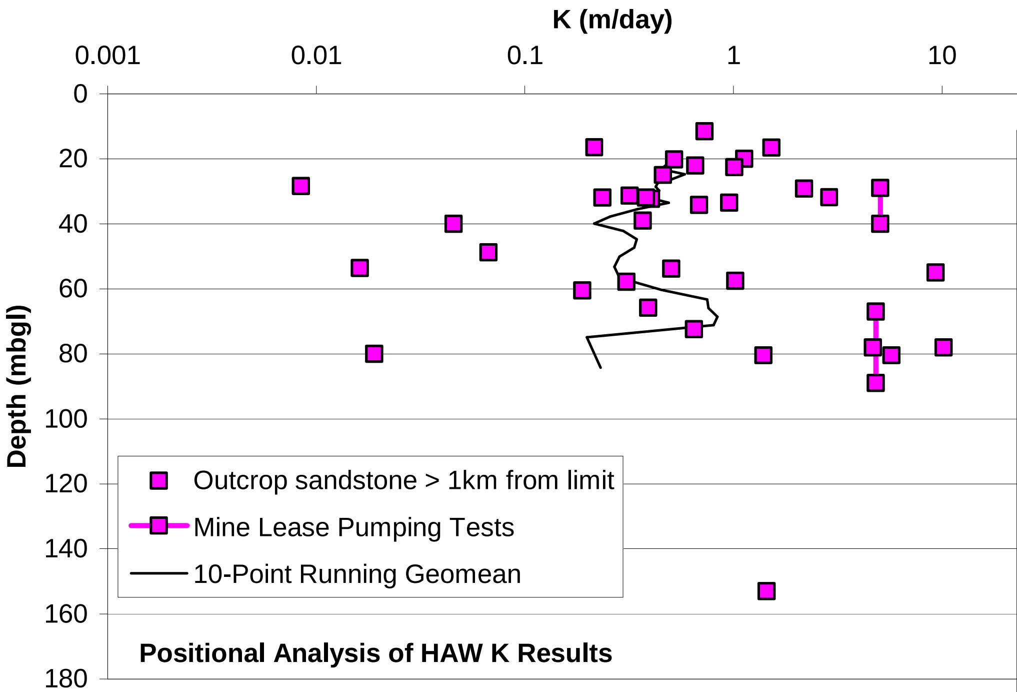



**Figure C1. Packer test K distributions for the regional Southern Coalfield and the Dendrobium mine leases, showing measurements obtained in coal seams proximal to full extraction workings, which have been deformed by shrinkage (from degassification) and stress reduction.**

**Figure C2. Positional analysis of Hawkesbury Sandstone K using specific capacities and pumping test results. The map shows the segregation of data into the following locations:**
*** Less than 1km from the lateral sandstone limit.**
*** Greater than 1km from the lateral sandstone limit, but not overlain by the Wianamatta Group.**
*** Wherever overlain by the Wianamatta Group.**
**Trends for Sandstone K versus depth for each grouping are shown overleaf.**





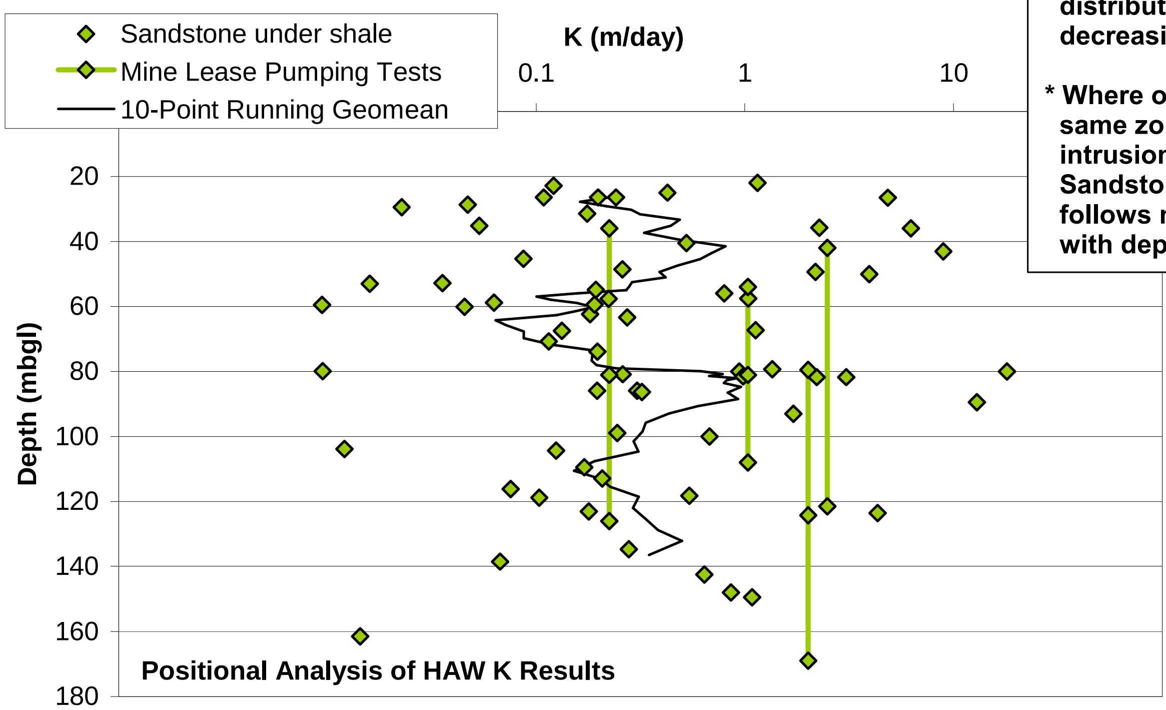
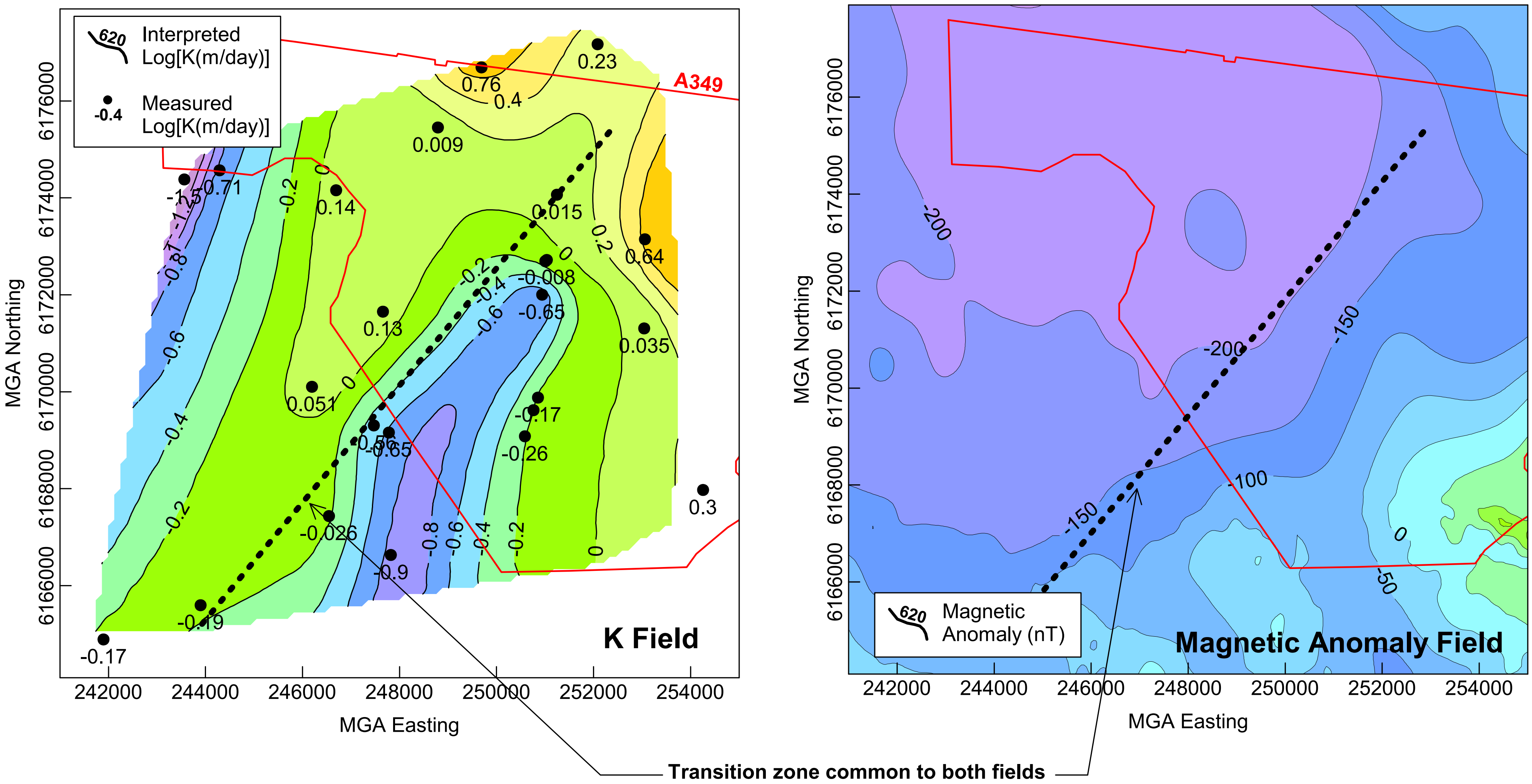




**Figure C3. The K versus depth distributions for Hawkesbury Sandstone, for the groupings shown in Figure C2. K is calculated from specific capacities and pumping tests. Interpretation of the results is as follows:**

- **At the extremities of the sandstone lateral extent (not overlain by WG), the K distribution follows a typical decreasing trend with depth.**
- **Further into the body of the Sandstone unit, but where no WG is present, the K distribution follows a weaker decreasing trend with depth.**
- **Where overlain by WG (the same zone as where igneous intrusions are present) the Sandstone K distribution follows no discernable trend with depth.**

**Figure C4. Comparison of the interpreted K distribution for Hawkesbury Sandstone (over a vertical interval between 14m to 44m above its base) to the regional magnetic anomaly.**



# Appendix D - Hydraulic Head Database

| Piezometer | Easting (MGA) | Northing (MGA) | RL Ground (mAHD) | RL Casing (mAHD) | Drilled Depth (mbgl) | Screen (mbgl) | | Sandpack (mbgl) | | Screened Stratum | L (m) | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | From | To | From | To | | | |
| **Hume Coal Monitoring** | | | | | | | | | | | | |
| H18A | 246696 | 6174166 | 691.74 | 691.67 | 108 | 96 | 99 | 95 | 99 | WW | 4 | |
| H18B | 246695 | 6174159 | 691.97 | 691.89 | 114 | 75 | 88 | 73 | 88 | HAW | 15 | |
| H19A | 243557 | 6174381 | 720.65 | 720.55 | 108 | 100 | 103 | 100 | 103 | WW | 3 | |
| H19B | 243562 | 6174379 | 720.46 | 720.36 | 88 | 70 | 81 | 69 | 81 | HAW | 12 | |
| H20A | 244258 | 6176920 | 703.25 | 703.18 | 80 | 71 | 77 | 71 | 77 | HAW | 6 | Dry (SWL < 626 mAHD) |
| H20B | 244255 | 6176930 | 703.67 | 703.59 | 114 | 80 | 86 | 78 | 86 | WW | 8 | |
| H23A | 250769 | 6169622 | 680.47 | 680.38 | 140 | 135 | 138 | 135 | 138 | WW | 3 | Decommissioned. |
| H23B | 250763 | 6169620 | 680.63 | 680.55 | 132 | 118 | 130 | 116 | 130 | HAW | 14 | Replaced by H142A to |
| H23C | 250755 | 6169617 | 680.76 | 680.69 | 100 | 84 | 97 | 82 | 97 | HAW | 15 | H142C |
| H32LDA | 249532 | 6173533 | 646.60 | 646.78 | 152 | 108 | 114 | 106 | 117 | WW | 11 | A and B in same hole |
| H32LDB | 249532 | 6173533 | 646.60 | 646.73 | 152 | 57 | 88 | 54 | 89 | HAW | 35 | |
| H35A | 250523 | 6172486 | 681.43 | 682.16 | 152 | 53 | 77 | 50 | 78 | HAW | 28 | |
| H35B | 250531 | 6172487 | 680.84 | 681.52 | 35 | 15 | 34 | 14 | 35 | WG | 21 | |
| H37A | 246551 | 6167440 | 703.79 | 703.70 | 111 | 101 | 105 | 101 | 107 | ICM | 6 | WW absent |
| H37B | 246546 | 6167438 | 703.77 | 703.69 | 90 | 72 | 87 | 70 | 90 | HAW | 20 | |
| H38A | 248783 | 6175453 | 658.53 | 657.67 | 117 | 105 | 108 | 103 | 110 | WW | 7 | |
| H38B | 248788 | 6175452 | 658.44 | 658.33 | 78 | 74 | 77 | 72 | 78 | HAW | 6 | |
| H38C | 248793 | 6175452 | 658.31 | 658.17 | 63 | 55 | 62 | 52 | 63 | HAW | 11 | |
| H42A | 250988 | 6166688 | 702.50 | 702.43 | 173 | 156 | 159 | 153 | 161 | WW | 8 | |
| H42C | 250985 | 6166678 | 702.00 | 701.92 | 150 | 142 | 150 | 135 | 150 | HAW | 15 | |
| H43XA | 247147 | 6178127 | 692.04 | 691.96 | 111 | 95 | 101 | 93 | 103 | WW | 10 | |
| H43XB | 247152 | 6178133 | 691.77 | 691.69 | 87 | 77 | 86 | 75 | 87 | HAW | 12 | |
| H44XA | 242285 | 6164084 | 641.94 | 641.92 | 12 | 8 | 11 | 7 | 12 | WW | 5 | |
| H44XB | 242281 | 6164077 | 647.00 | 646.96 | 5 | 4 | 5 | 3.5 | 5 | HAW | 2 | |
| H56XB | 245225 | 6169198 | 735.45 | | 140 | 132 | 140 | 130 | 140 | HAW | 10 | |
| H56XC | 245234 | 6169198 | 735.51 | | 26 | 19 | 25 | 17 | 26 | Basalt | 9 | |
| H72A | 252074 | 6177157 | 640.12 | 640.05 | 129 | 124 | 128 | 121 | 129 | WW | 8 | |
| H72B | 252083 | 6177169 | 640.43 | 640.36 | 99 | 92 | 98 | 88 | 98 | HAW | 10 | |
| H72C | 252091 | 6177180 | 640.85 | 640.77 | 46 | 39 | 45 | 35 | 46 | HAW | 11 | |
| H73A | 251015 | 6172718 | 656.46 | 657.00 | 172 | 151 | 169 | 149 | 172 | ICM Lower | 23 | |
| H73B | 251029 | 6172717 | 655.78 | 656.35 | 124 | 119 | 123 | 117 | 124 | WW | 7 | |
| H73C | 251035 | 6172717 | 655.50 | 656.13 | 86 | 79 | 85 | 77 | 86 | HAW | 9 | |
| H88A | 253059 | 6173144 | 655.44 | 655.37 | 156 | 143 | 146 | 141 | 148 | WW | 7 | |
| H88B | 253059 | 6173144 | 655.33 | 655.26 | 150 | 121 | 126 | 119 | 128 | HAW | 9 | |

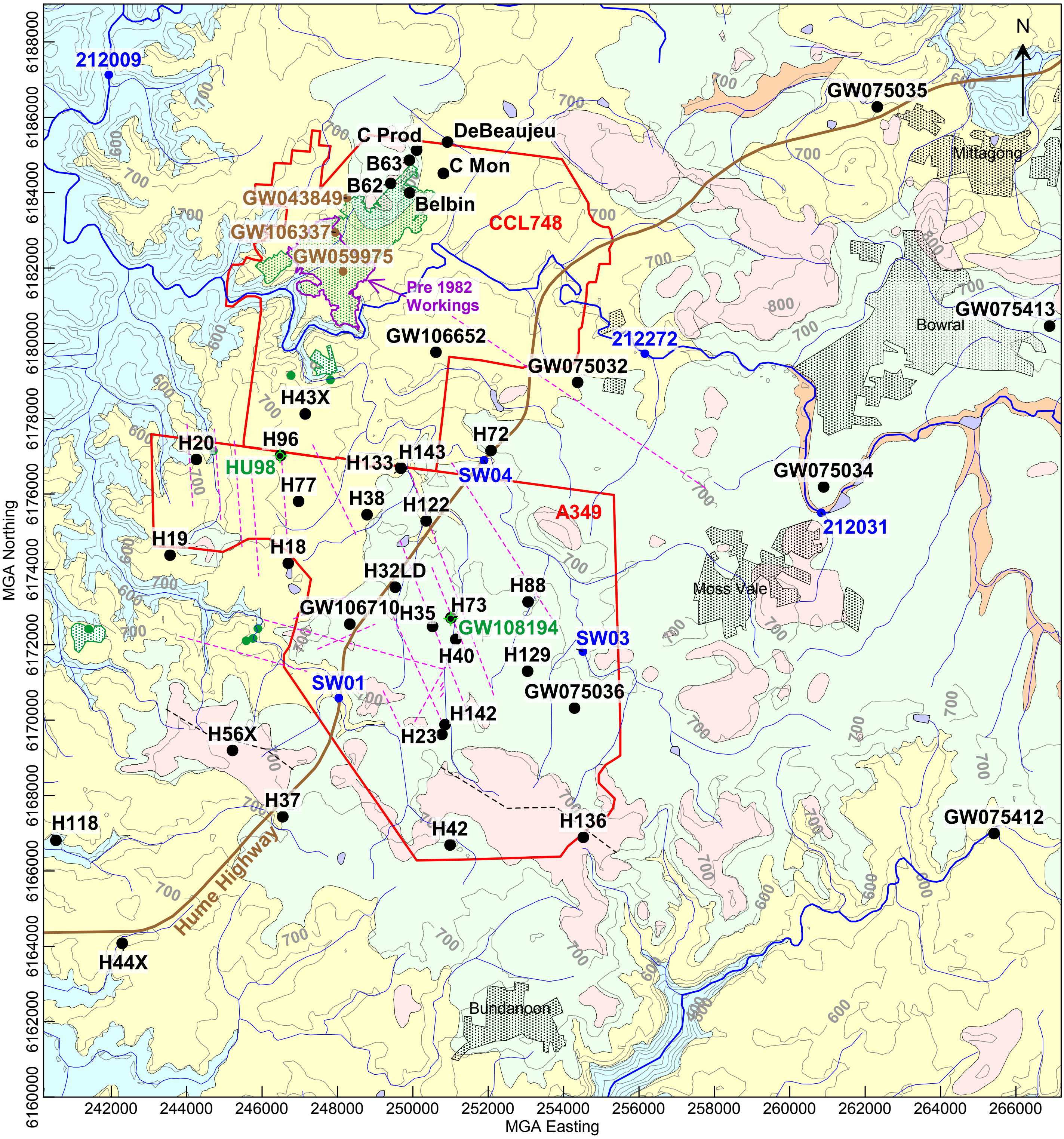
HAW: Hawkesbury Sandstone. WW: Wongawilli Seam. WG: Wianamatta Group. ICM: Illawarra Coal Measures. SS: Sandstone. Sh: Shale.

| Piezometer | Easting (MGA) | Northing (MGA) | RL Ground (mAHD) | RL Casing (mAHD) | Drilled Depth (mbgl) | Screen (mbgl) | | Sandpack (mbgl) | | Screened Stratum | L (m) | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | From | To | From | To | | | |
| **Hume Coal Monitoring** | | | | | | | | | | | | |
| H96A | 246489 | 6177025 | 699.21 | 699.14 | 147 | 111 | 120 | 108 | 120 | ICM Lower | 12 | |
| H96B | 246491 | 6177029 | 699.10 | 699.00 | 101 | 92 | 98 | 91 | 101 | WW | 10 | |
| H96C | 246494 | 6177045 | 683.00 | 682.94 | 89 | 69 | 87 | 67 | 89 | HAW | 22 | |
| H118A | 240529 | 6166811 | 612.50 | | 15.3 | 7 | 13 | 5 | 15.3 | HAW | 10 | Near swamp (under peat) |
| H129A | 253042 | 6171301 | 679.10 | 679.04 | 177 | 166 | 170 | 165 | 171 | WW | 6 | |
| H129B | 253044 | 6171306 | 679.20 | 679.11 | 177 | 146 | 153 | 146 | 153 | HAW | 7 | |
| H133A | 249685 | 6176683 | 648.15 | 647.98 | 141 | 119 | 126 | 115 | 127 | ICM Lower | 12 | Decommissioned. |
| H133B | 249688 | 6176688 | 648.17 | 648.04 | 113 | 108 | 113 | 108 | 113 | WW | 5 | Replaced by H143A to |
| H133C | 249690 | 6176694 | 648.03 | 647.94 | 84 | 80 | 83 | 77 | 84 | HAW | 7 | H143C |
| H136A | 254521 | 6166894 | 718.49 | 718.36 | 216 | 199 | 203 | 196 | 203 | WW | 7 | |
| H136B | 254517 | 6166890 | 718.52 | 718.40 | 168 | 157 | 168 | 155 | 168 | HAW | 13 | |
| H136C | 254513 | 6166887 | 718.51 | 718.40 | 60 | 52 | 59 | 50 | 60 | Basalt | 10 | |
| H142A | 250856 | 6169881 | 672.43 | | 130.8 | 127 | 130 | 126 | 131 | WW | 5 | Replacement for H23A |
| H142B | 250855 | 6169886 | 672.32 | | 119.8 | 112 | 118 | 110 | 120 | HAW | 10 | Replacement for H23B |
| H142C | 250855 | 6169892 | 672.23 | | 86.8 | 81 | 84 | 79 | 86.8 | HAW | 8 | Replacement for H23C |
| H143A | 249671 | 6176708 | 649.55 | | 125.8 | 115 | 125 | 116 | 126 | ICM Lower | 10 | Replacement for H133A |
| H143B | 249672 | 6176703 | 649.59 | | 113 | 109 | 112 | 107 | 113 | WW | 6 | Replacement for H133B |
| H143C | 249673 | 6176697 | 649.45 | | 95.9 | 92 | 95 | 88 | 95.9 | HAW | 8 | Replacement for H133C |
| H40_1 | 251140 | 6172143 | 656.51 | 656.51 | 129 | 120 | 120 | VWP | VWP | WW | Point | Packer testing. Core K. |
| H40_2 | 251140 | 6172143 | 656.51 | 656.51 | 129 | 107 | 107 | VWP | VWP | HAW | Point | |
| H40_3 | 251140 | 6172143 | 656.51 | 656.51 | 129 | 81 | 81 | VWP | VWP | HAW | Point | |
| H40_4 | 251140 | 6172143 | 656.51 | 656.51 | 129 | 39 | 39 | VWP | VWP | HAW | Point | |
| H77_1 | 246966 | 6175811 | 689.74 | 689.74 | 98 | 87 | 87 | VWP | VWP | WW | Point | Packer testing. Core K. |
| H77_2 | 246966 | 6175811 | 689.74 | 689.74 | 98 | 72 | 72 | VWP | VWP | HAW | Point | |
| H77_3 | 246966 | 6175811 | 689.74 | 689.74 | 98 | 58 | 58 | VWP | VWP | HAW | Point | |
| H122_1 | 250352 | 6175286 | 634.50 | 634.50 | 120 | 112 | 112 | VWP | VWP | WW | Point | Packer testing. Core K. |
| H122_2 | 250352 | 6175286 | 634.50 | 634.50 | 120 | 86 | 86 | VWP | VWP | HAW | Point | |
| H122_3 | 250352 | 6175286 | 634.50 | 634.50 | 120 | 45 | 45 | VWP | VWP | HAW | Point | |
| H122_4 | 250352 | 6175286 | 634.50 | 634.50 | 120 | 15 | 15 | VWP | VWP | HAW | Point | |
| GW106652 | 250614 | 6179763 | 652.32 | 652.85 | 120 | 25 | 120 | Open hole | | HAW | 95 | Intersects WW seam. |
| GW106710 | 248326 | 6172551 | 672.39 | 672.70 | 115 | 64 | 108 | Open hole | | HAW | 44 | |

HAW: Hawkesbury Sandstone. WW: Wongawilli Seam. WG: Wianamatta Group. ICM: Illawarra Coal Measures. SS: Sandstone. Sh: Shale.

| Piezometer | Easting (MGA) | Northing (MGA) | RL Ground (mAHD) | RL Casing (mAHD) | Drilled Depth (mbgl) | Screen (mbgl) | | Sandpack (mbgl) | | Screened Stratum | L (m) | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | From | To | From | To | | | |
| **Berrima Mine Monitoring** | | | | | | | | | | | | |
| Belbin (GW106150) | 249914 | 6183996 | | 691.40 | 186 | 132 | 186 | Open hole | | HAW | 54 | |
| Culpepper P (GW101581) | 250100 | 6185126 | | 693.00 | 41 | | 41 | Open hole | | HAW | < 41 | |
| Culpepper M (B28) | 250809 | 6184507 | | 677.90 | 143 | | 143 | Open hole | | HAW | > 100 | Bore collapsed mid 2012 |
| DeBeaujeu (GW028373) | 250915 | 6185343 | 678.00 | 678.00 | 50 | 7 | 50 | Open hole | | HAW | 42 | RL estimated from DEM |
| B62_1 | 249411 | 6184243 | 727.00 | 727.00 | 181 | 58 | 58 | VWP | VWP | HAW | Point | |
| B62_2 | 249411 | 6184243 | 727.00 | 727.00 | 181 | 126 | 126 | VWP | VWP | HAW | Point | |
| B62_3 | 249411 | 6184243 | 727.00 | 727.00 | 181 | 170 | 170 | VWP | VWP | WW | Point | |
| B63_1 | 249907 | 6184861 | 738.00 | 738.00 | 185 | 85 | 85 | VWP | VWP | HAW | Point | |
| B63_2 | 249907 | 6184861 | 738.00 | 738.00 | 185 | 133 | 133 | VWP | VWP | HAW | Point | |
| B63_3 | 249907 | 6184861 | 738.00 | 738.00 | 185 | 177 | 177 | VWP | VWP | WW | Point | |
| **Regional Government Monitoring** | | | | | | | | | | | | |
| G75032_1 | 254374 | 6178962 | 678.23 | 678.75 | 91 | 24 | 29 | 1 | 31 | HAW | 30 | |
| G75032_2 | 254374 | 6178962 | 678.23 | 678.65 | 91 | 73 | 88 | 2 | 91 | HAW | 90 | |
| G75033_1 | 273474 | 6170523 | 692.96 | 693.58 | 101 | 30 | 35 | 1 | 36 | SS | 35 | |
| G75033_2 | 273474 | 6170523 | 692.96 | 693.04 | 101 | 89 | 99 | 50 | 101 | SS/Sh | 51 | |
| G75034 | 260898 | 6176191 | 660.01 | 660.73 | 101 | 90 | 100 | 50 | 101 | WG | 51 | |
| G75035 | 262322 | 6186276 | 648.25 | 648.17 | 91 | 74 | 89 | 1 | 91 | HAW | 90 | |
| G75036 | 254286 | 6170323 | 660.24 | 660.87 | 100 | 73 | 84 | 2 | 85 | SS | 84 | |
| G75412 | 265421 | 6166998 | 650.07 | | 70 | 52 | 64 | 44 | 70 | SS | 26 | |
| G75413 | 266895 | 6180460 | 710.69 | | 151 | 108 | 151 | Open hole | | WG | 43 | |
| **Private Bores Overlying Berrima Mine Workings** | | | | | | | | | | | | |
| GW043849 | 248247 | 6183852 | | | 99 | 4 | 99 | Open hole | | | | WW top appr. 125mbgl. |
| Stock. Installed 01.02.1974. Water Level 76.2m below ground. Area mined after 1977. | | | | | | | | | | | | |
| GW106337 | 247940 | 6182940 | | | 122 | | 122 | | | | | WW top appr. 125mbgl. |
| Stock / Domestic. Installed 16.11.2002. Intersected coal seams. Went dry 17.08.2005 then backfilled (license cancelled). Area mined before 1977. | | | | | | | | | | | | |
| GW059975 | 248146 | 6181907 | | | 92 | 3 | 92 | Open hole | | | | WW top appr. 125mbgl. |
| Stock / Domestic. Installed 01.04.1983. Water Level 36.6m below ground. Area mined before 1977. | | | | | | | | | | | | |

HAW: Hawkesbury Sandstone. WW: Wongawilli Seam. WG: Wianamatta Group. ICM: Illawarra Coal Measures. SS: Sandstone. Sh: Shale.

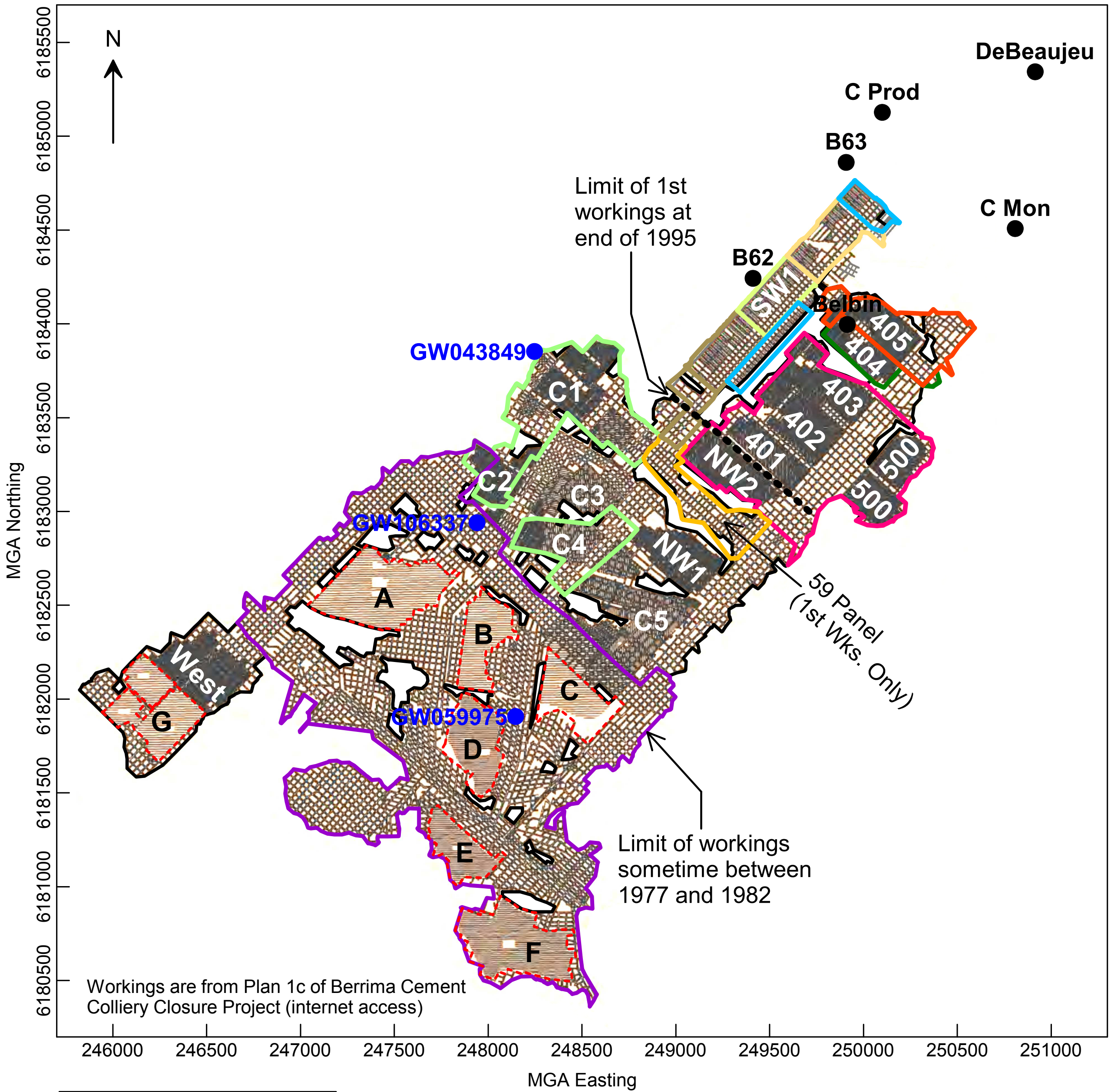



Subsurface flow barrier emplaced during model calibration.

- Alluvium
- Basalt
- Wianamatta Group
- Hawkesbury Sandstone
- Narrabeen Group (where present) and Permian Coal Measures
- Drainage course
- Water body
- Old mine footprint
- Old mine adit
- Interpreted or published fault
- GW106337 Hume pumping test bore
- 620 Topography (mAHD)
- H72 Groundwater monitoring piezometer / well
- GW106337 Private bore over workings
- SW01 Flow gauge
- Pipeline
- Built-up Area
- Hume Highway

| | | | |
|---|---|---|---|
| drawn | PT | client: | Hume Coal Pty Limited |
| approved | RJB | project: | Hume Coal Project<br>Groundwater Assessment |
| date | 29 Jul 2016 | title: | **Monitoring Piezometer and Well Locations** |
| scale | 1:150,000 | project no: GEOTLCOV25281AB | figure no: **Figure D1** |
| original size | A4 | | |

coffey
A TETRA TECH COMPANY




**Berrima Mining Schedule:**

- 1991 to 1995 (pillar extraction)
- 1996 to 2005 (1st wks. & pill. ext.)
- 2006 to 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013

**H72** Groundwater monitoring piezometer / well

**GW106337** Private bore over workings

**B** Unknown workings type. Most likely pillar extraction. Some goaf areas present.

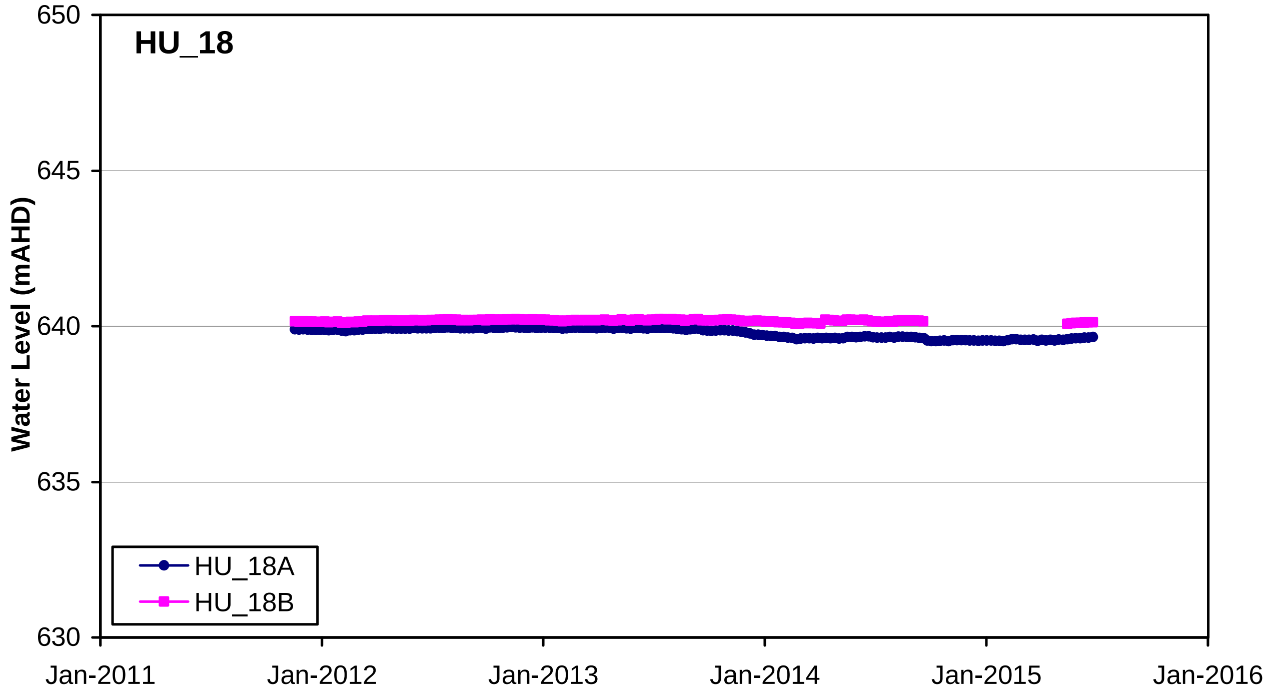
Mine limit some time between 1977 and 1982.

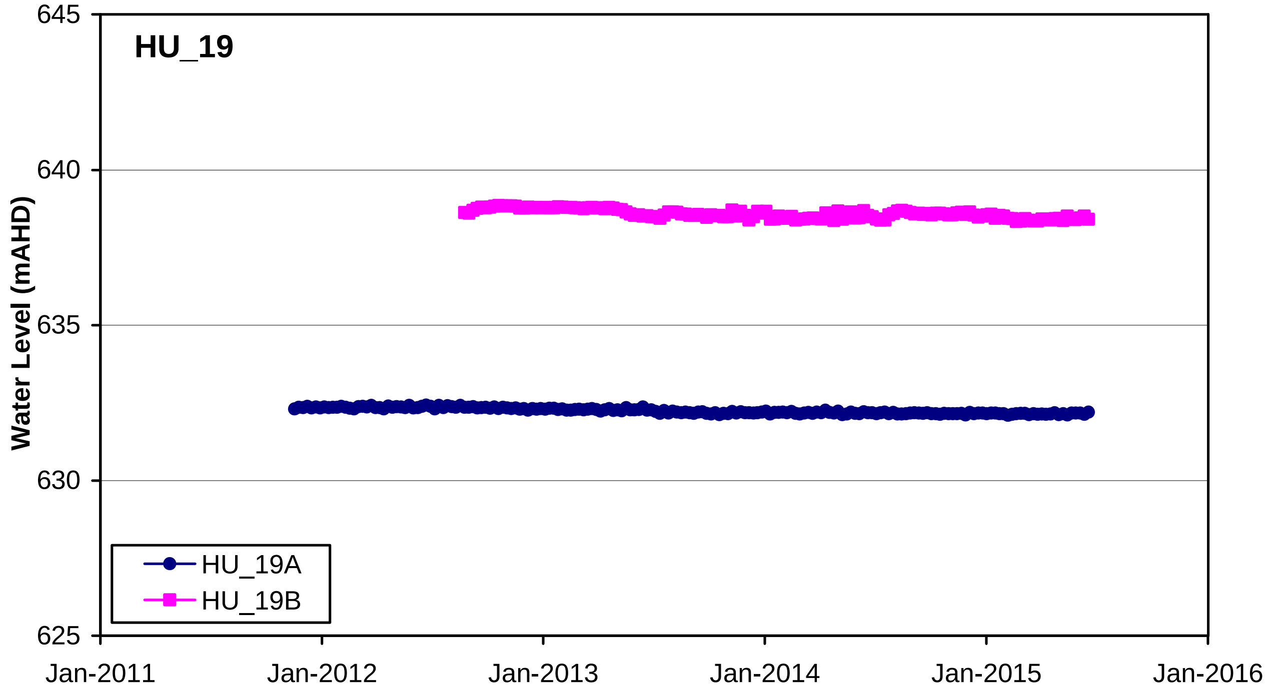
1st Workings

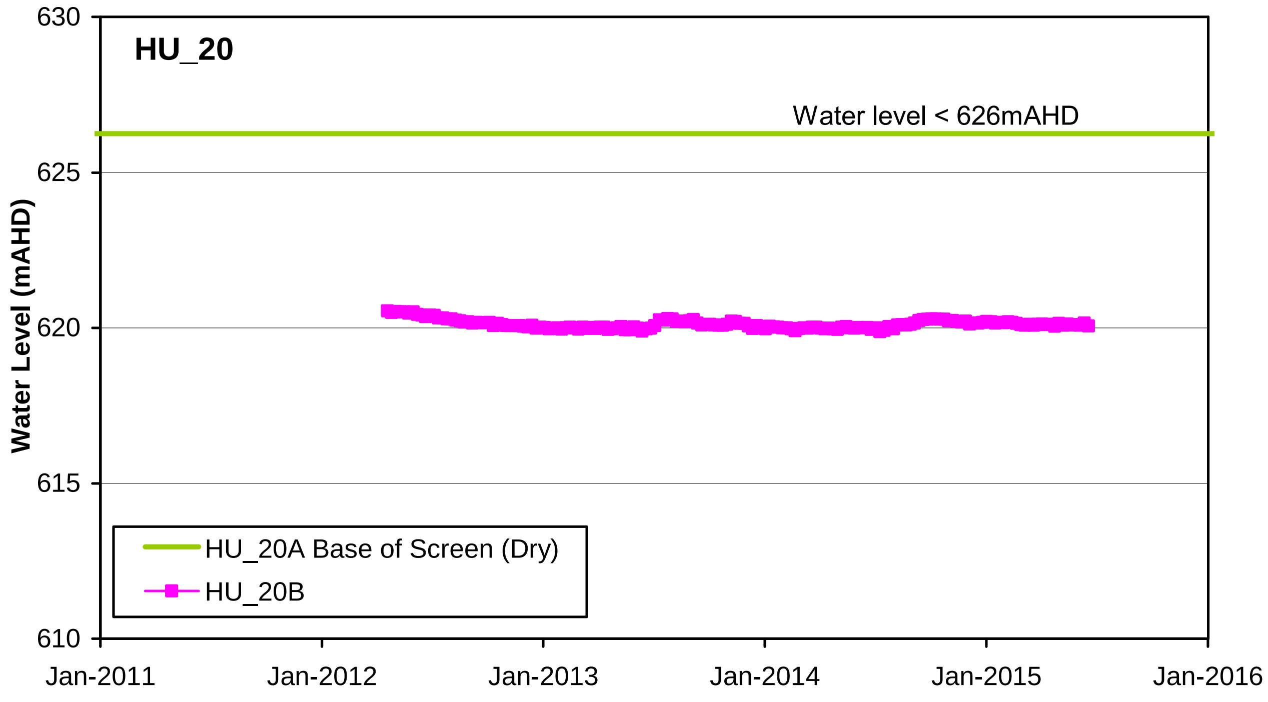
NW1 Pillar Extraction Panel

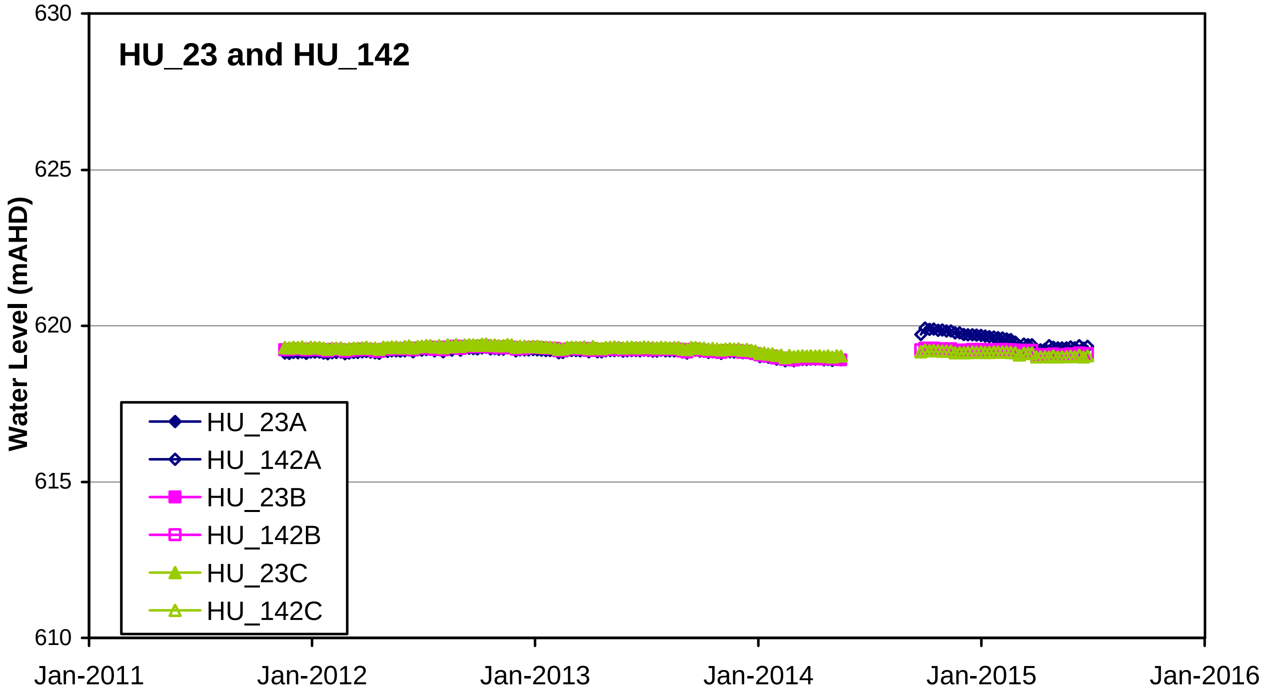
| | | | |
|---|---|---|---|
| drawn | PT | client: | Hume Coal Pty Limited |
| approved | RJB | project: | Hume Coal Project<br>Groundwater Assessment |
| date | 6 Jun 2016 | | |
| scale | 1:35,000 | title: | **Monitoring Piezometers/Wells (Berrima Mine)** |
| original size | A4 | project no: GEOTLCOV25281AB | figure no: **Figure D2** |

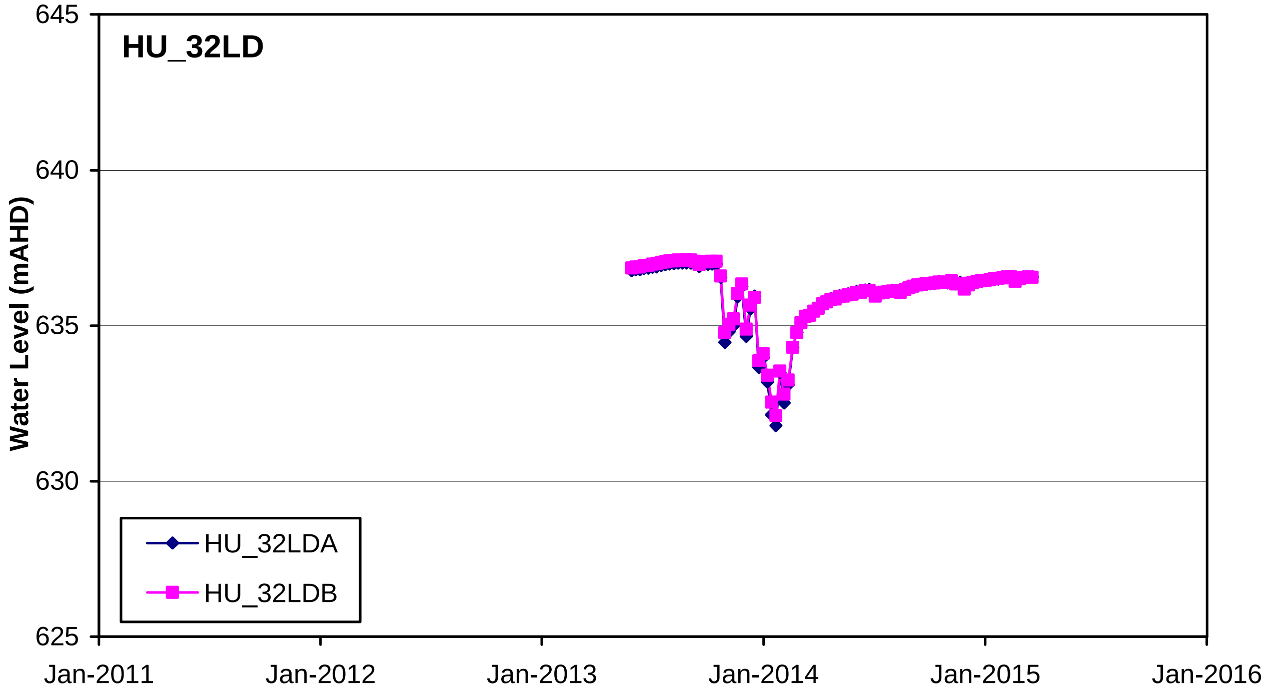
coffey
A TETRA TECH COMPANY

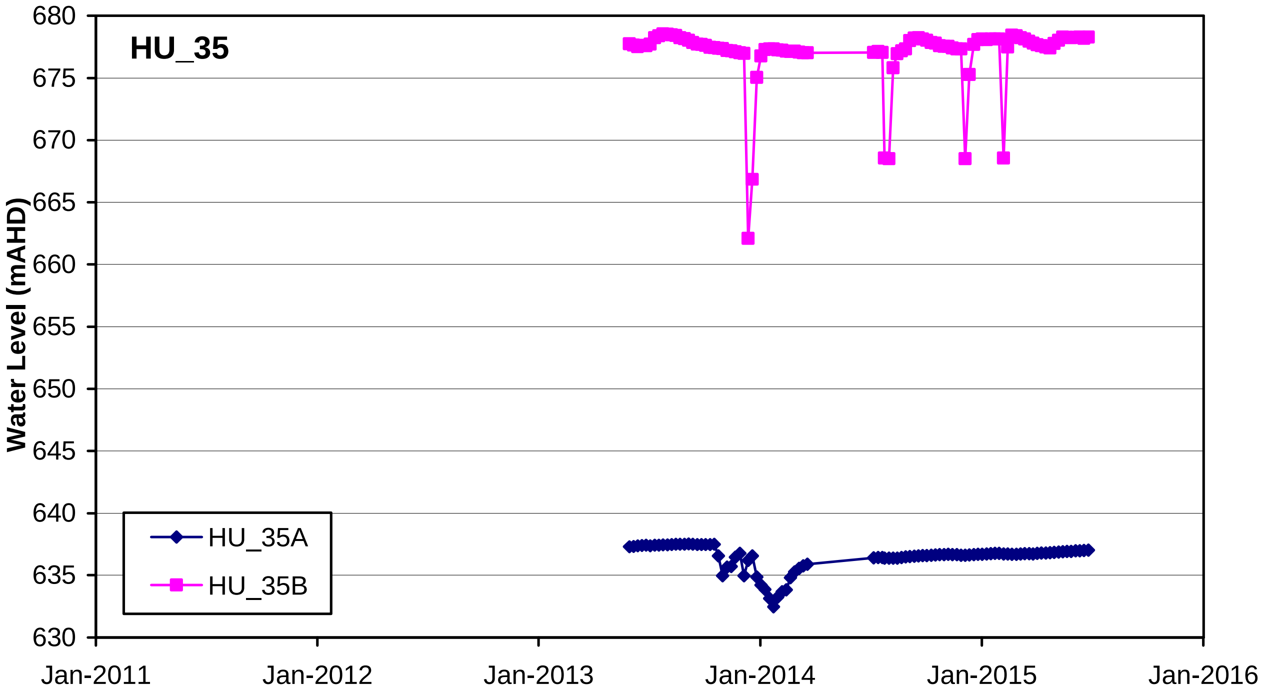

HU_18
Water Level (mAHD)
650
645
640
635
630
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_18A
HU_18B

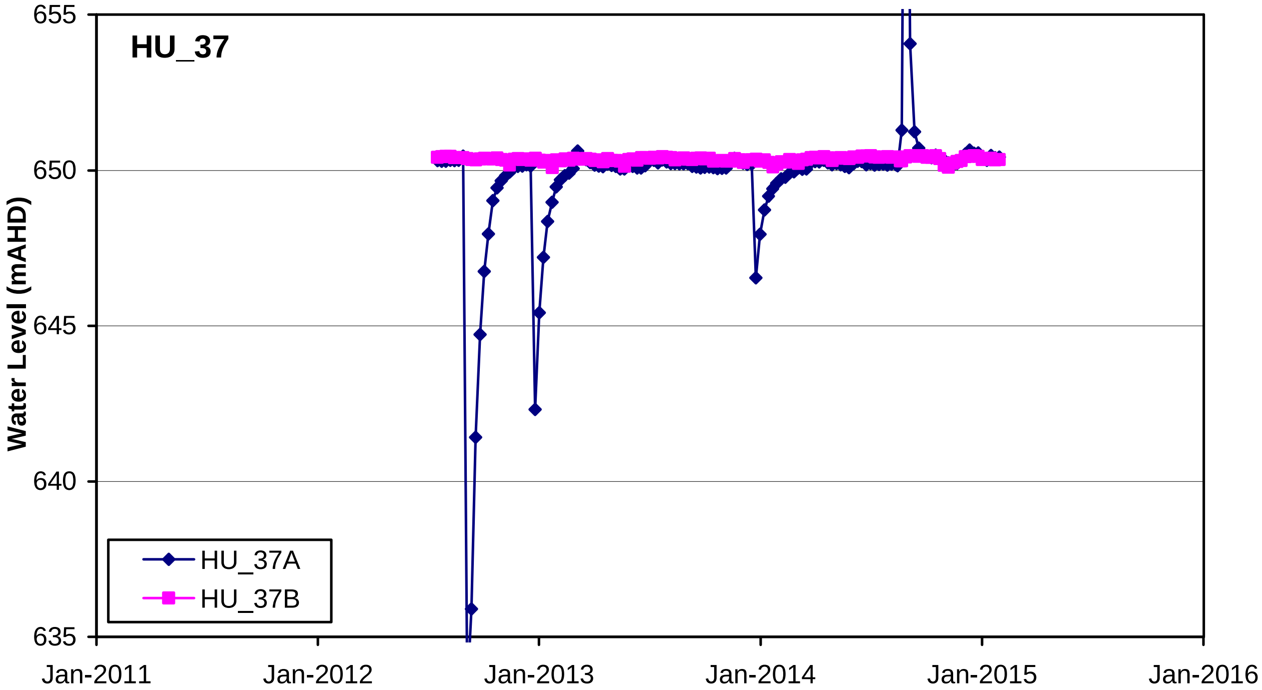

HU_19
Water Level (mAHD)
645
640
635
630
625
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_19A
HU_19B

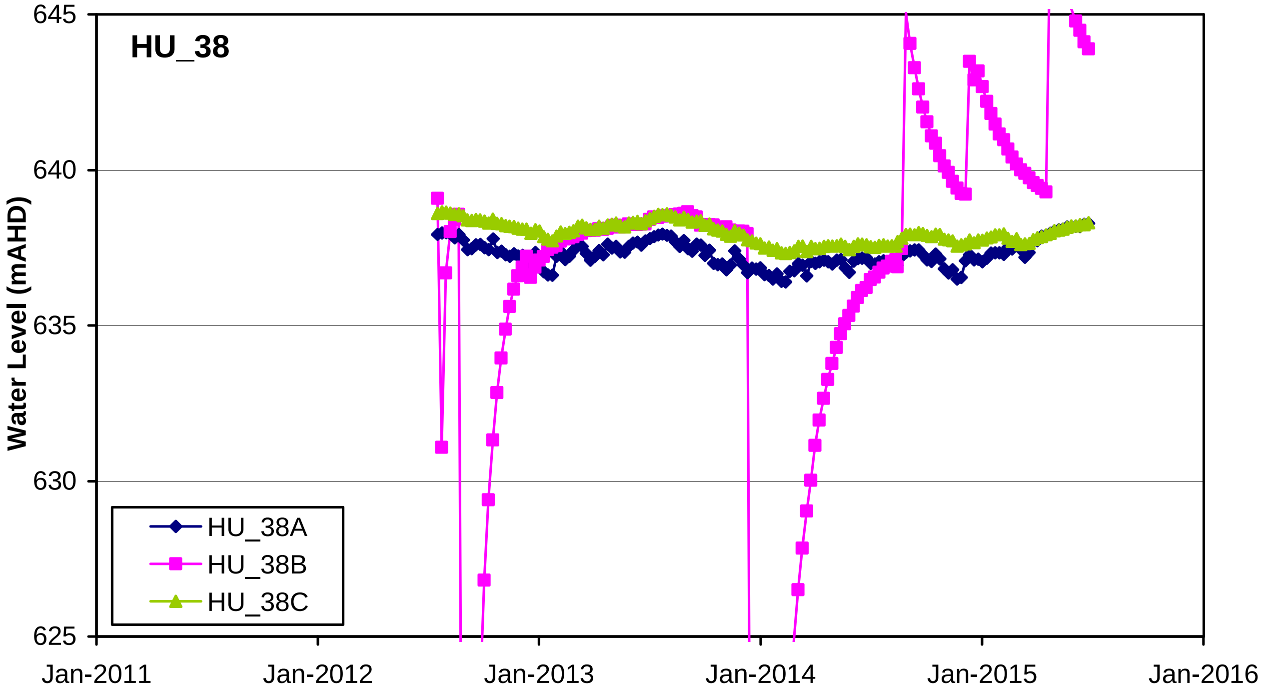

HU_20
Water level < 626mAHD
Water Level (mAHD)
630
625
620
615
610
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_20A Base of Screen (Dry)
HU_20B

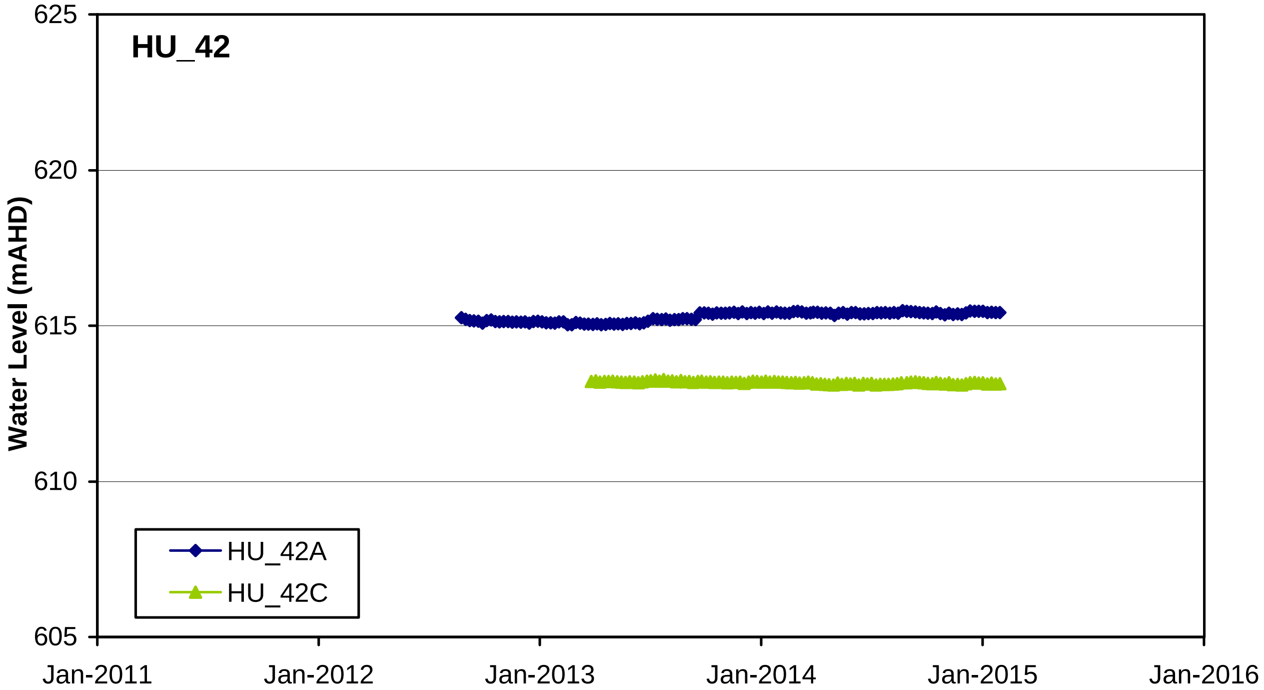

HU_23 and HU_142
Water Level (mAHD)
630
625
620
615
610
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_23A
HU_142A
HU_23B
HU_142B
HU_23C
HU_142C

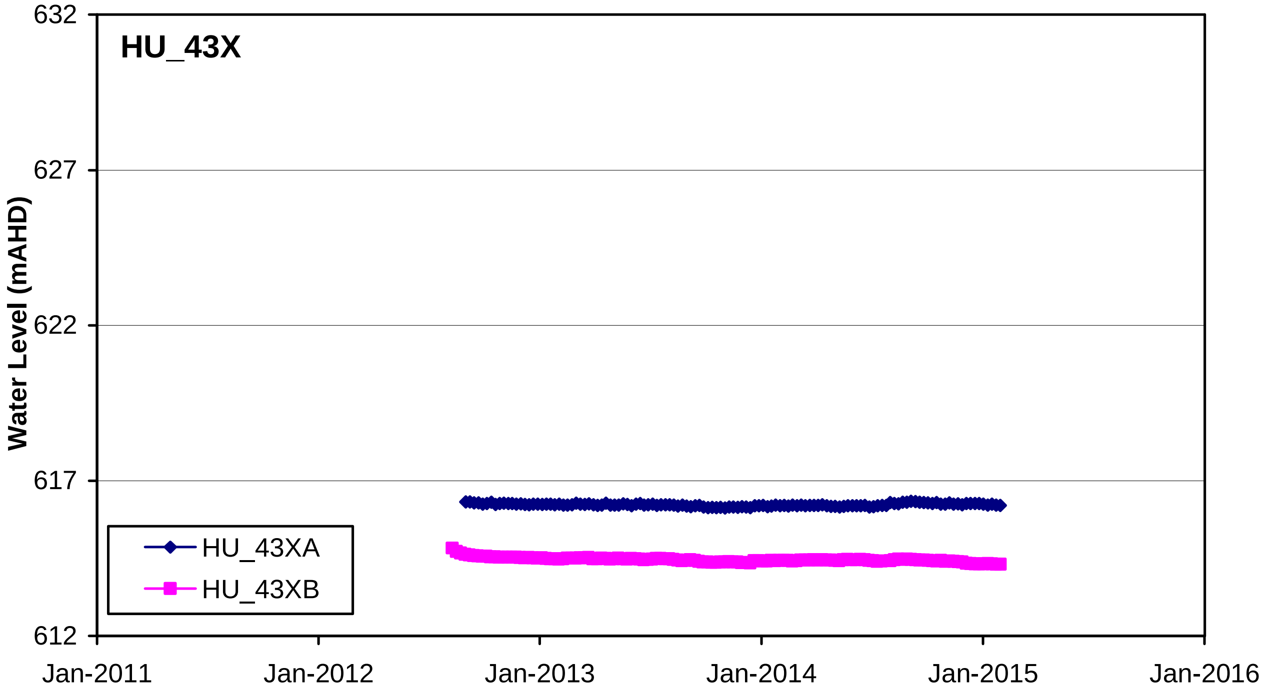

HU_32LD
Water Level (mAHD)
645
640
635
630
625
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_32LDA
HU_32LDB

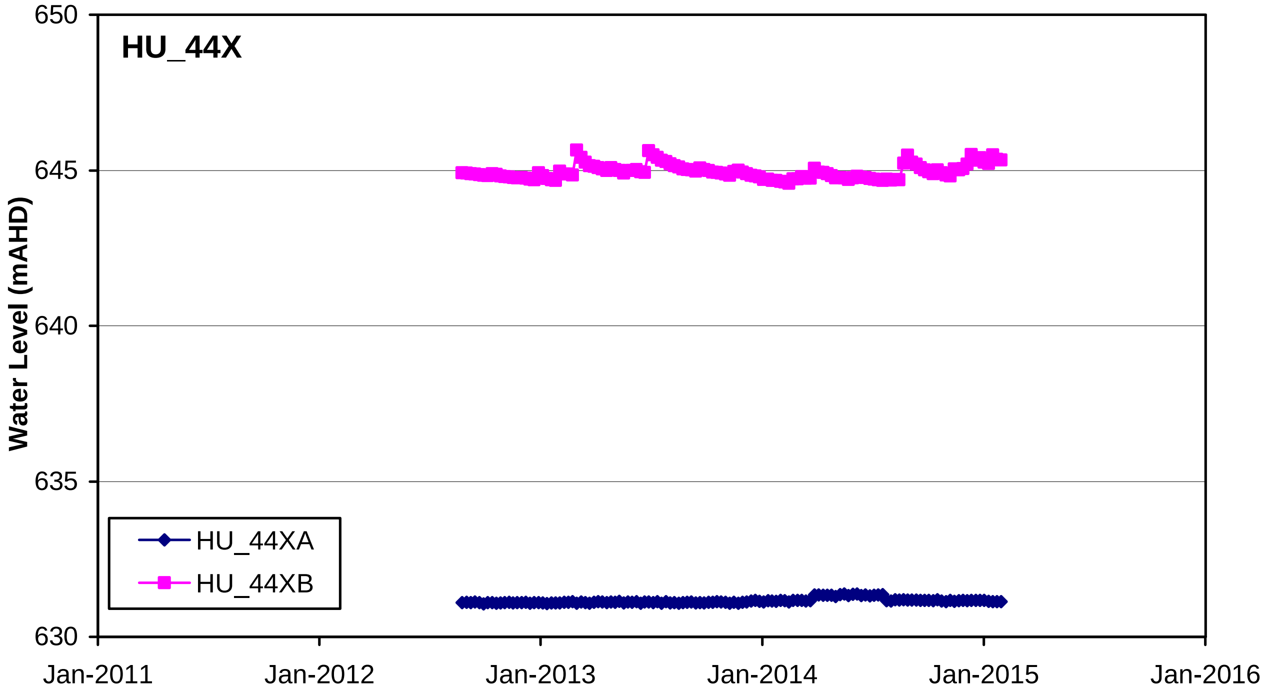

HU_35
Water Level (mAHD)
680
675
670
665
660
655
650
645
640
635
630
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_35A
HU_35B

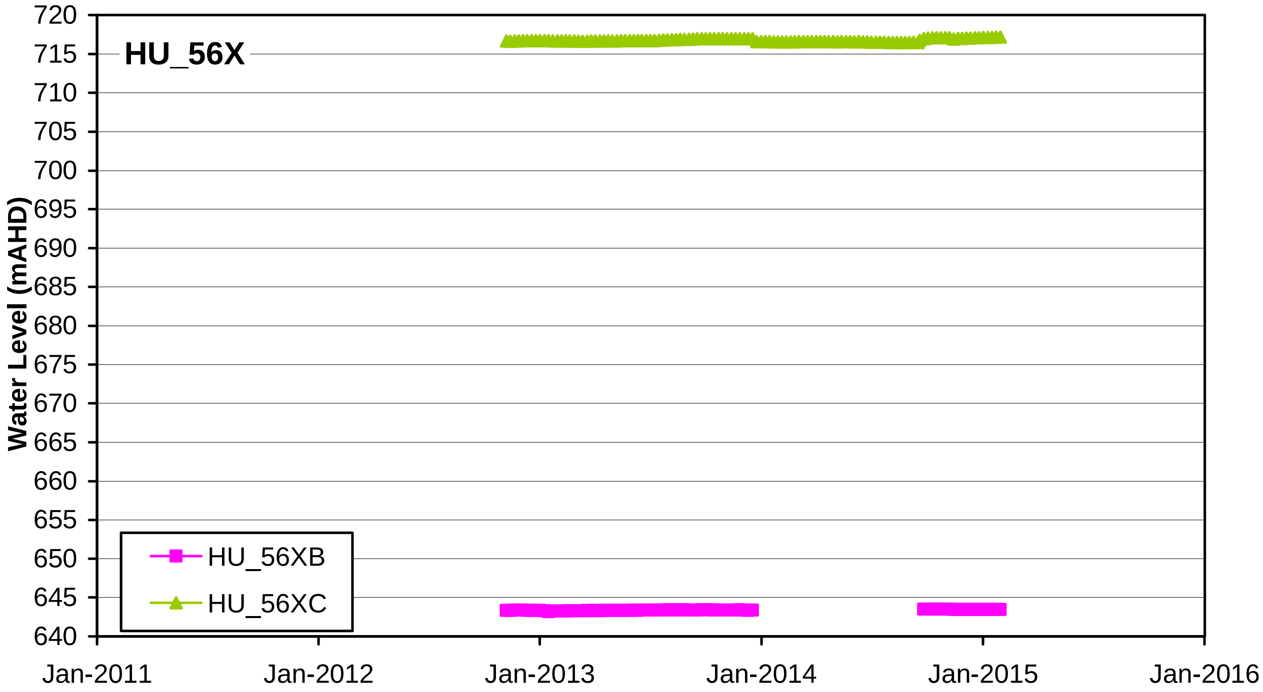

HU_37
Water Level (mAHD)
655
650
645
640
635
HU_37A
HU_37B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

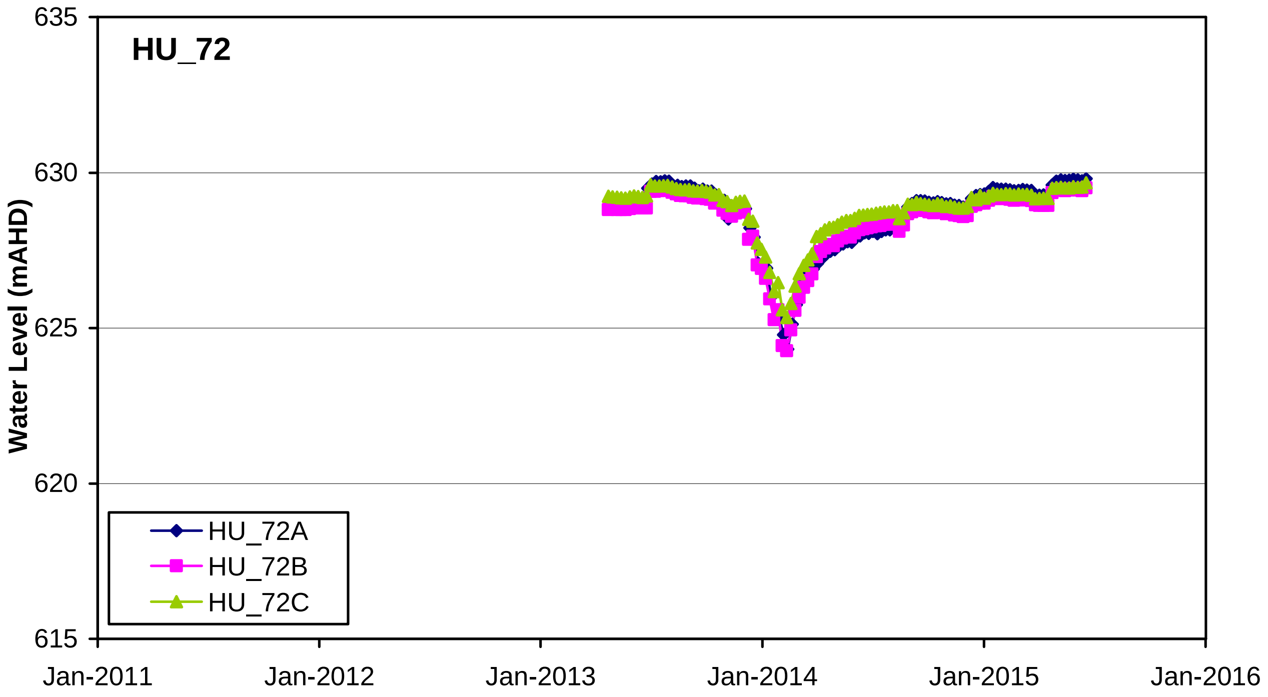

HU_38
Water Level (mAHD)
645
640
635
630
625
HU_38A
HU_38B
HU_38C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

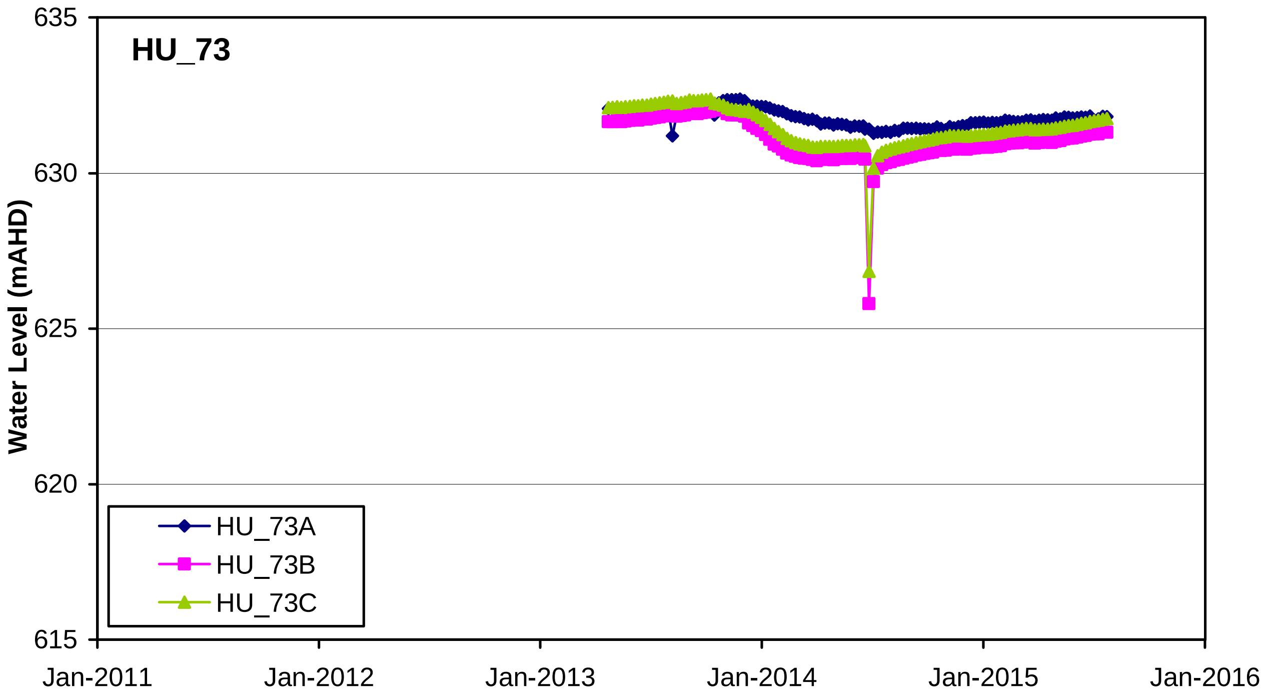

HU_42
Water Level (mAHD)
625
620
615
610
605
HU_42A
HU_42C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

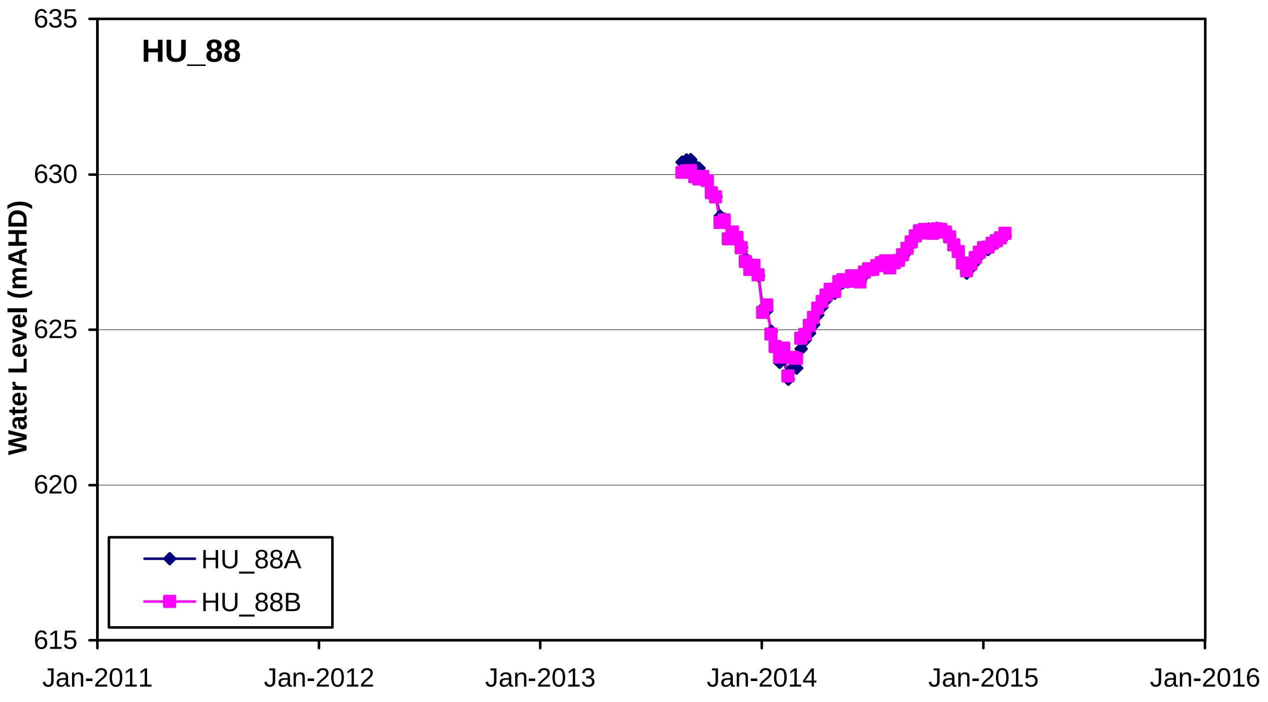

HU_43X
Water Level (mAHD)
632
627
622
617
612
HU_43XA
HU_43XB
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

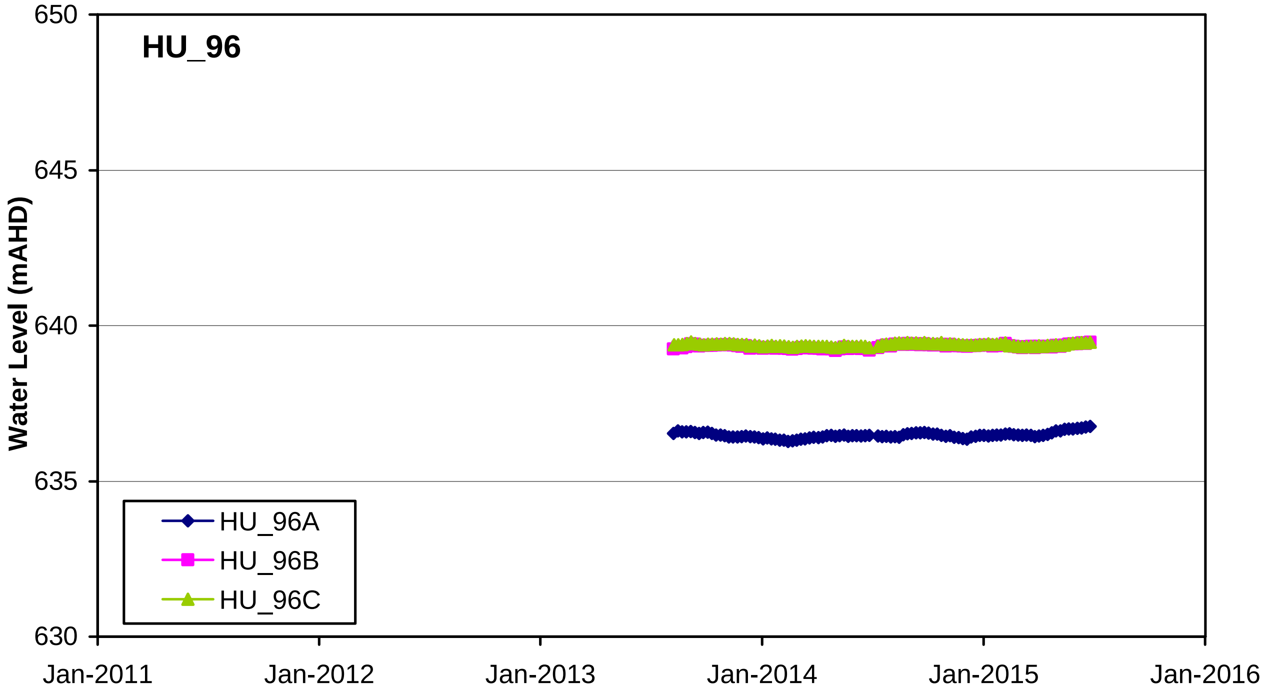

HU_44X
Water Level (mAHD)
650
645
640
635
630
HU_44XA
HU_44XB
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

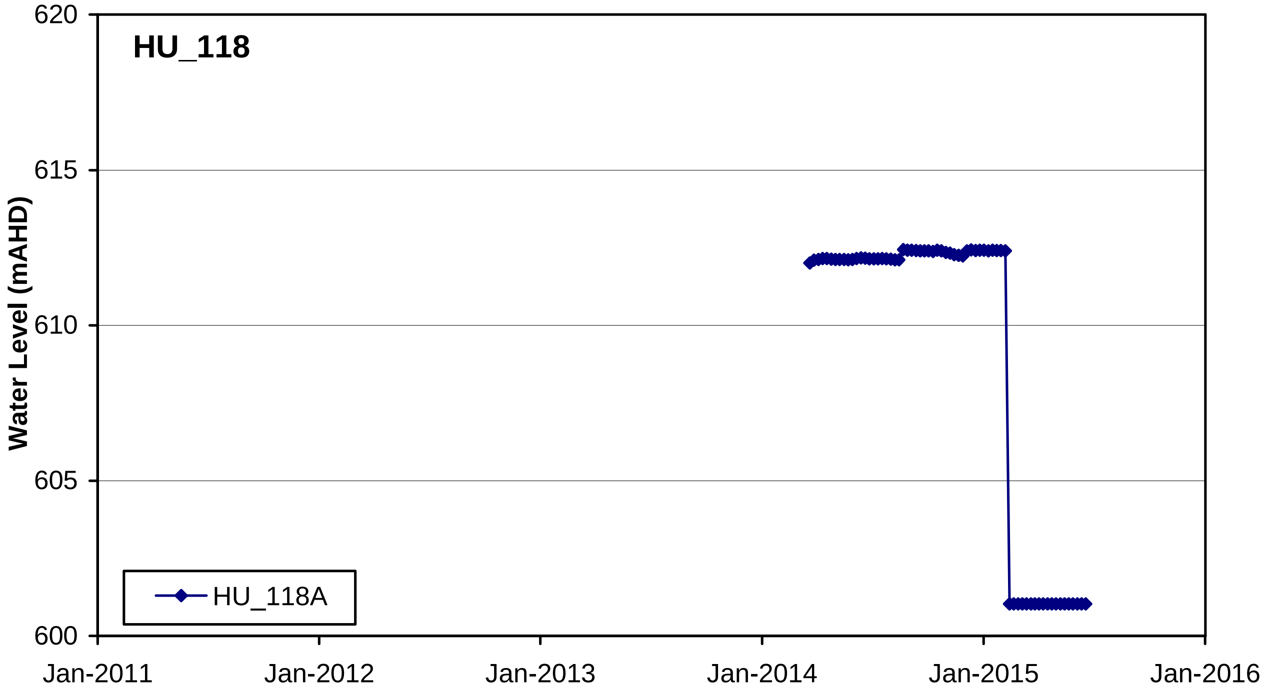

HU_56X
Water Level (mAHD)
720
715
710
705
700
695
690
685
680
675
670
665
660
655
650
645
640
HU_56XB
HU_56XC
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

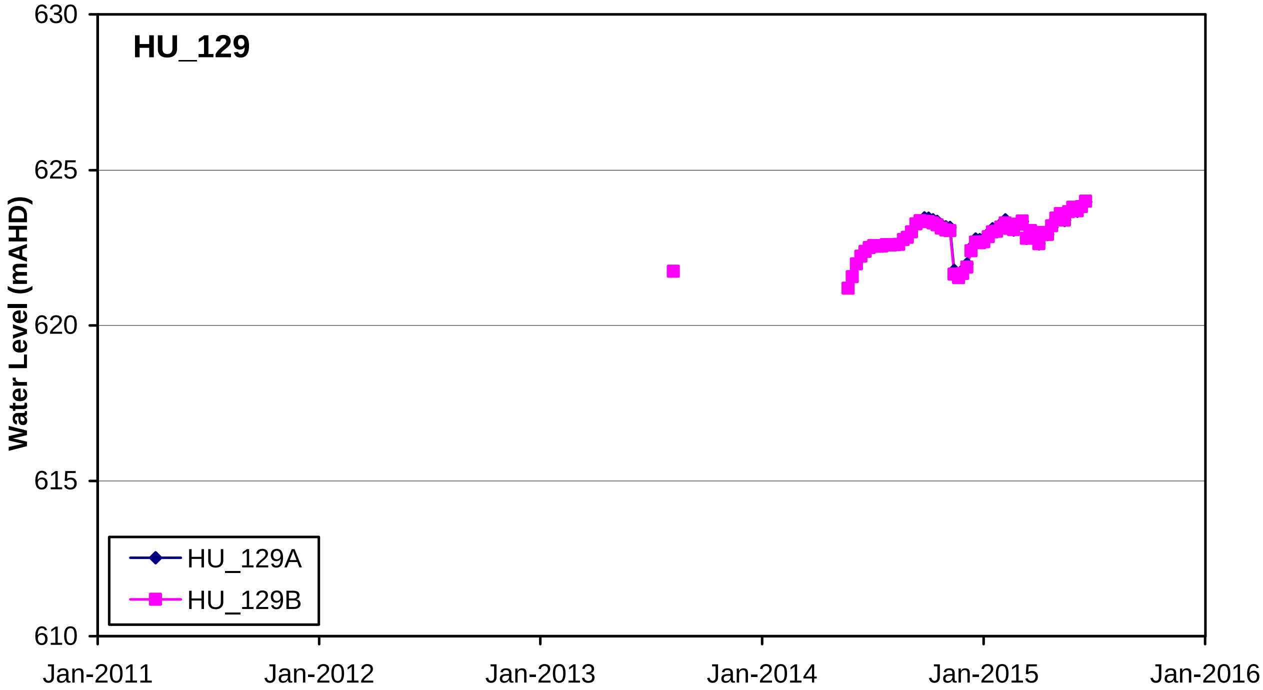

HU_72
Water Level (mAHD)
635
630
625
620
615
HU_72A
HU_72B
HU_72C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

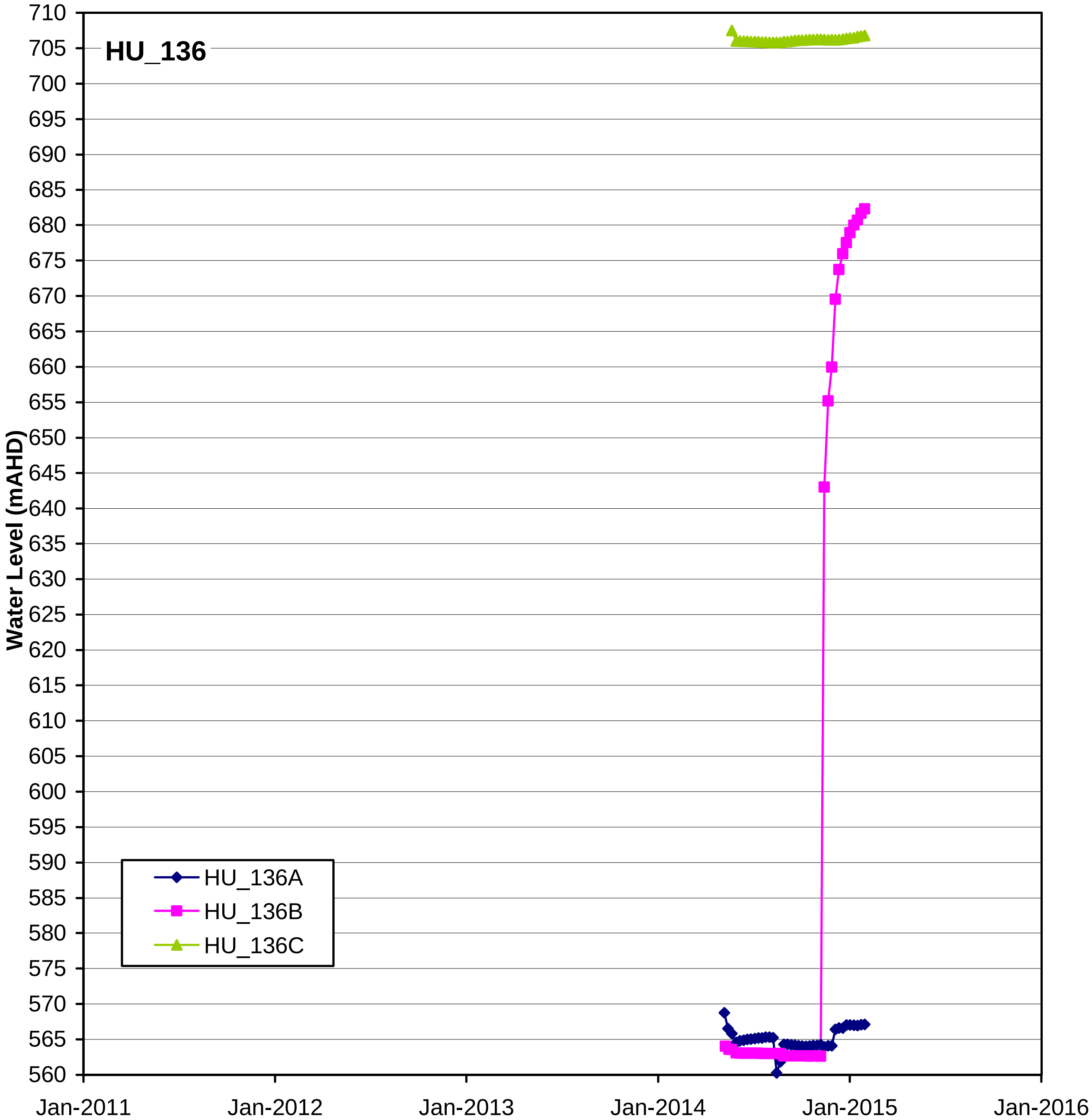

HU_73
Water Level (mAHD)
635
630
625
620
615
HU_73A
HU_73B
HU_73C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

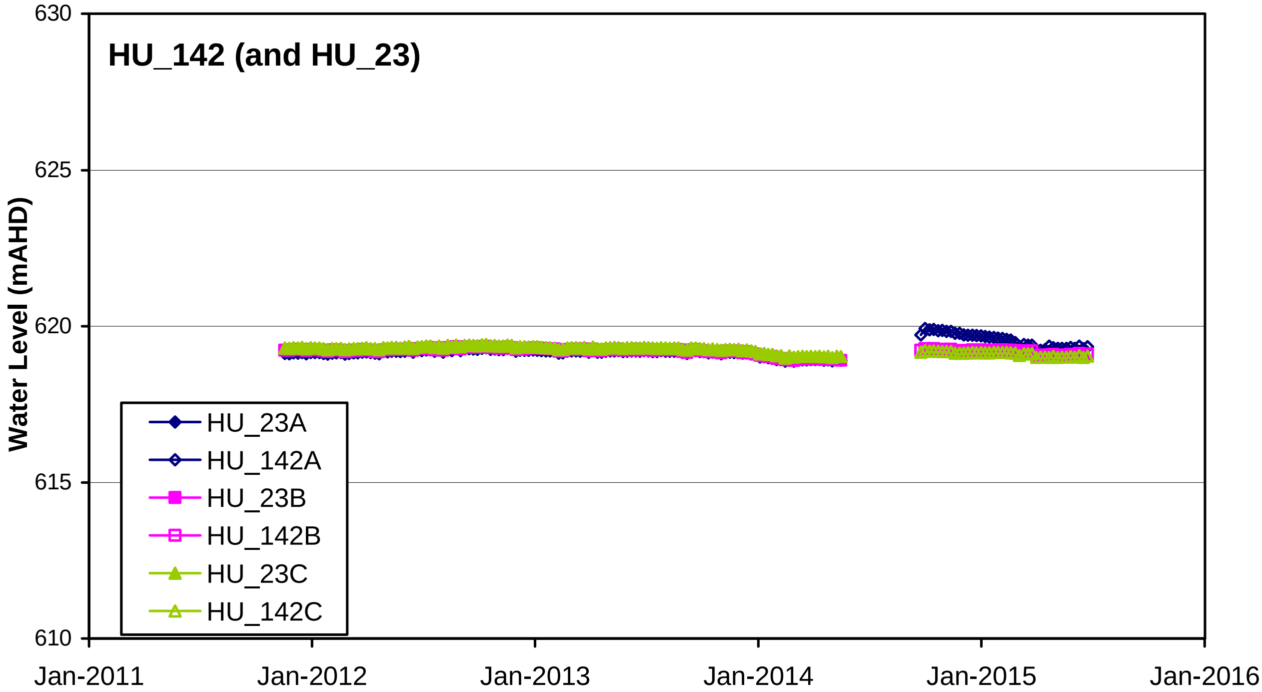

HU_88
Water Level (mAHD)
635
630
625
620
615
HU_88A
HU_88B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

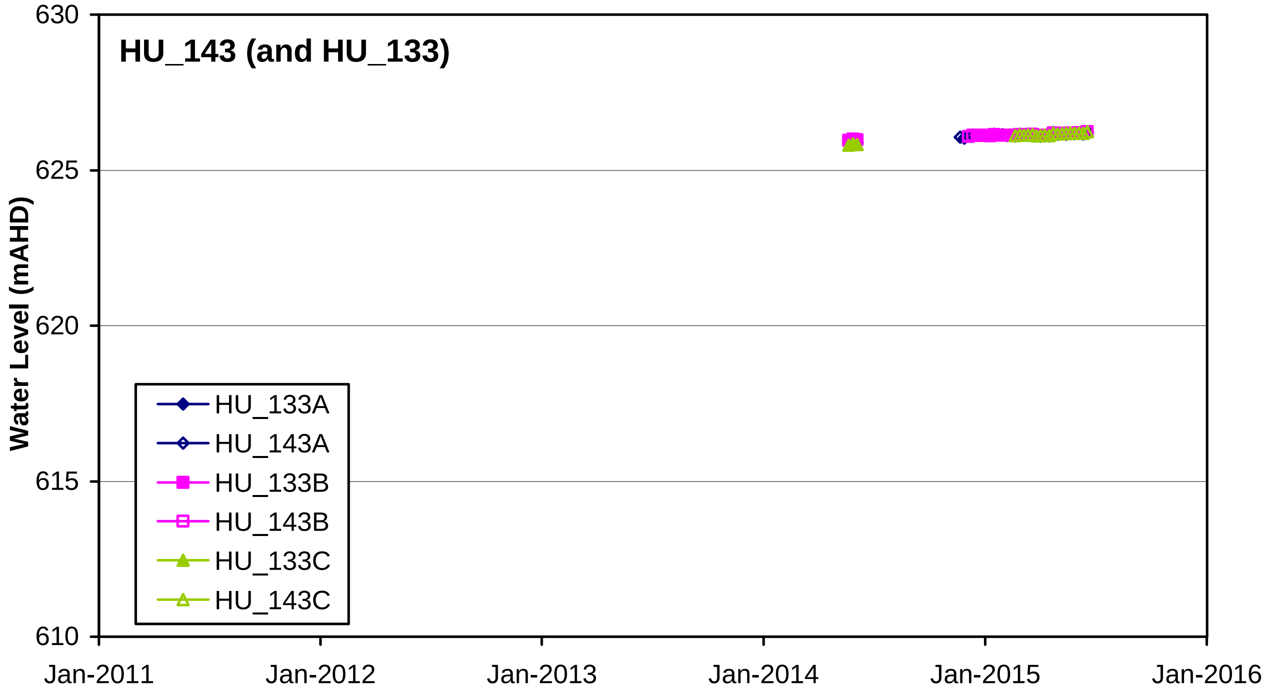

HU_96
Water Level (mAHD)
650
645
640
635
630
HU_96A
HU_96B
HU_96C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

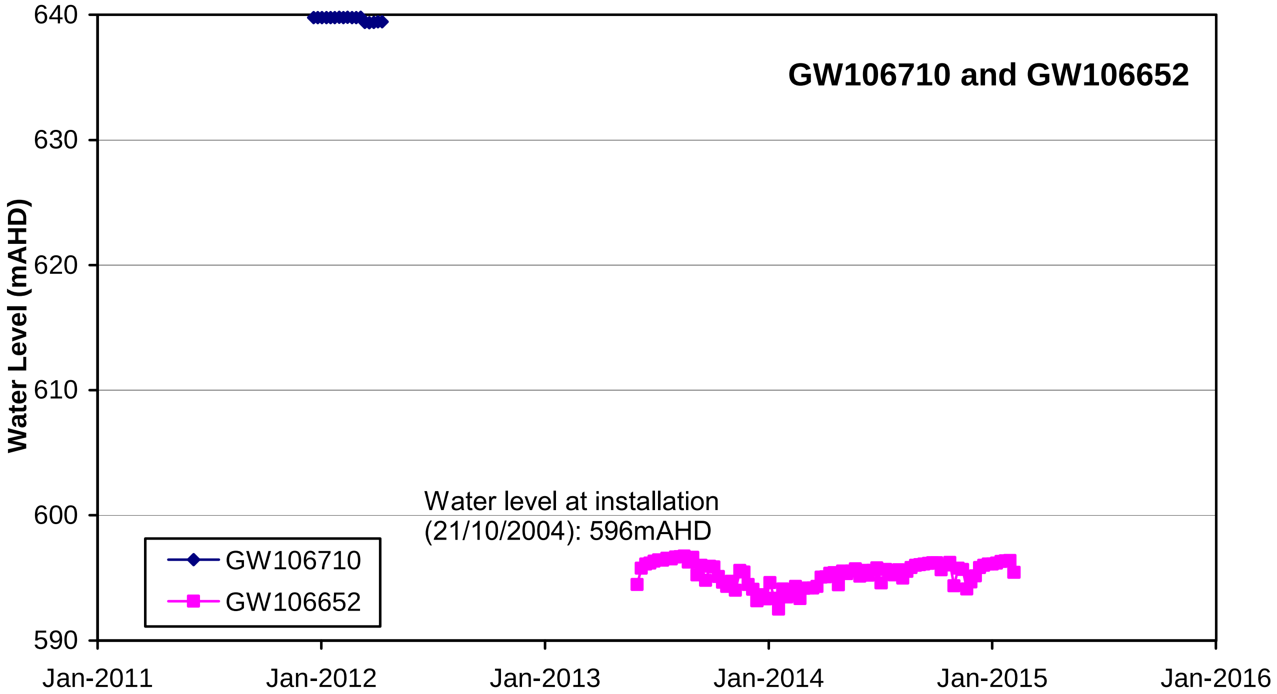

HU_118
Water Level (mAHD)
620
615
610
605
600
HU_118A
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

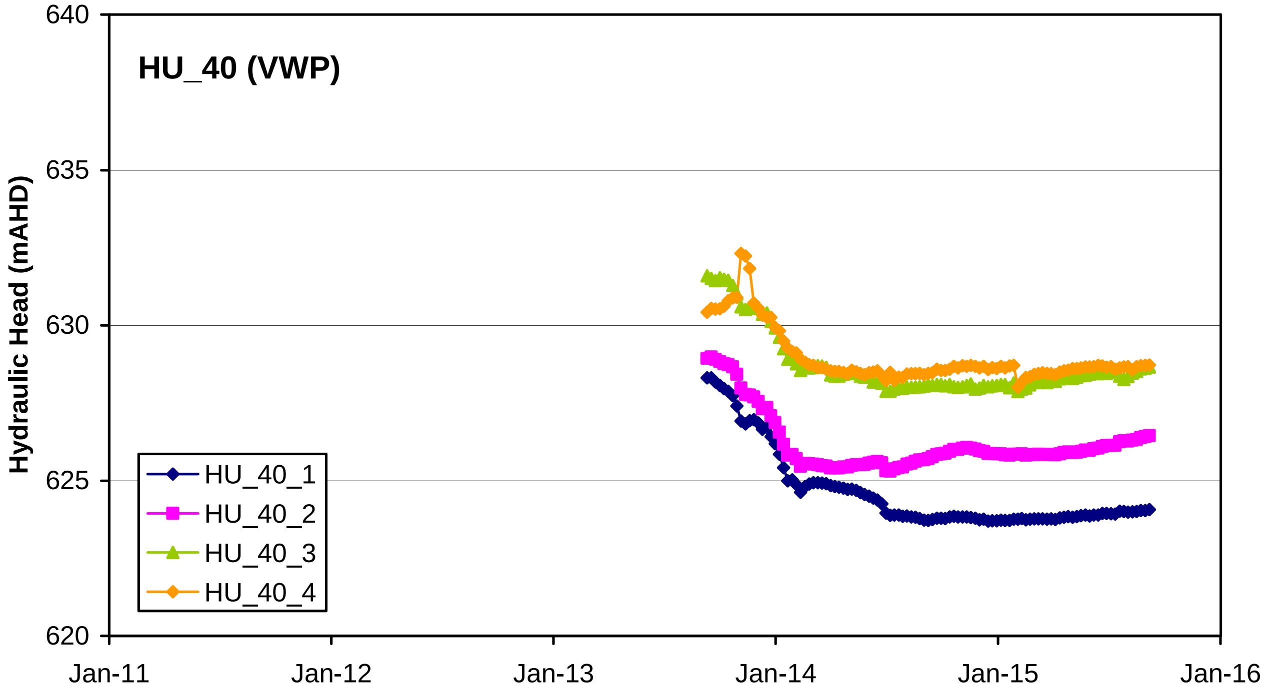

HU_129
Water Level (mAHD)
630
625
620
615
610
HU_129A
HU_129B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

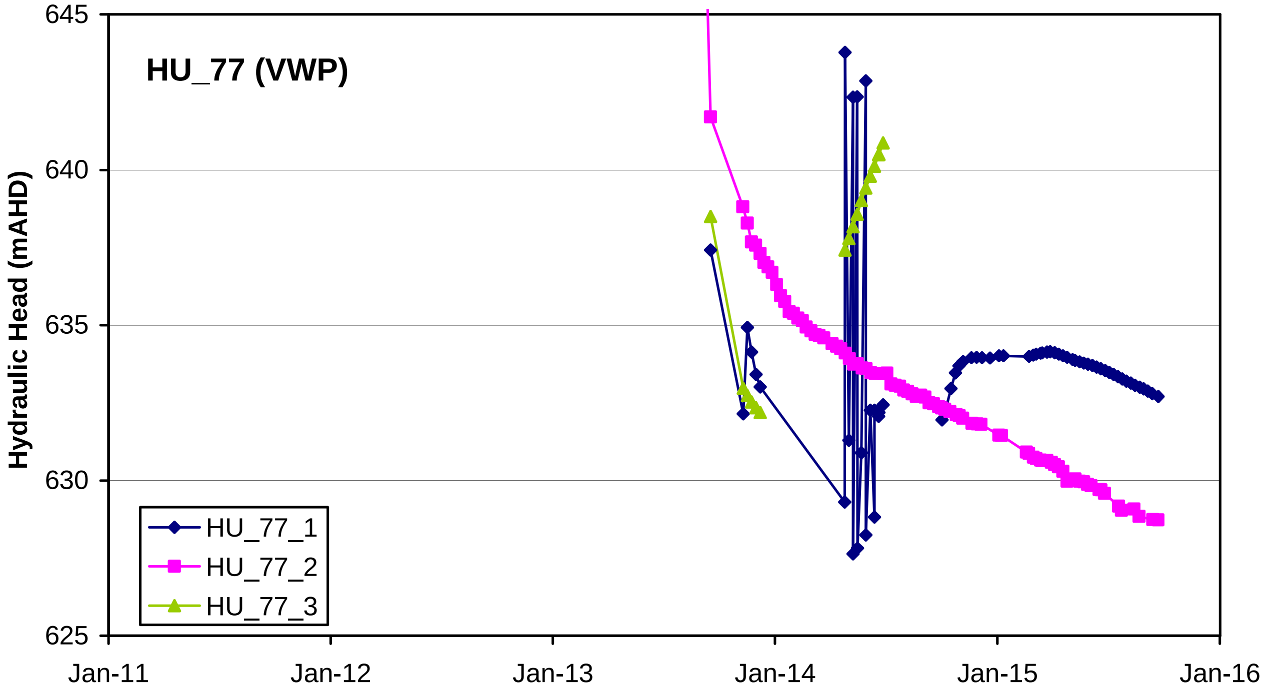

HU_136
Water Level (mAHD)
710
705
700
695
690
685
680
675
670
665
660
655
650
645
640
635
630
625
620
615
610
605
600
595
590
585
580
575
570
565
560
HU_136A
HU_136B
HU_136C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

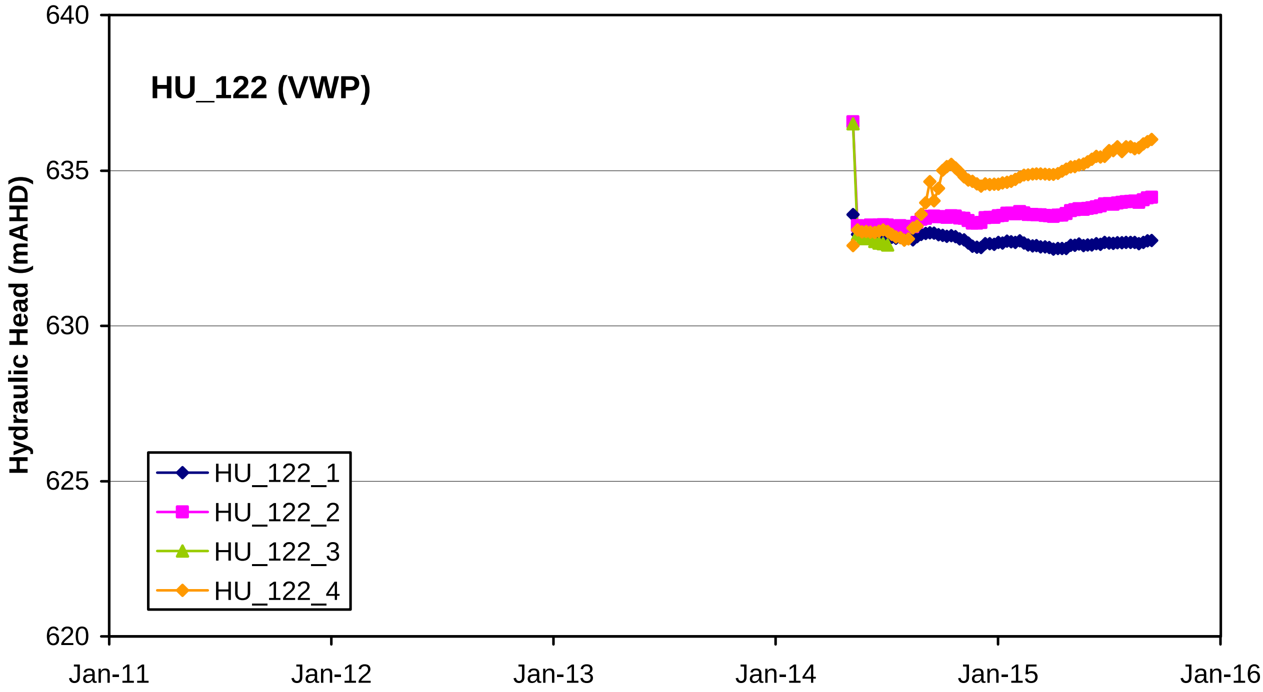

HU_142 (and HU_23)
Water Level (mAHD)
630
625
620
615
610
HU_23A
HU_142A
HU_23B
HU_142B
HU_23C
HU_142C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

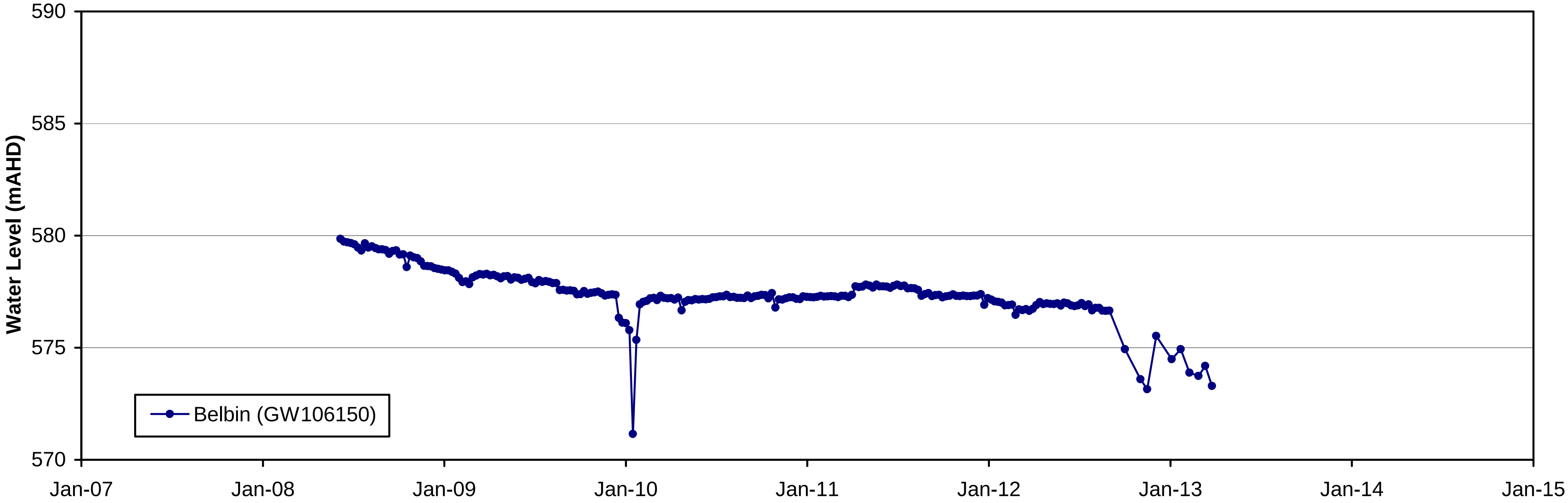

HU_143 (and HU_133)
Water Level (mAHD)
630
625
620
615
610
HU_133A
HU_143A
HU_133B
HU_143B
HU_133C
HU_143C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

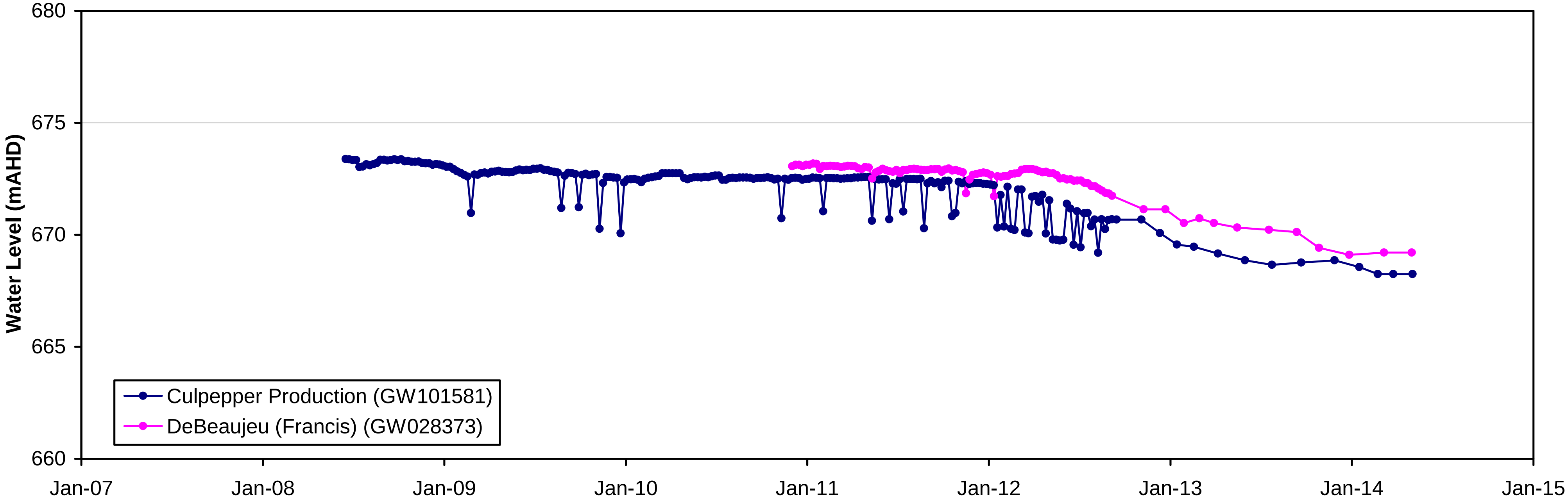

GW106710 and GW106652
Water Level (mAHD)
640
630
620
610
600
590
Water level at installation
(21/10/2004): 596mAHD
GW106710
GW106652
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

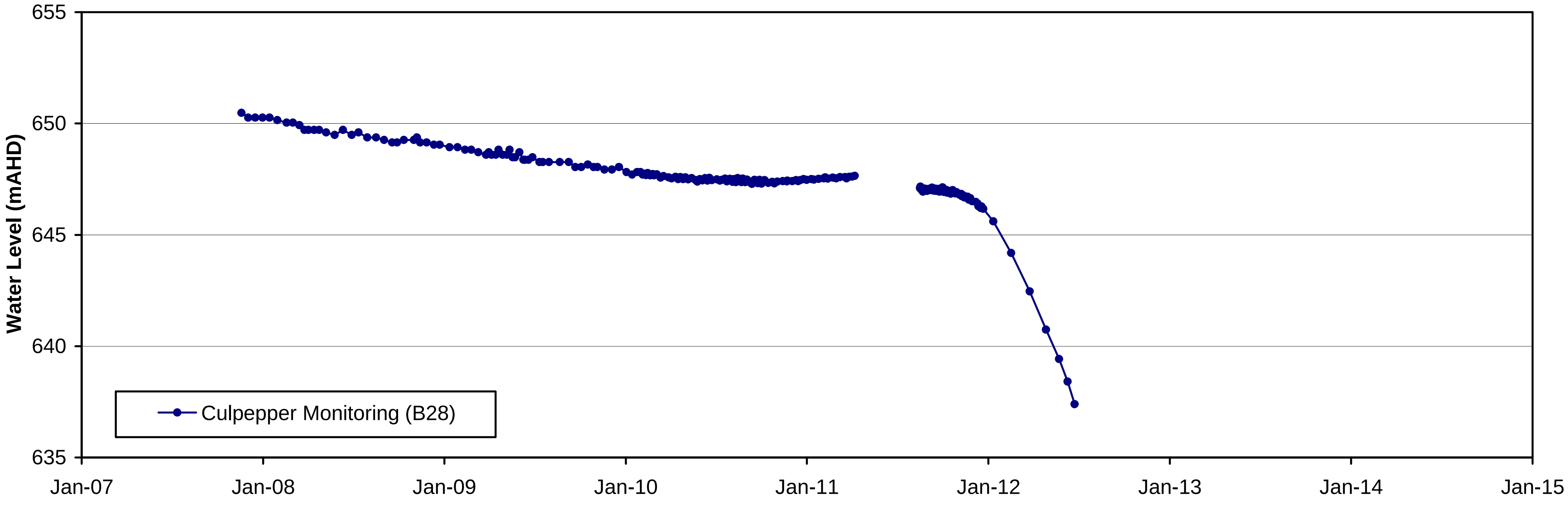

HU_40 (VWP)
Hydraulic Head (mAHD)
640
635
630
625
620
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
HU_40_1
HU_40_2
HU_40_3
HU_40_4


HU_77 (VWP)
Hydraulic Head (mAHD)
645
640
635
630
625
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
HU_77_1
HU_77_2
HU_77_3

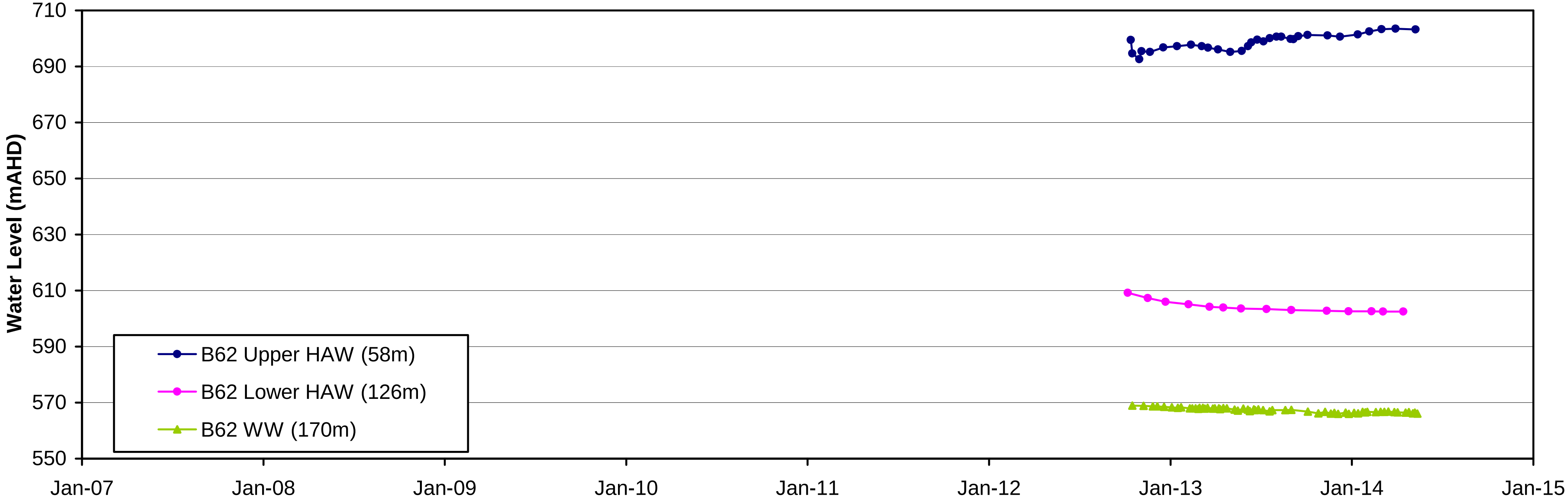

HU_122 (VWP)
Hydraulic Head (mAHD)
640
635
630
625
620
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
HU_122_1
HU_122_2
HU_122_3
HU_122_4


590
585
580
575
570
Water Level (mAHD)
Belbin (GW106150)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15

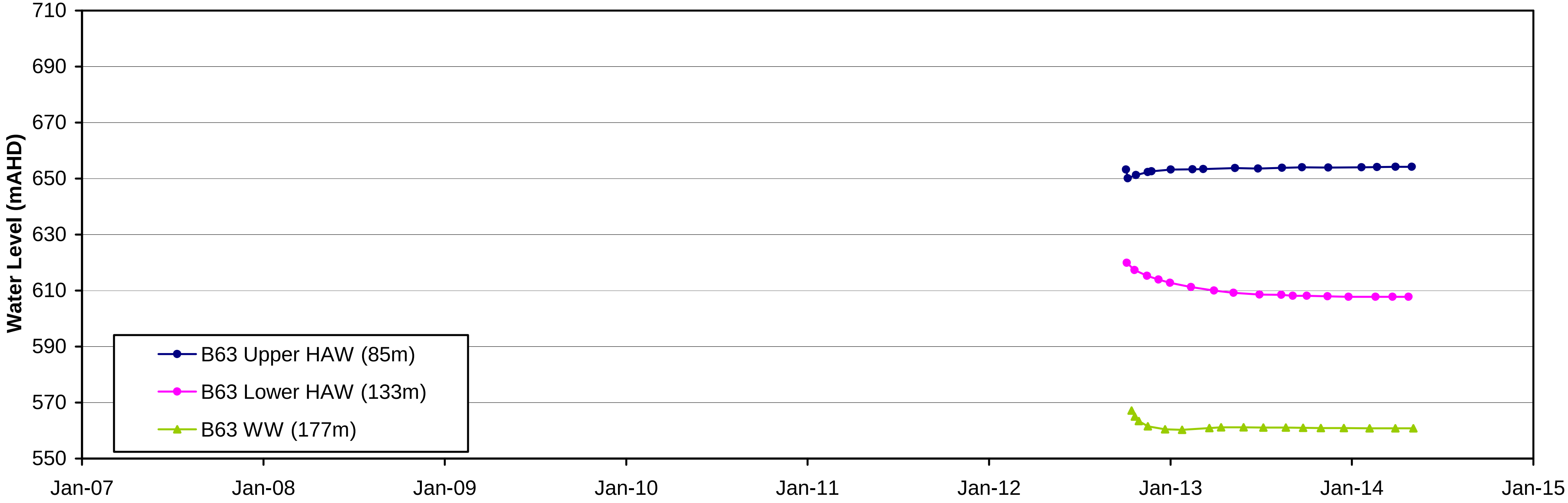

680
675
670
665
660
Water Level (mAHD)
Culpepper Production (GW101581)
DeBeaujeu (Francis) (GW028373)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



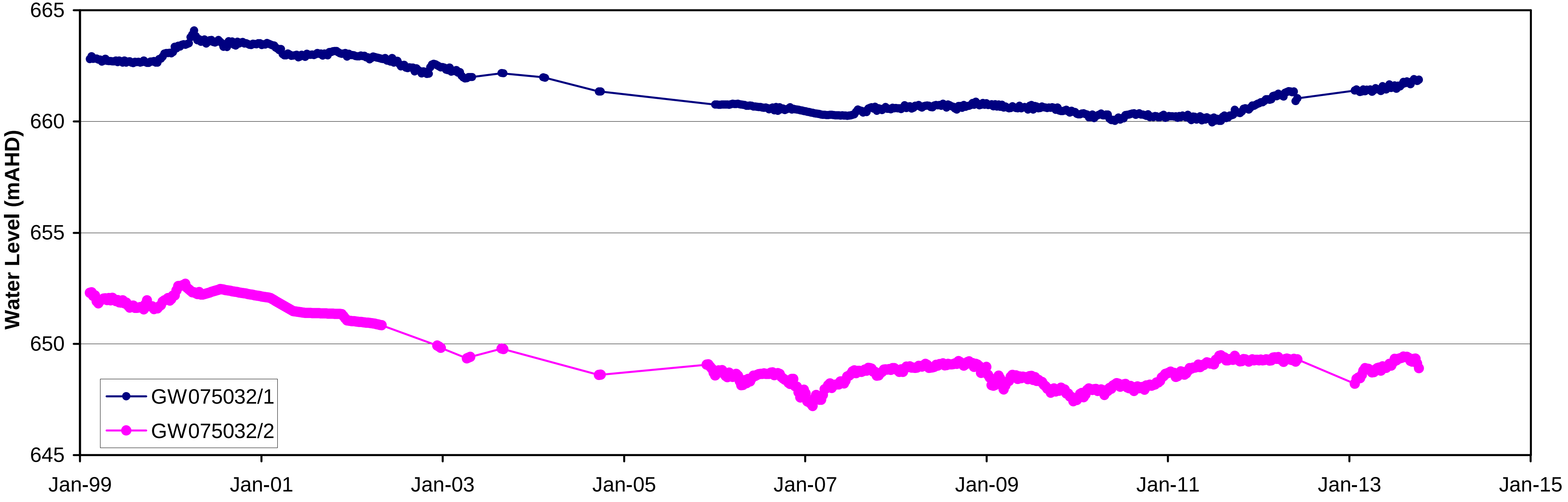
655
650
645
640
635
Water Level (mAHD)
Culpepper Monitoring (B28)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



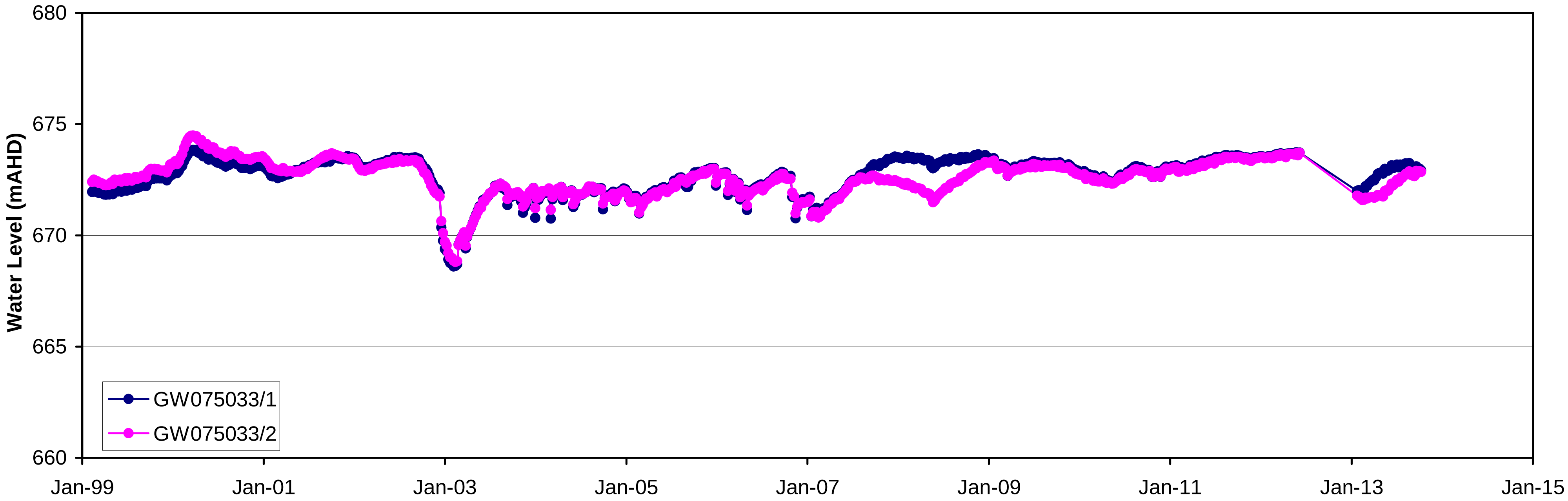
Water Level (mAHD)
710
690
670
650
630
610
590
570
550
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
B62 Upper HAW (58m)
B62 Lower HAW (126m)
B62 WW (170m)

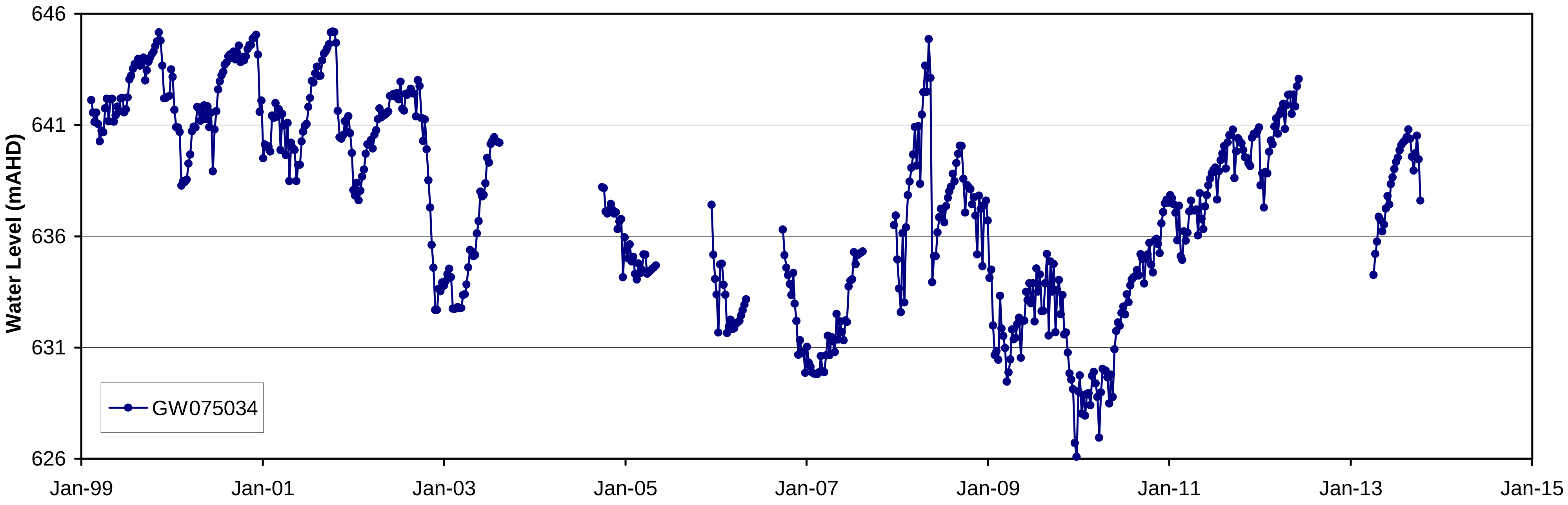
Water Level (mAHD)
710
690
670
650
630
610
590
570
550
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
B63 Upper HAW (85m)
B63 Lower HAW (133m)
B63 WW (177m)

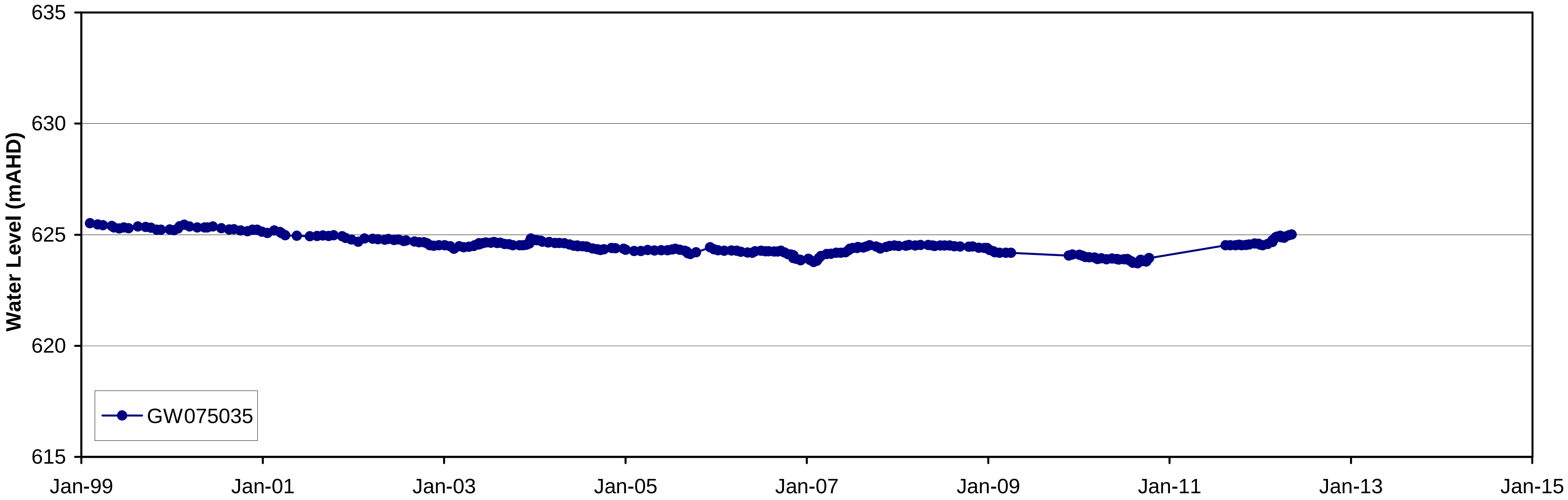


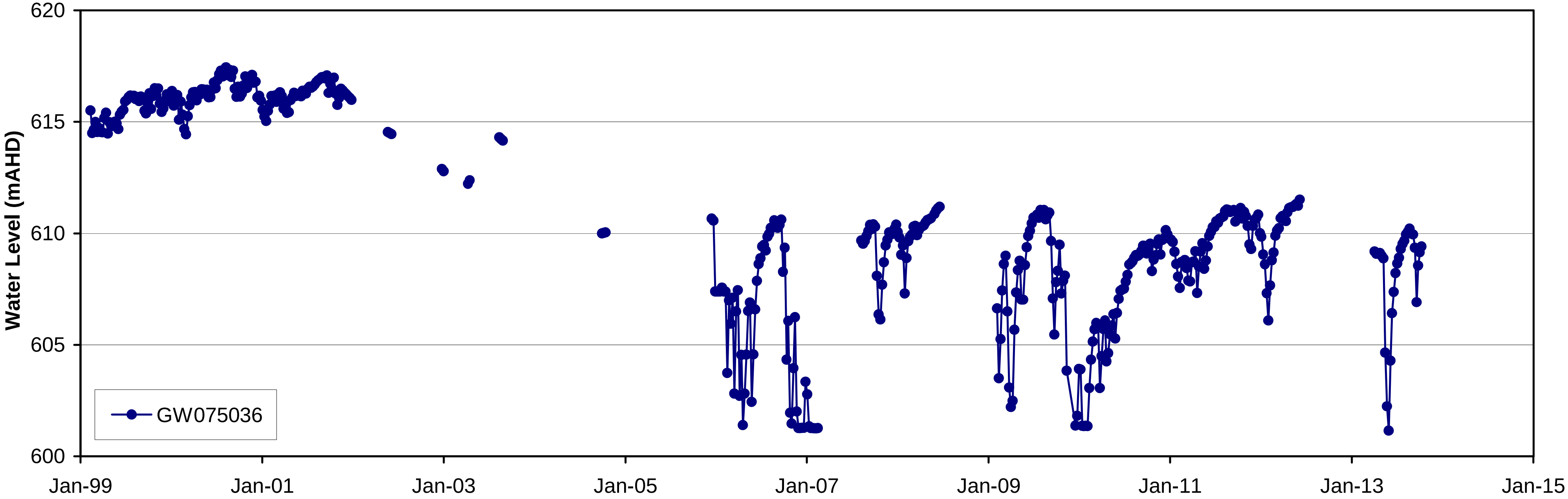
665
660
655
650
645
Water Level (mAHD)
GW075032/1
GW075032/2
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15

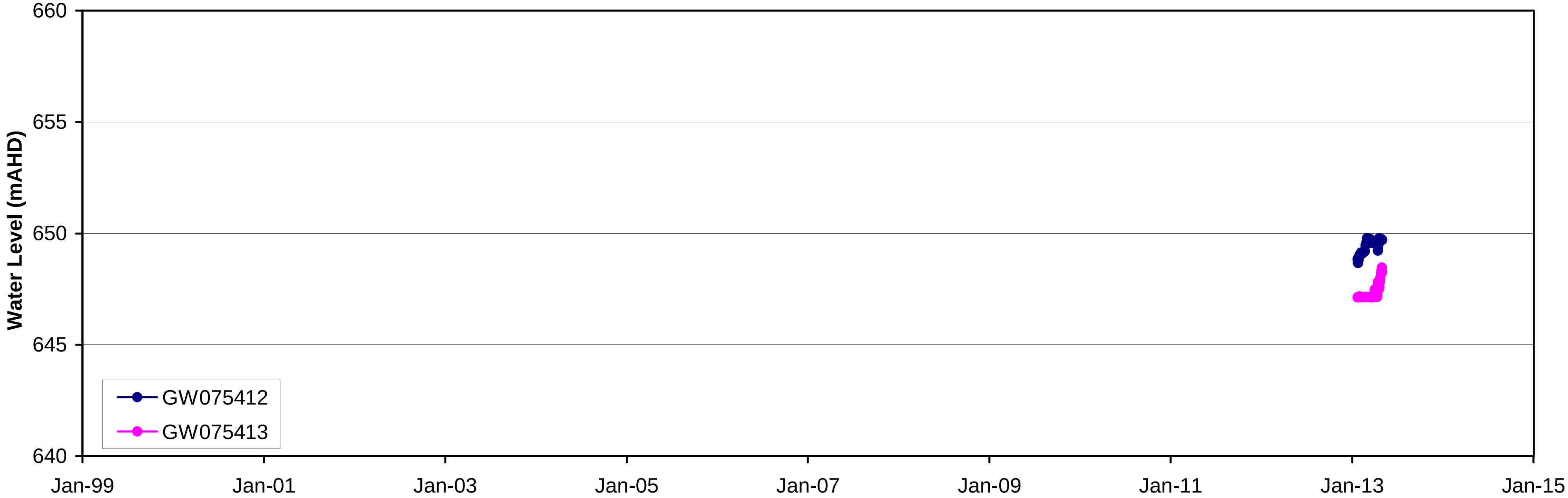
680
675
670
665
660
Water Level (mAHD)
GW075033/1
GW075033/2
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15


646
641
636
631
626
Water Level (mAHD)
GW075034
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15


635
630
625
620
615
Water Level (mAHD)
GW075035
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15

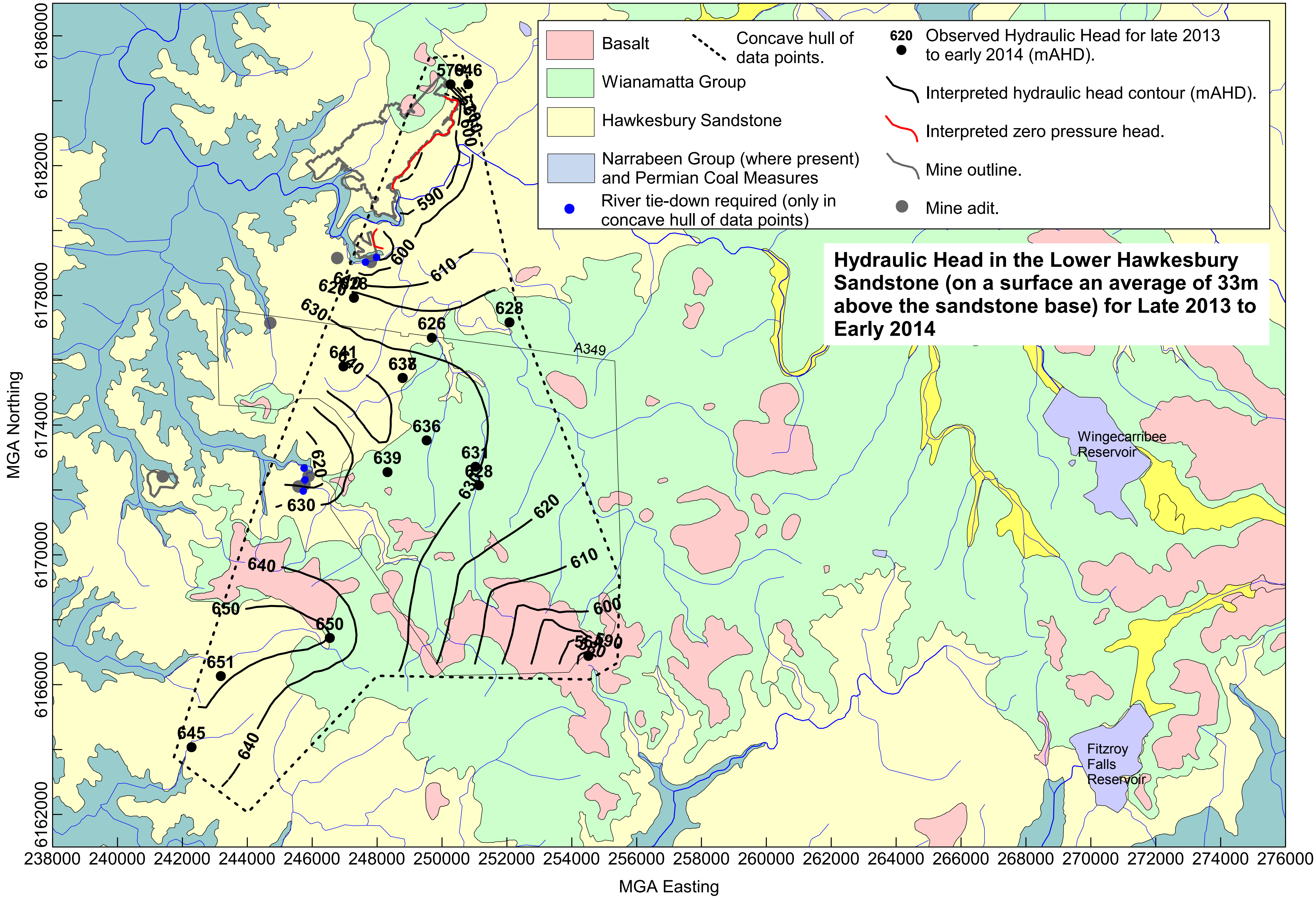


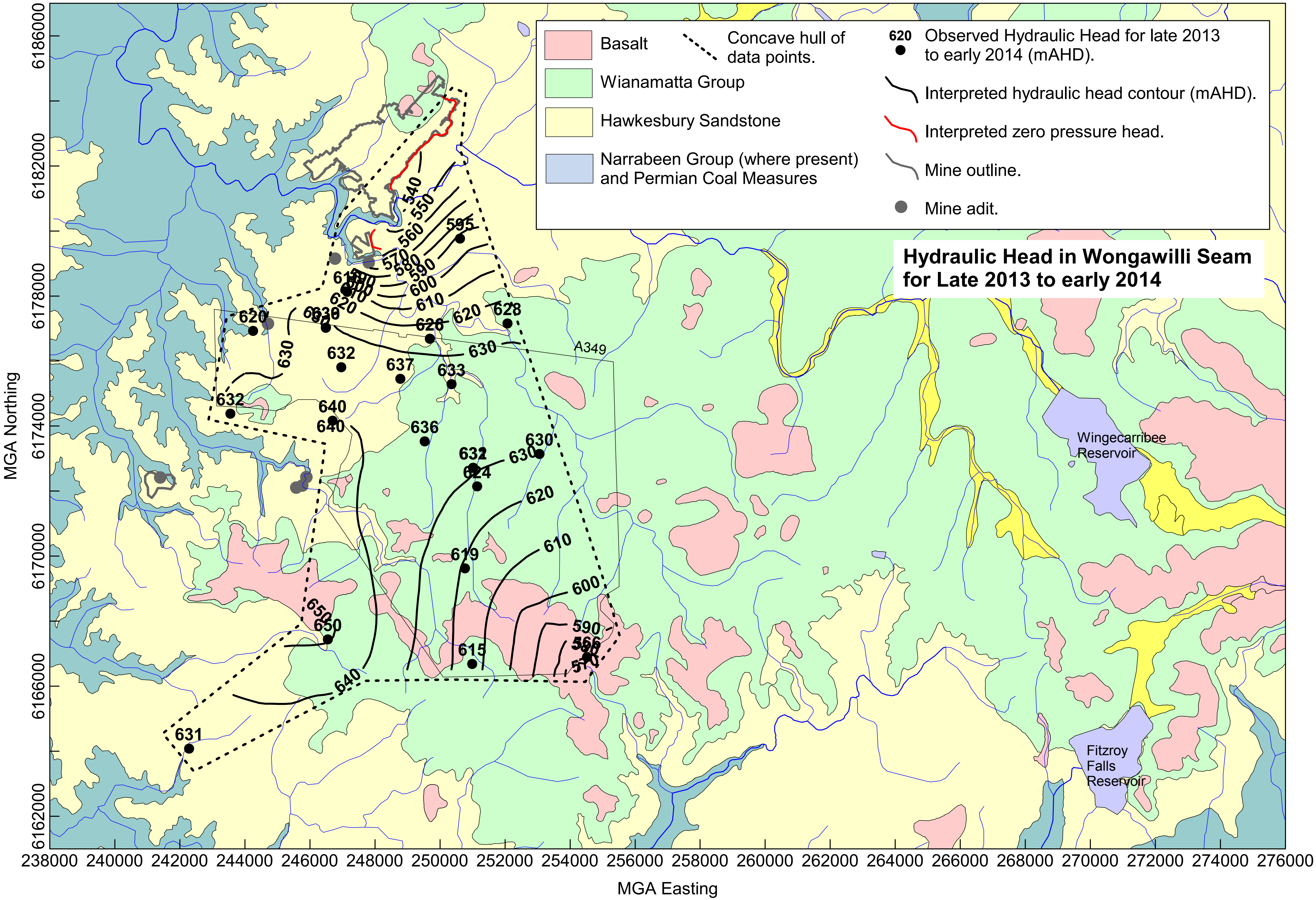
620
615
610
605
600
Water Level (mAHD)
GW075036
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15

660
655
650
645
640
Water Level (mAHD)
GW075412
GW075413
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15

# Appendix E - Hydraulic Head Surfaces


Basalt
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group (where present) and Permian Coal Measures
River tie-down required (only in concave hull of data points)
Concave hull of data points.
620 Observed Hydraulic Head for late 2013 to early 2014 (mAHD).
Interpreted hydraulic head contour (mAHD).
Interpreted zero pressure head.
Mine outline.
Mine adit.
Hydraulic Head in the Lower Hawkesbury Sandstone (on a surface an average of 33m above the sandstone base) for Late 2013 to Early 2014
Wingecarribee Reservoir
Fitzroy Falls Reservoir
A349
MGA Northing
MGA Easting
238000 240000 242000 244000 246000 248000 250000 252000 254000 256000 258000 260000 262000 264000 266000 268000 270000 272000 274000 276000
6162000 6166000 6170000 6174000 6178000 6182000 6186000



Hydraulic Head in Wongawilli Seam for Late 2013 to early 2014
Basalt
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group (where present) and Permian Coal Measures
Concave hull of data points.
620 Observed Hydraulic Head for late 2013 to early 2014 (mAHD).
Interpreted hydraulic head contour (mAHD).
Interpreted zero pressure head.
Mine outline.
Mine adit.
Wingecarribee Reservoir
Fitzroy Falls Reservoir
A349
MGA Northing
MGA Easting
6186000
6182000
6178000
6174000
6170000
6166000
6162000
238000 240000 242000 244000 246000 248000 250000 252000 254000 256000 258000 260000 262000 264000 266000 268000 270000 272000 274000 276000
540
550
560
570
580
590
600
610
620
630
640
650
595
628
626
632
637
633
636
630
624
619
615
631

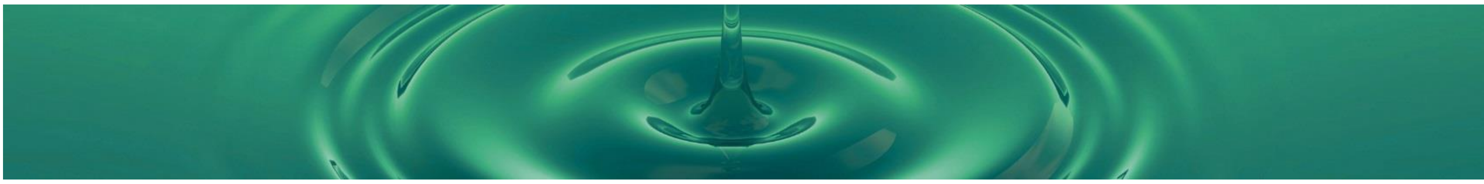
# Appendix F - Hydraulic Head Data for the Southeastern Basalt Body

## DATABASE OF WATER LEVELS IN AND AROUND THE SOUTHEASTERN BASALT BODY

| Bore | Easting (MGA) | Northing (MGA) | Network | Stratum | Ground Elevation* (mAHD) | Water Level (mAHD) | Probable date of water level measurement | Pressure Head (m) | Height above base of HAW (m) |
|---|---|---|---|---|---|---|---|---|---|
| GW011262 | 252352 | 6166970 | Private | Basalt | 723 | 719 | 1-Dec-55 | 5 | 170 |
| GW014121 | 252487 | 6166696 | Private | Basalt | 724 | 716 | 1-Dec-56 | 14 | 158 |
| GW014491 | 253454 | 6166753 | Private | Basalt | 730 | 721 | 1-Nov-56 | 7 | 180 |
| GW015061 | 251024 | 6166459 | Private | Basalt | 702 | 701 | 1-Dec-56 | 12 | 134 |
| GW050251 | 252889 | 6166923 | Private | Basalt top (weathered) | 733 | 728 | 1-Feb-79 | 9 | 180 |
| GW066761 | 253508 | 6166662 | Private | Basalt | 725 | 721 | 16-Oct-92 | 7 | 180 |
| GW066764 | 254253 | 6166435 | Private | Basalt | 712 | 698 | Unknown | 5 | 167 |
| GW066769 | 254252 | 6166466 | Private | Basalt | 711 | 704 | Unknown | 9 | 170 |
| GW066770 | 254362 | 6166160 | Private | Basalt | 710 | 700 | Unknown | 12 | 162 |
| GW067521 | 253702 | 6168715 | Private | Basalt | 683 | 665 | 28-Jan-92 | 9 | 137 |
| GW069007 | 254188 | 6166419 | Private | Basalt | 712 | 702 | 4-Nov-91 | 13 | 163 |
| GW069118 | 253610 | 6166800 | Private | Basalt | 727 | 709 | 25-Feb-91 | 6 | 171 |
| GW072154 | 253249 | 6166401 | Private | Basalt | 717 | 707 | 17-Jan-94 | 10 | 157 |
| GW072273 | 253044 | 6166546 | Private | Basalt (weathered) | 724 | 720 | 31-Jan-92 | 11 | 168 |
| GW072416 | 252451 | 6166806 | Private | Basalt | 723 | 716 | 24-Nov-94 | 8 | 165 |
| GW100256 | 254259 | 6166306 | Private | Basalt (weathered) | 712 | 704 | 10-Aug-93 | 11 | 166 |
| GW100257 | 254231 | 6166339 | Private | Basalt / Sandstone | 712 | 701 | 12-Aug-93 | 13 | 162 |
| GW101324 | 254223 | 6166588 | Private | Basalt | 712 | 705 | 26-Sep-95 | 4 | 175 |
| GW101421 | 254321 | 6165789 | Private | Basalt | 712 | 703 | 13-Mar-96 | 14 | 159 |
| GW102401 | 254158 | 6166186 | Private | Basalt / Shale | 719 | 705 | 20-Dec-96 | 32 | 145 |
| GW102621 | 254577 | 6166721 | Private | Basalt | 716 | 703 | 11-Dec-98 | 8 | 172 |
| GW102622 | 254626 | 6166784 | Private | Basalt | 719 | 707 | 13-Nov-98 | 20 | 165 |
| GW102623 | 254576 | 6166752 | Private | Basalt | 716 | 705 | 15-Nov-98 | 12 | 171 |
| GW102624 | 254548 | 6166844 | Private | Basalt | 719 | 708 | 18-Nov-99 | 6 | 179 |
| GW102964 | 253499 | 6166812 | Private | Basalt | 730 | 715 | 1-Jan-56 | 4 | 178 |
| GW104193 | 255989 | 6167862 | Private | Basalt | 686 | 680 | 13-Feb-02 | 15 | 164 |
| GW104198 | 252443 | 6166728 | Private | Basalt base | 724 | 713 | 5-Feb-02 | 13 | 156 |
| GW105097 | 253767 | 6167150 | Private | Basalt / Sandstone | 727 | 567 | 31-Oct-03 | 37 | 1 |
| GW106103 | 253879 | 6167685 | Private | Basalt base | 717 | 690 | 27-Feb-04 | 20 | 143 |
| GW107625 | 252749 | 6166539 | Private | Basalt | 723 | 716 | 15-Nov-05 | 12 | 161 |
| GW108271 | 254281 | 6167270 | Private | Basalt base | 717 | 702 | 26-Aug-06 | 47 | 132 |
| GW100720 | 253419 | 6166882 | Private | HAW below Basalt | 735 | 572 | 20-Oct-96 | 24 | 14 |
| GW102694 | 253410 | 6168417 | Private | HAW below Basalt | 707 | 618 | 1-Sep-99 | 44 | 48 |
| GW102757 | 251971 | 6167918 | Private | HAW below Basalt | 716 | 617 | 5-May-99 | 55 | 19 |

| Bore | Easting (MGA) | Northing (MGA) | Network | Stratum | Ground Elevation* (mAHD) | Water Level (mAHD) | Probable date of water level measurement | Pressure Head (m) | Height above base of HAW (m) |
|---|---|---|---|---|---|---|---|---|---|
| GW104727 | 252108 | 6169089 | Private | HAW below Basalt | 720 | 619 | 25-Mar-03 | 37 | 47 |
| GW104917 | 255641 | 6168126 | Private | HAW below Basalt | 676 | 611 | 28-Nov-02 | 64 | 43 |
| GW105093 | 252884 | 6165950 | Private | HAW Base / Top ICM | 702 | 576 | 19-Nov-03 | 25 | 4 |
| GW105308 | 250384 | 6167628 | Private | HAW below Basalt | 713 | 630 | 1-Mar-02 | 47 | 31 |
| GW105950 | 254257 | 6167973 | Private | HAW Base / Top ICM | 684 | 612 | 1-Jan-04 | 53 | 39 |
| GW110529 | 251309 | 6166226 | Private | HAW Base / Top ICM | 705 | 585 | 29-Oct-09 | 34 | -3 |
| H136A | 254521 | 6166894 | Hume | WW | 718 | 566 | 22-May-14 | 47 | -4 |
| H136B | 254517 | 6166890 | Hume | HAW | 718 | 564 | 22-May-14 | 7 | 34 |
| H136C | 254513 | 6166887 | Hume | RB | 718 | 708 | 22-May-14 | 44 | 140 |
| H42A | 250988 | 6166688 | Hume | WW | 702 | 615 | 23-Mar-14 | 70 | -7 |
| H42C | 250985 | 6166678 | Hume | HAW | 702 | 613 | 21-Aug-14 | 54 | 7 |

* Approximate for private bores (estimated from overplotting with digitial elevation model).



# APPENDIX F – HUME COAL PROJECT EIS GROUNDWATER ASSESSMENT VOLUME 2: MODELLING AND IMPACT ASSESSMENT (COFFEY 2016B)

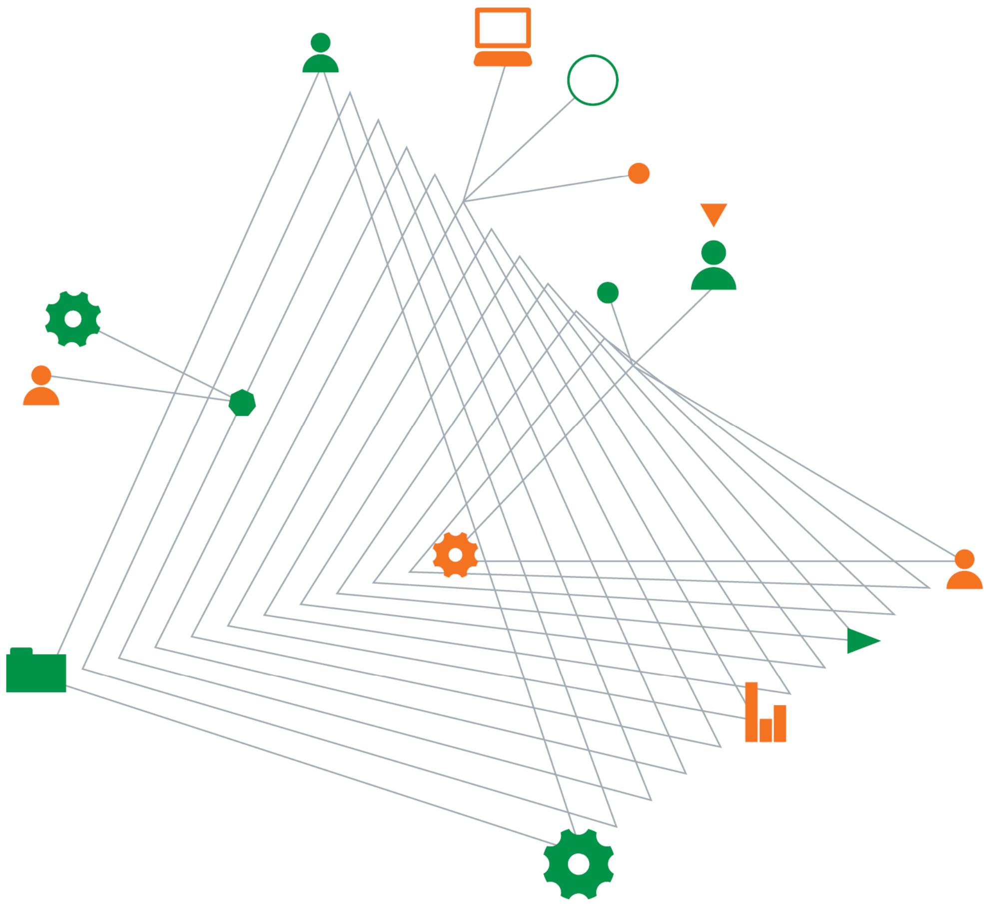
coffey
A TETRA TECH COMPANY

**Hume Coal Pty Limited**

**Hume Coal Project**

Groundwater Assessment Volume 2: Numerical Modelling and Impact Assessment

17 November 2016



Experience
comes to life
when it is
powered by
expertise

# Hume Coal Project

Prepared for
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17 November 2016

## Document authorisation

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For and on behalf of Coffey

**Paul Tammetta**
Associate Subsurface Hydrologist

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# Executive Summary

A regional numerical groundwater flow model was developed for the Hume Coal Project. Model calibration was successful in reproducing shallow groundwater discharges (stream baseflow), deep groundwater discharges (discharge to the Berrima mine void), and hydraulic heads, and has adhered strongly to the observed hydraulic conductivity distribution.

The combination of observations from the pumping tests undertaken by Hume, with shallow and deep discharge observations, allows the calibrated Kv distribution to be applicable to an appropriate scale and is considered to have a high level of reliability, including reliable representation of the effects of the high density of open bores present in the area, and the tectonic activity that has occurred in the area.

This has reduced the uncertainty in model outputs. The model is considered to be acceptably calibrated and fit for its purpose in simulating the groundwater system with application of the magnitude of the stress defined by the Hume mine schedule.

The model was subsequently used in a predictive capacity to assess impacts from Hume mining operations using the Pine Feather layout and method. Model predictive simulation results are as follows:

- The total volume of groundwater inflow that reports to the sump is calculated as 8.4 GL during the time the effects of mining are active in the groundwater system. The maximum inflow rate to the sump is 2.7 ML/day (1000 ML/year) in year 17 of mining.
- The total volume of groundwater inflow that reports to the void is 24.3 GL during the time the effects of mining are active in the groundwater system. The maximum inflow rate to the void is 5.1 ML/day (1860 ML/year) in year 15 of mining.
- The drawdown footprint achieves a maximum size at about 17 years since the start of mining. The zone of highest drawdown in the footprint migrates according to worked areas. At 17 years, the 2 m differential drawdown* contour at the water table extends a maximum of about 2 km past the southeast corner of the mine footprint. The duration of differential drawdown of the water table varies between about 15 years and 60 years. Recovery of the water table over most of the area, to 2 m differential drawdown, is largely complete within about 60 years after the start of Hume mining.
- Maximum total drawdown of the water table greater than 2 m occurs at several locations where there are shallow water levels. These areas have been provided to the ecology team to consider potential impacts to ecosystems that may be present at these locations.
- No direct leakage from the Wingecarribee River, induced by Hume operations, is calculated by the model. Model results indicate that 98% of the total inflow to the Hume mine workings is satisfied by interception of baseflow to streams, and release of groundwater storage from media. 2% of the inflow is satisfied by leakage from Medway Reservoir (a total leakage of approximately 804 ML over 22 years, or an overall average over the period of approximately 0.1 ML/day). Baseflow interception induced by Hume operations is largest for Medway Rivulet. Baseflow analysis of flow observations from Medway Rivulet suggests the average baseflow measured at these gauges (over the monitoring period) is about 3 times larger than the calculated future maximum baseflow interception.
- Of the 117 private bores identified as residing in the potential drawdown zone, 99 bores are assessed as being subject to a differential drawdown of 2 m or more. The overall average proportion of the maximum total drawdown that is caused by Hume operations is 87%. Groundwater extraction by private users accounts for the remaining 13%. The duration of the period for each bore where differential drawdown is greater than 2 m ranges between 2 months and 65 years, with an average of 34 years. The majority of these bores have recovered back to 2

m differential drawdown by 60 years since the start of mining. Five of these bores are likely to be intersected by mining because they penetrate the mined zone.

* Differential drawdown is calculated as the difference between drawdowns from the active Hume mining scenario (which gives the total drawdown) and a null scenario where the Hume operation is inactive (giving a null case drawdown). The differential drawdown is thus that drawdown due only to the Hume operation.

# 1. Introduction

This is the second of two volumes that present the results of a groundwater assessment for the Hume Coal Project. The assessment was undertaken by Coffey Geotechnics Pty Ltd (Coffey) for Hume Coal Pty Limited (Hume). The purpose of the assessment was to assess impacts on the groundwater system and groundwater users due to the proposed mining. Results of the assessment will be used to support an application for development consent.

Approval for the Hume Coal Project is being sought under Part 4, Division 4.1 of the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) and the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). An environmental impact statement (EIS) is a requirement of the approval processes. This groundwater assessment forms part of the EIS. It documents the groundwater assessment methods and results, and outlines initiatives built into the project design to avoid and minimise impacts on the groundwater system.

The assessment comprised compilation and analysis of a groundwater database, development of a hydrogeological conceptual model, and development of a groundwater flow numerical model to simulate drawdown on the groundwater system and on private water bores from mining. This volume presents numerical model development, calibration, and predictive simulations and results.

An analysis of a substantial database of observations compiled from data provided by Hume and published sources, was undertaken to support development of the hydrogeological conceptual model and subsequent numerical model development and calibration. That analysis is reported in Volume 1. This volume should be read in conjunction with Volume 1.

## 1.1. Background

Hume proposes to develop and operate an underground coal mine and associated mine infrastructure (the 'Hume Coal Project') in the Southern Coalfield of NSW. Hume is a wholly owned subsidiary of POSCO Australia. Hume holds exploration Authorisation 349 (A349), which covers an area of 89 $km^2$ to the west of Moss Vale, in the Wingecarribee local government area (LGA). A349 adjoins the southern boundary of the Berrima Colliery lease (CCL748). The underground mine will be developed within A349 and associated surface infrastructure facilities will be developed within and north of A349. The project area and its regional setting are shown in Drawing 1. Drawing 1 shows the interrelationship between A349, the mining lease application area, the proposed workings, and the model domain boundary; the latter two features are further discussed in this report and the numerical simulation report.

The project has been developed following several years of technical investigations to identify and address potential environmental, social and economic constraints. This has allowed for the development of a well-considered, practical and economic project design that will enable effective resource recovery, while minimising adverse impacts to the environment and community.

Hume proposes to use a non-caving first workings mining layout and method, which is a low impact method having negligible subsidence effects, and offering a significant amount of protection to overlying hydrostratigraphic media and surface features. The mining target is the Wongawilli Coal Seam of the Permian Illawarra Coal Measures.

### 1.1.1. Project description

The project involves developing and operating an underground coal mine and associated infrastructure over a total estimated project life of 23 years. A full description of the project, as assessed in this report, is provided in Chapter 2 of the main EIS (EMM 2016). In summary, the project involves:

- Ongoing resource definition activities, along with geotechnical and engineering testing, and other low impact fieldwork to facilitate detailed design.
- Establishment of a temporary construction accommodation village.
- Development and operation of an underground coal mine, consisting of approximately two years of construction and 19 years of mining, followed by a closure and rehabilitation phase of up to two years, leading to a total project life of 23 years. Some coal extraction will commence during the second year of construction during installation of the drifts, and hence there will be some overlap between the construction and operational phases.
- Extraction of approximately 50 million tonnes (Mt) of run-of-mine (ROM) coal from the Wongawilli Seam, at a rate of up to 3.5 million tonnes per annum (Mtpa). Low impact mining methods will be used, which will have negligible subsidence impacts.
- Following processing of ROM coal in the coal preparation plant (CPP), production of up to 3 Mtpa of metallurgical and thermal coal for sale to international and domestic markets.
- Construction and operation of associated mine infrastructure, mostly on cleared land, including:
  - One personnel and materials drift access and one conveyor drift access from the surface to the coal seam.
  - Ventilation shafts, comprising one upcast ventilation shaft and fans, and up to two downcast shafts installed over the life of the mine, depending on ventilation requirements as the mine progresses.
  - A surface infrastructure area, including administration, bathhouse, washdown and workshop facilities, fuel and lubrication storage, warehouses, laydown areas, and other facilities. The surface infrastructure area will also comprise the CPP and ROM coal, product coal and emergency reject stockpiles.
  - Surface and groundwater management and treatment facilities, including storages, pipelines, pumps and associated infrastructure.
  - Overland conveyors.
  - Rail load-out facilities.
  - Explosives magazine.
  - Ancillary facilities, including fences, access roads, car parking areas, helipad and communications infrastructure.
  - Environmental management and monitoring equipment.
- Establishment of site access from Mereworth Road, and minor internal road modifications and relocation of some existing utilities.
- Coal reject emplacement underground, in the mined-out voids.
- Peak workforces of approximately 414 full-time equivalent employees during construction and approximately 300 full-time equivalent employees during operations.
- Decommissioning of mine infrastructure and rehabilitation of the area once mining is complete, so that it can support land uses similar to current land uses.

The project area, shown in Figure 1.1, is approximately 5,051 hectares (ha). Surface disturbance will mainly be restricted to the surface infrastructure areas shown in Figure 1.2, though will include some other areas above the underground mine, such as drill pads and access tracks. The project area generally comprises direct surface disturbance areas of up to approximately 117 ha, and an underground mining area of approximately 3,472 ha, where negligible subsidence impacts are anticipated.

A construction buffer zone will be provided around the direct disturbance areas. The buffer zone will provide an area for construction vehicle and equipment movements, minor stockpiling and equipment laydown, as well as allowing for minor realignments of surface infrastructure. Ground disturbance will generally be minor and associated with temporary vehicle tracks and sediment controls as well as minor works such as backfilled trenches associated with realignment of existing services. Notwithstanding, environmental features identified in the relevant technical assessments will be marked as avoidance zones so that activities in this area do not have an environmental impact.

Product coal will be transported by rail, primarily to Port Kembla terminal for the international market, and possibly to the domestic market depending on market demand. Rail works and use are the subject of a separate EIS and State significant development application for the Berrima Rail Project.

## General site description

The project area is approximately 100 km southwest of Sydney and 4.5 km west of Moss Vale town centre in the Wingecarribee LGA (refer to Drawing 1 and Figure 1.1). The nearest area of surface disturbance will be associated with the surface infrastructure area, which will be 7.2 km northwest of Moss Vale town centre. It is in the Southern Highlands region of NSW and the Sydney Basin Biogeographic Region.

The project area is in a semi-rural setting, with the wider region characterised by grazing properties, small-scale farm businesses, natural areas, forestry, scattered rural residences, villages and towns, industrial activities such as the Berrima Cement Works and Berrima Feed Mill, and some extractive industry and major transport infrastructure such as the Hume Highway.

Surface infrastructure is proposed to be developed on predominately cleared land owned by Hume Coal or affiliated entities, or for which there are appropriate access agreements in place with the landowner. Over half of the remainder of the project area (principally land above the underground mining area) comprises cleared land that is, and will continue to be, used for livestock grazing and small-scale farm businesses. Belanglo State Forest covers the northwestern portion of the project area and contains introduced pine forest plantations, areas of native vegetation and several creeks that flow through deep sandstone gorges. Native vegetation within the project area is largely restricted to parts of Belanglo State Forest and riparian corridors along some watercourses.

The project area is traversed by several drainage lines including Oldbury Creek, Medway Rivulet, Wells Creek, Wells Creek Tributary, Belanglo Creek and Longacre Creek, all of which ultimately discharge to the Wingecarribee River, at least 5 km downstream of the project area (Figure 1.1). The Wingecarribee River's catchment forms part of the broader Warragamba Dam and Hawkesbury-Nepean catchments. Medway Dam is also adjacent to the northern portion of the project area (Figure 1.1).

Most of the central and eastern parts of the project area have very low rolling hills with occasional elevated ridge lines. However, there are steeper slopes and deep gorges in the west in Belanglo State Forest.

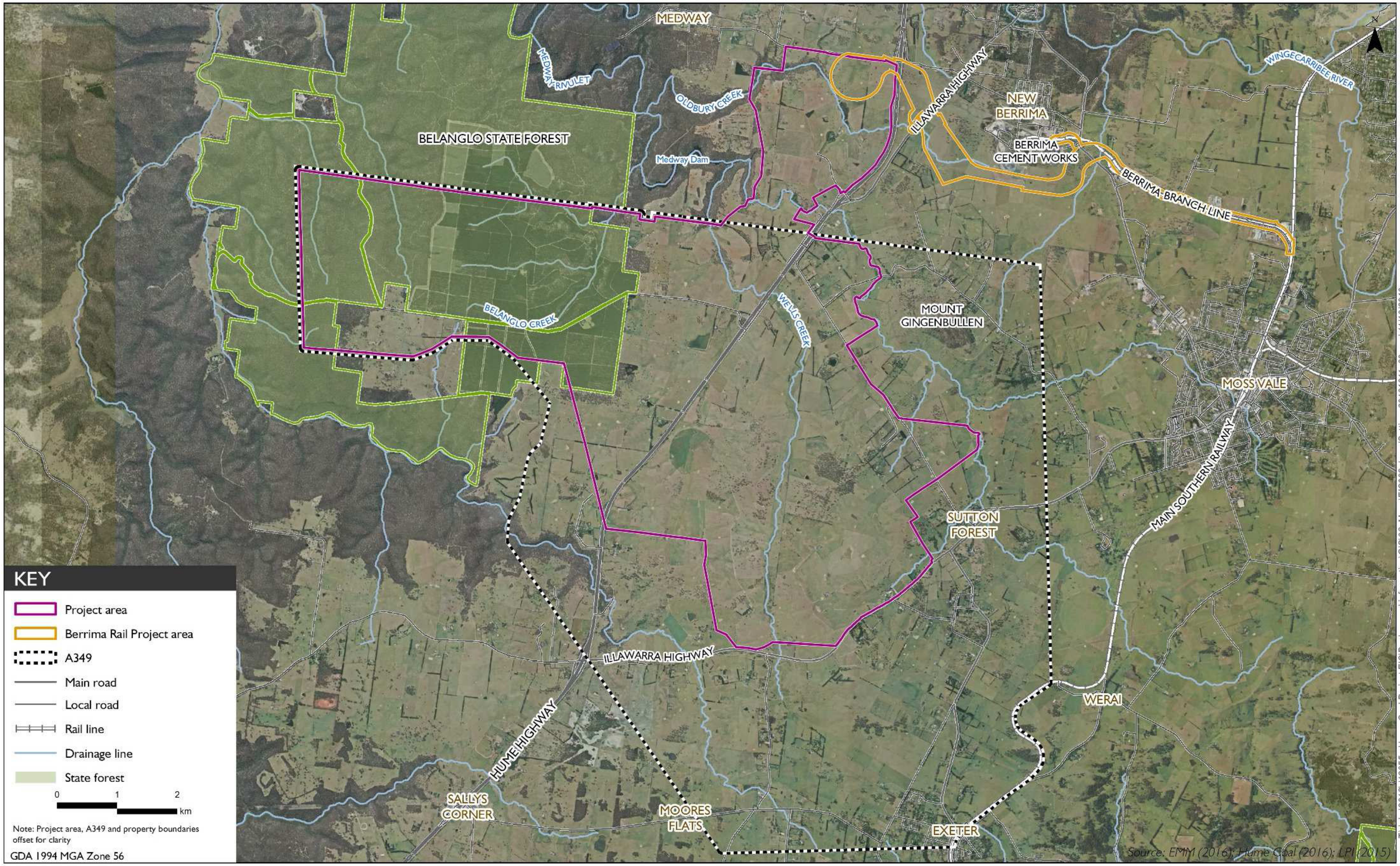


**Figure 1.1. Local context**

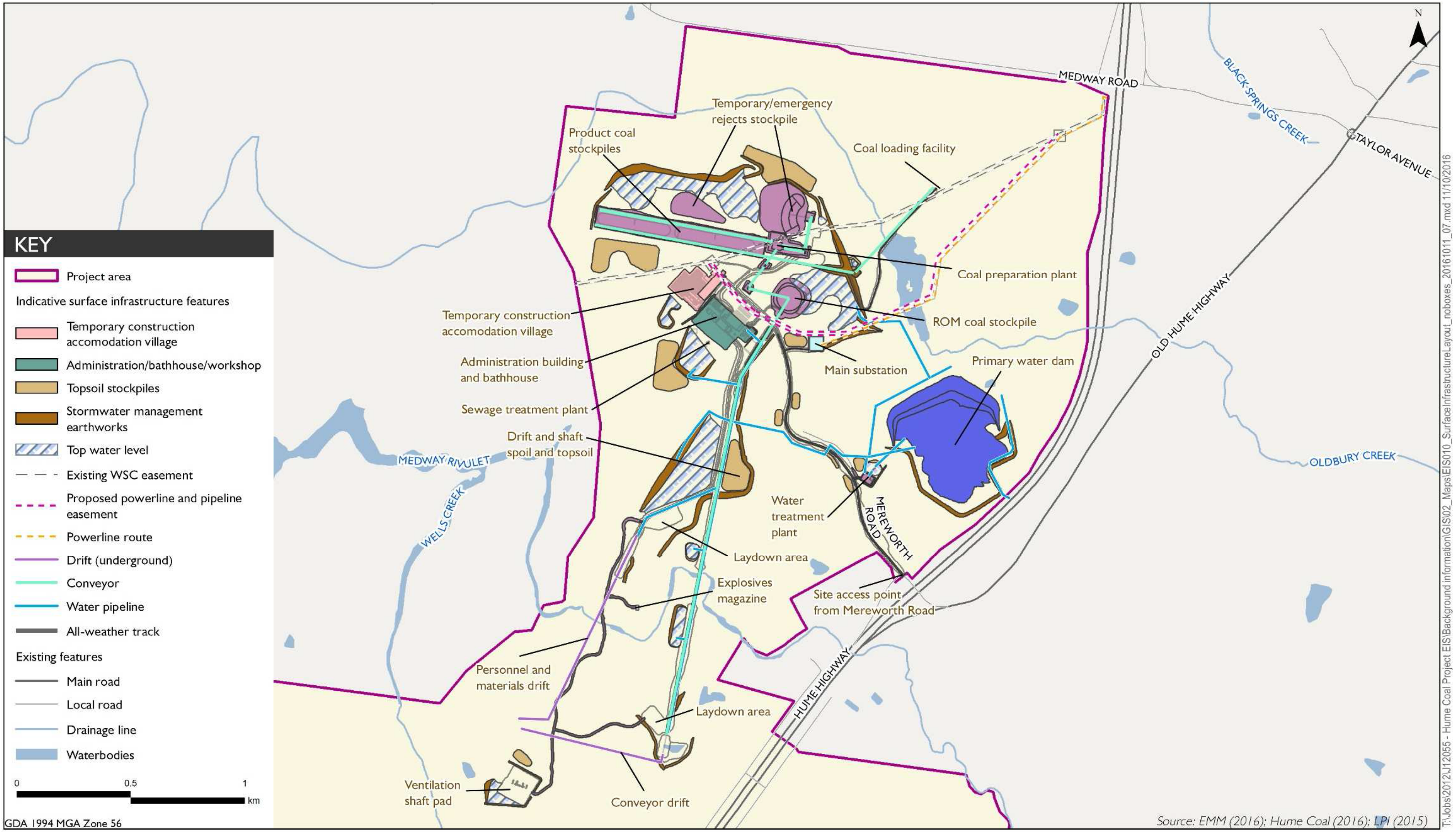


**Figure 1.2. Indicative surface infrastructure layo** **ut.**

Existing built features across the project area include scattered rural residences and farm improvements such as outbuildings, dams, access tracks, fences, yards and gardens, as well as infrastructure and utilities including roads, electricity lines, communication cables and water and gas pipelines. Key roads that traverse the project area are the Hume Highway and Golden Vale Road. The Illawarra Highway borders the south-east section of the project area.

Industrial and manufacturing facilities adjacent to the project area include the Berrima Cement Works and Berrima Feed Mill on the fringe of New Berrima. Berrima Colliery's mining lease (CCL 748) also adjoins the project area's northern boundary. Berrima colliery is currently not operating with production having ceased in 2013 after almost 100 years of operation. The mine is currently undergoing closure.

### 1.1.2. Assessment guidelines and requirements

This groundwater assessment has been prepared generally in accordance with the following:

- Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A, and Boronkay A. 2012. Australian groundwater modelling guidelines. Waterlines Report Series, Number 82. National Water Commission, Canberra.
- NSW Department of Primary Industries (Office of Water). 2012. NSW Aquifer Interference Policy: NSW Government policy for the licensing and assessment of aquifer interference activities. September.

## 1.2. Previous mining

Mining has occurred in the area since the 1800s. Mines in the area are now abandoned, all believed to be underground, comprising (see Drawing 1):

- Berrima Mine, located to the north of Wingecarribbee River on the Berrima Mine lease. The workings are the most extensive of any mine in the area and comprise 1st workings and pillar extraction in the Wongawilli seam. Mining operations commenced in 1926 and ceased in 2013. Mechanisation (and full extraction) commenced in 1968 (EMGA 2011). Production varied between 0.13 and 0.46 Mt/year and was reported as 0.25 Mt/year in 2009 (EMGA 2011). The workings are currently under care and maintenance, remaining largely empty and draining to the Wingecarribee River. Groundwater impacts from this mine can be identified in monitoring piezometer hydrographs. The owner is considering sealing the mine to reduce or eliminate drainage to the river. Groundwater and surface water quality, and groundwater levels, around the mine are monitored by Boral.
- The Loch Catherine Mine (abandoned), opened in 1924 with an anticipated maximum possible production of 200 t/day. It is located underneath the current Berrima Colliery stockpile on a localised zone of Hawkesbury Sandstone bounded by Medway Rivulet and the Wingecarribee River. The mine worked the Wongawilli Seam and ceased in 1958 (BCSC 1993). It included some mechanised workings utilising shuttle cars. Full extraction is thought to have occurred based on the shape of the mine footprint, and its presence in the Mine Subsidence Compensation Act on the list of compulsory contributors to the compensation fund. The adits are still open, and iron staining is evident in the water pooled at the mine entries.
- Southern Colliery (abandoned), located on Foxgrove Road about 5 km from the Hume lease boundary. Mining appears to have occurred in the Tongarra Seam. This was a small scale mine which ceased operations many years ago.
- Numerous adits at coal seam outcrops along escarpments (see Drawing 1, not all identified) for pre-mechanisation (manual) abandoned workings. Typical examples are Black Bobs, Belanglo (abandoned in the 1950s), Belanglo Extended, and Flying Fox collieries to the west and the north

of the Hume lease, and Erith Colliery near Bundanoon. These were likely to be very small operations, probably mining less than 100,000 t in total. Most are not sealed and drain into local watercourses. They typically consist of two headings extending in from outcrop by a few hundred metres. Belanglo was a small operation along Black Bobs Creek, presumed to be on the southern side of the creek, to the west of the Hume Highway. Murrimba Colliery was on the eastern side of Black Bobs Creek in approximately the same location and was abandoned after hitting a full face of stone a few hundred metres from the creek (coincident with a high magnetic anomaly). Belanglo Colliery is located in the Berrima lease in a tributary of Medway Rivulet.

Two adits have also been discovered along Longacre Creek. The workings are of unknown length. They are above one another (in the Tongarra and Wongawilli seams). Historical literature discusses a number of old mines in the area around the Loch Catherine mine, and it is likely that other small scale abandoned mine workings are present along the coal seam outcrop in this area.

# 2. Proposed mining

Hume will undertake a first workings mining layout and method. Mining is to be carried out in separate compartments known as panels. A panel consists of a number of plunges (parallel tunnels driven into the seam with unmined coal between plunges) connected by gate roads driven along the long dimension of the panel. A panel of the Hume first workings method is dissimilar to a panel in longwall mining with respect to post-mining deformation. All tunnels in a panel occur within the seam. Each panel is separated from the next by unmined coal. A group of panels forms a mining block, where each panel in the block is connected by a set of main headings that allow access for workers, equipment and ventilation, and also provide mined coal during their development. The set of headings remains open until mining of the last panel in the block is finished. Figure 2.1 is a detail of two panels for reference in the following discussion.

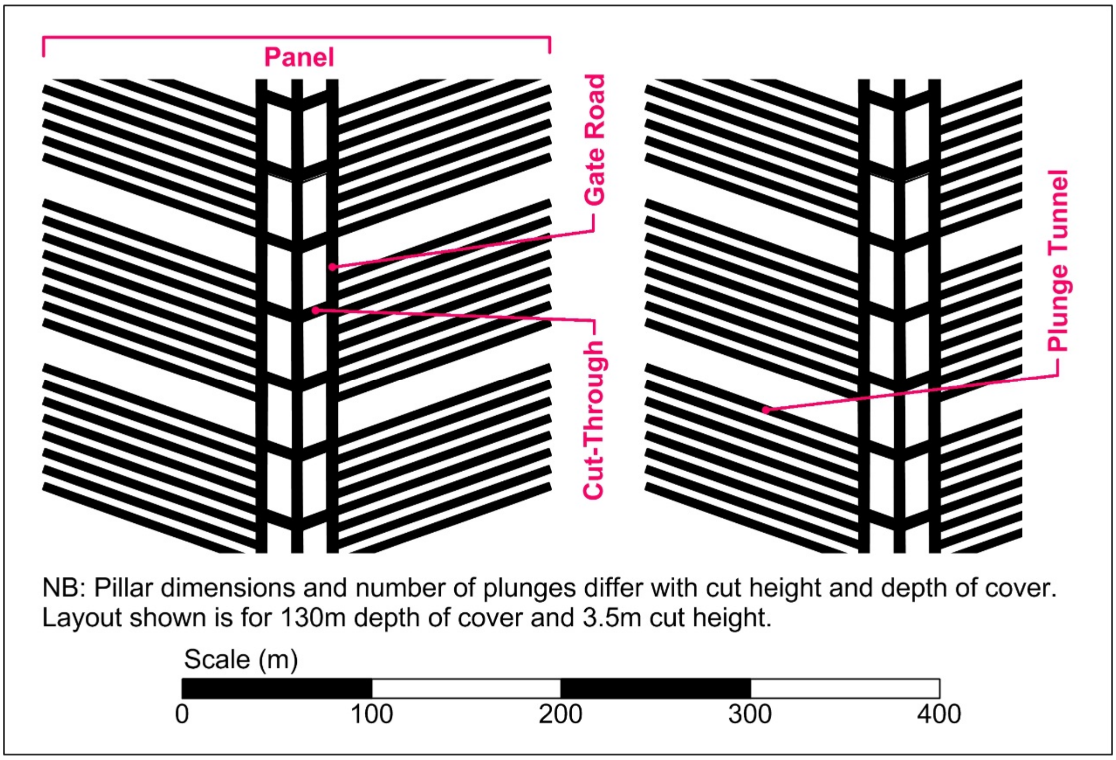


**Figure 2.1. Detail of mine openings for the first workings mining method. Black areas indicate removed coal. Refer to Table 1 for panel dimensions and other information.**

A mining height of 3.5 m has been adopted. Where the coal seam is thinner than 3.5 m, a cutoff height of 1.8 m has been assumed. All panels are initially developed with gate roads (and associated cut-throughs) that are driven off the main headings in a direction parallel to the panel long dimension. Gate roads are positioned down the centre of the panel. The mining method is non-caving, with additional workings comprising plunges (tunnels) that are driven off the gate roads. These openings are separated by pillars that are designed not to fail post-mining. This results in openings remaining open post-mining, without caving (goaf is not created). Relaxation in the immediate roof over the openings is generally limited to less than 3 m into the overlying roof.

Figure 2.2 shows the panel layout to be used for the Hume mine, and made the subject of predictive simulations. Panel and headings names are also shown. Mining comprises 54 panels, four main headings (three of which have flanking plunges attached directly to them), two shafts, and one sump.

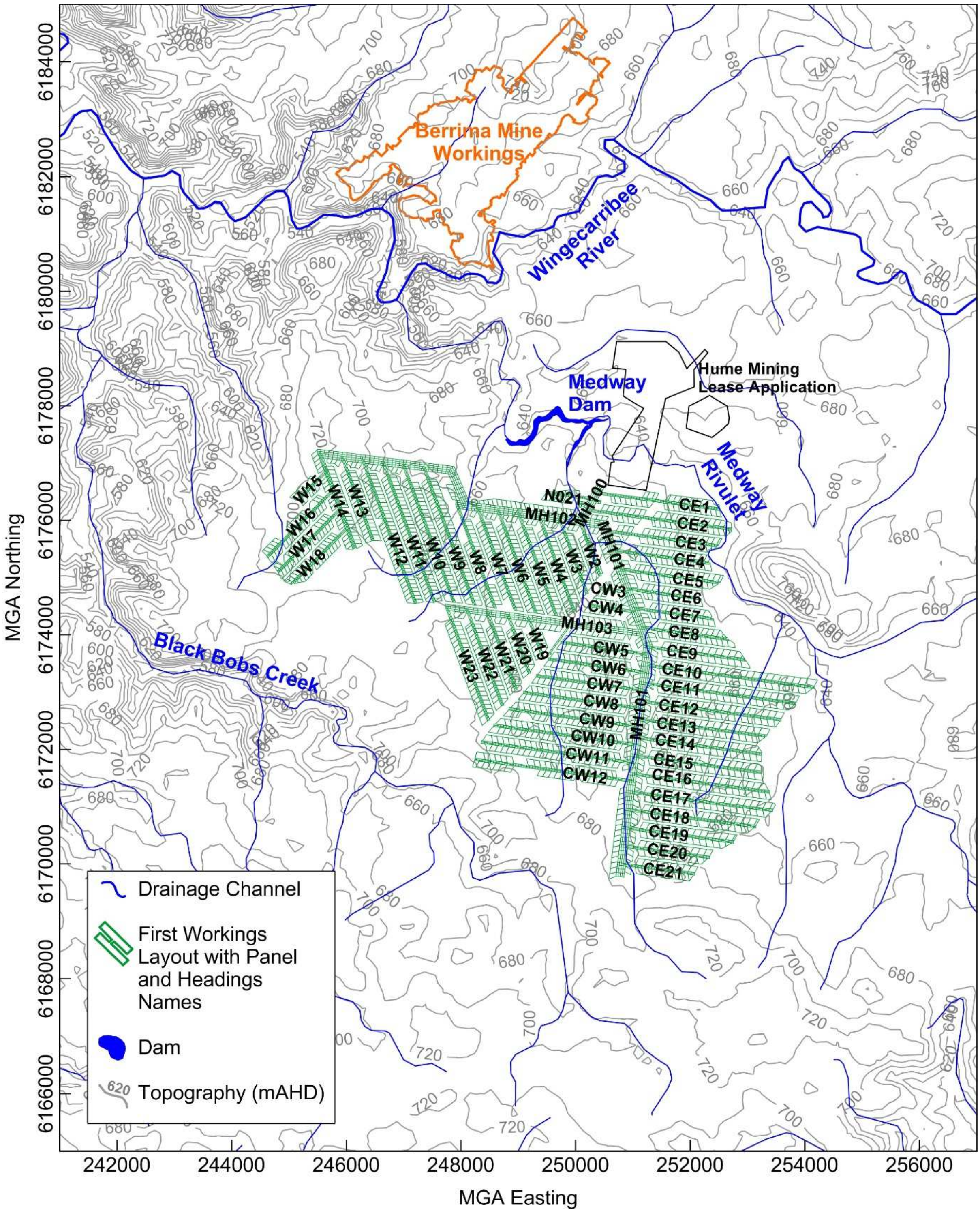


**Figure 2.2. Hume mine panel layout used in predictive simulations.**

Table 1 lists salient features of the mine layout. Appendix A provides tables listing mined volumes on a panel and annual basis, a plan showing the variation of mining height over the mined area, and the mining schedule. The schedule illustrates the direction of mining.

**Table 1. Hume first workings mining method characteristics.**

| | |
|---|---|
| **Maximum Mining Height (m)** | 3.5 |
| **Typical Panel Width (m)** | 270 |
| **Inter-panel Distance (m)** | 50 |
| **Calculated Height of Desaturation (H) (m above working section roof)** | 2 |
| **Total extracted coal volume (ML) *** | 32666 |
| **Mine Life (years)** | 19 |
| **Method Details** | Non-Caving.<br>Spine of 3 gate roads along panel centreline.<br>120 m tunnels (plunges) extending from gate roads. |

* 1000 $m^3$ = 1 ML.

Rock and coal fragments left over from washing and processing of coal (tailings) are combined with mine water to form a mixed slurry. Disposal of the slurry is known as co-disposal. For the Hume mine, co-disposal will be made to the underground voids.

Several groundwater drawdown mitigation measures have been modelled, comprising backfilling of the mined void with co-disposed tailings, sealing individual panels as they are mined (using bulkheads rated to withstand equilibrated hydraulic heads), and injection of mine inflow back into the void through the bulkheads (should excess water be available). These measures are designed to reduce the total groundwater drainage into the workings and thereby reduce drawdown in the overburden.

# 3. Model development

A regional groundwater flow numerical model has been developed to simulate underground mining in the Hume lease. The model was developed using MODFLOW-SURFACT Version 3, distributed by Hydrogeologic, Inc. (Virginia, USA). It is an advanced version of the standard USGS MODFLOW algorithm and is able to simulate variably saturated flow. The software can accommodate unsaturated zones at depth. MODFLOW-SURFACT is operated within the Visual Modflow (Version 2009) pre- and post-processing environment, developed by Schlumberger Water Services.

## 3.1. Layers and grid

The active model area (the model domain) is shown in Drawing 1. It covers 752 $km^2$. Its boundary follows natural features and has been selected so that the hydraulic heads in the model are controlled by rainfall recharge and groundwater sinks at the extremities of the model area (in conjunction with interior boundary conditions such as the mines and drainage channels). This eliminates difficulties associated with the uncertainty in, and control of, groundwater fluxes to or from constant head cells or general head boundaries on the boundary of the model area. An exception is Wingecarribee Reservoir (on the eastern model boundary) which is considered valid to simulate using a local constant head condition in the top model layer (see below).

The model grid comprises 15 layers (two of which are inactive) with 379 columns and 425 rows. Cell dimensions are 50 m x 50 m over the Hume lease, expanding to 50 m x 100 m over the Berrima lease, then to 200 m x 200 m over the remaining area. The finer grid is placed where detail is required during model calibration and predictive simulations.

13 model layers are used to represent hydraulic contrasts between hydrostratigraphic units, maintain adequate depth resolution, and permit modelling of behavioural changes arising from deformation. These layers and their average thicknesses are listed in Table 2.

Based on the assessment of hydraulic heads in the southeastern basalt body (see Volume 1), the Robertson Basalt is not explicitly simulated in the main model. A large vertical hydraulic head gradient is present between the basalt and underlying media, and a desaturated zone is interpreted to occur underneath most of the Wianamatta Group (WG) underlying the basalt. The basalt was therefore modelled separately (Appendix H). The basalt is conceptualised as a stable source of recharge to the WG and its presence is incorporated in the recharge rate for the WG underlying the basalt. This greatly facilitates the functioning of the model and reduces the requirement to estimate further parameters for which observations are not available.

Structure contours for the model layers were created by first resolving six key horizons in detail (bases of the Tertiary Basalt, Wianamatta Group, Hawkesbury Sandstone, Wongawilli Seam, Illawarra Coal Measures (ICM), and Shoalhaven Group). Additional structure contours for other layers (for example, subdivision of the Hawkesbury Sandstone) were developed from these six fundamental surfaces using constant offsets or proportioned thicknesses.

The Hawkesbury Sandstone is represented by six layers to facilitate the development of hydraulic head profiles in proximity, and allow the effects of deformation to be incorporated. The bottom two layers for the Hawkesbury Sandstone (Layers 6 and 7) are to accommodate roof relaxation from mining where the interburden or plies above the working section are absent.

Layer 8 represents sediment dominant lithologies, and contains the Wongawilli Seam R ply (WWR Ply).

**Table 2. Model layer thicknesses.**

| Stratum | Model Layer | Average Layer Thickness (m) |
|---|---|---|
| Wianamatta Group | 1 | 55 (where present) |
| Hawkesbury Sandstone | 2 | 53 (where overlain by WG). Reduces from this average, to nil (from edge of WG to limit of sandstone) |
| | 3 | 30 |
| | 4 | 34 |
| | 5 | 7 |
| | 6 | 2 |
| | 7 | 2 |
| Interburden (Narrabeen Group, WWR Ply, and Farmborough Claystone) | 8 | 4* |
| Wongawilli Seam above mined section | 9 | 2* |
| | 10 | 2* |
| Wongawilli Seam mined section | 11 | 3.5 |
| Illawarra Coal Measures | 12 | 19 (min. 2, max. 49) |
| Shoalhaven Group | 13 | 120 |

* Hume lease area. Not present everywhere (minimum model layer thickness is 0.1 m).

The Mt Gingenbullen intrusion (see Drawing 1) occurs on the northeastern lease boundary. A detailed analysis of the potential role of intrusions has been undertaken in Volume 1. Given the observed extents of disturbed zones in the Berrima lease area, and observations made at other coal mines, the intrusion is not explicitly modelled (see Volume 1).

A discussion on the Cement Works Fault is provided in Volume 1. Available hydraulic head observations show no perturbation due to this fault. Given the large change in displacement over a relatively short distance, and comparison to the magnetic intensity field, the fault has not been explicitly modelled since, in the absence of intersection, and due to its relatively localised nature, its ability to influence the evolution of the hydraulic head field from Hume mining operations is considered limited.

Hydraulic parameters for rock are defined according to depth below ground. 15 parameter zones have been used to discretise the decrease in hydraulic conductivity (K) and storativity with depth. Anisotropy in the K field is modelled for the vertical direction.

Figure 3.1 shows a cross section of the model layering (along Row 242, MGA Northing 6174000) through the mine lease from west to east. The finer grid over the Hume mine area and coarser grid to the east can be seen.

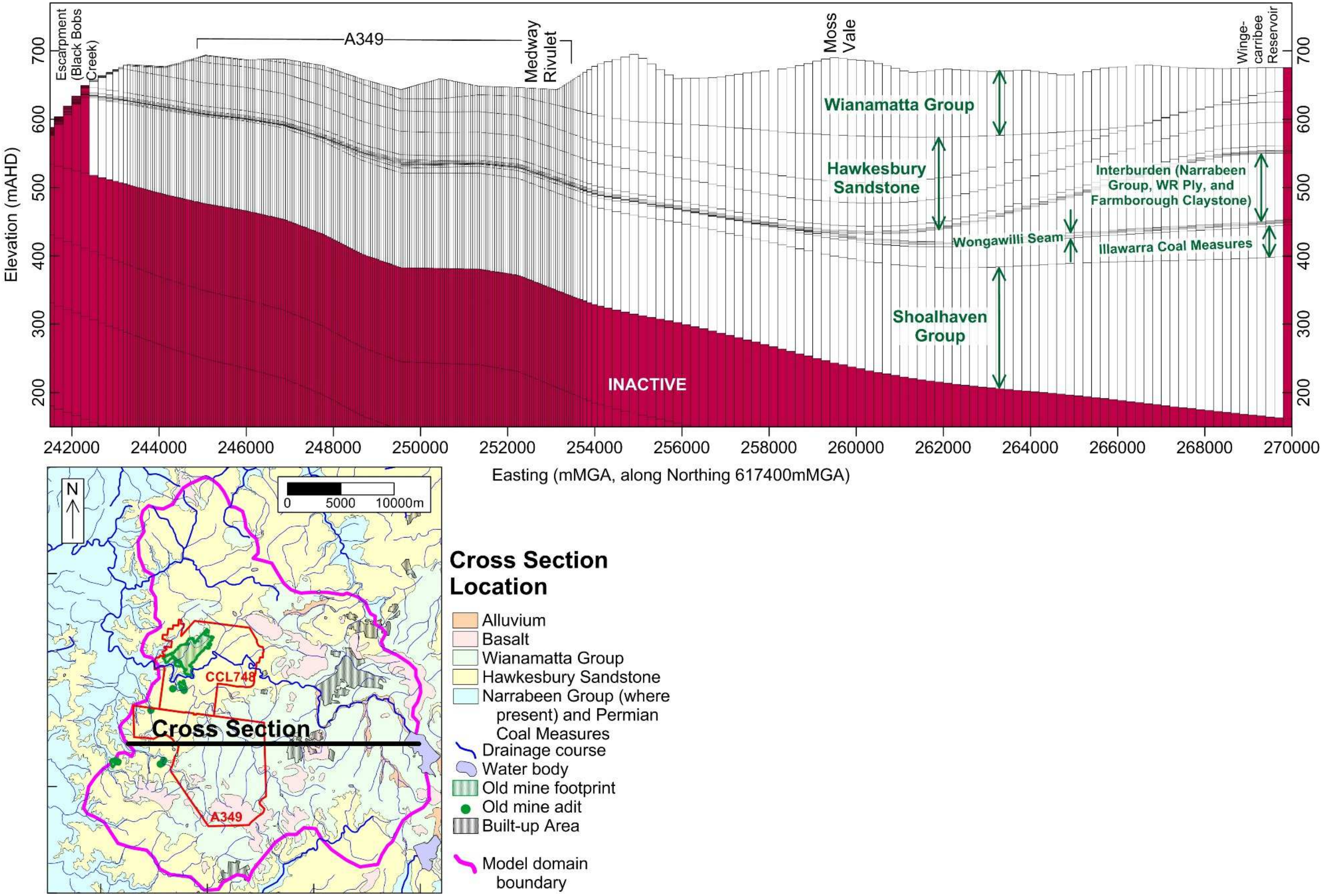


**Figure 3.1. Model cross section illustrating model layering and grid along Row 242.**

## 3.2. Boundary conditions

All layers were designated as variable type layers (a layer that will allow both unconfined and confined behaviour).

The model boundary has been selected sufficiently distant from the mine area to significantly reduce the potential for flow normal to the boundary occurring due to stresses imposed at the mine. The boundary conditions at the extremity of the model area consist of:

- No-flow at topographic divides.
- Discharge zones at drainage channels.
- Local constant head at Wingecarribee Reservoir.
- Discharge zones at escarpments.

Escarpments are treated as a line of drain cells to simulate consumption of groundwater at the escarpment by seepage and evapotranspiration. The western escarpment (limit of the Illawarra Coal Measures) approaches the proposed workings in some areas. Interpretation of observed hydraulic heads indicates drawdown decreases rapidly below the mined coal seam (see Figure 6.1 of Volume 1); a behaviour observed at virtually all mines in stratified sedimentary systems (where Kv is smaller than Kh). Drawdown from the proposed Hume mine can only migrate west of the western escarpment through the Shoalhaven Group.

Wingecarribee Reservoir provides a strong, reasonably constant hydraulic control in the upper model layer. Vertical gradients at Government piezometer GW075033 are negligible and reservoir water levels are reasonably constant.

### 3.2.1. Rivers and creeks

The Wingecarribee River was simulated using the River package, due to its quasi-permanent nature and proximity to the proposed mine. This allows two-way transfer of water between the channel and the subsurface. Two groups of river cells are used (for 50 m x 50 m cells and 50 m x 100 m cells) to allow the use of a single notional vertical K (Kv) of 0.1 m/day for the notional riverbed material. This is considered reasonable and moderately high, providing strong hydraulic connection between water in the channel and groundwater in the underlying media.

Medway Dam, an in-stream storage on Medway Rivulet, was also simulated using the River Package. No information was available for the base of the dam. Riverbed conductance was set to 25 $m^2$/day for 50 m x 50 m cells, based on simulation of leakage from Avon and Cordeaux dams in the Dendrobium mine area (HC 2010, Coffey 2012). It assumes the presence of residual soil at the dam base. For this cell size, and a soil thickness of 2 m at the dam base, Kv of the soil is 0.02 m/day. This is high for soils of WG origin and is considered conservative.

Remaining drainage channels were simulated using the Drain package due to their ephemeral nature, or distance from the imposed stresses. Flow monitoring for streams on the mine lease indicate these drainage channels are ephemeral. Drain conductance was set to a high value of 1000 $m^2$/day, allowing the media hydraulic properties to control leakage to the channels. Elevations for the inverts of these and other channels over the model domain are based on digital elevation information available from the Australian Government, checked against LiDAR topographic survey data for the Hume Lease.

### 3.2.2. Reservoirs

Wingecarribee reservoir, on the eastern model boundary, was simulated with a local constant head condition in the top model layer. Analysis of its water levels indicates a minimal change with time, with virtual equilibrium over the last several years. Water may exchange with the subsurface in either direction. The reservoir storage capacity is considered large compared to any changes in groundwater exchange rates caused by mining, so that the specified head is approximated as invariant with changes in groundwater exchange. The water level elevation was held invariant at 676 m AHD for all simulations.

### 3.2.3. Rainfall recharge and evapotranspiration

Rainfall recharge was applied as a constant percentage of incident rainfall recorded at Moss Vale (Bureau of Meteorology (BOM) Station 68045) over quarterly periods. The average long-term annual rainfall for the mine lease is estimated as 957 mm, similar to the average rainfall at Moss Vale. Rainfall recharge is applied to the topmost active cell in each vertical column. Net recharge to the saturated zone from irrigation is considered minor in comparison to rainfall recharge and is therefore not considered separately in the model.

Evapotranspiration (ET) was applied over the entire domain with a maximum rate of 3 mm/day and extinction depth of 1.5 m, based on land surface types and proportions.

### 3.2.4. Unconsolidated sediments

According to the published geology map, alluvium occurs only along the upper reach of the Wingecarribee River (see Drawing 1). Its extent is limited to close proximity to the river channel, and is a small proportion of the total recharge area encompassed by the mine capture zone. While it may afford greater rainfall recharge, most of the recharge is considered to be in intimate connection with the river channel, and would discharge to the channel. Its extent is considered minor. Borehole logs identifying the strata between the alluvium and rock were unavailable. However, alluvial sequences such as this one commonly overlie a layer of residual soil, present at the start of the depositional phase, which may compact with increasing alluvial thickness. For this case, any compacted residual soil would be of Wianamatta Group origin and be clay-dominant. On an area basis, recharge to underlying fractured media from the alluvium is considered a negligible component of the total recharge to these media.

Leakage from the alluvium into the mine void is therefore considered a small component of the total inflow, with rock providing the majority of the inflow. For the current study the assumption is made that the contribution to mine inflow (or to dewatered rock) from unconsolidated sediments is negligible compared to rock, based on the site geology and borehole logs (see Volume 1).

Major pumping is not known to occur from the alluvium, and it is not considered by the NSW DPI to be a separate groundwater source in the relevant water sharing plan.

### 3.2.5. Mine workings

#### Height of drainage above non-caving workings

The first workings mining method to be adopted by Hume is non-caving. Some parts of the existing Berrima and Loch Catherine voids, are also non-caving workings where the height of deformation is nominally 2 m into the roof. The deformation height is also the adopted height of groundwater drainage. This type of mining was extensively practised prior to the advent of mechanisation but is rarely undertaken now. It is the preferred mining method for the Hume project as it significantly minimises groundwater impacts compared to full extraction mining.

Deformation (dilation) from 1st workings consists of enlargement of defect apertures and minor cracking in the roof above mine openings, extending upwards a maximum of approximately 3 m above the roof of the working section, depending on road width, horizontal stress magnitudes, roof rock strength, and rock bolting (or other support) strategy. This is based on typical published measurements from extensometers placed in headings roofs (see for example Sweby 1997, Whittles 1999, and British Coal Corporation 1996). Dilation typically extends approximately 2 m into the roof for common 1st workings mine plans. Extensional strains in the overburden are significantly smaller, and extend a shorter vertical distance, than full extraction mining.

The anticipated roof bolting strategy for the proposed PF mine layout is as follows:

- Bolting of gate roads at a density of between 4 x 1.8 m bolts per 1.5 m, up to 6 x 2.1 m bolts per 1 m. The most likely scenario would be 4 x 1.8 m bolts per 1 m.
- Gate road intersections may have higher bolt densities, with 4 x 4 m flexi bolts common practice, or alternatively, moving from a 4-bolt pattern to a 6-bolt pattern through the intersection and for 10 m either side.

The bolted interval is the most likely region of the roof to experience deformation, however current roof bolt installation practice is for installation under pre-tension of between 5 t and 10 t which assists in closing roof delaminations. For resin-encapsulated bolts, the resin backpressure may create additional fracturing in some cases, however the roof support system for the Hume mine plan has been designed to avoid these effects.

A 3 m relaxation height is considered to be excessively conservative if applied over the entire mine footprint, since:

- The mine roof will act more stiffly in some areas, particularly in the shallower areas of the mine (for example, less than 150 m overburden thickness).
- First workings recovery is approximately 35%, which will have the effect of increasing pillar stiffness.

To estimate a reasonable relaxation height, a sensitivity analysis was undertaken with the model, prior to predictive simulation, to assess the change in mine inflows for relaxation heights of 2 m and 4 m. This was applied over an area representative of the typical extent of an actively draining area at an instant in time. This analysis is reported in the sensitivity section. Results indicate an increase in inflow of 4.3% between 2 m and 4 m relaxation heights. Observational databases indicate a relaxation height of less than 2.5 m is common for first working mines. Given the small change in inflow between 2 m and 4 m heights, and the design of the Hume mine plan, the most representative relaxation height applicable over a large area of non-caving workings is considered to be 2 m, and this was adopted for predictive simulations.

## Height of drainage above caved workings

Parts of the existing Berrima and Loch Catherine voids are full extraction workings where caving has occurred. These comprise panels of extracted 1st workings pillars. Heights of desaturation (H) above full extraction panels are calculated according to the equation of Tammetta (2013) for longwall panels. Local and international observations indicate H for pillar extraction panels is between 50% and 60% of H for a longwall panel with equivalent geometry (Tammetta 2013). 60% is used in this work.

For calibration purposes H above the Berrima and Loch Catherine voids was first calculated for individual panels. Figure 3.2 shows the full extraction panels for the Berrima and Loch Catherine voids, and their calculated H. Refer to Drawing 1 for the locations of these mines with respect to each other. These are old workings with variable panel shapes. To simplify calibration, an average H of 53 m above the roof of the working section was adopted for the full extraction panels for these voids, based on the general similarity in H amongst the panels (see Figure 3.2). 1st workings areas of the Berrima void are given a relaxation height of 2 m above the working section roof.

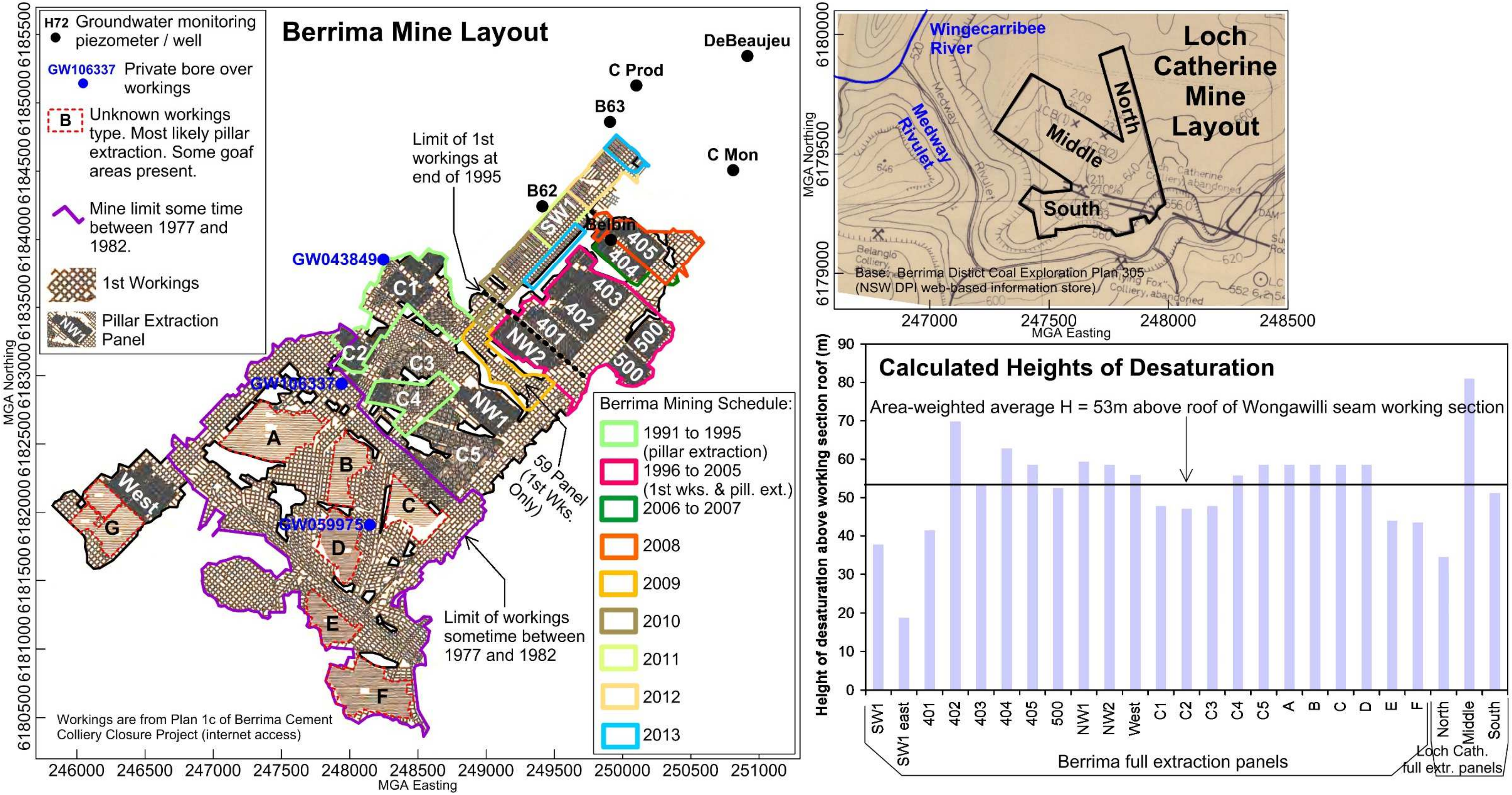


**Figure 3.2. Full extraction panels for Berrima and Loch Catherine mines, and calculated heights of desaturation.**

## Model implementation

The creation of mine openings, and the associated ground deformation, creates a compressional zone (the pressure arch and abutments; Booth 1986) around the deformed zone due to changes in the stress field caused by deformation. Figure 3.3 illustrates the warping of vertical and horizontal stress vectors around both full extraction panels and 1st workings openings. For non-caving first workings no goaf occurs (because pillars do not fail) and stress perturbations occur over a smaller area (compared to caving systems).

For mining techniques that involve full extraction, caving creates a complex change in the K field, with increases and decreases in pre-mining K occurring (Tammetta 2015). Figure 3.3 shows interpreted areas of K reduction, assuming flanking of workings by other same-type workings, based on Tammetta (2015). Changes in the K field occur over a significantly smaller zone for non-caving mine openings. Detailed spatial simulation of the resulting K field would require micro-discretisation, untenable for a regional model with numerous panels or non-caving mine openings. For a regional model, the resulting K field imparted by the stress concentration zone around an opening is incorporated using the conductance of drains used to simulate mine openings and the overlying drained zones. This also avoids the problem of estimation of post-mining K in the drained zone (where desaturation occurs and estimation of K via calibration is not possible).

H is estimated a-priori for full extraction (caved) and non-caving workings, and drains are used to simulate drainage in each layer intersected by the deformed zone (the collapsed zone for full extraction, and the relaxation zone for non-caving workings). H for non-caving workings is a few metres whereas H for full extraction panels is comparable to the panel width (depending on panel geometry and overburden thickness).

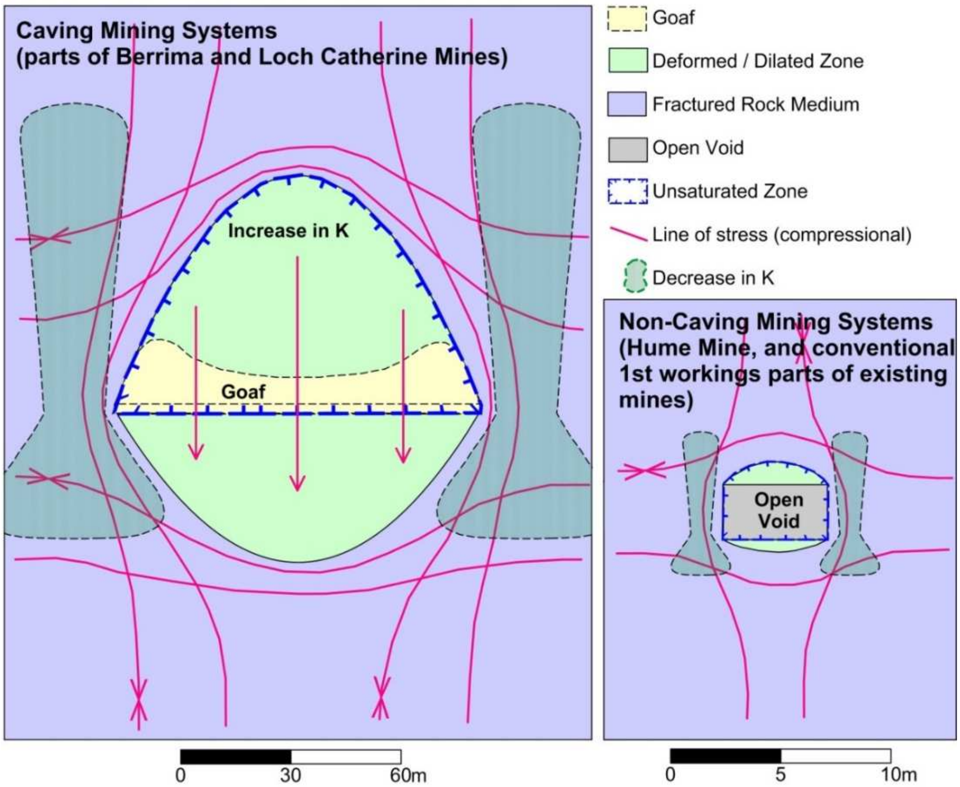


**Figure 3.3. Conceptualisation of the perturbation of stress trajectories and changes in K in fractured media caused by underground mining.**

### Potential changes in hydraulic conductivity above the relaxed zone

An assessment of mine subsidence (MA 2015) used the work of Ditton and Frith (2003) to assess the likely maximum localised values of horizontal strain (compressive and tensile) in the Hawkesbury Sandstone in the mine lease. Results are predictive horizontal strains above the workings of 0.01% and 0.018%, using two different methods of calculation. An upper threshold of 0.02% was used for assessment of impacts. Results in MA (2015) indicate that predicted extensional strains for the first workings method, above the relaxed zone adopted in the model, will be insufficient to activate movement of defect apertures, since the relaxation will be consumed by elastic expansion of the matrix, with negligible change in defect aperture. These results support the modelling assumption of nil change in the hydraulic conductivity field above the relaxed zone in the Hume Mine.

### Berrima Mine

A review of available literature provided useful observations made during the course of mining at the Berrima Colliery, for use in model implementation. A summary is provided below.

Panels mined near the end of mine life generally comprised five gate roads driven at 5.5 m width and 2.3 m height. Pillar dimensions varied from 37.5 m to 45 m centres. Development and extraction of runouts on the left panel side was undertaken concurrently with panel development. The right runouts were extracted on retreat but were sometimes split on advance. Full extraction of pillars occurred after splitting, at 25 m centres (once parallel to the cut-through).

Mining conditions were generally good with minimal roof support required. Roof bolting was undertaken at 2 m spacing with 2 roof bolts per row at 3 m spacing (1.25 m from each rib wall). Spacing was decreased when passing through sections of soft roof.

## 3.2.6. Pumping from private bores

The model simulates pumping from the following private water bores located in the model domain:

- 83 high extraction bores with associated aquifer access licences. These bores are generally used for irrigation or other industrial purposes. The combined level of entitlement is 14.5 ML/day (5300 ML/year).
- 299 bores approved for stock and/or domestic use.

No metering of actual usage is known to be undertaken by regulatory agencies for the area. Pumping was therefore a variable. Stock / domestic bores were assigned a constant pumping rate of 3 ML/year (0.008 ML/day) (Lowe et al 2009, SAMDBNRMB undated). The total pumping rate for high-extraction bores was varied slightly during calibration, with the optimal rate found to be 14.1 ML/day, or 97% of the allocation. This rate most probably takes into account pumping from unlicensed bores, and / or possible pumping in excess of allocation at licensed bores.

For bores whose hydraulic interval penetrates multiple model layers, pumping is partitioned according to the transmissivity of the layer compared to the transmissivity of the total penetrated interval. This means pumping rates may decrease should one or more intersected layers dry during the course of the simulation.

# 4. Model calibration

Given the age of the Berrima and Loch Catherine mines, model calibration was undertaken in two stages as follows:

- Stage 1: Mining at Berrima finished recently but had been active between 1926 and 2011. The first stage of calibration comprised a transient simulation simulating a notional period of 32 years, as an approximation for the evolving hydraulic head field due to mining effects between 1926 and 2011, to obtain a reasonable starting head distribution for the point in time at the beginning of the main calibration period (January 2011). The modelled January 2011 hydraulic head distribution is used as the starting hydraulic head field for the main transient calibration.
- Stage 2: Transient calibration over the main calibration period (1 January 2011 to 31 December 2014), covering mining of the last stages of the Berrima workings.

Observations for the period 1 January 2015 up to the dates of observation availability in mid 2015 (ranging between March and July), as at the time of calibration, were reserved for the verification phase. Parameter change was performed manually.

## 4.1. Calibration targets

Calibration targets comprised:

- Hydrographs of hydraulic head from the Berrima and Hume monitoring networks (Parsons Brinckerhoff 2015). Target hydrographs were selected according to the following criteria:
  - Characterisation of mining-induced drawdown.
  - Longer monitoring periods.
  - Smaller screen intervals.

  The calibration hydraulic head dataset comprised hydrographs covering intervals of between 1 and 3 years at 49 points in the subsurface, at 23 locations. The calibration target piezometers and their locations are listed in Appendix B. Appendix B also lists piezometers not used for calibration and the reasons for their exclusion. There is evidence that water levels at the DeBeaujeu and Culpepper monitoring bores are influenced by Berrima mining. These bores, while having long hydraulic intervals, were retained as the best available monitoring points for characterisation of mining-induced drawdown at distance from the Berrima workings.
- Observed shallow groundwater discharges (estimated baseflow to drainage channels).
- Observed deep groundwater discharges (estimated discharge to the Berrima mine void).
- The observed K distribution for moderate observation scales (similar to the model discretisation).

## 4.2. Sources of uncertainty in hydraulic head calibration targets

Numerical simulation of regional groundwater systems requires calibration to observations. The reliability of results is generally a function of the reliability in observations, and the ability of the model to replicate these observations. In comparing modelled hydraulic heads from the discretised medium of a model domain to measured hydraulic heads from a natural continuum, the following sources of uncertainty are introduced, regardless of calibration quality:

- Accuracy of VWP data. The accuracy of VWP data is considered to be not better than ±10 m.

- Model layer thickness and the vertical position of a piezometer screen interval with respect to the model layer. Vertical hydraulic gradients in proximity to mining may be significant. Away from mining, smaller gradients are observed. In a finite difference numerical model, a layer will have only one head value per cell (an average value, applicable to the centre of the cell). Assuming a 50 m thick layer and a vertical hydraulic gradient of 0.5, with a measurement point located at either the top or the bottom of the layer, then if the model is perfectly replicating the system, the observed and modelled heads will differ by half of 25 m, or 12.5 m. This difference depends on several factors, the most significant of which are the layer thickness and the vertical hydraulic head gradient.
- The Berrima mine schedule. The mining schedule for Berrima is not known in detail, and generally only to a resolution of yearly blocks. An attempt has been made to replicate it based on typical mining practices and experience. Plans available in various publications show the extent of workings, and the mine footprint, at a few points in time. Coal extraction is assumed to have ceased in early 2013.
- Large screen intervals in bores. Observations from private bores DeBeajeu and C Prod are considered important targets for calibration however their screened intervals (greater than 40 m) span two or more model layers. A reasonable departure of modelled water levels from observed water levels is therefore expected for these bores, regardless of calibration quality.

## 4.3. Calibration results

Transient calibration was undertaken for the period 1 January 2011 to 31 December 2014 with monthly stress periods. Rainfall recharge was applied as a percentage of incident rainfall. Parameter change was performed manually. Verification was undertaken for the period 1 January 2015 to 27 August 2015. Hydraulic head observations were available up to July 2015 and Berrima discharge observations to August 2015.

Prior to calibration, it was suspected that subvertical groundwater flow barriers associated with the southern basalt bodies (see Volume 1) might be critical in replicating the hydraulic head field. These barriers were interpreted from analysis of the three-dimensional hydraulic head field, and airborne geophysical survey data. The calibration phase indicated that hydraulic head observations at southern piezometer nests (east to west) H56X, H37, H42, and H136 could not be replicated without inclusion of such barriers. Therefore, during the calibration phase, sub-vertical flow barriers were incorporated as follows (see Figure 4.1):

- Vertical barriers to groundwater flow offering significantly reduced K normal to their planes, but unimpeded K along their planes.
- 10 m thick with a fault core K of 0.001 m/day, based on observations from large scale barriers elsewhere.
- The barriers do not penetrate into the basalt.

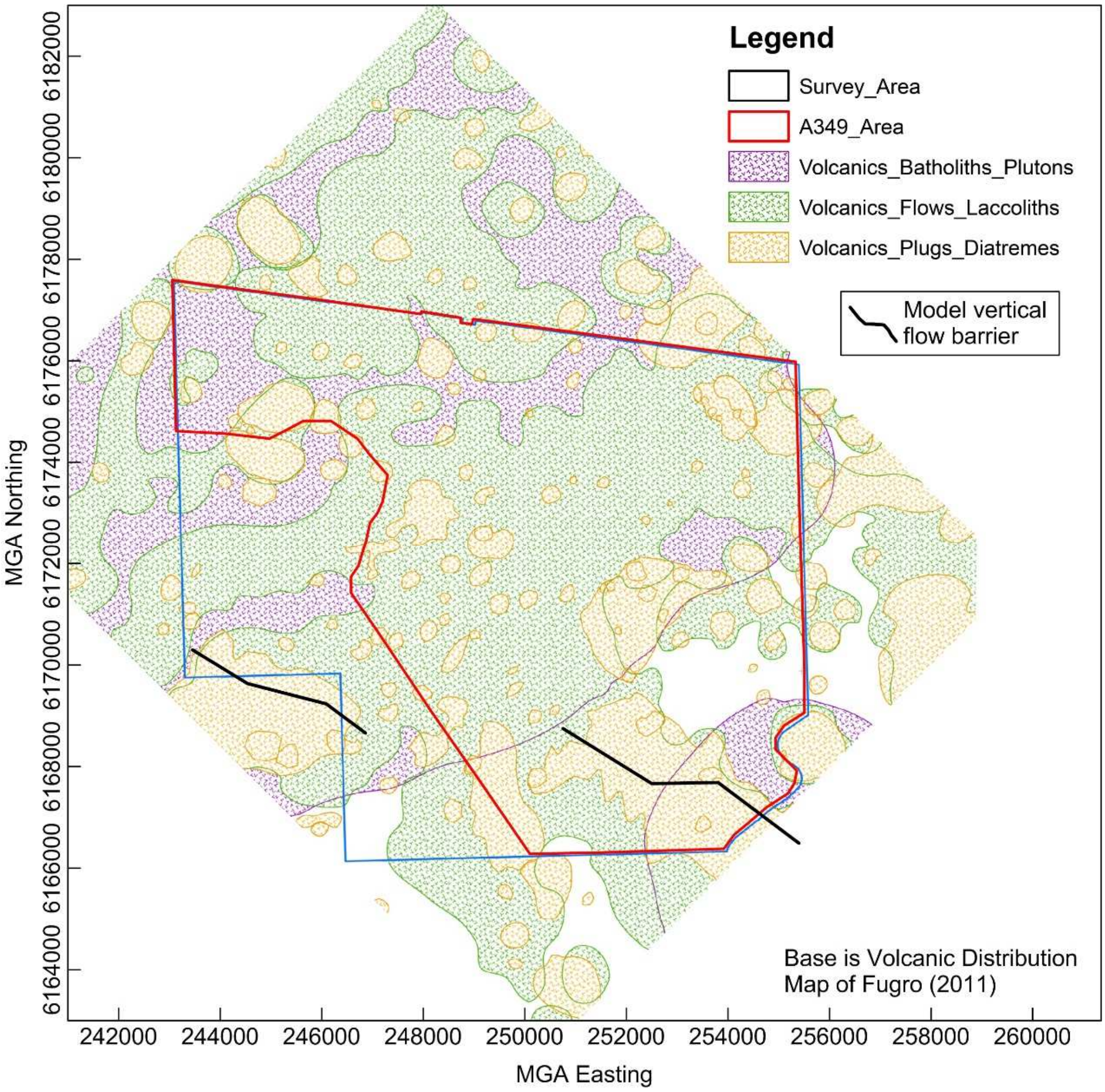


**Figure 4.1. Modelled flow barriers incorporated during the calibration phase. The volcanic interpretation is after Fugro (2011).**

## 4.3.1. Hydraulic heads

### 27 August 2015

Figure 4.2 shows modelled and observed hydraulic heads for the end of the verification period (modelled water levels for 27 August 2015, compared to actual observations ranging between April and June 2015). The normalised root-mean-squared (NRMS) error is 11.9 % and considered reasonable, given the VWP outliers B62_Upper and B63_WW, comparison of non-coincident modelled and observed water levels, and other factors. B62_Upper and B63_WW are poorly matched however these are VWPs and their reliability is lower than for standpipes. Residuals are reasonably normally distributed.

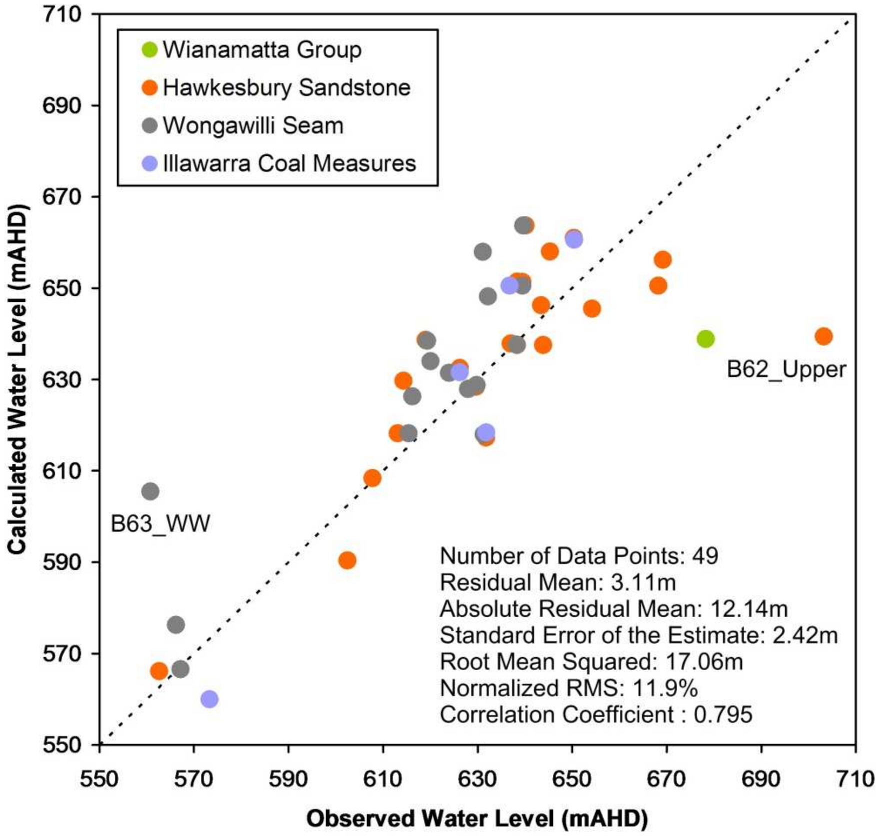


**Figure 4.2. Comparison of last available observed water levels (March to July 2015) and model-calculated water levels for 27 August 2015.**

The residual mean is 3.1 m, small compared to the total variation in head during the calibration (and predictive) phases, and a small proportion of the saturated thickness above the mined horizon. The offset will overestimate mine inflows by less than 5%. The offset is mainly due to:

- Uncertainty in stream invert elevations.
- Uncertainty in private pumping.

A proportion of modelled stream invert elevations are higher than actual, in the central model area. The digital elevation model (DEM) for the entire model domain was obtained from the Geoscience Australia web-based data service. This model was compared to detailed laser-based elevations (LiDAR, considered more accurate than the DEM) obtained by Hume for the mine lease. The comparison indicated good agreement but with a variation of about ±8 m AHD. The proportion of inverts that are higher than the LiDAR equivalents, combined with the defined drainage channel lines not occurring precisely over the minima in the DEM, have influenced the calibration results.

The mean residual for the seven Berrima network observations is smaller than overall, indicating the stronger control of the Wongawilli Seam hydraulic head condition in the mined zone on hydraulic heads surrounding the Berrima mine.

Figure 4.3 presents a north-south cross section of modelled hydraulic head through the Berrima mine for 27 August 2015, for comparison to the interpreted hydraulic head cross section for late 2013 / early 2014 (also shown). Recognising the offset of the modelled cross-section down hydraulic gradient, and the difference in times, the replication of the vertical hydraulic head distribution is considered reasonable. The model calculates saturation to be present above partial extraction (1$^{st}$ workings) areas of the Berrima, and the absence of saturation above full extraction areas.

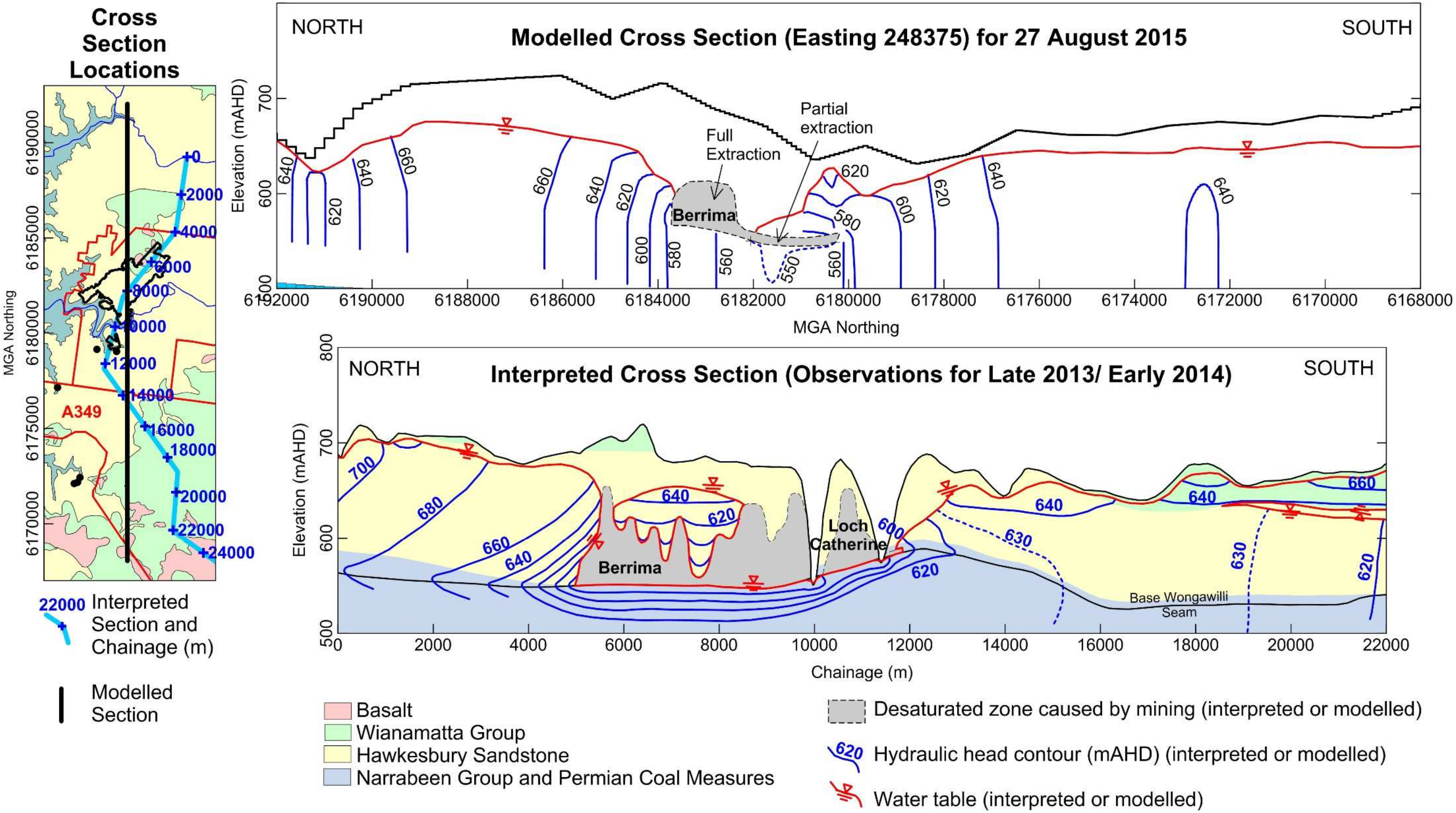


**Figure 4.3. Modelled hydraulic heads along a north-south cross section through Berrima mine for 27 August 2015, compared with interpreted hydraulic heads for late 2013 / early 2014 along a nearby cross section.**

Figure 4.4 shows the modelled water table for 27 August 2015, representative of conditions prior to mining at the proposed Hume mine. Flow along the water table surface is from outcrop sandstone areas along the western boundary (rainfall recharge to sandstone), and Wingecarribee reservoir on the eastern boundary (reservoir leakage), to drainage channels to the south, northeast, and west. The lower reaches of Wingecarribee River and Medway Rivulet are groundwater discharge areas.

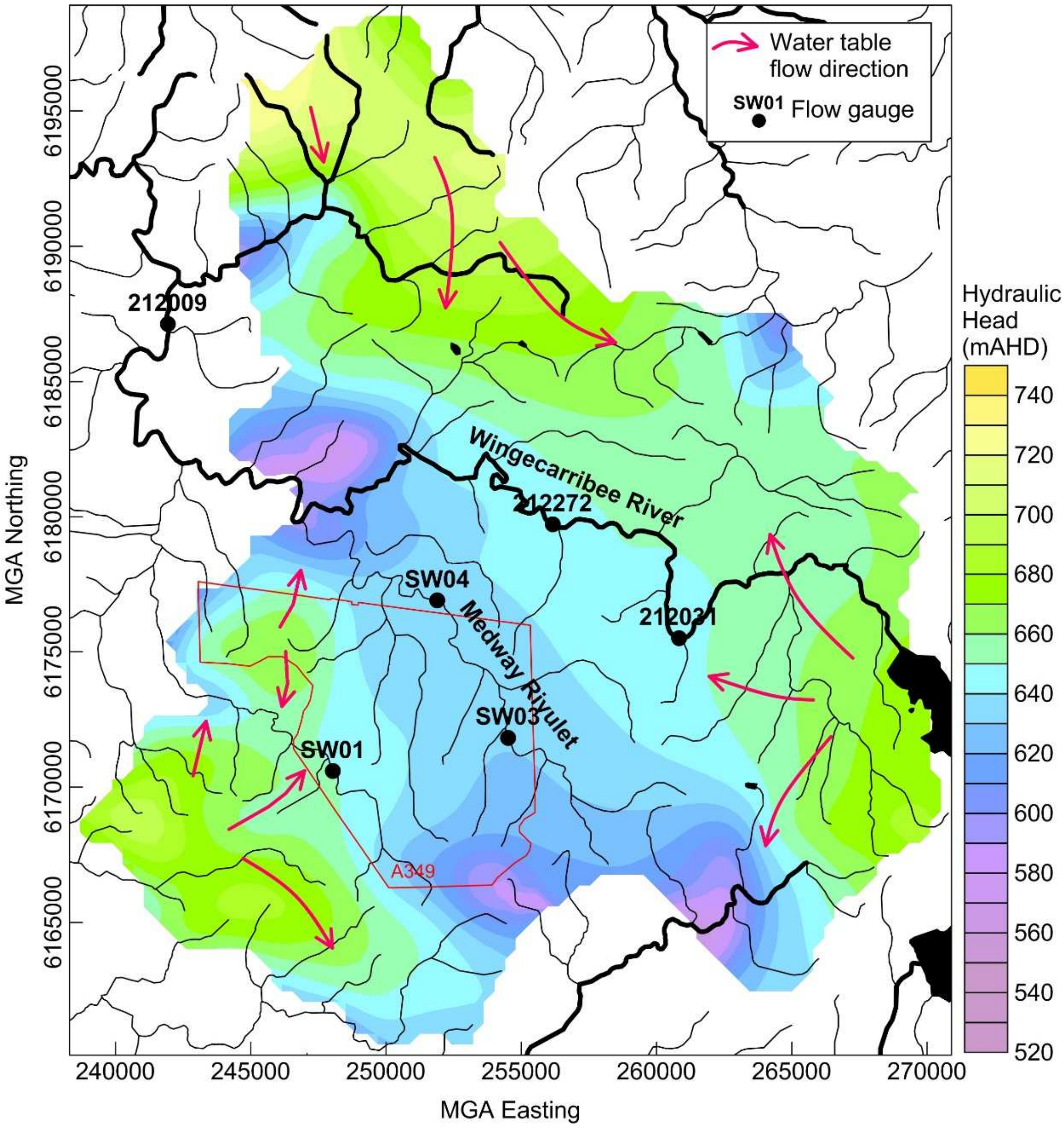


**Figure 4.4. Modelled water table for 27 August 2015.**

## Hydrographs

Appendix B presents modelled and observed hydrographs of hydraulic head. Observed heads are reasonably reproduced overall. Drawdown from Berrima mining (seen at B62, B63, DeBeaujeu, and C Prod) is also reasonably reproduced. B62_Upper and B63_WW are poorly matched, however the other four observation datasets for B62 and B63 are reasonably matched.

### 4.3.2. Hydraulic properties

Calibrated media properties are listed in Table 3.

**Table 3. Calibrated media properties.**

| Stratum | Model Layer | Average Depth to Base in Hume Lease (mbgl) | Kh[a] (m/day) | Kv[b] (m/day) | Specific storage ($m^{-1}$) | Specific yield | Kv/Kh |
|---|---|---|---|---|---|---|---|
| Wianamatta Group | 1 | 30 | 1 | 0.01 | $1 \times 10^{-6}$ | 0.01 | 0.01 |
| Hawkesbury Sandstone | 2 | 56 | 0.6 | 0.001 | $1 \times 10^{-6}$ | 0.01 | 0.0017 |
| | 3 | 86 | 0.05 | 0.003 | $7 \times 10^{-7}$ | 0.008 | 0.06 |
| | 4 | 120 | 0.03 | 0.0005 | $7 \times 10^{-7}$ | 0.008 | 0.017 |
| | 5 | 127 | 0.01 | 0.0005 | $7 \times 10^{-7}$ | 0.005 | 0.05 |
| | 6 | 129 | 0.005 | 0.001 | $5 \times 10^{-7}$ | 0.005 | 0.2 |
| | 7 | 131 | 0.005 | 0.001 | $5 \times 10^{-7}$ | 0.003 | 0.2 |
| Interburden* | 8 | 133 | 0.005 | 0.001 | $5 \times 10^{-7}$ | 0.003 | 0.2 |
| Wongawilli Seam above mined section | 9 | 135 | 0.005 | 0.001 | $5 \times 10^{-7}$ | 0.003 | 0.2 |
| | 10 | 137 | 0.005 | 0.001 | $5 \times 10^{-7}$ | 0.003 | 0.2 |
| Wongawilli Seam mined section | 11 | 140 | 0.005 | 0.001 | $5 \times 10^{-7}$ | 0.003 | 0.2 |
| Illawarra Coal Measures | 12 | 160 | 0.0001 | 0.0001 | $5 \times 10^{-7}$ | 0.003 | 1 |
| Shoalhaven Group | 13 | 250 | 0.0001 | 0.0001 | $5 \times 10^{-7}$ | 0.003 | 1 |

a. Kh denotes lateral hydraulic conductivity (K). b. Kv denotes vertical K. mbgl denotes metres below ground level. * Narrabeen Group, WWR Ply, and Farmborough Claystone.

Figure 4.5 compares calibrated and observed K (refer to Volume 1 for a discussion of K measurements). Large-scale measurements of K are mostly representative of the lateral component of the K tensor (except where specifically analysed for Kv, where measurements allow). The calibrated Kh distribution is considered to reasonably represent K observations. Large scale Kv for the Hume area is heavily affected by its tectonic history and associated intrusive activity, and the high density of private open water bores. The calibrated Kv distribution is considered a reasonable replication of the large scale Kv distribution in the subsurface. It is supported by calibration to shallow and deep groundwater discharges, and important large scale Kv estimates from the two long-term pump tests undertaken by Hume on the mine lease in 2014. These three datasets are independent of each other.

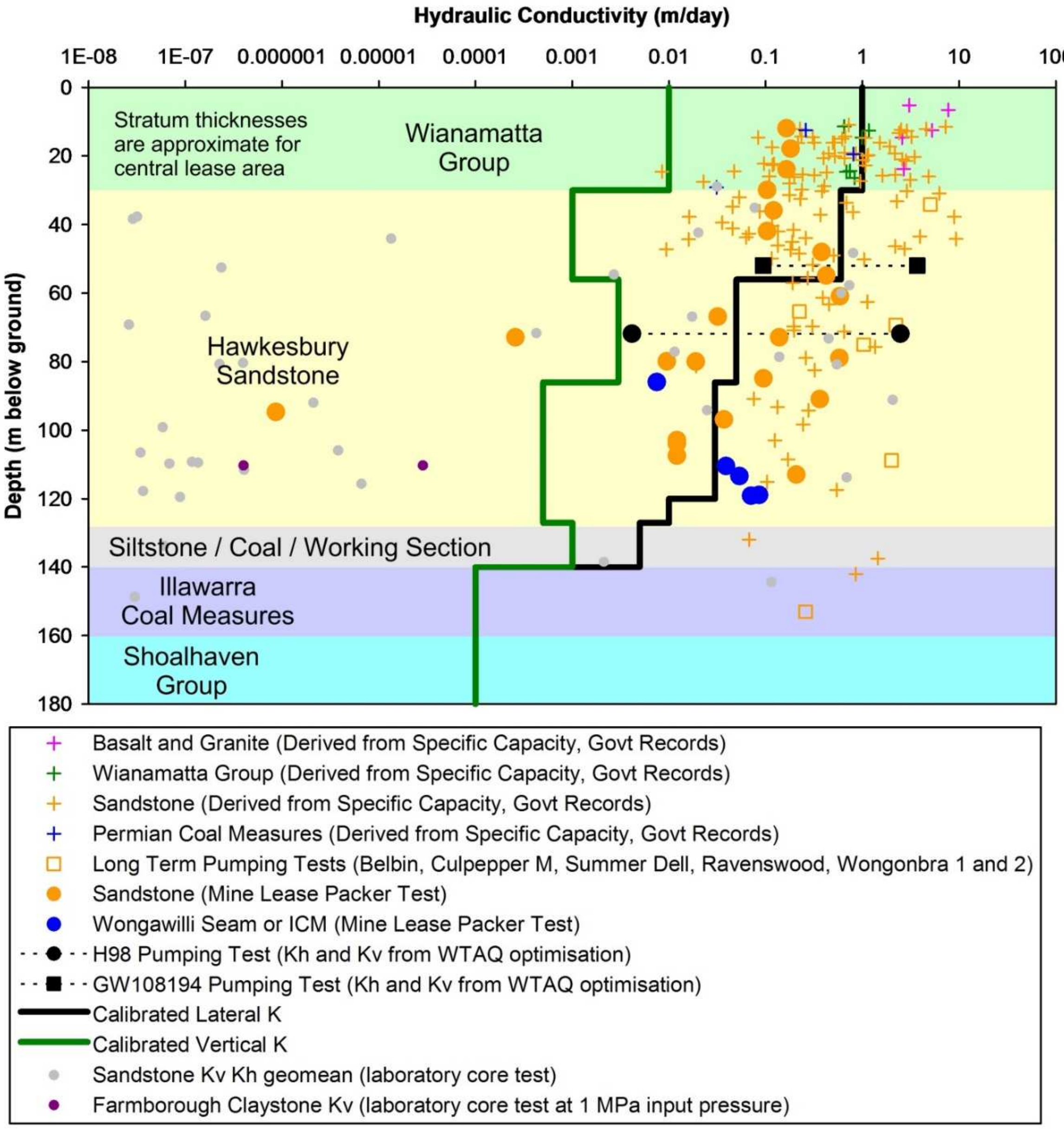


**Figure 4.5. Comparison of calibrated and observed hydraulic conductivity.**

### Berrima Mine drain conductance

The calibrated drain conductance for Berrima mine workings is 0.1 $m^2$/day (for 50 m x 100 m cells). For 50 m x 50 m cells (the cell size over the Hume mine footprint), the equivalent conductance is 0.05 $m^2$/day (see the discussion in the Predictive Simulation section below).

For the case of numerical simulation of development headings for proposed mining in Area 3B in the Dendrobium mine lease (Coffey 2012), a drain conductance of 0.1 $m^2$/day was calibrated for a depth of around 300 m, for 50 m x 50 m cells. For this model also, hydraulic heads, K, and flows (shallow and deep) were simultaneously reasonably replicated. The similarity between calibrated conductances at Berrima and Dendrobium indicates that the application of the calibrated conductance for predictive simulation of the Hume mine is reasonable.

## 4.3.3. Recharge and discharge

### Recharge

The mine lease and model domain have estimated area-weighted long-term average annual rainfalls of 957 mm and 949 mm respectively. The actual rainfall applied to the model domain over the simulation period (Moss Vale) was 4.81 m, slightly above average. The calibrated rainfall recharge rate is 1.8% of incident rainfall.

### Shallow discharge

78% of the catchment for flow gauge 212009 (or 467 $km^2$) occurs within the model domain. The estimated baseflow at this gauge is 1.5% of average annual rainfall over the catchment. Assuming this rate is applicable over the calibration period, the estimated baseflow to the intersected part of the catchment would be about 18 ML/day. The modelled baseflow to the Wingecarribee River and its tributaries in the model domain was 12 ML/day at the end of the simulation period. The model does not simulate basalt; when an estimate for the basalt baseflow component (between 30% and 40%) is removed from the observationally-based estimate, the modelled baseflow is considered to compare favourably with it.

### Deep discharge

Figure 4.6 shows the observed discharge from the Berrima mine void and the modelled inflow over the calibration period. The adopted observation dataset for Berrima Mine inflow is discussed in Volume 1. The observed discharge from the void is assumed to be a reasonable representation of the discharge to the void from surrounding media.

David (2015) reports that the most accurate period of discharge readings is April to November 2014. Modelled inflows are considered to accurately replicate observed discharge over this period. Modelled inflows slightly overestimate other less reliable measurements. Some overestimation by the model is likely to be due partly to calculation of H (the vertical extent of desaturation) for pillar extraction panels as 60% of their longwall equivalents; 55% is likely to be a better representation in this case (see Tammetta 2013). Modelled inflows are considered to accurately match the observation dataset.

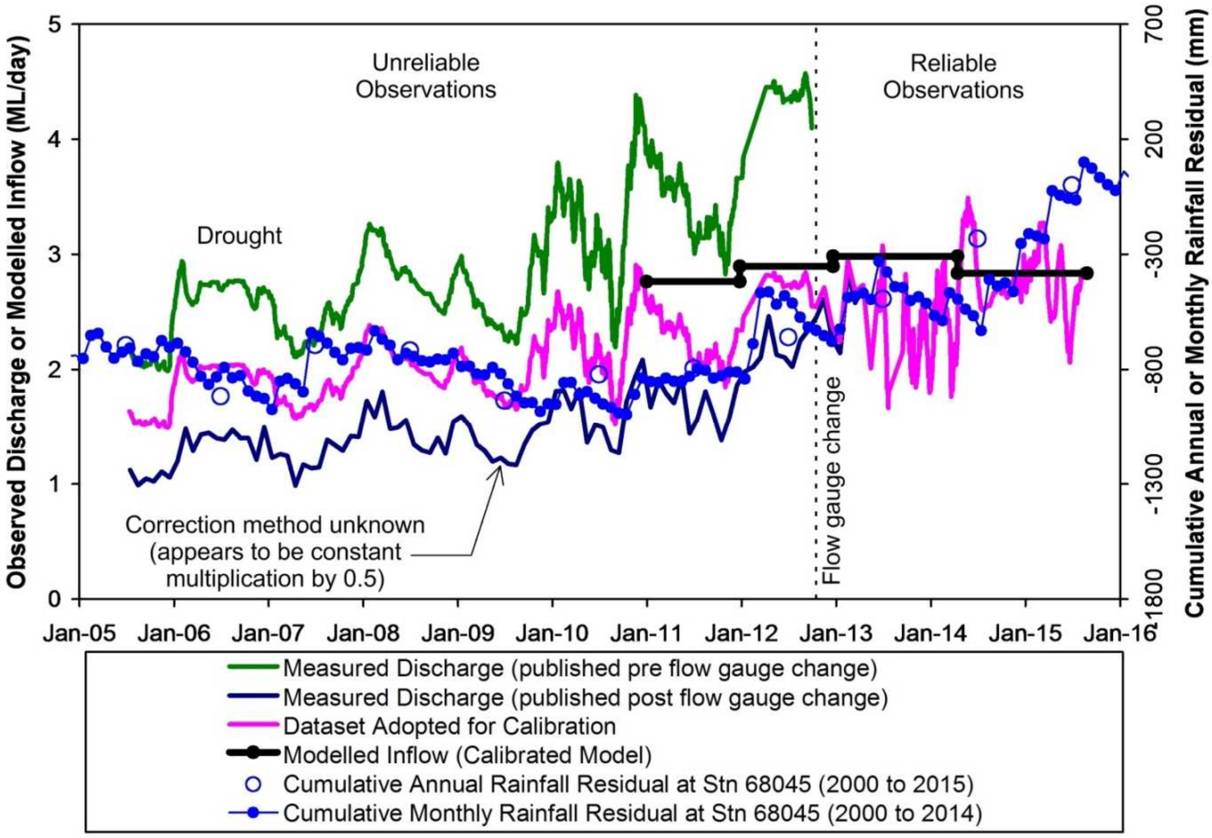


**Figure 4.6. Observed discharge from, and calibrated inflows to, the Berrima mine void over the calibration and verification periods combined.**

## 4.3.4. Flow budget

The modelled average flow budget for the domain over the calibration and verification periods combined (1 January 2011 to 27 August 2015) is listed in Table 4. The flow budget discrepancy is considered reasonable.

**Table 4. Modelled average flow budget over the calibration and verification periods combined.**

| IN (ML/day) | | OUT (ML/day) | |
|---|---|---|---|
| Rainfall Recharge | 37.5 | Baseflow to Wingecarribee River | 11.9 |
| Release from Media Storage | 12.2 | Baseflow to other Rivers and Creeks | 10.3 |
| Leakage from Reservoirs | 2.3 | Berrima Mine Inflow (to river) | 2.9 |
| Leakage from Medway Dam | 0.5 | Loch Catherine Mine Inflow (to river) | 0.5 |
| | | Inflow to Other Mines (to rivers) | 0.7 |
| | | Private Pumping | 14.6 |
| | | Evapotranspiration | 14.2 |
| TOTAL | 52.7 | TOTAL | 54.9 |
| Discrepancy: -2.2 ML/day (-4.1%) | | | |

## 4.3.5. Model fitness for purpose

The hydrogeological conceptual model and numerical groundwater model have been developed based on the following four crucial, large, and totally independent observation datasets:

- Hydraulic heads.
- Hydraulic conductivity.
- Shallow groundwater discharge (baseflow to streams).
- Deep groundwater discharge (drainage to the existing Berrima mine void).

The numerical model is simultaneously reasonably replicating all four datasets, which considerably reduces uncertainty in outputs, and has allowed a reliable estimation of the Kv versus depth distribution (fundamental for predictive simulation of deep discharges). The model Kv distribution also accords with a $5^{th}$ group of critical observations: Kv estimated from the long-term pumping tests undertaken by Hume on the mine lease in 2014. Calibrated storage parameters accord with several observations in the database. The model is therefore considered fit for estimating impacts from proposed mining in the Hume lease area, and is considered to provide a reliable basis for predictive simulation.

The model is expected to conform to approximately 70% of the criteria for Class 3 models, with remaining aspects of the model conforming to Class 2 criteria, according to the classification system in the Australian Groundwater Modelling Guidelines (Barnett et al 2012).

For the Class 3 model criterion that predictive “stresses are not more than 2 times greater than those included in calibration”, the quantity to be used in defining the stress is not explicitly stated in the guidelines. However, most of the examples used to define stress in the guidelines are fluxes (for example, rainfall recharge or pumping). The document defines stress as a process that leads to the removal or addition of water from or to a groundwater system. Using a spatial extent criterion, the model calibrated herein would conform to the Class 2 criterion for predictive stress magnitude. However, using a flux criterion, predictive modelling indicates that the predictive stress (the Hume mine) generates about 6 ML/day, compared to around 3 ML/day for the main calibration stress (the Berrima mine). With the inclusion of the Loch Catherine mine, and other mines, the model would conform to the Class 3 predictive stress magnitude criterion.

# 5. Predictive simulation

The calibrated model has been used as the basis for a predictive model that simulates mining in the Hume Lease area. The predictive model is used for impact assessment.

## 5.1. Model settings

The following settings have remained unchanged from the calibration model:

- Subsurface media geometry and hydraulic parameters.
- Rainfall recharge applied at 1.8% of the area-weighted long-term annual average rainfall of 949 mm for the model domain, without variation).
- Wingecarribee reservoir water level (676 m AHD).
- Kv of 0.1 m/day for the Wingecarribee River.
- Riverbed conductance of 25 $m^2$/day (for 50 m x 50 m cells) for Medway Dam.
- Existing mine workings (extent and drain conductance), passively draining to rivers. It is understood the owners of Berrima Colliery are considering sealing the discharge adit. It is not known if this will occur.
- Drain and river invert elevations, and other imposed boundary conditions at the model extremities.

Hume mining occurs in 50 m x 50 m cells. The calibrated mine drain conductance for the Berrima mine applies to 50 m x 100 m cells. Under the assumption that the major part of the induced flow field is vertical (with the conductance parameter behaving similarly to a riverbed conductance) the drain conductance for Hume mine workings is set to 0.05 $m^2$/day. This also assumes similar stress distributions around mine openings for the existing Berrima and proposed Hume workings. This parameter is the subject of a sensitivity analysis (see section 5.2.2).

The starting hydraulic head field for predictive simulations is the modelled hydraulic head distribution of 27 August 2015, obtained from the calibration model. Proposed mining comprises the main change to the calibration model to create the predictive model; implementation is discussed below.

## 5.2. Pumping from Hume-owned bores

There are several Hume-owned bores which will be used during mining. These bores are listed in Table 5. The total volume of entitlement that is expected to be available for these bores is 962 ML/year. In predictive simulations, allocations for these bores are used for mining, with farming activities utilising any unused allocation. The predictive scenario pumping schedule for these bores is as follows:

- GW108194 and GW108195 are never pumped.
- The remaining five bores are pumped at full annual entitlement, less the volume required to cover total mine take (inflow to the sump and inflow to the void), while mine take is less than the entitlement.
- The pumped water is used first for water balance deficit satisfaction, then for irrigation. The pumped amount reduces as mine take increases, and is extinguished when mine take reaches 962 ML/year.
- When mine take is higher than the total Hume entitlement, bores are not pumped.

**Table 5. Private bores passing to Hume ownership prior to mining.**

| Bore Number | Easting (mMGA) | Northing (mMGA) | Licence Number | Allocation (ML/year) | Licensed Purpose | Use during mining |
|---|---|---|---|---|---|---|
| GW053331 | 251462 | 6177338 | 10CA111696 | 488 | Domestic / stock / irrigation | Pumping at maximum licensed rate, except when allocation is applied to mine inflow. |
| GW031686 | 251953 | 6178061 | | | | |
| GW059306 | 252123 | 6178404 | | | | |
| GW057908 | 250955 | 6176276 | 10CA111712 | 179 | Domestic / stock / irrigation | |
| GW106491 | 249802 | 6173568 | 10CA112150 | 100 | Irrigation | |
| Assumed future purchase | | | | 75 | To be confirmed | |
| GW108195 | 250939 | 6172001 | 10CA112196 | 120 | Irrigation | No Pumping |
| GW108194 | 251005 | 6172692 | | | | |
| GW025588 | 252124 | 6178343 | 10WA109649 | N/A | Stock | Minor pumping |
| GW031684 | 253137 | 6178647 | 10WA109694 | N/A | Domestic | |
| GW031685 | 252179 | 6178221 | 10WA109707 | N/A | Domestic | |
| GW031687 | 252013 | 6178679 | 10WA109708 | N/A | Domestic | |
| GW109084 | 250446 | 6170161 | 10WA111035 | N/A | Stock / domestic | |

## 5.2.1. Mine water balance

Calculation of an approximate mine water balance was required for the predictive simulation. The mine water balance deficit is satisfied by

- Pumping from Hume bores; and /or
- Withdrawal of water from recovering mine voids.

Pumping from Hume bores is available only in early years, since their allocation is required to cover increasing mine take as mining progresses.

Changes in bore pumping (both Hume and private bores) and withdrawal from recovering voids caused changes in mine inflows and therefore changes in the water balance deficit and mine take amounts. This therefore required an iterative simulation process.

Table 6 lists the components comprising mine water inputs and demands, and the resulting deficit, using results from the final simulation run (further discussed below in the results section).

**Table 6. Mine water inputs and demands (using optimised results).**

| Mining Year | IN (ML/year) | | OUT (ML/year) | | | | | | | | Net Water Balance (ML/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ground runoff + pond rain-on less pond evaporation [A] | Ground-water Inflow to mine sump | Net CHPP process water demand [B] | Tailings makeup water demand [D] | Product coal handling demand [C] | ROM coal stockpile demand [C] | Underground Operations | | MIA demand [C] | Bathhouse, crib rooms, etc [B] | |
| | | | | | | | ROM coal added water [D] | Ventilation loss [D] | | | |
| 1 | 125 | 127 | 6 | 0 | 110 | 28.1 | 13 | 30 | 5 | 14 | 46 |
| 2 | 125 | 181 | 27 | 166 | 110 | 28.5 | 58 | 49 | 16 | 14 | -162 |
| 3 | 125 | 282 | 47 | 257 | 111 | 28.7 | 96 | 49 | 20 | 14 | -216 |
| 4 | 125 | 326 | 54 | 220 | 112 | 29.5 | 86 | 49 | 36 | 14 | -150 |
| 5 | 125 | 331 | 81 | 296 | 113 | 29.8 | 96 | 49 | 41 | 14 | -264 |
| 6 | 125 | 332 | 94 | 355 | 112 | 29.5 | 105 | 49 | 39 | 14 | -341 |
| 7 | 125 | 595 | 81 | 367 | 112 | 29.6 | 107 | 49 | 43 | 14 | -83 |
| 8 | 125 | 373 | 58 | 392 | 113 | 29.7 | 107 | 49 | 43 | 14 | -308 |
| 9 | 125 | 434 | 59 | 382 | 113 | 29.7 | 113 | 49 | 44 | 14 | -245 |
| 10 | 125 | 389 | 65 | 261 | 113 | 29.8 | 98 | 49 | 46 | 14 | -162 |
| 11 | 125 | 428 | 60 | 284 | 113 | 30 | 93 | 49 | 46 | 14 | -135 |
| 12 | 125 | 457 | 69 | 283 | 113 | 29.9 | 100 | 49 | 44 | 14 | -120 |
| 13 | 125 | 492 | 77 | 364 | 113 | 29.9 | 112 | 49 | 46 | 14 | -188 |
| 14 | 125 | 409 | 75 | 471 | 113 | 29.7 | 112 | 49 | 45 | 14 | -375 |
| 15 | 125 | 425 | 71 | 553 | 112 | 29.6 | 103 | 49 | 42 | 14 | -424 |
| 16 | 125 | 489 | 65 | 310 | 112 | 29.6 | 88 | 49 | 41 | 14 | -95 |
| 17 | 125 | 985 | 76 | 293 | 113 | 29.8 | 105 | 49 | 44 | 14 | 386 |
| 18 | 125 | 792 | 47 | 254 | 112 | 29.5 | 87 | 49 | 38 | 14 | 287 |
| 19 | 125 | 513 | 24 | 110 | 111 | 28.8 | 39 | 49 | 20 | 14 | 242 |

A. Long-term runoff coefficient 0.2. Average rainfall 0.957 m/year. Ground: area 735110 $m^2$; net accession 0.191 m/year. Water: area: 202900 $m^2$; net accession -0.078 m/year.
B. Specified by Hume.
C. Parsons Brinckerhoff. 2015. Hume Coal Project - Stage 1 (Preliminary) Water Balance Report. Report 2200538A-WAT-REP-001 Rev2, prepared for Hume Coal. September.
D. "HUM1652-373 Water Balance Spreadsheet mdb060516.xlsx" received 7 May 2016 from Palaris.

Withdrawal from recovering voids is undertaken only when bulkheads are established at the entries to the respective panels. Specific voids were targeted, comprising panels sealed during mining years 3 to 7, as follows:

- Panels W6 to W8.
- Panels W9 and W10.
- Panels W11 to W13.
- Panels W14 to W18.

Deficits and mine take beyond year 7 were satisfied by withdrawal from panels W14 to W18.

Initial withdrawal from voids would be carried out by pumping water from behind the bulkhead (through pipes and valves in the bulkheads, or from bores penetrating the voids and sealed throughout overburden media). Once panels W14 to W18 are sealed, withdrawal from them would be undertaken using permanent bores penetrating those voids and sealed throughout overburden media.

## 5.3. Proposed mining

Mining occurs for a period of 19 years (nominally 2021 to 2039 inclusive). Approximately 50 Mt will be mined. Table 7 lists the yearly mining schedule and other information discussed below.

Mining advance is simulated by activation of drains when a part of the seam is mined. The drain elevation is set to 0.1 m above the mined floor level. The drain condition is imposed in any layer intersected by the drained zone above a panel or mine opening. The model simulates development of main headings and panel gate roads prior to secondary extraction. Figure 5.1 illustrates the typical progress of mining for the first workings method. The majority of changes in media hydraulic properties occur in the drained zone, but since this zone is maintained in a dewatered state, these changes do not significantly impact the functioning of the model. Changes in media properties above the drained zone are considered negligible for non-caving methods, and the overall vertical K field between ground surface and the top of the relaxed zone does not change.

Figure 5.2 illustrates the adopted heights of desaturation with respect to model layering.

**Table 7. Yearly mined volume and co-disposed tailings emplaced.**

| Calendar Year | Mining Year | Run-of-Mine Coal (Mt) | Mined Volume ($m^3$) | Co-Disposed Tailings Emplaced ($m^3$) |
|---|---|---|---|---|
| 2021 | 1 | 0.38 | 247980 | 0 |
| 2022 | 2 | 1.69 | 1102692 | 345471 |
| 2023 | 3 | 2.82 | 1839725 | 534062 |
| 2024 | 4 | 2.54 | 1665325 | 456877 |
| 2025 | 5 | 2.82 | 1841464 | 613792 |
| 2026 | 6 | 3.08 | 1994056 | 737812 |
| 2027 | 7 | 3.15 | 2045160 | 762305 |
| 2028 | 8 | 3.16 | 2040342 | 813945 |
| 2029 | 9 | 3.31 | 2154903 | 794062 |
| 2030 | 10 | 2.87 | 1888687 | 542602 |
| 2031 | 11 | 2.73 | 1772364 | 589989 |
| 2032 | 12 | 2.95 | 1915615 | 587177 |
| 2033 | 13 | 3.28 | 2132458 | 756667 |
| 2034 | 14 | 3.29 | 2102426 | 978965 |
| 2035 | 15 | 3.04 | 1853594 | 1148742 |
| 2036 | 16 | 2.59 | 1671060 | 644259 |
| 2037 | 17 | 3.08 | 2013607 | 609421 |
| 2038 | 18 | 2.55 | 1640445 | 526792 |
| 2039 | 19 | 1.14 | 743896 | 227761 |
| 2040 | | | | 75316 |
| | TOTAL | 50.48 | 32665796 | 11746020 |
| Total co-disposed tailings volume as a proportion of total mined volume | | | | 0.36 |

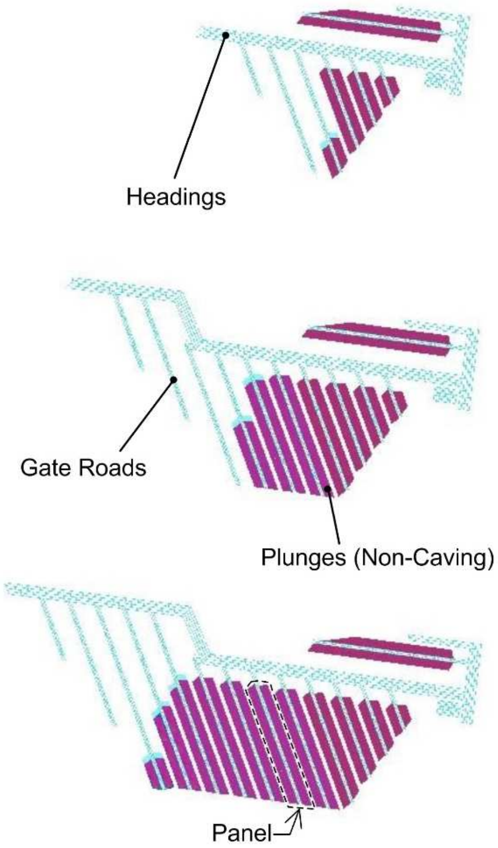


**Figure 5.1. Evolution of headings and workings for the Pine Feather method over three instants in time (time moves forward from top to bottom).**

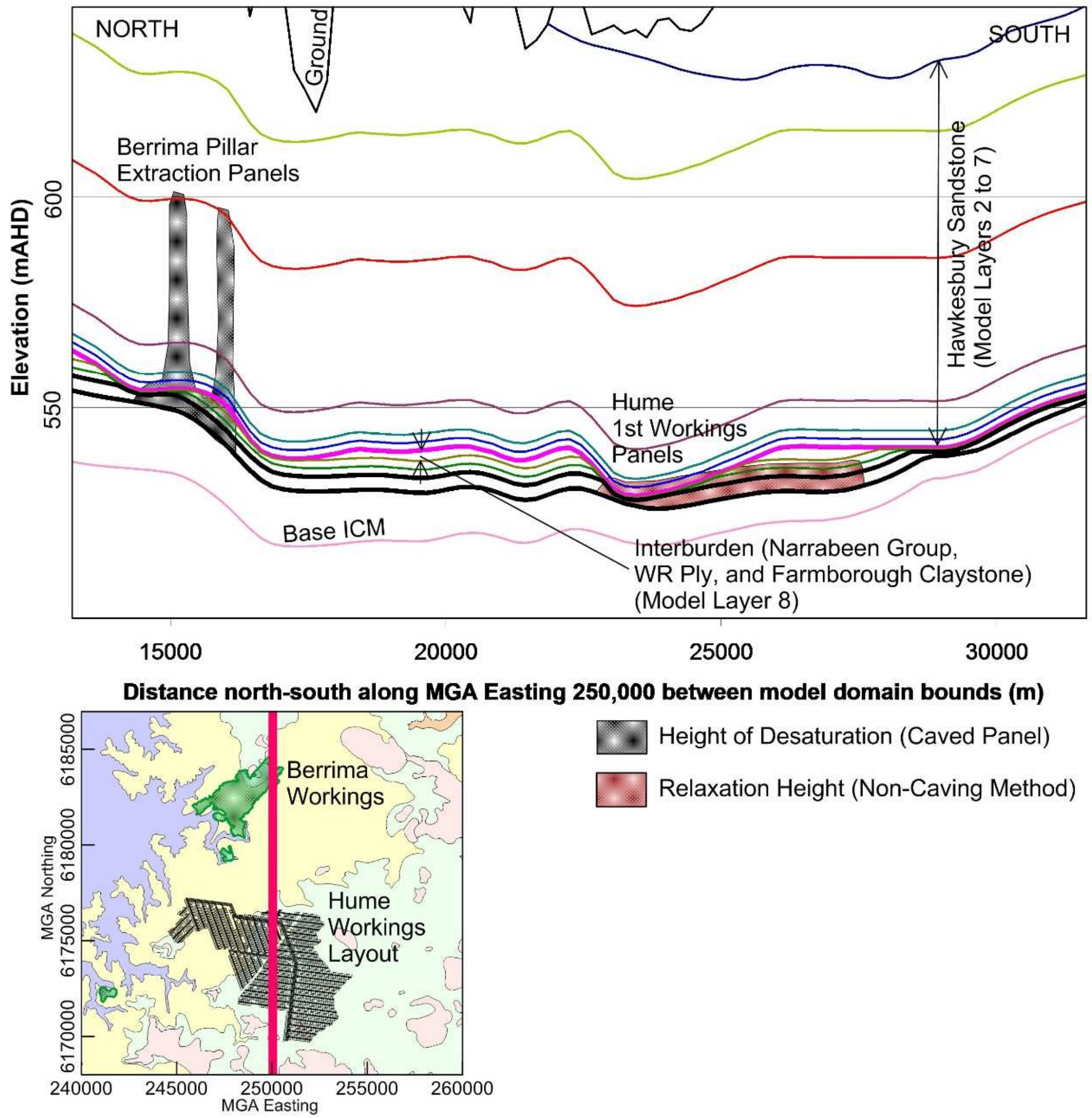


**Figure 5.2. Interrelationship between model layering and adopted heights of desaturation above workings types.**

### 5.3.1. Mitigation measures

The following three groundwater mitigation measures for the Hume mine were simulated:

- Sealing individual panels as they are mined, using bulkheads rated to withstand equilibrated hydraulic heads. Bulkheads are water-tight seals placed in panel gate roads at their juncture with main headings, when the panel is complete. They are also placed at the start of main headings when the headings are no longer required.
- Backfilling of the mined void with co-disposed tailings. In its final state (following extraction of decanted water) it is non-draining (it neither accepts nor releases water, and is inert with respect to groundwater fluxes). The decanted water is not included in co-disposed tailings volumes used in numerical simulation.
- Injection of mine water back into the void through the bulkheads, should excess water be available. Bulkheads will be constructed to provide a seal capable of withstanding the applied water pressures at post-mining equilibration of the hydraulic head field. Injection would be carried out through access pipes built into the bulkheads.

These measures operate during mining. Mine water balance calculations undertaken during iterative predictive simulation indicate that negligible water was available for bulkhead injection.

Panels are sealed about one week after completion. Co-disposal of tailings begins prior to this, following extraction in plunges; it lags the workings area by about 200 m. Co-disposed tailings emplacement is estimated to fill approximately 36% of the total mine void space. Main headings are sealed after the block of panels serviced by them is completed.

During mining, active void dewatering is not undertaken where water pools downdip of the workings area. Figure 5.3 conceptualises the fate of groundwater inflow to the mine void depending on the direction of mining with respect to the dip of a panel. Appendix C presents a plan of estimated inflow areas where pumping will not be required, based on mined seam structure contours and mine layout. Inflow to these zones contributes to void refilling. The mining rate is faster than the encroachment of the beach (formed by the mine pool) in these situations.

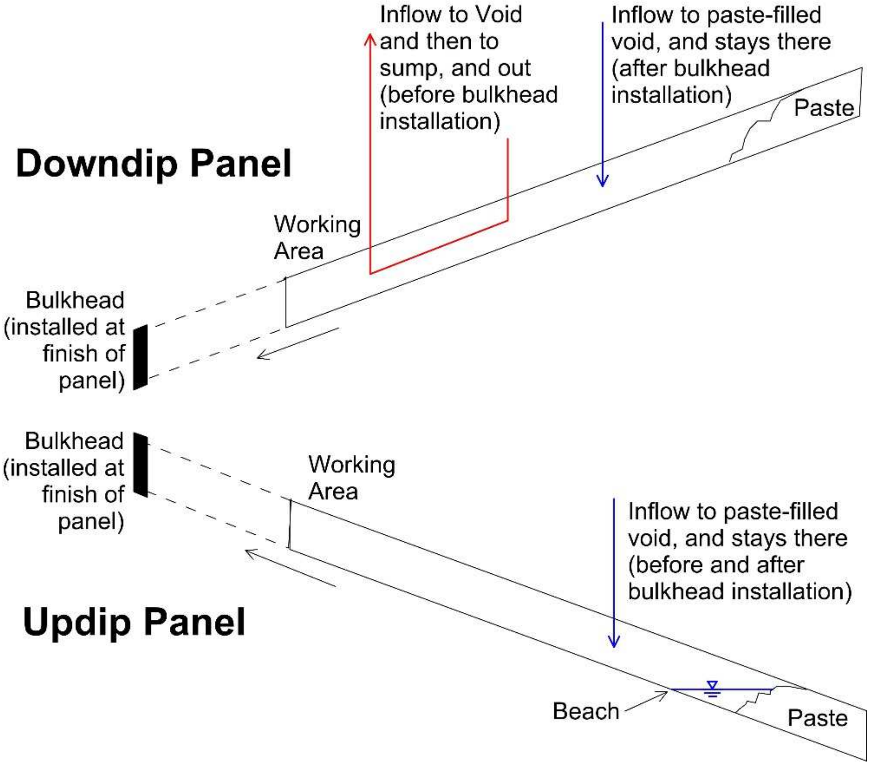


**Figure 5.3. Conceptualisation of the fate of groundwater inflow to the workings, depending on panel dip with respect to mining direction.**

## Model implementation

Model implementation of the mitigation measures and post-mining water level recovery is carried out in a simplified way to reduce uncertainties.

During mining, drainage into the mined void is carried out using the drain mechanism (see above). To simulate the mitigation measures, the drain cells for a panel are active only for the time required for the total drained water to be equivalent in volume to the remaining void of that panel after injection behind the bulkheads and co-disposed tailings emplacement. The remaining void is calculated from a-priori schedules of injection behind bulkheads and co-disposed tailings emplacement (listed in Table 7). Predictive simulation was undertaken in an iterative fashion until the modelled total water exiting the drains for a panel was within 1% of the remaining mined volume for that panel (that is, with co-disposed tailings emplacement and injection volumes removed), and taking account of water withdrawn to satisfy water deficits. This methodology is illustrated in Figure 5.4.

This approximation circumvents the difficulty inherent in using a Darcian flow algorithm (flow in a resistive medium by the action of a potential energy field) to simulate a void that fills by hydrodynamic processes. Since the vast majority of the remaining mined volume is present in the roadways (rather than the roof), and the K field above the drained zone undergoes negligible change, and H penetrates only 2 m into the roof, the approximation negligibly impacts the head differential applied to the drained zone during recovery, and negligibly impacts the post-mining hydraulic head field above the relaxed zone (see Figure 5.4). The post-mining storage capacity in the model in the void zone is less than 1% of the actual storage capacity, which results in the void zone being filled quasi-instantaneously relative to the time-scale of recovery, and negligibly impacts recovery times. The lateral hydraulic head gradient in the mined seam is also small in the fully recovered state, as it would be in the actual state.

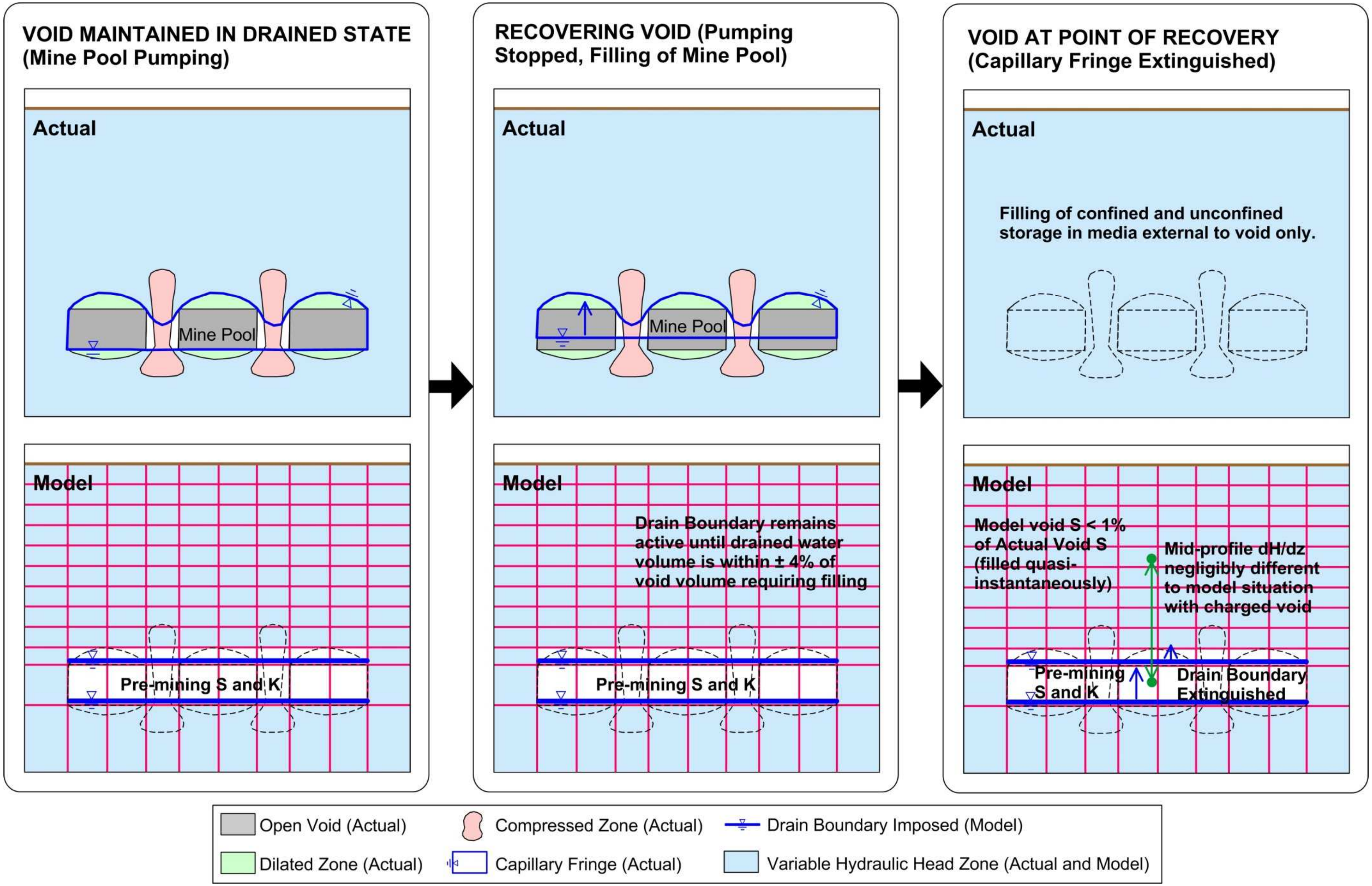


**Figure 5.4. Methodology used in the numerical model to simulate mine drainage and post-mining recovery.**

### 5.3.2. Modelled scenarios

Predictive simulation was undertaken for a period of 100 years for the most probable future scenario. Predictive model simulation years and mining schedule years are equivalent. The future scenario comprises:

- Use of the first workings mining method and layout.
- Average rainfall.
- Co-disposed tailings emplacement filling 36% of the mined void.

Three sensitivity simulations were also undertaken. Modelled scenarios are listed in Table 8. Run 1 comprises the simulation used for predictive impact assessment.

The sensitivity runs were undertaken for a scenario excluding bulkhead injection, considered to be more sensitive to the changes specified in Table 8.

**Table 8. Simulated future scenarios**

| Run Identifier | Details | Purpose |
|---|---|---|
| 1 | First workings method BASE CASE<br>Co-disposed tailings void filling proportion 36%.<br>Injection behind panel bulkheads active.<br>Average rainfall. | Impact Assessment |
| Null | Identical to Run 1 except no Hume mining. | Differential Impact Calculation |
| S1 | Relaxation Height: 2 m and 4 m. | Sensitivity Analysis |
| S2 | Kv: Calibrated and x 3 down the profile, for layers 1 to 5 (WG and HAW) | |
| S3 | Hume Mine Drain Conductance: 0.05 and 0.1 $m^2$/day. | |

# 6. Predictive results

9 iterations were required to reduce the total water balance error for the mine, and its interaction with the mine take, to 0.009 (0.9%). The mine water balance is in deficit for 15 of the 19 mining years (years 2 to 16 inclusive). Negligible amounts were available for reinjection behind bulkheads.

## 6.1. Inflows to mine workings

Figure 6.1 shows the modelled inflows to the mine workings. Inflow to the active mine area (the sump) ceases after year 19, when pumping within the mine ceases. Inflow behind the sealed bulkheads (mine void) ceases at the end of year 22 following the start of mining (3 years after cessation of mining), beyond which groundwater recharge is consumed by media storage around the void (recovery of elastic storage and recovery at the water table). The time of overall maximum impact for groundwater storage release and drawdowns (discussed below) is at approximately 17 years since the start of mining.

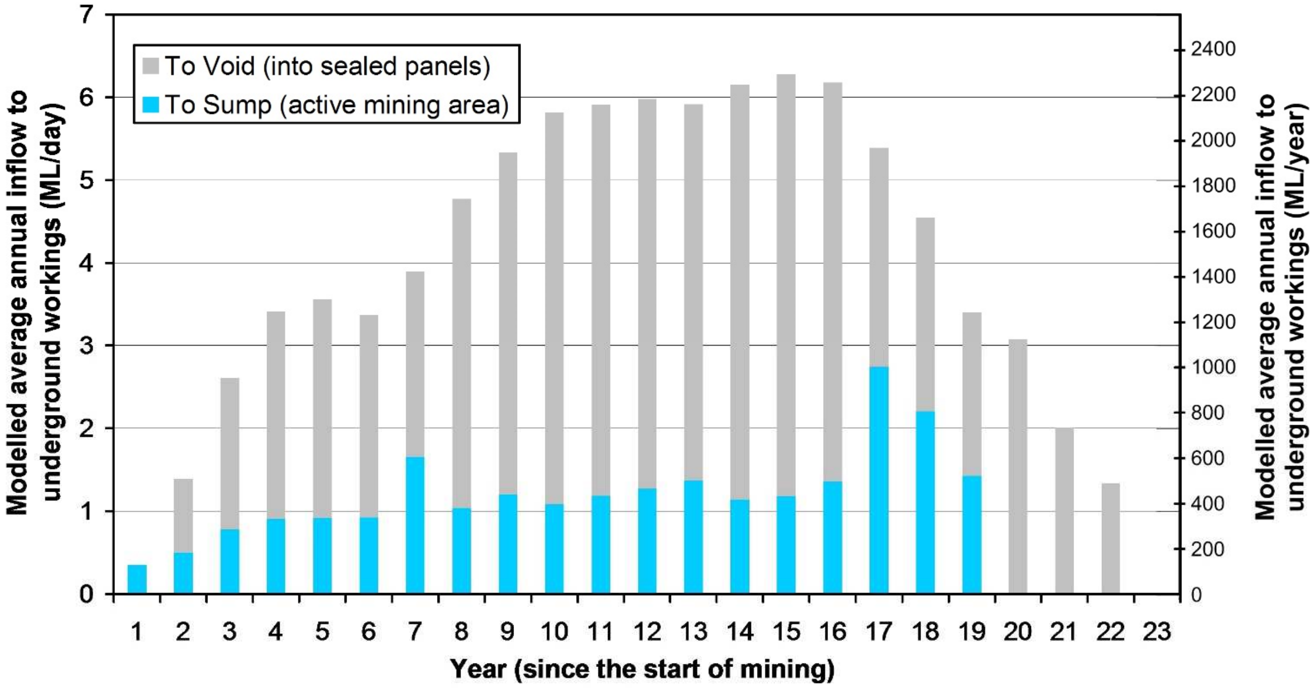


**Figure 6.1. Modelled inflows to the mine void for the active mining case.**

Table 9 lists maximum inflows and total accounts.

**Table 9. Maximum flow rates and total accounts during the period of active stress induced by the mine.**

| Maximum Rates over the Period of Active Stress* | | |
|---|---|---|
| **Mine Inflow Component** | **GL/year** | **ML/day** |
| Sump | 1.00 | 2.74 |
| Void | 1.86 | 5.10 |
| Total | 2.29 | 6.28 |
| **Total Accounts over the Period of Active Stress** | | |
| **Component** | **Total (GL)** | |
| Mined Volume | 32.7 | |
| Inflow to Mine Void (Modelled) (3.3 GL pumped out to satisfy mine water demand deficit) | 24.3 | |
| Co-disposed tailings Volume (36% of Mined Volume) | 11.7 | |
| Injected Volume (Modelled) | nil | |
| Inflow To Mine Sump (Modelled) | 8.4 | |

* The time to reach maximum is not necessarily coincident for each item.

## 6.2. Flow budget

The modelled average flow budget for the domain over the period of mine inflow (mining, and simulation, years 1 to 22 inclusive) is listed in Table 10 for the case where Hume mining is active. The flow budget discrepancy is considered reasonable. The increased leakage from reservoirs from 2015 (0.2 ML/day) is mostly due to private pumping.

**Table 10. Modelled average flow budget over the period of mine inflow (mining and simulation years 1 to 22 inclusive) for the case of active Hume mining.**

| IN (ML/day) | | OUT (ML/day) | |
|---|---|---|---|
| Rainfall Recharge | 34.9 | Baseflow to Wingecarribee River | 10.2 |
| Release from Media Storage | 7.4 | Baseflow to other Rivers and Creeks | 10.9 |
| Leakage from Reservoirs | 2.4 | Berrima Mine Inflow (to river) | 2.5 |
| Leakage from Medway Dam | 0.6 | Loch Catherine Mine Inflow (to river) | 0.4 |
| | | Inflow to Other Mines (to rivers) | 0.6 |
| | | Private Pumping | 11.0 |
| | | Hume Mine Inflow | 2.6 |
| | | Evapotranspiration | 10.4 |
| TOTAL | 45.4 | TOTAL | 48.6 |
| Discrepancy: -3.2 ML/day (-6.8 %) | | | |

Comparison to the null case indicates that at 17 years since the start of mining, baseflow interception of overlying streams makes up approximately 23% of the total inflow.

The water balance deficit is satisfied by pumping from the following voids:

- Panels W6 to W8: 6% of deficit.
- Panels W9 and W10: 17% of deficit.

- Panels W11 to W13: 25% of deficit.
- Panels W14 to W18: 52% of deficit.

The modelled average flow budget for the domain over simulation years 1 to 22 inclusive for the null case (Hume mining is not active) is listed in Table 11. The flow budget discrepancy is considered reasonable.

**Table 11. Modelled average flow budget over simulation years 1 to 22 inclusive for the null case (Hume mining is inactive).**

| IN (ML/day) | | OUT (ML/day) | |
|---|---|---|---|
| Rainfall Recharge | 34.9 | Baseflow to Wingecarribee River | 9.0 |
| Release from Media Storage | 6.4 | Baseflow to other Rivers and Creeks | 11.2 |
| Leakage from Reservoirs | 2.4 | Berrima Mine Inflow (to river) | 2.5 |
| Leakage from Medway Dam | 0.5 | Loch Catherine Mine Inflow (to river) | 0.4 |
| | | Inflow to Other Mines (to rivers) | 0.6 |
| | | Private Pumping | 13.0 |
| | | Hume Mine Inflow | 0.0 |
| | | Evapotranspiration | 10.3 |
| TOTAL | 44.3 | TOTAL | 47.0 |
| Discrepancy: -2.8 ML/day (-6.0 %) | | | |

# 6.3. Drawdown

Changes to the hydraulic head field from Hume mining operations are discussed as the following:

- Total drawdown (cumulative; includes Hume and other users). This is the drawdown from the beginning of the simulation period, for the scenario where all stresses in the model are operating, including the Hume mining operation, the draining mine void at Berrima, and private pumping. This is the active Hume mining scenario. The total drawdown is thus the cumulative drawdown due to all stresses.
- Differential drawdown (Hume only; excludes other users). This drawdown is calculated as the difference between drawdowns from the active Hume mining scenario (which gives the total drawdown) and the null scenario where the Hume operation is inactive (giving a null case drawdown). The differential drawdown is thus that drawdown due only to the Hume operation.

## 6.3.1. Temporal drawdown

Apart from private bores (discussed below), temporal drawdown has been obtained at the following 16 virtual monitoring piezometer locations (shown in Figure 6.2):

- Locations G1 to G11: Drawdown at potential groundwater dependent ecosystem (GDE) areas.
- Locations A1 to A5: Drawdown over the Hume mine footprint, and along a line extending away from it in a southeasterly direction.

Actual piezometers are not used since they are not precisely located at required horizons, and many will be eliminated by mining with time. For virtual piezometer locations, the uppermost virtual piezometer provides the modelled water table elevation, since it is located in the layer where the water table resides (the model provides a single hydraulic head value for a single layer).

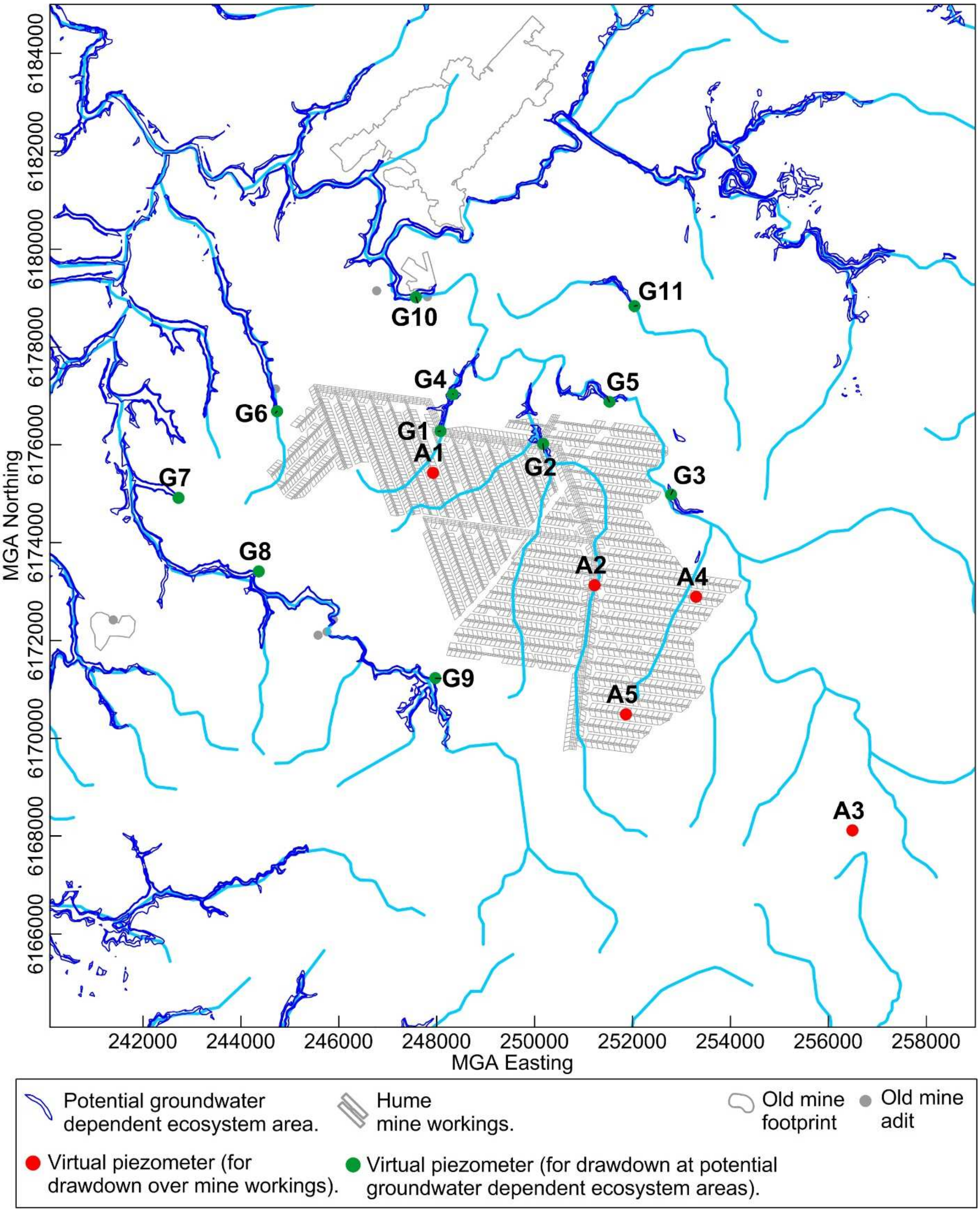


**Figure 6.2. Locations of virtual piezometers used for obtaining hydraulic head and drawdown information at specific locations.**

Figure 6.3 shows the modelled differential drawdown over the main headings (piezometer nest A2) and over the southern part of the workings (piezometer nest A5), showing the vertical hydraulic head gradient that is generated by the mine in overlying strata. Virtual piezometer A2 is located over the main headings and this is the more impacted area of the mine as the mains remain open throughout mining.

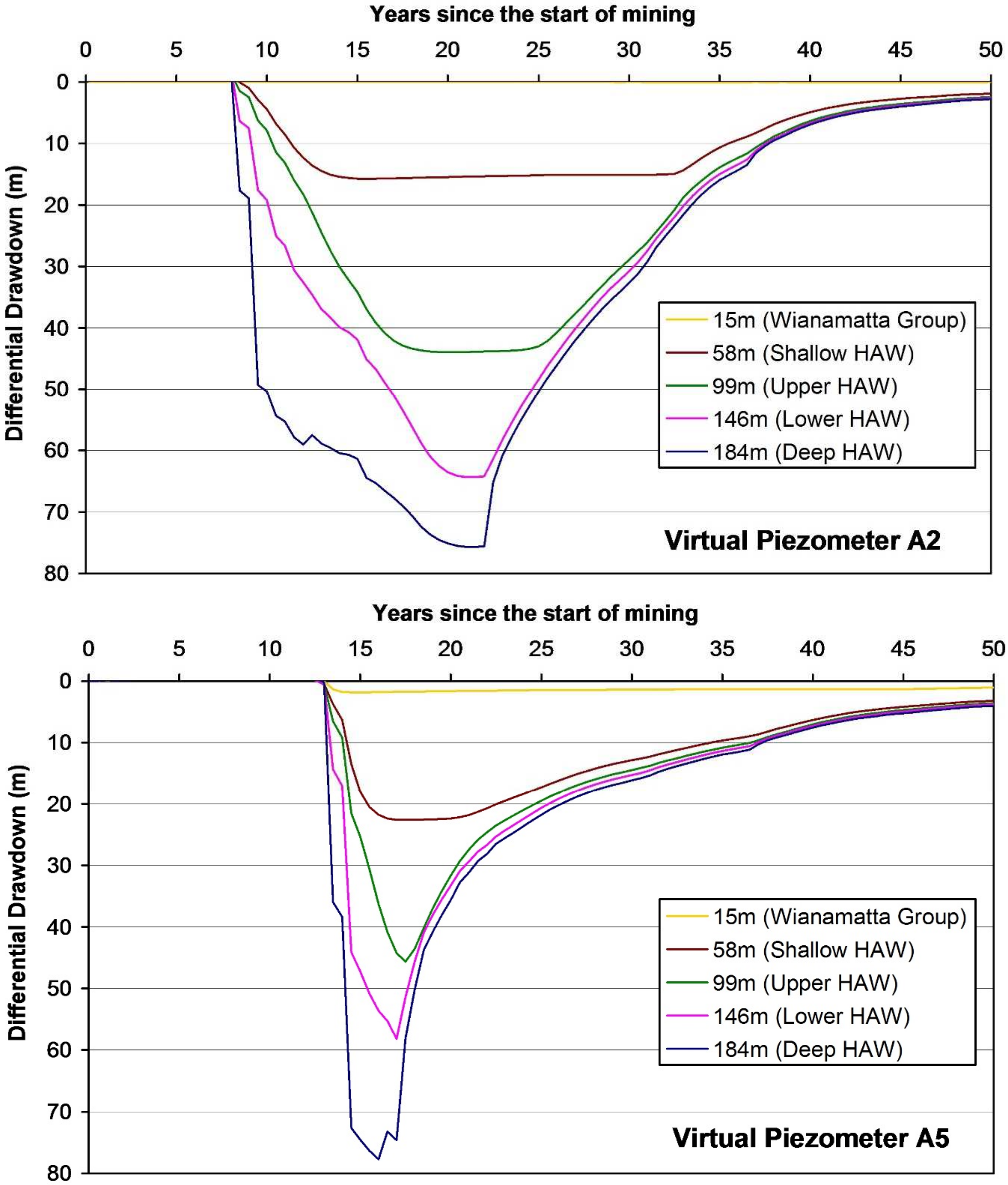


**Figure 6.3. Differential drawdown at virtual piezometer nests A2 and A5.**

Table 12 lists the modelled maximum total and differential drawdowns at the water table at each of the virtual piezometer nests, and the proportion of the total drawdown caused by Hume operations.

**Table 12. Maximum drawdown of the water table at virtual piezometer nests.**

| Piezometer Nest* | Location Relative to Mine Footprint | Maximum Drawdown (m) | | Proportion of Total Drawdown caused by Hume operations (%) |
|---|---|---|---|---|
| | | Total | Differential | |
| A1 | Inside | 25.28 | 22.84 | 90 |
| A2 | Inside | 0.22 | 0.02 | 11 |
| A3 | Outside | 8.05 | 0.88 | 11 |
| A4 | Inside | 9.02 | 5.35 | 59 |
| A5 | Inside | 6.06 | 1.82 | 30 |
| G1 | Inside | 23.21 | 20.95 | 90 |
| G2 | Inside | 0.18 | 0.00 | 2 |
| G3 | Inside | 5.02 | 2.51 | 50 |
| G4 | Outside | 20.31 | 18.14 | 89 |
| G5 | Outside | 0.31 | 0.01 | 2 |
| G6 | Outside | 6.63 | 3.57 | 54 |
| G7 | Outside | 5.00 | 1.44 | 29 |
| G8 | Outside | 4.61 | 1.50 | 33 |
| G9 | Outside | 7.09 | 4.89 | 69 |

* Nil differential drawdown calculated at G10 and G11 at the water table.

Nil differential drawdown was calculated at G10 and G11 at the water table. The maximum differential drawdown of the water table reaches to 25.3 m (at A1) at locations inside the mine footprint and to 20.3 m (at G4) at locations outside the mine footprint. Hume operations account for the majority of the total drawdown inside the mine footprint.

Maximum total drawdown of the water table greater than 2 m, of which a component is due to Hume mining, occurs at all virtual piezometer locations except A2, G2, G5, G10, and G11. Significant drawdown of the water table at potential GDE locations has the potential to affect groundwater dependent ecosystems that may be present.

Appendix D provides total and differential drawdowns for the water table and the base of the Hawkesbury Sandstone for the virtual piezometers. The modelled differential drawdown at G10 and G11 was nil for all horizons.

Figure 6.4 shows modelled differential drawdown of the water table at the virtual piezometer nests. Drawdowns follow relatively complex trends that result from a combination of mitigation measures active during mining, and the ground surface elevation with respect to lithological horizon structure contours. Hydrographs indicate that the overall time instant of maximum impact to the groundwater system (in conjunction with drainage to the mine void; see Figure 6.1) is at about 17 years since the start of mining (2 years before the end of mining).

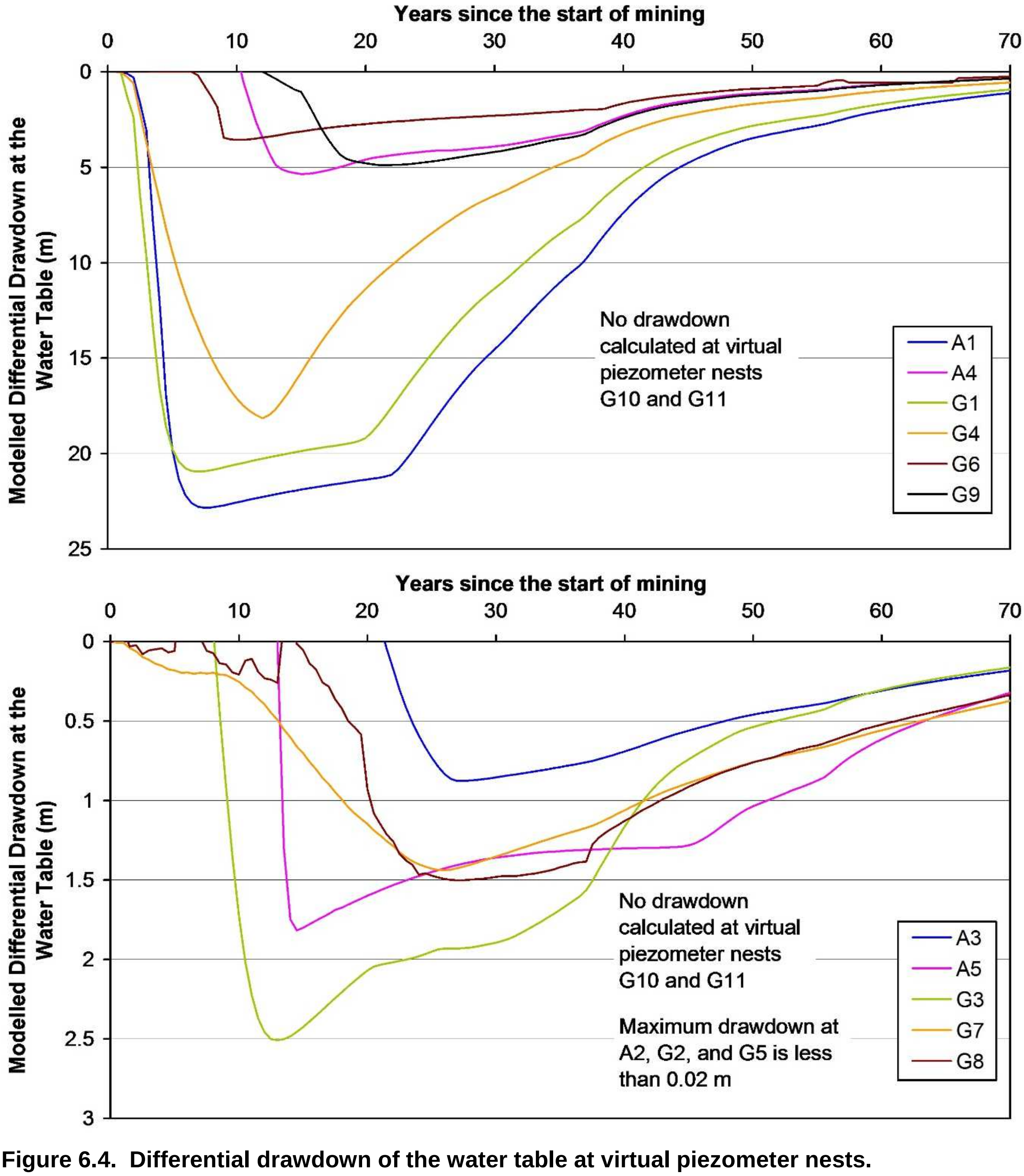


**Figure 6.4. Differential drawdown of the water table at virtual piezometer nests.**

## Recovery time

Recovery of drawdown is presented for differential drawdowns. Total drawdown does not recover to less than 2 m at several virtual locations, due to the effects of private pumping and continued drainage at the Berrima void.

Figure 6.5 shows the duration of time for which differential drawdown of the water table is 2 m or greater, at the virtual piezometer locations. This situation occurs only at seven of the 16 virtual piezometer locations.

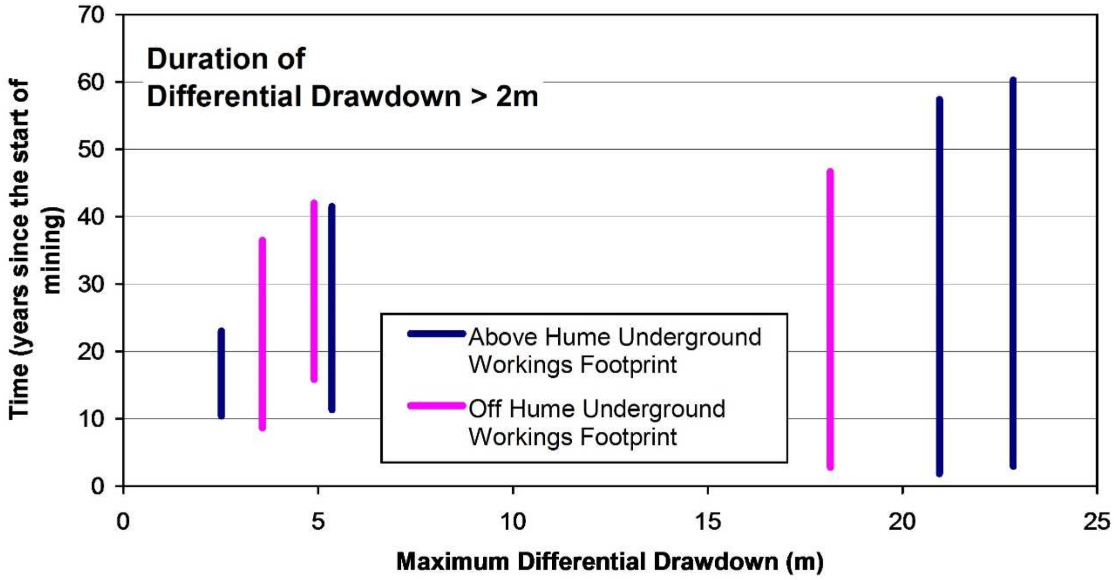


**Figure 6.5. Duration of time for which differential drawdown of the water table is 2 m or greater, at virtual piezometer locations.**

Differential drawdowns greater than 2 m occur for longer times over the workings footprint. The duration varies between about 15 years and 60 years. Recovery of the water table over most of the area, to 2 m differential drawdown, is largely complete within about 60 years since the start of mining.

## 6.3.2. Spatial drawdown

### Water table

Figures 6.6 and 6.7 show the differential drawdown of the water table at 17 and 30 years since the start of mining, respectively. Contours of total drawdown of the water table for these times are shown in Appendix E.

Contours for differential drawdown of the water table form a complex pattern that results from a combination of mitigation measures active during mining, and the ground surface elevation with respect to lithological horizon structure contours. At 17 years, a maximum differential drawdown of about 45 m occurs in a small localised area over the western footprint.

The drawdown extent expands to the east, due to the recharge influx at the western sandstone extremity and the effect of the regional easterly stratigraphic dip on the K field. At 17 and 30 years the 2 m differential drawdown contour extends about 2 km and 4 km respectively past the southeast corner of the mine footprint.

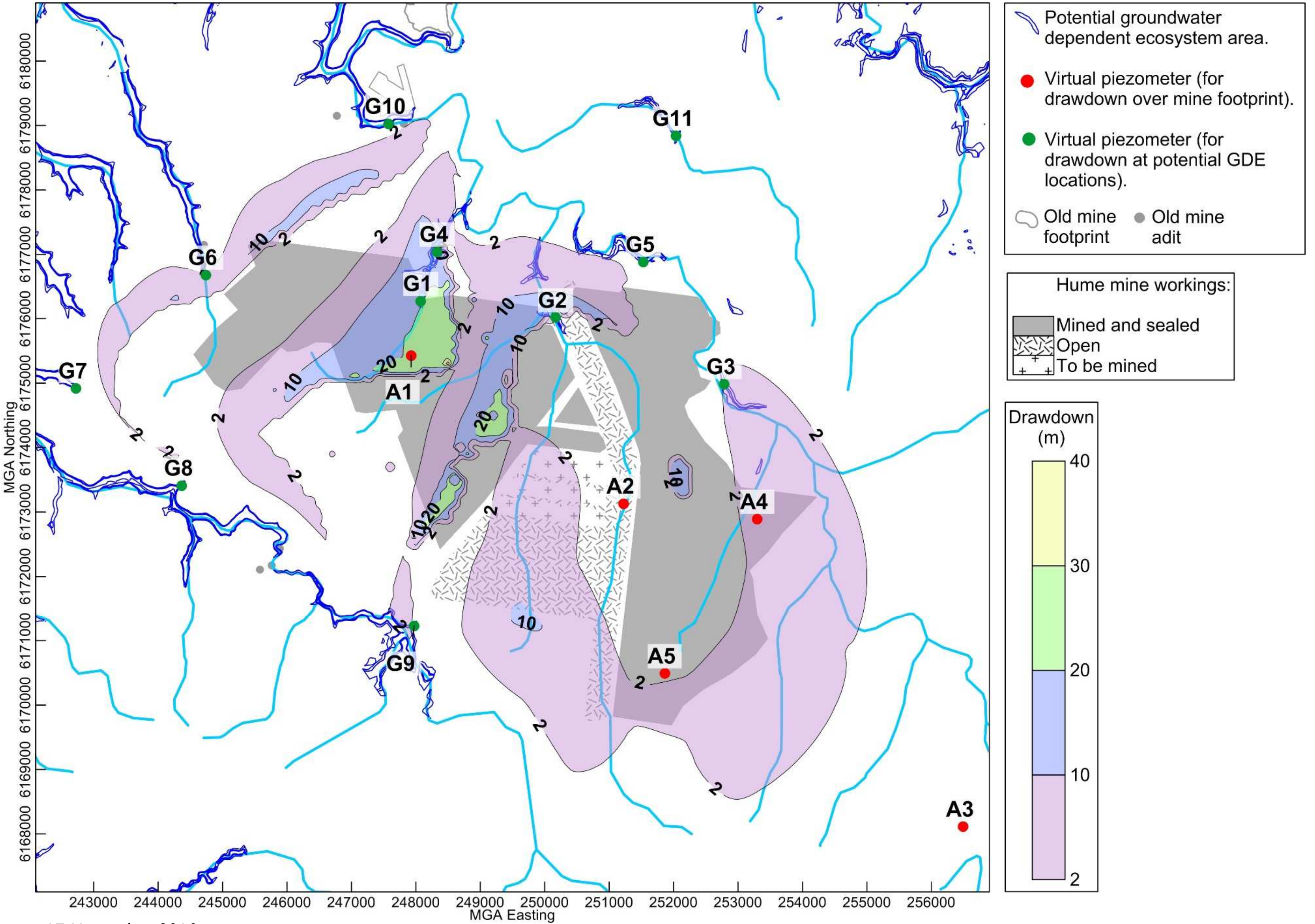


**Figure 6.6. Differential drawdown of the water table at 17 years since the start of mining.**

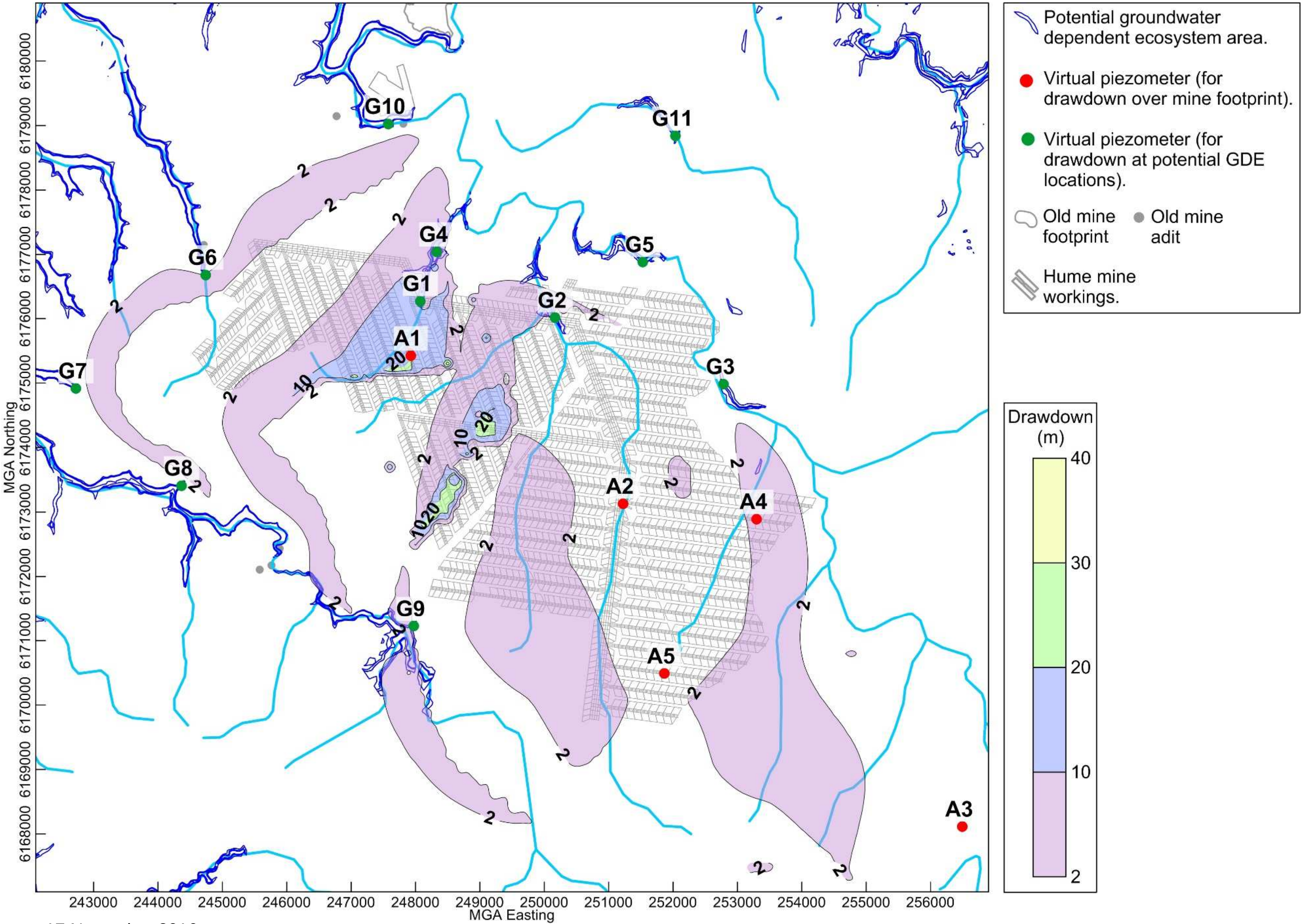


**Figure 6.7. Differential drawdown of the water table at 30 years since the start of mining.**

## Cross Section

Figure 6.8 shows a north-south cross-section of modelled total head, pressure head, and total drawdown through the mine footprint. The total hydraulic head illustrates quasi-horizontal contours above the workings that indicate downward vertical hydraulic head gradients. Gradients can achieve values greater than one for short periods following emplacement of a void. The duration for gradients greater than one depends on recharge and discharge fluxes, and the hydraulic characteristics of the media. Pressure head contours illustrate decreases in pressure moving down through the profile over the workings.

Drawdown contours show the shape of the drawdown envelope, and the increase in drawdown moving down through the profile over the mine footprint. The shape of the drawdown contours is typical for depressurisation induced in a horizontally stratified resistive medium by drainage at depth.

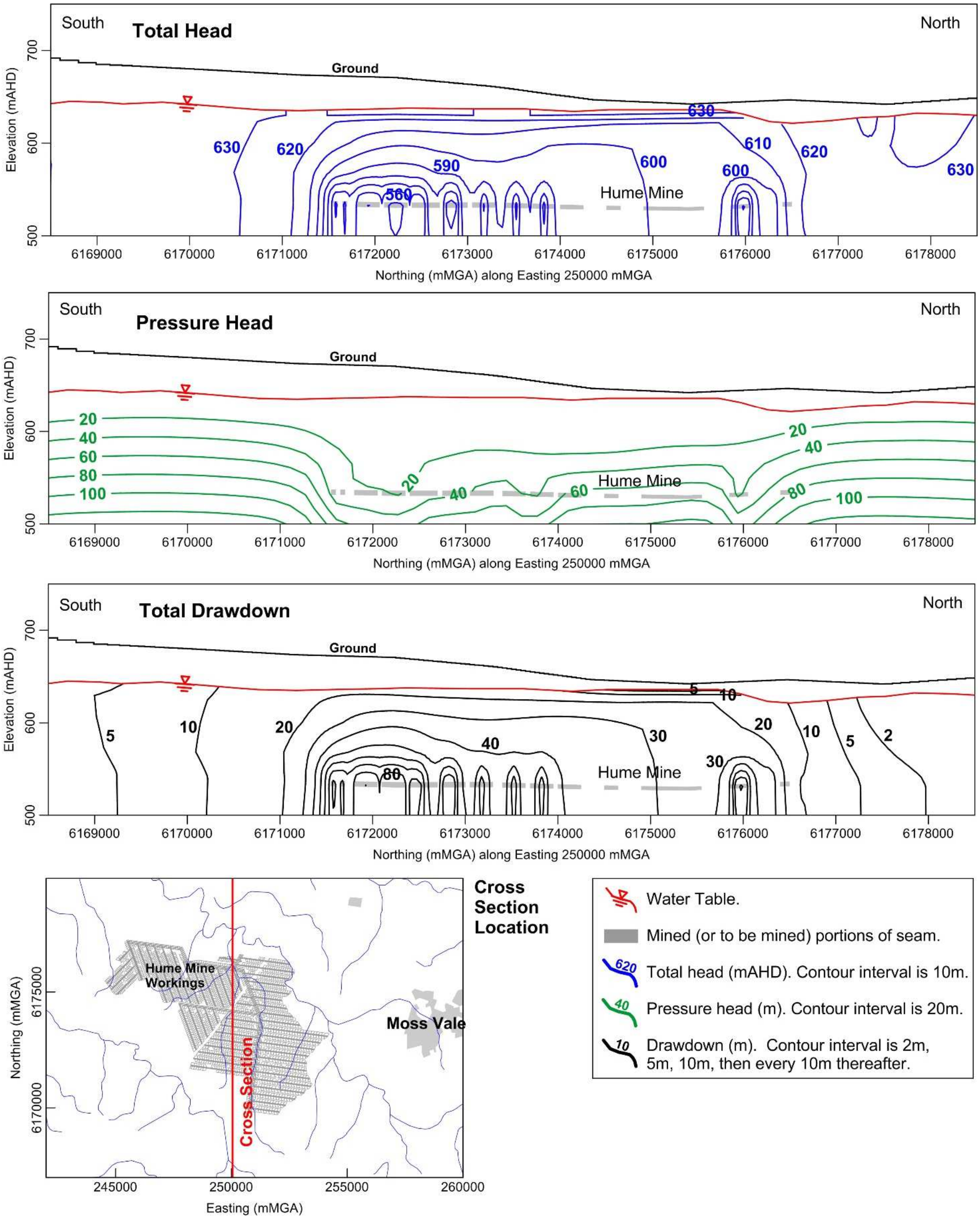


**Figure 6.8. Modelled total head, pressure head, and total drawdown (depressurisation) along a north-south cross section at 17 years since the start of mining.**

# 7. Impact assessment

## 7.1. Water sources

Under the AIP the NSW Government requires mines to consider how their water take may impact upon adjacent and connected water sources. The Water Sharing Plans for the Greater Metropolitan Region (DPI 2011a, 2011b), outline the delineation of both groundwater and surface water sources in this area. Table 13 lists the sources that overlie and are adjacent to the Hume area and Figure 7.1 shows the zones defining these sources.

For the assessment of surface water for the Hume project, the Lower Wingecarribee River and Medway Rivulet surface water zones have been further divided into smaller catchments.

**Table 13. Water source zones and numbering adopted in the model**

| Source Type | Source Zone | Hosting Groundwater Source Zone |
|---|---|---|
| Ground-water | Nepean Management Zone 1 (NMZ1) | N/A |
| | Nepean Management Zone 2 (NMZ2) | |
| | Sydney Basin South (SBS) | |
| Surface Water | Upper Wingecarribee River | NMZ1 |
| | Lower Wingecarribee River in groundwater zone NMZ1<br>Lower Wingecarribee River in groundwater zone NMZ2<br>Black Bobs Creek<br>Longacre Creek | NMZ1<br>NMZ2<br>NMZ1<br>NMZ1 |
| | Medway Rivulet<br>Oldbury Creek<br>Belanglo Creek<br>Wells Creek<br>Wells Creek Tributary | NMZ1 |
| | Lower Wollondilly River | NMZ1 |
| | Nattai River in groundwater zone NMZ1<br>Nattai River in groundwater zone NMZ2 | NMZ1<br>NMZ2 |
| | Bundanoon Creek | SBS |

Estimation of water drawn from streams and from media storage, within the various source zones, requires these components to be disaggregated for each groundwater source. A surface water source may straddle two or more groundwater sources, in which case the surface water source needs to be disaggregated into the relevant groundwater source areas.

In the current work, release from groundwater storage is decomposed into:

- Storage release that is normally baseflow, but is reduced by mining (referred to as intercepted baseflow).
- Storage release that is caused by mining.

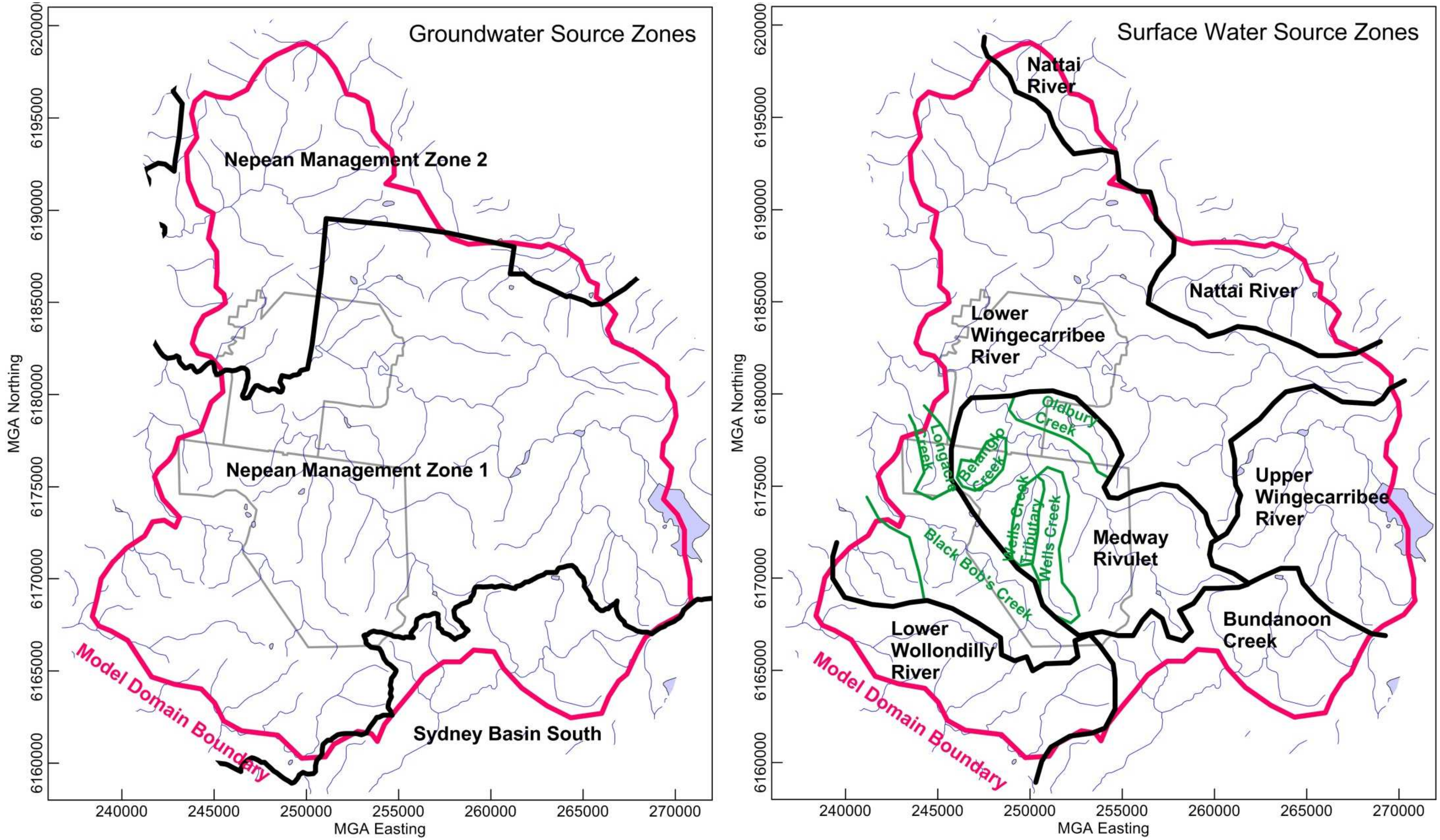


**Figure 7.1. Groundwater and surface water sources and zones.**

DPI (2011a) defines water of surface water sources as that water:

- occurring naturally on the surface of the ground within the boundaries of the water sources as shown on the DPI (2011a) Plan Map, and
- in rivers, lakes, estuaries and wetlands within the boundaries of these water sources as shown on the DPI (2011a) Plan Map.

This definition excludes water contained in coastal sands, any fractured rocks or porous rocks, the area below the mangrove limit, any alluvial sediments, or the Kangaroo River, Mooney Mooney Creek, and Mangrove Creek water sources.

### 7.1.1. Model results

No loss from the surface water body residing in the Wingecarribee River channel was calculated by the model. Model results indicate that 98% of the total inflow to the Hume mine workings is satisfied by interception of baseflow to streams, and release of groundwater storage from media. 2% of the inflow is satisfied by leakage from Medway Reservoir (a total leakage of approximately 804 ML over 22 years, or an overall average over the period of approximately 0.1 ML/day).

Intercepted baseflow and released storage are regenerated by rainfall recharge direct to the media. The loss from Medway Reservoir is regenerated by rainfall recharge direct to the media, and the portion of surface runoff from the catchment that collects and remains stationary in the reservoir. The overall modelled source / sink discrepancy is -1.3%.

Table 14 lists the maximum intercepted baseflow induced by the Hume Mine for each surface water source in the model domain. Table 15 lists the maximum flow emanating from media storage induced by the Hume Mine for each groundwater source in the model domain.

**Table 14. Induced maximum intercepted baseflow for surface water sources in the model domain.**

| Surface Water Source | Maximum rate of baseflow interception induced by the Hume Mine (ML/day) | | Time to Maximum rate (years since the start of mining) |
|---|---|---|---|
| Upper Wingecarribee River | | N/A* | |
| Lower Wingecarribee River (whole source) | | 0.849 | 13 |
| Lower Wingecarribee River excluding Black Bobs and Longacre Creeks. | 0.800 | | 17 |
| Black Bobs Creek | N/A* | | |
| Longacre Creek | 0.311 | | 13 |
| Medway Rivulet (whole source) | | 0.927 | 11 |
| Medway Rivulet excluding Oldbury, Belanglo, and Wells Creeks, and Wells Creek Tributary. | 0.841 | | 11 |
| Oldbury Creek | 0.002 | | 11 |
| Belangalo Creek | 0.017 | | 9.5 |
| Wells Creek | 0.075 | | 1.5 |
| Wells Creek Tributary | 0.033 | | 1.5 |
| Lower Wollondilly River | | 0.050 | 26 |
| Nattai River | | N/A* | |
| Bundanoon Creek | | 0.024 | 28 |

* Nil baseflow interception calculated.

**Table 15. Induced maximum groundwater flow losses (release from media storage) for groundwater sources in the model domain.**

| Groundwater Source | Maximum rate of release from groundwater storage induced by the Hume Mine* (ML/day) | Time to Maximum rate (years since the start of mining) |
|---|---|---|
| Nepean Management Zone 1 (NMZ1) | 5.206 | 15 |
| Nepean Management Zone 2 (NMZ2) | 0.003 | 2 |
| Sydney Basin South (SBS) | 0.042 | 25 |

* Intercepted baseflow is not included (it is reported in Table 14).

Baseflow interception is a maximum for Medway Rivulet (0.9 ML/day at 11 years since the start of mining). The average total flow at flow gauge SW04 over the period of monitoring is 51.8 ML/day, with an average estimated baseflow of 3.3 ML/day. Insufficient data were available for SW04 to undertake an assessment of annual baseflow proportion versus rainfall. These functions usually have an element of curvature (see Volume 1), however a linear relation can be used for a reasonably small interval around the data collection condition. The average baseflow during average rainfall would be about 3 ML/day, about triple the maximum intercepted baseflow calculated by the model.

These results suggest the drainage channels in the Medway Rivulet catchment are likely to be able to sustain the loss in baseflow over a large range of climate conditions, without impacting other users of the Medway Rivulet water supply.

Six-monthly accounts as calculated by the model for intercepted baseflow and groundwater storage release due to Hume operations are listed in Appendix F.

## 7.2. Drawdown in private bores

Registered private bores within a 9 km radius of the mine footprint centroid were extracted from the NSW DPI groundwater database in December 2015. This identified 363 private bores (excluding Hume monitoring piezometers and two abandoned bores). Predictive simulation provided the extent of the 2 m differential drawdown (drawdown due only to Hume operations) contour for model layers. Private bores were selected for impact analysis according to the following criteria:

- Bores located inside the 2 m differential drawdown contour for the mined seam at 17 years, and outside the contour to the southeast. The seam is where the largest drawdowns in any hydrostratigraphic unit are developed, and the time of such drawdown in the seam is at 17 years since the start of mining.
- Bores located inside the 2 m differential drawdown contour for the water table at 17 years and outside the contour to the southeast. Inclusion of bores outside the contour takes account of the migrating drawdown of the water table following Year 17.

These criteria ensure that calculated differential drawdowns of 2 m or more are captured. The drawdown footprint generally contracts moving upward, except to the southeast where some migration in a southeasterly direction occurs (see Figure 6.6). These criteria define the potential impact zone for private bores from Hume operations. The model calculates differential drawdowns of less than 2 m outside these criteria.

117 private bores were identified as residing in the potential drawdown zone. Available bore logs suggest 116 bores are completed in Triassic and Permian media of the Sydney Basin and one is completed in basalt (GW106103). For bores that are located in the area of outcrop of the basalt body, the majority of those that are screened in basalt are located south of the major subvertical hydraulic

barrier under the basalt body (see Volume 1), where the basalt thickness is significantly greater than north of the feature.

Table 1 in Appendix G lists the private bores and relevant information as obtained from government records, or as estimated. Map 1 in Appendix G shows bore locations. Drawdown in the basalt bore was assessed using a separate model as discussed below.

The lithology log for bore GW067521 lists basalt as the intersected stratum, however it is interpreted to be in shale of the Wianamatta Group (WG) based on the following:

- The elevation of the logged basalt is grossly inconsistent with structure contours for the base of the basalt developed from nearby bores. The latter indicate termination of the basalt along a line similar to current published geology maps.
- The bore is located north of the basalt limit as shown on current geological maps.
- Dark grey to black shale of the WG is known to have been mistaken for basalt in lithology logs for other registered bores in the Sydney Basin.

The drawdown at each bore was calculated as the transmissivity-weighted average of drawdown in each model layer intersected by the bore hydraulic interval (the interval over which water in the bore communicates with the external medium).

## 7.2.1. Drawdown in the basalt bore

Due to the method of emplacement, basalt bodies host a palaeosol horizon at the interface with underlying media that has been significantly heat affected and may typically be highly weathered. This horizon is typically of significantly lower K than surrounding media, and usually acts to retard vertical drainage from the basalt body to underlying media. If several lava flow events comprise the basalt body, palaeosol horizons may also be dispersed throughout the basalt sequence, imparting a strong vertical anisotropy to the basalt body.

Hydraulic head observations for the basalt bodies in the Hume area indicate negligible vertical hydraulic head gradients in the basalt, suggesting the body was emplaced over a relatively short period. There is a large vertical hydraulic head gradient between the basalt bodies and underlying media, suggesting the palaeosol horizon at the base of the basalt retards vertical drainage.

To assess drawdown impacts to the private bore in basalt (GW106103) due to mining, a separate numerical model, targeting a smaller area than the main model, was developed. The conceptualisation of the system upon which the model is based is as interpreted in Coffey (2016). Use of a separate model greatly facilitates characterisation of Kv of the retarding layer underlying the basalt, which is the main parameter upon which drawdown in the basalt body depends. Appendix H provides information regarding the basalt model.

## 7.2.2. Model results

Drawdowns are discussed as both of the following:

- Total drawdown (cumulative; includes Hume and other users): The drawdown actually developed at the bore for the active Hume mining scenario. This is the drawdown which must be used to assess the functioning of the bore following impacts.
- Differential drawdown (Hume only; excludes other users): The drawdown caused only by Hume operations. It is calculated as the difference between a null case (all processes operating, except for Hume operations) and the active Hume mining scenario. It is used to calculate the proportion of total drawdown at a private bore that is caused by Hume operations only.

Total drawdowns have only been used to assess whether any bores go dry, and to calculate the proportion of total drawdown caused by Hume operations. A large number of total drawdown hydrographs also do not recover to within 2 m of pre-mining water levels (that is, the effects of private pumping and drainage at Berrima, in the absence of Hume operations, causes drawdowns in excess of 2 m by the end of the simulated period).

Of the 117 private bores identified as residing in the potential drawdown zone, 99 bores are assessed as being subject to a differential drawdown of 2 m or more. Table 2 in Appendix G lists the maximum total and differential drawdown developed at each private bore, and the times required to achieve these maximums. This table also provides the times (in years since the start of mining) when 2 m differential drawdown first occurs at a private bore, and when the differential drawdown recovers back to 2 m. Appendix G also shows total and differential drawdown hydrographs for each bore for reference.

Figure 7.2 shows a histogram of the maximum differential drawdown at private bores. 18 bores have a maximum differential drawdown of 2m or less. The overall average proportion of the maximum total drawdown that is caused by Hume operations is 87%.

The drawdown developed at each bore is heavily dependent on bore location (whether on the mine footprint or more distant) and bore hydraulic interval (and particularly the proportion of shallower media intersected). At a given location, shallower media undergo smaller drawdowns than deeper media.

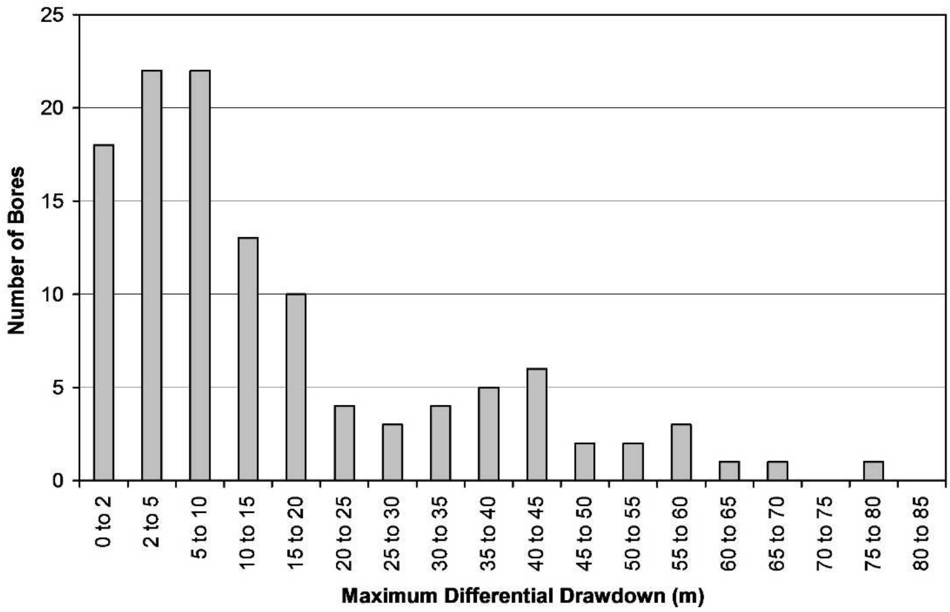


**Figure 7.2. Histogram of maximum differential drawdown in private bores.**

Figure 7.3 provides a spatial summary of the modelled maximum differential drawdown (for bores where it is 2m or greater), at the private bores, and bore screened strata. Also shown is the time to maximum differential drawdown (in years since the start of mining, for clarity). Year 1 of mining is provisionally 2021. Larger drawdowns generally occur over the mine footprint.

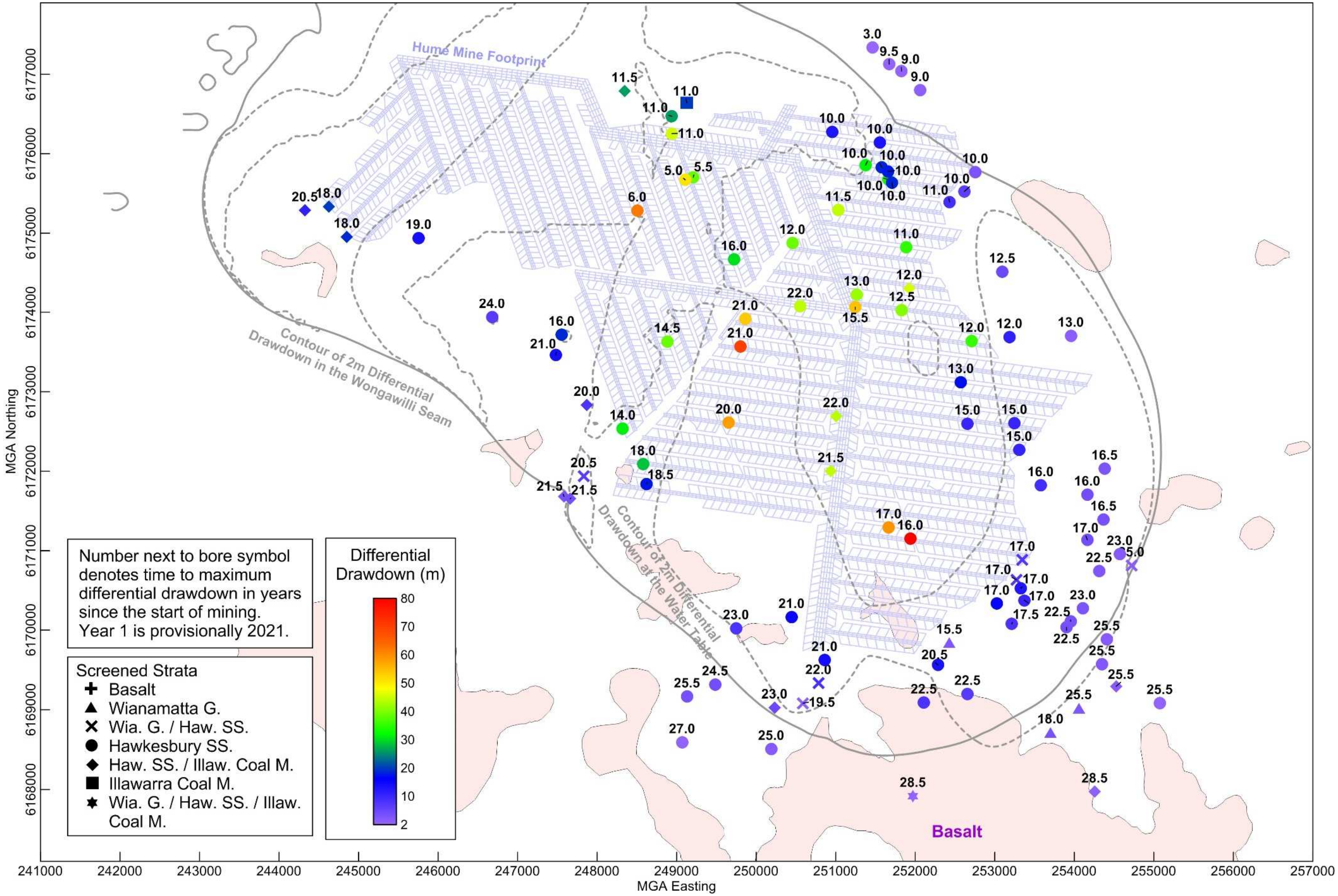


**Figure 7.3. Spatial distribution of modelled maximum differential drawdown at private bores (and the time to maximum differential drawdown) and private bore screened strata.**

Figure 7.4 shows the duration of the period for each bore where differential drawdown is greater than 2 m. The start and end of each period is given as years since the start of mining. Durations of these periods range between 2 months and 65 years, with an average of 34 years. The majority of private bores have recovered to less than 2 m differential drawdown by 60 years since the start of mining.

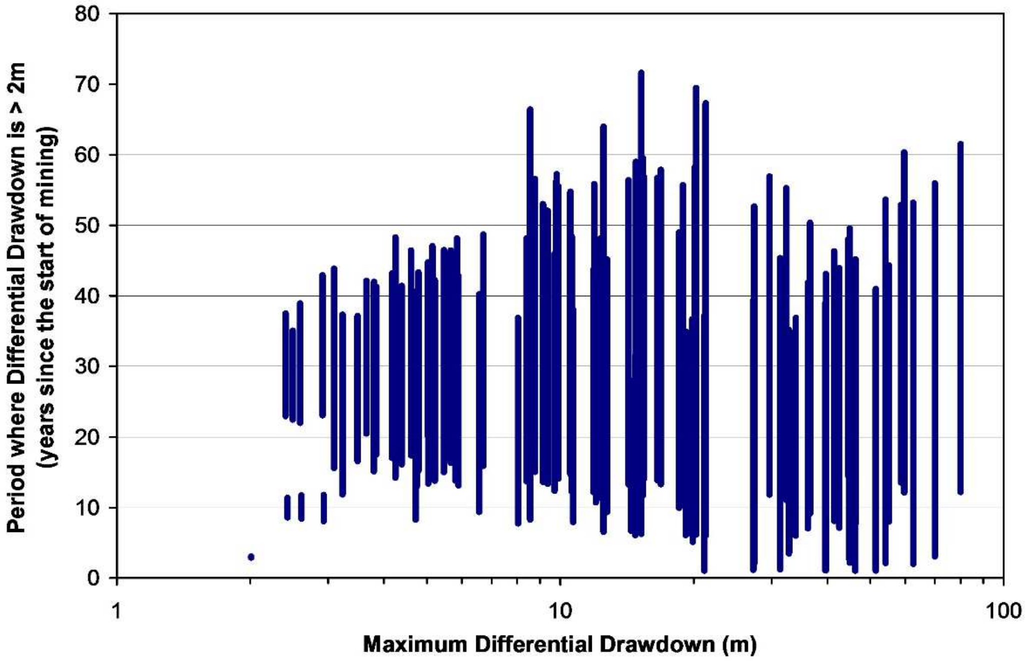


**Figure 7.4. Duration of the period for each private bore where differential drawdown is greater than 2m.**

Table 16 provides a summary of bores that may require replacement during mining, due to the nature of the impact. They are identified on Map 1 in Appendix G. Impacts include potential structural impacts which the groundwater models cannot simulate. Of these bores, five are likely to be intersected by mining.

In developing a threshold for the maximum distance between the base of a bore and the roof of the mined section, within which there may be structural impact, provision was made as follows:

- A mined section height of 3.5 m above the floor of the Wongawilli seam.
- A relaxation zone of 2 m with an additional 2 m for uncertainty.
- An error of ±8 m in relating the adopted digital elevation model to true ground level, and to bore logs.
- An error of ±2 m for bore depth in incorporating government database roundoff error and measurement error.

**Table 16. Private water bores that may require replacement during mining.**

| Bore | Impact | Proportion of total drawdown due to Hume operations at start and end of dry period (%) | |
|---|---|---|---|
| GW106710 | Over mine footprint and penetrates to within 14 m of working section roof (allowance for uncertainty). May be drained by mining. | N/A | |
| GW107535 | | | |
| GW110236 | | | |
| GW108195 | Over mine footprint and penetrates to within 4 m of working section roof. May be drained by mining. | | |
| GW052538 | Over mine footprint and penetrates to working section roof or below. Likely to be intersected by mining during Year 7. | | |
| GW072672 | Over mine footprint and penetrates to working section roof or below. Likely to be intersected by mining during Year 8. | | |
| GW102588 | Over mine footprint and penetrates to working section roof or below. Likely to be intersected by mining during Year 7. | | |
| GW104745 | Over mine footprint and penetrates to working section roof or below. Likely to be intersected by mining during Year 8. | | |
| GW108194 | Over mine footprint and penetrates to working section roof or below. Likely to be intersected by mining during Year 10. | | |
| GW023322 | Goes dry approximately for the period 13 to 15 years since the start of mining. | 99 | 99 |
| GW026136 | Goes dry approximately for the period 13 to 27 years since the start of mining. | 93 | 94 |
| GW032319 | Goes dry approximately for the period 9 to 11 years since the start of mining. | 98 | 99 |
| GW035590 | Goes dry approximately for the period 16 to 33 years since the start of mining. | 57 | 68 |
| GW047157 | Goes dry approximately for the period 4 to 6 years since the start of mining. | 99 | 99 |
| GW048345 | Goes dry approximately for the period 10 to 13 years since the start of mining. | 95 | 97 |
| GW064613 | Goes dry approximately for the period 2 to 13 years since the start of mining. | 98 | 99 |
| GW066798 | Goes dry approximately for the period 8 to 12 years since the start of mining. | 96 | 99 |
| GW104486 | Goes dry approximately for the period 10 to 17 years since the start of mining. | 91 | 95 |
| GW106489 | Goes dry approximately for the period 18 to 22 years since the start of mining. | 95 | 96 |
| GW106491 | Goes dry approximately for the period 18 to 24 years since the start of mining. | 96 | 97 |
| GW108825 | Goes dry approximately for the period 8 to 12 years since the start of mining. | 94 | 92 |
| GW037851 | Water column* reduces to < 4 m | N/A | |
| GW067305 | | | |
| GW067319 | | | |
| GW068965 | | | |
| GW105744 | | | |

* The distance between the base of the bore and the bore water level.

# 8. Parameter sensitivity analysis

Results of the three parameter sensitivity runs (see Table 8) are as follows:

- Relaxation height of 2 m and 4 m. These heights were applied over an area representative of the typical extent of an actively draining area at an instant in time (about 11 $km^2$). Results indicated an increase in inflow of 4.3%.
- Kv distributions as follows:
  - The calibrated Kv distribution (listed in Table 3).
  - Calibrated Kv of model layers 1 to 5 (see Table 3) multiplied by 3. These layers comprise the Wianamatta Group and Hawkesbury Sandstone between the water table and the mine workings.

  The higher Kv case produces an overall 28% increase in mine inflow. Inflows are considered sensitive to the Kv distribution, in comparison to other parameters.
- Hume mine drain conductance of 0.05 $m^2$/day (calibrated) and 0.1 $m^2$/day. Only a comparatively small change in inflows occurs between these cases.

The results of the sensitivity analysis indicate that the Kv distribution is one of the most important parameters for the simulations. This parameter is one of the most difficult to characterise. For the model reported herein, this parameter has been reasonably resolved by calibration to the following three crucial and completely independent sets of observations:

- Shallow groundwater discharges (stream baseflow).
- Deep groundwater discharges (Berrima mine inflow).
- Kv estimated from the two long-term pumping tests undertaken by Hume in 2014. Both tests were conducted with multiple observation piezometers down the depth profile, and drawdowns were assessed taking into account partial penetration and vertical anisotropy.

The combination of observations from the pumping tests undertaken by Hume, with shallow and deep discharge observations, allows the calibrated Kv distribution to be applicable to an appropriate scale and is considered to have a high level of reliability, including reliable representation of the effects of the high density of open bores present in the area, and the tectonic activity that has occurred in the area.

# 9. Conclusions

A regional numerical groundwater flow model has been developed for the Hume Coal Project. Model calibration has been successful in reproducing shallow groundwater discharges (stream baseflow), deep groundwater discharges (discharge to the Berrima mine void), and hydraulic heads, and has adhered strongly to the observed hydraulic conductivity distribution.

The combination of observations from the pumping tests undertaken by Hume, with shallow and deep discharge observations, allows the calibrated Kv distribution to be applicable to an appropriate scale and is considered to have a high level of reliability, including reliable representation of the effects of the high density of open bores present in the area, and the increased hydraulic conductivity imparted by tectonic activity that has occurred in the area.

This has reduced the uncertainty in model outputs. The model is considered to be acceptably calibrated and fit for its purpose in simulating the groundwater system with application of the magnitude stress defined by the Hume mine schedule.

The model was subsequently used in a predictive capacity to assess impacts from Hume mining operations using the Pine Feather layout and mining method. Model predictive simulation results are as follows:

- The total volume of groundwater inflow that reports to the sump is calculated as 8.4 GL during the time the effects of mining are active in the groundwater system. The maximum inflow rate to the sump is 2.7 ML/day (1000 ML/year) in year 17 of mining.
- The total volume of groundwater inflow that reports to the void is 24.3 GL during the time the effects of mining are active in the groundwater system. The maximum inflow rate to the void is 5.1 ML/day (1860 ML/year) in year 15 of mining.
- The drawdown footprint achieves a maximum size at about 17 years since the start of mining. The zone of highest drawdown in the footprint migrates according to worked areas. At 17 years, the 2 m differential drawdown contour of the water table extends a maximum of about 2 km past the southeast corner of the mine footprint. The duration of differential drawdown of the water table varies between about 15 years and 60 years. Recovery of the water table over most of the area, to 2 m differential drawdown, is largely complete within about 60 years after the start of mining.
- Maximum total drawdown of the water table greater than 2 m occurs at several locations where there are shallow water levels. These areas have been provided to the ecology team to consider potential influence on ecosystems that may be present at these locations.
- No direct leakage from the Wingecarribee River, induced by Hume operations, is calculated by the model. Model results indicate that 98% of the total inflow to the Hume mine workings is satisfied by interception of baseflow to streams, and release of groundwater storage from media. 2% of the inflow is satisfied by leakage from Medway Reservoir (a total leakage of approximately 804 ML over 22 years, or an overall average over the period of approximately 0.1 ML/day). Baseflow interception induced by Hume operations is largest for Medway Rivulet. Baseflow analysis of flow observations from Medway Rivulet suggests the average baseflow measured at these gauges (over the monitoring period) is about 3 times larger than the calculated future maximum baseflow interception.
- Of the 117 private bores identified as residing in the potential drawdown zone, 99 bores are assessed as being subject to a differential drawdown of 2 m or more. The overall average proportion of the maximum total drawdown that is caused by Hume operations is 87%. Groundwater extraction by private users accounts for the remaining 13%. The duration of the period for each bore where differential drawdown is greater than 2 m ranges between 2 months and 65 years, with an average of 34 years. The majority of these bores have recovered back to 2

m differential drawdown by 60 years since the start of mining. Five of these bores are likely to be intersected by mining because they penetrate the mined zone.

# 10. Limitations

Modelling is a useful tool to simulate complex subsurface media and to predict water balances and water levels when groundwater stresses are applied. In fractured media with large mining stresses, the modelling results will not exactly represent conditions on a local scale but are more representative on a medium to regional scale. Actual observations made in the future, during Hume mine operation, may differ from predictions made herein.

Model results also do not take into account disturbance of significant but unknown extraordinary defects or extraordinary structural features (those occurring as significant outliers of the typical defect population), which can extend the drained zone associated with the workings, as estimated herein, via the creation of extreme permeability pathways extending beyond the estimated drained zones.

Model results should be reviewed following 12 months of mine operation. Should predictions differ significantly from observations, model recalibration may be necessary.

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# Important information about your **Coffey** Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

## Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

## Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

## Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

## Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

## Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

## Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they incorporate the report findings.

# Important information about your **Coffey** Report

## Data should not be separated from the report*

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

## Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment. Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

## Rely on Coffey for additional assistance

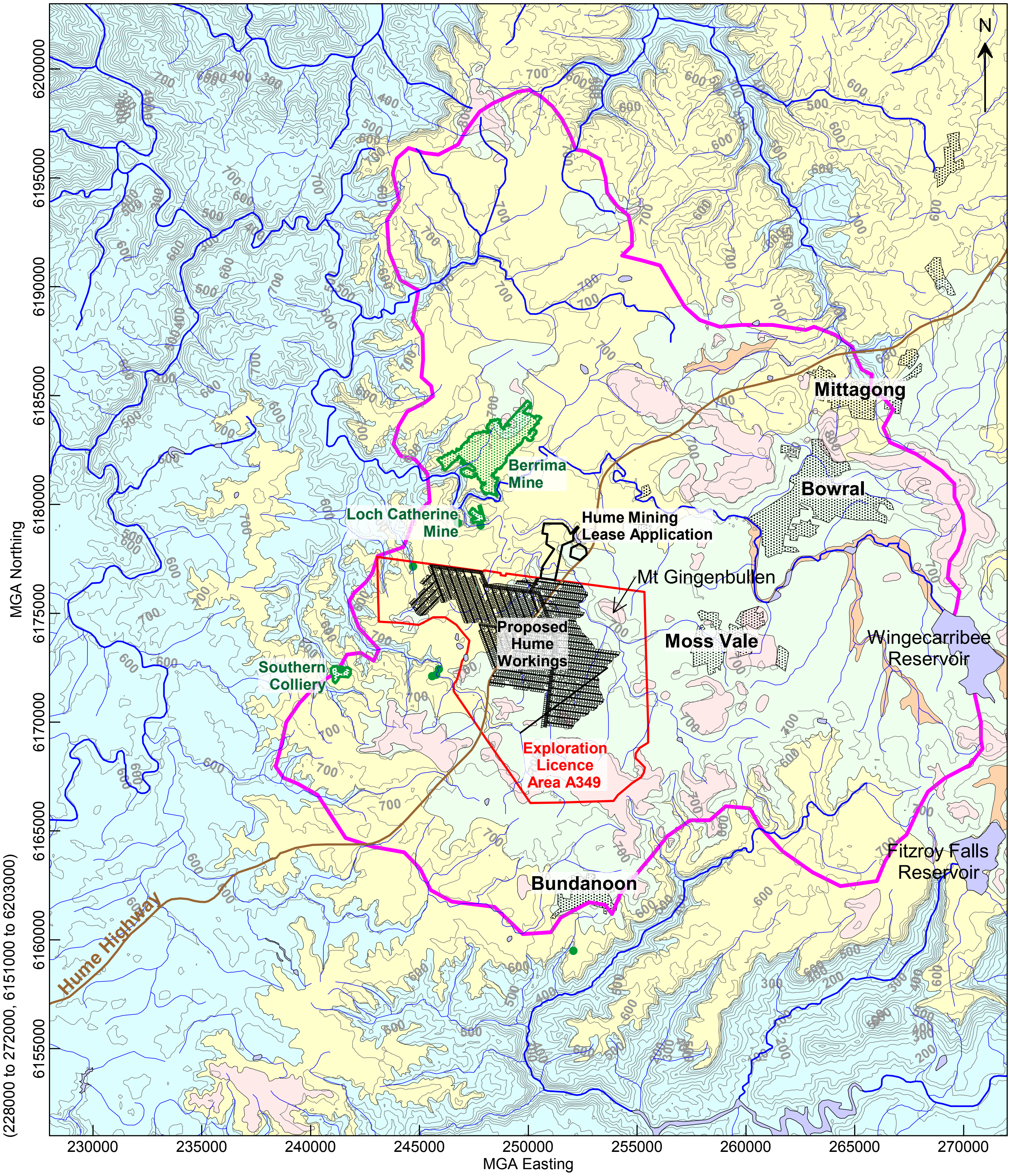
Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design towards construction, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

## Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.

Drawings




Alluvium
Basalt
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group (where present) and Permian Coal Measures

Drainage course
Water body
Old mine footprint
Old mine adit
Interpreted or published fault

620 Topography (mAHD)
Model domain boundary

Pipeline
Built-up Area
Hume Highway

| | | | |
|---|---|---|---|
| drawn | PT | client: | Hume Coal Pty Limited |
| approved | RJB | project: | Hume Coal Project Groundwater Assessment |
| date | 30 Jun 2016 | | |
| scale | 1:250,000 | title: | **Regional Locality Plan** |
| original size | A4 | project no: GEOTLCOV25281AB | figure no: **Drawing 1** |

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