# APPENDIX I

Appendix I - Groundwater Assessment, Peer Review of Tahmoor South Numerical Groundwater Model

This page has been left blank intentionally.

# TAHMOOR SOUTH PROJECT EIS:

## Groundwater Assessment

FOR

Tahmoor Coal Pty Ltd

PREPARED BY

NPM Technical Pty Ltd

trading as

Hydrosimulations

**Project number:** TAH004

**Report:** HS2018/52

**Date:** December 2018

# DOCUMENT REGISTER

| Revision | Description | Authors | Date | Comments |
|---|---|---|---|---|
| A | Initial Draft | Braiya White, Joel Vernon, Will Minchin | 01/11/2018 | Initial Draft for review |
| B | Final draft | Braiya White, Will Minchin | 19/11/2018 | Incorporating Peer Review comments |
| C | Final | Will Minchin | 17/12/2018 | Incorporating comments from coordinating consultant |
| | | | | |

| File: |
|---|
| e:\hydrosim\tahmoor\reports\tah004\hs2018-052c_tahmoorsouth(central)_gwassessment.docx |

# EXECUTIVE SUMMARY

The ‘Tahmoor South’ Project is an underground coal development project targeting the Bulli Coal seam coal resource within Consolidated Coal Leases (CCL) 716 and 747 in the Southern Coalfield, 80 km southwest of Sydney.

This report has been prepared for Tahmoor Coal Pty Ltd (“Tahmoor Coal”). The aim of this report is to provide the groundwater assessment for the Environmental Impact Statement (EIS) for the Tahmoor South Project (“the Project”). The assessment relies on data analysis, development of a hydrogeological conceptual model and on numerical modelling of potential risks of mine development in terms of the New South Wales Aquifer Interference (AI) Policy requirements. The modelling was undertaken in consideration of the Murray-Darling Basin Commission (MDBC) *Groundwater Flow Modelling Guideline* (MDBC, 2001) and the relatively new *Australian Groundwater Modelling Guidelines*, sponsored by the National Water Commission (Barnett *et al*., 2012).

A review of literature and data was carried out as a basis for the development of conceptual and numerical models. This included review of currently available information on geology, rock mass hydraulic properties, neighbouring mine workings and strata geometry for the area, and also included discussion on modelling of potential effects of longwall mining on the overlying strata.

The complexity and confidence of the numerical groundwater model developed as part of this study is adequate for this groundwater assessment (i.e. an ‘Impact Assessment Model’ of ‘Class 2’ confidence, based on the relevant national guidelines). The impact assessment modelling has been achieved by simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the proposed development.

The key findings of the groundwater assessment with respect to the EIS process and the AI Policy are summarised in **Table ES 1-1**.

Based on the findings of the groundwater assessment, the Tahmoor South proposed development falls within the Level 2 Minimal Impact Considerations of the AI Policy for the ‘Highly Productive’ Groundwater source comprising the Permo-Triassic porous rock aquifer. Hence, a Groundwater Management Plan (GWMP) will be required. The GWMP will need to define groundwater level triggers, and a trigger action response plan (TARP), with management responses to triggers, including investigation and mitigation measures, including consideration of replacing some of the existing groundwater monitoring bores/piezometers.

With respect to the nearby Thirlmere Lakes, a High Priority Groundwater Dependent Ecosystem listed in the relevant Water Sharing Plan, the predicted changes in groundwater-surface water interaction and consequent reduction in surface water level due to the Tahmoor South Project are considered negligible. Cumulative effects of mining activities, including historical operations at Tahmoor Mine, have been modelled and quantified and assessed as minor.

### Table ES1-1Summary of AI Policy Assessment – Sydney Basin Porous Rock

| **Aquifer** | Sydney Basin Porous Rock<br>(Nepean Groundwater Source, Management Zone 2) |
|---|---|
| **Category** | Highly Productive |

| **Level 1 Minimal Impact Consideration** | **Assessment** |
|---|---|
| **Water Table**<br>Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any:<br>high priority groundwater dependent ecosystem; or<br>high priority culturally significant site;<br>listed in the schedule of the relevant water sharing plan.<br>OR<br>A maximum of a 2 m water table decline cumulatively at any water supply work. | The relevant Water Sharing Plan is the 'Greater Metropolitan Groundwater Sources' (dated 1 October 2011).<br>There are no Culturally Significant Sites in the Study Area listed in the WSP. Hence there are no known risks of mine development to such sites.<br>There are several high priority Groundwater Dependent Ecosystems (GDEs) in the Study Area:<br>Thirlmere Lakes - There is a risk of drawdown of less than 0.03 m from the Tahmoor South Project and to 0.05 m peak drawdown from cumulative mining effects within the alluvium beneath the lakes. The cumulative impact is close to or above the 10% threshold criterion. *More detail on the effects on surface water levels within the lakes is presented in the Surface Water Assessment (HEC, 2018b).*<br>Other High Priority GDEs (e.g. O'Hares Creek and Macquarie Rivulet) are beyond the boundaries of the impact assessment model. Far field effects from Tahmoor South will not reach these features.<br>There is likely risk of drawdown in excess of the water supply work drawdown criterion within the Permo-Triassic strata.<br>**Level 2 minimal impact consideration classification.** |
| **Water pressure**<br>A cumulative pressure head decline of not more than a 2m decline, at any water supply work. | Likely risk of drawdown at groundwater works in excess of the criterion within the Permo-Triassic strata.<br>**Level 2 minimal impact consideration classification.** |
| **Water quality** | Mining-induced changes to the hydraulic properties and depressurisation of the strata in the Tahmoor South Project area will result in mixing of potentially chemically different groundwater between overlying and underlying units. However, it is considered unlikely that this will result in changes to the beneficial uses of groundwater in the Permo-Triassic rock units. The risk of water quality impacts decreases with distance from the mine footprint.<br>**Level 1 minimal impact consideration classification.** |

# TABLE OF CONTENTS

**LIST OF TABLES**



**LIST OF FIGURES**

(all figures in a separate volume accompanying report text)

**LIST OF APPENDICES**

## ABBREVIATIONS

| | |
|---|---|
| AI | Aquifer Interference (Policy) |
| BFI | baseflow index |
| BHPB | BHP Billiton |
| BoM | Bureau of Meteorology |
| BSAL | Biophysical Strategic Agricultural Land |
| BSO | Bulli Seam Operations mine (Appin) |
| C | degrees Celsius |
| CCL | Consolidated Coal Lease |
| Clst | claystone |
| CL&W | Department of Industry - Crown Lands and Water Division (formerly DPI Water) |
| CSG | coal seam gas |
| DoEE | Federal Depatrment of Environment and Energy |
| DPI Water | NSW Department of Primary Industries Water (now CL&W) |
| EC | electrical conductivity |
| EIS | environmental impact statement |
| EPA | Environment Protection Authority |
| EPBC | Environment Protection and Biodiversity Conservation Act 1999 |
| EPZ | enhanced permeability zone (in and above mine goaf) |
| ET | evapotranspiration |
| FDC | flow duration curve |
| GDE | groundwater dependant ecosystems |
| GHB | MODFLOW's General Head Boundary package |
| GIS | geographic information systems |
| GL | gigalitre(s) |
| GMA | groundwater management area |
| GPR | Ground Penetrating Radar |
| GWL | groundwater level |
| HoF | height of fracturing (above mined seam) |
| k | hydraulic conductivity |
| kh or kx | hydraulic conductivity – horizontal |
| kv or kz | hydraulic conductivity – vertical |
| LDP | licensed discharge point |
| LOM | life of mine |
| LTA | long-term average |
| LW | longwall |
| mAHD | metres above Australian Height Datum |
| mBGL | metres below ground level |
| MDBC | Murray Darling Basin Commission |
| mg/L | milligrams per litre (measure of salinity) |
| ML | megalitre(s) = 1,000,000 litres |
| ML | mining lease |
| mm/a | millimetres per annum |

| | |
|---|---|
| Mtpa | Mega tonnes per annum |
| MZ | Management Zone |
| NSW | New South Wales |
| OEH | NSW Office of Environment & Heritage |
| PE | potential evaporation |
| Q10, Q90, QX | flow exceeded X% of the time (on a flow duration curve) |
| RIV | MODFLOW's River package |
| RMSE | root-mean-square error |
| ROM | run of mine |
| SEARs | Secretary's Environmental Assessment Requirements |
| SFR1 | MODFLOW's Stream Flow Routing package |
| SRLUP | Strategic Regional Land Use Policy |
| sRMS | scaled Root-Mean-Square |
| Ss | Specific storage |
| Sst | Sandstone |
| STRM | Shuttle Radar Topography Mission (digital elevation data) |
| Sy | Specific yield |
| TARP | Trigger Action Response Plan (for underground coal mines) |
| TDS | total dissolved solids |
| ToR | Terms of Reference |
| VWP | Vibrating Wire Piezometers |
| WAL | Water Access Licence |
| WSP | Water Sharing Plan |

# 1 INTRODUCTION

The Tahmoor South Coal Project (the Project) is an underground coal project targeting the Bulli Seam coal resource within Consolidated Coal Leases (CCL) 716 and 747. The Project proposes to extend the existing Tahmoor Mine, which has been operational on CCL 747 and CCL 716 and Mining Leases (MLs) 1308, 1376, 1539 and 1642 since 1979. **Figure 1-1** shows the location of the Tahmoor Mine, which is located approximately 3 km south of Tahmoor, 4 km north of Bargo, and about 80 km south-west of Sydney, New South Wales.

The mine is operated by Tahmoor Coal Pty Ltd ('Tahmoor Coal'). Exploration activities and environmental studies for the Tahmoor South Project commenced in 2010 and a Groundwater Assessment for pre-feasibility purposes was carried out for Tahmoor Coal by Heritage Computing in 2012 (Heritage Computing, 2012a).

The Tahmoor Mine is situated in the central part of the Southern Coalfield which has a number of operating underground coal mines. Coal mines located in the Southern Coalfield include South32's Dendrobium Mine and Bulli Seam Operations (historical Appin and West Cliff mines), Tower Mine, Russell Vale Mine, and Cordeaux mine. Within the footprint of the Tahmoor Mine the coal seam is around 375-500 metres (m) deep, which is a similar to most other mines in the Southern Coalfield. Underground mining generally requires dewatering of the geological strata, which is considered an 'Aquifer Interference' (AI) activity under the NSW Aquifer Interference ('AI') Policy.

The groundwater assessment will focus on the "minimal impact considerations" prescribed in the AI Policy.

The AI Policy requires estimation of "all quantities of water that are likely to be taken from any water source during and following cessation of the activity and all predicted impacts associated with that activity...". Water take and impact estimation is to be based on a "complex modelling platform" for any mining activity not subject to the Gateway process, where the model makes use of the "available baseline data that has been collected at an appropriate frequency and scale and over a sufficient period of time to incorporate typical temporal variations".

This report documents the groundwater impact assessment for the Project. The groundwater impact assessment relies on numerical modelling of potential risks of mine development in terms of the AI Policy requirements. This report forms part of the Environmental Impact Statement (EIS) for the Project, which is State significant development pursuant to the provisions of Part 4, Divison 4.1 of the NSW *Environmental Planning and Assessment Act 1979 (EP&A Act).*

## 1.1 REQUIREMENTS FOR THE EIS

Requirements for the EIS were specified by the NSW Secretary of the Department of Planning and Environment (DPE) and also by other agencies, of which the NSW Department of Industry - Crown Lands and Water Division ['CL&W'] (formerly the Department of Primary Industries Water - DPI Water) is the most relevant for the Groundwater Assessment. These are tabulated in the following sections.

### 1.1.1 SECRETARY'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS (SEARS)

The SEARs related to water resources are as follows:

| | |
|---|---|
| An assessment of the likely impacts of the development on the quantity and quality of surface and groundwater resources, having regard to EPA's, CL&W's (i.e. DPI Water/CL&W's) and WaterNSW's requirements and recommendations; | Section 6 |

| | |
|---|---|
| An assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, water supply infrastructure and systems and other water users; | Sections 1.4, 3.6, and 6.3 and 6.4 |
| an assessment of any drinking water catchment losses from mining, and whether the development can be operated to achieve a neutral or beneficial effect on water quality in the Sydney Drinking Water Catchment, consistent with the provisions of State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011; | Sections 6.3 and 6.8, and the Surface Water Assessment report (Hydro Engineering & Consulting [HEC], 2018b). |
| A detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply and transfer infrastructure and water storage structures; | refer to the Surface Water Assessment report (HEC, 2018c). |
| The proposed surface water and groundwater monitoring regime, which should include a comprehensive array of shallow and deep piezometers and extensometers across the underground mining area which are capable of detecting fluctuations in groundwater levels and the influence of fracture networks on regional groundwater resources | Section 3.8.2, 6.11 |
| An assessment of the potential flooding impacts of the development | refer to the Surface Water Assessment report (HEC, 2018d). |

Supplementary SEARs were provided in a separate letter, dated 14/02/2018, with a focus on the requirements of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The requirements relevant to water resources are listed below

| | |
|---|---|
| The EIS should provide a description of the location, extent of the identified water resource potentially affected by the project | Sections 1.4.1, 3.4, 3.7.2, 3.8. |
| Assessment of impacts - Substantial and measurable changes to the hydrological regime of the water resource, for example change to the volume, timing, duration or frequency of ground and surface water flows | Sections, 5.4, 5.5, 5.6, 5.7, 6 |
| Assessment of impacts - Substantial and measurable change in the water quality and quantity of the water resource – for example a change in the level of salinity, pollutants or nutrients in a wetland. | Sections, 5.4, 5.5, 5.6, 5.7, and 6.8 |

### 1.1.2 INDEPENDENT EXPERT SCIENTIFIC COMMITTEE (IESC) GUIDELINES

The assessment has been carried out considering the Information Guidelines formulated by the IESC (2015).

### 1.1.3 CL&W (DPI WATER) REQUIREMENTS

CL&W also supplied requirements to be fulfilled by the EIS (in a NSW DPI Water letter, dated 24/05/2017). This document raised general issues that the EIS should address:

| | |
|---|---|
| Adequate and secure water supply for all activities for the life of the mine; | Section 6.3 |
| Compliance with the rules in any relevant Water Sharing Plans (WSP), which in this case are:<br>▪ Water Sharing Plan for the Greater Metropolitan Regional Groundwater Sources 2011 (‘WSPGMRGWS’); and<br>▪ Water Sharing Plan for the Greater Metropolitan Unregulated River Water Sources 2011). | Section 6.3 and Surface Water Assessment (HEC, 2018b). |
| Compliance with the rules of any relevant legislation; | Sections 1.4 and 6.10. |
| Baseline monitoring (minimum fortnightly data sampling for 2 years prior to mine operations) of all surface water and groundwater sources and dependent ecosystems within and adjacent to the mining operation area for calibration of models and development of trigger criteria; | Section 3.4.4 and 3.8.2, ‘Shallow Groundwater Monitoring’ report (Geoterra, 2013a), and Surface Water Assessment (HEC, 2018a). |
| Predictive assessments of potential impacts to surface water and groundwater sources, basic landholder’s rights to water, adjacent licensed water users and dependent ecosystems and monitoring to enable comparisons with ongoing monitoring; | Sections 5 and 6. |

| | |
|---|---|
| Mitigation strategies to address impacts on surface water and groundwater sources and dependent ecosystems for the operational and post mining phases of the proposal and final landform. | Section 6.10 |

Additional CL&W requirements for the Groundwater Assessment were that "the assessment within and adjacent to the mine areas must include, but not limited to, the following":

| | |
|---|---|
| Detail all groundwater sources and identify highly productive groundwater, as defined under the NSW Aquifer Interference Policy; | Sections 1.4, 3.6, 6.3 and 6.4. |
| Identify existing groundwater users, including the dependency on groundwater to riverine baseflows, and provide details of potential impacts on these users; | Sections 3.8.1, 3.4, 3.6, 3.8.7, 3.9 and 4.6. |
| Identify potential Groundwater Dependent Ecosystems (GDEs) with particular emphasis on high priority GDEs identified in Schedule 4 of the *WSPGMRGWS*; | Sections 3.4and 3.6. |
| Baseline monitoring (at least fortnightly for at least 2 years) for groundwater quantity and quality for all aquifers and GDEs; | See Section 3.8.2 and 'Shallow Groundwater Monitoring' report (Geoterra, 2013a). |
| Description of aquifer hydraulic properties, chemical characteristics and connectivity; | Sections 3.8.6, 3.8.5, 3.8.4 and 3.8.7. |
| Assessment of GDE condition and water quality and quantity requirements for both terrestrial and aquatic systems; | In Biodiversity Assessment by Niche (2018). |
| Details of the results of any models or predictive tools use to predict groundwater drawdown, inflows into the site and impacts on affected water sources and water users; | Sections 5 and 6. |
| Assessment of the potential effects of mining operations on the quality of groundwater, both in the short and long term, including any pollutants potentially infiltrating into groundwater sources and proposed waste water disposal methods and approval from relevant authority; | Section 6.8, 2.2.1, and Surface Water Assessment (HEC, 2018b). |
| Demonstration of how the groundwater extraction will be managed within defined limits so that groundwater level and quality, which are critical for GDEs, will not be disrupted, and there is sufficient flow to sustain ecological process and maintain biodiversity; | This requirement is impractical given the nature of the proposal. Inflow (extraction) cannot be controlled. |
| Protective measures that will minimise any impacts on groundwater sources, users and GDEs; and | Section 6.11 |
| Determination of critical thresholds for negligible impacts to groundwater sources and GDEs. | Licensing in Section 6.3, assessment against AIP criteria in Section 6.4. |

### 1.1.4 WATERNSW REQUIREMENTS

WaterNSW supplied requirements to be fulfilled by the EIS (in a letter, dated 24/05/2017), of the relevant points are as follows:

| | |
|---|---|
| Mine proposal and mine layout | Section 2.1, 2.3 |
| Geology and mapping of structures | Section 3.7.3 |
| Hydrogeological fluxes between surface and ground waters | Section 3.4, 3.8.7 |
| Description of all water monitoring points (surface and ground waters) | Sections 3.8.2, 3.4.4, |
| Impacts on water quantity and quality of adjacent water resources including Pheasants Nest Weir, Nepean River, Cow Creek and their tributaries and groundwater systems connected to these catchments and Warragamba Dam. | Sections 5.7, 6.3.3, 6.8 |
| Details of proposed measures to be adopted to mitigate impacts and effectiveness of the measures including environment performance measures. | Section 6.11 |
| Details of proposed monitoring of groundwater levels and quality, and information on how this will be used to monitor and mitigate water resources impacts. | Sections 3.8.2 and 6.11 |

#### 1.1.5 ENVIRONMENTAL PROTECTION AUTHORITY (EPA) REQUIREMENTS

EPA submitted requirements in a letter data 24/05/2017, of which the following is relevant.

| | |
|---|---|
| A groundwater assessment be undertaken in relation to any expansion of the Reject Emplacement Area, considering hydrogeological conditions, groundwater monitoring. | Assessment of existing Reject Emplacement Area is presented in Section 3.8.5 |

#### 1.1.6 DEPARTMENT OF ENVIRONMENT AND ENERGY TERMS OF REFERENCE

Tahmoor Coal referred the Project to the Federal Department of the Environment and Energy (DoEE) (EPBC ref: 2017/8084) in October 2017. The Project was subsequently declared a controlled action by the DoEE on 12 January 2018. The Project is a 'large coal mining development' and one 'considered to have a real chance or possibility that the proposed action is likely to have a significant impact on a water resource'. Therefore, the Project requires approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and the assessment must meet the requirements of the Act and the DoEE. Following the declaration of a controlled action, the NSW DPE issued Supplementary SEARs on 14 February 2018.

The assessment requirements of the DoEE, as set out in the Supplementary SEARs, relevant to this Groundwater Assessment are listed below, referencing the section(s) in this report where each is addressed:

| | |
|---|---|
| A description of the important water resources within the site and in surrounding areas, consistent with the Independent Expert Scientific Committee on CSG and Large Coal Mining Development's *Information Guidelines* for such proposals | Section 1.4.1 and Section 3. |
| A description of water related assets that are dependent on any important water resources, including an estimation of the water requirements of those assets (i.e. regional water use). | Section 3 in general, and Sections 3.4, 3.6, and 3.8 in particular. |
| Description of all the relevant impacts of the action (impacts during construction, operational and decommissioning phases must be addressed). | Sections 3.10, 5 and 6. |
| The EIS should identify and address cumulative impacts. | Parts of Section 5 in general, but specifically Section 5.2, and Section 6. |
| The documentation must include information to address all relevant impacts on water resources and water related values, including but not limited to potential impacts to MNES.<br><br>In addition to the issued SEARs, this may include a great consideration of cumulative impacts and on-going monitoring regimes. | Sections 5 and 6.<br><br>Cumulative impacts in Section 5, and Section 6.<br><br>On-going monitoring in Sections 3.8.2 and 6.11. |
| The EIS must include and substantiate the proposed avoidance and mitigation measures. | Section 6.11 |
| The EIS must provide details of the likely residual impacts on MNES that are likely to occur after the proposed activities to avoid and mitigate are considered, including identification of the significant residual impacts | Residual impacts described throughout Sections 5 and 6. |

## 1.2 SCOPE OF WORK

The key tasks for this assessment are:

- Development of a regional-scale 3-dimensional numerical groundwater flow model based on data analysis and conceptual model development;
- Steady state and transient model calibration to observed groundwater level data, mine inflows and local baseflow, using only one or two parameter zones for each hydrostratigraphic unit;

- Transient prediction for the mine plan by tracking the extraction schedule with time, followed by a minimum 100 year simulation of the post-mining recovery period;
- Preparation of this Groundwater Assessment report for the Tahmoor South Project, including assessment of potential underground mine groundwater impacts and also cumulative impacts with other mines and groundwater users (bores). This assessment will focus on the criteria specified by the AI Policy:
  - Licensable takes of water (and their partitioning between sources);
  - Water table drawdown;
  - Pressure head drawdown;
  - Groundwater quality impacts;
  - Identification of further information requirements that may be needed where determination of the AI Policy criteria cannot be made; and
  - Proposed measures to avoid, mitigate and/or offset (if necessary) potential impacts on groundwater resources, and recommendations for future groundwater monitoring to measure actual impacts on groundwater resources associated with the development.
- The work, including data analysis conceptualization and modelling, has been Peer Reviewed by Dr Prathapar Sanmugan of Prathapar and Associates.

## 1.3 PROPOSED MINE DEVELOPMENT

The Project is a proposed underground coal mining operation with an operational life of approximately 13 years. Coal would be mined by the longwall method from the Bulli coal seam in the Illawarra Coal Measures, within the bounds of CCL 716 and CCL 747. Expected maximum coal output is about 4 Mtpa ROM.

Development activities, such as underground development works and pre-gas drainage, are proposed to begin in 2019. Longwall mining is expected to occur from about 2023 to 2035. Existing surface infrastructure at the Tahmoor Mine will be used for the Tahmoor South Project.

Tahmoor Mine use the longwall method for coal extraction. Longwall mining typically removes large rectangular panels of coal from a coal seam, often 100-400 m wide, often 1-2 km long but up to 5-7 km long and between 2 and 4.5 m high. Plans and longwall geometry for the Project are discussed in Section 2.3. The removal of the coal results in the overlying strata or overburden caving into the void, resulting in stresses propagating upward and outward. Fracturing and deformation of these strata then results in some changes, from very large to no change, in the permeability and storage properties of this overburden. SCT (2013) have assessed the characteristics of the overburden and the fracturing mechanisms. This behaviour is considered within this Groundwater Assessment.

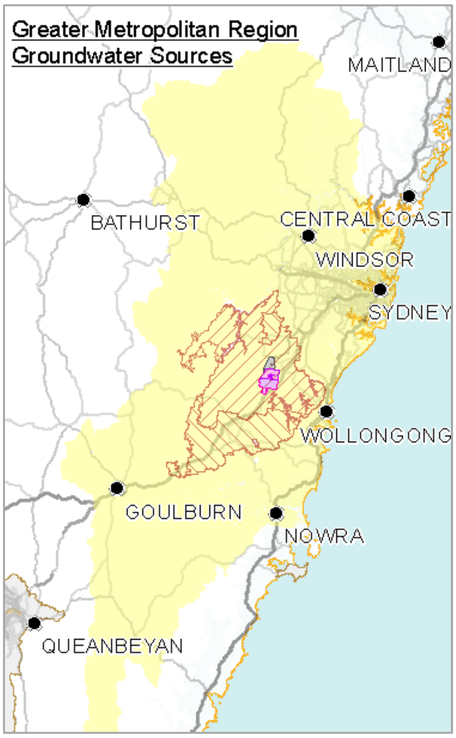
## 1.4 WATER REGULATION

CL&W implements water regulation according to the Water Management Act 2000. A primary objective of this policy is the sustainable management and use of water resources, balancing environmental, social and economic considerations.

### 1.4.1 WATER SHARING PLANS AND GROUNDWATER MANAGEMENT AREAS

Water Sharing Plans (WSPs) have been declared across much of the State, and these establish rules for sharing and trading both groundwater and surface water between competing needs and users.

The WSP covering the Tahmoor South Project is the 'Greater Metropolitan Region Groundwater Sources' Plan. The area of this WSP is shown as shaded yellow on the right[1] (from south of Queanbeyan to north of Bathurst). This plan commenced in 2011.




This WSP comprises several Groundwater Sources, some of which are shown in **Figure 1-2**. These Groundwater Sources are used to manage the average long-term annual volume of water extracted. The source directly relevant to the Tahmoor South Project is:

- Sydney Basin – Nepean Sandstone.

Other relevant Groundwater Sources include:

- Sydney Basin – Central, located some 10 km to the east and northeast;
- Sydney Basin – South, located around 15-20 km east and southeast; and
- Goulburn GMA, located more than 25 km to the west and south.

The Project may result in an impact or 'take' of groundwater from those neighbouring GMAs. Modelling and discussion of such impacts is presented in Section 6.3.

The Sydney Basin – Nepean Sandstone Groundwater Source is further subdivided into Management Zones (MZ), as shown using hatching on **Figure 1-2**. The Project lies within Nepean Management Zone 2, while Zone 1 covers the southern 'third' of the GMA as well as a smaller area to the west of Camden. The Nepean Sandstone Groundwater Source has annualised limit on entitlement (LTAAEL) of 99,568 ML (NOW, 2011), while current entitlement is 28,841 ML (based on the WaterNSW *Water Register*). The volume of 'Unassigned Water' is not available on the public Water Register and needs to be confirmed with CL&W.

The Greater Metropolitan Region Unregulated Water Sources WSP is the relevant plan for surface waters for the Project. Within this WSP the Upper Nepean River source is the relevant management area, of which the following MZ cover the project site:

- Pheasants Nest Weir to Nepean Dam MZ;
- Stonequarry Creek MZ; and
- Maldon Weir MZ.

### 1.4.2 NSW AQUIFER INTERFERENCE POLICY

The NSW AI Policy is designed to provide a framework for the assessment of impacts following from the taking of water under a proposed development, such as the Tahmoor South Project. The AI policy divides groundwater sources into "highly productive" and "less productive" categories based on salinity and aquifer yield. The areas defined by the NSW

[1] See also Appendix 1 of http://www.water.nsw.gov.au/__data/assets/pdf_file/0005/548105/wsp_metro_groundwater_background.pdf

government as highly and less productive aquifers are presented in **Figure 1-3**. No distinction has been made vertically by CL&W between the higher-yielding Hawkesbury Sandstone groundwater system and the lower yielding Narrabeen Group groundwater system, or the Permian (and deeper) groundwater systems present at greater depths.

As outlined in Section 3.8.1, most groundwater exploited for human or environmental purposes in the Study Area comes from the Hawkesbury Sandstone, and only a small fraction from the Narrabeen Group or underlying coal measures. Hence the focus of this study is the impact that can propagate to the shallower stratigraphic units, most importantly the more utilised Hawkesbury Sandstone.

The water sources that are directly relevant to the Tahmoor South Project are:

- The 'Highly Productive' porous rock aquifers of the Nepean Sandstone GMA (Management Zones 1 and 2); and
- The other 'Less Productive' fractured rock aquifers of the Sydney Basin– Central and Sydney Basin - South GMAs;
- For reference the neighbouring Goulburn GMA, is classified as a 'Less Productive' aquifer, but this GMA is unlikely to be affected by this Project.

Note that the areas under the major lakes has also been designated 'Less Productive' by the NSW Government (i.e. CL&W). This is correct for the geological units present beneath Lake Burragorang, however probably incorrect for the aquifers beneath Lakes Nepean, Cordeaux, Avon and Cataract. The aquifers beneath the lakes should be treated as per the adjacent areas, i.e. as part of the 'Highly Productive' Nepean Sandstone GMA.

The AI Policy also specifies 'minimal impact considerations' for both highly productive and less productive aquifers; these comprise thresholds for water table and groundwater pressure drawdown, and changes in groundwater and surface water quality. Different minimal impact considerations are specified for:

- Highly productive groundwater;
- Less productive groundwater;
- Water supply works;
- Listed Groundwater Dependent Ecosystems (GDEs); and
- Culturally significant sites.

The estimated impacts on these are described in Section 6.

### 1.4.3 BIOPHYSICAL STRATEGIC AGRICULTURAL LAND AND 'GATEWAY' PROCESS

The NSW Government released the Strategic Regional Land Use Policy (SRLUP) in 2012. The policy applies to State significant mining developments that require a new mining lease under the NSW *Mining Act 1992*. In such cases, applicants are required to obtain a gateway certificate or a Site Verification Certificate (SVC) before proceeding to lodging a development application.

There is no mapped BSAL within the Project Area. The closest area of BSAL is approximately 15 km north-northeast. Further, verification via soil sampling was undertaken in the Project Area to confirm no BSAL occurs. Subsequently, the Project received a Site Verification Certificate on 5 February 2018 pursuant to clause 17C (1) of the *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* stating that the land required for surface disturbance without existing surface mining tenure is not BSAL.

## 1.5 REPORT STRUCTURE

The remainder of this report is structured in the following fashion:

**Section 2** describes the background to the Tahmoor South Project, the history of coal mining at Tahmoor and in the Southern Coalfield in general, the water licences held by Tahmoor Coal, as well the current plan and schedule for the proposed Tahmoor South mine.

**Section 3** describes the existing conditions, defining the physical setting at Tahmoor Mine and in the region, including details of topography, climate, hydrology and surface drainage and groundwater dependent ecosystems. Section 3 also describes the geological and hydrogeological conditions, including discussion of groundwater level and quality data, analysis and discussion of groundwater recharge and hydraulic conductivity (permeability) of the strata in which the Tahmoor South Project is to be located. There is also discussion of historical inflows to the existing Tahmoor Mine and surrounding mines in the Southern Coalfield.

**Section 3.9** describes the hydrogeological Conceptual Model developed from the earlier parts of Section 3.

**Section 4** details the groundwater flow model developed for impact assessment purposes, including the software chosen, the model extent and layering, the types of boundary conditions used to represent the significant hydrogeological processes, and then details of the 'history-matching' or calibration of model output to observed water levels, baseflows and mine inflows.

**Section 5** presents the predictive modelling of the Tahmoor South Project that has been carried out using the calibrated groundwater model detailed in Section 4. The predictive scenarios and a series of sensitivity runs are described, and a selection of outputs or results from these are presented to describe the predicted behaviour of the system in response to the Tahmoor South mine and also the cumulative impacts in response to all mining activities in the area.

**Section 6** presents a summary of the groundwater-related impacts based on the results of the predictive modelling and other data analysis, including an estimate of the likely groundwater licensing requirements for the Project and an impact assessment in line with the NSW AI Policy.

Concluding remarks are provided in **Section 7**, including a summary of the potential impacts on groundwater as well as some recommendations for future work in relation to the groundwater management aspects of this Project.

Numerous figures are used to describe the data and modelling and are contained in a separate volume. Appendices for this Groundwater Assessment are provided within this text volume, and the figures in an accompanying volume.

# 2 EXISTING AND PROPOSED OPERATIONS

The following subsections describe the background to the Tahmoor South Project, the history of coal mining at Tahmoor and in the Southern Coalfield in general, the water licences held by Tahmoor Coal, as well the current plan and schedule for the proposed Tahmoor South mine.

Two terms are used frequently in the following sections and are defined as:

- **Project area** – the area within and immediately around the Tahmoor Mine leases; and
- **Study area** – a much larger area, as shown on **Figure 1-1**, and defined as such to encompass the geological and hydrological features that might be important to the Project and to the numerical model built for the purpose of impact assessment.

## 2.1 PROJECT BACKGROUND

Tahmoor Mine has two main mine areas, which are identified on **Figure 2-1**:

- Tahmoor and Tahmoor North; approved and mined since 1979. Expected mine life until approximately 2022. This covers much of CCL 716 and MLs 1308, 1376 and 1539; and
- Tahmoor South; this project. Expected mine life from 2023-2035. This covers the remainder of CCL716 and the eastern half of CCL747.

The Tahmoor Mine extracts coal via the longwall method. Some areas of 'pillar extraction' were mined out at Tahmoor in the late 1970s and early 1980, but since 1987 longwall mining methods have been the sole method employed.

## 2.2 HISTORICAL OPERATIONS

**Tahmoor and Tahmoor North**

Mining of the Bulli Coal Seam at Tahmoor Mine began in 1979, with bord and pillar mining to 1986 in three areas. From 1987, 31 complete longwalls have been completed in the areas designated 'Tahmoor' and 'Tahmoor North'. Longwall 31 was completed on 17/08/2018.

Access from surface to mine is via a 'drift', and this is marked on **Figure 2-1**. The drift is an inclined open shaft cut from the surface, extending through the Hawkesbury Sandstone through the full Narrabeen Group sequence down to the Bulli Seam at the pit bottom. Water entering the drift from the Hawkesbury Sandstone is collected in the 'mid-Drift' ring sump, close to the Hawkesbury Sandstone-Bald Hill Clay interface. Any groundwater entering the drift below this point will be collected at the base of the Drift at pit bottom.

**Tahmoor South**

The Tahmoor South Project has not been mined. The Project is planned to begin mining at or near the end of Tahmoor North in 2022. There will be minimal overlap of the active mining phase of the two longwall operations.

### 2.2.1 WATER LICENSING - USE AND DISCHARGE

Tahmoor Mine holds a single Water Access Licence (WAL) under the Water Management Act (2000), as outlined below:

| Works approval | WAL title | Issued | Purpose | Share |
|---|---|---|---|---|
| 10WAI18745 | WAL36442 | Dec 2013 | Mining<br>Dewatering (groundwater) | 1642 units |

Tahmoor Mine holds a discharge licence from the NSW EPA, allowing the discharge of wastewater and 'made water' from the underground mine to surface water. This is permitted under Environment Protection Licence (EPL) 1387. The discharge points and conditions governing these are dealt with in the Surface Water Impact Assessment (HEC, 2018b).

The Project would utilise the existing groundwater extraction and discharge licences. Discussion of the current licensed volume and its sufficiency for planned Tahmoor South operations is presented in Section 6.3.

## 2.3 FUTURE OPERATIONS

**Tahmoor North**

Longwall 32 commenced on 29/10/2018. W1-W5 are scheduled for extraction in the period 2019-2022. Panels from Longwall 22 onward have a void width of 285 m.

**Tahmoor South**

The Project consists of 9 longwalls, numbered 101-109. These are shown and labelled on **Figure 2-1**. Panel widths are proposed to be up to 305 m. By comparison, historical panel widths at Tahmoor were 170-235 m (Longwalls 1-21), up to 285 m (Longwalls 22-onward). Longwall cutting heights are proposed to be up to 2.9 m, as per Tahmoor North.

These longwalls will connect back into the central part of the existing Tahmoor Mine, utilising most of the same mine infrastructure, both underground and at the surface.

## 2.4 NEIGHBOURING MINES

The Southern Coalfield has around 15 coal mining operations, which are shown on **Figure 2-2**. Of importance to the operation at Tahmoor, specifically with regard to the need for a 'cumulative assessment' of groundwater impacts as required by the Aquifer Interference Policy, are the nearest mines (operator in brackets):

- Bulli Seam Operations (BSO) (South32 / Illawarra Coal). This includes the operations referred to as Appin, West Cliff and Tower Mines (2 km northeast of Tahmoor South).
- Russell Vale Colliery (previously NRE No.1) (Wollongong Coal) (13 km southeast).
- Dendrobium Mine (South32 / Illawarra Coal) (12 km to the southeast).
- Cordeaux Mine (South32 / Illawarra Coal) (12 km to the east).

The schedule of these operations is shown in parallel in **Figure 2-3**. This forms the basis for stresses within the historical (calibration) groundwater model as well as for the predictive modelling of impacts (described in Sections 4 and 5).

Most of the mines within the Southern Coalfield extract from the Bulli Coal seam or Wongawilli Coal seam, although historically some also mined other seams within the Illawarra Coal Measures, such as the Balgownie Coal seam. Longwall mining is the primary method of coal extraction, although pillar methods have been employed in the past.

# 3 EXISTING CONDITIONS

This section provides an analysis of the natural characteristics of the Study Area. The Study Area is shown as a red rectangle on **Figure 3-1** and **Figure 3-2**. This area was made large and centred on the Tahmoor Mine, extending beyond Lake Burragorang to the west, past Wollongong to the south east, beyond the Illawarra Escarpment in the east, and into the suburbs of Sydney in the north and north east. The Study Area was also defined large enough to encompass the subsequent groundwater model used for impact assessment. The following subsections are used to describe and analyse the characteristics of the area:

- Topography;
- Rainfall;
- Evaporation;
- Surface drainage (i.e. lakes and reservoirs, rivers and creeks);
- Designated areas (e.g. National Parks, declared Water Supply Catchments);
- Groundwater Dependent Ecosystems;
- Geology; and
- Groundwater Flow Systems, including discussion of anthropogenic use of groundwater, groundwater flow patterns and gradients, recharge, hydraulic properties (e.g. permeability), groundwater-surface water interaction, and inflows to coal mines.

These lead to the development of the hydrogeological conceptual model (Section 3.9).

## 3.1 TOPOGRAPHY

The Tahmoor Mine is situated at an average elevation of 280 mAHD, although elevations range between from about 100 mAHD to about 370 mAHD due to the highly incised nature of major watercourses in this area (see **Figure 1-1**). Generally, topography trends from higher in the south, i.e. the Southern Highlands around Mittagong, at approximately 700-800 mAHD, which form the southern edge of the Nepean catchment. Topography declines to the north into the centre of the Sydney Basin, to around 20-50 mAHD near Liverpool.

Three other features within the Study area are notable from **Figure 3-1**:

- The sharply defined ‘Illawarra Escarpment’, just inland of the coast and 20 km to the east of the Project, across which topography falls around 300-500 m;
- The wide and incised valley of the Nattai River and Lake Burragorang, which are 12-15 km west of the Project;
- Numerous watercourses, of which the major ones are highly incised. Often there is a 50-100 m change in elevation between valley bottom and the local interfluve.

## 3.2 RAINFALL

Data were obtained for two Bureau of Meteorology (BoM) weather stations near to the mine, as outlined in **Table 3-1**.

**Table 3-1 Rainfall stations (Bureau of Meteorology) near Tahmoor**

| STATION NAME | STATION NUMBER | Mean Rainfall (mm/a) | Easting (zone56) | Northing (zone56) | Elevation (mAHD) |
|---|---|---|---|---|---|
| Picton Council Depot | 068052 | 805 | 280100 | 6216600 | 165 |
| Buxton | 068166 | 858 | 271750 | 6208200 | 420 |

Picton Council Depot has a record from 1880 to present day, recording over 91% of months in that period. Buxton has a shorter record, starting in 1966 and running until present, recording 90% of months in that period.

The distribution of long-term average rainfall, as calculated by BoM, is presented in **Figure 3-2** (along with the locations of the two selected rainfall gauges). The main feature of this distribution is that there are some topographic controls on rainfall, specifically associated with the presence of the Illawarra Escarpment (see **Figure 3-1**). There is a clear decrease in rainfall with distance from the Illawarra Range (Illawarra Escarpment) where average rainfall is over 1,600 mm/a to the west, where rainfall is 750-800 mm/a at Lake Burragorang.

Because of the gaps in the data series at each of the Picton Council Depot and Buxton stations, a combined series has been used to derive a cumulative departure from mean rainfall trend for Tahmoor. This is presented on the upper chart in **Figure 3-3**. These data show that the long-term trend in rainfall in the Nepean catchment comprises a long period of lower than average rainfall between around 1890-1950, with severe multiple year droughts in about 1900 ('Federation Drought') and 1936-45 ('WWII Drought') (Verdon-Kidd and Kiem, 2009). This was followed by a sustained period of above average rainfall until the early 1990s, and the subsequent 'Millennium Drought' (about 1997-2011).

## 3.3 EVAPORATION

The closest climate station with available pan evaporation (PE) data is Prospect Reservoir (Station 067019[2]), located about 40 km to the northeast of the Project at elevation 61 mAHD. Mean annual PE at Prospect is 1,314 mm/a.

A profile of each of the average rainfall (from the combined series described in Section 3.2) and potential evaporation has been presented on the lower chart in **Figure 3-3**. This presents the profile throughout the year specified as the average rate in mm/d in each month. Both rainfall and evaporation follow a general sinusoidal trend which is at its maximum in summer for both parameters, while minimum rainfall occurs in August-September which contrasts a little with minimum PE, which occurs in June-July.

A rainfall deficit occurs for all months of the year (for mean rainfall and PE) except May-July. Pan evaporation is about twice as high as rainfall during the summer months.

The annual average Area Actual Evapotranspiration shown by BoM's mapping[3] is approximately 680 mm/a at Tahmoor. BoM defines Area Actual Evapotranspiration as that evapotranspiration that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an area average.

## 3.4 SURFACE DRAINAGE

**Figure 3-1**, **Figure 3-2** and **Figure 3-4** show that drainage occurs from the Illawarra Escarpment, which is both the regional high point and also the high rainfall area. The escarpment acts as a divide, with some creeks and probably springs flowing off the eastern side to the coast and coastal plain (in the south around Wollongong where such a plain exists), but with most rivers and creeks flowing west into the Nepean catchment, via the dammed lakes shown on **Figure 3-4**.

The Tahmoor South Project, and bulk of the Study area for this Groundwater Assessment, lies within the Hawkesbury-Nepean Catchment, of which the Nepean River and its tributary the Bargo River are the major watercourses of interest. The Nepean River is perennial and

---

[2] http://www.bom.gov.au/climate/averages/tables/cw_067019_All.shtml#other
[3] http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp

flows from the south through Lake Nepean, across the Study area and just east of the Tahmoor South Project, and to the north through Camden toward Penrith (**Figure 1-1** and **Figure 3-4**).

The Avon and Cordeaux Rivers are the largest tributaries to the Nepean, with the confluence of these lying about 4 and 6 km respectively to the east of the Project. The Bargo River flows through the middle of the Tahmoor mine leases, before flowing into the Nepean River on the eastern side of CCL716 (see **Figure 3-4**).

To the west of Tahmoor Mine are Blue Gum Creek and Little River. Blue Gum Creek is a tributary to Little River, and this in turn is a tributary to the Nattai River and Lake Burragorang.

### 3.4.1 LAKES

To the west of Tahmoor Mine are the Thirlmere Lakes, lying along the upper reaches of Blue Gum Creek (see **Figure 2-1** or **Figure 3-4**). The lakes are, in order from upstream to downstream, Lake Gandagarra, Lake Werri Berri, Lake Couridjah, Lake Baraba and Lake Nerrigorang. More detail on these significant water features is provided in Section 3.6.

The NSW government installed gauging around the Thirlmere Lakes (**Table 3-2**, **Figure 3-5**).

**Table 3-2 Thirlmere Lakes gauging sites**

| SITE | Waterbody | Easting | Northing | ZeroGauge (mAHD) |
|---|---|---|---|---|
| 212067 | Werri Berri | 273500 | 6210300 | 299.74 |
| 212068 | Gandangarra | 273700 | 6210950 | 301.47 |
| 212066 | Couridjah | 273630 | 6209350 | 300.26 |
| 212065 | Baraba | 273030 | 6209470 | 303.94 |
| 212063 | Nerrigorang | 272870 | 6210380 | 299.33 |
| 212064 | Blue Gum Creek | 272200 | 6210100 | 302.87 |

### 3.4.2 RESERVOIRS

**Table 3-3** lists the five major water storage reservoirs in the Study Area, as shown on **Figure 3-4**. These are operated by WaterNSW and are designed to capture and store water for Sydney's drinking water supply.

**Table 3-3 Major water storage reservoirs**

| RESERVOIR | Nearest location relative to Tahmoor South | SURFACE AREA (approx.) ($km^2$) | FULL STORAGE LEVEL (approx.) (mAHD) |
|---|---|---|---|
| Lake Burragorang (Warragamba Dam) | 18 km northwest of the Project | 72 | 116.7 |
| Lake Nepean | 3 km south of the Project | 3 | 317.2 |
| Lake Avon | 6 km south-southeast of the Project | 9.5 | 320.2 |
| Lake Cordeaux | 14 km east-southeast of the Project | 7.5 | 303.9 |
| Lake Cataract | 18 km east of the Project | 8.5 | 289.9 |

### 3.4.3 SPRINGS

No significant springs or soaks have been mapped or located in the vicinity of the Project, either in published data or as part of the 'Shallow Groundwater Assessment' and bore census conducted by Geoterra (2013a).

It is, however, likely that such features would exist, from saturated and from perched aquifers within the Permo-Triassic strata, especially within the Hawkesbury Sandstone. Any springs would result in some groundwater discharge at surface before flowing into local watercourses.

### 3.4.4 SURFACE WATER FLOW MONITORING

The nearest NSW government operated stream flow gauging stations are listed in **Table 3-4** and shown on **Figure 3-4** and **Figure 3-5** (the latter figure shows only Stonequarry Creek at Picton).

Because flow records are not available for 212209 (Nepean River at Maguire's Crossing), it has not been included here, and only summary information could be found for 212208 (Maldon Weir).

**Table 3-4 Stream flow gauging station summary**

| GAUGE NUMBER | 212053 | 212056 | 213200 | 212208 |
|---|---|---|---|---|
| Gauge Name | Stonequarry Ck at Picton | Cataract River at the Bubble | O'Hares Ck at Wedderburn | Nepean River at Maldon Weir * |
| Status | Active | Inactive | Active | Unknown |
| Catchment Area ($km^2$) | 83.9 | 214.0 | 73.0 | 945 |
| Easting (zone56) | 279944 | 290104 | 300844 | 281590 |
| Northing (zone56) | 6215560 | 6212989 | 6217740 | 6212590 |
| Distance from centre of Tahmoor South | 9km to the north | 14 km to the northeast | 25 km to the northeast | 9km to the north |
| Average flow (ML/day) | 15.0 (1990-2010) | ~29 (1999-2003) | 62 (1978-2011) | 188 |
| Average flow yield (mm/a) | 65.4 | 47 | 312 | 73 |
| Zero gauge elevation (mAHD) | 147.803 | 6.64 | 166.87 | ~109 |

* Summary information for Maldon Weir sourced from Bio-Analysis (2009). No flow records available. Location and elevation calculated by HydroSimulations.

The sites listed above are in addition to those around Thirlmere Lakes (Section 3.4.1).

Surface water monitoring has also been carried out for local features around the Project area. These sites are presented in **Table 3-5** and shown on **Figure 3-5**, noting that although somewhat affected by mining, these sites still provide valuable 'baseline' data.

**Table 3-5 Tahmoor South surface water monitoring sites**

| SITE ID | DATE COMMENCED | WATERCOURSE | COMMENT | EASTING | NORTHING |
|---|---|---|---|---|---|
| TSP-SW-1 | 17/03/12 | Bargo River | Control | 273654 | 6200818 |
| TSP-SW-9 | 16/02/12 | Hornes Ck | Control | 275703 | 6203771 |
| TSP-SW-13 | 29/02/12 | Bargo River (Fire Rd) | Impacted | 276921 | 6208668 |

| SITE ID | DATE COMMENCED | WATERCOURSE | COMMENT | EASTING | NORTHING |
|---|---|---|---|---|---|
| TSP-SW-15 | 29/02/12 | Dog Trap Ck | Impacted | 279490 | 6206378 |
| TSP-SW-16 | 3/03/12 | Dog Trap Ck | Impacted | 278893 | 6205422 |
| TSP-SW-21 | 29/06/12 | Nepean River at Maldon Weir | Impacted | 281600 | 6212612 |
| TSP-SW-18 | 1/11/12 | Eliza Ck | Impacted | 281291 | 6207228 |
| TSP-SW-20A | 31/01/13 | Dry Ck | Impacted | 281781 | 6207126 |
| TSP-SW-23 | 23/11/12 | Carters Ck | Impacted | 282269 | 6204787 |
| TSP-SW-24 | 13/02/13 | Cow Creek | Impacted | 281604 | 6202353 |
| TSP-SW-14 | 2/01/12 | Bargo River | Impacted | 279764 | 6207753 |
| TSP-SW-22 | 6/02/12 | Teatree Hollow | Impacted | 277834 | 6207970 |

Flow duration curves for selected sites are presented in **Figure 3-6**, noting that for most of these there is up to two years of data.

These flow duration curves indicate relatively long and flat tails at Bargo River (Site 14), Maldon Weir (Site 21), and a number of the more minor sites, e.g. Hornes Creek (Site 9). Such a shape is fairly characteristic of baseflow-fed streams, even if the magnitude of the lower flows (i.e. Q90-Q70) is not substantial at <50 and <10 ML/d respectively. Note that the curve for Maldon Weir looks particularly flat because of the lack of a pronounced high flow peak at Q20, Q10. This may simply be due to incorrect rating of high flows at this weir.

Further inspection of **Figure 3-6** suggests that the 'easterly' creeks - Eliza, Dry and Carters creeks - have the lowest flows. Carters Creek and Dry Creek have the steepest flow duration curves suggesting baseflow discharge is a less significant process at low flows in these catchments. However, this last observation may also be a function of these creeks having smaller surface water catchments than most of the other sites presented in Figure 3-6. While some creeks appear to have only a minor contribution from baseflow, there is no evidence for complete disconnection between streams and groundwater.

Further analysis of groundwater-surface interaction is presented in Section 3.8.7.

## 3.5 DESIGNATED AREAS

National Parks, State Forests and 'drinking water catchments' (WaterNSW's 'Special Areas') are all present on land adjacent to Tahmoor Mine Leases areas, as shown on **Figure 3-4**.

The closest of these areas is the Thirlmere Lakes National Park, with its boundary on the western side of West Parade. This area is almost coincident with the Warragamba 'Special Area with Restricted Entry' zone managed by WaterNSW. This Special Area is in place to protect water quality and quantity around Lake Burragorang, as part of Sydney's water supply. Additionally, the Metropolitan Special Area exists to the immediate south-east of the extent of proposed longwalls. Effects on water quality in these water supply catchment areas are assessed in the Surface Water Assessment (HEC, 2018b).

## 3.6 GROUNDWATER DEPENDENT ECOSYSTEMS (GDE)

In order to identify potential GDEs in the area a review of the following literature and mapping was carried out:

- WSP for the Metropolitan Groundwater Sources and specifically for the Sydney Basin – Nepean Groundwater Source;

- National GDE Atlas (BoM); and
- Federal Department of the Environment and Energy; (http://www.environment.gov.au/biodiversity/index.html)

The High Priority GDEs and the High Priority Endangered Ecological Vegetation Communities, as stated in the WSP, are marked with red circles on **Figure 3-4**. The locations plotted in **Figure 3-4** are based on the location (easting and northing) contained in the legislative document, which is only correct to around 1 km. Because of this, **Figure 3-4** also presents the mapped physical features, including the individual Thirlmere Lakes.

### 3.6.1 THIRLMERE LAKES

The Thirlmere Lakes are a series of shallow freshwater bodies located along a horseshoe bend in Blue Gum Creek (Vorst, 1974; Russell *et al*, 2010), and are listed as a High Priority GDE in the WSP. The easternmost of them are located about 650-700 m from the nearest (and previously approved) Tahmoor North longwalls (LW17-18), and some 3,500 m from the nearest proposed Tahmoor South longwalls (LW 103-105) as shown on **Figure 2-1**.

The NSW government's quantitative monitoring of groundwater levels began in 2013, while lake level monitoring began in late 2013, acknowledging Pells monitoring of Lake Couridjah during 2012-13. While these records are relatively short, it is known that the lakes have been subject to periods of wetting and drying throughout their history. In recent times the Lakes have been the subject of multiple studies reflecting on the impact, or not, of the existing Tahmoor Mine (e.g. Russell *et al*, 2010; Pells, 2011, the NSW government's Thirlmere Lakes Inquiry, Pells and Pells, 2016; Schädler and Kingsford, 2016; and Banerjee, Raval, and Timms, 2016).

As part of the Thirlmere Lakes Inquiry, the following conclusions were made in Heritage Computing (2012b):

- *The Thirlmere Lakes appear to act as a naturally losing system under both dry and wet conditions;*
- *Rainfall trend analysis shows that the district has been experiencing drought conditions dating from 1992 of a severity similar to the 1935-1949 depression/war drought;*
- *Temperature trend analysis shows an unprecedented change in behaviour since 2000 with coincident steady rises in both maximum and minimum* [rainfall] *residual masses;*
- *The drying out of Lake Nerrigorang is not due to erosion of the Bald Hill Claystone as postulated in the Pells Report;*

Additionally, the Thirlmere Lakes Inquiry found (as reported in NSW Chief Scientist and Engineer, 2013), amongst other conclusions, that

- ***Finding 10*** - *There is evidence to suggest that mining has contributed to changes in groundwater tables and hydraulic gradients in the Hawkesbury Sandstone but it is not possible to disentangle groundwater changes due to mining, from those due to private bores, which access the groundwater, natural climate change (droughts), and anthropogenic climate change (primarily increased temperature).*
- ***Finding 12*** - *It is not possible to say whether the impact of mining on groundwater in the Hawkesbury Sandstone is temporary or long-lasting. There is evidence from local private and Xstrata bores of both possibilities.*

The other High Priority GDEs listed in the WSP in the Study Area are >20 km (O'Hares Creek) and >25 km away (Macquarie Rivulet Estuary). Due to the distance and the fact that other historical/current mining operations are located between Tahmoor and these GDEs, far-field effects from mining at Tahmoor are not anticipated to reach these GDEs.

The High Priority Endangered Ecological Vegetation Communities, as listed in the WSP and which are near to the Project, are:

- Temperate Highland Swamps on Sandstone; and
- Cumberland Plain Woodland (Cumberland Plain Shale Woodlands and Shale-Gravel Transition Forest);

The Cumberland Plain Woodlands are more diffuse and are typically located in the northern half of the Study Area and further north. Detailed mapping in the project area has been carried out by Niche, however regional occurrences are shown on maps by DEWHA (2009)[4]. Based on inspection of those maps, there are small isolated pockets of this community immediately at and north of the Tahmoor Mine. This habitat is typically located on soils developed on the shales of the Wianamatta Formation. Endangered Ecological Communities (EECs) identified in around the Project are not solely reliant on groundwater (Niche, 2018). Impacts to these EECs are addressed in the Biodiversity Assessment Report.

Occurrences of the Temperate Highland Swamps on Sandstone, marked as open green squares on **Figure 3-4**, are located in the Southern Highlands about 20-25 km to the south of Tahmoor South longwalls.

## 3.7 GEOLOGY

The following section is broken into subsections describing the outcrop geology, stratigraphic framework, structural setting and coal seams at Tahmoor.

### 3.7.1 OUTCROP GEOLOGY

The Project is located in the inland portion of the Southern Coalfield of NSW, and within the Sydney Basin. The primary sources of geological mapping used in this study are:

- Southern Coalfield – 1:100,000. Moffit R.S., 1999, Southern Coalfield Regional Geology 1:100,000, 1st edition. Geological Survey of New South Wales, Sydney.
- Statewide Geology - 1:250,000. This digital (GIS) dataset is a compilation of the various 1:250,000 map tiles, of which the key is the Wollongong map (Rose, 1966).

A synthesis of these two map sources is presented in **Figure 3-7**, and a stratigraphic column for the Southern Coalfield is presented in **Figure 3-8**.

With respect to the area around Tahmoor Mine, the main difference noted between the Southern Coalfield map and the Statewide mapping/Wollongong mapsheet is the extent of outcropping Bald Hill Claystone along incised valleys to the west of the Tahmoor mine leases. The Southern Coalfield map indicates outcropping Hawkesbury Sandstone along these valleys, while the Wollongong mapsheet indicated that this has been eroded away to expose the older Bald Hill Claystone along parts of Blue Gum Creek and Couridjah Creek, although these exposures are truncated along the edge of the mapsheet. **Figure 3-7** shows mapping based primarily on the Southern Coalfield map, with slight modification to those creek valleys, and the lower reaches of Little River, to the west of the Tahmoor Mine, i.e. the Bald Hill Claystone exposures have been added.

The geology around Tahmoor Mine comprises interbedded sandstones, siltstones, shales of the Triassic Wianamatta Group, Hawkesbury Sandstone and Narrabeen Group, and the interbedded sandstones, siltstones, and coal seams of the Permian Illawarra Coal Measures,

4 Available: http://www.environment.gov.au/biodiversity/threatened/communities/maps/pubs/112-map.pdf

and the Shoalhaven Group. Sill and dyke intrusions have been identified from surface mapping and drilling records.

Alluvium is not extensive in this area. It is typically limited to the recent and Quaternary aged alluvium along watercourses in the north of the Study Area. Alluvium is also mapped around the Thirlmere Lakes, and is recorded as Cretaceous age 'laterised alluvium' (Moffit, 1999). The alluvium at Thirlmere Lakes may reach a thickness of 50-60 m and, based on the logs presented in **Table 3-6**, consists primarily of sandy clays and clayey sands between 1-9 m thick, sometimes with a thin layer of sandier alluvium at surface. These bore logs were sourced from the NSW government bore database and also from Vorst (1974) and Pells (2011).

### Table 3-6 Logs from bores in Thirlmere Lakes alluvium

| **Bore: GW075410** | (NSW government monitoring bore) | | |
|---|---|---|---|
| **Depth from (mBGL)** | **Depth to (mBGL)** | **Thickness (m)** | **Lithology** |
| 0 | 1 | 1 | Topsoil |
| 1 | 2 | 1 | Sand, brown |
| 2 | 9 | 7 | Sand, brown/white |
| 9 | 10 | 1 | Sand, white, with Clay |
| 10 | 12 | 2 | Sandy Clay, orange |
| 12 | 14 | 2 | Sandy Clay, brown/orange |
| 14 | 17 | 3.50 | Sandstone, orange, weathered |

Bore GW075409 is deeper, however alluvial sequence is thinner than in 075410.

| **Bore: "BH2"** | (historical bore*, from Vorst, 1974) | | |
|---|---|---|---|
| **Depth from (mBGL)** | **Depth to (mBGL)** | **Thickness (m)** | **Lithology** |
| 0 | 1 | 1 | Medium sand |
| 1 | 3 | 2 | Sandy clay |
| 3 | 7.5 | 4.5 | Sandy clay |
| 7.5 | 7.8 | 0.3 | Medium sand |
| 7.8 | 9 | 1.2 | Sandy clay |
| 9 | 9.3 | 0.3 | Medium sand |
| 9.3 | 11.3 | 2 | Sandy clay |
| 11.3 | 12 | 0.7 | Medium sand |
| 12 | 12.8 | 0.8 | Clay |
| 12.8 | 14.3 | 1.5 | Sandy clay |
| 14.3 | 17.3 | 3 | Peat |
| 17.3 | 18 | 0.7 | ?? clay |
| 18 | 25.5 | 7.5 | Sandy clay |
| 25.5 | 26 | 0.5 | No sample |
| 26 | 29.5 | 3.5 | Sandy clay |

* located midway between Lake Nerrigorang and Lake Baraba

Based on other historical logs in Pells (2011) and given the consistently elevated water levels in Lake Baraba compared to the upstream and downstream lakes, it seems likely that there is a higher occurrence of fines, e.g. clays or low permeability organics (peat), in the near-surface sediments at Baraba

HydroSimulations (HS) is not aware of specific data for the lake sediments, however it is likely that the bed sediments themselves are variable and stratified due to variable depositional environments[5]. Most lakes have more fines toward the centre of a lake and with coarser materials along the shoreline, with sediment size being related to the energy of the environment in which deposition occurs (a point also made in Vorst, 1974).

### 3.7.2 STRATIGRAPHIC LAYERS

Interpreted stratigraphy in bore logs from the Tahmoor lease area were provided to HS for use in developing a regional geological model. Interpretation was carried out by MBGS (2013). The interpreted thickness of each unit within each bore is summarised in Appendix A.

**Figure 3-10** shows two geological cross-sections, one east-west and one north-south, through the Study Area. These are based on the regional geological model constructed for this study (more detail on the construction of that model in Section 4.3).

These sections indicate:

- The Bulli Coal seam, which is barely visible at the scale of the two cross-sections, is present at depths of approximately 200 m near the Nattai River, deepening to around 400 m through Buxton and within the axis of the Camden Syncline. East of the syncline and toward the escarpment, the depth of this seam remains relatively constant. In the north-south direction, the seam is closest to surface in the south, and almost 500 m deep in the north. In the south, the shallower nature of the Permian Coal measures means that other coal seams, including the Wongawilli, are closer to the surface, which is an important reason why the Wongawilli seam is more frequently exploited in the southern part of the Southern Coalfield.
- The relative thickness of the two younger sandstone formations, the Triassic Hawkesbury Sandstone (up to 300 m thick) and Bulgo Sandstone (up to almost 250 m). The lower Narrabeen Formation units and Permian Coal Measures above the Kembla Sandstone are relatively thin in the area around Tahmoor and to the north. The Hawkesbury and Bulgo Sandstone units thin to the south.
- Hawkesbury Sandstone dominates the outcrop area, except in the north, where the younger Wianamatta Formation is present. There are Wianamatta Formation hill cappings present around Tahmoor, especially around Tahmoor North.
- Bald Hill Claystone occurs at subcrop for much of the area, usually beneath a significant thickness of outcropping Hawkesbury Sandstone. Toward the west and the south this unit is closer to or at surface. These areas are around Little River and the middle reaches of Blue Gum Creek (west and downstream of the Thirlmere Lakes) and around Mt Burke and Lake Nepean to the south. At Lake Nepean and at other locations on the escarpment (see **Figure 3-7**), the Bald Hill Claystone has been eroded away, exposing the Bulgo Sandstone or older formations.

### 3.7.3 GEOLOGICAL STRUCTURE

The regional dip of stratigraphic units is similar to topographic dip (see Figure 3-10), so there is a component dip from south (Southern Highlands) to north (into the Sydney Basin), as well dip as from both the west and the east into the centre. This is congruent with the understanding of the Camden Syncline (labelled on **Figure 3-9** which plunges from south to

[5] Barber, 2018 (Hons thesis – unpublished at the time of reporting) provides further information, and appears to confirm this.

north. The regional south-north dip is around 1 in 60 or just less than 1°. The topographic dip to the north is slightly less than the structural dip, so that the Bulli Coal seam is closer to the surface at the southern edge of the Tahmoor South area (approximately 350 m deep) compared to in the north of the Tahmoor North area (about 400-450 m).

Geological structure is shown on **Figure 3-9** and **Figure 3-11**. This shows data from the Southern Coalfield map (Moffitt, 1999), as well as mapping undertaken by Tahmoor Coal, which is derived in part from recent seismic surveys of the site (see Velseis, 2013).

The dominant known geological structure is the Lapstone Structural Complex, which extends some 160 km from Bargo through to Penrith and Richmond in the north. Around Tahmoor the Lapstone Complex manifests itself as the Nepean Fault.

The Nepean Fault has a throw of up to 26 m at the Bulli Seam within the Tahmoor South Project area (Velseis, 2013), and is likely not a single continuous fault, but a series of *en echelon* faults, which can be effectively mapped within a single linear fault zone. In essence, the Eastern Fault, labelled on **Figure 3-9**, is the 'fault ramp' of the southern-most end of the Nepean Fault, where fault displacement is in the order of 5-10 m.

Other features of note are:

- the Camden Syncline, which plunges from south to north, and is located about 3.3 km east of the eastern-most Tahmoor South longwall panels, and more or less coincident with the Nepean River at this point;
- Bargo Fault, heading more or less west, which diverges from the Nepean Fault and crosses the mined area of Tahmoor North;
- the Central and Western Faults, which trend NW-SE, just off the proposed southern limit of the Tahmoor South longwalls. There are other smaller faults mapped within the extent of the historical Tahmoor workings. The alignment of the Central Fault is essentially congruent with the course of Horne's Creek (labelled on **Figure 3-4**), suggesting that the creek exists at this location due to the influence of this structural feature;
- Victoria Park Fault, lying near to the west of the Tahmoor North longwalls 26-31;

The 'T1' and 'T2' faults which are present at the western edge of the previously mined out Tahmoor longwalls (see mine schedule on **Figure 2-1**), between the mine and the Thirlmere Lakes. These faults lie to the north and northwest of the proposed Tahmoor South longwalls. These faults are postulated by Pells Consulting (2011) to be:

  - more continuous than suggested by the current mapping;
  - more permeable than the host rock; and therefore
  - connect the area around (under) the Thirlmere Lakes with the Tahmoor Mine. This is pertinent to the historically mined longwall areas, namely potenteially allowing hydraulic connection to the Lakes from:
    - Tahmoor Longwalls LW21-24/25, mined out in 2003-2008, along the T1 fault;
    - Tahmoor Longwalls LW14-16, mined out in the mid-1990s, along the T2 fault.
- Tahmoor Coal confirmed that no unusual conditions were encountered when this area was mined (refer to Section 3.8.8). There is evidence that the T2 fault might be conductive at LW16, but not so at neighbouring longwalls. Predictive modelling to investigate the impacts of these faults being more conductive is presented in Sections 5.2.1 and 6.
- Mount Tomah Monocline, and other monoclines (Nepean, Balmoral) with similar orientation to the Central and Western Faults, also lying to the south of the proposed Tahmoor South workings. Monoclines, unlike faults, are likely to have a continuation

of the warped geological units (e.g. coal seams), rather than having these displaced and truncated.

#### 3.7.4 COAL RESOURCES

Proposed mining operations at Tahmoor South target the Bulli Coal seam toward the top of the Illawarra Coal Measures; this is the same target seam as the historical and future mining at Tahmoor and Tahmoor North.

Most other mines in the area target the Bulli seam, however those to the south (e.g. Dendrobium) target the older and deeper Wongawilli Seam, where that seam is closer to the surface and hence more accessible (refer to **Figure 3-10**) than it is at Tahmoor or further north. There are other coal seams, such as the Balgownie and Tongarra; however these are not mined as extensively as the Bulli or Wongawilli seams, due to seam thickness, mining depth and coal quality.

## 3.8 GROUNDWATER FLOW SYSTEMS

The major hydrostratigraphic units within the Study Area are the Sydney Basin Permian and Triassic rock units, and within the Nepean GMA these aquifers are classified as ‘Highly Productive’ by CL&W as shown on **Figure 1-3**. This classification is based on aquifer yield and groundwater quality. Within this broad classification of Permian and Triassic rock units (see stratigraphic column in **Figure 3-8**) the primary aquifer is the Hawkesbury Sandstone. This unit forms a porous rock aquifer of moderate resource potential, tending to higher resource potential in areas where secondary porosity (jointing and fracturing) is more developed, such as in structural zones like the Lapstone Monocline/Nepean Fault zones.

Smaller quantities of water can be extracted from parts of the Narrabeen Group, such as the Bulgo Sandstone, or from the Illawarra Coal Measures. The whole sequence comprises interlayered sandstone, claystone, siltstone, and, within the Permian strata, coal seams, to significant depth (>400-500 m).

The minor hydrostratigraphic units at Tahmoor are:

- Thirlmere Lakes alluvium: a body of alluvium, attributed as being Cretaceous in age, associated with Blue Gum Creek. It primarily comprises clayey sands and sandy clays (see Section 3.7), reaching a maximum thickness of 40-60 m or more, although restricted to within a thin valley, being only a hundred or a few hundred metres wide.
- Wianamatta Formation shales: poorly permeable, with typically poor water quality. This unit is typically present around the northern part of the Tahmoor lease as hill cappings and has been eroded from above the Hawkesbury Sandstone to the south of the lease. Springs can develop within the Wianamatta Formation, and also at the contact with the Hawkesbury Sandstone.

Groundwater is likely to flow between these hydrostratigraphic units, although inter-aquifer flow rates are likely limited by the contrasting permeability between these units. For example, the majority of groundwater flowing through the alluvium is likely to have been derived from rainfall recharge and river leakage directly into the alluvials, and is likely to primarily discharge out of the alluvium directly, rather than draining into underlying rock strata. Groundwater flow through the porous (and fractured) rock aquifer, and out of it via the alluvium, creeks and evapotranspiration, will probably occur at significantly slower rates than in the alluvium, even considering the clay-rich nature of the Thirlmere Lakes alluvium.

#### 3.8.1 GROUNDWATER USE

**Figure 3-12** shows the groundwater bores registered on the NSW government PINNEENA database. There are 982 registered groundwater bores within the Study Area. The 41 bores that were surveyed by Geoterra (2013a) for the Project's bore census are also shown in the inset of **Figure 3-12**.

Based on a search of the Water Register and Pinneena information was obtained, 791 bores within the Study Area returned matches with Water Access Licences (WAL). Based on this search, there is a licensed groundwater entitlement of 3,272 ML/a for private or small scale government use. There is some additional 981,000 ML/a associated with unregulated river licences held by government agencies, although these licences are also associated with licensed groundwater works. Additionally, there is approximately 1,000 ML/a of unlicensed groundwater use for stock and domestic purposes, which is based on the assumption that use for these purposes is 1-2 ML/a. An approximate breakdown of the groundwater use is presented in **Figure 3-13**.

Most of the groundwater usage in the area is from the Hawkesbury Sandstone or from surficial alluvium and basalt aquifers (about 89% of the total), with about 10% from the Bulgo Sandstone. This is probably due to generally lower bore yields, poorer water quality, and increased drilling costs for accessing deeper units.

### 3.8.2 GROUNDWATER MONITORING

The groundwater monitoring network at Tahmoor Mine is shown on **Figure 3-5**. This network is used for operational monitoring of the Tahmoor North area, as well as providing baseline data for the Tahmoor South Project.

During their assessment of the nearby BSO ('Appin') Mine, the NSW Planning Assessment Commission (PAC) (PAC, 2010) suggested that the monitoring network should have "similar dimensions to the proposed … mine layout". **Figure 3-5** shows that the spatial coverage of the groundwater monitoring network around the Tahmoor South Project area is more than adequate for both baseline monitoring and to facilitate operational monitoring.

**Table 3-7** summaries the duration and frequency of groundwater monitoring around the Tahmoor Mine, at local government sites and sites operated by Tahmoor Coal. CL&W/DPI Water requirements are that baseline monitoring be conducted for a period of at least 2 years at fortnightly intervals. **Table 3-7** shows that much of the monitoring has been in place since 2012 or earlier. The Tahmoor South Project is planned to commence in 2023, so there will be a more than sufficient baseline dataset before operations begin.

The entries in **Table 3-7** are entered in their respective groups and should be reviewed alongside **Figure 3-5**.

There are five bore installations within the Tahmoor North mine area, each with 6-8 vibrating wire piezometers installed at different locations within the stratigraphic sequence from the Bulli Coal up to the surface ('seam-to-surface'). These typically began acquiring data in 2010.

There are multiple piezometers installed in bore TBF040c, which is located above Tahmoor Longwall 10A. These were installed in early 2014.

There are nine shallow bores (P1-P9) that have been monitored, and all but two remain active. Monitoring at P5 and P6 has been discontinued, and most of these bores have had data loggers installed. Data for P1-P6 started being collected in 2004-05, with P7 and P8 being monitored from mid-2008. Monitoring at P9 began relatively recently, with the first data acquired in September 2017.

Within the monitoring network utilised by this study, there are four NSW Government monitoring bores at Thirlmere Lakes. These were installed in mid-2011 and monitor the shallow Hawkesbury Sandstone and/or alluvium.

**Table 3-7 History of Groundwater Monitoring around the Tahmoor Mine**

| Group | Bore | 2008 | | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | Monitoring frequency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tahmoor North VWP | TNC028 | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | | | | sub-daily |
| | TNC029 | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | | sub-daily |
| | TNC036 | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| | TNC040 | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| | TNC043 | | | | | | X | X | X | X | X | X | X | X | | X | X | X | X | | | | sub-daily |
| LW10A | TBF040c | | | | | | | | | | | | | X | | | | | | | | X | |
| local shallow piezos / bores | P1 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | Daily |
| | P2 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | Daily |
| | P3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | Daily |
| | P4 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | Monthly |
| | P5 | X | X | X | X | X | X | | | | | | | | | | | | | | | | Monthly, then daily |
| | P6 | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | | | | | | Monthly |
| | P7 | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | Daily |
| | P8 | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | Daily |
| | P9 | | | | | | | | | | | | | | | | | | | | | | Daily |
| NSW Govt obs. bores | GW075409/1 | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | | | Monthly, then daily |
| | GW075409/2 | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | | | Monthly, then daily |
| | GW075410 | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | | | Monthly, then daily |
| | GW075411 | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | | | Monthly, then daily |
| ***Tahmoor South VWP*** | | | | | | | | | | | | | | | | | | | | | | | |
| (dual) | TBC001 | | | | | | X | | | | | | | | | | | | | | | | sub-daily |
| (dual) | TBC002 | | X | X | X | X | X | X | X | | | | | | | | | | | | | | sub-daily |
| (dual) | TBC005 | | | | | | X | X | X | | | | | | | | | | | | | | sub-daily |
| (multi) | TBC009 | | | | | | | X | X | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC010 | | | | | | | X | X | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC012 | | | | | | | | X | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC014 | | | | | | | | X | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC015 | | | | | | | | X | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC016 | | | | | | | | X | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC017 | | | | | | | | X | X | X | X | X | X | | | | | | | | | sub-daily |
| (multi) | TBC018 | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (dual) | TBC019 | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (multi) | TBC020 | | | | | | | | | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC021 | | | | | | | | | X | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC022 | | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (multi) | TBC023 | | | | | | | | | X | X | X | X | X | | | | | | | | | sub-daily |
| (multi) | TBC024 | | | | | | | | | | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (dual) | TBC025 | | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (multi) | TBC026 | | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (multi) | TBC027 | | | | | | | | | | | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (dual) | TBC028 | | | | | | | | | | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC030 | | | | | | | | | | X | X | X | X | | | | | | | | | sub-daily |
| (dual) | TBC031 | | | | | | | | | | X | X | X | X | | | | | | | | | sub-daily |
| (multi) | TBC032 | | | | | | | | | | | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (multi) | TBC033 | | | | | | | | | | | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (multi) | TBC034 | | | | | | | | | | | X | X | X | X | X | X | X | X | X | | | sub-daily |
| (dual) | TBC036 | | | | | | | | | | | X | X | X | | | | | | | | | sub-daily |
| (multi) | TBC037 | | | | | | | | | | | | | | | | | | | | | | |
| (multi) | TBC038 | | | | | | | | | | | X | X | X | | | | | | | | | sub-daily |
| (multi) | TBC039 | | | | | | | | | | | | X | X | X | X | X | X | X | X | | | sub-daily |

E:\HYDROSIM\TAHMOOR\Tech\Groundwater Level\[GWLtargets_2018.xls]REPORT

There are thirty monitoring bores installed around the Tahmoor South Project Area. 17 of these are 'dual' piezometer installations, usually monitoring the Bulli Coal seam and the Wongawilli Coal seam. The remaining 13 sites are 'multi' piezometer installations, monitoring water levels from seam-to-surface. Some installations have five piezometers, many have eight piezometers, and some 10 or 11 piezometers. This allows monitoring of water levels throughout the stratigraphic sequence, at locations within the mine footprint as well as in locations outside the mine lease.

A number of the VWP installations have ceased operating, and some are providing suspect data (see *Data Quality Analysis* at the end of Section 3.8.2). A recommendation is that if the Project is approved then a detailed review be undertaken, with a programme of targeted replacement a likely outcome (Section 6.11).

Water quality sampling has been carried out at 29 local bores since early 2013, 6 of which are Tahmoor Coal monitoring bores and the remainder being private landowner bores (see GeoTerra, 2013a). Additionally, there is monitoring of water quality within deeper horizons of the stratigraphic sequence. This is done via sampling of TBC035 (see GeoTerra, 2013a) and also monthly sampling, since January 2012, of the water pumped out of the mine, which is primarily groundwater. Monitoring of this water stream is done within the underground pump lines. Monitoring of water quality at the discharge point (LDP1) has been carried out since 2008. This mine water stream is a mixture of low electrical conductivity (EC) potable water, treated mine water plus groundwater from various units within the local geological sequence which have variable salinity, both vertically and laterally (see discussion on LDP1 salinity in Section 5.9).

Monitoring of creek and river level, flow and water quality is conducted at numerous sites around the Tahmoor/Tahmoor North and Tahmoor South areas. For most sites in the Tahmoor South area this began in early 2012 and since late 2012 or early 2013 at the other sites. More detail is available in the Surface Water Assessment (HEC, 2018a).

### 3.8.3 GROUNDWATER LEVEL ANALYSIS

The Project groundwater monitoring network is shown on **Figure 3-5**. This section of the report presents analysis of:

- Time series of (shallow) Hawkesbury Sandstone and deeper aquifer water levels;
- Water table mapping (contouring) and calculation of unsaturated depth;
- Water level mapping (contouring) of two deeper units – the Bulgo Sandstone and the Bulli Seam;
- Hydraulic gradients within stratigraphic units; and
- Vertical head profiles within bores equipped with multi-level piezometers.

**Hydrograph analysis – shallow bores**

**Figure 3-14** presents water level time series from a series of bores (P1 to P9) monitored by Tahmoor Coal. Other than P1, these are open holes within the Hawkesbury Sandstone and commentary on these, and on other shallow water levels including the NSW government monitoring bores at Thirlmere Lakes and from bores captured as part of the bore census, is detailed in Geoterra (2013a) and Geoterra (2016). The P1-P9 hydrographs are presented in **Figure 3-14** and **Figure 3-15** alongside the cumulative rainfall residual, the start and end dates of nearby Tahmoor North longwalls, as well as a plan showing their location around Tahmoor North. Because these bores are located very near or above existing mining operations at Tahmoor North, as opposed to being in the un-mined Tahmoor South area, they are useful for observing the response, if any, of water levels in shallow aquifers due to longwall mining.

Analysis and inspection of this data indicates:

- Water levels in P1 respond to mining stresses as longwalls pass this location. P1 shows a classic 'scallop' shape, drawing down by 6 m from 276 mAHD as LW22 is mined out, flattening out while other nearby longwalls are mined, and then some recovery in mid-2008. This period is then followed by another period of drawdown of about 2 m. Whether the second period of drawdown is mining related or not is less conclusive than the earlier drawdown because the relevant longwalls are further away. By late 2013 water levels in P1 have almost recovered to their 2004-05 level, with water levels recovering to 275.6 mAHD in mid-2017. Changes in water level since this time are considered to be responding to variations in rainfall;

- Water level responses in P2 are similar to those in P1, although levels respond most strongly to longwalls 23B (5 m drawdown) and 24B (almost 8 m drawdown) being mined out below this location. Further drawdown also occurs midway through the mining of longwalls 25 and 26 (about 4 m drawdown). Whether the drawdown in late 2009 is linked to the decline in rainfall at that time is unclear, but both instances could be mining related. By late 2013 P2 water levels had not recovered in the same manner that water levels recovered in P1, however subsequently, by March 2017, P2 water levels had recovered to 250 mAHD compared to 251 mAHD in 2004;
- Early water levels in P3 are not well understood. The rising trend in the bore has been verified; however, this trend contrasts to trends in other bores in this area as seen in water levels in the other bores P1-P8. A possible cause might be deformation of the strata at or near this bore, caused by longwalls on either side of this bore. However, this is speculative and given the timing of the rising trend, starting before any of the three nearest longwalls were mined out, this seems unlikely. There is a clear mining effect from longwall 26, which results in drawdown up to a maximum of 8 m. From January 2017 to July 2018 water levels remained between 241 and 244 mAHD;
- Water levels in P4 appear to be controlled mainly by rainfall, although there are signals within the hydrograph that might be related to mining, such as the 1 m dip and recovery in Feb-2010 (longwall 25) and again in Feb-2012 (longwall 26, approximately 0.5 m drawdown). Following commencement of longwall 29 there was a 1 m dip in water level, but the bore has subsequently recovered since August 2015;
- P5 is no longer monitored due to land access no longer being available to this site. The hydrograph presents data available up until late 2010 and appears to correlate well with the rainfall trend;
- P6 water levels do not appear to respond to climate or to mining and are at a significantly different base level to the nearby bores at P7 and P8 (1-2 km away). It is inferred that the intervening Nepean Fault interrupts groundwater flow, resulting in the different base level. The Nepean Fault also mitigates the mining signal, resulting in a lack of drawdown associated with longwalls 25 and 26. Monitoring of water levels at P6 was discontinued in 2014;
- P7 clearly shows the influence of longwall 25 and 26 as a classic ‘scallop’ shape. As these longwalls are commenced, water levels in this bore decline (by 8 m in late 2008, and again by 4 m in mid-2011) and then subsequently recover to somewhere close to their pre-longwall level. It is worth noting that the recovery after the commencement of longwall 25 occurs without a corresponding rise in the rainfall trend, while the lesser recovery occurring after the drawdown caused by the commencement of longwall 26 does occur during a more significant rise in the rainfall trend. From 2013 to 2018 water levels have consistently followed a rising trend;
- P8 shows a very steady hydrograph. It is possible that the mild shifts in this hydrograph are due to mining or climate effects. A probable explanation for the relative uniformity of the water levels is that the Nepean Fault is having some influence on holding water levels steady, probably as a more permeable zone that allows increased recharge through this area;

- Bore P9 was installed in September 2017, so no long-term trend information is available (**Figure 3-15** and **Appendix B Figure B1.6**). The bore is located along Redbank Creek between Longwalls 31 and 32 (the panel currently being extracted). The base level for this bore is around 4 m lower than P4 (closest bore, 1.7 km away) but similar to levels recorded at P5 (2.3 km away). For the year of data available the maximum water level fluctuation is about 7 m (2 m in the shallowest piezometer at 20 mBG). This fluctuation is due to the passing of Longwall 31. Water levels in the 60 m piezometer have recovered to close to pre-Longwall 32 levels, suggesting that a change in storage is the primary mechanism for the drawdown. The upper piezometers appear to have been sheared off in May-2018, so recovery is inferred based on the deeper water level record but is not confirmed. It is expected that similar drawdown response will occur with the passing of Longwall 32 (commenced 29 October 2018), based on comparison with bores P2 and P3.

These bores tend to recover more quickly than is often conceptualised for areas surrounding longwall mines. This is likely to be a result of bores being affected more by bedding plane shear or similar mechanisms, which increase horizontal permeability (and perhaps specific yield), but without connection to the goaf which would lead to longer-term drainage and depressuriation. This is particularly the case for P-bores located outside the mine footprint.

**Bores at Thirlmere Lakes**

**Figure 3-16** presents lake and groundwater levels at Thirlmere Lakes (monitoring locations shown on **Figure 3-5**). These records are from 2012, so show only 'post-mining' conditions, given that the Tahmoor longwalls nearest the lakes were extracted in the 1990s (**Figure 2-1**).

Lake Baraba levels are noticeably higher than those of the other lakes. Commentary by Vorst (1974) and others is that Lake Baraba is more like a swamp than a lake, indicating differing hydrology, probably caused by some difference in subsurface conditions.

Comparison of GW075409/1 and /2 with Lake Couridjah levels indicates that Couridjah is a losing system, with alluvial water levels consistently about 2 m below lake stage, and HBSS levels a further 8-10 m below.

Comparison of GW075410 groundwater levels and Nerrigorang lake levels indicates that the relationship is variable, i.e. both gaining (with groundwater levels up to 3-4 m higher than lake stage in periods) and losing (groundwater levels about 2 m lower than lake stage at other times).

Comparison of HBSS groundwater levels at GW075411 and Gandangarra lake levels suggests that Gandangarra is also a losing system, however this is a less certain relationship than at the other two sites given that the local bore does not monitor the alluvium. Also, the HBSS water levels are not in clear synchronisation with the rainfall trend illustrates that the HBSS is not directly connected with the surface, possibly with recharge first being directed to/through the alluvium.

In summary, the westernmost lake (Nerrigorang) is likely the only lake to be a gaining (or variably gaining-losing) system, while the others are likely to be losing only. Conceptually this fits the fact that Nerrigorang has been the last lake to remain wet in the past – it is supported by groundwater baseflow, where the others are less likely to be.

Focussing on two of the groundwater level hydrographs – GW075410 (near Nerrigorang) and GW075409/2 (near Couridjah). The hydrographs both show short-term deviations from the rainfall trend. These typically occur in the summer months, and are indicative of the effects of groundwater pumping, probably for irrigation or domestic use. Geoterra (2014 – unpublished) commented that local bores are actively pumped, including GW101247 which is close to GW075410. Initially HS considered that these might be the signatures of evaporative loss from the shallow water table, however review of the gradients of the groundwater level hydrograph and inconsistency of this behaviour points to short-term groundwater extraction being the cause. At GW075409/2 the short-term effects do not suggest any additional loss of water from Gandangarra as a result of pumping. At GW075410, the pumping exacerbates the magnitude and duration of the downward gradient (losing condition) from Lake Nerrigorang. HS suggests the losses are likely small, but cannot be quantified from the current dataset. As far as HS are aware, the pumping is not metered, so the temporal pattern and magnitude of local pumping would be unknown, other than being estimated from the entitlement.

**Hydrograph analysis – deep bores**

Water levels from 15 bores installed in Tahmoor South and 5 bores in Tahmoor North, installed with vibrating wire piezometers (VWPs), were collected and processed by Geosensing Solutions or by GES (see also discussion of quality review at the end of Section 3.8.3).

The water level data from these VWP bores were inspected as part of this assessment. A discussion of two Tahmoor North bores installed with VWPs is provided here for two sites that exhibit some effects of mine operation (**Figure 3-17**), and all other plots are in **Appendix B**. These two bores are marked on the small map on **Figure 3-14**, and are located above Tahmoor North longwalls that have been mined out since 2014.

Inspection and analysis of the TNC028 and TNC029 VWP data (**Figure 3-17**) indicates:

- **TNC028** collects data for six piezometers however, the data from the Bald Hill Claystone (BHCS) piezometer was suggested to be unreliable and therefore the hydrograph only shows the standing water level of the other five. In this instance theTNC028 BHCS hydrograph was deemed unreliable due its behaviour being inconsistent with water levels in the overlying Hawkesbury Sandstone and underlying Bulgo Sandstone. This error is likely to have been caused during the installation of the piezometer, or due to its location in very low permeability strata. It can take a while, maybe years, after bore construction/installation for pressures to equilibrate in such low permeability material.
- TNC028 overlies Longwall 29. The hydrograph indicates that the Bulli Seam has been depressurised by (or in advance of) mining. During Longwall 29 significant depressurisation occurred in the Narrabeen Formation (Geoterra, 2016), with the Bulgo Sandstone water level declining by 50-75 m. Effects were observed in the Hawkesbury Sandstone piezometers, but drawdown appeared limited, although effects after 2015 cannot be ascertained as this bore was decommissioned.
- In 2008-09, there was an inferred upward gradient from deeper to shallower units at TNC028, however this has been reversed by mining.
- **TNC029** shows the hydrographs from six piezometers. TNC029 overlies the chain pillar between Longwalls 29 and 30. The lower transducers failed as mining approached and TNC029 was decommissioned on 10 August 2015 prior to being undermined (Geoterra, 2016).
- The Bulli Seam has been substantially depressurised, while the Bulgo and Scarborough Sandstones display partial depressurisation (Geoterra, 2016).
- Again, there is head separation of about 20-25 m between water levels in the upper and lower parts of the Hawkesbury Sandstone, with inferred downwards flow, and similar head separation between the upper and lower Bulgo Sandstone piezometers, with inferred upwards flow. The 60 m HBSS piezometer does not display any significant drawdown.

The other three Tahmoor North VWP bores show the effects and influence of mining and rainfall (**Appendix B**), although much of the influence has been since September 2013:

- **TNC036** is located 1.9 km from the nearest mined longwall. It has seven VWP transducers installed. Heads in the Bulli Coal fell by 12 m in the period Dec-2010 to May-2013, although no decline of more than a metre or two is evident in the other units. This logger was out of commission for a long period prior to 2016 (GES, 2017). Partial depressurisation is observed in the Hawkesbury Sandstone, Bulgo Sandstone and the Bulli Seam (Geoterra, 2016).
- **TNC040**, also lies about 1.9 km from the nearest longwall and 1.4 km from the nearest development area in the coal seam. Heads in the Bulli Seam fell by 10 m in September 2013, and then recovered substantially over the next 3-4 months. No similar decline is evident in the other units at that time. However, the overlying Bulgo Sandstone did show a smaller decline, less than one metre, from Sept-2013 to Jan-2014. In 2016, partial depressurisation is observed in the Hawkesbury Sandstone, Bulgo Sandstone and the Bulli Seam (Geoterra, 2016). Depressurisation of the Bulli Seam and more subdued decline in Bulgo Sandstone has continued in 2017. HS was informed that the Bulli Seam VWP failed in mid-2018.
- **TNC043** is located at the south-eastern corner of Longwall 32 approximately 1050 m north east of Longwall 29. The data for this installation is suspect, although the trends (upward or downward) are probably useful even if the magnitude of water levels in mAHD are not confidently known. Significant declines in the Bulli Seam and Bulgo Sandstone water levels in TNC043 have occurred since July 2010. The Bulli Coal seam shows a substantial decline of ~25 m, and the Bulgo Sandstone a decline of around 15 m over all piezometers. The gradient of this decline has become steeper since July 2015, with this period accounting for 10 m of the decline observed in the Bulli Seam. Piezometers in the overlying Hawkesbury Sandstone do not display a similar trend, with water levels in these bores seemingly rising.

**Water level mapping**

This subsection presents mapping of water levels for the water table/Hawkesbury Sandstone, the Bulgo Sandstone and Bulli Coal. Most the data shown on the figures discussed here is from mid-2013, which is the period with maximum data from the mine's piezometers. It is augmented with data from other times (e.g. 'time-of-drilling' observations at nearby bores) to increase spatial coverage.

Geoterra (2013a) mapped the water table within the Hawkesbury Sandstone around the site. This involved classifying bores by their stratigraphy, understanding whether the measured water level in a bore was in the upper part of the Hawkesbury Sandstone which has multiple water levels across its full thickness (see earlier points about VWPs TNC028 and TNC029 or the later discussion of vertical head profiles), and mapping or interpolating the water table considering the elevation of stream reaches likely to interact with groundwater.

The 'local' water table dataset produced by Geoterra was provided to HS, and this was then extended using regional data, mainly from the NSW government bore database. The 'extension' of this data was done by interpolating the provided contours alongside bore water levels from Groundwater Works bores interpreted to be in the Hawkesbury Sandstone. The results are shown on **Figure 3-18**. This shows the following:

- A piezometric surface that is the water table for much of the area, at least as far north as the Wianamatta Shale outcrop located near and to the north of to the north of the Tahmoor longwall 23 (see **Figure 3-18**). At this point and further north, the contoured surface represents water levels in the upper part of the Hawkesbury Sandstone, which is overlain by the Wianamatta Shales. The Wianamatta Formation or overlying alluvium likely holds the true water table in these northern areas;

- A regional south to north-east pattern of flow, although there is evidence of a weak groundwater divide roughly in line with the western edge of the mine lease. This runs from around Mittagong in the south, through the Thirlmere Lakes area and to the north-west of Tahmoor North. From this divide groundwater flows to the east and north-east, generally towards the Nepean River, and to the west draining to the Blue Gum Creek/Little River/Nattai River catchment;
- Far to the south-east of the Project, based on inspection of topography and rainfall (**Figure 3-1** and **Figure 3-2**), it is likely that groundwater gradients will be from south-east to north-west from the escarpment towards the Nepean River.

**Figure 3-19** presents a map of the unsaturated depth (depth to water table) based on the mapping of the Hawkesbury Sandstone water levels presented earlier. Inspection of **Figure 3-19** shows that water levels are typically 30-60 m below surface within the Hawkesbury Sandstone for much of the area in and around the Tahmoor Mine leases, other than around the more incised watercourses, where it is closer to or at surface.

**Figure 3-20** and **Figure 3-21** present water level contours for the Bulgo Sandstone and Bulli Seams respectively for August 2013. This date was chosen because it is a period where there is a relative abundance of data, i.e. some piezometers have failed since that time as discussed above. These water level contours are of more limited spatial extent than for the Hawkesbury Sandstone water level mapping due to the availability of data for these deeper, less utilised aquifer units. Thus, some of the contouring, particularly to the north and south, is simply interpretive or assumed based on topography and the trends seen in the water table mapping.

The other assumption is that water levels in the Bulli Coal seam have been drawn down to seam level in old or current Tahmoor workings. This is a valid assumption for active mine areas, however some recovery may have occurred in previously mined areas that have been sealed off and are no longer accessed. Because of the drawdown around mine workings, the water level mapping for the Bulli Coal seam (**Figure 3-21**) suggests that the regional south-to-north gradient is reversed in the vicinity of the mine, although the area for which this occurs is fairly limited. The radius of influence around the mine workings, in the Bulli seam, appears to be around 600-1000 m. SCT (2013) also analysed groundwater pressures and observed pressure reduction at 700-1200 m from the nearest longwall. These findings are supported by data from the Bulli seam for TNC028 (see **Figure 3-17** which is only about 500 m from the latest Tahmoor North longwall.

All the water level maps suggest that the main recharge area is around Mittagong in the Southern Highlands to the south of the mine. Some discharge will occur to the upper Nattai River near to Mittagong; however, the main flow direction is to the north or NNE. Regional discharge is likely to occur to the incised rivers, including some to the Little River/Nattai River, or further to the north (i.e. groundwater flow beyond the northern edge of the study area).

**Hydraulic gradient analysis**

HS applied in-house software to calculate lateral hydraulic gradients between bores screened within the main ‘aquifer’ units around Tahmoor Mine. The results are presented as:

- Upper and lower Hawkesbury Sandstone – **Figure 3-22**;
- Bulgo and Scarborough Sandstones – **Figure 3-23**; and
- Bulli and Wongawilli Coal seams – **Figure 3-24**;

On these figures, the size of each blue circle corresponds to the calculated head gradient between two bores in the same aquifer (e.g. both in upper Hawkesbury Sandstone), and the circle is positioned at the mid-point between those bores. The aim of this analysis was to detect where unusual hydraulic gradients were located and consider the likely cause. I.e. a cluster of large circles might identify a barrier fault (low K) or some other feature. The main features observed are:

- High gradients across the Nepean Fault, between bores P8 and P6 to the east of the site (see Hawkesbury Sandstone analyses on **Figure 3-22**). This is also seen in the earlier hydrograph analysis of the P-series bores.
- Moderate gradients are calculated east of the site on the upper Hawkesbury Sandstone analysis map; however the cause of these is unknown.
- Moderate gradients are calculated in the Bulgo and Scarborough Sandstones around Tahmoor North. This could be due to calculation of gradients across the Bargo Fault, or more likely due to the mine workings approaching these bores from the south and depressurising water levels in some bores (see earlier hydrograph analysis of TNC028 and TNC029).
- Large relative gradients in the Bulgo Sandstone to the south of the site, near to the Central Fault, e.g. between bores TBC024 and TBC033.
- Large gradients calculated across the proposed Tahmoor South ‘Central Domain’ and near to the historic Tahmoor workings, which have depressurised the Bulli seam in that area.

Some water level data is available for the upper Hawkesbury Sandstone for assessment of the role of the ‘T1’ and ‘T2’ faults lying between the westernmost Tahmoor longwalls and the Thirlmere Lakes. See the inset on **Figure 3-9** for the location of these faults, and see **Figure 3-22** for the calculated gradient. Although gradients are low, these data are inconclusive. The data neither supports the concept of these faults acting as a barrier as the data indicates that there is only a small gradient between the nearest bores lying on either side of the T1 fault, where an enhanced gradient would have suggested the fault acts as a barrier. Nor does the data provide evidence to support the role of either fault being conductive.

**Vertical head profiles**

There are 20 VWP bores with multiple levels (**Figure 3-5**). Vertical head profiles from a selection of four of these bores are presented in **Figure 3-25** and **Figure 3-26**. The remainder of those completed for this study are shown in Appendix C. **Figure 3-25** and **Figure 3-26** show the vertical placement of each of the piezometers, the stratigraphic unit the piezometer monitors, the water level (potentiometric head) measured, and the pressure head (as vertical lines). The resultant profiles show the changes in head down a multi-string bore and illustrate where connection between various horizons might be strong or weak. The resultant vertical gradient, either up or down, is shown on the stratigraphic column in each figure.

Findings from these selected bores are:

- **TBC020** is located in the Eliza Creek catchment. A consistent downward gradient is observed from the surface down to the Bulgo Sandstone, except for some minor variation across the middle/lower Hawkesbury Sandstone. There is more variation in the direction of the gradient below this, i.e. across the Stanwell Park Claystone, Wombarra Claystone and around the coal seams. Water levels in the Wongawilli Seam appear to vary most through time of all the units, but without much variation in the overlying or underlying formations. Anomalous behaviour is likely to have an instrumental cause with the VWP equipment;

- **TNC040**, located in the north of Tahmoor North and just north of the current longwall, does not show the same temporal variation as is evident in parts of the TNC020 profile. This bore also shows a couple of 'sinks' within the profile, with one within the middle Hawkesbury Sandstone and one within the lower Bulgo Sandstone. These could be due to local pumping within those horizons, or are suggestive of the preferential flow paths through more permeable horizons in the stratigraphic sequence;
- **TBC033** is located very close to the Central Fault, just west of the edge of the proposed Tahmoor South 'Central Domain' workings. This shows significant head separation, up to 50 metres, across the stratigraphic sequence, with a 'U' shape indicating a 'sink' in the middle of the sequence, this one within the lower Bulgo Sandstone. A mild sink is located, according to the profile, in or near the Bald Hill Claystone, although this hydrograph was raised as 'suspect' in the Quality Assurance (QA) check of water levels done by GES. The variation observed across this profile suggests that the fault is not more permeable than surrounding strata, as higher permeability should result in equilibration of heads between stratigraphic units;
- **TBC018** is located very close to the Nepean Fault, just east of the edge of the proposed Tahmoor South mining area. With the exception of the upper Wongawilli, there is much less head separation, and therefore a gentler gradient, down this profile than in TBC033. This supports the concept that this fault is more permeable than surrounding strata, allowing heads in the various stratigraphic units to equilibrate to some degree.

Following on from discussion of the T1 and T2 faults in the preceding section regarding (lateral) hydraulic gradient analysis, no multi-level bores are located close to either the T1 or T2 faults, so no assessment can be made as to the nature of these structural features.

A potentiometric head cross-section has been prepared for a line running from Thirlmere Lakes, south-eastwards to bore TBC032 and then eastwards to bore TBC020 and the Nepean River (**Figure 3-25**). This indicates mild vertical head gradients except where mining has occurred. Although there appears to be south-easterly flow away from the water table beneath Thirlmere Lakes, there is evidence for a weak groundwater divide between the lakes and the mine (see also **Figure 3-18**). There is an apparent groundwater sink at depth near bores TBC018 and TBC020 in the vicinity of the Nepean Fault Zone. Between Bargo River and Nepean River, on the cross-section, there is a very mild lateral head gradient.

**Data Quality Assessment**

It is recognised that measurement of water levels is susceptible to error. This error is generally less in standpipes than in VWPs. Coffey (2012) assessed water levels measured in VWPs deliberately installed in close proximity to one another. From this analysis, the accuracy of VWP could be summarised as two VWPs in the same vertical and horizontal location would report a water levels within +/-8m of one another around 50% of the time; however, there could be as much as to +/-40m difference between the two.

A process of quality assessment was carried out by HS before, during and after the analysis of groundwater levels is in an iterative fashion. In addition, the VWP data was reviewed in a quality control audit by Groundwater Exploration Services Pty Ltd (GES). Commentary on the quality of individual piezometer hydrographs was provided to HS, primarily identifying those piezometers/hydrographs deemed unreliable, usually by having behaviour that was inconsistent with water levels in neighbouring piezometers. The unreliable data was generally attributed to installation issues or equipment error. The data from these multi-level sites are a key dataset for the subsequent modelling undertaken as part of this Groundwater Assessment (Section 4 and Section 4.8 in particular).

For the purposes of groundwater modelling, weightings have been applied to each observation ('target') to account for perceived data reliability, with 1 being completely reliable and 0 (zero) being completely unreliable. About 70% of the data at Tahmoor were weighted as '1' (good'), and the rest weighted 0.5, 0.1 or 0 (16% were '0'), although it is likely that some other data is unreliable without it being recognised as such (e.g. as per the discussion in GES, 2017).

### 3.8.4 GROUNDWATER RECHARGE

The initial step taken in assessing the likely rainfall recharge in the Study Area was through review of the Report Card for the Nepean Groundwater Source (NOW, 2011a) and the background document to the WSP (NOW, 2011b). The relevant information is presented in **Table 3-8**, including that recharge is around 6 % of long-term average (LTA) rainfall.

**Table 3-8 Summary of the Nepean GMA groundwater source**

| AREA | AVERAGE RAINFALL | | INFILTRATION | TOTAL ESTIMATED RAINFALL RECHARGE | |
|---|---|---|---|---|---|
| ($km^2$) | (ML/a) | (mm/a) | (% rainfall) | (ML/a) | (mm/a) |
| 3857 | 3,741,377 | 970* | 6 % | 224,483 | 58 |

* calculated by HS. All other data taken from NOW, 2011a,b.

Literature review of some modelling studies carried out in the Southern Coalfield yielded the information presented in **Table 3-9**.

Even considering the relative outcrop area of the Hawkesbury Sandstone and Wianamatta Formation compared to alluvium in the Nepean GMA (refer to **Figure 3-7**) the values reported in **Table 3-9** are variable compared to the 6 % of rainfall value provided by NOW (2011b).

Following the literature review, analysis of water table hydrographs, chloride mass balance and baseflow analysis was carried out. These are presented in the following sections.

**Table 3-9 Summary of recharge in adjacent modelling studies**

| RECHARGE (mm/a) | RECHARGE AS % LTA RAINFALL | COMMENT | STUDY / MINE | REFERENCE |
|---|---|---|---|---|
| 11 | ~1.4 % | Hawkesbury Sandstone | Bargo Pre-Feasibility | Heritage Computing (2012a) |
| 4 | ~0.5 % | Wianamatta Shale | | |
| 150 | ~19 % | Alluvium | | |
| 40-65* | 5 % of 850, 1050 and 1200 mm/a | Hawkesbury Sandstone (across three rainfall zones) | Appin BSO | Heritage Computing (2010) |
| 78* | 7.5 % | Wianamatta Shale | | |
| 200* | 20 % | Alluvium | | |
| ~30 | 2.7 % of ~1100 mm/a | Calibrated value across numerical model domain (primarily Hawkesbury Sst) | Dendrobium (regional) | Coffey (2012) |
| ~65 | 6.5% | primarily Hawkesbury Sst | Dendrobium (regional) | HydroSimulations (2016) |

* not stated explicitly – calculated by HydroSimulations

**Water table fluctuation**

Analysis using the Water Table Fluctuation ('WTF') method (Scanlon *et al*., 2002) was carried out on bores monitoring shallow aquifers, either alluvium or shallow Hawkesbury Sandstone.

Bores with good transient records of water level have been used. Some have less than a year's worth of data, in which case they have been factored up by 2, in order to roughly estimate the recharge that might have occurred in the first 'half' of the year. The results are summarised in **Table 3-10**.

The main uncertainties and assumptions associated with this method are:

- Value of specific yield (Sy) to use. The following analysis has used an expected minimum, mean and maximum Sy and compared results;
- Whether rises in the hydrograph are a result of recharge, or from other sources. For example, whether recovery was due to local pumping or the cessation of drawdown from other sources;

The method is best used for hydrographs which rise conspicuously and over short periods of time. This is typically not the case here, especially for bores in the Hawkesbury Sandstone, as many of which are either open or screened at 30-70 m below ground. However, the available dataset for the bores for which transient records are available is a limitation.

In summary, the results of the water table fluctuation analysis suggest that:

- Rainfall recharge to the alluvium is expected to be 40 to 250 mm/a, probably around 80-145 mm/a (~4-16 % of rainfall);
- Rainfall recharge to the Hawkesbury Sandstone is expected to be much lower, at around 4-20 mm/a (~0.5-2 % of rainfall).

## Table 3-10 Recharge estimation using WTF method

| BORE | PIEZO | PERIOD | | WL RISE (m) | GEOLOGY | Sy (estimated) | | | RECHARGE (mm/a) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MIN | BEST | MAX | MIN | BEST | MAX |
| P6 | | Mar-07 | Oct-07 | 0.24 | HBSS** | 0.005 | 0.015 | 0.04 | 1.2 | 3.6 | 9.5 |
| P6 | | Feb-08 | Nov-08 | 0.5 | HBSS | 0.005 | 0.015 | 0.04 | 2.5 | 7.5 | 20 |
| P6 | | Jan-09 | Jul-09 | 0.01 | HBSS | 0.005 | 0.015 | 0.04 | 0.05 | 0.2 | 0.4 |
| P6 | | Jan-10 | Dec-10 | 0.45 | HBSS | 0.005 | 0.015 | 0.04 | 2.2 | 6.8 | 18 |
| P6 | | Mar-11 | Sep-11 | 0.21 | HBSS | 0.005 | 0.015 | 0.04 | 1 | 3.2 | 8 |
| P8 | | Jan-10 | Nov-10 | 0.35 | HBSS | 0.005 | 0.015 | 0.04 | 1.7 | 5.3 | 14 |
| P8 | | Mar-11 | Jan-12 | 0.23 | HBSS | 0.005 | 0.015 | 0.04 | 1.1 | 3.5 | 9 |
| GW102439 | | Aug-13 | Oct-13* | 0.41 | HBSS | 0.005 | 0.015 | 0.04 | 2 | 6. | 16 |
| TGW1 | | Jul-13 | Oct-13* | 0.23 | HBSS | 0.005 | 0.015 | 0.04 | 1.2 | 3.5 | 9 |
| TGW3 | | Jul-13 | Oct-13* | 0.97 | HBSS | 0.005 | 0.015 | 0.04 | 9.7 | 29 | 78 |
| TGW4 | | Jul-13 | Oct-13* | 0.06 | HBSS | 0.005 | 0.015 | 0.04 | 0.6 | 1.8 | 5 |
| TGW5 | | Jul-13 | Oct-13* | 0.02 | HBSS | 0.005 | 0.015 | 0.04 | 0.2 | 0.6 | 1.6 |
| GW075409 | -01 | Jan-12 | Oct-12 | 1.37 | Alluv** / HBSS | 0.02 | 0.05 | 0.15 | 27 | 69 | 205 |
| GW075409 | -01 | Jan-13 | Apr-13 | 1.7 | Alluv / HBSS | 0.02 | 0.05 | 0.15 | 34 | 85 | 255 |
| GW075410 | | Jan-12 | Oct-12 | 5.61 | Alluvium | 0.02 | 0.05 | 0.15 | 112 | 280 | 841 |
| GW075410 | | Jan-13 | Apr-13 | 5.55 | Alluvium | 0.02 | 0.05 | 0.15 | 111 | 278 | 832 |
| GW075411 | | Jan-12 | Oct-12 | 1.83 | Alluvium | 0.02 | 0.05 | 0.15 | 92 | 274 | 37 |

* period only 'half' the expected 'recharge season' so calculated recharge has been multiplied by 2 to account for recharge assumed to occur in early 2013 (i.e. prior to monitoring).

** HBSS = Hawkesbury Sandstone; Alluv = Alluvium

**Chloride mass balance**

The chloride mass balance method (Cartwright *et al.*, 2008) relies on a comparison of average annual rainfall, the observed chloride concentration in groundwater, and the chloride loading of local rainfall to calculate the likely infiltration recharge.

At Tahmoor, chloride concentrations in the shallow Hawkesbury Sandstone aquifer vary from about 160 to 1900 mg/L, with a median of 400 mg/L (Geoterra, 2013a). The chloride loading was sourced initially from DPI (1996), with the nearest location being at Belanglo, approximately 40-50 km to the southwest of Tahmoor. There the chloride loading was 8.5 kg/ha/a. Geoscience Australia's MapConnect website[6] indicated local chloride loading to be 13.7 kg/ha/a. Based on the range in both groundwater chloride and chloride in rainfall, recharge calculated using this method ranges from 0.4 to 14 mm/a for Hawkesbury Sandstone, with 3 to 8 mm/a being more likely. This is in agreement with work done by CSIRO (Crosbie, 2015), which suggested that recharge was about 5-21 mm/yr in this region.

**Baseflow yield**

Further discussion of groundwater-surface water interaction is provided in Section 3.8.7. Rainfall recharge is expected to be matched by discharges as follows:

$$Recharge = Discharge = Baseflow\ (BF) + Evapotranspiration\ (ET) + GWabs + GW\ flow\ out$$

A given estimate for baseflow (in mm/a) allows the estimation of an expected minimum recharge value (given that other discharge processes are likely to occur). EC-constrained baseflow estimates in Section 3.8.7 suggest that baseflow is likely to be 1-2% of LTA rainfall, a figure supported by Advisian (2016). This would indicate that the minimum recharge to the area as a whole would be around 10-20 mm/a.

**Summary**

The regional recharge of 6% of LTA rainfall stated in NOW (2011b) is a useful starting point, however local studies (see **Table 3-9**) and analysis of field data suggests that recharge to the consolidated Hawkesbury Sandstone and Wianamatta Formation is likely to be half of this, if not even less, on the order of 2-3% of LTA rainfall in the area around Tahmoor and Bargo. The higher average rate stated in NOW (2011b) might apply across the Nepean Groundwater Source as a whole, as it encompasses areas of higher rainfall to the south (Southern Highlands) and east (escarpment) of Tahmoor.

Recharge to the alluvium can be from rainfall recharge as well as river leakage. Recharge to the alluvium is likely to be higher, on the order of 10-20% of LTA rainfall.

### 3.8.5 GROUNDWATER QUALITY

Groundwater quality data for the Study Area, in the form of electrical conductivity (EC), are summarised in **Figure 3-28**. These data were sourced from publicly available data from the NSW government Groundwater Works/Pinneena database, and from the bore census conducted by Geoterra (2013a). The information in the Groundwater Works database is a mix of qualitative (e.g. 'fresh', 'brackish') and quantitative (e.g. '500 ppm'). In order to convert or standardise these qualitative entries to an approximate quantitative measure some assumptions have been made[7]. The resultant quantitative salinities were classified as shown on **Figure 3-28**, as well as assigning the various bores to layers using the geological model built for this study.

---

[6] http://mapconnect.ga.gov.au/MapConnect/ [Groundwater] [accessed 204, but now defunct]
[7] assumptions such as, e.g. groundwaters described as 'Good' or 'Fresh' were assigned as 0-500 ppm, 'Fair' = 500-1000 ppm, 'Stock'= 1000-3000 pm, 'Poor' or 'Brackish' = 3000-7000 ppm, 'V. salty' = >8000 ppm.

The data indicate that:

- The majority of the data is available for the Hawkesbury Sandstone. This hydrogeological unit shows a range of salinities, from fresh through to saline, with an approximate median value of around 500 mg/L, based on the usually qualitative entries in the NSW bore database. The average salinity from the 23 samples in the Tahmoor bore census was 1,050 mg/L.
- Alluvium and Wianamatta Formation water is also of mixed quality. It is likely that evaporative concentration of salts could occur in alluvial aquifers, especially in clayey facies. The marine origin and low permeability of the Wianamatta Shales tends to lead to higher salinities in this unit.
- There is little data for the Narrabeen Group or Illawarra Coal Measures. Older units such as the Shoalhaven Group exhibit a range of salinities from fresh to saline.

A summary of groundwater quality at Dendrobium indicated:

- fresher conditions in the Hawkesbury Sandstone, with a median salinity of 80 mg/L;
- a median salinity of 280 mg/L for the Bulgo Sandstone; and
- median salinities for the mine goaf, i.e. the Permian Coal Measures, including the Wongawilli Seam and possibly the Bulli Coal Seam), in three different mine areas of approximately 500, 650 and 900 mg/L.

Publicly available data from AGL's Camden Gas Project indicated an average TDS of about 380 mg/L for Hawkesbury Sandstone groundwater (Parsons Brinckerhoff, 2013). An average TDS of 11000 mg/L and a range 3200-27500 mg/L was reported for groundwater from the Illawarra Coal Measures, which includes the Bulli Coal seam.

The apparently fresher conditions are likely due to the higher rainfall (**Figure 3-2**) and lower evaporation at Dendrobium than inland at Tahmoor or at Camden, which lies even closer to the centre of the Sydney Basin. A general trend for increasing salinity with depth is expected at Tahmoor.

In comparison to the groundwater salinity data, **Table 3-11** shows that surface water sampling from around Tahmoor showed that surface water is fresher.

**Table 3-11 Surface water salinity**

| SITE | | SALINITY (mg/L) | | |
|---|---|---|---|---|
| | | MINIMUM | MEAN | MAXIMUM |
| Site 1 | Bargo River - Control Site | 80 | 108 | 138 |
| Site 9 | Horne's Creek | 95 | 213 | 473 |
| Site 13 | Bargo River - upstream | 65 | 120 | 178 |
| Site 22 | Tea Tree Hollow Creek | 1,062 * | 1,162 * | 1,368 * |
| Site 14 | Bargo River - downstream | 68 | 548 | 968 |
| Site 15 | Dog Trap Creek - downstream | 84 | 127 | 167 |
| Site 16 | Dog Trap Creek - upstream | 93 | 598 ** | 6,894 ** |
| Site 18 | Eliza Creek | 65 | 542 | 879 |
| Site 20A | Dry Creek | 99 | 163 | 283 |
| Site 21 | Nepean River - Maldon Weir | 15 | 115 | 218 |

| SITE | | SALINITY (mg/L) | | |
|---|---|---|---|---|
| | | MINIMUM | MEAN | MAXIMUM |
| Site 23 | Carter Creek | 132 | 282 | 408 |
| Site 24 | Cow Creek | 60 | 83 | 131 |

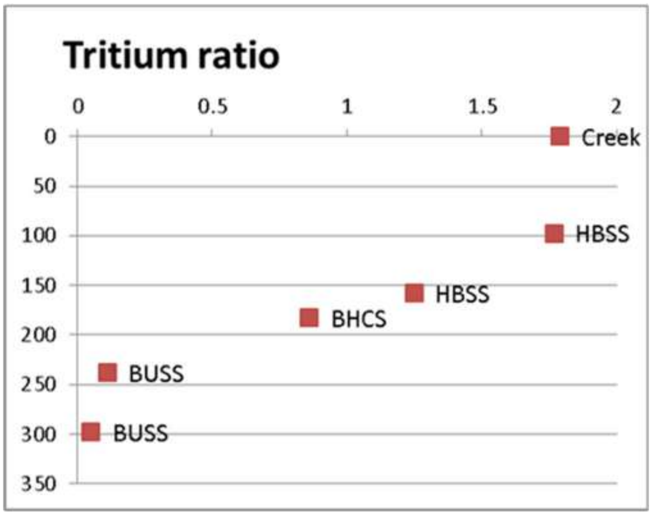
* influenced by wastewater discharge from mine

** skewed by a single outlier (without this value, mean = 180, max = 288 mg/L)

The min-max range or variation in surface water EC indicates that evaporative concentration of surface water could occur, however inputs from more saline groundwater are the more likely cause of the variation in river salinity, other than at Tea Tree Hollow, which is influenced by the licensed site of discharge from the mine.

Based on advice from Geoterra (Andrew Dawkins, pers comm.), there is no discernible spatial pattern or trend in the shallow Hawkesbury Sandstone EC data.

Geoterra (2013a) presents some profiles of salinity within bore TBC035, as well as further chemical and isotopic analysis of groundwater. A summary of the main observations and conclusions to be drawn is outlined here:




- Salinity samples from multiple levels in bore TBC035 show clear contrast in salinity over time between the shallowest and deepest intervals, with the shallowest intervals exhibiting the greatest range in EC: typically high salinity in summer, freshening through autumn, and rising the following winter/spring.
- Tritium samples from the same multi-level bore showed a clear decreasing downward trend in tritium with depth. Table 5 from Geoterra (2013a) is reproduced as a chart here, with depth in metres on the vertical axis. The youngest water (indicated by high tritium concentrations) is in the stream and shallowest aquifers. The oldest water lies below the Bald Hill Claystone (BHCS). There is a pronounced change in Tritium ratio between the lower HBSS, BHCS and underlying Bulgo Sandstone (BUSS).
- This suggests that:
  - the average rate at which vertical leakage can percolate down through the stratigraphic sequence is greatly increased between the lower HBSS or BHCS sample intervals and the upper BUSS interval. Some water may be able to travel more quickly through joints or fractures in the BHCS or upper BUSS, however the average time of travel is slow across these lower HBSS-BHCS-BUSS intervals; and/or
  - Recharge to the BUSS could be coming from a different source, that is, laterally, rather than vertically down.
- Figure 6 from Geoterra (2013a) presents oxygen and hydrogen isotope analysis, which indicate:
  - Reduced connection between the deepest two or three sample intervals (BHCS and BUSS) and the shallower intervals; and/or

- Recharge to those lower intervals is sourced from rainfall at higher altitudes than recharge to the outcropping Hawkesbury Sandstone, based on “depletion relative to the local meteoric water line being due to an altitude effect” (Geoterra, 2013a).

A Reject Emplacement Area (REA) located within the surface infrastructure area has been operated by Tahmoor for most of the period of historical mining. It is located on outcropping Hawkesbury Sandstone, just south of the Bargo River. Two piezometers monitor groundwater adjacent to the REA (**Table 3-12**, **Figure 3-5**). Based on Geoterra’s last inspection, TGW5 is blocked, but TGW4 is in good condition (Andrew Dawkins, pers comm).

**Table 3-12 Reject Emplacement Area Monitoring Bores**

| Bore | Easting | Northing | SWL (mbgl) | Intake (mbgl) | Lithology | Comment |
|---|---|---|---|---|---|---|
| TGW4 | 278362 | 6207827 | 39.92 | 50.8-54.8 | Hawkesbury Sst. | Downgrad. of REA |
| TGW5 | 278446 | 6206332 | 31.08 | 50.5-54.5 | Hawkesbury Sst. | Upgradient of REA |

Geoterra (2013b) conducted a review of water quality data at these piezometers, noting that pH was in the range 6.4-6.6 (i.e. close to neutral). Electrical conductivity was higher in TGW5 (upgradient of the REA) than in TGW4 (downgradient), suggesting no increase in salinity. Geoterra observed some exceedeances for specific analytes at TGW4-5 but noted that these were consistent with groundwater sampled elsewhere in the Bargo/Pheasants Nest/Tahmoor area (and away from the REA). Based on this, there was no evidence of an adverse effect from the rejects wthin the REA on local groundwater quality.

### 3.8.6 HYDRAULIC PROPERTIES

**Figure 3-5** shows the locations of deep bores around Tahmoor, many of which were subject to drill-core sampling and packer testing for this Project. These analyses are detailed within SCT (2013). A summary and discussion of the hydraulic conductivity data is presented here.

**Hydraulic Conductivity (k)**

For the purpose of describing or quantifying how water flows through a porous or fractured medium, the term ‘permeability’ is used interchangeably with ‘hydraulic conductivity’ in this report.

The laboratory core measurements of hydraulic conductivity are summarised in **Figure 3-29**, and packer test derived hydraulic conductivities are illustrated in **Figure 3-30.** The main points to be drawn from these charts are:

- Variation between measured horizontal core permeabilities compared to the values derived from packer tests. This is not uncommon and is expected because packer tests measure the (local-scale) joint and fracture permeability whilst the core data typically measure the host rock mass permeability (i.e. conductivity of the intergranular pore spaces).
- Based on packer test permeabilities there is generally little contrast between units termed as ‘Sandstone’ and ‘Claystone’, noting that ‘Claystones’ are not necessarily less permeable than ‘Sandstones’. In reality these units, outside of areas where they are ‘massive’, are each comprised of many layers or laminations of sandstone, siltstone, claystone and conglomerates. Comparing ‘Sandstone’ and ‘Claystone’ units in the core permeability data suggests that there is little coherence in the data, other than that the ‘Claystone’ results fall in narrower bands than those in the ‘Sandstone’ units, and have consistently lower core vertical permeabilities.
- The packer test dataset from Tahmoor suggests a decreasing permeability with depth of the rock mass as a whole, however the trend seems to be in two parts:

  - decreasing from the Hawkesbury Sandstone down to the Wombarra Claystone, an apparent step up between Wombarra Claystone and the Bulli Coal seam; and
  - a further decreasing trend in the units older than the Bulli Coal. There is a weak trend of decreasing matrix permeability with depth observed in the core data.
- The difference in the strength of the trend in the packer and core data is unsurprising, as depth of cover is unrelated to matrix lithology, although this can cause some reduction of intergranular pore space. Depth of cover has more influence on the presence or absence, and the magnitude of open joints and fractures, with more open joints expected at shallower depths.
- The core data set provides a useful lower bound on hydraulic conductivity, however packer tests do not necessarily provide the upper bound, due to the scale at which testing is effective. Pumping tests may, or may not, be able to stress connected joint and fracture networks, leading to higher measured permeabilities.
- Horizontal permeability from packer tests ranges from <8.6E-7 m/d, being the lowest measurable value in these tests and recorded in multiple units, to 0.45 m/d in the Hawkesbury Sandstone. Permeabilities within the Hawkesbury Sandstone generally lie at least one or two orders of magnitude higher than in the other, deeper units. At Tahmoor, coal permeability tends to lie between 1E-4 and 1E-3 m/d.
- Horizontal conductivity in the rock matrix ranges from 8.6E-7 m/d for Wombarra Claystone to 1.4E-2 m/d for the Hawkesbury Sandstone.
- Vertical hydraulic conductivity of the rock matrix based on core data ranges from 8.6E-8 m/d to 1.1E-2 m/d. The median vertical permeability for the rocks lying above the Bulli Seam is 5.6E-7 m/d, while the harmonic mean[8] is 3.2E-6 m/d. The greatest variation is observed in the Hawkesbury Sandstone, Bulgo Sandstone, Scarborough Sandstone, and Bald Hill Claystone, although this is likely related to the frequency of testing at Tahmoor of these units relative to others.
- Bald Hill Claystone core horizontal permeabilities (**Figure 3-29**) are influenced by the presence of a sample noted by the laboratory as 'fractured' with a measured permeability of 4.8E-3 m/d. Whether this sample was fractured already or fractured during testing is unclear. However, it has been preserved within the dataset, because if the sample was fractured prior to retrieval from the subsurface, then this result would reflect the in-situ characteristics of the Bald Hill Claystone. In any case, the next highest recorded BHCS permeability was not much lower, at 3.3E-3 m/d. The mean, however, is less than 1E-5 m/d. Mean vertical permeability is <1E-6 m/d.
- Observed horizontal to vertical hydraulic conductivity ratios have a:
  - range of 0.4 (i.e. vertical permeability greater than horizontal) to about 1500. The high ratios of 1000-1500 are most frequently found in the Loddon and Lawrence Sandstones, and suggest significant vertical anisotropy in this unit which occurs below the Bulli Coal seam. The Stanwell Park Claystone is the other unit with noticeably high vertical anisotropy.
  - an arithmetic mean of 145;
  - a geometric mean of about 3; and
  - a median of just over 1.

[8] Of the three main 'mean' values (arithmetic, geometric and harmonic) which are used to describe the central tendency of a set of data, the harmonic mean of a set of numbers tends toward the smallest elements in the dataset. In comparison to the arithmetic mean (what is typically used as 'mean' or 'average') it therefore tends to mitigate the impact of larger outliers and enhance the impact of values at the lower end of the scale. In the case of hydraulic conductivity data, where there is scope for the range of permeability to range across multiple orders of magnitude, the harmonic or geometric means are better for estimating the central tendency of the data without being skewed toward even a small number of large outliers. The harmonic mean is typically used to characterise vertical hydraulic conductivity (Domenico and Schwartz, 1998).

  - This was defined using the ratio of each sample for which both parameters were measured successfully.
- Alluvial hydraulic conductivity has not been measured at or near the site.
- Coal Cliff Sandstone is included on the charts, as it is found at the north-eastern edge of the site and forms a layer within the regional geological model constructed for this study. However given the absence of the Coal Cliff Sandstone within the mine footprint it has not been tested as part of this program.

**Hydraulic properties of fault zones**

As described in Section 3.7 there are a number of geological structures mapped around the Study Area and even within the bounds of the Project, as shown on **Figure 3-9** and **Figure 3-11**.

The largest of these are the Nepean Fault (trending north-south) and several NW-SE trending features (faults and monoclines) through parts of the existing mine and south of the Project.

The Nepean Fault is known have different properties to the host geological units. It could be either a hydraulic barrier or a conductive fault, as it is observed that there are large hydraulic gradients across the fault. Tahmoor Coal has observed water inflows to the mine to be higher than normal at a point where the mine workings intersected the fault zone, which indicates that the Nepean Fault is more permeable than the surrounding geology.

Further discussion of increased inflows during the intersection of longwall 16 is presented in Section 3.8.8. However, the intersection of other faults, such as the Bargo Fault and Victoria Park Faults, by mining has not produced notable additional water inflows. Investigative drilling into fault zones has also proved difficult. For this reason it is believed that most of the faults in the area act as barriers to flow, possibly because of the presence of fines or mineralisation within the fault zone.

Dykes and sills, including the large 'Yerrinbool Igneous Complex', present within the coal measures and other units are thought to enhance hydraulic conductivity along their upper and lower cindered and fractured margins, but this is thought to be limited to a very local scale effect, based on core data inspection. The main igneous rock mass is likely to be less permeable that surrounding sedimentary units.

**Specific Yield (Sy)**

Specific yield, together with porosity and specific storage, usually decreases with depth. Studies conducted in the Sydney metropolitan area and elsewhere indicate a specific yield of between 0.01 and 0.02 is reasonable for typical Hawkesbury Sandstone (Tammetta and Hewitt, 2004). Specific yields for Sydney Basin sedimentary strata in the context of drainage due to longwall subsidence generally vary between 0.005 and 0.015.

Alluvium is expected to possess a specific yield in the range of 0.03 to 0.2, depending on the dominance of silt/clay or sand/gravel.

Three measurements of total porosity (n), which is an upper limit for Sy, on core from bore TBC037 were available:

- Two for the Hawkesbury Sandstone, where n =5.3 to 11%; and
- One for the Bald Hill Claystone, with n = 4%.

**Specific Storage (Ss)**

Direct test data is not generally available for specific storage (Ss).

The specific storage of Hawkesbury Sandstone has been estimated to be about:

- 1E-6 m-1 in the shallower zones where fracture flow is the dominant flow process (Kelly et al., 2005); and
- 1.5E-6 m-1, for intervals between ground surface and 300 m depth based on pumping tests in Hawkesbury Sandstone from Tammetta and Hawkes (2009).

Model calibration parameterisations at other mines in the Southern Coalfield suggest that Ss is in the order of 1E-7 to 3E-5 $m^{-1}$ for the coal seams, and about 1E-6 $m^{-1}$ for overburden or interburden. Values in line with the Dendrobium regional model (Coffey, 2012) were used initially in this case, although increased during calibration, more in line with the calculations described below.

Good estimates of specific storage can also be made based on Young's Modulus and porosity, based on calculations in Mackie (2009). Calculations for this Project suggested that for coal, Ss generally lies in the range 5E-6 $m^{-1}$ to 5E-5 $m^{-1}$, and interburden from 1.7E-6 (unfractured, fresh rock) to 8E-6 (fractured rock).

For the parameterisation of this model, a broad trend of decreasing specific storage with depth was used, representing the concept that joints and fractures are more likely to be open nearer the surface and more likely closed due to overburden pressure at depth.

### 3.8.7 GROUNDWATER-SURFACE WATER INTERACTION

**Baseflow separation and chloride mass balance**

Baseflow estimates from Tahmoor Coal's monitoring sites at Hornes Creek and Bargo River are presented in **Table 3-13**. The government gauging station on Stonequarry Creek (gauge 212053) was not analysed because of the lack of river EC in the Pinneena database.

**Table 3-13 Baseflow Estimation on Local Watercourses**

| WATERCOURSE / STATION | CATCHMENT AREA ($km^2$) | BASEFLOW INDEX (BFI) | BASEFLOW YIELD (mm/a) | BASEFLOW AS % OF RAINFALL |
|---|---|---|---|---|
| Hornes Creek | 17 | 4-55% | 3-50 | 1-5% |
| Bargo River^ | 51 | 6-70% | 9-48 | 1-6% |

^ HEC (2018a) estimated 10% for the BFI for upstream Bargo River

Two methods have been applied to calculate baseflow:

- Digital filters, such as the HYSEP method (Sloto, 1986); and
- A chloride or EC mass balance method, which constrains baseflow estimates using river salinity (EC) data, an estimate of groundwater salinity (see Section 3.8.4), and a record of river flows, and combines these in a mass balance approach.

As discussed in Cartwright *et al.* (2013), and based on experience elsewhere in comparing such methods, the EC-constrained estimates are more reliable and lower compared to the much higher and more uncertain estimates produced using digital filters, such as the HYSEP method. Therefore, the BFI for Hornes Creek is likely to be 4-15% based on EC-constrained analysis rather than up to 50 or 55%. Likewise, Bargo River BFI is likely to be in the range 6-20%, rather than up to 70%. The lower estimates consistent with independent estimates by HEC (2018a) noted in the footer of **Table 3-13**, and with the conclusions of Advisian (2016). This suggests that baseflows in the area will be on the order of 1-2% of rainfall.

**Analysis of flow differentials**

**Figure 3-31** displays the gauged daily flows and calculated differentials based on the following combinations of gauges:

- Site 1 (Bargo River – upstream) + Site 9 (Hornes Ck – tributary) against Site 13 (Bargo River - downstream);
- Site 16 (Dog Trap Creek – upstream) against Site 15 (Dog Trap Creek – downstream).

**Figure 3-5** outlines the monitoring locations. The analysis has been restricted to days when observations are available for all the component gauges; that is three gauges on the Bargo River and two on Dog Trap Creek.

Because of the relatively small distances between gauges the differences are assumed to only represent any losses to and gains from groundwater between these combinations of gauges. This assumes that evaporation and surface water use and inflows from other sources (such as other ungauged tributaries) are negligible.

This analysis shows the following:

- The 'upper Bargo' is generally gaining (65% of the 435 days in the analysis), and 'gains' are stronger than the observed losses, noting that these are probably due mainly to incoming overland flow or tributary inflows. Mild losses occur mainly during November-January, and are typically 0 to 1.5 ML/d. This magnitude of the gains and losses is often large compared to the flows measured at Site 13, frequently 10-50% and sometimes larger.
- Analysis of flows on Dog Trap Creek shows similar behaviour to the 'upper Bargo' analysis. Gains are less frequent on the hydrograph, with a loss calculated as occurring on 57% of the 189 days in the analysis. There is no data available for the summer of 2012-13, however losses calculated during other periods are typically 0.1-0.5 ML/d, which can be 10-110% of the flow calculated at Site 15.

Although volumetric gains are greater on the whole than losses, the Bargo River and Dog Trap Creek both lose water into the underlying Hawkesbury Sandstone aquifer for a significant proportion of the time. This inference is strengthened by the fact that the estimated flow losses are underestimates due to a lack of accounting for inflows from several small ungauged tributaries between gauging stations, particularly along the Bargo River between Site 1 and Site 13. There are few licensed groundwater abstractions along or near to this reach of the river (**Figure 3-12**), and hence unaccounted groundwater usage impacts on stream flows are not expected to compromise this water balance analysis.

The losses along the Bargo River could be natural, however, and particularly in areas closest to Site 13, they could be due to any persistent drawdowns imposed by earlier mining in longwall panels 14-19 or even longwalls 3-9 (see **Figure 2-1**). Similarly, the losses on Dog Trap Creek could be natural or be due to earlier mining of longwalls 8, 10-13).

The occurrence of losing streams is also clear when inspecting data presented in Section 5.2.2 in Geoterra (2013). Two of the piezometers presented in that analysis are nested; GW075409-1 is in the alluvium, while GW075409-2 is in the Hawkesbury Sandstone. The hydrograph shows a clear and consistent downward gradient, and assuming good connection between the lakes and the alluvium, this head separation indicates leakage from the alluvium and therefore the lakes and Blue Gum Creek to the Hawkesbury Sandstone. This downward leakage is consistent with the downward head gradient occurring throughout the 18 month period (late 2011 to early 2013) for which data is presented in Geoterra, 2013a.

### 3.8.8 MINE INFLOWS

**Figure 3-32** presents a history of the calculated inflows ('water make') at Tahmoor Mine. In the past inflows were calculated via a mass balance approach. This accounted for water pumped into the mine as part of operations, from Sydney Water's mains or other sources, and all the water pumped out. The faint green/grey line on **Figure 3-32** shows the total pumped out of the mine each day.

Two separate calculations for inflow are presented on **Figure 3-32**. The first was provided by Gilbert and Associates (now HEC), the second by Tahmoor Coal. There was a period during which measurement of the correct parts of the water balance was not carried out, hence the lack of calculated water make for the period 2002-08.

As seen on **Figure 3-32** and in **Table 3-14**, Tahmoor Mine's inflows range between 1 and 4.5 ML/d, with the various peaks and troughs through the record. In the last 4-5 year period, total water make has been fairly steady at around 3-4 ML/d.

A fraction of the calculated water make is from inflows collected in the 'mid-Drift sump', located toward the base of the Hawkesbury Sandstone within the 'drift' that provides access from the surface to the underground mine. A consistently reliable record of historical inflows to the mid-Drift sump is not currently available. However, the best estimates are that 0.5 ML/d are typically collected at this site. This volume is accounted for within the total volume reported on **Figure 3-32**, and comes from the Hawkesbury Sandstone aquifer(s). The remainder, the water make in the Bulli seam mine, comes from the deeper units, although may also be partially or ultimately sourced from the Hawkesbury Sandstone.

An effort was made to attribute peaks and troughs to longwalls and then to any faults that were mapped across these longwalls, however the analysis did not show anything conclusive. The mapped faults did not typically result in higher inflows. Other than at the Nepean Fault (see below), the only possible candidate for increased inflow along geological structure was in longwall 16, where the T2 fault oriented NW-SE crosses through this longwall, the preceding LW15 and to the edge of LW14 (shown on Figure 3-11). An increase in inflows was experienced during the mining of LW16, although not during LW15 or LW14. This could be:

- coincidental, as the mine inflow records are based on a whole-of-mine water balance, rather than monitoring specific longwalls in the underground mine; or
- Indicative of more permeable fault-affected conditions above LW16. Following on from discussion about the behaviour of the T1 and T2 faults (Section 3.7.3). This suggests that the T2 fault, as intersected in LW16 might be more conductive than the surrounding strata. However, the lack of an inflow response to mining through the same fault in LWs14 and 15 suggests that if it is indeed more conductive through LW16 it is not so along its full length. In any case, given the potential significance of the behaviour of these faults, predictive modelling to investigate the possible impacts of T2 being a conductive feature is discussed in Sections 5.2.1and 6.

Following the analysis of the inflow hydrograph and mine schedule, further discussion with Tahmoor Coal indicate that faulting did not result in increased water make, with the exception of where mains (roadways) intersected the Nepean Fault zone to the east of LWs 24 and 25 (see **Figure 2-1**). At this location some increased inflows were encountered.

**Table 3-14** summarises available historical inflow data for Tahmoor and nearby Southern Coalfield mines. Some of this information has been sourced from Coffey (2012).

By comparison it seems that Tahmoor is a wetter mine than some others in the Southern Coalfield, although this might be in part due to a large mined area than at others. Parts of the Dendrobium Mine are known to experience short bursts of high inflows, correlated with high rainfall events. This effect is not known to occur at Tahmoor.

**Table 3-14 Summary of Inflows to Tahmoor and neighbouring Mines**

| MINE | AVAILABLE RECORD | INFLOW [ML/D] | | |
|---|---|---|---|---|
| | | MINIMUM | MEAN | MAXIMUM |
| Tahmoor | 1995-2002, 2009-2017 | 0.3 | 2.75 | 5 |
| Appin & Tower | 2007-2009 | 0.06 | 1.9 | 2.8 |
| Dendrobium | 2003-2017 | 0 | 3.6 | 13.5 |
| Cordeaux | 1992-2002 | -- | 1.2 | -- |
| Bellambi / NRE No1 / Russell Vale | 2005-2009 | 0.05 | 0.4 | 0.7 |

**Figure 3-33** was prepared to illustrate the areas within Tahmoor Mine that are relatively wet or dry and the drainage systems, as well as some of the drainage measures that would occur if the Tahmoor South Project is approved. A copy of a plan provided by Tahmoor Coal, which shows more detail on pump locations and pump details are provided in Appendix D.

This figure indicates the following:

- a couple of areas noted as particularly wet, both of which appear related to the Nepean Fault. Surprisingly these both occur slightly to the down-dip side of the mine, emphasising the conductive nature of the Nepean Fault.
- dry areas are noted along the western edge of the mine (near to longwalls 22-27) and near to just down-dip of longwalls 1-2;
- two main drainage catchments in the underground mine, one which is pumped out via the Shaft 3 pump, and the other via the two pumps located at Pit Bottom:
  - Shaft 3 captures inflows coming in through longwalls 14-19. In recent times, 5-10 years after the last of those longwalls was mined out, this line has been pumping around 0.75 ML/d; and
  - the remainder of Tahmoor and Tahmoor North is pumped out through pumps at Pit Bottom, and in recent times this has been in the order of 2.3 ML/d.

Pumping data from each of the main pumping lines was to be used in the calibration of the numerical model; however Tahmoor Coal indicated that unrecorded internal transfers underground between sumps occurs, as well as occasional temporary storage of groundwater within goaf areas followed by recovery at a later time. This meant that the day-to-day records are not reliable enough to use for this purpose, and averages over longer periods must be used.

## 3.9 INVESTIGATION INTO FRACTURING ABOVE LONGWALLS

Longwall mining typically removes large rectangular panels of coal from a coal seam, often 100-400 m wide and up to 6-8 km long and 2-4.5 m high. In the case of Tahmoor South, the longwalls are proposed to be 280 and 300 m wide (most 300 m), and the mined thickness will be up to 2.9 m. The removal of a panel of coal then results in the overburden caving into the void, resulting in stresses propagating upward, and outward, through the overlying strata. Fracturing and deformation of these strata then results in some changes, from very large to no change, in the permeability and aquifer storage properties of this overburden.

More on the conceptual model of fracturing and deformation is included in Section 3.10. The conceptual model of the impacts of mining on the permeability of caved and deformed overburden has been based on the authors' experience of monitoring and groundwater modelling gained at Tahmoor and in other locations to date, combined with the recent research available for subsidence impacts on aquifer materials. This includes the report commissioned by Tahmoor Coal on the down-hole investigation into fracturing above a longwall at Tahmoor (SCT, 2014), as well as the predicted changes to permeability in the goaf and overburden via geotechnical modelling with FLAC (SCT, 2013). The SCT (2014) report on the 'Height of Fracturing' (HoF') hole is particularly important in the development of the conceptual model of this process at Tahmoor because it shows *in situ* behaviour of groundwater levels in response to mining at Tahmoor at a location that is only a few hundred metres from the proposed Tahmoor South longwalls.

### 3.9.1 LONGWALL 10A HEIGHT OF FRACTURE BOREHOLE (SCT, 2014)

Tahmoor Coal commissioned SCT to carry out investigative drilling and analysis of a variety of methods (SCT, 2014) of the conditions above Tahmoor Longwall 10A. This longwall was extracted in 1992. A summary of SCT (2014) is provided here with reference to **Figure 3-34**, which is a reproduction of Figure 12 from SCT (2014).

Borehole TBF040c was successfully drilled to a total depth of almost 243.9 m, terminating almost 50 m into the upper Bulgo Sandstone. Core logging showed a general trend of increasing defect frequency with depth from about 70 m to the bottom of the hole, as well as occurrences of 'borehole breakout'[9] from 75-80 m depth. Borehole breakout is a sign of stress and SCT interpreted this location as the height to which mining-induced fractures occur above the mined seam.

Water levels in the Hawkesbury Sandstone in TBF040c were essentially constant through time, and the depth to water in the Hawkesbury Sandstone was consistent with trends from elsewhere around the site, including sites away from longwalls. This suggests no enhanced connection between the longwall/goaf and the Hawkesbury Sandstone due to mining of Longwall 10A or adjacent panels. The implication is that there is no observable long-term impact on groundwater resource availability in the Hawkesbury Sandstone from mining in Tahmoor longwalls 8, 10-13.

The water level profile down the bore shows heads are essentially the same through the Hawkesbury Sandstone, as measured in three piezometers 75, 100 and 165 m below ground (mBG) and in the Bald Hill Claystone located 175 mBG. It is only below this point that heads begin to decline. Water levels measured at three points in the upper Bulgo Sandstone decline, slowly at first and then more sharply between 205 and about 220-226 mBG. The drawdown in this last interval is approximately 80 m, indicating a strong downward gradient. The implication of this is that while fraturing and borehole breakout were observed higher in the borehole, at shallow depths the fracturing was not connected in a vertical sense, nor permeable enough in a horizontal sense to result in significant chagses to the piezometry of the Hawkesbury Sandstone. At greater depths (closer to the seam), the degree of permeability enhancement increased, particularly in the vertical direction, resulting in significant loss of groundwater pressure.

SCT postulate that the Bald Hill Claystone is not the reason for the head separation observed between the fractured Bulgo Sandstone and the shallow Hawkesbury Sandstone. The Bald Hill Claystone is simply coincidental to the top of the zone or strata influenced by longwall mining. This would seem to be supported by the fact that the hydraulic conductivities in the packer and core testing dataset (see Section 3.8.6) for the Bulgo Sandstone and Bald Hill Claystone are not significantly different.

**Figure 3-34** shows estimates from two empirical models:

- Height of complete groundwater drainage (Tammetta, 2012);
- Height of connected fracturing ("A-zone") (Ditton and Merrick, 2014).

---

[9] This is a type of failure in a rock mass. SCT (2014) states that borehole breakout indicates the concentration of horizontal stresses at the location of the 'breakout'.

SCT (2014) state that the observed and inferred drawdown in this borehole "are consistent with the approach forwarded by Tammetta". HS note that the observations are also consistent with the Ditton Geology Model at this location. These empirical methods, and means of estimating the height of connected fracturing, are discussed further in **Section 3.10.4**.

## 3.10 HYDROGEOLOGICAL CONCEPTUAL MODEL

This section synthesizes or integrates the conclusions and analysis described in previous sections, as well as the discussion of longwall mining impacts on hydrogeology (see discussion below and **Figure 3-35**). Sketches of the conceptual hydrogeological models of pre- and post-mining system are presented in **Figure 3-36** and **Figure 3-37**. These are generalised, such as the pre-mining conceptual model not including details of the existing impact from the Tahmoor/Tahmoor North operations. Note that these are simplified representations of the pre-mining, which even assumes no existing mining at Tahmoor, and mining-impacted environments.

### 3.10.1 RECHARGE

Recharge to the Hawkesbury Sandstone is predominantly derived from rainfall recharge, and from leakage from streams to the aquifer. Analysis presented in Section 3.8.4 suggests recharge to the Hawkesbury Sandstone is low, at about 10-20 mm/a or 2-3% of LTA rainfall.

Some recharge to the Thirlmere Lakes alluvium possibly occurs from the underlying and adjacent Triassic Hawkesbury Sandstone rock aquifer at times, although in general the head gradient between the alluvium and aquifer (see Section 5.2.2 in Geoterra, 2013a and discussion at the end of Section 3.8.7 in this report) indicates leakage from the lakes and Blue Gum Creek to the underlying Hawkesbury Sandstone. Based on the analysis in Section 3.8.7, losing streams, or streams that switch between losing and gaining behaviours, seem to be a common occurrence in this area. Losing behaviour may occur a relatively substantial proportion of the time. Therefore, leakage from streams to shallow aquifers is considered to be a significant recharge mechanism.

Recharge to the Triassic and Permian aquifers is lower than that to the alluvium because of its inherently lower capacity to receive and transmit water due to its significantly lower hydraulic conductivity and storage properties. The shallow groundwater hydrographs in Geoterra (2013a) and the vibrating wire piezometer data (either **Figure 3-17** or **Appendix B**) show only relatively small responses to seasonal recharge.

It is expected that recharge to outcrops of older geological units, such as the Bald Hill Claystone, Bulgo Sandstone, will be less than to the Hawkesbury Sandstone, due to their generally lower permeability.

Buried or subcropping strata will be recharged via leakage from overlying units, provided that the heads allow a gradient to recharge a particular unit. Lateral flow from upgradient will also play a role in providing recharge, and in the units below the Bald Hill Claystone this mechanism appears to be more dominant than vertical leakage. This is implied by the chemistry and isotope data (Geoterra, 2013a), along with the head profiles presented earlier.

### 3.10.2 DISCHARGE

Discharge from the Permo-Triassic rock aquifers is primarily to the streams (see Section 3.8.7), but also to evapotranspiration from shallow groundwater in lower lying areas where the fractured rock is at outcrop. A small component of the water balance is extracted for anthropogenic use by production bores, where groundwater entitlement within the Nepean Groundwater Source was around 16,300 ML/a (NOW, 2011b) but now about 25,000 ML/a, or 11% of total estimated recharge. Assuming that actual use is somewhere around 30% of entitlement, this means that groundwater use is around 3-4% of recharge.

There is only a small area of alluvium around Tahmoor (mainly along Blue Gum Creek). Discharge from alluvium is primarily via evapotranspiration from shallow water table areas and some baseflow to the lakes and watercourses.

Current hydraulic heads in the coal measures show minimal vertical or horizontal gradients, with exceptions at TNC028, TNC029 and TBC001 due to mining at Tahmoor/Tahmoor North visible in hydrographs. Also, some drawdown followed by full or partial recovery is evident in shallow bores (e.g. P7) located directly above or very close to longwall panels. Drawdown from neighbouring mines to the northeast, east and southeast does not appear to have impacted the Tahmoor site.

Currently, and over the last 10-20 years, inflows at Tahmoor and Tahmoor North have been around 2-4 ML/d, with some short-term peaks outside of this range. Following any mining at Tahmoor South, significant hydraulic vertical gradients will be created, and groundwater discharge into the Tahmoor South workings will become an important component of the water balance.

### 3.10.3 HYDRAULIC PROPERTIES

Across all formations, permeability has a general trend of decreasing with depth, except for a step change around the Bulli Seam (see **Figure 3-30**). Based on the trend(s) with depth, the hydraulic conductivity measurements from the site indicate that the rock units can be set into three broad groups:

- Hawkesbury Sandstone is relatively permeable, with secondary porosity from both natural porosity, such as joints and bedding planes, and subsidence induced fracturing above longwalls, contributing heavily to its ability to transmit water;
- Narrabeen Group strata are relatively tight formations, which are less permeable than the surrounding strata, especially the Hawkesbury Sandstone; and.
- the Illawarra Coal Measures are slightly more permeable than the overlying Narrabeen Group.

The Hawkesbury Sandstone and Bulgo Sandstone have the greatest potential as ‘aquifers’, although the Bulgo Sandstone exhibits a wide range of permeability based both on core and packer testing. The Scarborough Sandstone has a much lesser potential to act as an aquifer.

Of the claystone units, all exhibit lower vertical permeabilities (based on core testing) than the neighbouring sandstones, however packer testing does not indicate as much variability. This is possibly because the ‘sandstone’ units, which are typically much thicker than the claystone units, have laminations of siltstone and claystone within them, meaning that core samples taken from these units, and therefore the lithology tested, will be more variable. In the presence of secondary porosity, such as from jointing and bedding planes, packer testing is less affected by such differences in lithology because of the dominance of flow through this secondary porosity at the larger scales over which packer testing is effective.

Packer testing is considered more reliable for characterising horizontal hydraulic conductivity, while core testing of vertical permeability is considered a good guide to characterising the lower bounds on vertical permeability.

Sands in the upper horizons of alluvial deposits at the Thirlmere lakes will have, by implication, relatively high permeability. However, the sandy clays which seem to dominate the rest of the alluvial sequence will be far less permeable.

The only geological structures within the Study Area that are known or thought to act as conduits to flow are the Nepean Fault (high confidence of this behaviour, based on observations regarding inflows to Tahmoor North), and possibly in parts of the T2 fault (within Tahmoor LW16). This is based on the discussion in Section 3.8.8.

Other mapped faults have been encountered during mining, with no observable increase in inflow. Thus, most of the faults in the area are thought to act as barriers to flow, emphasising that the conceptual model is not that they are impermeable, just less permeable than most of the surrounding rock mass.

Some storage properties have been measured at the Tahmoor site. Calculations presented in Section 3.8.6 indicate relatively low specific yields of about 1.5% for the Hawkesbury Sandstone and lower for other rock units, and specific storages in the range 5E-7 to 5E-6 $m^{-1}$.

### 3.10.4 IMPACT OF MINING ON OVERBURDEN AND THE GROUNDWATER REGIME

Only a brief discussion of the key terms and concepts, as we have applied them to the hydrogeological conceptual model and subsequent groundwater flow modelling, is provided here. Refer to SCT (2013), SCT (2014), PSM (2017), Galvin (2017a) and various PAC reports (e.g. PAC, 2010) for a more complete description.

Forster and Enever (1992) carried out studies at NSW mines that used both pillar and longwall extraction methods. They developed a conceptual model to describe a sequence of deformational zones (as seen in **Figure 3-35**) that exists above both the longwall *and* pillar extraction areas. Given the need for simplification to assist in conceptualisation, these are described and drawn as zones, but in reality it is likely that the zones occur as a continuum. The conceptual zones, as have been adopted in this study to describe and then simulate the changes that occur to the geological strata around the Tahmoor Mine, are:

- the caved zone (note that this also includes the 'mined zone', which is the extracted coal seam);
- the fractured zone, consisting of:
  - a lower zone of connective-cracking; and
  - an upper zone of disconnected-cracking;
  - the constrained zone; and
  - the surface (cracking) zone.

HS also consider a zone underlying the goaf, where unloading of 'floor' strata causes some deformation (Meaney, 1997 and Karacan *et al*, 2011). We have termed this deformed "floor" strata.

The rocks in the connective-cracking part of the fractured zone will have a substantially higher vertical permeability than the undisturbed host rocks. This will encourage groundwater to move out of rock storage downwards towards the goaf. At the very top of the fractured zone, where cracking becomes disconnected, the vertical movement of groundwater will be enhanced but should not be significantly greater than under natural conditions. This is consistent with observations by SCT (2014) at the HoF hole, where it was clear that a downward gradient existed in the lower Hawkesbury Sandstone, but there was neither the connectivity nor gradient strong enough to alter groundwater levels to any observable degree within the Hawkesbury Sandstone.

Depending on the height of connected and disconnected fracturing (which are dependent on the width of the longwall panels, cutting height and the depth of mining) and the presence of low permeability lithologies, there can be a zone of 'disconnected' fracturing (or a 'constrained zone') in the overburden that acts to mitigate the upward migration of depressurisation. Rock layers are likely to sag without breaking, and bedding planes are likely to open. As a result, some increase in horizontal permeability could still be expected, but the less frequent vertical fracturing will lead to disconnection in the that direction, meaning there is little change in vertical permeability.

In the surface zone, near-surface fracturing can occur due to horizontal tension at the edges of a subsidence trough. Cracking at the surface will typically <20 m; McNally and Evans (2007) stated this is usually but not always transitory. Water loss from surface features into the cracks will not continue downwards towards the goaf but return to surface somewhere down-gradient. This has occurred in earlier mining at Tahmoor, e.g. along the Bargo River and Redbank Creek. The likelihood of future occurrences of surface cracking and upsidence above Tahmoor South are discussed in the assessment by MSEC (2018), including deformation above and off-set from the longwall footprint. Leakage of surface water into the surface zone can result in the water quality of any re-emergent water being inferior to that of surface flow in an undisturbed environment (McNally and Evans, 2007). Surface water impacts of the project are discussed and assessed in HEC (2018b).

The strata movements and deformation that accompany subsidence will alter the hydraulic and storage characteristics of aquifers and aquitards. As there will be an overall increase in rock permeability, groundwater levels will be reduced either due to actual drainage of water into the goaf or by a flattening of the hydraulic gradient without drainage of water in accordance with Darcy's Law.

As water moves from a level near the top of the fractured zone down toward the mine void, and as result of an increasing ability for the deformed and fractured rock mass to drain in this direction, somewhere within the fractured zone groundwater pressures will reduce towards atmospheric pressure (that is, there is zero pressure head). This does not mean that these areas are dry, simply that there is free drainage through the cracks and fractures, and that recharge from above is insufficient to match downward drainage. Although as Galvin (2017b) notes that these are not universally accepted, empirical models can be used to estimate the vertical height to which this occurs (e.g. HS, 2016; Galvin, 2017b). At this mine both the Ditton Geology Model (Ditton and Merrick, 2014) and Tammetta (2013) method appear suitable (**Section 3.9.1**). Based on the conclusion of SCT (2014) [at Longwall 10A] and SCT (2013) [geotechnical modelling for Tahmoor South] the Tammetta method has been used in this project.

The representation of the zone of enhanced permeability, i.e. the caved, fractured, and constrained zones, above the mine void/goaf on **Figure 3-37** is meant to represent a 'likely' case at Tahmoor South, and not the most extreme case. Calculation of the likely height of fracturing above the Tahmoor South longwalls is provided in SCT (2013), and this indicates that for 300 m longwall panels, a 2.4 m mined seam thickness and a 400 m depth of cover, the height to which the fractured zone will extend is around 200 m above the seam. This would place the top of this zone somewhere in the mid-upper Bulgo Sandstone, and into the Bald Hill Claystone or even the base of the Hawkesbury Sandstone in the southernmost panels of the Tahmoor South Mine. Some further analysis, by HS, of the likely height of fracturing is presented in the numerical modelling chapter (see **Section 4.6**).

# 4 GROUNDWATER SIMULATION MODEL

The following subsections describe the groundwater flow model developed for impact assessment purposes, including the software chosen, the model extent and layering, the types of boundary conditions used to represent the significant hydrogeological processes, and then details of the ‘history-matching’ or calibration of model output to observed water levels, baseflows and mine inflows.

## 4.1 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the National Guidelines sponsored by the National Water Commission (Barnett *et al*., 2012). These guidelines build on the 2001 MDBC groundwater modelling guideline, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The 2012 guide has replaced the model complexity classification of MDBC (2001) by a "model confidence level". The Tahmoor South model may be classified as Class 2 (effectively “medium confidence”), which is an appropriate level for this project context. The 2012 guidelines do not prescribe a confidence level for particular purposes. The guidelines suggest elements of the modelling that indicate a different confidence level, such as data quality, data availability and complexity of processes to be simulated. An assessment of this model, using the example template provided in Barnett *et al*. (2012) is provided in Appendix E, where a green star indicates a valid characteristic or indicator for the model used in this study. This suggests a model with confidence level 2 to 3, based on the various factors suggested by Barnett *et al*, (2012). However, considering the model on the whole and the objectives of the study, a confidence level of 2 is more appropriate.

Under the 2001 modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. The earlier guide (MDBC, 2001) describes this model type as follows: “*Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.”*

Initially numerical modelling was done using MODFLOW-SURFACT (written by HGL), however given the desire to add local-scale mesh refinement around Thirlmere Lakes, HS used an alternative software. Numerical modelling has been undertaken using MODFLOW-USG, which is distributed by the United States Geological Survey (USGS). MODFLOW-USG is a relatively new version of the popular MODFLOW code (McDonald and Harbaugh, 1988) developed by the United States Geological Survey (USGS). MODFLOW is the most widely used code for groundwater modelling and has long been considered an industry standard.

MODFLOW-USG represents a major revision of the MODFLOW code, in that it uses a different underlying numerical scheme: control volume finite difference (CVFD), rather than traditional MODFLOW’s finite difference (FD) scheme. ’USG’ is an acronym for Un-Structured Grid, meaning that MODFLOW-USG supports a variety of structured and unstructured model grids, including those based on cell shapes including prismatic triangles, rectangles, hexagons, and other cell shapes (Panday *et al*., 2013). The CVFD method also means that a model cell can be connected to an arbitrary number of adjacent cells, which is not the case with a standard FD scheme.

HS have not used the fully flexible mesh capability (i.e. irregular polygon cells) but have used a structured rectangular finite-difference grid, with one exception. MODFLOW-USG has allowed a finer grid resolution to be focused solely on Thirlmere Lakes (**Figure 4-1**). A second advantage of MODFLOW-USG is that cells that are not required in the model may be omitted rather than deactivating cells or retaining "dummy" layers (e.g. for layer pinch-outs).

Additionally, MODFLOW-USG is able to simulate variably saturated flow and can handle desaturation and re-saturation of multiple hydrogeological layers without the “dry cell” problems of traditional MODFLOW. This is pertinent to models which simulate layers, such as surficial regolith, which frequently alternate between unsaturated and saturated, as well as the depressurisation and desaturation that occurs due to mine excavation. Traditional versions of MODFLOW can handle depressurisation and desaturation to some extent, but model cells that are dewatered (water level reduced below cell bottom) are replaced by “dry” cells, which can interfere with the simulation of various processes and cause model instability

The model complexity is adequate for simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the proposed development. This is based on the availability of groundwater level data, mine inflow data and stream flow/baseflow data, and the use of this to calibrate the numerical model while constraining the input hydraulic properties (namely hydraulic conductivity) with the packer and core testing datasets.

The solver used in the simulation is the MODFLOW-USG Sparse Matrix Solver (SMS) (Panday *et al*., 2013), which employs Newton Linearization for the implementation of Upstream Weighting which is required for dealing with variable saturation. In addition, through the SMS package we employ the unstructured pre-conditioned conjugate gradient (PCGU) solver of White and Hughes (2011). Head close tolerance (HCLOSE) is set to 0.04 m.

## 4.2 MODEL TIMING

The driver behind model timing, for both calibration and predictive runs, is the historical and proposed schedule for operations at Tahmoor North and Tahmoor South, while considering the operation of neighbouring mines, as described in Section 2.4 and **Figure 2-3**. Operations at Tahmoor started over 30 years ago. A steady state calibration stress period was used to initialise the model using a ‘natural’ condition, using average climate and no mine stresses.

The subsequent transient stress periods simulate mining stresses at Tahmoor and neighbouring mines from 1980 to mid-2018. Rather than adopting, for example, monthly or quarterly stress periods, this model uses stress periods based on longwalls activating or ceasing, as per the schedule in **Figure 2-3**. Most stress periods are around 180 days (6 months), but vary from 20 days to over a year long. There are 69 stress periods in the calibration model (the initial steady state period plus 68 transient stress periods), and 63 in the predictive period.

Of the 131 transient stress periods, 113 periods have 4 time steps, and then the longer or more numerically difficult stress periods have been assigned with 5, 6, 8 or even 11 time steps to aid the solution. Time step lengths are increased by a constant factor 1.414 throughout the simulation.

## 4.3 MODEL LAYERS AND GEOMETRY

**Figure 4-1** shows the extent of the groundwater model domain which extends 52.9 km from west to east and 61.2 km from south to north, covering an area of approximately 3,237 km$^2$.

Impact assessment models developed for an EIS require a reasonable amount of detail to be incorporated at an appropriate scale. This includes a reasonable approximation of longwall dimensions (in the case of Tahmoor Mine, these range from to 170 to 300 m wide), some representation of development headings and roadways, which are typically less than 30-50 m, as well as providing detail around small lakes, watercourses and bores. Additionally, the model must be also used to carry out an assessment of the cumulative impacts of Tahmoor and the mining at BSO, Dendrobium, Russell Vale and Cordeaux coal mines.

Initially we started with a uniform cell size of 100 m x 100 m, meaning that the model domain is discretised into the following dimensions: 16 layers, 612 rows and 529 columns. Later in the project, the decision was made to refine the mesh around Thirlmere Lakes and upper Blue Gum Creek. This was done using the quadtree refinement available in MODFLOW-USG. This has resulted in 25 m cells around the lakes, as shown in the inset on **Figure 4-1**. There are now 2,877,930 active cells in the groundwater model.

The stratigraphic sequence is represented by the 16 model layers outlined in **Table 4-1**. The layering is based on the conceptual hydrogeology described in Section 3.7.

The lateral extent and the discretisation in the lateral and vertical planes required by the objectives of the study mean that this model is large, even very large for a groundwater model. This has significant implications for the practicality of the model, namely in terms of data management and data processing, model run times and disk space requirements.

Within the Tahmoor mine lease area, geological surfaces were extracted from the Tahmoor geological resource model produced by MBGS (2013). Additionally, bore data, interpreted by MBGS was also provided. Initially, this bore data was used to understand the likely thickness of the important stratigraphic units within the Study Area. A simple summary of the interpreted thickness of such units within the various local bores is presented in Appendix A.

Geological surface information for surrounding mines was extracted from data and modelling made available by Illawarra Coal (South32), specifically for:

- BSO mine, geological surfaces from the groundwater model (Heritage Computing, 2010);
- Dendrobium mine, geological surfaces from the groundwater model (Coffey Geotechnics, 2012; HS, 2014, 2016);

The regional scale geological surface mapping of the base of the Narrabeen Group (essentially the top of the Bulli Coal Seam) in the Southern Coalfield Geological Map (Moffitt, 1999), as digitised by HS, was also used in constructing the modelled geological surfaces beyond the extent of the various mine-related geological models provided.

All interpolation was carried using the ArcGIS 'Topo To Raster' tool, which is based on a spline interpolation method, and allows interpolation from multiple datasets, including multiple bore point input files, the XYZ points from the mine-scale geological model (MBGS, 2013) and polyline contours (from published data – Moffitt, 1999, or hand-drawn for this study).

The Southern Coalfield mapping of outcrop geology was used to constrain the subsurface extent of each modelled hydrostratigraphic unit as much as possible, and to define the elevation of the relevant units where they outcrop by combing the outcrop mapping with the DEM (see Section 3.1 for details of the DEM created for this project). Note that in some areas the geological mapping is quite detailed such as along the Illawarra Escarpment, however along the Nattai and other gorges to the west of Tahmoor Mine, the geology is more simplified. This includes the use of "Narrabeen Group" in the mapping, rather than definition of the Bald Hill Claystone, Bulgo Sandstone and other units within the Narrabeen Group. This, combined with the high topographic relief in these areas with gorges of 50, 100 m or even greater depth, means that there can be significant error in the elevation assigned to one or more geological layers in these areas.

### Table 4-1 Stratigraphic Framework and Model Layer Assignment

| LYR | LITHOLOGY / STRATIGRAPHY | MEAN THICKNESS (m) | LUMPED UNITS | COMMENT |
|---|---|---|---|---|
| **1** | Alluvium / basalt / Wianamatta Formation / Hawkesbury Sst | 30 | Alluvium, basalts, volcanic intrusion at surface, Wianamatta Formation (WMFM) or outcropping Hawkesbury Sandstone (HBSS). | |
| **2** | Wianamatta Formation / Hawkesbury Sst | 40 | WMFM / HBSS | WMFM if WMFM extends beneath alluvium or basalt, otherwise HBSS. |
| **3** | Hawkesbury Sst (lower) | 55 | HBSS | |
| **4** | Bald Hill Claystone | 20 | BHCS | |
| **5** | Bulgo Sandstone | 55 | BGSS | |
| **6** | Bulgo Sandstone | 55 | | |
| **7** | Stanwell Park Claystone | 13 | Stanwell Park Claystone (SPCS) | |
| **8** | Scarborough Sandstone | 12 | Scarborough Sandstone(SBSS) - upper | |
| **9** | Scarborough Sandstone | 12 | Scarborough Sandstone(SBSS) - lower | |
| **10** | Wombarra Claystone | 19 | Wombarra Claystone (WBCS) | . |
| **11** | Coal Cliff Sandstone | 1 at Tahmoor, otherwise 20 m | Coal Cliff Sandstone (CCSS) / WBCS | Where CCSS absent, this layer represents the lower 1 m of Wombarra Claystone. |
| **12** | Bulli Coal seam | 2.2 | | |
| **13** | Loddon / Lawrence Sandstones | 40 | | |
| **14** | Wongawilli Coal seam | 5 | This based on total coal ply thickness added on to the base of the lower Wongawilli, rather than total thickness from Wongawilli top to bottom. | |
| **15** | Kembla Sandstone | 10 | | |
| **16** | Older units | 100 | Assumption of 100 m for underlying strata; mainly lower Permian Coal Measures and Shoalhaven Group | |

Bore data, usually from the NSW government's Groundwater Works/Pinneena database, but also from various historical mineral exploration bores, has been used to populate elevations and thicknesses away from the mines. Data is very sparse to the west of the Tahmoor Mine, mainly because much of that area is undeveloped and within National Park.

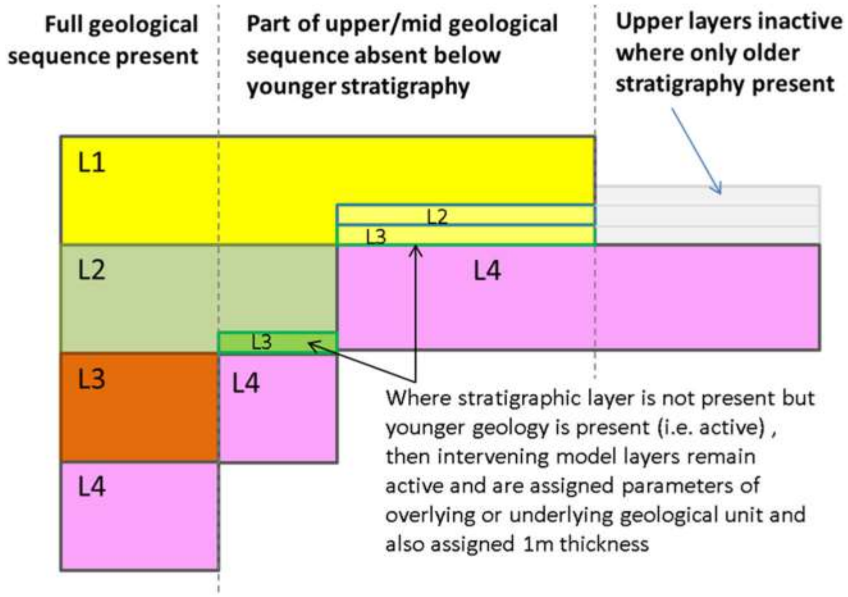
After the DEM (ground surface), the top of the Bulli Coal seam was the next surface produced given that it is the one which Tahmoor Coal and the other Bulli seam mines focus on, and also because of the availability of the regional structure contours from Moffitt (1999). The thickness of the Bulli Coal seam was then extrapolated from the Tahmoor Mine geological resource model, and the Appin and Dendrobium geological models' seam thickness data. All other layers were then built above and below the Bulli Seam.

The resulting regional geological model is presented (as isopachs) in Appendix F. Minimum model layer thickness was set to 1 m for all layers, with the exception of Alluvium (layer 1), which was assigned a minimum thickness of 5 m. Some further comments regarding specific layers follows here:

- The thickness of alluvium and basalts (both in layer 1) was mapped across the Study Area by interpreting the presence of unconsolidated material or basalts in bore logs from the Pinneena bore database. Some bores situated outside of mapped basalt and alluvium/colluvium (based on the outcrop geology - **Figure 3-7**) indicated the presence of unconsolidated material or basalt. These have been ignored.
- The thickness of the alluvial deposits at Thirlmere Lakes has been based on both available data and commentary in Section 3.7. A maximum of 50 m has been adopted.
- The Wongawilli Coal seam is made up of multiple plies, and at Tahmoor the coal thickness has been calculated and added to the mapped floor of the Wongawilli seam, as the floor is more easily picked in logs than the roof. This means that the modelled roof of the Wongawilli lies a few metres below the top of the uppermost mapped Wongawilli Coal ply[10].
- The Coal Cliff Sandstone is present in the eastern 'half' of the Study Area, such as at Appin and Dendrobium mines, but absent at Tahmoor. The subcrop extent is reasonably well defined by Tahmoor and Appin bore data, however away from these areas, the extent of this unit it assumed. It is expected that it simply grades into the lower part of the Wombarra Claystone, and is lithologically indistinguishable from the Wombarra Claystone in this area.
- Layers have typically been carried through any mapped igneous intrusions, including the large sill at the southern edge of the Tahmoor South Project area.

It should be noted that all MODFLOW layers are fully present across the active model area, except in the case where the geological layer is no longer present, where it has been eroded away or not deposited, in which case it is inactivated. The exception to this is where a stratigraphic unit is absent but overlying and underlying stratigraphic units are present. In this case MODFLOW layers are passed through the top of the first 'active' underlying geological layer. In this case the model layer is assigned a nominal 1 m thickness and given the properties of that underlying geology. This is shown in the following sketch.

[10] A ply is a thickness or layer within a sequence of laminated material (e.g. a coal seam, or timber plyboard). The Wongawilli Seam consists of multiple thin coal layers or plies.




The sketch only uses 4 model layers as an example, rather than the full 16 layers of the Tahmoor South groundwater model.

On the whole this approach allows each layer to represent a single hydrogeological unit, so that impacts on specific hydrogeological units can be readily extracted from the MODFLOW model output files. The exception is model Layer 11, which is Coal Cliff Sandstone in the 'east' or the lower 1 m of the Wombarra Claystone in the 'west'.

A representative east-west model cross-section is presented in **Figure 4-2** for model row 320 (GDA zone 56, Northing: 6203050) passing through the Tahmoor South Project.

The model domain has been designed to be large enough to prevent significant boundary effects on model outcomes associated with mining-related stress on the groundwater environment because of mining at Tahmoor, Tahmoor North and Tahmoor South. The model extends east and west to the edge of or beyond the extent of the Bulli Coal seam. This is defined by where the Bulli Coal outcrops along the Nattai River in the west and along the Illawarra Escarpment in the east (see **Figure 3-7**). The model extends far enough north and south, where there are not obvious geological and hydrological controls to allow likely stresses, i.e. the drawdown caused by operation of the Tahmoor Mine, to dissipate without intercepting model boundaries.

## 4.4 BOUNDARY CONDITIONS

The model domain and boundaries shown in **Figure 4-1** have been selected to incorporate any potential receptors (i.e. surface water bodies) that could be adversely affected by mining. Following is detailed information on each of the modelled boundary conditions.

### 4.4.1 INITIAL WATER LEVELS

Although not strictly a boundary condition, a description of the source of initial heads is provided here. During steady state calibration, initial water levels were taken, at first, from the top of Layer 1, then the heads from subsequent calibration runs were used, speeding up model run times and reducing mass balance errors.

Transient model runs used initial heads taken from the relevant steady state run (i.e. the steady state run that had the same set of hydraulic conductivity and recharge.

### 4.4.2 WATERCOURSES

Creeks and rivers throughout the model domain were modelled using MODFLOW's River (RIV) package. This package allows a head (or depth of water) to be set, and this has been varied based on the inferred behaviour of each watercourse. Headwater streams have no head of water in them and therefore can gain baseflow but not lose flow. Larger, downstream rivers have a greater head applied, and so can gain or lose flow to/from the groundwater system.

Stream bed elevations were parameterised as the value of the 100 m DEM, which was built considering the minimum observed elevation in each cell. This was based on 2013 LiDAR survey provided by Tahmoor Coal, or taken from the 1 second SRTM Derived Hydrological Digital Elevation Model (DEM-H) version 1.0 (ANZLIC identifier: ANZCW0703014615), available from Geoscience Australia.

Stream bed hydraulic conductivity was set to 0.02 m/day on sandstone outcrop and stream bed thicknesses were set to 1 m.

Use of the River package, rather than using Drains, means that creeks and rivers remain a potential source of water to the underlying porous rock aquifers, which is in agreement with the data analysis and conceptualisation presented in Sections 3.8.7 and 3.9.

Stream channel widths were set considering:

- Geomorphological survey of the Tahmoor South area by Gippel / Fluvial Systems (2013), who attributed channel width and bankfull width at 248 sites;
- Aerial photos and GIS mapping of Thirlmere Lakes; and
- Field inspection of a small number of sites.

Where specific geomorphological data was not available, simple rules for attributing stream width were used, based on the approximate 'order' of the streams within the model This is whether a stream represents a minor creek, a larger creek or a major river. Widths varied from 4-6 m for minor creeks to 10-20 m along the larger rivers, such as the Bargo and Nepean Rivers. These widths were based on the width data obtained from Gippel / Fluvial Systems (2013).

### 4.4.3 LAKES AND RESERVOIRS

There are small natural lakes, such as Thirlmere Lakes, and larger, man-made reservoirs (see **Table 3-3**) within the model domain. These two simple classes of waterbody have been represented as follows:

- Thirlmere Lakes: using the MODFLOW River package. Because the record of historical lake levels is only short (i.e. other than estimates from aerial photos etc.), lake stages were set at constant levels. These were set at an estimated 'median' level as follows: Gandangarra (304.6 mAHD), Werri Berri (302 mAHD), Couridjah (302.5 mAHD), Baraba (304.5 mAHD), and Nerrigorang (301 mAHD). The bed conductance was then modified based on the maximum loss rate (to groundwater) as estimated from the surface water model (HEC, 2018b), resulting in bed conductances of 0.6-1.25 $m^3$/d/m. These were lower than initially set but are in line with the conceptualisation that while parts of the lake bed are sandy, there are fines and organics, which can restrict bed permeability (Section 3.7.1).

  Note that once the model had been calibrated, a series of models were run with differing stages (i.e. lakes that are empty, moderate, full) for the Thirlmere Lakes to account for this variability – this is described at the end of Section 5.2.1.

- Reservoirs are simulated using the MODFLOW River package. These are set with non-time varying elevations, as set out in **Table 3-3** and **Figure 4-1**, and a conductance of 2 $m^2/d$.

### 4.4.4 RECHARGE

Recharge to the groundwater system was used as a model calibration parameter over a range of zones based on the dominant geological outcrop and long-term average rainfall (**Figure 4-3**).

These zones are based on comparison of recharge rates in the alluvium and Hawkesbury Sandstone (Section 3.8.4) and given the relative abundance of the Wianamatta Shale at outcrop, a zone has been set for this geology as well. Other outcrop geologies, such as the Bald Hill Claystone and Bulgo Sandstone, are likely to experience lower recharge rates than the Hawkesbury Sandstone. However, given the relatively small areas of outcrop of these units around Tahmoor, they have been included in the Hawkesbury Sandstone zones.

Recharge values were initially set in line with the recharge values quoted in the NOW, 2011a (see Section 3.8.4). Later the evidence from steady state calibration and the analysis bore hydrograph fluctuation and baseflow yields indicated that recharge needed to be reduced, as per the discussion in Section 3.8.4.

Modelled transient recharge for all recharge zones follows the approach outlined in the following paragraphs, but values were scaled according to the calibrated steady state model's average annual recharge for each zone.

For the transient calibration model, recharge was distributed in time by comparing total rainfall, the potential evaporation (based on a repeated monthly cycle of the data presented in Section 3.3) and calculating the rainfall excess. Than some empirical weightings have been applied to allow months with a higher excess to result in a greater proportion of infiltration. Furthermore, infiltration was then decayed, representing a smoothed release from the soil store, which is not explicitly represented in the groundwater model, to the underlying aquifer. The decay factor applied was 0.7, meaning that 70% of the infiltration is released within the same month it arrives in the soil zone, followed by 70% of the remainder in the next month. On reflection, this decay/smoothing was probably unnecessary given the length of the stress period but is not considered to have an adverse effect on model predictions.

The resultant trend in recharge is presented in **Figure 4-4**. This method, while not as complex as methods of rainfall-runoff-recharge estimates results in a reflection of transient soil moisture deficit (by comparing rain and PE). The monthly totals were then aggregated into the model stress periods, as per the timing discussed in Section 4.2.

### 4.4.5 EVAPOTRANSPIRATION

Evapotranspiration was simulated using MODFLOW Evapotranspiration (EVT) package. The extinction depth applied to MODFLOW for the primary vegetation or land use zones has been estimated at 0.8-1 m for urban / grassed / pasture areas, and 3 m for trees. The spatial extent of these broad vegetation types was based on the National Scale v4 land use mapping by ABARES[11]. The potential rate of evapotranspiration from the water table has been set at 183 to 365 mm/yr – less than the overall potential rate of evaporation as measured by BoM (Section 3.3), noting that evapotranspiration from the water table occurs alongside evapotranspiration from the soil zone and surface.

[11] http://www.agriculture.gov.au/abares/aclump/land-use/data-download

#### 4.4.6 REGIONAL GROUNDWATER INFLOW AND OUTFLOW

Those edges of the model domain where it is expected that groundwater will be transmitted in or out of the model domain, primarily in the west, north and south, were assigned as MODFLOW General Head Boundaries (GHBs), as shown on **Figure 4-1**. This allows for groundwater flow down-basin. GHBs simulate groundwater flow into and/or out of the model domain according to a specified head and conductance.

Specified GHB heads were iteratively assigned considering observed water levels in particular areas on the model boundary, for example on the southern boundary of the model, and on the modelled steady state heads during the calibration process. The assigned heads are constant through time, being far enough from the area of interest (Tahmoor Mine) that any variation in heads at these boundaries is insignificant for the objectives of this study. This is in accordance with guidance provided in Barnett *et al*, 2012.

GHB conductances were assigned based on cell dimensions (approximate layer thicknesses and widths), calibrated hydraulic conductivities of each model layer, and the assumption of a 50 m (half model cell) length dimension. As such, conductance values were typically in the range 0.002 to 7 $m^2$/day.

As lateral flow through aquitards and other thin layers is necessarily low, GHBs were only set in the following model layers:

- Hawkesbury Sandstone (Layer 2);
- Bulgo Sandstone - upper (Layer 5);
- Scarborough Sandstone - lower (Layer 8);
- Bulli Coal seam (Layer 12);
- Kembla Sandstone (Layer 15); and
- Basement (Layer 16).

#### 4.4.7 GROUNDWATER USE

Existing groundwater bores registered with CL&W and those of the Tahmoor bore census (Section 3.8.1; Geoterra, 2013a), as shown in **Figure 3-12**, were not included in the model. This is because of the uncertainty around the actual extraction rather (rather than the entitlement). Ultimately this means that the model predicts only the effects of mining in the 'cumulative impact' scenarios, and does not account for bore pumping effects, on features like GDEs, watercourses.

#### 4.4.8 NO FLOW BOUNDARIES

**Figure 4-1** shows grey areas, which are the inactive areas. These are typically in each of the corners of the model. Within each layer there are some areas which are inactive, which are generally where the various modelled hydrostratigraphic units are eroded away or not deposited at outcrop, where older units are at outcrop. In addition, the eastern area towards and including the Metropolitan Mine has been excluded arbitrarily as activities in this area would offer no incremental cumulative effect. It was assumed that the cumulative impact assessment to be carried out for the Tahmoor South Project would not need to consider mines located beyond the nearest neighbouring mine in a particular direction. In the case of Metropolitan mine, the Appin/BSO mine lies between the Tahmoor and Metropolitan mines, and so groundwater drawdown caused by Metropolitan is unlikely to have any additional effect on groundwater resources near Tahmoor beyond and above any impact already caused by the Appin/BSO mine. Hence the 'no flow' boundaries are drawn to include the nearest neighbouring mines, but not beyond those.

Based on these no flow boundaries, the active model area is 1,730 km$^2$. There are 2.9 million active cells in this model – on reflection this is too many, but at the time that the model mesh was originally designed, HS were unsure of the detail required for cumulative impact assessment requirements and erred on the side of more detail. The implication of the model size and long run times meant that uncertainty analysis had to be limited (Section 4.10).

#### 4.4.9 MINE WORKINGS

The historical and proposed underground mining and dewatering activity at the following mines was defined in the transient historical and predictive models using MODFLOW Drain cells within the mined coal seams, mainly the Bulli Coal seam, but also the Wongawilli Coal seam in the case of Dendrobium:

- Tahmoor South – this Project;
- Tahmoor and Tahmoor North;
- Appin, West Cliff and Tower ('Bulli Seam Operations')
- Russell Vale (formerly Bellambi/NRE No.1);
- Cordeaux; and
- Dendrobium.

The mines were simulated in the transient and predictive models, as shown in **Figure 2-3**.

Modelled drain elevations were set to 0.1 m above the base of each worked seam. These drain cells were applied wherever workings occur and were progressed through temporal increments in the transient model setup. A drain conductance value of 100 m$^2$/day was applied for all longwalls, roadways and development headings.

After goaf areas were mined out, Drains were inactivated in both the panel area and the neighbouring gate roads. Drains representing mains and roadways required for the continued operation of the mine were maintained as active until the end of their operational life, which could be as late as the end of the Tahmoor operation, until 2022 in Tahmoor North, or until around 2040 in Tahmoor South.

Hydraulic parameters were also changed with time in the goaf and surrounding enhanced permeability zone (EPZ) directly after mining of each longwall panel (see Section 4.6 for details), whilst simultaneously activating drain cells along advancing development headings. The development headings were activated in advance of the active mining and subsequent subsidence, either one stress period ahead of active mining or based on a schedule provided by Tahmoor Coal. Although the modelled coal seam void should be dominated by the MODFLOW Drain mechanism, the horizontal and vertical permeabilities were increased, as in Section 4.6, to simulate the highly disturbed nature of materials within the goaf.

Appin and Dendrobium operations were simulated with as detailed a mine schedule as was available for this purpose, while for the other mines longwall and development heading Drain cells were left on to the end of the predicted mine life after they were initially activated. This should lead to a conservative estimate of their impact for the cumulative impact assessment part of this study.

## 4.5 HYDRAULIC PROPERTIES

The modelled hydraulic zones and values are reflective of the conceptual (and geological) model. The distributions of hydraulic properties in each model layer are shown in Appendix G, while the zones and their calibrated values are presented in **Table 4-2**.

The zones changed very little during calibration, except for the zonation of faults. This was based on whether certain faults were to be treated as conductive or as barriers, and if so, how conductive or impermeable (see Zones 30 and 31 in **Table 4-2**).

Previous studies and investigations within the region (e.g. Heritage Computing, 2010 – BSO/Appin, Heritage Computing, 2012 - Tahmoor South ('Bargo') Pre-feasibility, and various assessments at Dendrobium), in conjunction with core and packer testing data collected for the Tahmoor South project, provided the initial basis for chosen hydraulic property parameters used within the modelling component of this project (refer to Section 3.8.6).

The hydraulic properties in Table 4-2 are the calibrated hydraulic conductivities for the various stratigraphic units incorporated into the groundwater model. Although automated sensitivity was used in the steady-state calibration process, care was taken to ensure that the hydraulic properties reflect the measured and estimated ranges for each of the strata types, as discussed in Section 3.8.6. The calibrated parameters are compared to measured horizontal (packer test) and vertical (core test) results on **Figure 4-5**. This figure shows that the modelled parameter values are well constrained by the observed dataset.

The parameters used to define the fractured zone, constrained zone etc. in early model runs were calculated based on the geometry of the hydro stratigraphic layers and the host permeability, which was combined into a user-specified 'ramp function' (see Section 4.6.1), but this ramp function was then subject to calibration. This calibration of the hydraulic properties within the various zones of deformation was performed in the effort of matching groundwater inflow to the underground mine and hydraulic heads around the mine.

Coarse zones of hydraulic properties, usually a single zone per stratigraphic layer, are a simplification of reality. However, the large size of this model, the use of MODFLOW-USG Time-Varying Material properties ('TVM') package to represent enhanced permeability above longwalls, and the resultant model run times (transient calibration model takes about 36 hours to run), the use of more parameters in calibration was considered impractical.

Table 4-2 Calibrated Hydraulic Properties by Stratigraphic Unit

| Layer | | Zone | Kx [m/day] | Kz [m/day] | Ss [m$^{-1}$] | Sy |
|---|---|---|---|---|---|---|
| 1 | Alluvium | 1 | 10 | 3.00e-2 | 1.03E-4 | 1.14E-1 |
| 1 | Alluvium – clay rich | 21 | 5.00E-1 | 2.00e-2 | 1.03E-4 | 3.00E-2 |
| 1 | Basalt | 19 | 2.00e-2 | 1.00e-1 | 1.19E-5 | 2.00E-2 |
| 1, 2 | Wianamatta Formation | 2 | 1.50E-2 | 2.80E-4 | 1.02E-6 | 1.06E-2 |
| 1 | Hawkesbury Sandstone - upper | 3 | 1.80E-1 | 8.00E-4 | 6.00E-6 | 1.60E-2 |
| 2 | Hawkesbury Sandstone - mid | 23 | 7.00E-2 | 8.00E-5 | 6.00E-6 | 1.10E-2 |
| 3 | Hawkesbury Sandstone - lower | 24 | 4.00E-2 | 9.00E-5 | 6.00E-6 | 1.10E-2 |
| 4 | Bald Hill Claystone | 4 | 3.00E-4 | 8.00E-6 | 6.00E-6 | 7.00E-3 |
| 5 | Bulgo Sandstone - upper | 5 | 8.50E-2 | 6.00E-6 | 6.00E-6 | 1.00E-2 |
| 6 | Bulgo Sandstone - lower | 25 | 7.5E-3 | 7.00E-6 | 7.00E-6 | 1.00E-2 |
| 7 | Stanwell Park Claystone | 6 | 1.20E-4 | 1.04E-6 | 6.00E-6 | 2.50E-3 |
| 8 | Scarborough Sandstone - upper | 7 | 6.00E-4 | 4.00E-6 | 2.50E-6 | 6.00E-3 |
| 9 | Scarborough Sandstone - lower | 27 | 4.00E-4 | 3.00E-6 | 4.50E-6 | 7.50E-3 |
| 10, 11 | Wombarra Claystone | 8 | 1.20E-4 | 1.00E-6 | 5.00E-6 | 2.00E-3 |
| 11 | Coal Cliff Sandstone | 9 | 2.00E-4 | 8.00E-6 | 4.00E-6 | 6.00E-3 |
| 12 | Bulli Coal Seam | 10 | 7.00E-4 | 3.60E-7 | 7.00E-6 | 8.00E-3 |
| 13 | Loddon, Lawrence Sandstones | 11 | 1.50E-4 | 3.30E-7 | 2.50E-6 | 5.00E-3 |
| 14 | Wongawilli Seam | 12 | 3.70E-4 | 3.70E-7 | 4.00E-6 | 5.00E-3 |
| 15 | Kembla Sandstone | 13 | 1.20E-4 | 6.50E-7 | 2.00E-6 | 5.00E-3 |
| 16 | Lower Permian Coal Measures | 14 | 1.10E-4 | 2.50E-6 | 1.00E-6 | 4.00E-3 |
| 16 | Shoalhaven Group | 15 | 1.00E-4 | 1.00E-6 | 3.06E-6 | 5.00E-3 |
| 1-13 | Igneous intrusion / sill | 20 | 1.00E-6 | 1.00E-7 | 1.02E-6 | 5.00E-3 |
| 1-2 | Hawkesbury Sandstone – artificially high kz to simulate connection between surface (layer1) and mid-HBSS (layer 2) or lower-HBSS (layer3) where upper - or upper and mid-HBSS eroded away | 39-40 | 5.00e-2 | 5.00e-2 | 6.00E-6 | 1.60E-2 |
| 1-12 | Conductive fault (e.g. Nepean Fault) | 30 | 6.00E-3 | 6.00E-3 | Not differentiated from host strata, i.e. if in zone 10, then uses zone 10 S parameters | |
| 1-12 | Conductive fault (e.g. Eastern Fault) | 31 | 9.00E-4 | 1.00E-4 | | |
| 1-12 | Barrier fault (most other faults) | 32 | 5.00E-5 | 7.00E-7 | | |
| Zones may be present in layers other than those mentioned here, but that is to deal with the limitation of MODFLOW requiring layers to be continuous through the model domain. In these areas, layers are typically only 1 m thick. | | | | | Model run: V4TR038 | |

## 4.6 IMPLEMENTATION OF THE ENHANCED PERMEABILITY ZONE

Sections 3.8.6 and 3.9 provide background and conceptual information on the impact of mining on the properties of overburden. In regard to the simulation of the changes to permeability within and above the goaf, we have termed this zone the 'Enhanced Permeability Zone' or EPZ. A schematic of this is shown in **Figure 4-6.**

### 4.6.1 MODEL SIMULATION

The layer definition within the model has allowed each of the two main mined coal seams to be represented individually. Because the target coal seams are model layers 12 (Bulli seam) and 14 (Wongawilli seam – at Dendrobium, which is modelled as part of the Cumulative Impact Assessment), there is flexibility in the model to simulate the fractured zone to various heights. This ensures that the impact of progressive stress and deformation, resulting in caving and fracturing, associated with the progression of longwall mining is adequately represented.

Tahmoor and Tahmoor North longwalls are in the range 170-285 m wide. Tahmoor South mine longwall panels are proposed to be 285 m (Longwalls 106, 107, 201 and 204) or 305 m wide (the remaining longwalls). Calculations of the likely height of the fractured zone ("H") have been based on work by Tammetta (2013). It is acknowledged that Tammetta devised this empirical method to calculate the height of groundwater drainage above the mined seam, rather than the height of the fractured zone, however Tammetta (2014) states: "*H is the height of complete groundwater drainage above a mined longwall panel as proposed by Tammetta (2013), and is the same as the height of the collapsed zone*". Therefore, the use of Tammetta's H is viewed as an appropriate means of estimating the height of connected fracturing within the overburden within this study.

The Tammetta (2013) method has been adopted on a cell-by-cell basis for the groundwater modelling (as shown in **Figure 4-7**), so that the variation in panel width and depth of overburden are accounted for.

The left-hand pane in **Figure 4-7** presents the estimated height of the connected fracture zone, presented as a height above the longwall (coal seam). The calculated height of the fractured zone above Tahmoor and Tahmoor North longwalls varies between 91 and 210 m, with an average and median of 153 and 157 m respectively. The calculated height of the fractured zone above Tahmoor South longwalls varies between 61 and 256 m, with an average and median of 195 and 186 m respectively. As stated previously (Sections 3.9.1 and 3.10.4), these are calculated based on Tammetta (2013) and these values compare well with values for Tahmoor South as modelled in FLAC by SCT (2013) (130-150 and 200 m for panels of 250 and 300 m width respectively).

Across the whole of the Tahmoor mine area, including Tahmoor South, the calculated ratio of height of the fractured zone (h) to panel width (w) is 0.38 to 0.87 (see the middle pane in **Figure 4-7**), with a mean and median of 0.62 and 0.59 respectively. The ratio is greater in the southern parts of Tahmoor South.

This also means that the height to which connected fracturing occurs and the stratigraphy affected by that deformation is variable across the site. As can be seen in the third pane in **Figure 4-7**, connected fracturing above Tahmoor and Tahmoor North longwall panels is estimated to occur up to and within the Bulgo Sandstone (model layer 5). However, within the southern parts of Tahmoor South there is an increased likelihood of connected fracturing extending into the Bald Hill Claystone (green areas in the third pane of **Figure 4-7**) and into the lower Hawkesbury Sandstone (blue areas). This suggests that there may be greater inflow when mining in those areas, and greater effects (i.e. drawdown) in the Hawkesbury Sandstone and near-surface in those areas.

Within the EPZ, the height of the various conceptual zones (**Figure 4-6**) are calculated as follows:

- Connected fractured zone based on Tammetta (2013) – as described above;
- Height of the caved zone was assumed to occur over a height equal to 8 x the mined seam thickness (this is toward the upper end of estimates by Guo *et al*. (2007) and Kendorski (2006) who suggest that this zone is 5-10 and 2-10 times the mined seam thickness respectively; and
- The floor was assumed to be deformed by unloading, resulting in the parting of bedding planes, down to a depth of 30 m below the base of the coal seam.

Profiles based on these calculations from some representative points around the Tahmoor and Tahmoor South area are presented in **Figure 4-8**. Note that these from calibrated model host parameter values and are based on single cell locations within the various mining areas, and that there will be variability in the heights of the deformation zones and the enhanced hydraulic conductivity values across the Project area due to the cell-by-cell nature of the calculations.

**Figure 4-9** presents a summary of the degree of enhancement of vertical hydraulic conductivity (Kv) that has been simulated in the groundwater model. The percentage on the X-axis represents the number of cells within the proposed Tahmoor South mine footprint, including roadways and longwall panels. The figure shows that across most of the model cells above the panels, there is significant enhcanment (>1000 times host Kv) of the layers below Bulgo Sandstone. Within the lower Bulgo Sandstone, about 10% of the mine footprint is simulated as having Kv enhancement of 1000 times (or more), while in the upper Bulgo and Hawkebsury Sandstone the degree of enhancement is simulated as being 3 to 30 times for parts of the longwall footprint, as per the spatial distrubtions in **Figure 4-7.**

It is acknowledged that there is uncertainty associated with the choice or calibration of enhanced permeabilities within the vertical column above and below the longwall areas that constitutes the EPZ. There is some research indicating that some geological units are stronger or less prone to fracturing (e.g. Adhikary and Wilkins, 2012 indicates that some Southern Coalfield claystones may be more effective at limiting water flow into mine workings than previously thought), or may 'self-heal' due to higher clay content. The converse may also be true – other units may be more prone to fracturing. At Tahmoor, investigative drilling and analysis was carried out at bore research into the conditions in the 'Height of Fracture' (HoF) borehole. As described in the Section 3.9.1 fracturing was observed within the Bulgo Sandstone and above the Bald Hill Claystone in the Hawkesbury Sandstone. SCT noted that the water level responses suggested *connected* fracturing only occurring below the Bald Hill Claystone at that longwall, with the possibility that the position of the Bald Hill Claystone compared to the zones of connected and disconnected fracturing being merely coincidental.

**Hydraulic conductivity**

Hydraulic conductivities within the conceptual zones of the EPZ (see **Figure 4-6**) were simulated as follows:

Mined seam as having horizontal hydraulic conductivity enhanced to 10 m/day and vertical hydraulic conductivity enhanced to 1 m/day.

Caved zone horizontal hydraulic conductivity enhanced to 10 m/day while vertical hydraulic conductivity was increased to 0.1 m/day.

In the fracture zone a 'ramp' function or log-linear monotonic function was applied to the fractured zone to estimate the vertical hydraulic conductivity field within this deformation zone. This allows the increased permeability to reduce with height above the goaf, as well as allowing the permeability change to account for variable layer thickness. Limits for the variability were governed by the predicted fracture height and assumed upper and lower bounds on vertical hydraulic conductivity in the fractured zone. Within the fractured zone, horizontal hydraulic conductivity was enhanced by a factor of 3. Horizontal hydraulic conductivity was enhanced by 20% if the cell straddles the boundary between the connected fractured zone and disconnected fracture zone above it. This could be lower than reality – horizontal permeability enhancement is considered as part of the sensitivity runs, specifically the run with a greater height of fracturing (Section 5.2.1).

Similarly, horizontal hydraulic conductivity of the underlying model cells (within Model Layer 13: Loddon Sandstone) was increased by a factor of 2 x the host values. The assumption was made that the unloading effect only affects the upper 30 m of the seam floor strata, and as such the conductivity increase was thickness-weighted accordingly.

**Storage properties**

In one of the sensitivity runs (Section 5.2.1) storage properties (Sy) were also increased in the mined and caved zones. Within the coal seam layer, Sy was set to 0.1 for the longwall areas, based on the fact that rubble from collapsed overburden caves into and partially fills this zone. For the layers within the caved zone (but above the mined seam), Sy was increased according to the extension of the rock mass and increase in porosity due to caving-induced subsidence above each longwall panel. This rock mass extension is due to:

- The creation of a mine void (mined thickness at Tahmoor Mine is typically 2.5-2.9 m);
- Subsidence at ground surface of about half the mine void thickness; and
- The host rock now filling the space between the floor of the mined seam and the new ground surface. This means that calculation of the approximate additional void space within the overburden can be calculated.

The resulting increase in porosity (and Sy) was assigned to the overlying layers by thickness-weighting the deformed and host porosities of the caved and host zones, respectively. The deformed Sy for the heavily disturbed layers above the goaf (mined seam) is approximately 0.06, usually extending through the Wombarra Claystone into the lower Scarborough Sandstone. This is an enhancement of about 10-12 times the host value.

**Development headings**

Development headings and roadways in the Tahmoor underground mine were simulated as having a horizontal hydraulic conductivity of 50 m/d. Vertical hydraulic conductivity for roadways was not changed from the host value. In one of the sensitivity runs (Section 5.2.1) specific yield of these roadways, which remain open and not filled with collapsed strata, was set to 0.4 on the basis that the roadway itself has a porosity of 1, but most of the roadways are around 30-40 m wide within a 100 m wide model cell, which is ratio of 0.4.

**Implementation in the groundwater model**

In order to simulate strata deformation and the enhancement of hydraulic properties above longwalls and within development headings, hydraulic properties were changed using the Time-varying Material properties (TVM) package of MODFLOW-USG (HydroAlgorithmics, 2014). This allows varying property values with time. Fracturing was instigated by altering host properties in accordance with mine progression using ratio multiplier, with the enhanced properties outlined in earlier subsections in Section 4.6.1.

**Other Southern Coalfield mines**

In order to simulate longwall operations at nearby mines, enhanced permeabilities were required for those. Height of fracture calculations and were available from the following studies, and were used for this model without alteration:

- Appin/BSO – model by Heritage Computing, 2010. This was applied to Tower, Appin and West Cliff areas.
- Dendrobium – based on HS experience at that mine; and
- Russell Vale / Bellambi / NRE No.1 – historically primarily used pillar extraction, so no EPZ was simulated. There are some areas of this mine where longwall mining was used, so modelled impacts above this mine are likely less severe than in reality.

## 4.7 MODEL VARIANTS

Both steady state and transient model types were calibrated during this study. In practice the process was iterative. After some initial steady state calibration, transient calibration was performed, then steady state modelling was checked and revised, then finally transient modelling was done again. The 'calibrated' transient models developed for this groundwater assessment are summarised here:

- Steady-state model of pre-mining conditions - used to produce a set of initial water levels as well as horizontal and vertical hydraulic conductivities for use in the subsequent transient calibration model period;
- Transient calibration model (Tahmoor and Tahmoor North operations 1980-2017). Calibration against groundwater levels and mine inflows; and
- Transient predictive model extending through the end of the Tahmoor North operations (~2022), then through the operation of Tahmoor South (2023-2035), and the simulation of post-mining recovery through to 2500 (i.e. >450 years post-mining) (see Section 5).

### 4.7.1 MODEL VERIFICATION

In some modelling studies a process of model verification is carried out after the calibration phase. No formal process of model verification was carried out after transient calibration in this study. All relevant data were used in the steady state and transient calibration phases.

## 4.8 MODEL CALIBRATION

### 4.8.1 APPROACH

The aim of this task was to simulate the mine workings at Tahmoor/Tahmoor North, as well as at surrounding mines, in combination with the transient climate sequence outlined in Section 4.4.4. This process resulted in some modification to initial parameters, using historical heads and mine inflows, and to a lesser extent baseflows, while paying attention to constraining or calibrating the hydraulic conductivities to the observed horizontal and vertical permeability dataset. The process was initially carried out using the first version of the model, in MODFLOW-SURFACT and using both PEST (automated) and manual calibration techniques. Then once the model was converted to MODFLOW-USG only minor changes were made.

During the calibration process, additional water level observations from bores known to be mining-affected were added to the target dataset:

- TBF040c, the 'HoF' borehole (see Section 3.9.1) above Tahmoor Longwall 10A;

- Borehole EAW7–S1936 (at Illawarra Coal's Appin mine), which is adjacent to Appin Area 7 longwalls.

These provided additional targets against which to assess the performance of the model to simulate the mining and longwall-induced deformation processes.

### 4.8.2 MODEL PERFORMANCE AND RESULTS

**Model run time**

The model takes about 36 hours to run the historic calibration period (i.e. to Stress Period 68), which is slow and limits the ability to perform sensitivity or uncertainty analysis. The model solver uses a Head Close criterion of 0.04 m and the Upstream-Weighting method for simulating variably conditions.

**Groundwater Levels - Summary**

A summary of the model's performance against target groundwater levels is presented in **Figure 4-10**.

There were a total of 2168 groundwater level 'targets' from 253 bores/piezometers suitable for calibration over the period 1980-2017. Weightings have been applied to each target to account for perceived data reliability (see end of Section 3.8.3), with 1 being reliable and 0 (zero) being completely unreliable. 1596 of the 2168 targets have a weighting of 1; 222 have a weighting of 0.5; 127 weighted between 0.1 and 0.5; and 223 are weighted as zero. Only those targets with a weighting of greater than 0.1 are shown on **Figure 4-10**.

The calibration statistics for the calibrated transient model are 3.7% Scaled Root Mean Square (sRMS) and an absolute residual mean of 21 m. It should be considered that some of the large residual arise simply because of a mismatch in timing between modelled and observed behaviour, specifically roadway development or possibly because of advanced gas drainage.

The model is a reasonable match to historical data. Inspection of the summary chart (**Figure 4-10**), alongside the statistics, shows that:

- There is a slight skew toward modelled water levels being higher than observed. However, there is still a reasonably uniform distribution of residuals either side of the line of perfect fit;
- 31% of modelled heads lie within 10 m of the observed level, and 73% within 20 m;
- The model tends to overestimate the extent, or possibly just the speed (see below) of drawdown, which is the reason for many of the Layer 12 – BUCO observations, and Layer 8 – SBSS modelled groundwater levels trending down more steeply than the observed data on **Figure 4-10**.

In response to comments by the peer reviewer, calibration statistics for the major stratigraphic units have been calculated and are presented in **Table 4-3**. This table shows increasing error in the deeper layers where there is greater, more severe drawdown and higher gradients around the mine. Reasons for this are discussed below. However, overall, it shows less error in the shallow units which are connected to the surface water features and which host almost all the private bores.

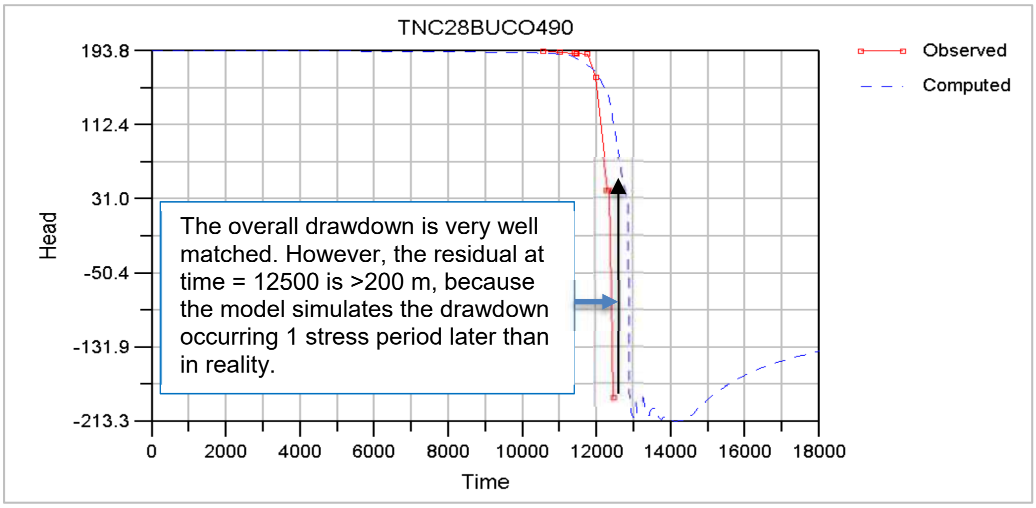
### Table 4-3 Calibration statistics by major stratigraphic unit (model layer)

| Stratigraphic unit | Count of observations | sRMS (%) | Average residual (m) |
|---|---|---|---|
| Upper HBSS, alluvium (Layer1) | 56 | 2.9% | -0.7 |
| HBSS | 160 | 6.2% | 4.7 |
| lower HBSS | 106 | 5.2% | 0 |
| Bald Hill Claystone | 48 | 5.3% | -0.9 |
| Bulgo Sandstone | 119 | 6.3% | -8.6 |
| Scarborough Sandstone | 13 | 9.8% | 5.3 |
| Wombarra Claystone | 32 | 36.0% | -5.6 |
| Bulli Coal seam | 101 | 13.1% | -21.8 |
| Wongawilli Coal seam | 97 | 21.1% | -14.6 |

Source: T:\TAHMOOR\Model\Processing\CalibrationHydrographs\TahmSthv04Run045_calibration_v4_Report.xlsx

Potential sources of error when comparing simulated and observed water levels are:

- Structural errors in the model, including the vertical and horizontal discretization of the model and resulting 'coarse' representation of features and hydraulic gradients at scales of a model cell (or layer) or less. For example, strong vertical gradients may mean that a model, which predicts average water levels for a cell, will struggle to replicate an observed water level if that water level is from the upper or lower portion of that layer. For a layer that is 50 metres thick and where a gradient is 1 in 10, this leads to errors of +/- 5m.
- Structural errors may also occur because of the discretisation of time in the model. In this case, stress period lengths are variable, usually 1-6 months. Behaviour within this may significantly influence the observed water level, and the model may either not simulate the relevant stress or may smooth out the response to such a stress. An example is illustrated in the following sketch, which shows a large residual but also suggests that the model does a reasonable job of simulating groundwater levels and their response to mining.




Another example is that there is a discrepancy in observed and computed water levels between observed water levels of 0 and 60 mAHD, which are water levels from the Appin mine EAW7 borehole. These represent a timing influence, thought to be from the representation of the Appin / BSO mine plan in this model compared to the actual progression of that mine (more on this in the discussion of Hydrographs, below).

- Measurement error in observations, being less, say 0.01-0.1 m in standpipes that have been surveyed, to +/-8 or more metres in VWPs (see end of Section 3.8.3). Further it is important to consider the findings of GES (2017) "*It is noted that the records for the Tahmoor North VWP monitoring network are compromised by many issues which include logger failures and data processing / installation record errors*." While we have done our best to 'weight' bad data out, some of the issues include uncertainty about installation depth/formation (i.e. model layer), and we endeavour to use data rather than not.
- Imperfect representation of hydraulic properties and recharge. This includes both the 'average' value of permeability, as well as this model's use of coarse zones for defining hydraulic properties which then simplifies the real-world complexity and variability of such properties.

**Groundwater Levels - Hydrographs**

Charts comparing modelled and observed hydrographs are presented in Appendix H. Refer to **Figure 3-5** for borehole locations. Hydrographs for shallow boreholes at Thirlmere Lakes and around Tahmoor North are presented first, followed by hydrographs for seam-to-surface piezometers installations around Tahmoor mine and one at Appin (bore EAW7).

The assigned aquifer storage properties were considered to match simulated hydrographs reasonably well against the observed data, given the single Ss and Sy value assigned to each stratigraphic unit.

The simulated water levels at each of the NSW government shallow monitoring bores at Thirlmere Lakes are within 5 or 10 m of observed. Seasonal fluctuations in groundwater levels in these bores is reasonably well calibrated. Simulated fluctuations in bores GW75409 (both -01 and -02) and GW75411 at Thirlmere Lakes are good, although could be larger at the Gandangarra bore (GW75410). All the water levels in these bores are consistently low. The simulated head separation at the nested site (GW75409-01 and -02) is overestimated.

Hydrographs from Tahmoor Coal's shallow bores indicate similar issues. The matches between absolute magnitudes are mixed. Modelled water levels at P1, P5 and P8 are quite good, at < 10 metres offset than observed, while at P2, P4 and P5 they are worse, at about 30 m offset. Generally however, fluctuation in water levels at these bores is well represented, including the seasonal fluctuations at P5 and the apparent longwall-related drawdown and subsequent recovery in late 2008-2011 at P7 (refer to discussion of water level trends in Section 3.8.2).

Hydrographs for selected piezometers within the seam-to-surface piezometer strings in ten boreholes are then presented. Some general comments follow, as well as comments on some of the 'key' monitoring locations. Comments are not made on every hydrograph or bore.

Simulated groundwater pressures within the Tahmoor lease areas are generally flat, whereas some of the observed data exhibit greater fluctuation. Some of the observed fluctuations are considered non-natural however and are possibly the result of piezometer equilibration since installation.

For example, borehole TBC009 is located over 4 km south of any historical mining at Tahmoor, while TBC018 is located almost 2 km from any historical local mining. Bulgo Sandstone water levels in TBC009 (marked "BG322") show an obvious decline over 2011-12, as do water levels in the TBC018 Bulli Coal ("BU") piezometer during 2012-13. These responses, like others in the area, do not appear to be a result of mining. In the case of the TBC009 the cause is unknown, and in the case of the TBC018 Bulli Coal piezometer, the cause seems to be more likely due to equilibration of water levels after piezometer installation.

The weaknesses in model calibration are likely due to the use of a single property zone across a modelled stratigraphic layer, with the exception of the vertical definition applied to the Hawkesbury, Bulgo and Scarborough Sandstones, in the context of actual localised aquifer property variability. Alternatively, recharge variability may not be adequately represented.

During calibration some of the significant mechanisms for improving model calibration to groundwater levels were to reduce hydraulic conductivities within some geological units, notably the Bulgo Sandstone and increase the storage parameters in various units. This improved the modelled drawdown in Bulli Coal seam and Bulgo Sandstone water levels in TNC028 and TNC029, which are near to the recent Tahmoor North longwalls. At TNC028 there is a good match between the modelled and observed drawdown in late 2012-2013 in the Bulli Coal seam, while modelled drawdown in the lower Bulgo Sandstone is simulated, although at about half the rate as seen in the observed hydrograph.

Borehole TNC043 is 1.5 km northeast of recent mining. At TNC043 the decline in water level in the Bulli Coal seam, upper and lower Bulgo Sandstone and lower Hawkesbury Sandstone is not matched by the model. It is not known whether these declines are due to mining.

TNC036 also exhibits a decline in water levels in the Bulli Coal, between 2010 and flattening out toward 2013. However, due to the early rise in water levels in 2009 in that piezometer it unclear whether the decline is due to mining or some equilibration after installation.

Apart from the data at Tahmoor North bore TNC028 and Tahmoor HoF hole (TBF040c, sometimes also referred to as TNC040), the best available monitoring of mining effects on water levels is from Appin EAW7. The hydrographs indicate the model does an excellent job of simulating mining impacts in the Bulli Coal, as well as in the overlying Scarborough Sandstone and Bulgo Sandstone. There is some discrepancy between the time at which drawdown occurs, however this could be due to mine developing in a different manner than specified by the mine plan that was available for this study. However, the simulated drawdown curve through 2011-2013 is an excellent match to the observed. Modelled water levels in the Scarborough Sandstone do not exhibit the same rise in 2011-12 as seen in the observed hydrograph, but the subsequent drawdown is a good match of the observed.

**Groundwater Levels – vertical head profile**

**Figure 4-11** presents water levels measured in TBF040c (TNC040) in early 2014 against modelled water levels from the corresponding period as well as modelled heads at the time that the underlying longwall was extracted (in the early 1990s). Modelled pressure heads are plotted on the right-hand chart.

**Figure 4-11** shows a good match down the profile, with modelled heads being a good match for those in the Hawkesbury Sandstone (both modelled and observed unaffected by mining) and the Bulgo Sandstone (both modelled and observed influenced by mining). The model tends to overestimate drawdown in the Bald Hill Claystone compared to observed water levels. Below the upper Bulgo Sandstone, where there are no observed readings, the model simulated negative pressures in response to mining, which matches well with the zero-pressure concept postulated by Tammetta (2013). The model simulates some recovery to positive pressures by 2014 – it is not possible to confirm this is correct. Positive pressure heads are simulated in the layers below the mined Bulli Coal seam.

**Groundwater Levels – contour maps**

**Figure 4-12** presents two maps of the modelled water table; one a pre-mining water table (essentially c. 1980), and the modelled water table from late 2013 (chosen to match the period shown on **Figure 3-18**-**Figure 3-21**). There is no discernible difference in the two maps, although it is acknowledged that it can be very difficult to spot differences in such contour maps, even if differences do occur. The general south to north/northeast pattern of flow, seen in the observed or interpreted water table data (**Figure 3-18**), is shown in the model results. Stronger gradients are simulated around the large watercourses, such as the Nepean River and Bargo River (both of which flow northward) and Lake Burragorang (west of Tahmoor).

**Figure 4-13** presents the modelled water levels for the Bulli seam, for the same time periods as described above. This can be compared against the interpreted water level map on **Figure 3-21**. The regional gradient to the north or northeast, as seen in the observed data (**Figure 3-21**), is present in the modelled water levels. The expected cone of depression (drawdown) around the recent workings in the Tahmoor and Tahmoor North areas of the mine, as well as drawdown from recent workings at Appin in the northeast, is also shown. Drawdown in the Bulli Seam has a lateral extent of about 1.5-2 km from the edge of the mine footprint.

**Mine inflows**

Mine inflows were extracted from the groundwater model files using the 'Zone Budget' utility (written by the USGS). This was done on a zone-by-zone basis for the various mine areas within the model domain. The groundwater model was setup to allow extraction of water budget information multiple times within each stress period, allowing the detail of the generally higher early-time inflows to be captured as well as the end-of-stress-period inflows, which is important as discussed in Mackie (2013). Inflows were then calculated on a time-weighted-average basis from these time steps.

Comparison of modelled mine inflows against the historical record at Tahmoor is presented on **Figure 4-14**. The calibrated model's hydrograph is the orange series, marked 'Modelled v4TR045'. This shows that while the model does not represent all peaks and troughs, it matches the magnitude of inflow to an appropriate degree, and is very good for the period since 2014.

The historical average inflow to the Tahmoor underground mine is 2.75 ML/d, based on the years 1995-2002 and 2009-2013. For the same period the average of the modelled inflow to the mine is 2.3 ML/d – a variance of 20%. For the recent period 2013-2018, the modelled average is 4.02 ML/d compared to an observed average of 4.06 ML/d (a variance of 1%).

A comparison was of modelled and observed inflow (for the period to 2014) for two of the other mines simulated within the Tahmoor groundwater model. At Dendrobium, modelled inflow averages 4.5 ML/d (higher than the observed average of 3.6 ML/d for the period to 2014), while at Appin and Tower, the modelled average is 1.4 ML/d compared to 1.9 ML/d (observed data in **Table 3-14**). These are considered sufficient for cumulative impact assessment.

**Baseflow**

Simulated river flows were extracted from the numerical model at five locations corresponding to monitoring locations (both local and regional monitoring points). The results are presented in **Table 4-4**, considering that the model does not simulate runoff or regulated flows, only baseflow.

The modelled flows represent baseflow. These are in the correct order of magnitude based on the discussion in Section 3.8.7:

- Hornes Creek calculated BFI is up to 15% (approx.), modelled ratio is 25%.
- Stonequarry Creek BFI < 10%, and the model ratio is 13%.
- Bargo River, Nepean River BFI are up to 20% (approx.), modelled ratio is 40-50%.

### Table 4-4 Comparison of modelled baseflow and observed flow

| SITE | OBSERVED FLOW Q99-Q01 RANGE | MODELLED MIN-MAX RANGE | OBSERVED MEAN | MODELLED MEAN |
|---|---|---|---|---|
| Stonequarry Ck | 0 to 560 | 0.5 to 6.0 | 15 | 2.0 |
| Bargo R (SW1) | 0.2 to 34.1 | 3.3 to 5.7 | 4.8 | 4.3 |
| Bargo R (SW14) | 3.3 to 137.4 | 5.2 to 13.9 | 16.8 | 8.2 |
| Hornes Ck (SW9) | 0.2 to 35.4 | 0.2 to 1.8 | 2.7 | 0.7 |
| Maldon Weir (SW21) | 11.3 to 104.6 | 13.6 to 38.3 | 47.5 | 21.0 |

All units in ML/d. Source: E:\HYDROSIM\TAHMOOR\Model\Processing\ZonBud\RivBaseflow_v4TR045_Zbud_Calc.xlsx

Considering that this was not the primary focus of the calibration, the results are good. Maximum modelled baseflows are considerably less than observed, except in the case of Menangle Weir. Menangle Weir is downstream of the reservoirs, and therefore regulated, so less weight is put on this observation. Generally, the range in modelled flows compares well to the observed range, considering that the top end of the observed flows is runoff-dominated.

A source of error in comparing observed and modelled flows is the difference in the timing or frequency of the two. Actual river flows which are observed on a daily basis and therefore able to capture the short-term extreme low- or high-flow events, while modelled flows are averaged over many months, and therefore very unlikely to be able to match short-term peaks and troughs.

#### Water balance

The mass balance reported by MODFLOW at the end of the historical calibration period (stress period 69) is 0.01%, and within the 1-2% threshold suggested by Barnett *et al*, 2012.

The averaged water balance for the transient calibration model across the entire model area for the calibration period is summarised in **Table 4-5**.

### Table 4-5 Calibrated transient model water balance (1980-2018)

| COMPONENT | MODFLOW package | INFLOW (ML/d) | OUTFLOW (ML/d) |
|---|---|---|---|
| Rainfall recharge | Recharge | 190.4 | -- |
| Evaporation from shallow groundwater | EVT and RSF ('rejected recharge') | -- | 78.8 |
| Leakage and baseflow at watercourses and lakes/reservoirs | Rivers | 9.1 | 114.1 |
| Regional groundwater throughflow | GHB | 0.6 | 4.7 |
| Mine inflow | Drains | -- | 5.7 |
| Storage | Storage | 66.6 | 63.3 |
| **Total** | | **266.7** | **266.7** |

E:\HYDROSIM\TAHMOOR\Model\Processing\WaterBalance\v4TR038\TahSthv4TR045_wholemodel.xlsx

This suggests that, overall, the near-surface processes like recharge, evapotranspiration and the exchange between streams and shallow aquifers, are the most significant processes in the catchment. Mine inflows, from all the simulated mines constitutes around 2% of the total water balance.

## 4.9 CALIBRATED MODEL PARAMETERS

### 4.9.1 HYDRAULIC PROPERTIES

Calibrated hydraulic properties, i.e. hydraulic conductivity and storage parameters, are presented in **Table 4-2** and **Figure 4-5**. In terms of hydraulic conductivities, these are well constrained by the observed data.

The hydraulic conductivities presented here are lower than those in SCT (2013) for both the host permeability and permeability for the deformed strata. This is likely an issue of scale, similar to the concept described above, as the modelling in SCT relies on 1 m thick layers (compared to the layering in the groundwater model – refer to **Table 4-1**).

Based on both the response of the modelled heads within the upper Bulgo Sandstone and Bald Hill Claystone in the HoF bore TBF040c and, possibly in the future, as mining progresses towards the TNC bores, there could be further effort applied, on a local scale, to better understand and model the vertical hydraulic conductivities in and around the upper Narrabeen Group. The sense at this point is that the modelled hydraulic conductivity of the Bald Hill Claystone or the underlying Bulgo Sandstone may still be too high. This would result in an overestimation of environmental effects at in shallow aquifers and at surface. This is particularly likely in the thicker model layers, which are often at least 50 m and up to 100-150 m thick. The concept is that each stratigraphic unit is composed of many laminations or horizons of material of variable permeability. Joints and fractures will increase the permeability across these layers, however the opportunity for set of joints or fractures to provide connection between the top and bottom of a model layer of such thickness is limited. The general trend would then be for vertical permeabilities to approach the core permeability data (Section 3.8.6) and suggests that the rock matrix permeabilities govern vertical flow across stratigraphic units, rather than fracture permeabilities. This is a concept that could be explored further.

In the EPZ, higher permeabilities than those adopted for calibration would be inconsistent with recorded mine inflows.

### 4.9.2 RECHARGE

Calibrated average recharge rates are:

- 75-182 mm/year (~8-14 % of rainfall) to the alluvium;
- 19-35 mm/year (2.1-2.7 % of rainfall) to outcropping shales of the Wianamatta Formation and on intrusions; and
- 33-74 mm/year (3.7-5.7% of rainfall) to outcropping Hawkesbury Sandstone and other Triassic and Permian outcrop.

The calibrated values are in good agreement with the discussion in Section 3.8.4.

## 4.10 UNCERTAINTY ANALYSIS

Following discussion with reviewers and consideration of the Australian Groundwater Modelling Guidelines (Barnett *et al*, 2012) and a range of literature, an analysis of model uncertainty was carried out. This was done to provide information on the error present in the predictions. Such model errors are due to the process of fitting the model to observed data which have errors (measurement noise) and to the limitations of any model in trying to capture all the detail and complexity present in the real world ('structural error').

The model is large, and has a long run-time, based on the requirements to consider neighbouring mines and sensible hydraulic boundaries. This restricts the ability to use rigorous uncertainty methods that could involves hundreds or thousands of model runs.

The assessment carried out relied on linear analysis methods. This is consistent Barnett *et al (*2012), which state "When appropriate for the prediction of interest, linear uncertainty methods should be considered a primary tool for conveying the modelling estimate of uncertainty because they are less computationally intensive than other methods". One of the key factors is the computational requirement, given the previously mentioned size of the Tahmoor South groundwater model. Linear analysis was therefore based on the Section 5 of Doherty (2010b) using GENLINPRED, from the PEST suite of tools (John Doherty / Watermark Numerical Computing), to provide estimates on the error associated with the prediction of groundwater heads at a selection of sites in the strata above Tahmoor South mine longwalls.

### 4.10.1 LINEAR ANALYSIS

GENLINPRED uses the Jacobian Matrix (JCO[12]) calculated by PEST to carry out linear analysis. The JCO is written by PEST after it has considered incremental changes to each of the parameters specified by the user as being able to be modified. The requirement to write the JCO applicable to the transient model would be about 70 model runs, which was considered excessive, both in terms of time but also of disk space, even with a 'cut-down model. Therefore, a JCO from an earlier PEST iteration was used in with GENLINPRED. This has 21 parameters, of which 10 are horizontal permeability (kx) and 11 vertical permeability (kz). These horizontal and vertical hydraulic conductivities are associated with the hydrogeological units extending from the seam to the surface, namely:

- Alluvium (kz only),
- Hawkesbury Sandstone (3 model layers),
- Bald Hill Claystone,
- Bulgo Sandstone (2 model layers),
- Stanwell Park Claystone,
- Scarborough Sandstone (2 model layers) and
- Wombarra Claystone.

The analysis considered four sites (monitoring bore locations), two within or above the Central Domain (TBC009 and TBC032) and two to the east around Eliza Creek. These are all multi-piezometer installations, and the pre- and post-calibration modelled heads in six layers have been considered. These are the upper and lower Hawkesbury Sandstone, Bald Hill Claystone, upper and lower Bulgo Sandstone and the Bulli Coal seam.

### 4.10.2 RESULTS

From the GENLINPRED has provided two sets of results, the first on parameter 'identifiability', and the second on the error variance associated with the groundwater level predicted at a 3D location.

Models of complex systems can involve a large number of parameters. Some of these parameters cannot be derived from observed data through model calibration or regression

[12] The matrix is stored in the PEST .JCO file, and so this abbreviation is used here for the matrix as well as the file

techniques. Such parameters are said to be 'un-identifiable'; the remaining parameters are 'identifiable'. Doherty and Hunt (2011) state:

> *"Where this value is zero for a particular parameter, the calibration dataset possesses no information with respect to that parameter. Where it is 1, the parameter is completely identifiable on the basis of the current calibration dataset (though cannot be estimated without error because its estimation takes place on a dataset that contains measurement noise)."*

The left-hand charts on **Figure 4-15** show the calculated identifiability for the 21 parameters assessed, as calculated from the predicted heads in the six layers at the four monitoring sites listed in the previous section. This shows that the highly identifiable parameters are the Hawkesbury Sandstone kx (for all three layers), the kz for the 'middle' Hawkesbury Sandstone and for the Bald Hill Claystone, and both vertical and horizontal permeability for the Bulgo Sandstone. The horizontal permeabilities for the Stanwell Park Claystone and Scarborough Sandstone are only moderately identifiable, and the others 'un-identifiable'. There is only limited alluvium and few observations in the alluvium near the Tahmoor Mine, hence the low identifiability of that parameter. The uncertainties associated with the un-identifiable parameters cannot be reduced with the current set of observed data. Future data gathering should concentrate on those moderately and poorly identifiable parameters. Any future modelling should concentrate on the identifiable parameters, unless the set of observed data has changed considerably.

GENLINPRED calculated the variance in predicted groundwater levels at the sites and stratigraphic units listed at the end of Section 4.10.1. The standard deviation, which is the square-root of variance, is presented here, as it is the more familiar concept for defining the 'spread' in a dataset.

The upper right-hand chart on **Figure 4-15** shows that the standard deviation of the predicted groundwater levels in the various layers, using the pre-calibration model, were in the range 6-21 m. This is potential for error associated with assignment of a value to the hydraulic conductivity parameters basis solely on the so-called 'expert knowledge' of that parameter. That expert knowledge could be based on previous experience of the permeability of a sandstone and/or information gleaned from packer test and core data. Once the model calibration process has progressed, the standard deviation or variance associated with the predicted groundwater levels has fallen (improved), to 0.1-0.5 m (mean = 0.3 m). This is particularly important in the shallow layers, regarding predicted impacts on the water table (Sections 5.6 and 6.4).

The lower right-hand chart on **Figure 4-15** shows the source of error on predicted groundwater levels in the six layers. The sources of error are either due to the estimation of all horizontal hydraulic conductivity parameters or the estimation of vertical hydraulic conductivity parameters. The pre- and post-calibration source of error is presented. This analysis shows that most of the error in pre-calibration was associated with the horizontal hydraulic conductivities (red series typically greater than the light blue). Calibration has reduced the error, and for most layers the post-calibration source of error between horizontal and vertical permeabilities is similar (orange similar to green), except in the case of the Bulli Coal seam water levels, where horizontal hydraulic conductivity remains the main source of error variance.

## 4.11 MODEL LIMITATIONS

There is uncertainty in formation elevations and thicknesses away from the Project site and away from the other mines from which data has been used. This is particularly to the west of the Tahmoor Mine, where there is little data. The Project geological model has been extrapolated on the basis of seam and formation dip, outcrop geology and topographic data.

Some water level records, particularly those which are 'time-of-drilling' water levels from the NSW bore database, used to provide some calibration targets and to infer groundwater flow directions, are low quality. In general, they provide snapshot information at the time of construction of a bore and the data span many decades. In particular, the vertical head distribution away from the Project site is not known.

A substantial dataset of hydraulic property measurements has been obtained via packer tests and core lab analysis at Tahmoor Mine. There is often a substantial range in these properties. Due to the size of the groundwater model, single 'representative' values of horizontal and vertical hydraulic conductivity have been applied. This is a simplification of the more complex and varied nature of these properties in reality.

Deep measurements of groundwater pressures (using vibrating wire piezometers) are not always stable or consistent, and the direction of the vertical head gradient has not been established definitively.

The degree of enhancement of permeabilities (mostly vertical) in the underground fractured zone, as a result of mining, cannot be known *a priori*. Assumptions have been made and likely bounds assessed through modelling and sensitivity analysis. The calibration of mine inflows, however, means that there is some control or constraint on these properties.

The scale of model cells (100 m laterally, and variable vertically) limits the ability to accurately simulate some behaviours and features, particularly where hydraulic gradients are steep, such as near to mined longwall panels.

There is imperfect matching of observed groundwater levels due to a number of factors. These are inconsistencies and instability in deep groundwater pressures, model scale (see previous point), imperfect representation of hydraulic properties in a model, and well as the inability to represent the complexity of subsurface systems, particularly those in fractured rock.

# 5 PREDICTIVE MODELLING

## 5.1 MINING SCHEDULE

A summary of the schedule that was used for the Tahmoor South underground mine expansion in the groundwater model is provided in **Figure 2-3**. This figure outlines the stress period setup for the mining period of the transient predictive model run. The prediction period runs for the proposed active mine life of Tahmoor South, followed by post-mining recovery to the year 2500. For this groundwater assessment, the lengths of the modelled stress periods are a best match to longwall panel durations at Tahmoor and contemporaneous neighbouring mines. The ~450-year recovery period was subdivided into 23 stress periods, starting at stress periods of around 6-months, then one year and progressing out to stress periods each 100 years in length at the end of the predictive run.

## 5.2 MODELLING APPROACH

### 5.2.1 PREDICTIVE SCENARIOS AND SENSITIVITY RUNS

The potential impacts of the development were assessed by making comparisons between the following predictive scenarios:

| | |
|---|---|
| **Scenario A:** | The 'Null' Run (as described in Barnett *et al*, 2013) or 'Natural' run – all aquifer interference activities removed from simulation, i.e. no mines (Tahmoor or any other), no longwall/subsidence impacts on strata, and no groundwater extraction from bores. |
| **Scenario B:** | All mining activities are simulated, except for the Tahmoor South Project, according to the schedule in **Figure 2-3**. |
| **Scenario C:** | All mining activities. This is the same as Scenario 'B', however the Tahmoor South Project is operating according to the schedule in **Figure 2-3**. |
| As noted earlier, groundwater extraction bores are not simulated given the uncertainty around actual extraction versus entitlement, as well as due to the possible presence of unregistered bores. | |

- These allow the net impact of the development on the hydrogeological environment to be evaluated separately from the other processes:
- When Scenarios B and C are compared, the difference between the two represents the impact of the operation of the Tahmoor South Project.
- When Scenarios A and C are compared, the difference between the two represents the cumulative impact of all the mining activities.

Further to those scenarios, a few sensitivity runs have been carried out to test the impacts of various hydrogeological features and behaviours. These sensitivity runs are all focused on 'conservative' runs that we anticipate would result in typically greater inflow or greater connection to the surface than anticipated (e.g. there is a run with a greater height of fracturing, but not a run with a lesser height of connected fracturing). The runs are as follows:

- A single run to test the possibility that the barrier faults are 'weaker' (more permeable) than simulated in the baseline model. The faults in question are those simulated in the southern part of the Tahmoor Mine (Western and Central Faults – **Figure 3-11**), as well as those to the north and northwest of the mine. These were simulated in the calibrated model as having a hydraulic conductivity of 5E-05 (kx) and 7E-07 m/d (kz). In this sensitivity run, the hydraulic conductivity has been increased slightly to 5E-04 and 7E-06 m/d respectively. This horizontal hydraulic conductivity is then greater than most of the host horizontal hydraulic conductivities); and
- A single run to test the possibility that the T1 and T2 faults (labelled on **Figure 3-11**) act as conductive features. The applied hydraulic conductivity for these faults is 1E-04 (kx) and 1E-05 m/d (kz).

- A run to test the potential impact of the height of fracturing above the coal seam (refer to discussion of this behaviour in Section 3.9 and in SCT, 2013). The calibrated or base case predictive model uses a height of fracturing estimated from the Tammetta (2013) method for estimating the height of groundwater drainage. In this sensitivity run the height of fracturing has been increased to 1.5 x the Tammetta height as used in the base case model;
- A run using storage enhancement, particularly Sy (specific yield) enhancement in the TVM package (see Section 4.6). This is because inclusion of Sy enhancement is numerically difficult, particularly alongside simultaneous enhancements in permeability and imposition of large pressure gradients. Our experience is that this sometimes introduces anomalous spikes in groundwater levels and inflow, hence it has been used in one of the sensitivity runs to test the effect on the groundwater system, particularly on groundwater recovery after the cessation of mining.

These sensitivity runs have been run once each with the activities of Scenario C.

**Table 5-1 Summary of scenarios for impact assessment**

| MODEL RUN | SCENARIO | MINING | | PRIVATE BORE USERS | COMMENT / SENSITIVITY |
|---|---|---|---|---|---|
| | | TAHMOOR SOUTH | OTHER | | |
| V4TR045 | **Scenario C** | Yes | Yes (Tahmoor & others) | None | all mines, including Tahmoor South |
| v4TR046 | **Scenario A** | No | None | None | Null run |
| v4TR047 | **Scenario B** | No | Yes (Tahmoor & others) | None | all mines, but without Tahmoor South |
| v4TR048 | **Scenario C** | Yes | Yes (Tahmoor & others) | None | As v4TR045, but testing role of 'Southern Faults' |
| v4TR049 | **Scenario C** | Yes | Yes (Tahmoor & others) | None | As v4TR045, but testing role of 'T Faults' |
| v4TR050 | **Scenario C** | Yes | Yes (Tahmoor & others) | None | As v4TR045, but testing greater Height of Connected Fracturing |
| v4TR051 | **Scenario C** | Yes | Yes (Tahmoor & others) | None | As v4TR045, but including Storage enhancement in/above goaf |

Given the significance of the Thirlmere Lakes, some separate model scenarios were run, focussing on those features. The base case model was modified slightly by simulating different lake levels in each model scenario and estimating the natural leakage rate from each of the five Thirlmere Lakes to groundwater at different lake levels. Then the same model was run simulating the long-term effects on each lake of Tahmoor/Tahmoor North (i.e. a. simulating the mine(s) operating and dewatering for a theoretical 100 years to allow conservative drawdown propagation). The same model then with Tahmoor plus Tahmoor South. The relationship of lake levels versus natural leakage rates, and the predicted effects of the Tahmoor operations, were provided to HEC for input to their model (HEC, 2018b) to allow the effects of these to be calculated with respect to surface water behaviour.

## 5.3 MODEL IMPLEMENTATION

The underground mining and dewatering activity is defined in the model using Drain cells within the mined coal seams, with Drain elevations set to 0.1 m above the base of the coal seam. These Drain cells were applied wherever workings occur and were progressed through time increments coincident with the stress period durations.

The mine operators will seal off parts of the existing mine in about 2022 after extraction of the northernmost longwalls in Tahmoor North. The location of these seals are shown on **Figure 3-33** and Appendix D. Water levels will be monitored within the sealed sections to assess risk of movement of water from those areas back into actively used areas. Some existing Tahmoor areas will still be dewatered as part of on-going operations.

The model setup involved changing the parameters with time in the goaf and overlying fractured zones directly after mining of each panel (see Section 4.6.1). Drains are also used to simulate the development headings and roadways, and these are activated in advance of the active mining.

## 5.4 WATER BALANCE

Some regional water balances are presented here to get a regional picture of the consequences of the simulated mining. **Table 5-2** presents the modelled average water balance for the Tahmoor South mining periods for both the cumulative impact run and for the 'Null' run (see **Table 5-1**).

**Table 5-2 Transient model water balance to end of Tahmoor South (2018-2035)**

| COMPONENT | MODFLOW package | All Mines – v4TR045 | | Null Run – v4TR046 | |
|---|---|---|---|---|---|
| | | INFLOW | OUTFLOW | INFLOW | OUTFLOW |
| Rainfall recharge | Recharge | 190.6 | | 190.6 | |
| Evap. from shallow groundwater | EVT and RSF | | 85.7 | | 86.3 |
| Leakage and baseflow at watercourses and lakes | Rivers | 9.7 | 110.2 | 9.7 | 111.0 |
| Regional GW throughflow | GHB | 0.6 | 4.7 | 0.6 | 4.7 |
| Mine inflow | Drains | | 9.9 | | 0.0 |
| Storage | Storage | 15.3 | 5.6 | 1.7 | 0.4 |
| **Total** | | **216.2** | **216.1** | 202.5 | 202.4 |

E:\HYDROSIM\TAHMOOR\Model\Processing\WaterBalance\v4TR038\TahSthv4TR045_wholemodel.xlsx

This water balance is for the entire model area for scenarios A and C as described in Section 5.2. The key differences between the All Mines run and the Null (natural) run are (**Table 5-2**):

- Almost 10 ML/d of mine inflow (averaged 2018-2035) for all mines in the area.
- This is then met by changes to:
  - Groundwater storage, i.e. a decline in groundwater levels (approximately equivalent to 80% of the mines inflows);
  - Reduced baseflow (approximately equivalent to 10% of total mine inflows);
  - Reduced evapotranspiration (approximately equivalent to 10% of the inflow to mines).;

- A reduction in groundwater throughflow OUT and increase in groundwater throughflow IN (approximately equivalent to 1% of the inflow to mines).

A second water balance (**Table 5-3**) was derived, again for the whole of the model domain, but for the period 2036-2500, or the 'recovery' period.

**Table 5-3 Transient model water balance for recovery period (2036-2500)**

| COMPONENT | MODFLOW package | All Mines – v4TR045 | | Null Run – v4TR046 | |
|---|---|---|---|---|---|
| | | INFLOW | OUTFLOW | INFLOW | OUTFLOW |
| Rainfall recharge | Recharge | 169.8 | | 166.7 | |
| Evap. from shallow groundwater | EVT and RSF | | 75.6 | | 74.7 |
| Leakage and baseflow at watercourses and lakes | Rivers | 7.6 | 97.2 | 7.9 | 96.3 |
| Regional GW throughflow | GHB | 0.5 | 4.2 | 0.5 | 4.1 |
| Mine inflow | Drains | | 0.0* | | 0.0 |
| Storage | Storage | 0.2 | 0.9 | 0.0 | 0.0 |
| **Total** | | **178.1** | **177.9** | **175.1** | **175.1** |

E:\HYDROSIM\TAHMOOR\Model\Processing\WaterBalance\v4TR038\TahSthv4TR045_wholemodel.xlsx

*there are no mines simulated in this period.

The results indicate that groundwater storage would increase in the All mines scenario in this period due to groundwater level recovery around the mines, but at a relatively slow rate (0.7 ML/d - **Table 5-3**) compared to the storage depletion of about 13 ML/d during the period 2018-2035 (**Table 5-2**). Comparing the All mines run and the null run, the following changes are inferred as occurring following the cessation of mining activities, noting that these are averaged across a longer period:

- baseflow continues to be depleted at (0.8 ML/d) relative to the Natural scenario;
- evapotranspiration is reduced by about 0.9 ML/d; and
- there also remains some slight increase in induced groundwater inflow to the modelled catchment (<0.1 ML/d).

Further discussion on local effects, such as baseflow depletion in certain areas or to particular watercourses or groundwater take from Groundwater Sources, is discussed later in Section 5.7 and in Section 6.

## 5.5 PREDICTED MINE INFLOWS

Throughout the calibration and predictive periods, the zones of deformation around the longwalls simulated in the model were progressed in accordance with the approved and proposed mine plans.

Inflows predicted by the numerical model for the Tahmoor South workings are shown in **Figure 5-1**. The bold black line ('v4TR045') represents the base case model inflow to the Tahmoor South workings during the operation of the Tahmoor South Project. The green line 'Tahmoor North' shows the inflow to parts of the Tahmoor North mine that will remain dewatered, including the drift and portal areas. The other lines show the variance in modelled results based on the sensitivity model runs (Section 5.2.1).

The inflow rates are predicted to increase over the first third of the operational life at Tahmoor South from about 2 ML/day to an average of 4.7 ML/d for the proposed life of Tahmoor South. The model predicts that peak rates will be on the order of 7.5-8 ML/d in 2029-30 and 2032, noting that these rates are quoted as ML/d but averaged over model stress periods which are typically 6 months to a year – higher inflows may occur over shorter periods.

Most of the sensitivity runs support the peak of 7.5-8 ML/d, except for run v4TR050, which simulated the inflow if a greater degree of vertical fracturing occurred above the mine. This model run suggested that peaks could be up to 10 ML/d, and an overall average of approximately 6.7 ML/d through the life of Tahmoor South.

However due to the degree of correlation between the calibrated historical model (run v4TR045) and observed groundwater inflows (Section 4.8.2), the increased height of fracture simulation is thought too extreme to produce results reliable for licensing groundwater take. Progressive review and model revision should be done to confirm this if the mine is approved.

Over the life of mining within the Tahmoor South Project, these simulated inflows total about 21 GL (sensitivity run v4TR050 predicts up to 30 GL). In annual terms, the take averages 1,700 ML/a over the period of longwall mining. The peak flows across a year are predicted to be approximately 2850 ML/d in 2029, and about 2600 ML/a in 2032.

When considering the various sensitivity runs carried out as part of the predictive modelling (see Section 5.2.1) the ranges in peak and average inflow to the mine are as follows:

- Average inflows for the life of the Tahmoor South Project are predicted to range from 4.7 to 5.5 ML/d (1,700 to 2,000 ML/a); and
- Peak inflows occur during 2029 and 2032 in most of the sensitivity runs. Across a year, the predicted peak inflows are 2,850 ML/a, possibly up to 3,700 ML/a.

## 5.6 PREDICTED GROUNDWATER LEVELS

Hydrographs of the predicted water levels in a selection of model layers are presented for five sites in and around the Tahmoor South mine in **Figure 5-2** to **Figure 5-6**. The locations chosen are the locations of existing bores. The water levels presented in these figures are for many of the stratigraphic layers, usually more than are monitored or even intersected by the bores chosen. The locations chosen are highlighted with a red square on **Figure 3-5**, and have been chosen to show head response to mining and then the subsequent recovery, both within the mined areas as well in areas outside of the proposed longwalls but still relatively close to the mine. The results of the scenarios using the calibrated model set-up, as well as the sensitivity runs (see Section 5.2) are presented on these figures.

The following site is within the footprint of Tahmoor South longwalls;

- TBC032 (**Figure 5-2**) in the middle of the Central Domain.

The other three sites are located outside the Tahmoor South footprint;

- TBC026 (**Figure 5-3**) located 3 km to the east (ENE) of Tahmoor South.
- GW109159 (**Figure 5-4**), located 2 km north of Tahmoor South (near Bargo River).
- TBC022 (**Figure 5-5**), located 1.9 km to the southwest of the Central Domain (between Hornes Creek and the Bargo River), and
- Near GW075409 (**Figure 5-6**), located 3.7 km to the northwest of the Central Domain (adjacent to Lake Couridjah).

Refering initially to differences in modelled groundwater levels between the natural/null run (v4TR046), the full impact model run (v4TR045) and the modelled affect without mining in the proposed Tahmoor South area (v4TR047), the points to note from these predicted water levels are:

- Results from the full impact model run (v4TR045) show drawdown would be strongest in the mined coal seam. A peak drawdown of the Bulli Seam of 350 m drawdown at TBC032 (**Figure 5-2**) becomes less pronounced and severe in the overlying stratigraphy. In the Bulgo Sandstone drawdown is predicted to be approximately 270 m. The lower Hawkesbury is predicted to experience ~25 m of drawdown (50 m based on the most severe sensitivity run). The upper Hawkesbury is not predicted to experience much drawdown, with water levels within 1 m of the natural run (v4TR046) and the simulation without Tahmoor South (v4TR047). However, once mining is completed at Tahmoor, water levels in the upper Hawkesbury have been simulated as recovering to ~10 m above those in the natural and 'no Tahmoor South model' scenarios.
- Final recovery beyond natural levels is predicted to occur in these layers due to subsidence and fracturing causing greater vertical and horizontal connectivity through the strata around and above the underground mine and connecting areas with naturally higher levels to those with lower levels, resulting in recovery to an 'average' level.
- In the area to the east of Tahmoor South (**Figure 5-3**, bore TBC016) some similarities can be drawn to the water levels represented in **Figure 5-2**. The greatest drawdown is predicted to occur in the mined seam (~25 m) with marginally less in the Bulgo Sandstone (~15-20 m). Contrastingly however, the greatest drawdown is modelled to occur some time after the completion of mining at Tahmoor South, due to the distance between the workings and this location. In addition the Upper Hawkesbury does not display the same elevated water levels as modelled for bore TBC026, and modelled water levels in the full impact model are similar to the predictions for the natural and no Tahmoor South model runs.
- Similar to the predictions for TBC016, at GW109159 (**Figure 5-4**) and TBC022 (**Figure 5-5**), depressurisation is not predicted to be as severe, due to these locations being outside the footprint of the mine. The same pattern of high drawdown predicted within the Bulli Coal and weakening drawdown in the strata above is predicted.
- The model suggests that in the proposed mining foorptint (the Central Domain) (**Figure 5-2**) most of the recovery is complete about 150 years (year 2200) after the proposed cessation of operations at Tahmoor South.
- Within the longwall areas (**Figure 5-2**), recovery of water levels in the deeper Bulli Coal seam and Scarborough Sandstone layers is predicted to be incomplete, with a drawdown of 10-20 m in the lower Bulgo Sandstone and 20-30 m in the Bulli Seam predicted in 2500. Residual drawdown in 2500 is predicted to be much less in the upper layers.
- To the east (TBC016) and southwest (TBC022) of the Tahmoor South area the recovery is predicted to be quicker than at the site to the north of the Tahmoor South project (GW109159). That is, the recovery is predicted to take about 100 years, rather than 150 years. This is likely due to the position of the former two sites being upgradient of Tahmoor South, rather than downgradient.
- The results of the various sensitivity runs, as presented on **Figure 5-2** to **Figure 5-5**, indicate the following:
    - The sensitivity runs that modified the properties of the Southern Faults and the T-Faults show little significant change in water levels, either in terms of peak drawdown or recovery rate from the calibrated 'base case' model.

- The model runs that tested modifications to the height of the fractured (‘HoF’) zone above the coal seam (refer to Section 4.6) typically show more sensitivity than the others. The increased fracture zone height (“Higher HoF”) predicts greater drawdowns in the shallower layers because the shallower layers are more likely to have an enhanced connection to the underground mine than in the ‘base case’ model. This is then followed by a slightly quicker recovery in the deeper layers due to the greater connection between deeper and shallow aquifers in this sensitivity run.

The predicted groundwater drawdown near the significant GDEs (the Thirlmere Lakes) was also calculated (see hydrographs for groundwater beneath Lake Couridjah, **Figure 5-6**). It is important to note that the groundwater model produced estimates of groundwater drawdown, rather than the drawdown of surface water levels – those are assessed in HEC (2018b) with a short summary of that provided below. With respect to groundwater, key points are as follows:

Drawdown of shallow groundwater due to the Tahmoor South Project only at the Thirlmere Lakes is:

- 0.02 m peak and 0.01 m average (2020-onward) in the alluvium at Lake Gandangarra;
- 0.01 m peak and 0.01 m average (2020-onward) in the alluvium at Lake Werri Berri;
- 0.03 m peak and 0.01 m average (2020-onward) in the alluvium at Lake Couridjah;
- 0.02 m peak and 0.01 m average (2020-onward) in the alluvium at Lake Baraba;
- 0.02 m peak and 0.01 m average (2020-onward) in the alluvium at Lake Nerrigorang.

At Gandangarra, the maximum drawdown from Tahmoor South is predicted to occur in 2040. The model predicts greater drawdowns, peaking at up to 0.5-0.8 m, in the Hawkesbury Sandstone underlying the Thirlmere Lakes/Blue Gum Creek alluvium, however given the hydraulics of sandstone-alluvium aquifers (Section 3.8.3, **Figure 3-16**) it is primarily drawdown within the alluvium that drives any increased loss from the lakes (Section 6.4).

Considering the cumulative effect of mining in this area, the modelled drawdowns are:

- 0.05 m peak and 0.03 m average in the alluvium at Lake Gandangarra;
- 0.03 m peak and 0.02 m average in the alluvium at Lake Werri Berri;
- 0.05 m peak and 0.03 m average in the alluvium at Lake Couridjah;
- 0.05 m peak and 0.02 m average in the alluvium at Lake Baraba;
- 0.05 m peak and 0.02 m average in the alluvium at Lake Nerrigorang.

The sensitivity runs do not indicate greater possible drawdowns, even under the increased height of fracturing sensitivity run. Full recovery of shallow groundwater levels near the lakes is predicted to occur in around 2200.

The drawdowns described here result in changes to groundwater-surface water interaction in the Thirlmere Lakes catchment. The changes in these fluxes are presented in Section 5.8.

### 5.6.1 PREDICTED PRESSURE HEADS AND CONE OF DEPRESSION

**Figure 5-7** presents predicted pressure heads in various hydrostratigraphic units (model layers) presented as a west-to-east cross-section. These results are for the cumulative impact Scenario C (model run v4TR045). The aim is to show the differences between pre-mining pressures [upper pane], pressure at the end of mining at Tahmoor South (in 2040) [middle pane], and then ~250-yearsafter mining [lower pane].

The key feature of **Figure 5-7** is the zones of zero (or negative) groundwater pressure in and above the Tahmoor South mine workings at the end of mining (middle pane). Above both the Tahmoor South Central Domain these negative pressures are predicted to propagate up to the upper Bulgo Sandstone and Bald Hill Claystone. While negative pressures are not shown to be spreading into the base of the Hawkesbury Sandstone, the pressure shown at the base of that aquifer are predicted to be 10-50 m, which is equivalent to drawdowns of about **50-100 m** right at the base of the Hawkesbury Sandstone. In the shallower parts of the Hawkesbury Sandstone, the drawdowns are quite small, on the order of 5 m (i.e. pressure heads maintained at 0-50 m in the upper half of the Hawkesbury Sandstone – compare upper and middle panes of **Figure 5-7**).

In the lower pane of **Figure 5-7**, the model suggests that pressure heads will have almost recovered to pre-mining pressures by 2300. Within and above the mine workings, the pressure heads are about 325 m in the Bulli Seam, compared to 350 m in the pre-mining case (upper pane) (i.e. residual drawdown of about 25 m). At the level of the Bald Hill Claystone, the lower pane shows pressures of 150 m in the lower pane, very similar to those in the upper pane, suggesting recovery of pressures at this level (and in the shallower units).

**Figure 5-8** shows the spatial distribution of modelled drawdown (from all mining activities, not just Tahmoor South) in the water table and Bulli Seams in 2040, at the cessation of mining at Tahmoor South. The simulated effects of Tahmoor North, BSO and Dendrobium are also visible on **Figure 5-8**.

Generally, water table drawdown is <2 m across much of the Tahmoor South area, however the model does predict areas where drawdown of 5-10 m would occur within and around the proposed Tahmoor South footprint. There are isolated drawdown contours on this figure, located well away from mines, representing some model 'noise'.

In the Bulli Seam the drawdowns are much greater, as expected. The coal seam is to be dewatered within the mine footprint and depressurised around the mine (see also **Figure 5-7**). Drawdown in the Bulli Seam extends out about 3-4 km from longwalls (i.e. the 2 m contour), being about 25 m at 2 km.

## 5.7 PREDICTED BASEFLOW CAPTURE

'Baseflow capture' is the process of inducing leakage from a creek or river into the aquifer via a downward gradient or weakening an upward gradient from the aquifer into the watercourse and thereby reducing the rate at which baseflow occurs.

The results and impacts described here do not consider the impacts of subsidence-induced cracking at the surface, as has occurred historically at Tahmoor Mine and at other Southern Coalfields mines. Subsidence cracking usually results in some loss of surface flow over a short section of the river (tens or hundreds of metres - see Section 3.10.4). This process and effects of the baseflow losses reported here are dealt with in HEC (2018b).

**Table 5-4** presents a summary of the predicted baseflow capture. Gauged sites are marked on **Figure 3-5**. **Table 5-4** presents impacts as simulated by the predictive models that use the calibrated model configuration. The impact in ML/d stated is the maximum baseflow impact from any time in the predictive run and is provided for the Tahmoor South Project and a Cumulative Impact due to mining. More discussion on the timing of this peak impact at some of these sites is presented below.

The watercourses predicted to be most heavily affected by the Tahmoor South Project are:

- Dog Trap Creek – peak impact predicted to be 5.3% of mean flow;
- Tea Tree Hollow – peak impact predicted to be about 1.7% of mean flow; and

- Bargo River – peak impact of around 2% of mean flow.

**Table 5-4 Baseflow depletion at watercourses specified**

| WATERCOURSE | SITE USED FOR ASSESSMENT | TAHMOOR SOUTH IMPACT | CUMULATIVE MINING |
|---|---|---|---|
| | | Best estimate Max (ML/d) | Best estimate Max (ML/d) |
| Eliza Creek | SW-18 | 0.0 | 0.003 |
| Carters Creek | SW-23 | 0.0 | 0.004 |
| Dog Trap Creek | SW-15 | 0.26 | 0.28 |
| Tea Tree Hollow | SW-22 | 0.11 | 0.13 |
| Cow Creek | SW-24 | 0.005 | 0.022 |
| Stonequarry Ck | 212053 | 0.06 | 0.29 |
| Bargo River | SW-1 | 0.013 | 0.17 |
| Bargo River | SW-13 | 0.01 | 0.30 |
| Bargo River | SW-14 | 0.54 | 0.83 |
| Hornes Ck | SW-9 | 0.01 | 0.1 |
| Nepean River | SW-21 | 0.59 | 1.3 |

E:\HYDROSIM\TAHMOOR\Model\Processing\ZonBud\Riv&Lake_BaseflowCapture_4TR045&Sens_Calc.xlsx

The predicted maximum baseflow depletion impact on Blue Gum Creek is around 0.011 ML/d (Tahmoor South effect), while the mean impact of Tahmoor South is around 0.005 ML/d.

Cumulative impacts are typically much greater, which in most instances is a result of the relevant watercourse, such as Stonequarry Creek and Blue Gum Creek / Thirlmere Lakes being in closer proximity to approved Tahmoor/Tahmoor North longwalls (see **Figure 3-5**), such as Stonequarry Creek and Blue Gum Creek.

With respect to watercourses nearer to Tahmoor South, peak effects are likely to occur at different times, e.g. 2024 (Bargo River, SW1), 2035 (Dog Trap Creek) and many later in the life or after the operational life of Tahmoor South, such as in 2041 (Bargo River, SW13) or 2043 (Hornes Creek, Cow Creek).

## 5.8 CHANGE IN LAKE-AQUIFER INTERACTION AT THIRLMERE LAKES

In previous sections estimates of drawdown in shallow groundwater has been presented at or beneath a number of water features. The connection between shallow groundwater (water table aquifers) and surface water features is governed by the permeability of the aquifer material and of any surficial sediments (lake bed materials), and any head separation between the water body and the underlying aquifer.

Also, there may be no predicted decline in groundwater levels at or beneath a feature, however a decline in water levels further up-gradient may result in a loss of baseflow or stream flow to that feature. This could cause a decline in surface water levels in that feature without any perceptible decline in groundwater levels at that point.

For the Thirlmere Lakes, the base case model was modified slightly by simulating different lake levels in each model scenario, and estimating the natural leakage rate from each of the five Thirlmere Lakes to groundwater at different lake levels. Then the same model was run simulating the long-term effects on each lake of Tahmoor/Tahmoor North (i.e. a. simulating the mine(s) operating and dewatering for a theoretical 100 years to allow conservative drawdown propagation), and then the same again but with Tahmoor plus Tahmoor South. The natural leakage rates, and the predicted effects of the Tahmoor operations, were provided to HEC for input to the model to allow the effects of these to be calculated with respect to surface water behaviour (HEC, 2018b). The rates simulated by the groundwater model are summarised in **Table 5-5**, with rates in $m^3$/d.

**Table 5-5 Modelled leakage rate vs lake level at the Thirlmere Lakes**

| GANDANGARRA | | | | WERRI BERRI | | | | COURIDJAH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Level [mAHD] | Nat | TN | TN + TS | Level | Nat | TN | TN + TS | Level | Nat | TN | TN + TS |
| 298 | 2 | 11 | 12 | 298 | 0 | 15 | 17 | 298 | 0 | 12 | 12 |
| 300 | 6 | 17 | 17 | 300 | 17 | 32 | 34 | 300 | 4 | 20 | 21 |
| 302 | 15 | 26 | 27 | 302 | 60 | 78 | 79 | 302 | 5 | 18 | 19 |
| 304 | 103 | 119 | 125 | 304 | 262 | 289 | 302 | 304 | 128 | 145 | 150 |
| 306 | 441 | 458 | 464 | 306 | 600 | 632 | 645 | 306 | 355 | 375 | 381 |

| BARABA | | | | NERRIGORANG | | | | |
|---|---|---|---|---|---|---|---|---|
| Level [mAHD] | Nat | TN | TN + TS | Level | Nat | TN | TN + TS | Leakage rates in $m^3$/d |
| 303.3 | 0 | 4 | 5 | 298 | 5 | 11 | 14 | Nat = modelled natural leakage rate |
| 303.3 | 0 | 4 | 5 | 300 | 7 | 10 | 11 | TN = leakage rate for Tahmoor/Tahmoor North |
| 303.3 | 0 | 4 | 5 | 301 | 21 | 30 | 31 | |
| 304 | 0.7 | 5 | 6 | 302 | 66 | 77 | 84 | TN + TS = leakage rate with Tahmoor and Tahmoor South |
| 306 | 80 | 86 | 87 | 304 | 262 | 276 | 283 | |

E:\HYDROSIM\TAHMOOR\Model\Processing\ThirlmereLakes_HEC\Baseflow&LeakageCalc-Thirlmerelakes_TAHv4SS031_SummaryToHEC_Correction Re Model Accuracy.xlsx

These models, particularly those simulating low lake levels, were subject to some inaccuracy with the use of the Head Close threshold (0.04 m) in the solver (Section 4.8.2) (and a tighter threshold did not allow convergence). This meant that greater mining effects (of Tahmoor/Tahmoor North) were predicted at low lake levels than at higher lake levels – this was counterintuitive, especially considering the greater wetted area when lake levels are high, and the predicted leakage rates were modified slightly (i.e. re-sorted).

In terms of the flowpath and destination of any water leaking from Thirlmere Lakes, as noted in Section 3.8.3, groundwater gradients in the Hawkesbury Sandstone in this area are to the east (**Figure 3-18**). Based on this flow direction, 'downgradient' bores would be P1, P2, P3, P6 or P8 (**Figure 3-5**). Most of these are within the footprint of the mine, and some directly above already-extracted longwalls. Despite mild depressurisation due to mining in some of those bores, they show that positive groundwater pressures are maintained (generally >40 $mH_20$). While this does not preclude the occurrence of downward migration of groundwater from the Hawkesbury Sandstone into deeper units, it does suggest that the dominant flow direction remains horizontal and easterly toward the Bargo/Nepean Rivers in this unit. The implication is that any leakage from the Thirlmere Lakes is unlikely to drain directly into the mine workings and is more likely to continue to discharge to the Nepean River or tributaries.

## 5.9 SALT BALANCE FOR MINE INFLOW

Groundwater inflow to the underground mine is pumped back to surface. In this mine water stream is potable water that has been pumped down into the underground mine for use in various mining-related processes and for human consumption, and groundwater captured in the workings. The waste stream that returns to surface is monitored before it is discharged at

LDP1, the licensed discharge point. This monitoring has been carried out since 2008. The waste stream has an EC of 1500-2500 uS/cm (average 1900 uS/cm, equivalent to a TDS of 1150 mg/L). This is a mixture of low-EC potable water plus groundwater from various units within the local geological sequence which have variable salinity, both vertically and laterally. Based on daily records since 2006, about 700-800 $m^3$/d of potable water is pumped into the mine.

A salt balance was calculated by taking model results from the historical calibration model and then applying the method to the predictive model in order to estimate the salinity of future groundwater inflows. This was done by using the groundwater model to estimate the volume of groundwater that flows into the underground mine and which hydrogeological units it is sourced from. A representative salinity has been assigned, based on local and regional data. It is worth emphasising that groundwater salinity data can be variable across even a short distance within the same hydrogeological unit. Also, some of the best data is from Dendrobium mine and from AGL's Camden Gas Project. These two projects occur in the same strata as Tahmoor, but quite different salinities are encountered at each. Dendrobium tends to be fresher, while the Camden Gas Project has higher salinities, probably due to it being located much closer to the centre of the Sydney Basin and away from likely recharge areas. Due the variability in groundwater salinities (Section 3.8.5) the calibration and prediction of inflow and wastewater salinity is, therefore, only loosely constrained.

The historical salt balance was calibrated to observed salinity data from LDP1. The modelled salinity, based on the representative salinities for each model layer (stratigraphic layer) and the modelled mine inflows and groundwater balance is shown on **Figure 5-9** (upper), compared against the historical record. The match between the two is reasonable, given differences in model and measurement frequency and the variability in groundwater salinity data. Both modelled and recorded data take into account the historical water supply component into the underground mine, which is assumed to have an EC of 200 uS/cm (TDS = 120 mg/L).

The 'calibrated' salinities each in relevant hydrogeological unit were then applied to the predicted inflows to the Tahmoor South Project. The predicted salinity time series is presented on **Figure 5-9** (lower chart). This assumes that low salinity potable water will be required in a similar volume to as it has been 2006-14.

This modelling suggest that inflows could be less saline as mining occur in Tahmoor South, with predicted average salinities of about 1600 EC, with some spikes of 2000 EC. The generally lower predicted salinity during the operation of Tahmoor South is probably due to proportionally more groundwater being sourced from shallower and slightly less saline hydrogeological units, notably the Bulgo Sandstone and the Hawkesbury Sandstone. The over-riding conclusion is that, based on the groundwater salinity data available, as mining in Tahmoor South occurs salinity of the mine water is unlikely to rise significantly, and more likely to fall slightly.

# 6 POTENTIAL IMPACTS

## 6.1 FRAMEWORK FOR ASSESSMENT

This assessment focuses on the criteria specified by the minimal impact considerations of the AI Policy:

- Licensable takes of water (and their partitioning);
- Water table drawdown;
- Pressure head drawdown; and
- Groundwater quality impacts.

## 6.2 POTENTIAL IMPACTS ON GROUNDWATER

The main potential impacts on the groundwater regime due to underground mining arise from changes in bulk rock mass permeability caused by the fracturing associated with longwall subsidence, and the pumping out of groundwater that enters the mine as a consequence. This caving, and associated extraction of groundwater, has a number of effects on the hydrogeological system during and after mining operations that have been evaluated as part of the impact assessment. These can be summarised as follows:

- Inflow of water to the underground mine and the management of that mine water;
- Impacts on groundwater levels during and after operational mining, both within the Permo-Triassic strata and the alluvium associated with Thirlmere Lakes;
- Impacts on baseflow and stream leakage to and from the Bargo and Nepean Rivers and their tributaries during and after operational mining. This could also impact upon groundwater quality around streams; and
- Impacts on groundwater quality via mining-induced mixing of groundwater from different strata.

## 6.3 LICENSABLE TAKES OF WATER

The simulated ultimate sources of water taken by the proposed Tahmoor South mine expansion are described for the whole model area in Section 5.4. The NSW government (CL&W) licenses water take on the basis of the Water Sources described in Section 1.4. The Tahmoor Mine is within *Sydney Basin - Nepean Groundwater Source*, specifically within Management Zone (MZ) 2, and some 10-11 km from the nearest part of MZ1 (**Figure 1-2**). The Project is further still from other Groundwater Sources such as the *Sydney Basin – South* and *Sydney Basin - Central* areas.

The simulated total annual take of water from the Permo-Triassic rock aquifer as mine inflows (see Section 5.5) is derived from a range of depletion sources (as described in Section 5.4).

Based on the modelling results in Section 5.5 and in **Figure 5-1**, the likely peak groundwater inflow to the Tahmoor South project will be around 2,700-2900 ML/a. This result relies on the calibrated groundwater model set-up, rather than the configuration of the sensitivity runs. These peak inflows are expected to occur in the period 2028-2033 during the mining of Tahmoor South. The groundwater entitlement volume currently held by Tahmoor Coal is 1,642 ML/a (Section 2.2.1).

Sensitivity runs, specifically the run in which the height of the connected fractured zone above the goaf is increased by 50%, suggest that inflows could be approximately 30% higher than predicted by the 'base case' model. That is, inflows could be up to approximately 3,700 ML for a 12 month period.

As described in Section 4.8.2 (see also **Figure 4-14**) there is a high degree of correlation between the modelled inflows, for the calibrated historical model, with the observed inflows. Modelling of greater fractured zone heights produced inflow estimates about 30% higher than the 'base case' or calibrated model. Because of the good match between the 'base case' model and the variance given in the sensitivity modelling, the high inflows from the sensitivity run are considered overly conservative for licensing annual rates of groundwater extraction.

In order to calculate groundwater 'take' from the relevant Groundwater Sources (**Figure 1-2**) model water balances were assessed. These include a term 'Interzone Flow' and effects on General Head Boundaries which represents groundwater flow to/from other defined zones in the area, which are listed here:

- <u>Nepean MZ2</u> (the zone in which the Project lies);
- Nepean MZ1;
- Sydney Central;
- Sydney South.

These have been defined from the GIS layers provided by DPI Water/CL&W. The average change in flux between Nepean MZ2 and neighbouring zones were calculated.

The significant points from the modelled water balance are:

- On an average basis, only interzone fluxes for Nepean MZ1 and Sydney Basin – Central are affected by Tahmoor South, and only in the post-closure phase, i.e. it takes time for the drawdown to propagate.

The increased groundwater flows (takes) from Sydney Basin – Central peak at 0.03 ML/d or 1.2 ML/a as a result of the Tahmoor South Project. The increased groundwater flows (takes) from Nepean MZ1 also contributes 0.05 ML/d or 2.0 ML/a as a result of the Tahmoor South Project.

A summary of the groundwater licensing requirements for the Tahmoor South Project, based on the predicted water balances and mine inflows, is presented in **Table 6-1**.

**Table 6-1 Project Groundwater Licensing Summary**

<table>
<tr><th>WATER SHARING PLAN</th><th>WATER SOURCE / MANAGEMENT ZONE</th><th>Predicted Annual Inflow Volumes requiring Licensing (ML/a)</th></tr>
<tr><td rowspan="5">Greater Metropolitan Region Groundwater Sources (Water Management Act 2000)</td><td rowspan="2">Nepean Groundwater Source / Management Zone 2<br>(Porous Rock aquifer)</td><td>Avg. 1700-2000, of which:<br>▪ 1300-1600 from depleted storage during mine operation,<br>▪ 150-180 from reduced evapotranspiration,<br>▪ 170-200 from baseflow depletion,<br>▪ 6 from reservoirs (L. Nepean, L. Avon etc), and<br>▪ 1 from other groundwater flow from other GMAs and MZs (see below)<br><u>Likely max = 2850 ML/a</u></td></tr>
<tr><td>Tahmoor currently holds 1642 shares (Section 2.2.1).</td></tr>
<tr><td>Nepean Groundwater Source / Management Zone 1<br>(Porous Rock aquifer)</td><td>Average = <1; Max = 2.</td></tr>
<tr><td>Sydney Basin - Central Groundwater Source<br>(Porous Rock aquifer)</td><td>Average = <1; Max = 1.</td></tr>
<tr><td>Sydney Basin - South Groundwater Source<br>(Porous Rock aquifer)</td><td>Average = 0; Max = 0.</td></tr>
</table>

Based on the most recent Report Card for the Sydney Basin Nepean Groundwater Source (NOW, 2011a), there was 37,303 ML/a of Unassigned Water (equivalent to 102.2 ML/d). Unassigned Water is not reported on the NSW Water Register, so the current Unassigned Water will need to be confirmed with CL&W.

The Report Card also states that "Unassigned Water is unlikely to be made available in Management Zone 1" – the predicted water balances suggest that an average of <1 ML/a, and a maximum of 2 ML/a, is transferred from MZ1 to MZ2 on account of the proposed operation of Tahmoor South mine. This represents an insignificant component of the MZ1 groundwater resource.

The largest ultimate depletion source are watercourses within Nepean MZ2. The predicted baseflow capture for various watercourses was presented in Section 5.7. This analysis suggests that baseflow capture will result in a depletion of stream flow (or take) from the Nepean River. This is discussed further in Section 6.3.1.

### 6.3.1 PARTITIONING OF SIMULATED SURFACE WATER (BASEFLOW) IMPACTS

Total surface water depletion in this (surface) water source will be dealt with in the Surface Water Assessment (HEC, 2018b).

Model results for baseflow depletion for local watercourses will occur are summarised in **Table 6-2** (watercourses marked on **Figure 3-4**). This shows the Tahmoor South Project and Cumulative impacts (best estimate using the calibrated model configuration). The depletion as a percentage of mean flow is also provided for Project-specific and cumulative effects to guide the reader, but more detailed assessment of the effects is provided in HEC (2018b).

**Table 6-2 Baseflow depletion at local watercourses**

| WATERCOURSE | SITE USED FOR ASSESSMENT | TAHMOOR SOUTH IMPACT (ML/d) | CUMULATIVE MINING (ML/d) | Impacts as % of mean flow |
|---|---|---|---|---|
| | | Best estimate Max | Best estimate Max | |
| Eliza Creek | SW-18 | 0.0 | 0.003 | 0.0% - 0.5% |
| Carters Creek | SW-23 | 0.0 | 0.004 | 0.0% - 0.4% |
| Dog Trap Creek | SW-15 * | 0.26 | 0.28 | 5.3% - 5.7% |
| Tea Tree Hollow | SW-22 * | 0.11 | 0.13 | 1.7% - 2.1% |
| Cow Creek | SW-24 | 0.005 | 0.022 | 0.2% - 0.9% |
| Stonequarry Ck | 212053 | 0.06 | 0.29 | 0.4% - 1.9% |
| Bargo River | SW-1 | 0.013 | 0.17 | 0.3% - 3.6% |
| Bargo River | SW-13 * | 0.01 | 0.30 | 0.4% - 1.3% |
| Bargo River | SW-14 * | 0.54 | 0.83 | 1.7% - 2.6% |
| Hornes Ck | SW-9 | 0.01 | 0.1 | 0.4% - 3.8% |
| Nepean River | SW-21 | 0.59 | 1.3 | 1.2% - 2.7% |

* mean flows based on HEC (2018) AWBM modelling.

The result of mining at Tahmoor South, and both mining and groundwater pumping as part of the cumulative impact assessment, is a reduction in baseflow in three management zones in the Nepean River Water Sharing Plan, specifically to three MZs:

- Pheasants Nest Weir Nepean Dam MZ, which is predicted to experience baseflow depletion of around 0.04 ML/d (Tahmoor South), 0.5 ML/d (cumulative mining effect);

- Stonequarry Creek MZ: maximum baseflow depletion is predicted to be approx. 0.06 ML/d (Tahmoor South), 0.29 ML/d (cumulative mining effect);
- Maldon Weir MZ: maximum baseflow depletion is predicted to be approx. 0.6 ML/d (Tahmoor South), 1.3 ML/d (cumulative mining effect).

### 6.3.2 LEAKAGE FROM RESERVOIRS

There are five WaterNSW dams partly or wholly within the groundwater model domain. The predicted leakage rates associated with the Project are small. Capture of leakage/baseflow into Lake Nepean, being the closest to Tahmoor South, is predicted to be up to 0.007 ML/d for the project, and 0.006 L/d from Lake Avon.

### 6.3.3 NON-LICENSED REDUCTION IN WATER RESOURCES (SUPPLY CATCHMENTS)

As shown on **Figure 3-4**, WaterNSW manages the Metropolitan Special Area (to the east of Tahmoor Mine) and Warragamba Special Area (to the west).

The change in water balance for these two Special Areas was calculated from model results. These indicate greater effects, from Tahmoor South only and cumulatively, in the Metropolitan Special Area compared to the Warragamba Special Area.

In both cases, impacts are likely to be small, with the key changes to the water balances predicted as follows.

**Metropolitan Special Area**

In order to reduce impacts, the south-eastern ends of three of the proposed longwall panels were reduced in length so that they would not extend under the Metropolitan Special Area. The Tahmoor South Project is predicted to result in an average of 0.05 ML/d (18 ML/a) decline in baseflow in the Metropolitan Special Area. This impact is predicted to peak at 0.13 ML/d in around 2100 before declining again.

Cumulative mining impacts on the Metropolitan Special Area are mainly felt by reductions in baseflow and evapotranspiration from shallow groundwater. Baseflow is predicted to decline by an average of 0.15 ML/d (55 ML/a), with peak losses of 0.2 ML/d (81 ML/a) to occur in the period 2070-2110, before the impact on both lessens over the following period, although never fully recovers. This is due in part to cumulative impact of mining such as from the parts of the Tahmoor South Project adjacent this Special Area, but also including historical, current and proposed workings at Russell Vale, Cordeaux, and Dendrobium mines. Licensed and registered bores may also account for further cumulative effects on baseflow and reduced ET although these are simulated here.

**Warragamba Special Area**

Baseflow capture is predicted to peak at less than 0.005 ML/d (<2 ML/a) by the Tahmoor South Project. For context, inflows to Lake Burragorang (as a proxy for the resource within the Special Area) average at about 2800 ML/d (since 1909) or 1280 ML/d (since 2000). The depletion due to Tahmoor South is therefore <0.001%.

Cumulative impacts, including from the existing/approved Tahmoor Mine, on the Warragamba Special Area include a mean reduction in baseflow of approx. 0.005 ML/d (2 ML/a), which peaked at 0.1 ML/d (35 ML/a) in the 1980-90s. The (un-modelled) effects of bore pumping are likely to be greater in this area than in the Metropolitan Special Area, given the bore use to the northwest of Tahmoor Mine (**Figure 3-12**).

## 6.4 GROUNDWATER DEPENDENT ECOSYSTEMS

There are a number of high priority Groundwater Dependent Ecosystems (GDEs) listed in the relevant Water Sharing Plan, as outlined in Section 3.6 (see also **Figure 3-4**).

### 6.4.1 IMPACTS OF TAHMOOR SOUTH PROJECT

The predicted risks and impacts of mine development to High Priority GDEs are quantified in **Table 6-3**. **Figure 3-4** shows the location of the various features, and water table hydrographs for many of these features are provided in **Figure 5-6**. As stated in Section 5.6, these are groundwater drawdown estimates, and not reductions in surface water level. Reduction in lake levels is assessed in HEC (2018b); the main findings from that are summarised further after **Table 6-3**.

**Table 6-3 Project Baseflow Capture and Groundwater Drawdown at Priority GDEs**

| GDE | | PREDICTED MAX DRAWDOWN (m) | TIME TO WL RECOVERY | PREDICTED BASEFLOW CAPTURE | |
|---|---|---|---|---|---|
| | | | | MEAN | MAX |
| Thirlmere Lakes | Gandangarra | 0.02 | ~2150-2200 (150 years post-mining) | See **Table 5-5** | |
| | Werri Berri | 0.01 | | | |
| | Couridjah | 0.03 | | | |
| | Baraba | 0.02 | n/a | | |
| | Nerrigorang | 0.02 | n/a | | |
| North Pole Swamp | (upland swamp) | 0 | n/a | 0 ML/a | This is the nearest of the upland swamps, located 21 km south of the Project. |
| O'Hare's Creek | | These GDE are >23 km east and >29 km south of Tahmoor South Mine, and beyond the boundaries of the groundwater model used for impact assessment. The distance means that far field effects from Tahmoor South will not reach these features. | | | |
| Macquarie Rivulet | | | | | |

With respect to the potential effects on surface water levels within lakes themselves, an assessment was undertaken by HEC (2018b) using a calibrated lake water balance model (with inputs from the groundwater model – Section 5.8). The main conclusion from the modelling by HEC is as follows.

The lake water balance model predicts a negligible increase in groundwater recharge ('leakage') from the Lakes as a result of the Project, and a negligible decrease in outflows to Blue Gum Creek. These changes would be unmeasurable or imperceptible in the field and are approaching the limits of accuracy of the model. As a result, average modelled Lake water levels are predicted to decrease by very small amounts which will also be imperceptible. These changes are very small compared to natural variability. See HEC (2018b) for more details.

### 6.4.2 CUMULATIVE IMPACTS

Predicted cumulative drawdown impacts at the significant GDEs are quantified in **Table 6-4**, summarising effects such as those shown on **Figure 5-6**. These are for the cumulative impacts of all mines. The best estimate of peak drawdown is presented.

**Table 6-4 Cumulative Baseflow Capture and Groundwater Drawdown at Priority GDE**

| SITE | | PREDICTED MAX DRAWDOWN (m) | TIME TO WL RECOVERY | PREDICTED BASEFLOW CAPTURE | |
|---|---|---|---|---|---|
| | | | | MEAN | MAX |
| Thirlmere Lakes | Gandangarra | 0.05 | ~2150-2200 (150 years post-mining) | see **Table 5-5** | |
| | Werri Berri | 0.03 | | | |
| | Couridjah | 0.05 | | | |
| | Baraba | 0.05 | | | |
| | Nerrigorang | 0.05 | | | |
| North Pole Swamp | (upland swamp) | 0 | n/a | The nearest of the upland swamps to the Project | |

## 6.5 CULTURALLY SIGNIFICANT SITES

There are no Culturally Significant Sites listed in the relevant Water Sharing Plan. Hence there are no known risks of mine development to such sites.

## 6.6 SIMULATED IMPACTS ON GROUNDWATER LEVELS

### 6.6.1 IMPACTS OF TAHMOOR SOUTH PROJECT

The proposed Tahmoor South underground mine will cause depressurisation of the Permo-Triassic strata around the site. The Permian Bulli Coal seam within the mine footprint is predicted to be essentially dewatered during mining. Outside the mine footprint, depressurisation impacts on potentiometric pressures within Permo-Triassic strata will occur.

The maximum modelled drawdown impacts of the proposed mine development, along with the subsequent degree of water level recovery, are presented **Figure 5-2**, **Figure 5-3**, **Figure 5-7** and **Figure 5-8** (which shows cumulative drawdown, but the Tahmoor South drawdown can be inferred).

In general, and with reference to the figures listed above, the maximum water table drawdown associated with the Tahmoor South mine is around 1 m, with areas of >2 m (often 5-10 m) drawdown predicted to occur above and near the proposed Tahmoor South longwalls.

Recovery of the water table is complete across much of the area, which areas close to or above longwalls. There are no significant drawdowns or incomplete recovery in the Thirlmere Lakes alluvium in response to mining at Tahmoor South.

## 6.7 POTENTIAL IMPACTS ON EXISTING GROUNDWATER USERS

The simulated maximum drawdown impacts of the Tahmoor South mine expansion, in addition to the cumulative impacts of nearby groundwater users (bores) and surrounding mines on existing groundwater users in the region are presented for registered users, based on the Pinneena database and for specific bores identified in the project bore census (Geoterra, 2013a).

Because of the large number of registered bores in the active model area (791 bores), a list of the specific bores impacted above this 2 m maximum criterion are listed in Appendix I, while a summary of the number of registered bores impacted and the degree of impact is presented in **Table 6-5**. A map of the relevant bores, i.e. those at which a drawdown in excess of 2 m is predicted, and those predicted as being below the 2 m threshold is presented as **Figure 6-1**.

**Table 6-6** presents a list of the bores identified in the project bore census and presents the simulated drawdown impact at each. It should be noted that the drawdown values in **Table 6-5**, **Table 6-6** and Appendix I are the maximum impact at any given point in time in the predictive model. These tables are restricted to listing those bores that were modelled as being potentially impacted upon (cumulative or otherwise) in excess of the AI Policy criterion of 2 m maximum cumulative drawdown, for the base model and for the most severe drawdown from any of the sensitivity runs.

All listed drawdown impacts in **Table 6-5**, **Table 6-6** and Appendix I are modelled as occurring in the 'Highly Productive' porous Permo-Triassic rock aquifer. There are no known pumping bores within the most significant local alluvial body, the Thirlmere Lakes (Blue Gum Creek) alluvium.

To complete this task, bores were assigned to model layers (and aquifers) based on recorded bore location, mapped geological outcrop, such as the extent of the alluvial aquifer, and recorded bore depths where available. For these reasons it is possible that some bores have been incorrectly assigned to formations. Where no depth information is available for bores, model layer 1 has been assumed; i.e. it was assumed to be a shallow bore.

To avoid duplication, bores that are registered on Pinneena and were also picked up as part of the census are counted only in the 'registered bore' lists in **Table 6-5** and the count of afffected bores. However, for completeness, registered bores are included in **Table 6-6** where they were recrded as part of the project bore census.

### 6.7.1 IMPACTS OF TAHMOOR SOUTH PROJECT

The calibrated 'base case' model simulates a total of 30 registered bores (**Table 6-5**) and 3 census bores [which are unregistered] (**Table 6-6**) as potentially impacted by the Tahmoor South mine in excess of the 2 m drawdown criterion of the AI Policy (highlighted in red in Appendix I and **Table 6-6**). The number of bores impacted beyond 2 m rises to a possible 58 registered bores (**Table 6-5**) and 6 census bores (**Table 6-6**) respectively if predictive sensitivity is taken into account.

**Table 6-5 Number of Registered Bores with Predicted Impacts above threshold**

| DEGREE OF IMPACT | NO. OF BORES EXCEEDING THRESHOLD | | |
|---|---|---|---|
| | CALIBRATED 'BASE CASE' MODEL | | SENSITIVITY RUNS (MAX DRAWDOWN) |
| [m] | TAHMOOR SOUTH IMPACT | CUMULATIVE MINING IMPACT | ADDITIONAL BORES AFFECTED |
| **>2 metres** | **30** | 94 | +28 |
| Total bores in model area | 791 | | |

E:\HYDROSIM\TAHMOOR\Model\Processing\MaxDDN\Bores for Drawdown Assessment_v4TR045-047_&_senstivity_v3.xlsx

Of the 30 bores affected beyond 2 m due to the Tahmoor South project, 14 are predicted to experience greater than 5 m maximum drawdown, and 4 to experience greater than 10 m.

Tahmoor Coal have committed to "make good" provisions for any groundwater users shown to be adversely affected by mine operations and associated impacts (Section 6.11).

### 6.7.2 CUMULATIVE IMPACTS FROM MINING ACTIVITY

Accounting for cumulative impacts of mining at Tahmoor and the other mines within the groundwater model the number of impacted bores increases to 94 registered bores potentially affected (**Table 6-5**) and 8 sites from the project bore census (**Table 6-6**).

### Table 6-6 Modelled Impacts on Groundwater Bores from the Project Bore Census

| BORE | | | | | | | MODELLED MAXIMUM DRAWDOWN (at any time); [m] | | | Register-ed bore? |
|---|---|---|---|---|---|---|---|---|---|---|
| GW WORKS # (or alias) | LOCATION DESCRIPTION | EASTING | NORTHING | USED [Y/N] | DRILL DEPTH [m] | MODEL LAYER | TAHMOOR SOUTH IMPACT | CUMULATIVE MINING IMPACT | MAX IMPACT FROM SENSITIVITY RUNS TAHMOOR SOUTH | |
| GW011299 | near Thirlmere Lakes | 275273 | 6209450 | | | 1 | <2 | <2 | <2 | Y |
| GW073406 | near Thirlmere Lakes | 275273 | 6209444 | | | 1 | <2 | <2 | <2 | Y |
| GW062068 | near Thirlmere Lakes | 276581 | 6209579 | | | 1 | <2 | <2 | <2 | Y |
| Pulic | near Thirlmere Lakes | 276581 | 6209581 | | | 1 | <2 | <2 | <2 | N |
| GW101247 | near Thirlmere Lakes | 272151 | 6210333 | | 42 | 1 | <2 | <2 | <2 | Y |
| Smyth Well | near Thirlmere Lakes | 272238 | 6210218 | | | 1 | <2 | <2 | <2 | N |
| GW102439 | near Thirlmere Lakes | 274477 | 6210080 | | 115 | 1 | <2 | 7 | 11 | Y |
| TGW005 | Tahmoor South area | 278446 | 6206332 | N | | 1 | 3 | 3 | 4 | N |
| TGW004 | Tahmoor South area | 278363 | 6207827 | N | | 1 | <2 | <2 | <2 | N |
| TGW006 | Tahmoor South area | 279079 | 6203890 | N | | 1 | 3 | 3 | 5 | N |
| TGW003 | Tahmoor South area | 275956 | 6208076 | N | | 1 | <2 | 2 | 2 | N |
| TGW001 | Tahmoor South area | 273456 | 6207677 | N | | 1 | <2 | <2 | <2 | N |
| TGW002 | Tahmoor South area | 271875 | 6207163 | N | | 1 | <2 | <2 | <2 | N |
| P2 | Tahmoor North area | 277070 | 6211630 | | | 1 | <2 | 2 | 8 | N |
| P3 | Tahmoor North area | 277854 | 6211740 | | | 1 | <2 | 5 | 10 | N |
| GW067570 | Tahmoor North area | 277070 | 6213716 | | | 1 | <2 | <2 | 4 | Y |
| GW063525 | Tahmoor North area | 276568 | 6214326 | | | 1 | <2 | <2 | 3 | Y |
| GW042788 | Tahmoor North area | 280420 | 6210244 | | | 1 | <2 | <2 | <2 | Y |
| GW102344 | Bargo / Tahmoor South area | 280248 | 6206553 | | 110.00 | 1 | <2 | <2 | <2 | Y |
| GW014262 | Bargo / Tahmoor South area | 276764 | 6204587 | | 48.80 | 1 | <2 | <2 | <2 | Y |
| GW052016 | Bargo / Tahmoor South area | 280259 | 6203604 | | 110.00 | 2 | 7 | 8 | 13 | Y |

| BORE GW WORKS # (or alias) | LOCATION DESCRIPTION | EASTING | NORTHING | USED [Y/N] | DRILL DEPTH [m] | MODEL LAYER | MODELLED MAXIMUM DRAWDOWN (at any time); [m] TAHMOOR SOUTH IMPACT | CUMULATIVE MINING IMPACT | MAX IMPACT FROM SENSITIVITY RUNS TAHMOOR SOUTH | Register-ed bore? |
|---|---|---|---|---|---|---|---|---|---|---|
| GW053449 | Bargo / Tahmoor South area | 280369 | 6205813 | | 105.00 | 1 | 5 | 7 | 11 | Y |
| GW057969 | Bargo / Tahmoor South area | 281350 | 6206116 | | 108.00 | 2 | 3 | 5 | 7 | Y |
| GW072226 | Bargo / Tahmoor South area | 280704 | 6206868 | | 66.00 | 1 | <2 | <2 | <2 | Y |
| GW102418 | Bargo / Tahmoor South area | 278015 | 6201504 | | 79.00 | 1 | <2 | <2 | 4 | Y |
| GW019590 | Bargo / Tahmoor South area | 282131 | 6207118 | N | 80.00 | 1 | <2 | <2 | 3 | Y |
| GW028270 | Bargo / Tahmoor South area | 282471 | 6207897 | N | 83.80 | 1 | <2 | <2 | 2 | Y |
| GW100433 | Bargo / Tahmoor South area | 278540 | 6202588 | N | 126.00 | 1 | 32 | 33 | 70 | Y |
| G8 | Bargo / Tahmoor South area | 281559 | 6204177 | N | | 1 | 2 | 3 | 4 | N |
| GW072482 | Bargo / Tahmoor South area | 281952 | 6206909 | | | 1 | <2 | <2 | <2 | Y |
| GW104454 | Bargo / Tahmoor South area | 281410 | 6204568 | | | 1 | 2 | 3 | 5 | Y |
| GW101026 | Bargo / Tahmoor South area | 279751 | 6207946 | | | 1 | <2 | <2 | <2 | Y |
| GW106590 | Bargo / Tahmoor South area | 280442 | 6206344 | | | 3 | 5 | 8 | 11 | Y |
| GW107886 | Bargo / Tahmoor South area | 281276 | 6207377 | | | 1 | <2 | <2 | <2 | Y |
| GW007445 | Bargo / Tahmoor South area | 277454 | 6204323 | | | 1 | <2 | <2 | <2 | Y |
| GW056632 | Bargo / Tahmoor South area | 277202 | 6201580 | | | 1 | <2 | <2 | <2 | Y |
| GW059618 | Bargo / Tahmoor South area | 281587 | 6204277 | | | 1 | 2 | 3 | 4 | Y |
| GW101936 | Bargo / Tahmoor South area | 280604 | 6202851 | | | 2 | <2 | <2 | <2 | Y |
| G23 | Bargo / Tahmoor South area | 282654 | 6205666 | | | 1 | <2 | <2 | <2 | N |
| G24 | Bargo / Tahmoor South area | 278899 | 6201873 | | | 1 | <2 | <2 | <2 | N |
| G44 | Bargo / Tahmoor South area | 282388 | 6205638 | | | 1 | <2 | 2 | 3 | N |
| GW107546 | Bargo / Tahmoor South area | 278627 | 6204519 | | 41.00 | 1 | <2 | <2 | 4 | Y |
| GW051877 | Bargo / Tahmoor South area | 281673 | 6205875 | | 92.00 | 1 | <2 | 3 | 4 | Y |
| GW053450 | Bargo / Tahmoor South area | 282303 | 6205837 | | 120.00 | 2 | 2 | 4 | 5 | Y |

| BORE | LOCATION DESCRIPTION | EASTING | NORTHING | USED [Y/N] | DRILL DEPTH [m] | MODEL LAYER | MODELLED MAXIMUM DRAWDOWN (at any time); [m] | | | Register-ed bore? |
|---|---|---|---|---|---|---|---|---|---|---|
| GW WORKS # (or alias) | | | | | | | TAHMOOR SOUTH IMPACT | CUMULATIVE MINING IMPACT | MAX IMPACT FROM SENSITIVITY RUNS<br>TAHMOOR SOUTH | |
| GW054146 | Bargo / Tahmoor South area | 279886 | 6204676 | | 104.00 | 2 | 12 | 15 | 28 | Y |
| GW100562 | Bargo / Tahmoor South area | 277747 | 6201653 | | 91.00 | 1 | <2 | <2 | 4 | Y |
| GW102179 | Bargo / Tahmoor South area | 280953 | 6203826 | | 153.00 | 2 | 6 | 7 | 10 | Y |
| GW103235 | Bargo / Tahmoor South area | 281482 | 6208754 | | 134.00 | 3 | <2 | 3 | 4 | Y |
| GW103559 | Bargo / Tahmoor South area | 276499 | 6201858 | | 54.00 | 1 | <2 | <2 | <2 | Y |
| GW104008 | Bargo / Tahmoor South area | 280368 | 6205982 | | 140.00 | 3 | 3 | 4 | 6 | Y |
| GW104323 | Bargo / Tahmoor South area | 279259 | 6203318 | | 109.00 | 3 | 25 | 27 | 53 | Y |
| GW104689 | Bargo / Tahmoor South area | 276279 | 6201756 | | 66.00 | 1 | <2 | <2 | 2 | Y |
| GW105802 | Bargo / Tahmoor South area | 280547 | 6207174 | | 73.00 | 1 | <2 | 3 | 4 | Y |
| GW105847 | Bargo / Tahmoor South area | 277020 | 6204404 | | | 1 | <2 | <2 | 2 | Y |
| GW105883 | Bargo / Tahmoor South area | 277040 | 6204629 | | | 1 | <2 | <2 | <2 | Y |
| GW108538 | Bargo / Tahmoor South area | 281155 | 6205941 | | 66.00 | 1 | 2 | 3 | 4 | Y |
| GW109257 | Bargo / Tahmoor South area | 276603 | 6205052 | | 120.00 | 3 | 7 | 8 | 19 | Y |
| G53 | Bargo / Tahmoor South area | 276585 | 6201999 | | | 1 | <2 | <2 | <2 | N |
| GW109630 | Thirlmere area | 276049 | 6210284 | | 102.00 | 2 | <2 | 3 | 10 | Y |
| GW033916 | Thirlmere area | 273200 | 6206968 | | 108.20 | 1 | <2 | <2 | <2 | Y |
| GW037742 | Thirlmere area | 274479 | 6210236 | | 112.70 | 3 | <2 | <2 | 4 | Y |
| GW057274 | Thirlmere area | 272074 | 6211164 | | 115.00 | 2 | <2 | <2 | <2 | Y |
| GW111669 | Thirlmere area | 276232 | 6206450 | | 120.00 | 2 | <2 | 3 | 3 | N |
| GW013282 | Thirlmere area | 276627 | 6209270 | | 18.30 | 1 | <2 | 2 | 3 | Y |
| GW042825 | Thirlmere area | 273088 | 6207366 | | 114.60 | 1 | <2 | <2 | <2 | Y |
| GW032443 | Thirlmere area | 276415 | 6206336 | | 130.10 | 2 | 7 | 8 | 14 | Y |
| GW109032 | Thirlmere area | 271824 | 6206636 | | 132.00 | 1 | <2 | <2 | <2 | Y |

| BORE | LOCATION DESCRIPTION | EASTING | NORTHING | USED [Y/N] | DRILL DEPTH [m] | MODEL LAYER | MODELLED MAXIMUM DRAWDOWN (at any time); [m] | | | Register-ed bore? |
|---|---|---|---|---|---|---|---|---|---|---|
| GW WORKS # (or alias) | | | | | | | TAHMOOR SOUTH IMPACT | CUMULATIVE MINING IMPACT | MAX IMPACT FROM SENSITIVITY RUNS<br>TAHMOOR SOUTH | |
| GW037860 | Thirlmere area | 275178 | 6209914 | | 137.10 | 3 | <2 | 2 | 9 | Y |
| GW037289 | Thirlmere area | 275015 | 6209232 | | 137.10 | 3 | <2 | 3 | 5 | Y |
| GW035753 | Thirlmere area | 276668 | 6209703 | | 142.00 | 2 | 2 | 4 | 11 | Y |
| GW062068 | Thirlmere area | 272117 | 6205215 | | 149.40 | 3 | <2 | <2 | <2 | Y |
| GW037932 | Thirlmere area | 276597 | 6209616 | | 150.00 | 3 | 2 | 4 | 12 | Y |
| GW010584 | Thirlmere area | 272853 | 6211419 | | 95.00 | 1 | <2 | <2 | <2 | Y |
| GW012612 | Thirlmere area | 275340 | 6209548 | | 50.00 | 1 | <2 | <2 | <2 | Y |
| GW012611 | Thirlmere area | 275398 | 6210320 | | 57.90 | 1 | <2 | <2 | <2 | Y |
| GW034518 | Thirlmere area | 275711 | 6210081 | | 50.20 | 1 | <2 | <2 | 2 | Y |
| GW011234 | Thirlmere area | 274860 | 6209289 | | 76.20 | 1 | <2 | 2 | 5 | Y |
| GW011200 | Thirlmere area | 275883 | 6209314 | | 52.40 | 1 | <2 | <2 | <2 | Y |
| GW106281 | Thirlmere area | 275607 | 6210735 | | 60.90 | 1 | <2 | <2 | <2 | Y |
| GW105236 | Thirlmere area | 277018 | 6210748 | | 48.00 | 1 | <2 | <2 | 2 | Y |
| GW008548 | Thirlmere area | 275487 | 6211099 | | 73.00 | 1 | <2 | 2 | 4 | Y |
| GW042537 | Thirlmere area | 277099 | 6209867 | | 65.50 | 1 | <2 | 4 | 10 | Y |
| GW038060 | Thirlmere area | 274310 | 6209770 | | 121.90 | 1 | <2 | 2 | 4 | Y |
| GW110669 | Thirlmere area | 274680 | 6210364 | | 122.50 | 1 | <2 | <2 | 4 | Y |

source: E:\HYDROSIM\TAHMOOR\Model\Processing\MaxDDN\Bores for Drawdown Assessment_v4TR045-047_&_senstivity_v3.xlsx [CensusTableForReport]

## 6.8 POTENTIAL IMPACTS ON GROUNDWATER QUALITY

Mining-induced changes to the hydraulic properties and depressurisation of the strata in the mined area will result in mixing of potentially chemically different groundwater between overlying and underlying units. Initially the strong head gradients will mean that water from shallower aquifers will likely be unaffected, while groundwater in the deeper units and coal seams will be mixed with water flowing laterally and vertically toward the mine void. During the recovery phase the head gradients into the mine void will slowly weaken, and movement and mixing of water from the deeper layers into shallower units may occur.

There is the potential for the modification of flow paths through the zone of surface cracking (see Section 3.10.4). Resultant leakage of surface water into the shallow subsurface and subsequent re-emergence can result in a deterioration in the quality of that water. This will be considered in the Surface Water Assessment (HEC, 2018b).

Electrical conductivity data for the groundwaters in the Southern Coalfield indicates a general trend of increasing salinity with depth, with the Wianamatta Formation an exception to this. It is considered that mining-induced mixing of groundwater will result in changes to the salinity of the Hawkesbury Sandstone and Bulgo Sandstone, which are the two most commonly utilised aquifers. This is more likely in the Bulgo Sandstone, which is not as heavily utilised by bore users (Section 3.8.1), due to existing natural hydraulic gradients from the Illawarra Coal Measures up into the lower Bulgo Sandstone at many locations (see discussion of Vertical Head Profiles in Section 3.8.3). Where strata become fractured due to longwall extraction the connectivity between the poorer quality groundwater in the coal measures and the overlying Bulgo Sandstone will be increased. Subsequently, once this hydraulic gradient is re-established, which is predicted to occur after many decades, based on simulation of groundwater level recovery shown in **Figure 5-2** and **Figure 5-3**, then this may result in increased mixing of these groundwaters within the lower Bulgo Sandstone and possibly up in the lower Hawkesbury Sandstone.

It is possible that changes in salinity and specific nutrients (e.g. iron, manganese) could occur within the utilised groundwater systems in the Permo-Triassic rock aquifers in or around the mine lease. However, a reduction in the beneficial uses of the groundwater is unlikely. The risk of such impacts decreases with distance from longwall mine areas and associated rock mass deformation and fracturing. If a decline in water quality is detected in a private bore and is determined to be a result of mining, Tahmoor Mine's 'make good' provisions can be activated in response (Section 6.11).

### 6.8.1 IMPACTS OF TAHMOOR SOUTH PROJECT

There are no anticipated risks of reduced beneficial uses of the Nepean GMA porous rock aquifer as a result of the Tahmoor South mine.

The Project will continue to use the REA currently utilised by the Tahmoor/Tahmoor North operation. Monitoring has shown no adverse effects on groundwater quality due to reject emplacements, and this is expected to continue.

An assessment of surface water quality impacts on WaterNSW water supply catchments (Special Areas) has been carried out as part of the Surface Water Assessment (HEC, 2018).

## 6.9 OTHER IMPACTS OF MINING

**Mining near/under alluvial Water Sources**

The proposed underground at Tahmoor South mining will not take place beneath designated alluvial Water Source and will be 3-4 km from the nearest mapped body of alluvium lying along the Thirlmere Lakes and Blue Gum Creek.

Therefore, there is no need to consider the AI Policy's requirements for mining activity beneath or near to alluvial water sources, which are required for consideration when a mine approaches within a few hundred metres of a designated alluvial water source.

**Baseflow capture within WaterNSW Special Areas**

Quantification of baseflow capture impacts on Special Areas is covered in Section 6.3.3.

## 6.10 SUMMARY OF ASSESSMENT IN TERMS OF THE AI POLICY

**Table 6-7** summarises the preceding discussion of potential impacts of the Tahmoor South mine expansion in terms of the AI policy Minimal Impact Considerations.

### Table 6-7 Summary of AI Policy Assessment – Permo-Triassic Porous Rock

| | |
|---|---|
| **Aquifer** | **Sydney Basin Porous Rock**<br>**(Nepean Groundwater Source, Management Zone 2)** |
| **Category** | **Highly Productive Groundwater** |
| **Level 1 Minimal Impact Consideration** | **Assessment** |
| **Water Table**<br>Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any:<br>(a) high priority groundwater dependent ecosystem; or<br>(b) high priority culturally significant site;<br>listed in the schedule of the relevant water sharing plan.<br>OR<br>A maximum of a 2 m water table decline cumulatively at any water supply work. | The relevant Water Sharing Plan is the 'Greater Metropolitan Groundwater Sources' (most recent version from 1 October 2011).<br>There are no Culturally Significant Sites in the Study Area listed in the WSP. Hence there are no known risks of mine development to such sites.<br>There are three High Priority Groundwater Dependent Ecosystems (GDEs) in the Study Area:<br>Thirlmere Lakes - There is a risk of groundwater drawdown <0.03 m from Tahmoor South Project and 0.05 m peak drawdown from Cumulative Impact mining in the alluvium underlying the lakes – lake level reductions are discussed in HEC (2018). The cumulative impact groundwater drawdown is (close to or) above the 10% threshold criterion.<br>Other GDEs (e.g. O'Hares Creek and Macquarie Rivulet) are beyond the boundaries of the impact assessment model.<br>There is probable risk of drawdown in excess of the water supply work drawdown criterion within the Permo-Triassic strata.<br>**Level 2 minimal impact consideration classification.** |
| **Water pressure**<br>A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work. | Probable risk of drawdown in excess of the criterion within the Permo-Triassic strata.<br>**Level 2 minimal impact consideration classification.** |
| **Water quality**<br>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. | Mining-induced changes to the hydraulic properties and depressurisation of the strata in the Tahmoor South Project area will result in mixing of potentially chemically different groundwater between overlying and underlying units. However, it is considered unlikely that this will result in changes to the beneficial uses of groundwater in the Permo-Triassic rock units. The risk of such impacts decreases with distance from the mine footprint.<br>**Level 1 minimal impact consideration classification.** |

Given the simulated potential cumulative impact on the water table at Thirlmere Lakes as well as on existing groundwater users' bores within the Permian and Triassic strata, the Tahmoor South project falls within the AI Policy Level 2 classification of the minimal impact considerations. No other minimal impact considerations have been identified in this assessment.

## 6.11 MITIGATION AND MANAGEMENT

Based on the findings summarised in Section 6.10, the Tahmoor South project will require risk mitigation, prevention or avoidance strategies to be identified in this preliminary groundwater assessment. A Groundwater Management Plan (GWMP) will require development and approval, using the existing GWMP as a basis. This will need to define a groundwater monitoring strategy for the Project (if approved), and the specification of groundwater level triggers, and a Trigger Action Response Plan (TARP).

It is recommended that the Project continue to develop and maintain a regional groundwater monitoring network designed to monitor for the advent of the identified potential drawdown risks to existing users' water works. Much of the required infrastructure (i.e. monitoring bores) is already in place. The installation of this network and commencement of monitoring at Tahmoor South approximately 8-10 years prior to the proposed commencement of mining at the Project is commendable. However, we note (as per GES, 2017) that some monitoring sites, escpailly the TBC bores, might require repair/replacement/augmentation to improve confidence.

Given the number of bores that have either failed or been decommissioned, it is recommended that a full review of this be carried out if the Tahmoor South Project is approved, and at the time that the Tahmoor GWMP is revised. Pending Project approval, tree recommendations re: monitoring of groundwater levels are:

- To re-install at least one bore in the footprint of a Tahmoor North longwall (e.g. at TNC029) to monitor post-mining groundwater level and groundwater quality.
- Conduct a condition assessment of bores and monitoring equipment (VWPs) of TBC bores around Tahmoor South, with a specific update of the GWMP at that time. The revised GWMP should then include a proposal to replace some of the Tahmoor South TBC bores or re-instate piezometers as necessary prior to the commencement of mining.
- Monitoring in longwall centre-lines of pre- and post-mining conditions are recommended for Tahmoor South (consistent with recommendations in PSM, 2017). This should be done for the first longwall, and then every two or three after that. This should involve packer testing followed by installing VWPs at four elevations in the Hawkesbury Sandstone and then two in the Bulgo Sandstone to assist in defining a profile of fracturing and depressurisation above longwalls (like the Longwall 10A HoF hole but monitoring pre- and post-mining conditions). This would allow some adaption of longwall geometry if deemed necessary.

Additional reviews of groundwater monitoring data should be conducted on an annual basis (or more frequently as required), similar to that of GES (2017). This will assist in understanding actual groundwater drawdown levels to those predicted by the numerical model. This will also serve as progressive model 'verification'.

Bores that can allow water quality sampling from the mid/lower Hawkesbury Sandstone and Bulgo Sandstone are recommended around the Tahmoor South area.

Annual monitoring of the downgradient bore at the REA is recommended. Past performance indicates that there has been no adverse impact on groundwater quality, however monitoring should be carried out.

The mine should consider improvement to the measurement of the volumetric take (total mine inflow). Currently three pumps serve as the metering points, but it might serve the mine to better understand inflow to different parts of Tahmoor North, given that some areas of those workings might be used as storage for groundwater during the operation of Tahmoor South. The overall water take, accounting for freshwater inputs to the mine and inferred groundwater ingress, should be reported publicly on an annual basis, if not done so already. This can be used periodically, in conjunction with the regional monitoring network data, to verify the numerical modelling and the potential risks of mining activity identified in this assessment. This should include revision of the modelling and identified risks as required.

The simplest means of addressing and managing the potential bore impacts is via the existing process to allow the mine to 'make good' on the impacted users' water sources. Tahmoor Coal has been operating this process during the life of Tahmoor/Tahmoor North. The process allows for bore owners to apply to Tahmoor Coal if they believe their bore's level or water quality has declined and have an assessment of whether the mine is the cause of this. If it is deemed that the mine in responsible, then remedial actions could involve deepening and/or replacing bores and wells, and/or providing an alternative water source to affected users. Details of this are in the Tahmoor Groundwater Management Plan (Tahmoor Coal, 2016). As discussed with Tahmoor personal, this process has been successfully enacted twice in the last decade, with one bore owner being provided with access to municipal water supply (after a re-drilled bore proved unsuccessful) while the other bore owner's case was being dealt with by the government Mine Subsidence Board/Subsidence Advisory NSW.

Tahmoor Coal has committed to continue this 'make good' process through the proposed operation of Tahmoor South. Before such a process is instigated it is recommended that all water works identified as being potentially adversely affected in this assessment are surveyed for their existence, location, use, and construction details, and with periodic groundwater level and water quality monitoring carried out to provide a baseline. Subsequent to this, remedial action can be planned and undertaken as required.

# 7 CONCLUSIONS

The numerical model developed as part of the Groundwater Assessment for the Tahmoor South Project was designed to address the following:

- Development of a regional-scale 3-dimensional numerical groundwater flow model. This was based on data analysis and subsequent development of a conceptual hydrogeological model, as well as through consideration of elements of other specialist assessments produced for this project, notably:
  - Shallow Groundwater Baseline Monitoring (Geoterra, 2013a,b);
  - Subsidence (MSEC, 2018);
  - Ecology (Niche, 2018);
  - Surface water (HEC, 2018a,b,c,d);
  - Geotechnical Aspects and Permeability of Overburden (SCT, 2013); and
  - Height of Fracture (HoF) Report (SCT, 2014).
- Steady state model calibration to observed groundwater level data, using a single parameter zone for each hydrostratigraphic unit;
- Transient model calibration against observed groundwater level fluctuation data and against calculated groundwater inflows to the existing Tahmoor Mine;
- Constraint of the hydraulic conductivities by the well-populated permeability dataset based on core and packer tests at Tahmoor Mine;
- Transient prediction for the remaining Tahmoor North plan and the proposed 15-year Tahmoor South mine plan, conducted with a temporal resolution matching one longwall year being extracted per model stress period, of the extraction schedule, followed by a minimum 100-year simulation of the post-mining recovery period (>450 years post-mining was simulated);
- Preparation of this Groundwater Assessment report for inclusion in the Tahmoor South EIS that includes assessment of potential underground mine groundwater impacts and cumulative impacts with other existing and approved mines and groundwater extraction by other non-mining users. This assessment focussed on the criteria specified by the AI Policy:
  - Licensable takes of water (and their partitioning);
  - Water table drawdown;
  - Pressure head drawdown;
  - Groundwater quality impacts;
  - Identification of further information requirements that may be needed where determination of the AI Policy criteria cannot be made; and
- Proposed measures to avoid, mitigate and/or offset (if necessary) potential impacts on groundwater resources and recommendations for future groundwater monitoring to measure actual impacts on groundwater associated with the development.

A review of the data, literature and conceptual hydrogeology associated with other mines in the area, and other hydrogeological studies was carried out as a basis for model development. This was supported by a review of currently available information on geology, rock mass hydraulic properties, neighbouring mine workings and strata geometry for the area, as well as of the recent investigations carried out for Tahmoor Coal above Longwall 10A (SCT, 2014). Due consideration was given to the setup and creation of model boundaries and surface water/groundwater interaction processes. Justification for the modelling approaches that were used has been given within this report. Care was taken to ensure that hydraulic parameters within the model were maintained within realistic ranges that were based on actual measured data or published information for this region. Recharge rates were based largely on analysis of groundwater level and river flow data and on model calibration, but the zones and values in the model reflect the conceptual hydrogeology for the Study Area.

This groundwater assessment is designed to support the proposed Tahmoor South Project's EIS. This Project comprises underground coal mine workings in the Bulli Coal seam, the uppermost seam in the Permian-age Illawarra Coal Measures, using the longwall method.

These impacts were to be assessed for the 'highly productive' Permo-Triassic (Sydney Basin Nepean Groundwater Source) porous rock aquifer.

The key findings of this assessment are:

- The predicted total annual take of groundwater from the Permo-Triassic rock aquifer as mine inflows to the Tahmoor South Project is approximately 5 ML/d on average, peaking at an annualised rate of 7.5-8 ML/d (or up to 2,900 ML for a 12-month period) toward the end of the operational life of this Project in the mid-late 2030s. This mine inflow is derived from a range of depletion sources. Sensitivity analysis indicated a range in peak inflows from around 3,700 ML/a), however the best estimate for licensing to cover the predicted peak groundwater take by the Tahmoor South mine is 2,700 ML/a. Tahmoor already hold 1642 entitlement shares.
- The average groundwater take from neighbouring GMAs is:
  - <1 ML/a from the Nepean GMA MZ1,
  - <1 ML/a from Sydney Basin – Central, and
  - zero from Sydney Basin South.
- The take from the other areas are in the range 0-1 ML/a. In practical terms these do not appear significant enough to license as the total licence recommended for the mine from the Nepean GMA MZ2 is sufficient to cover the total take.
- The average total water take from the Permian fractured rock aquifer is 1700-2000 ML/a, with most via the depletion of aquifer storage, 200 and 180 ML/a each from reduced baseflow and evapotranspiration, and 1 ML/a from other groundwater sources (GMAs) as described above.
- Mining-induced changes to the hydraulic properties and depressurisation of the Permian and Triassic porous and fractured rock strata will result in mixing of potentially chemically different groundwater between overlying and underlying units. However, it is considered unlikely that this will result in changes to the beneficial uses of hydrogeological units utilised for water supply.
- A number of High Priority GDEs are identified in the relevant WSP:
  - The nearby Thirlmere Lakes are predicted to experience groundwater drawdown of <0.03 m due to the operation of Tahmoor South Project and less than 0.1 m from all nearby mines. The Tahmoor South Project is predicted to result in a small change in the rate of water loss from the lakes. Cumulative effects are predicted to be higher – these effects are address in the HEC (2018).
  - With the exception Thirlmere Lakes (above), the other High Priority GDEs are over 20 km away (e.g. O'Hares Creek, Macquarie Rivulet estuary) and so lie outside the active domain of the impact assessment model. Because of the distance they are expected to experience no drawdown impact or baseflow depletion as a result of the Tahmoor South Project. This statement is supported when considering the magnitude of drawdown impacts at Thirlmere Lakes (located <4 km away).

- The noted cumulative water table drawdown impacts at the Thirlmere Lakes mean that the proposal is classified within Level 2 of the AI Policy's minimal impact considerations.
- No culturally significant sites are identified in the relevant water sharing plan. Hence the proposal is not considered a risk to such sites.
- There is no proposed mining activity within the AI policy's specified proximities to any declared alluvial water sources, nor to the local Thirlmere Lakes/Blue Gum Creek alluvium, nor is there any proposed excavation of alluvial material. Hence the proposal poses no risks in this regard.
- The calibrated 'base case' model simulates 30 registered bores as being impacted upon by the proposed Tahmoor South mine in excess of the 2 m drawdown criterion of the AI Policy. Sensitivity analysis suggests that a further 28 registered bores might be affected beyond the 2 m threshold. Accounting for cumulative impacts, which have been calculated by simulating the operation of nearby mines, the number of potentially impacted bores increases to 94. A small number of unregistered bores, captured as part of the bore census, may also be affected (up to 8 such bores).
- The noted drawdown impacts on the Permian fractured rock aquifer mean that the proposal is classified within Level 2 of the AI Policy's minimal impact considerations.
- These simulated risks will require monitoring and mitigation measures. The latter will likely comprise deepening and/or replacing impacted bores and wells, and/or providing an alternative water source to affected users. Tahmoor Coal have committed to such 'make good' provisions for affected groundwater users.
- A Groundwater Management Plan will require development and approval. This will need to define groundwater level triggers, and Trigger, Action, Response Plans (TARP).

## 7.1 RECOMMENDATIONS FOR FUTURE WORK

Following approval of the Tahmoor South Project, it is recommended that this Groundwater Assessment and numerical model are regularly reviewed and updated for the purposes of on-going management, based on future events, possibly including:

- As mining progresses at Tahmoor North, longwalls will approach and potentially mine close to and even through more of the multi-level bores fitted with VWPs. These should provide additional information on the height to which depressurisation occurs, and the magnitude of any depressurisation, within the Permo-Triassic strata above the Bulli coal seam.
- Some replacement of failed bores around Tahmoor North and Tahmoor South – to be address in the next version of the GWMP.
- Pilot points calibration of some hydrogeological units (model layers) within the numerical model. The focus should initially be on the Hawkesbury Sandstone (layers 1-3), Bald Hill Claystone ($k_z$ of Layer 4), Bulgo Sandstone ($k_x$ and $k_z$ of Layers 5-6), and to a lesser degree on the Scarborough Sandstone ($k_x$ and $k_z$ of Layers 8-9) and Bulli Coal seam, as guided by the discussion on 'identifiability' in Section 4.10. This may also improve simulation of heads, and to a lesser degree on inflows to different areas of the Tahmoor mine which may be better understood in future if the monitoring of inflows is improved. However, this would also require significant changes to the numerical model to reduce the cell count and therefore reduce the model run time.
- Review of modelled timing of roadway development and longwalls to ensure scheduling is as accurate as possible. This might reduce some structural error in model calibration.

# 8 REFERENCES


Adhikary, D. and Wilkins, A. (CSIRO ACARP) 2012. *Reducing the Impact of Longwall Extraction on Groundwater Systems.* ACARP project C18016.

Advisian, 2016. *Literature Review of Underground Mining Beneath Catchments and Water Bodies*. Report for WaterNSW by Advisian, John Ross, PSM, Mactaggart and Grant Sutton & Assoc. December 2016.

Barber, E., 2018, *Crossing Three Deep Valleys: The Sedimentology, Geomorphology and Palaeo-environments of Thirlmere Lakes, N.S.W.* Honours Thesis, University of Wollongong *(unpublished).*

Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A., 2012, *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.

Bio-Analysis 2009. *Aquatic Ecology Assessment for Bulli Seam Operations*, Report for Illawarra Coal. http://www.bhpbilliton.com/home/aboutus/regulatory/Documents/Bulli%20Seam%20Operations/Appendix%20D%20-%20Aquatic%20Ecology%20Assessment.pdf

Cartwright, I., Weaver, T., and Tweed, S. 2008. *Integrating physical hydrogeology, hydrochemistry, and environmental isotopes to constrain regional groundwater flow: southern Riverine Province, Murray Basin, Australia*. IAH Special Publication, Vol 11, pp. 105-134. http://books.google.com.au/books?hl=en&lr=&id=_oiL-l4TxIoC&oi=fnd&pg=PA105&ots=Iix1fSWbCd&sig=6PAYyxn33OKGT23mvzdKsCZ_pO8#v=onepage&q&f=false

Cartwright, I., Gilfedder, B., and Hofmann, H. 2013. *Contrasts between chemical and physical estimates of baseflow help discern multiple sources of water contributing to rivers*. Hydrology and Earth System Sciences Discussions, 10, 5943-974.

Chow, V.T., 1959, *Open-channel hydraulics.* New York, McGraw-Hill.

Coffey, 2012. *Groundwater Study – Area 3B Dendrobium Coal Mine: Revised Numerical Modelling*. Report GEOTLCOV24507AB-AB2 to BHP Billiton. http://www.bhpbilliton.com/home/aboutus/regulatory/Documents/Dendrobium%20Subsidence%20Management%20Plan%20Area%203B/AttachmentC-Groundwater_Study.pdf

Coffey, 2012. *Groundwater Study – Area 3B Dendrobium Coal Mine: Data Analysis*. Report GEOTLCOV24507AB-AB1 to BHP Billiton. November 2012. Not publicly available.

Crosbie, R. 2015. *Groundwater recharge to coal basins in eastern Australia* – Bioregional Assessments programme. Presentation to the Australian Groundwater Conference, Canberra, November 2015.

Doherty, J. 2010. *PEST: Model-Independent Parameter Estimation User Manual* (5th ed.): Watermark Numerical Computing, Brisbane, Queensland, Australia.

Galvin, J.R., 2017a. *Review of PSM report on height of fracturing - Dendrobium Area 3B*, Review commissioned by the NSW Department of Planning and Environment.

Galvin and Associates, 2017b. *Expert Advice on Wallarah 2 – Subsidence Impacts*. Advice to NSW Planning Assessment Commission, 11 November 2017. http://www.pac.nsw.gov.au/resources/pac/media/files/pac/projects/2017/09/wallarah-2-coal-project/determination/determination-report-wallarah-2-20180116--with-appendices.pdf

Geoterra, 2013a. *Tahmoor South - Shallow groundwater baseline monitoring*. Report for Tahmoor Coal, document BAR3 - R1A.

Geoterra, 2013b. *Tahmoor South Project Reject Emplacement Area Acid & Metalliferous Drainage and Spontaneous Combustion Assessment,* Report for Tahmoor Coal, document BAR4-R1B.

Geoterra, 2016. *Tahmoor Colliery Longwall 29 Surface Water, Dams and Groundwater End of Panel Monitoring Report.* Report for Tahmoor Coal, document TA28-R1B.

Groundwater exploration Services [GES], 2017. Tahmoor Vibrating Wire Piezometer Monitoring Status Update, November 2017.

Guo, H., Adhikary, D.P., and Gabeva, D. (CSIRO), 2007. *Hydrogeological Response to Longwall Mining* - Exploration and Mining Report P2007/692. ACARP Project C14033.

Gippel, C.J. 2013. *Tahmoor South Project Environmental Impact Statement Technical Specialists Report - Geomorphology*. Fluvial Systems Pty Ltd, Stockton. Report for Tahmoor Coal, December 2013.

Harbaugh and McDonald, 1996. *User's Documentation for MODFLOW-96*, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model. U.S. GEOLOGICAL SURVEY Open-File Report 96-485.

Heritage Computing, 2010. *Bulli Seam Operations (BSO – 'Appin') Groundwater Assessment*. Report HC2010/7 for Illawarra Coal / BHP.

Heritage Computing, 2011. Recalibration of the Dendrobium Local Area Groundwater Model after Completion of Longwall 6 (Area 3A). Report HC2011/13 for Illawarra Coal / BHP.

Heritage Computing, 2012a. Bargo Coal Project Pre-Feasibility Study – Preliminary Groundwater Impact Assessment. Report HC2012/12 for Tahmoor Coal / Xstrata.

Heritage Computing, 2012b. *An Appraisal of Groundwater Conditions in the Vicinity of Thirlmere Lakes, NSW*. Report for Tahmoor Coal, doc HC2012/3. March 2012.

Heritage Computing, 2012c. Springvale Mine Modelling Review and Groundwater Mine Inflow Assessment. Report HC2012/14 for Springvale Pty Ltd.

Heritage Computing, 2012d. End-of-Panel Groundwater Assessment for Dendrobium Longwall 7 (Areas 3A). Report for Illawarra Coal, document HC2012/9.

Hutton, A.C., 2009. *Geological Setting of Australasian Coal Deposits*. University of Wollongong, NSW. http://ro.uow.edu.au/cgi/viewcontent.cgi?article=1772&context=scipapers

Hydro Engineering & Consulting [HEC], 2018a. *Tahmoor South Project - Surface Water Baseline Study*. Report for Tahmoor Coal, doc: J1210-2_SWBS_R2.

Hydro Engineering & Consulting [HEC], 2018b. *Tahmoor South Project - Surface Water Impact Assessment*. Report for Tahmoor Coal, doc: J1210-2_SWIA_R2.

Hydro Engineering & Consulting [HEC], 2018c. *Tahmoor South EIS - Water Management System and Site Water Balance*. Report for Tahmoor Coal, doc: J1210-2_WMSandSWB_R2.

Hydro Engineering & Consulting [HEC], 2018d. *Tahmoor South EIS - Flood Study*. Report for Tahmoor Coal, doc: J1210-2_SWFS_R1.

HydroGeologic Inc., MODFLOW SURFACT Software (Version 3.0), Herndon, VA, USA.

HydroSimulations (2016), *Dendrobium Area 3B - Longwalls 14-19 Subsidence Management Plan: Addendum to Groundwater Assessment and Response to Submissions,* Report HC2016/32 for Illawarra Coal.

IESC (2015). *Information Guidelines for the IESC advice on coal seam gas and large coal mining development proposals.* Available via. http://www.iesc.environment.gov.au/

Karacan, C., Ruiz, F.A., Cote, M., Phipps, S. 2011. *Coal Mine Methane: a review of capture and utilization practices with benefits to mining safety and greenhouse gas reduction*. International Journal of Coal Geology, 86 (2011) 121-156. http://www.epa.gov/cmop/docs/cmm-paper-2011.pdf

Mackie, C. D. 2013*. Post Processing of Zone Budgets to Generate Improved Groundwater Influx Estimates Associated with Longwall Mining*. Ground Water. 2013 Jul 29. doi: 10.1111/gwat.12097.

MBGS, 2013. *Tahmoor South Project Feasibility Study: Geology and Coal Resources*. Report for Glencore Xstrata, prepare by McElroy Bryan Geological Services, August 2013.

McNally, G. and Evans, R. 2007. *Impacts of longwall mining on surface water and groundwater, Southern Coalfield NSW*. Report by eWater CRC for NSW Dept of Environment and Climate Change. http://www.ewater.com.au/uploads/files/McNally_Evans-2007-Longwall_mining.pdf

Meaney, K. 1997. Investigation of the potential for pre-drainage of the lower seams at Appin Colliery utilising hydraulic fracturing. ACARP project C5036. CSIRO, Australia.

Moffit R.S., 1999, Southern Coalfield Regional Geology 1:100 000, 1st edition. Geological Survey of New South Wales, Sydney.

MSEC, 2018. *Tahmoor South Project – Longwalls 101 to 109. Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of the Environmental Impact Statement*. Report for Tahmoor Coal. MSEC997a.

Murray Darling Basin Commission, 2001. *Groundwater Flow Modelling Guideline*. Prepared by Middlemis, H., Merrick, N. and Ross, J., November 2000, Aquaterra Project No. 125, Final guideline issued January 2001.

Niche, 2018. *Tahmoor South Project – Biodiversity Assessment*. Report for Tahmoor Coal.

NSW Office of Water (NOW), 2011a. *Report Card for the Nepean Sandstone Groundwater Source*.

NSW Office of Water (NOW), 2011b. *Water Sharing Plan – Greater Metropolitan Regional Groundwater Sources: Background Document*. http://www.water.nsw.gov.au/__data/assets/pdf_file/0005/548105/wsp_metro_groundwater_background.pdf

NSW Government, 2012. *Aquifer Interference Policy*. September 2012.

NSW Chief Scientist and Engineer, 2013. *Thirlmere Lakes Inquiry – Review of the Final Report of the Independent Committee.* February 2013. http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0020/29621/CSE-Review-of-Thirlmere-Lakes-Inquiry-Final-Report.pdf

Parsons Brinckerhoff, 2013. *Water Quality Investigation Camden Gas Project*. Report for AGL Upstream Investments, July 2013.

Pells Consulting, 2011a. *The Water Levels of Thirlmere Lakes*. Pells Consulting Report P053.R1.

Pells Consulting, 2011b. *APPENDIX A* (to Thirlmere Lakes Report). http://www.pellsconsulting.com.au/downloads/appendicesToThirlmereLakesReport.pdf

Pells, P. and Pells, S. 2016(?). *The Water Levels of Thirlmere Lakes – Where did the water go and when will it return*?.

PSM, 2017. *Height of cracking - Dendrobium Area 3B, Dendrobium Mine* (No. PSM3021–002R), Report commissioned by the NSW Department of Planning and Environment.

Planning Assessment Commission (PAC), 2010. *Bulli Seam Operations – PAC Report*. NSW Planning Assessment Commission, July 2010. https://majorprojects.affinitylive.com/public/4acfbefb562c74c619405e3b4b37d00f/PAC%20Report.pdf

Prudic, D.E., Konikow, L.F., Banta, E.R. 2004. *A New Streamflow-Routing (SFR1) Package to Simulate Stream-Aquifer Interaction with Modflow-2000*: U.S. Geological Survey Open-File Report 2004-1042, 104 p.

Rose G., 1966, *Wollongong 1:250 000 Geological Sheet SI/56-09*, 2nd edition, Geological Survey of New South Wales, Sydney.

Russell G.N., Green R.T., Spencer J., Hayes J. (2010) *Thirlmere Lakes groundwater assessment*, NSW Office of Water, Sydney.

SCT, 2013. Review of Hydraulic Conductivity and Geotechnical Characteristics of the Overburden at Tahmoor South. SCT Report for Tahmoor Coal, Report TAH4083 Rev1.

SCT, 2014. Longwall 10A Height of Fracture Borehole for Tahmoor South Project – Observations, Measurements, and Interpretation. Report for Tahmoor Mine, doc TAH4125, March 2014.

Scanlon, B.R. Healy, R.W. and Cook, P. 2002. *Choosing appropriate techniques for quantifying groundwater recharge.* Hydrogeology Journal 10:18-39.

Schädler, S, and Kingsford, R.T., 2016. *Long-term changes to water levels in Thirlmere Lakes–drivers and consequences*. Centre for Ecosystem Science, UNSW.

Sloto, R.A. 1988. A computer method for estimating ground-water contribution to streamflow using hydrograph-separation techniques. National Computer Technology Meeting, Phoenix, Arizona.

Tammetta, P., 2013. *Estimation of the height of complete groundwater drainage above mined longwall panels*. Groundwater, Volume 51, No. 5, p. 723–734. Paper accepted 2012, published 2013.

Tammetta, P., 2014. Estimation of the Change in Hydraulic Conductivity above Mined Longwall Panels. Groundwater, gwat.12.153.

Tammetta, P. and Hawkes, G. 2009. *Pump testing of Mesozoic Sandstones*. IAH Sydney Basin Symposium, Sydney.

Tammetta, P., and Hewitt, P. 2004. *Hydrogeological properties of the Hawkesbury Sandstone in the Sydney Region*. Australian Geomechanics, Vol 39, No. 3, pp.91-107.

Turner, J., Lambert, M. and Knott, J. 1996. *Nutrient Inputs from rainfall in NSW State Forests.* Forest Research and Development Division, State Forests NSW.

University of Wollongong, 2012. *Bioregional Assessment project: Sydney Metropolitan, Southern Rivers and Hawkesbury-Nepean Catchments*. ro.uow.edu.au/cgi/viewcontent.cgi?article=1376&context=smhpapers

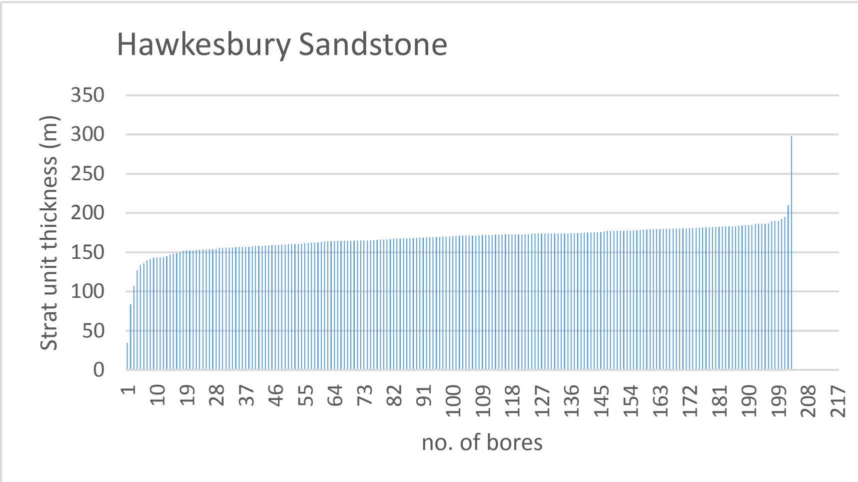
Verdon-Kidd, D.C. and Kiem, A.S. 2009. Nature and causes of protracted droughts in southeast Australia: Comparison between the Federation, WWII, and Big Dry droughts. Geophysical Research Letters, Volume 36, Issue 22, November 2009.

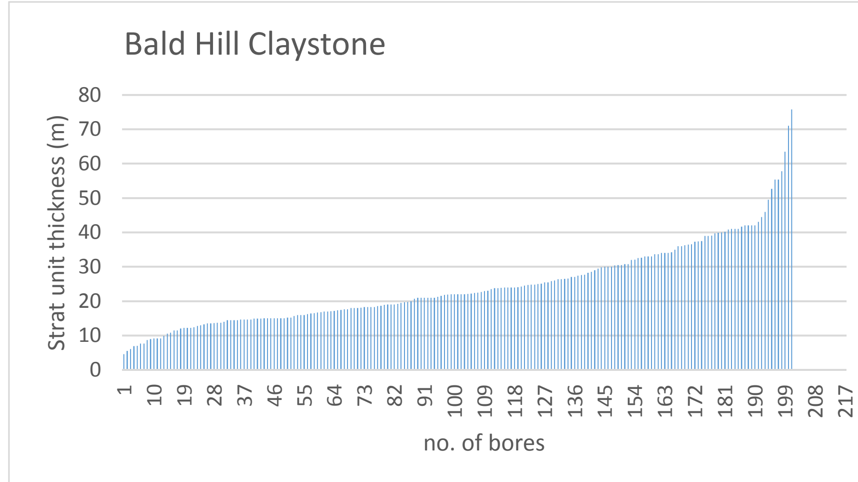
Vorst, P. 1974. *Geomporphic Environment and Evolution of Thirlmere Lakes, NSW*. Honours Thesis, Macquarie University.

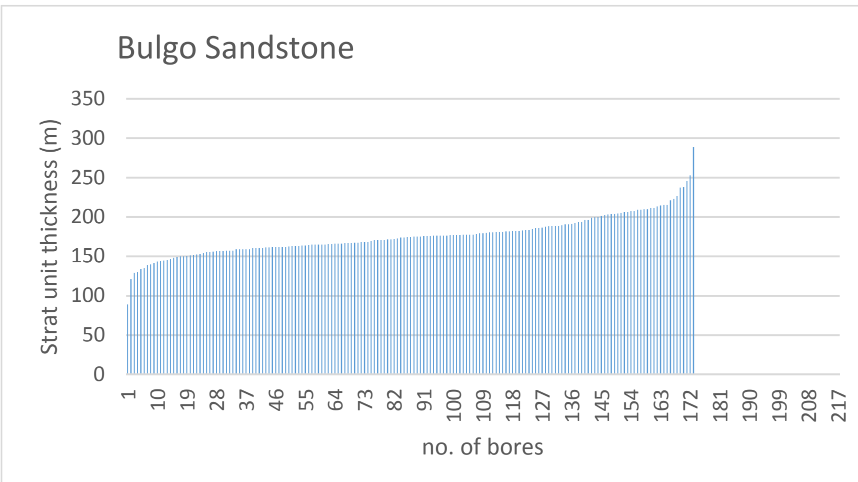
# APPENDIX A

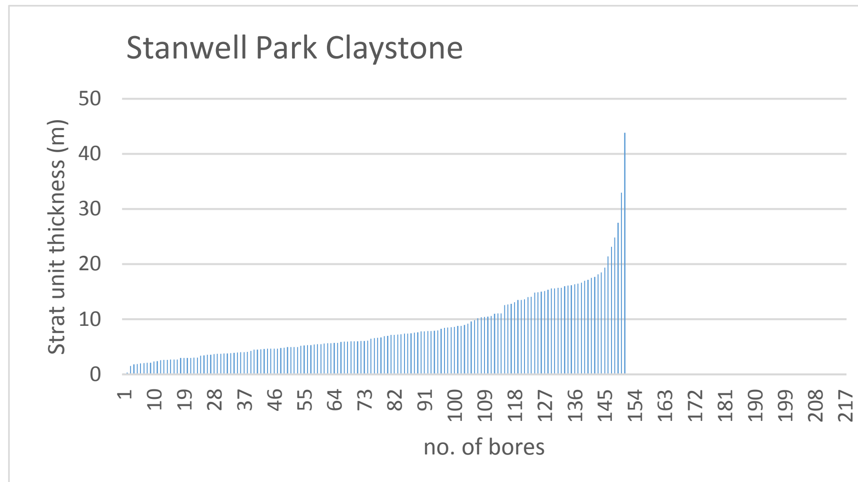
## Summary of stratigraphic thickness from Tahmoor bore logs

**Bore-by-bore stratigraphic interpretation**



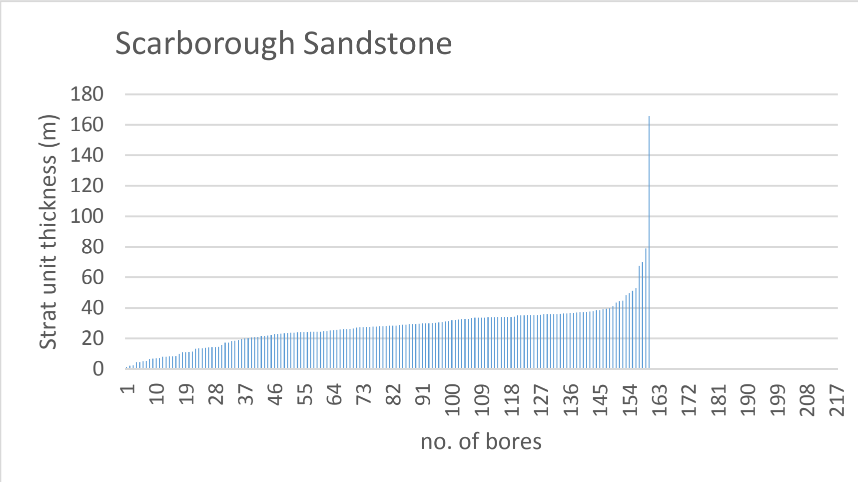



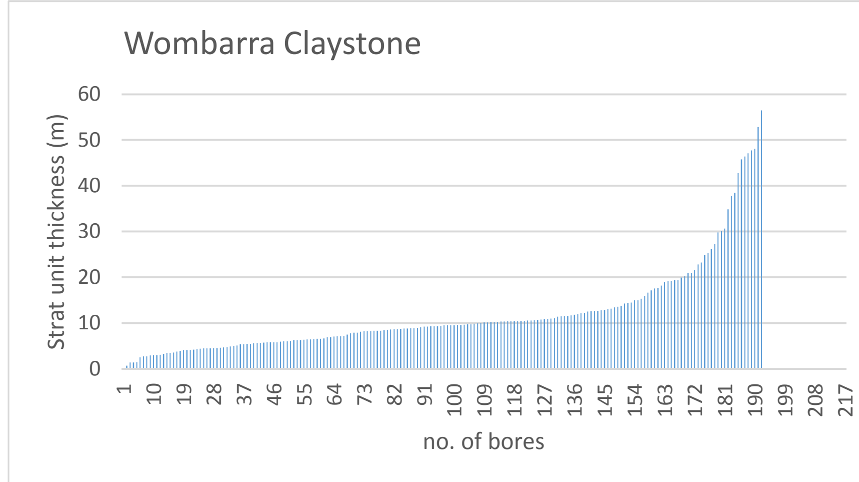



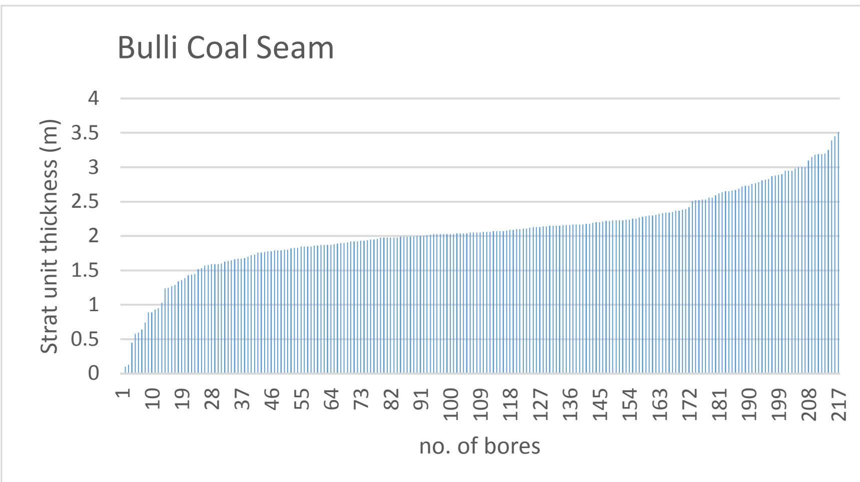



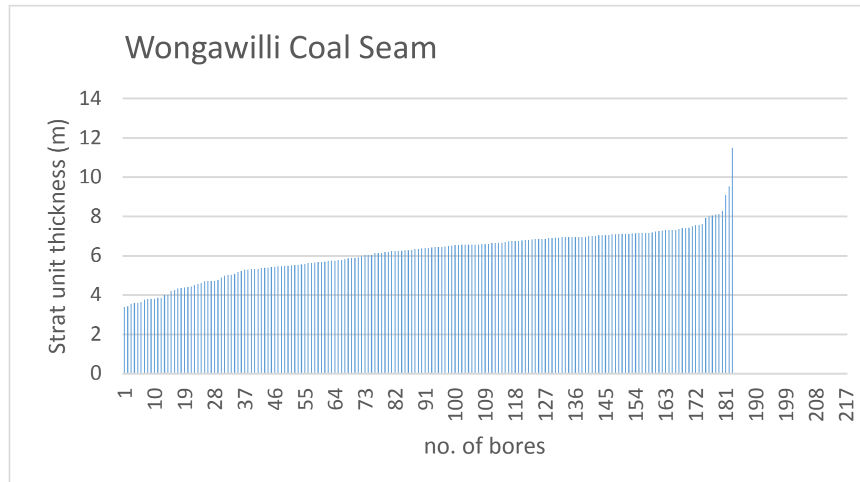

C:\HydroSim\TAH001\Tech\Geology\BoreholeData\[Bore_StratThickness_Summary.xlsx]BoreStratThicknessSummary

## Bore-by-bore stratigraphic interpretation




C:\HydroSim\TAH001\Tech\Geology\BoreholeData\[Bore_StratThickness_Summary.xlsx]BoreStratThicknessSummary

# APPENDIX B

## Vibrating Wire Piezometer (VWP) hydrographs (by Geosensing and GES)

# APPENDIX B

Vibrating Wire Piezometer (VWP) hydrographs
(by Geosensing and GES)

**Water level hydrographs from Vibrating Wire Piezometers**

# 1 TAHMOOR NORTH

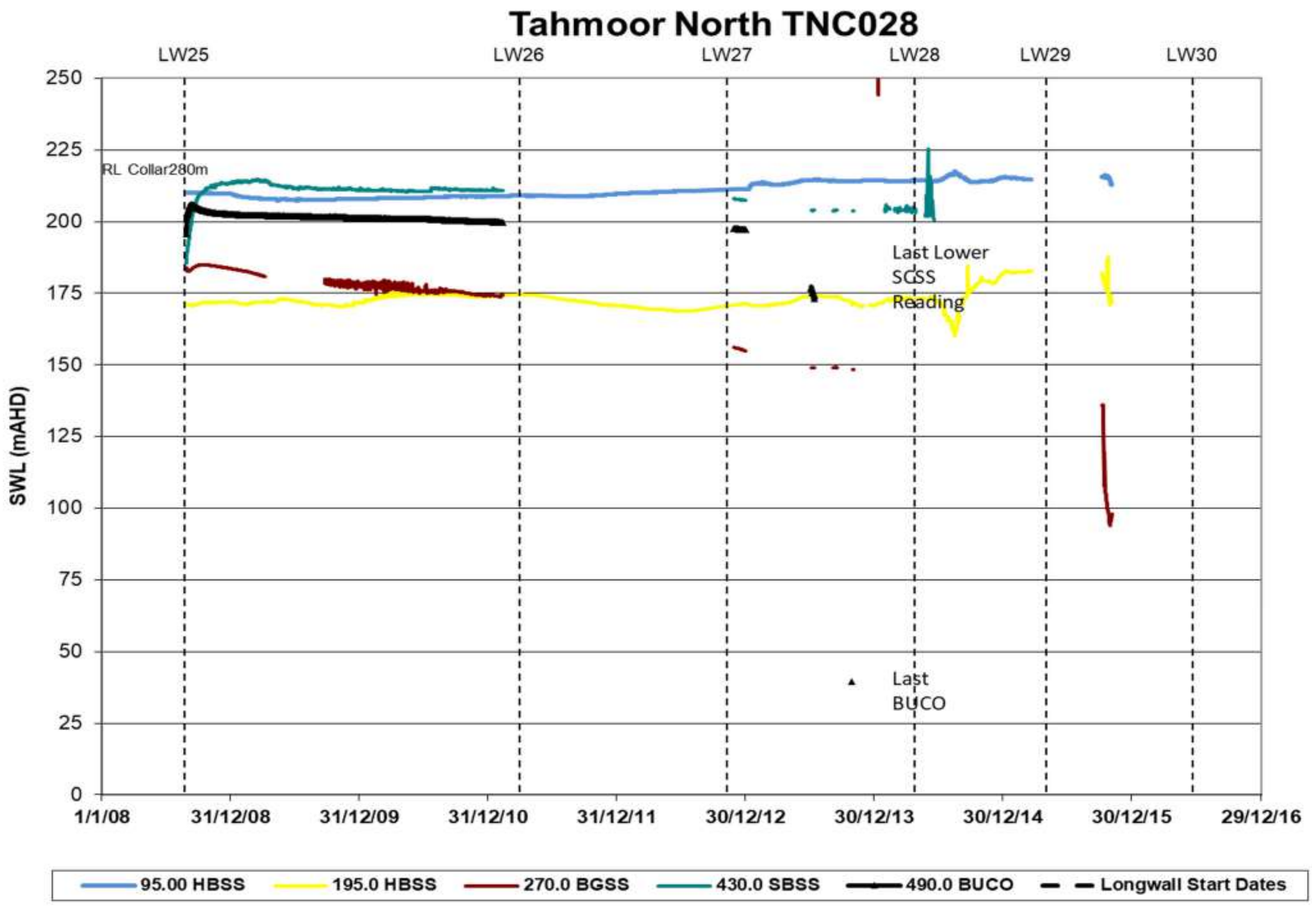



**Figure B1.1:** TNC028 Hydrograph (Decommissioned)

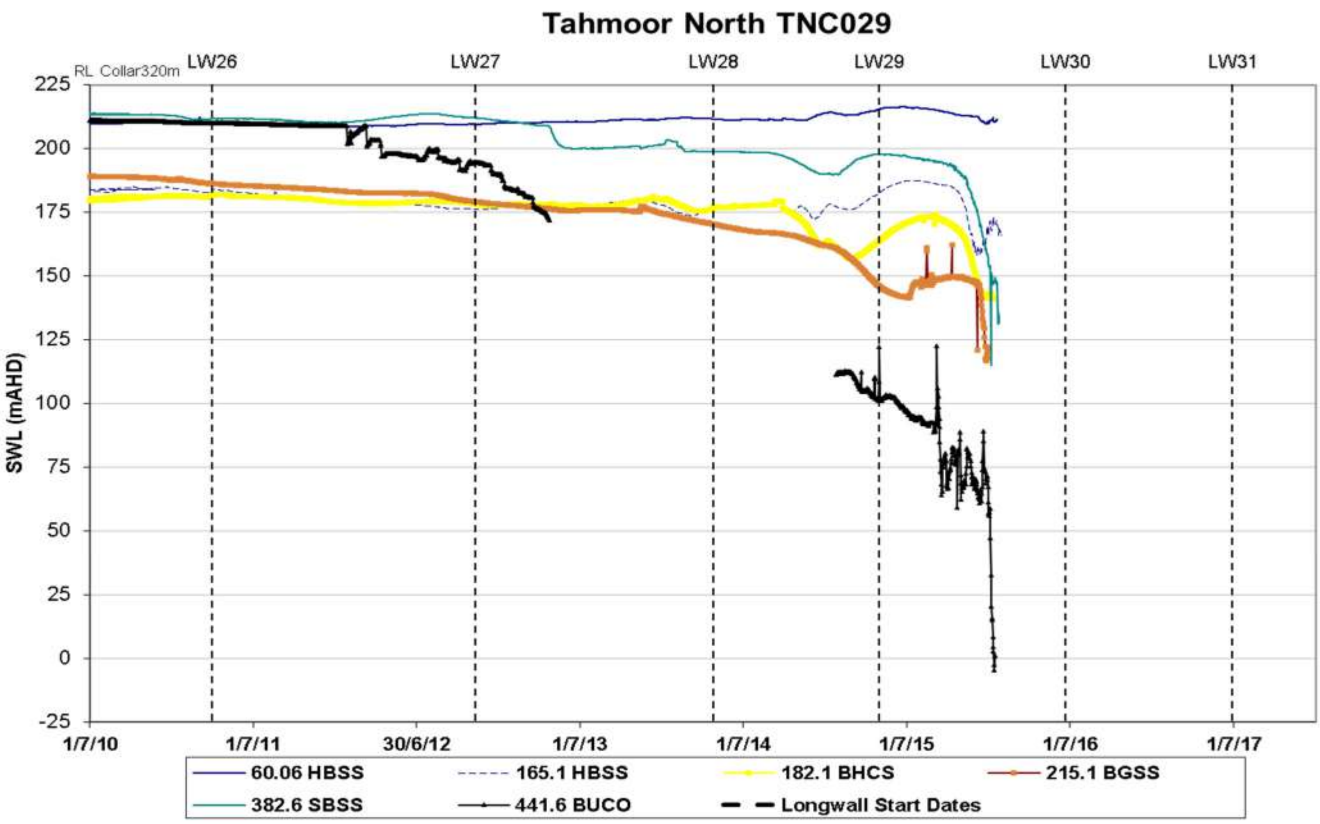



**Figure B1.2:** TNC029 Hydrograph (Decommissioned)

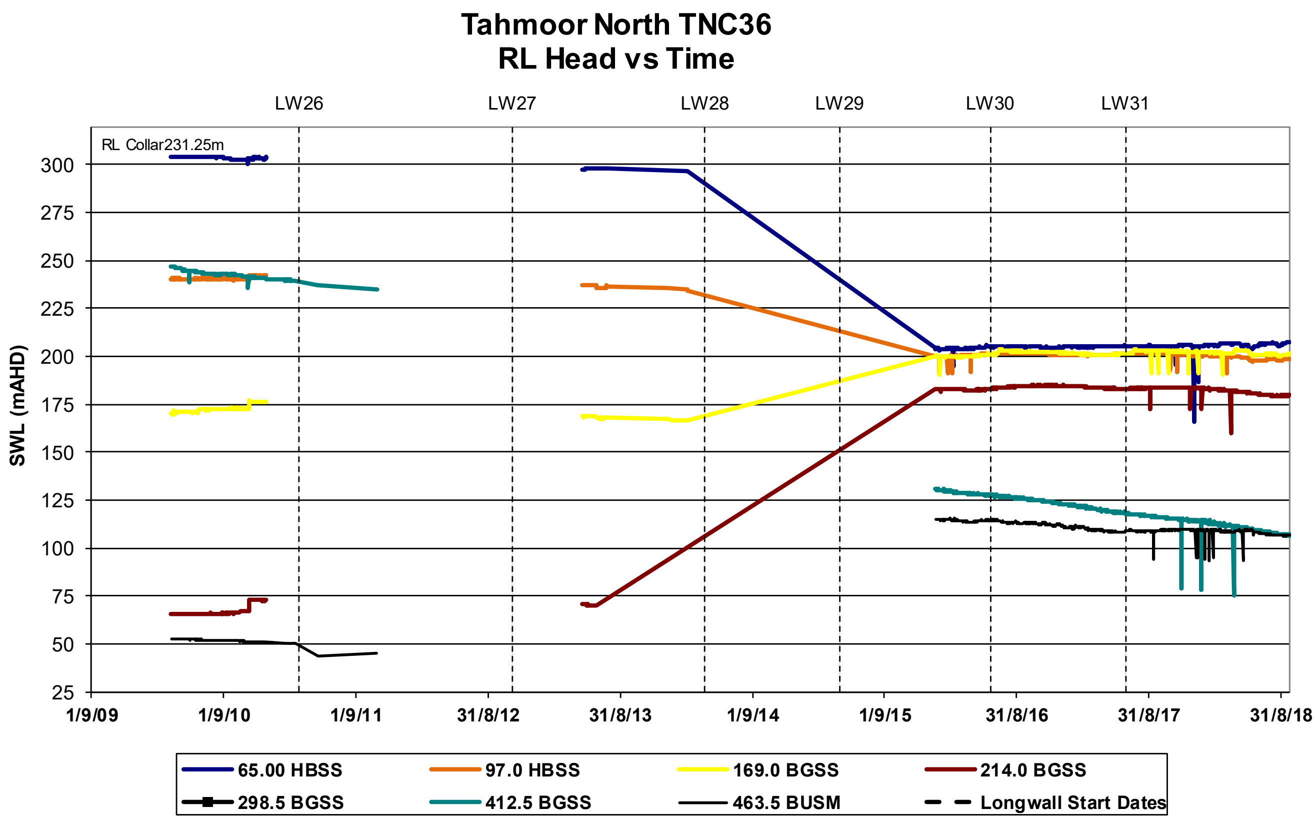



**Figure B1.3:** TNC036 Hydrograph

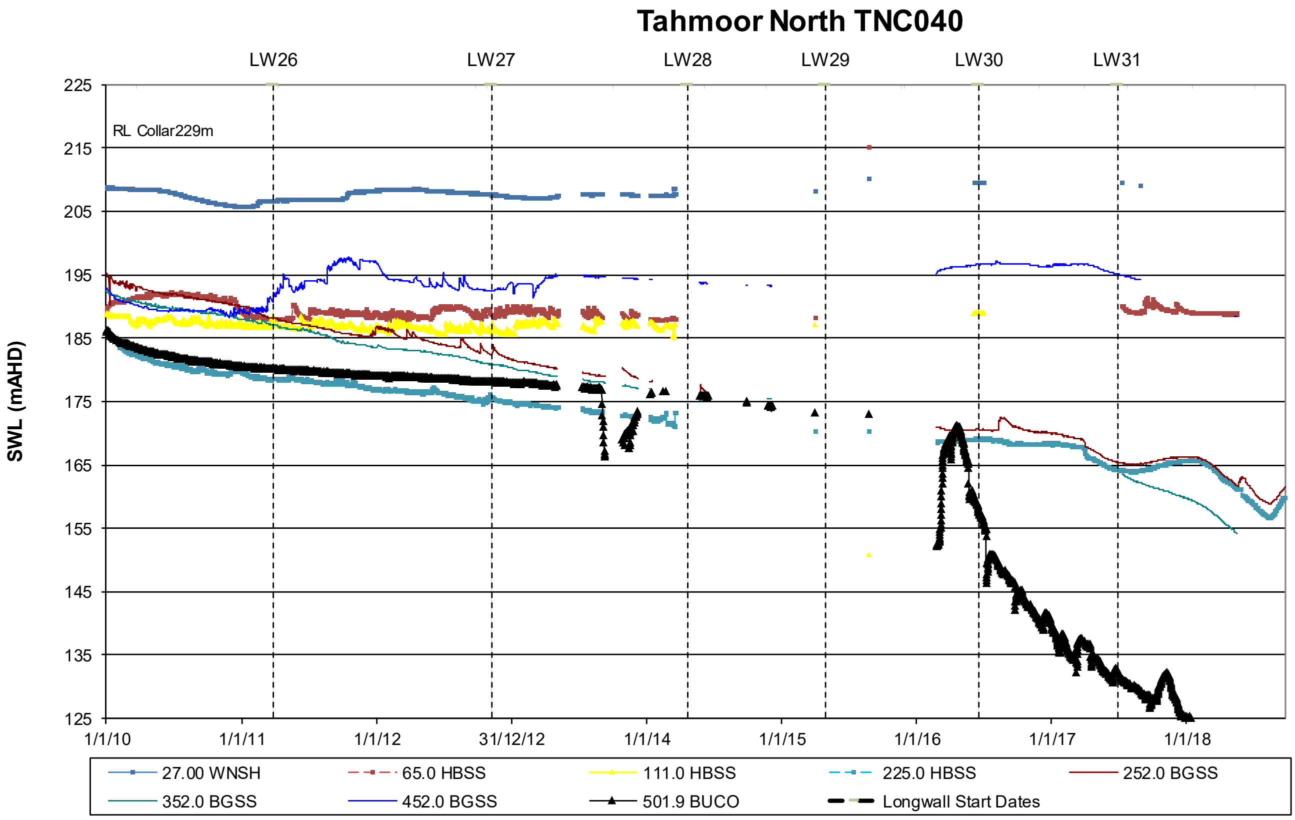
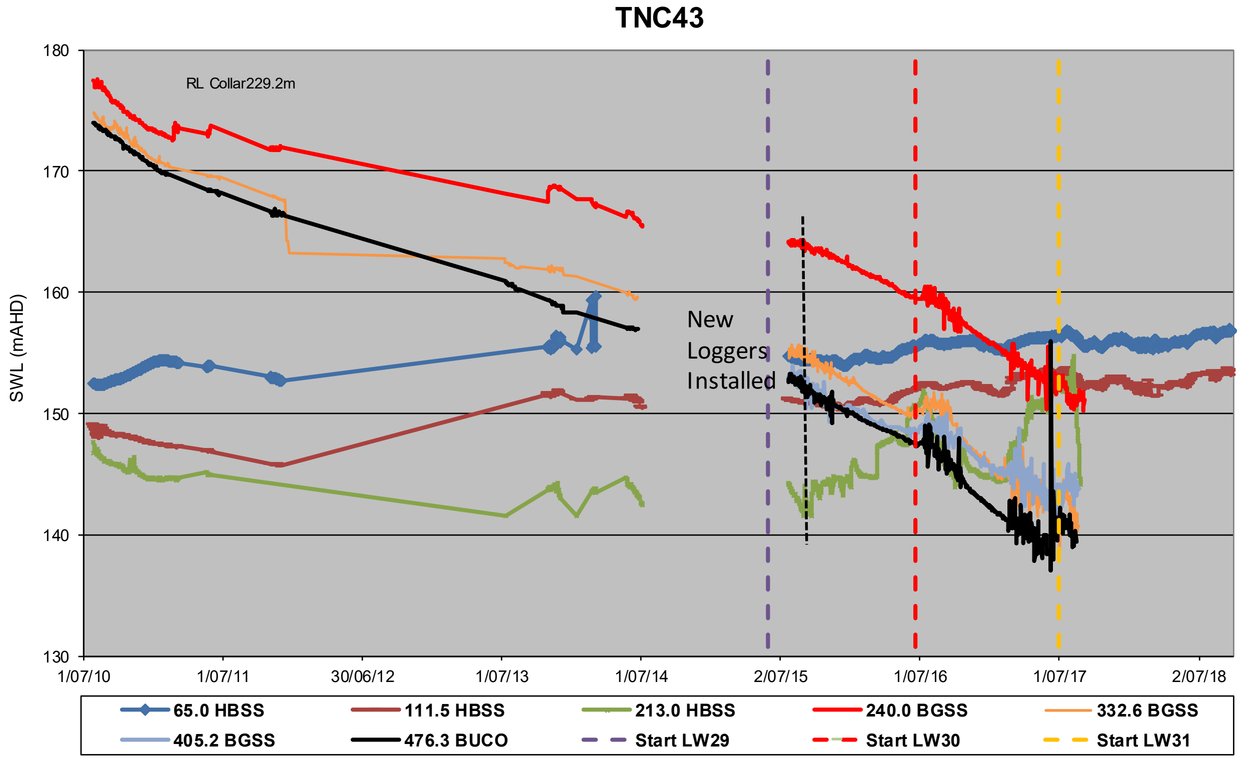



**Figure B1.4:** TNC040 Hydrograph



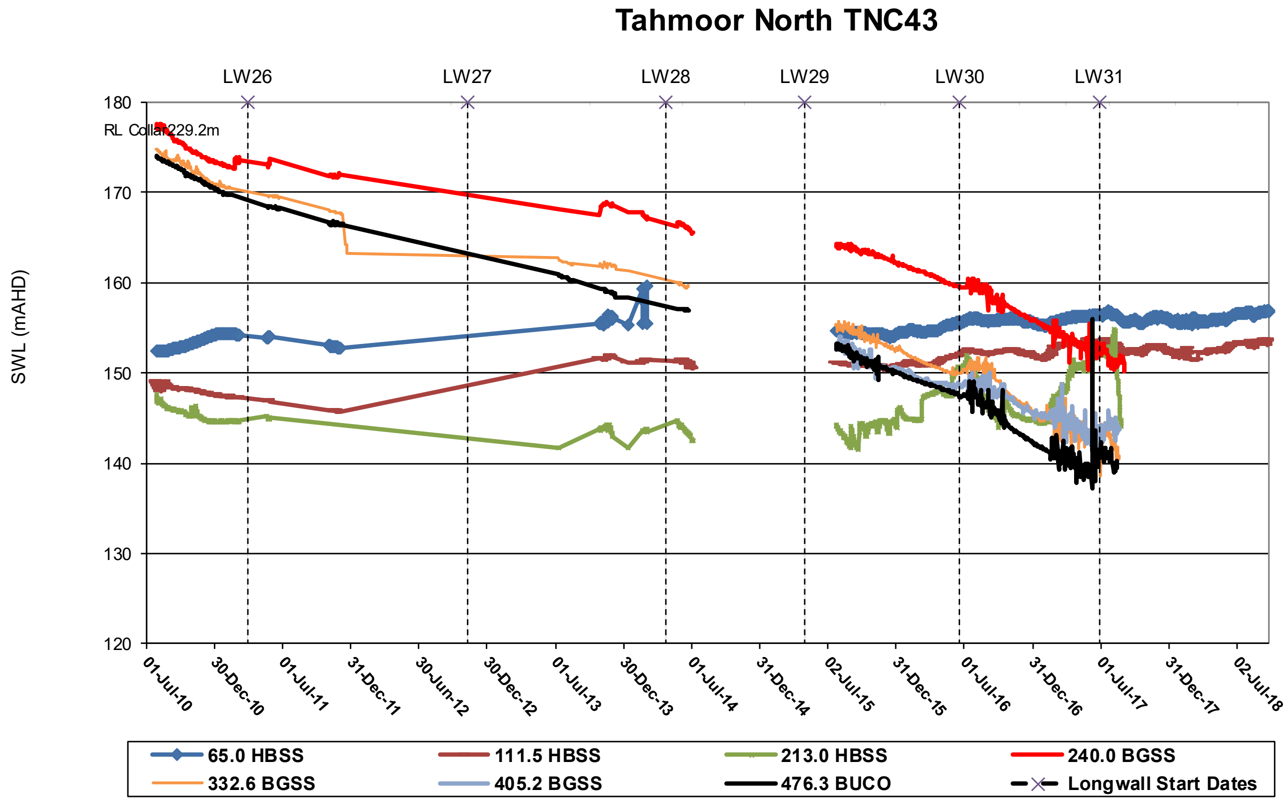




**Figure B1.5:** TNC043 Hydrograph

(two versions provided by GES based on plausible re-calculation of data)

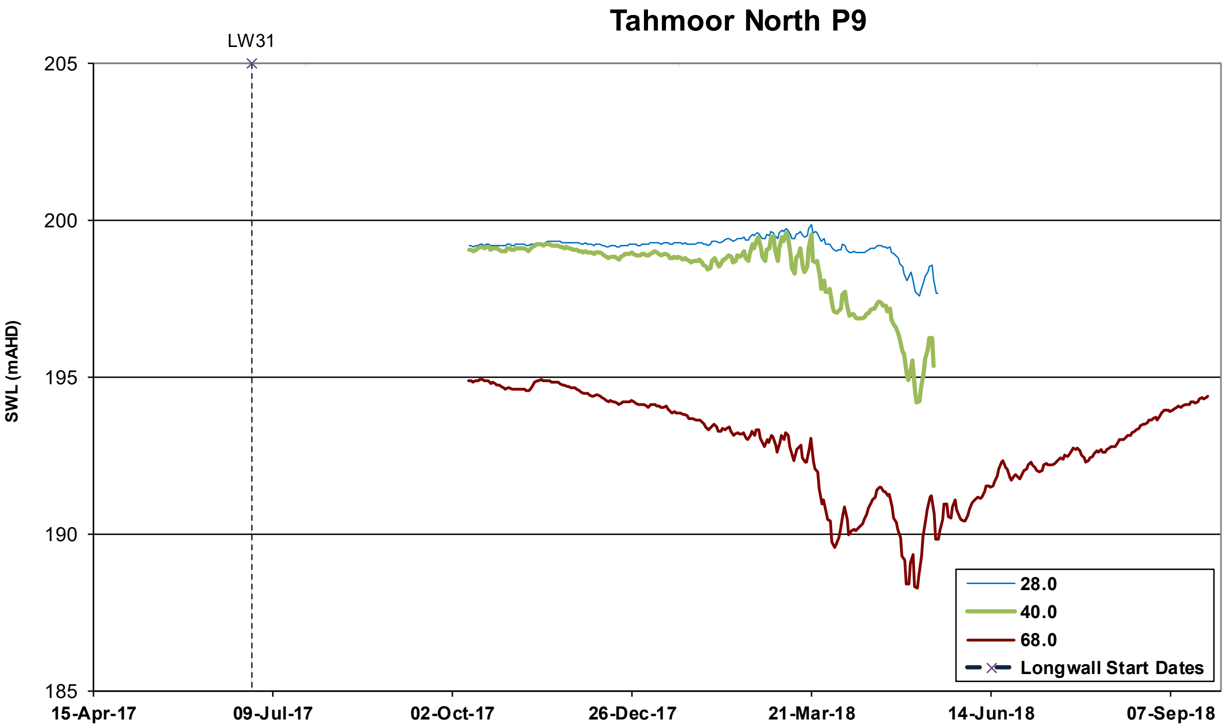



**Figure B1.6:** P9 Hydrograph

# 2 TAHMOOR / TAHMOOR SOUTH

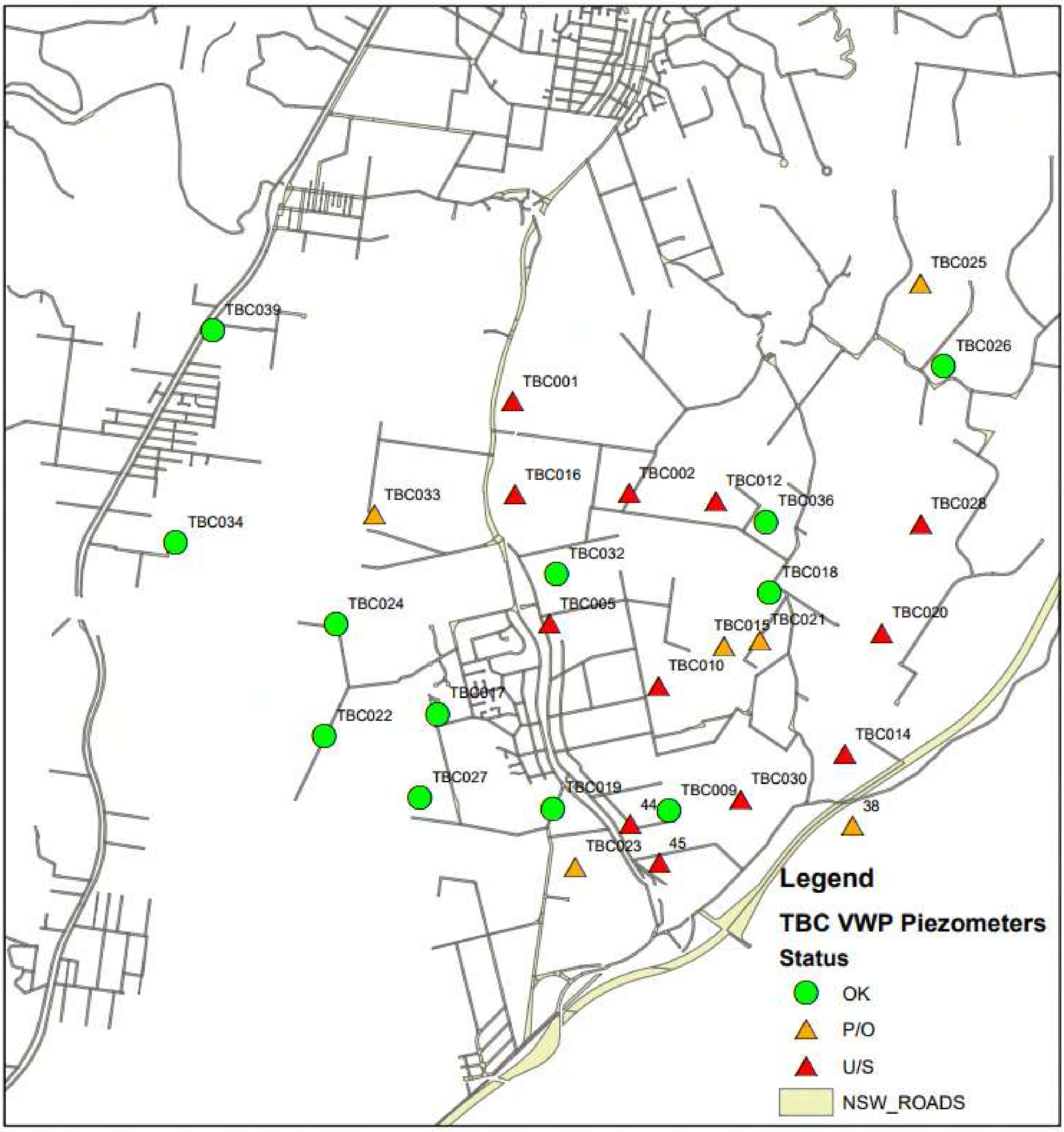



**Figure B2.1: Summary of TBC VWP status (from GES, 2017)**

(p/o = partial, as in some but not all piezometers function at that location

(u/s = un-serviceable, out of action)

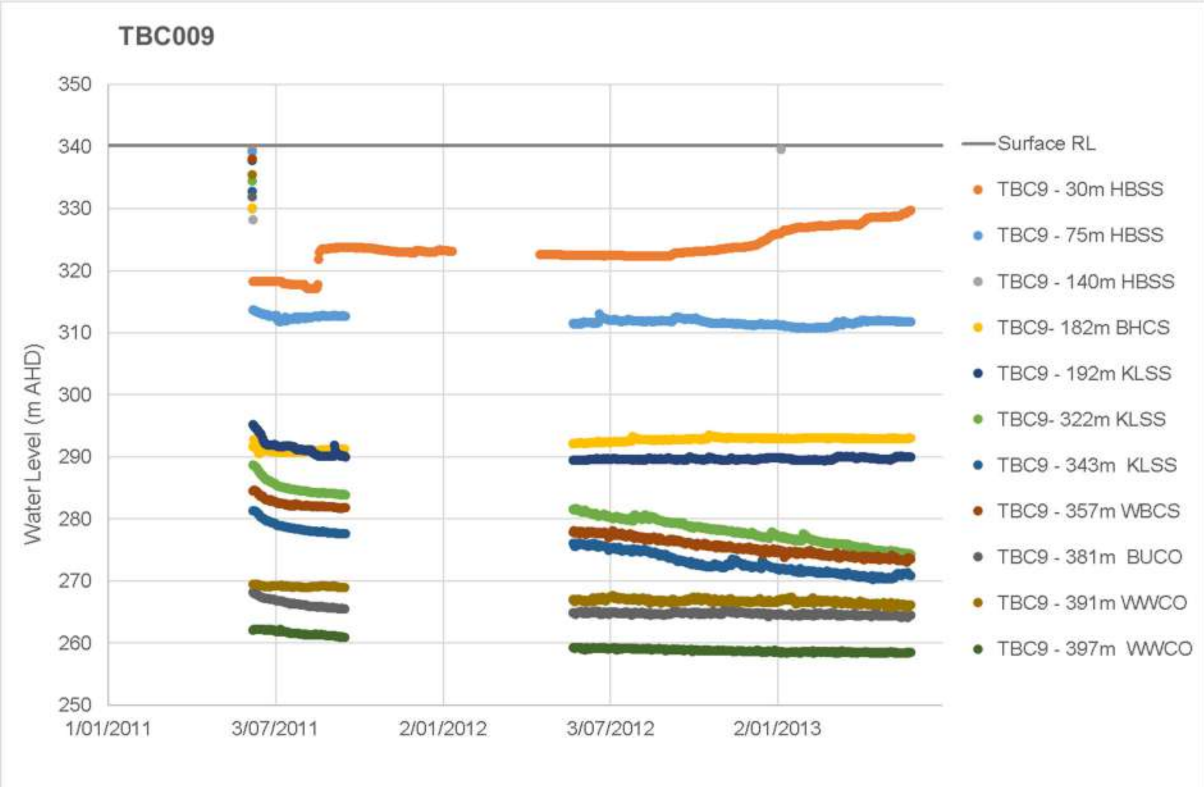



**Figure B2.2:** TBC009 Hydrograph. (out of service)

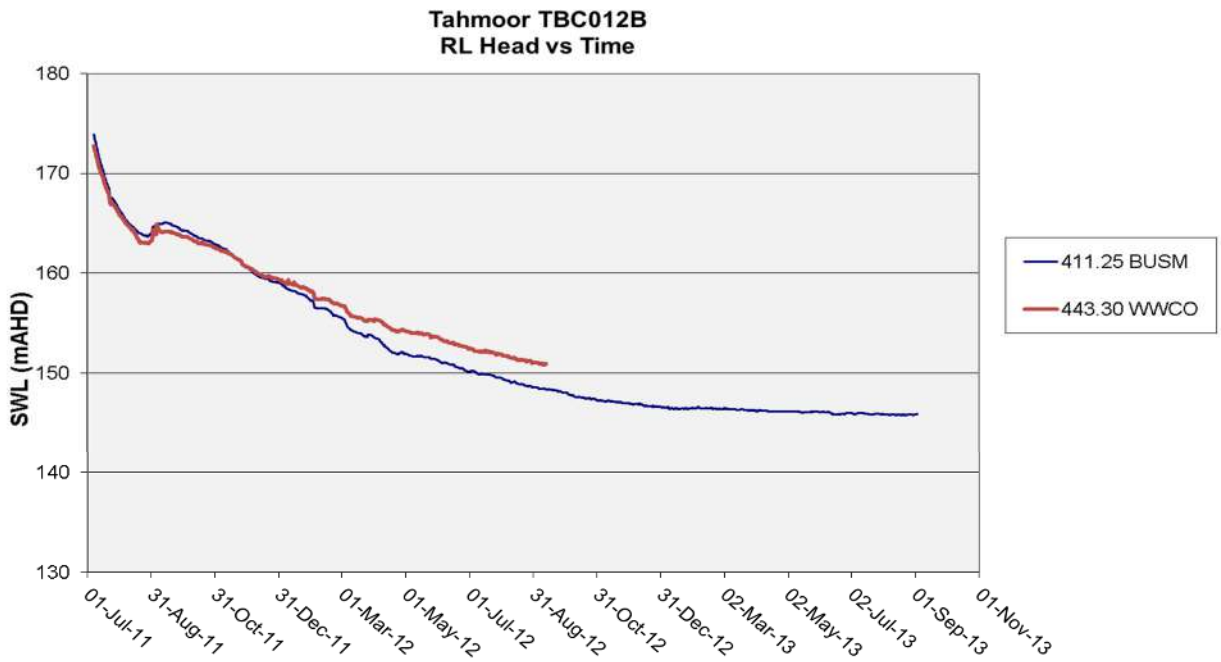



**Figure B2.3:** TBC012 Hydrograph. (out of service)

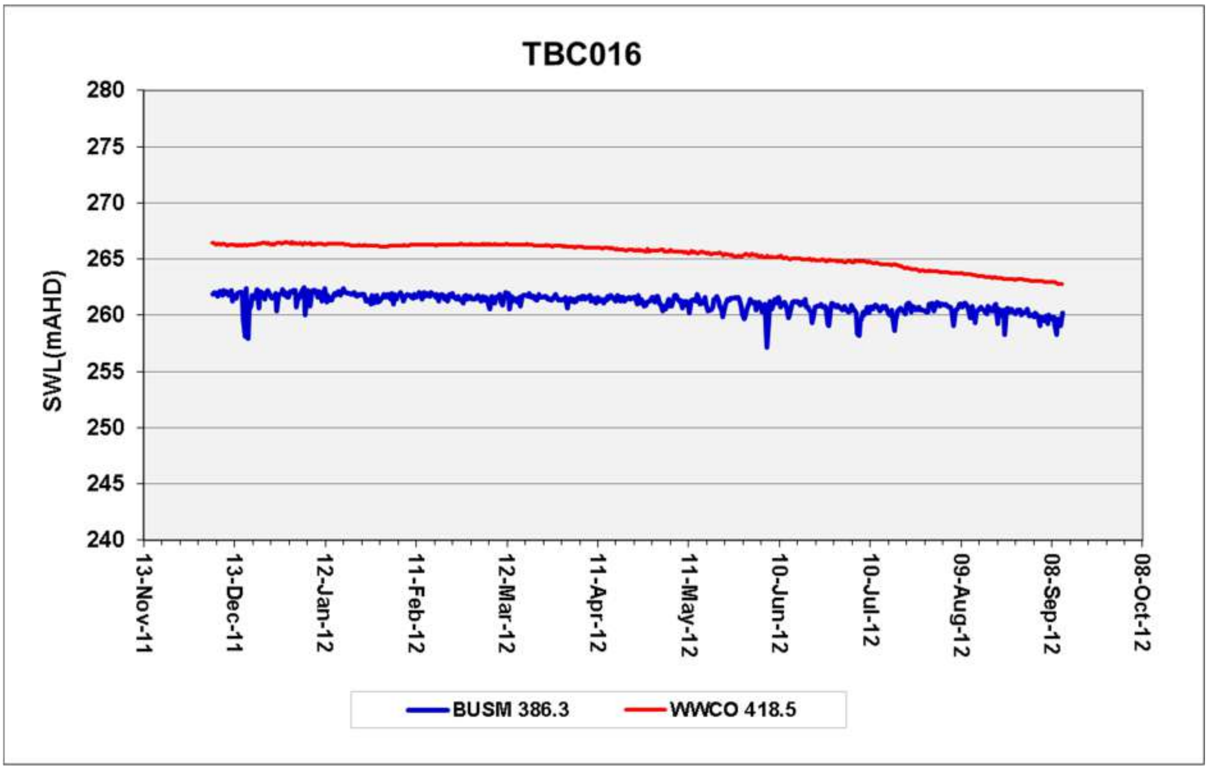



**Figure B2.4:** TBC016 Hydrograph. (out of service)

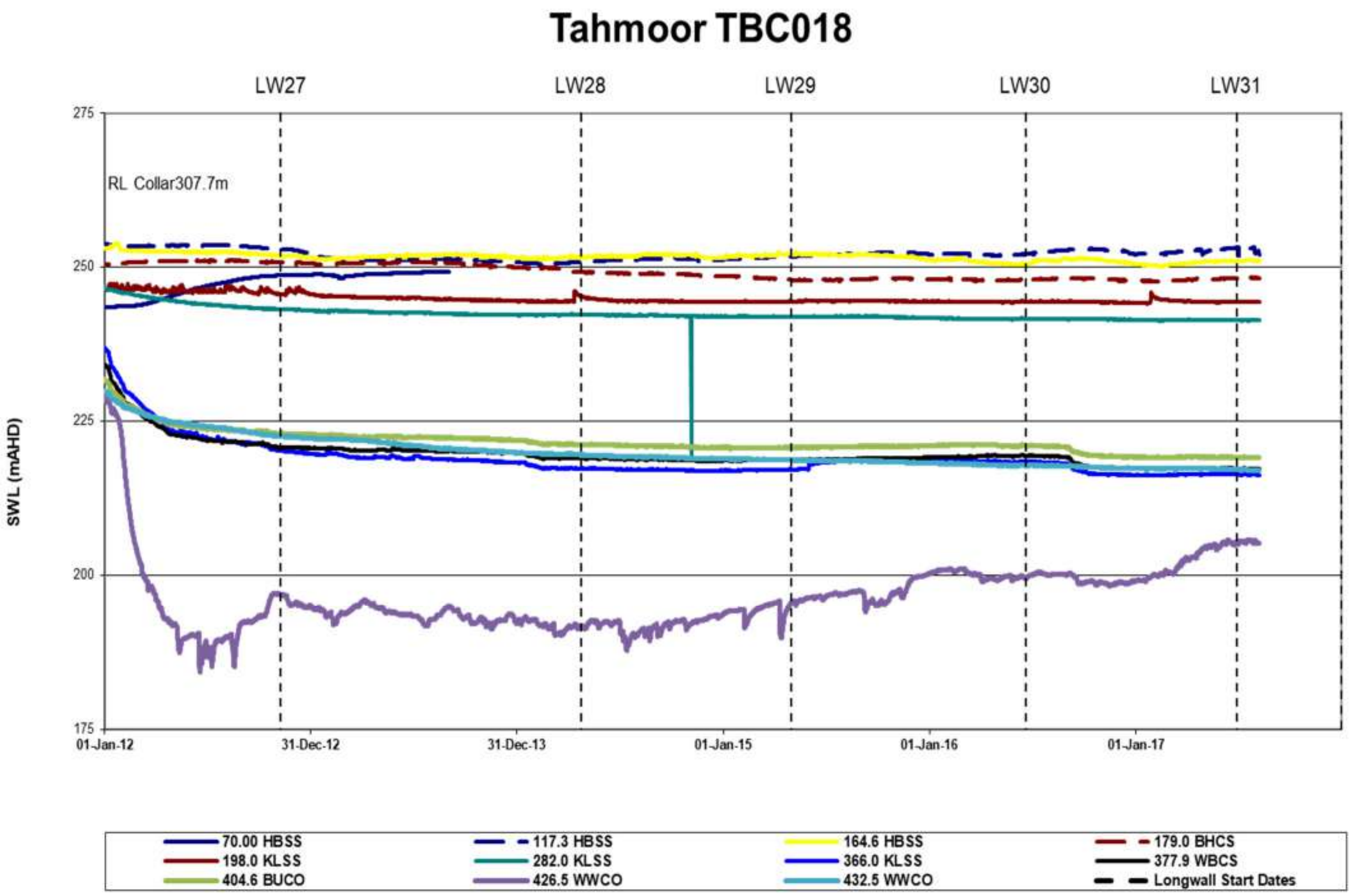



**Figure B2.5:** TBC018 Hydrograph

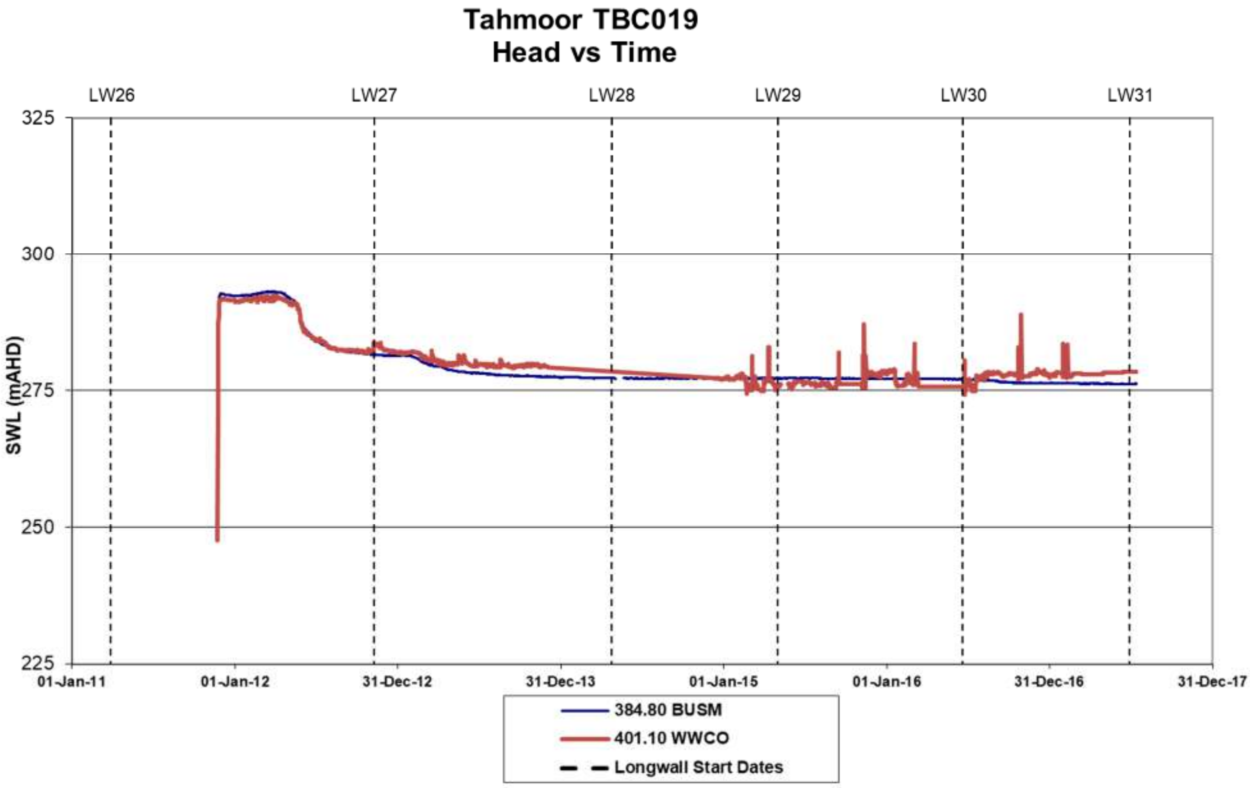



**Figure B2.6:** TBC019 Hydrograph

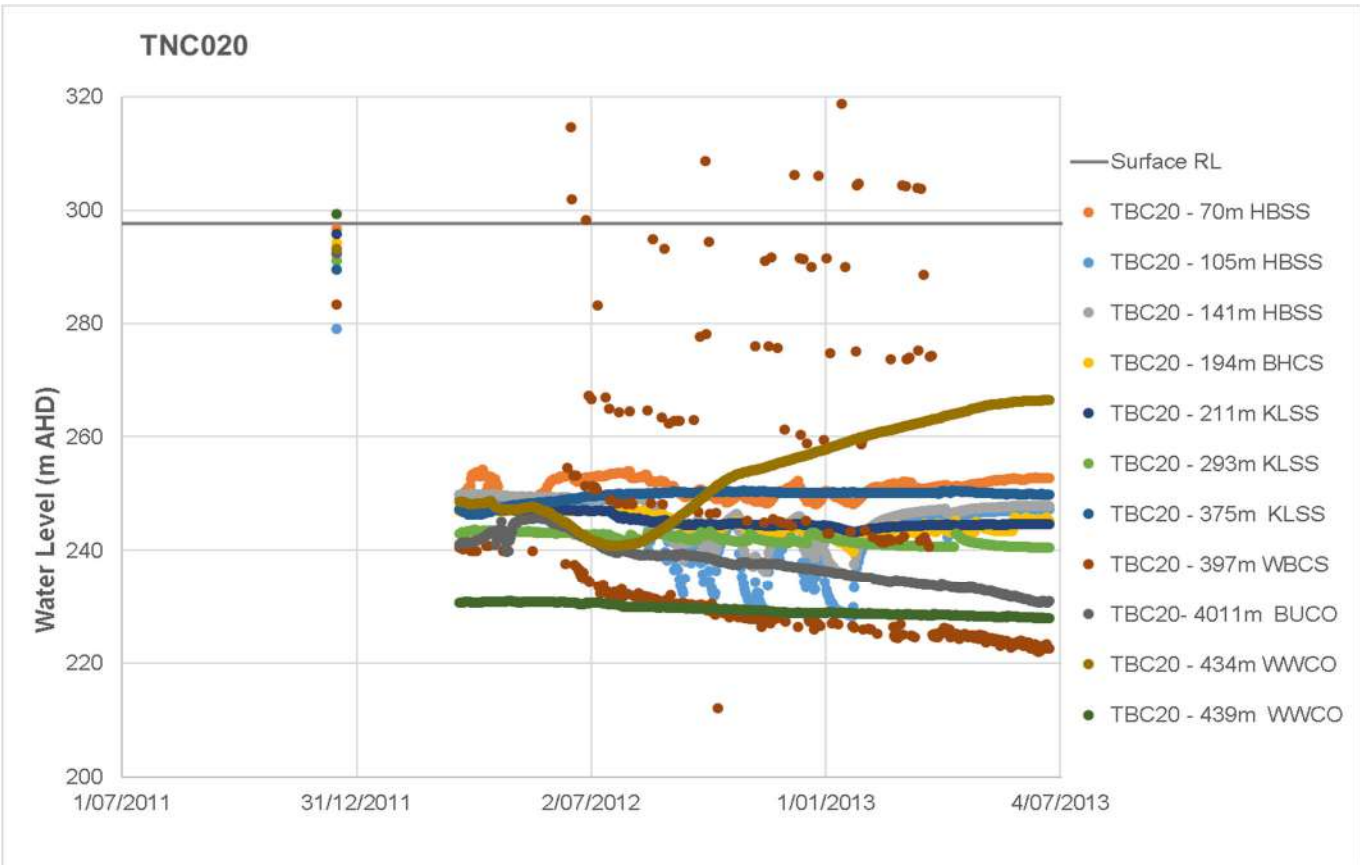



**Figure B2.7:** TBC020 Hydrograph. (out of service)

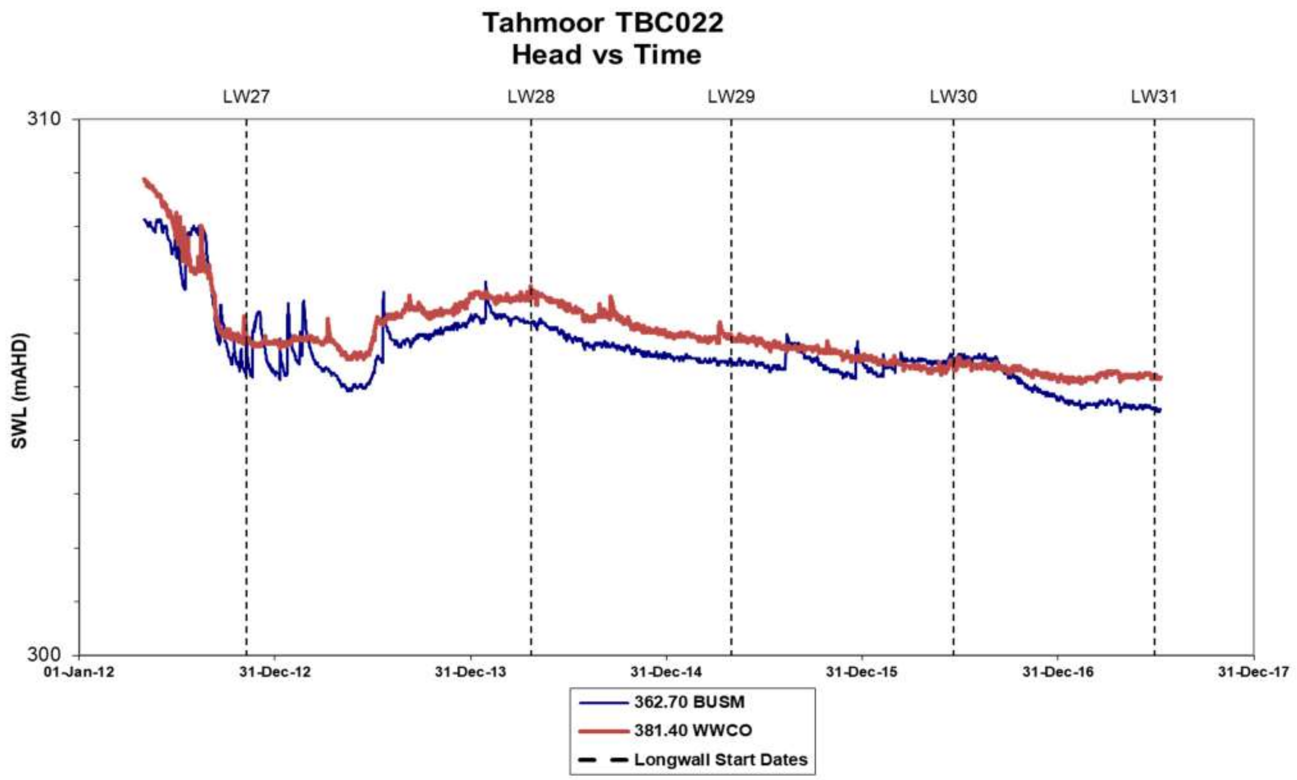



**Figure B2.8:** TBC022 Hydrograph

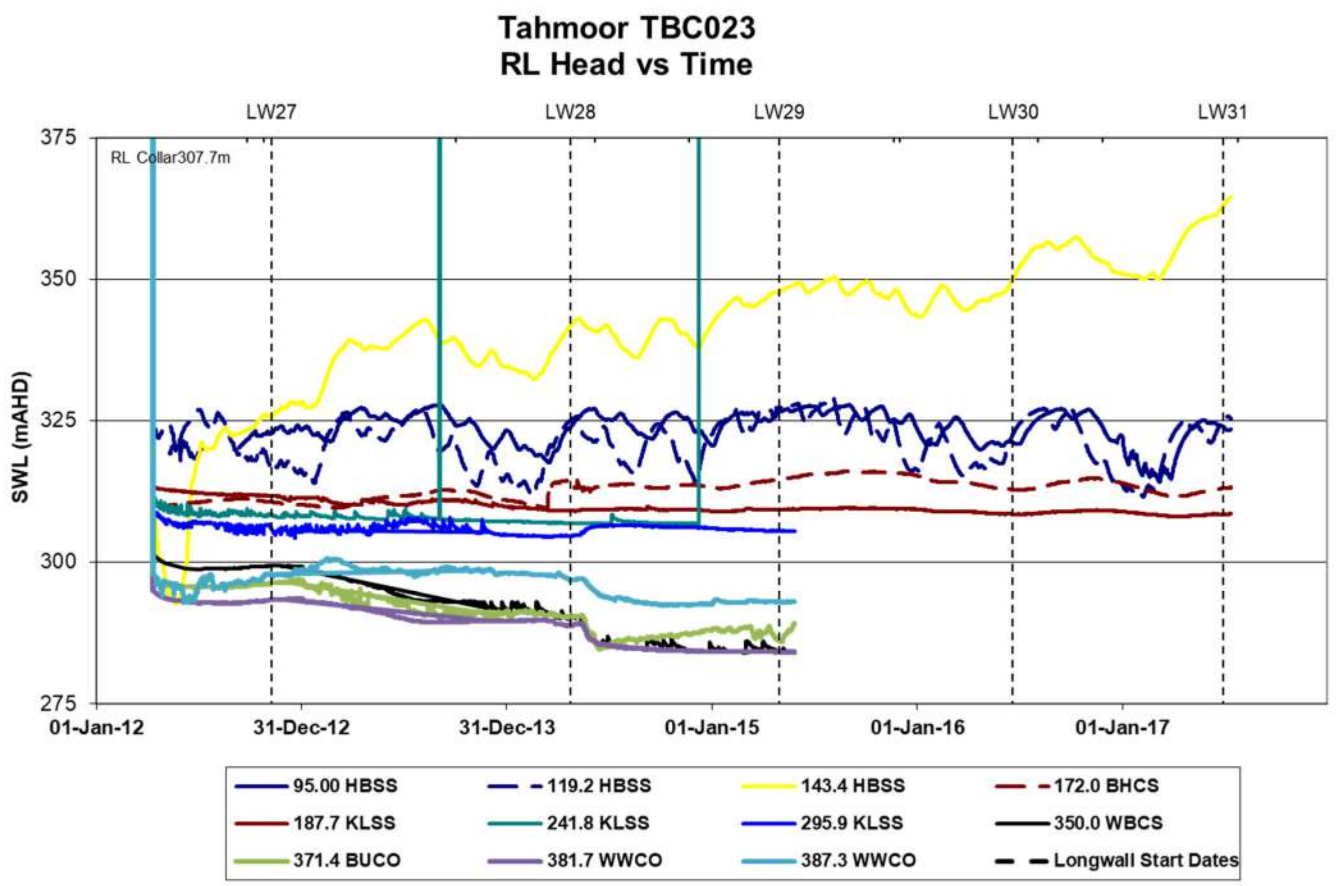



**Figure B2.9:** TBC023 Hydrograph (deeper piezos are out of service)

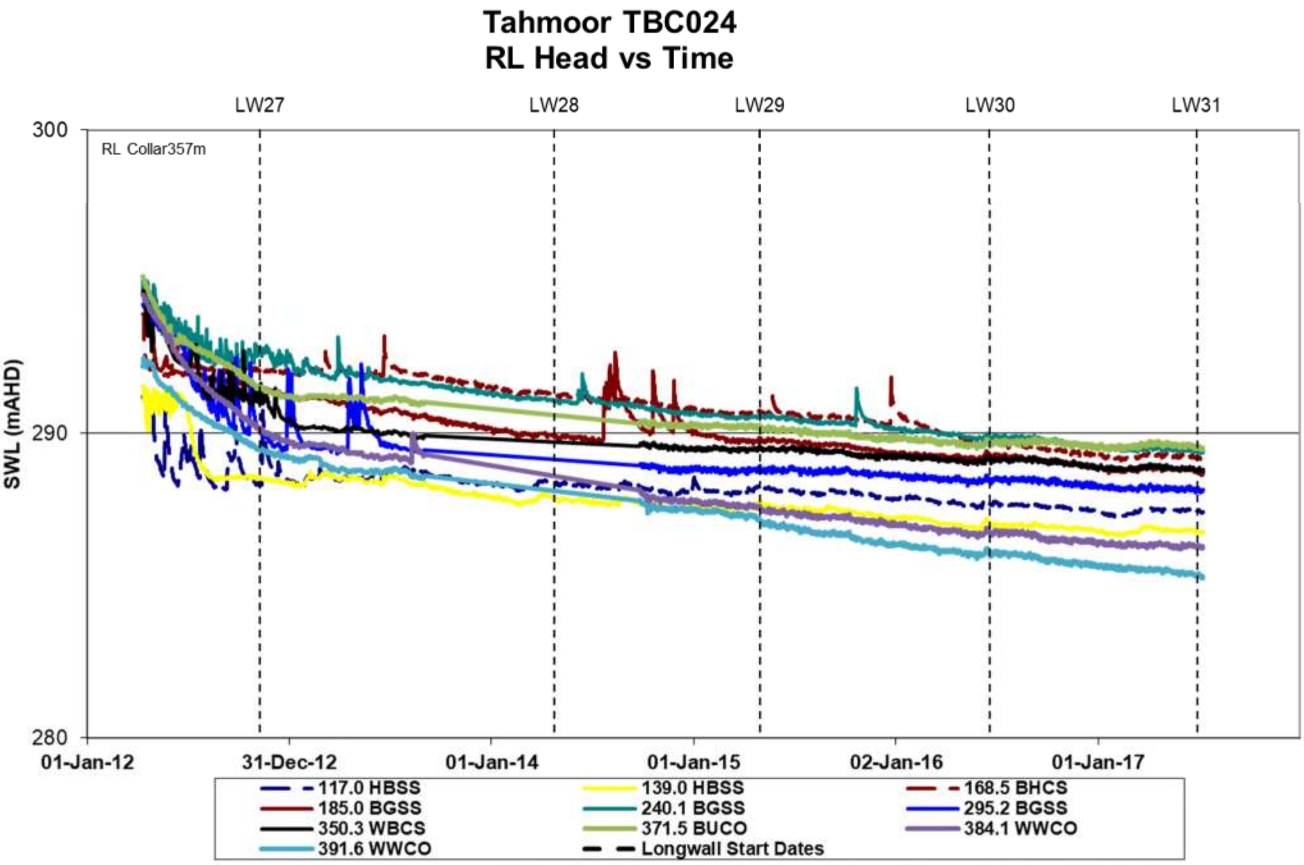



**Figure B2.10:** TBC024 Hydrograph

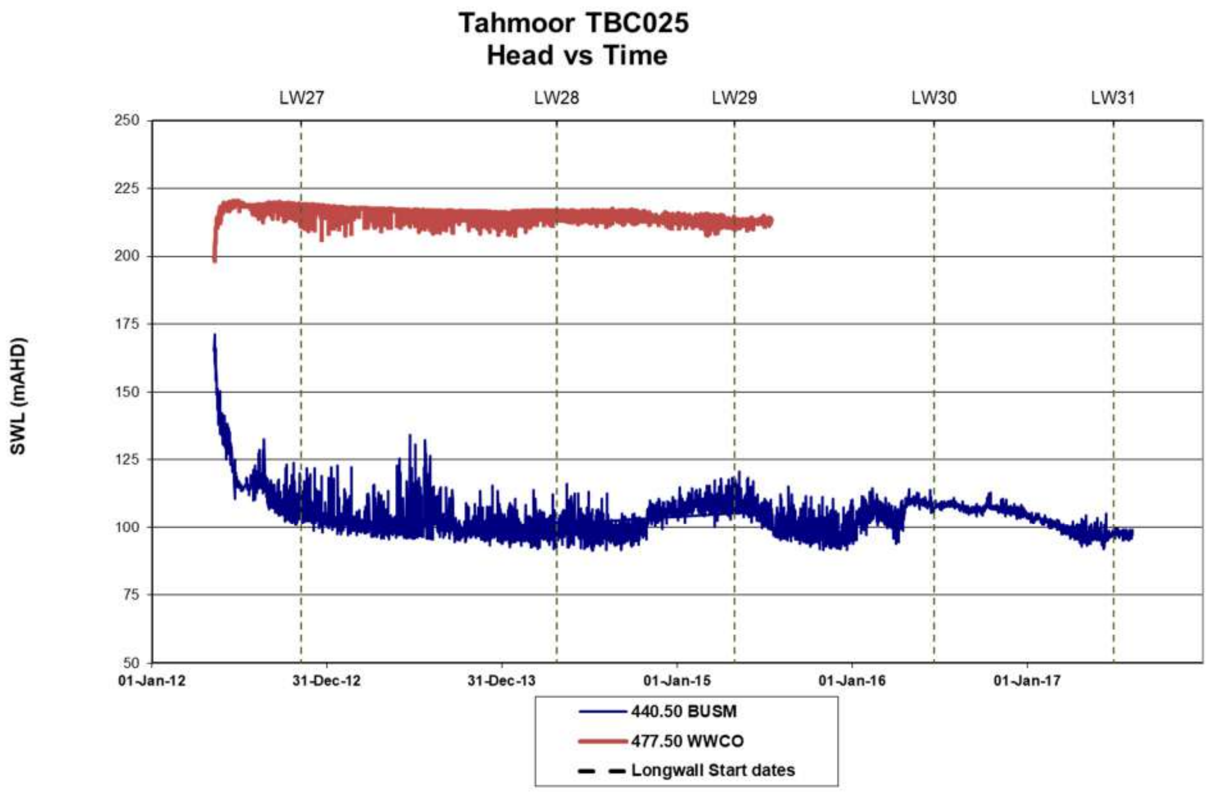



**Figure B2.11:** TBC025 Hydrograph (WWCO piezometer is out of service)

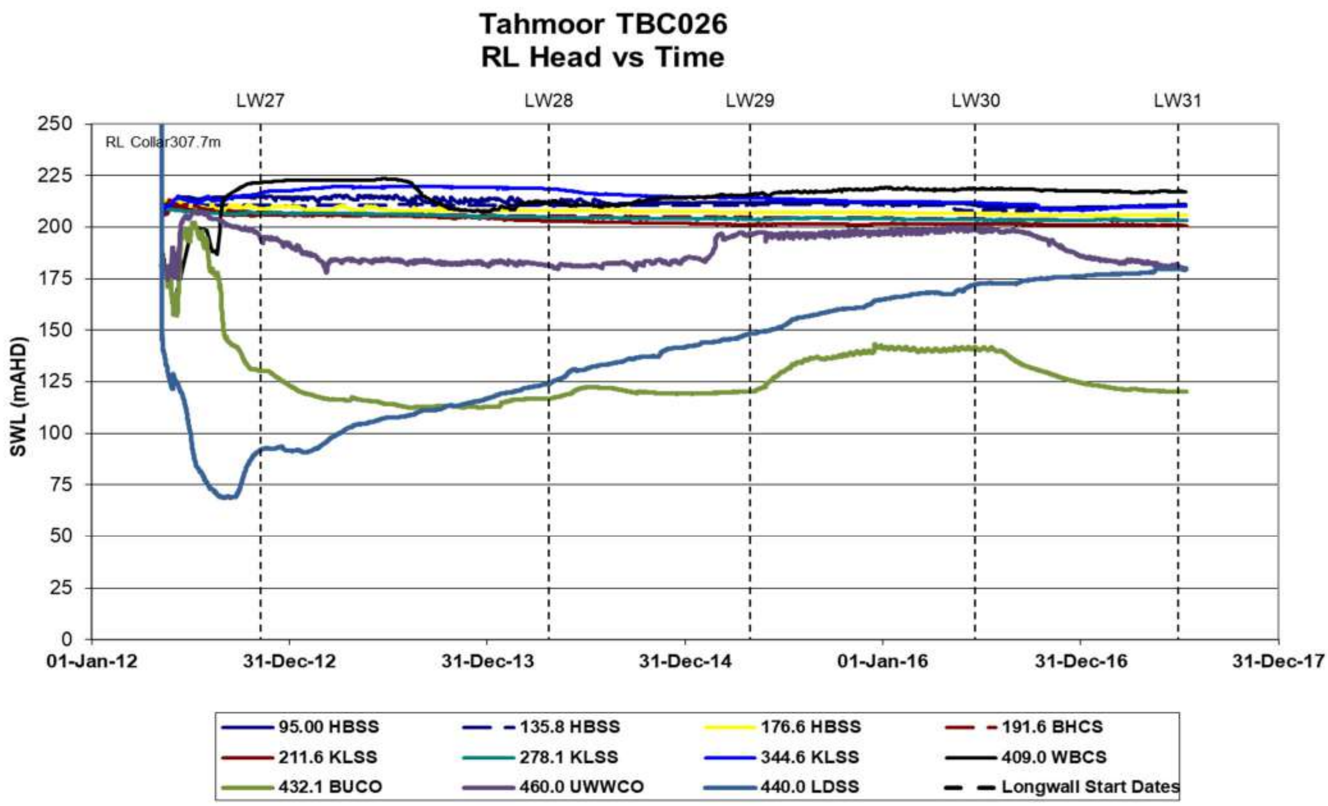



**Figure B2.12:** TBC026 Hydrograph

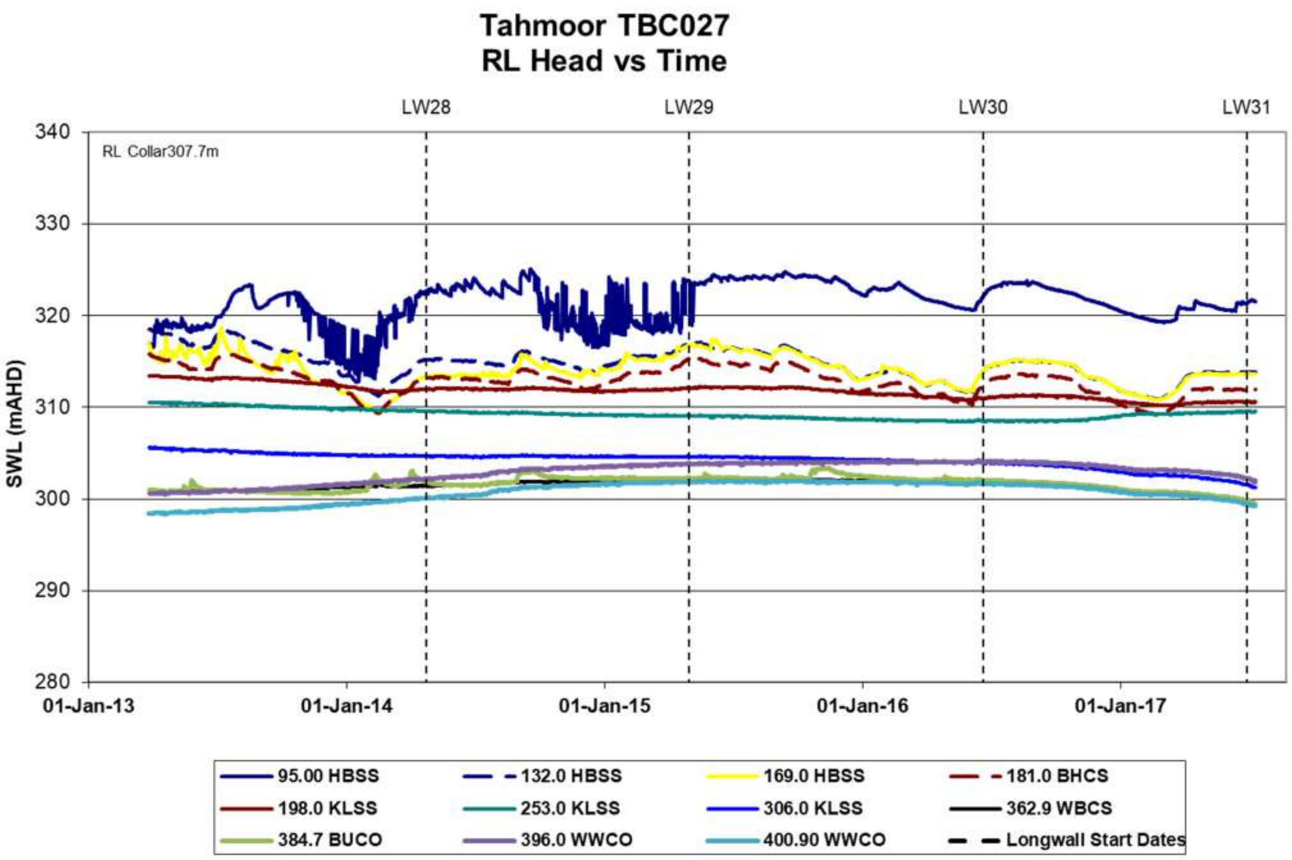



**Figure B2.13:** TBC027 Hydrograph

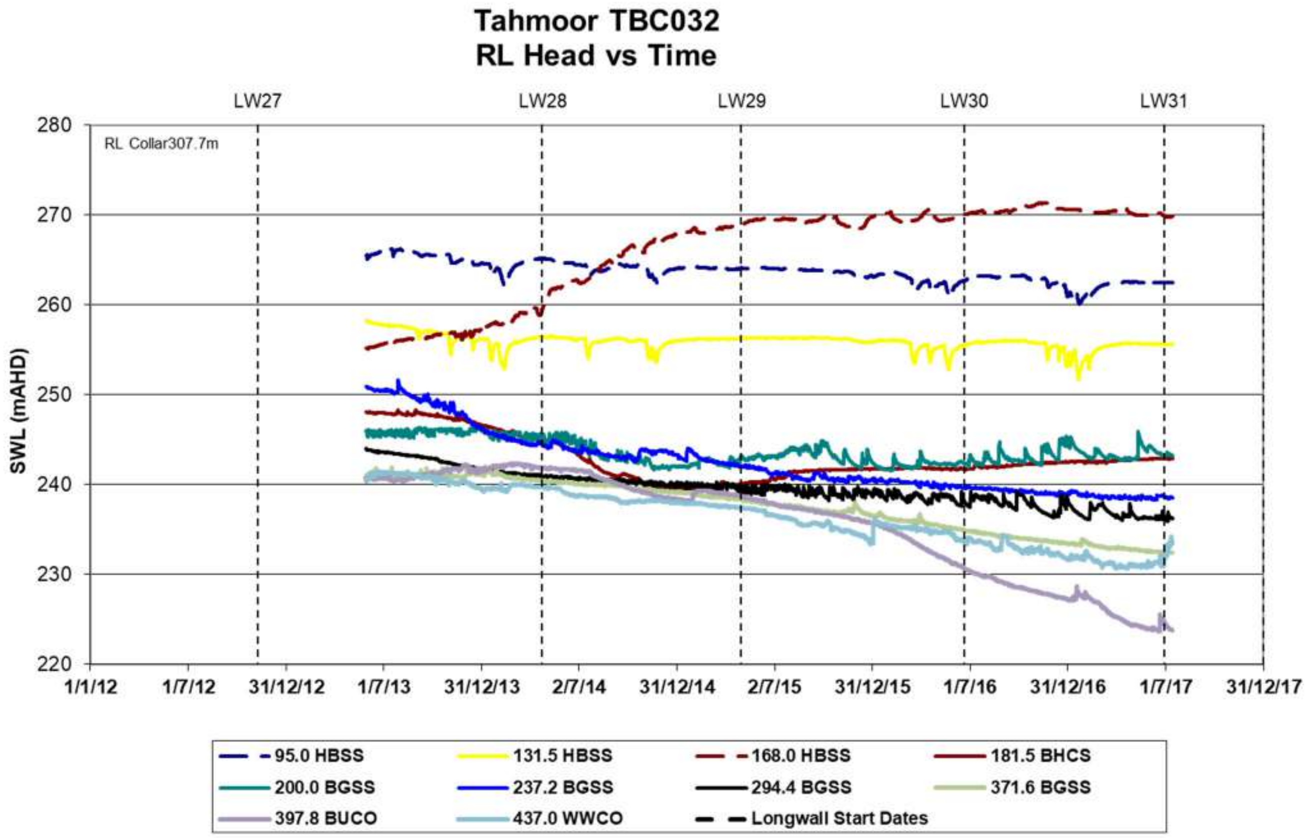



**Figure B2.14:** TBC032 Hydrograph

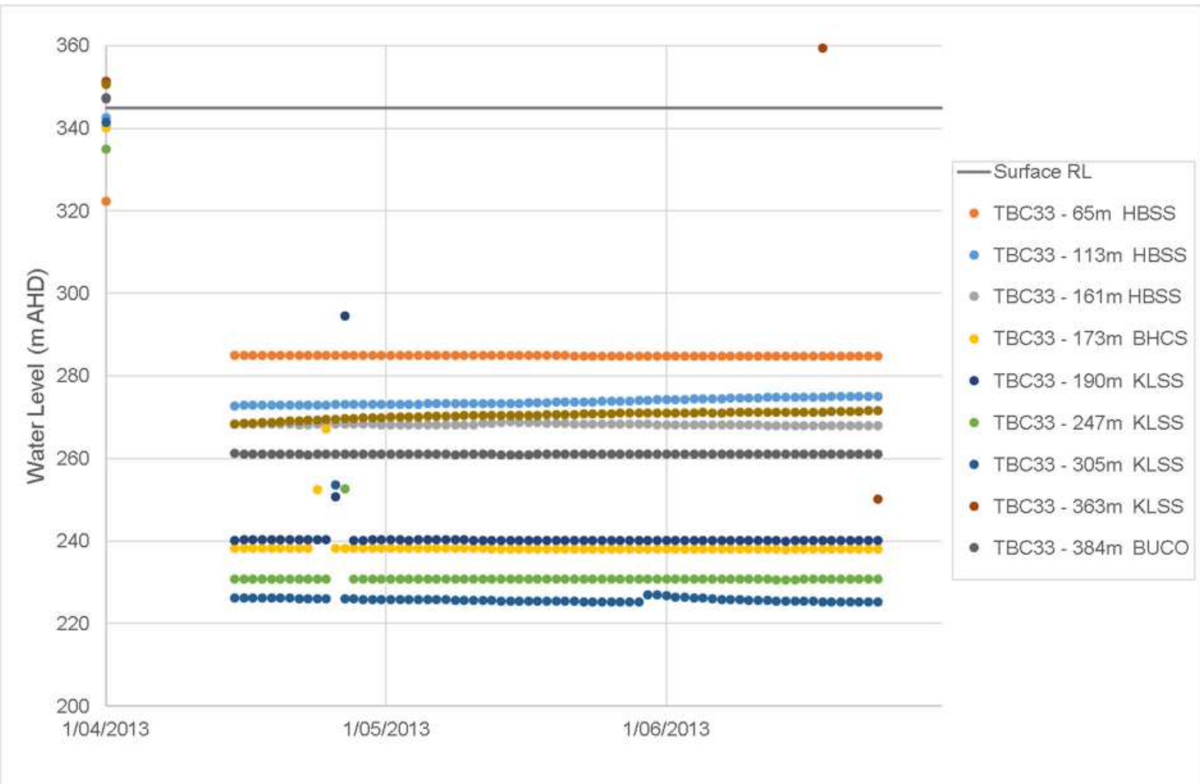



**Figure B2.15:** TBC033 Hydrograph. (out of service)

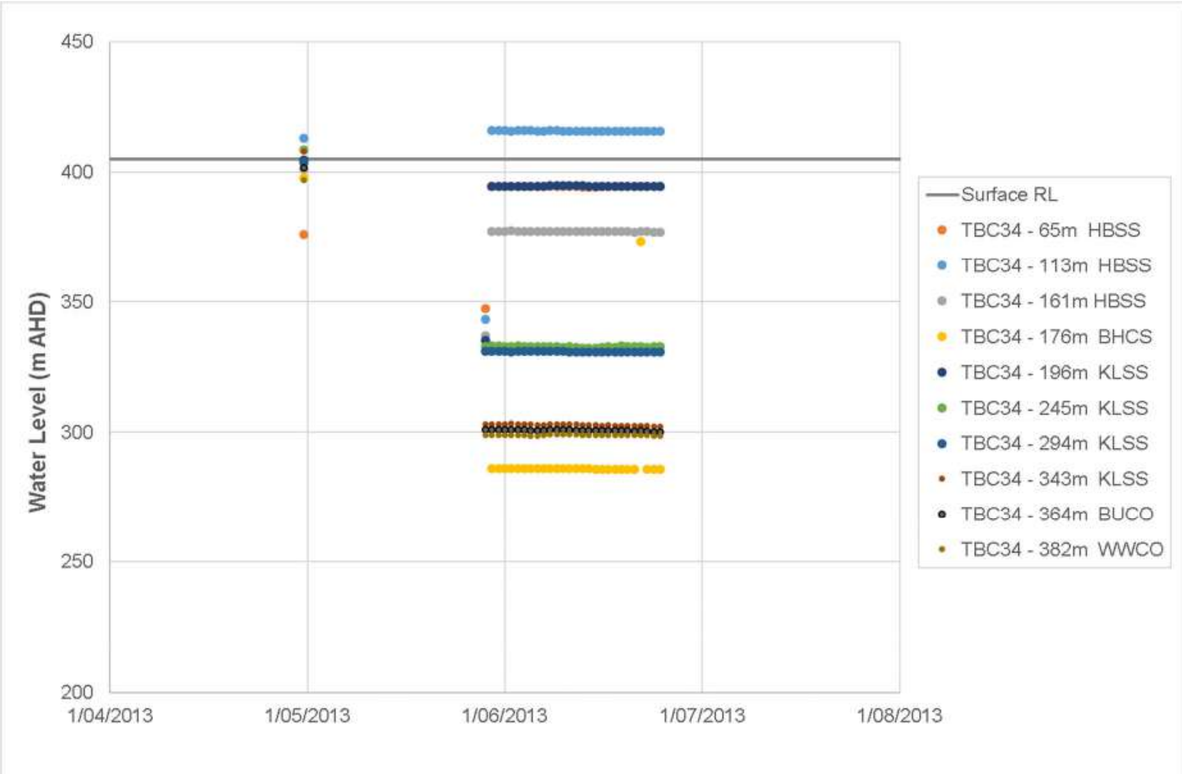



**Figure B2.16:** TBC034 Hydrograph. (out of service)

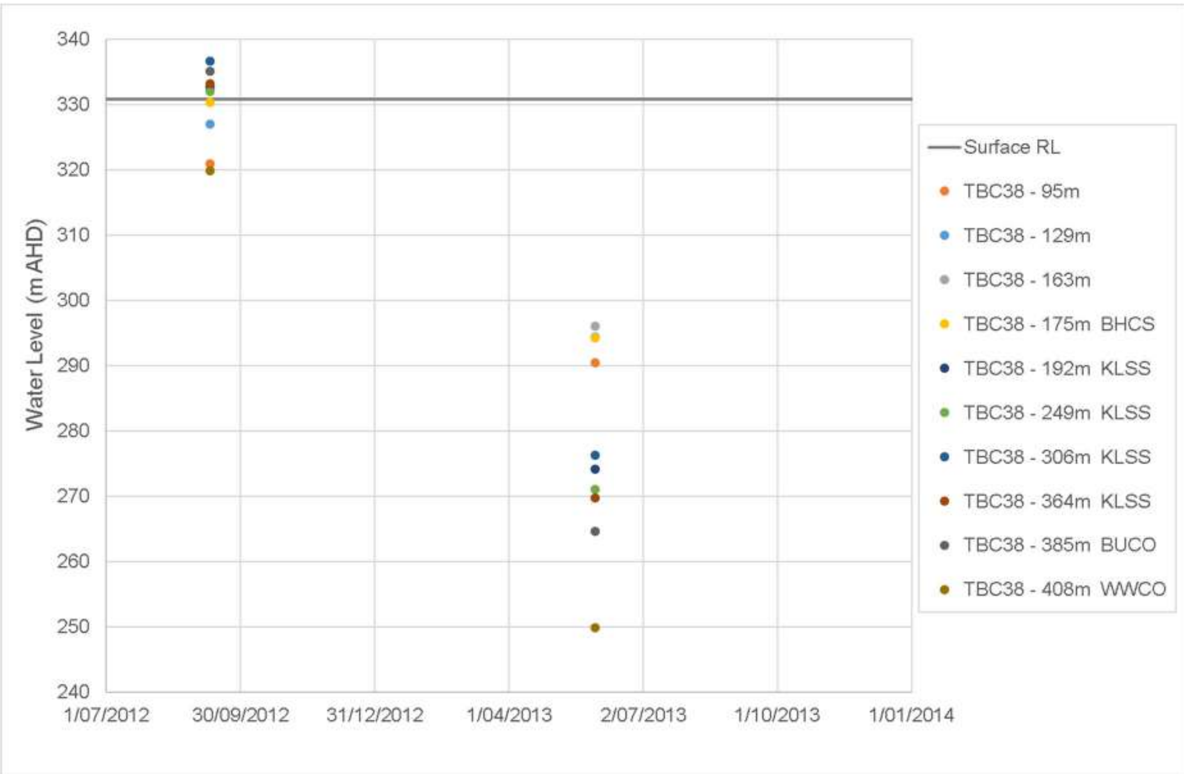
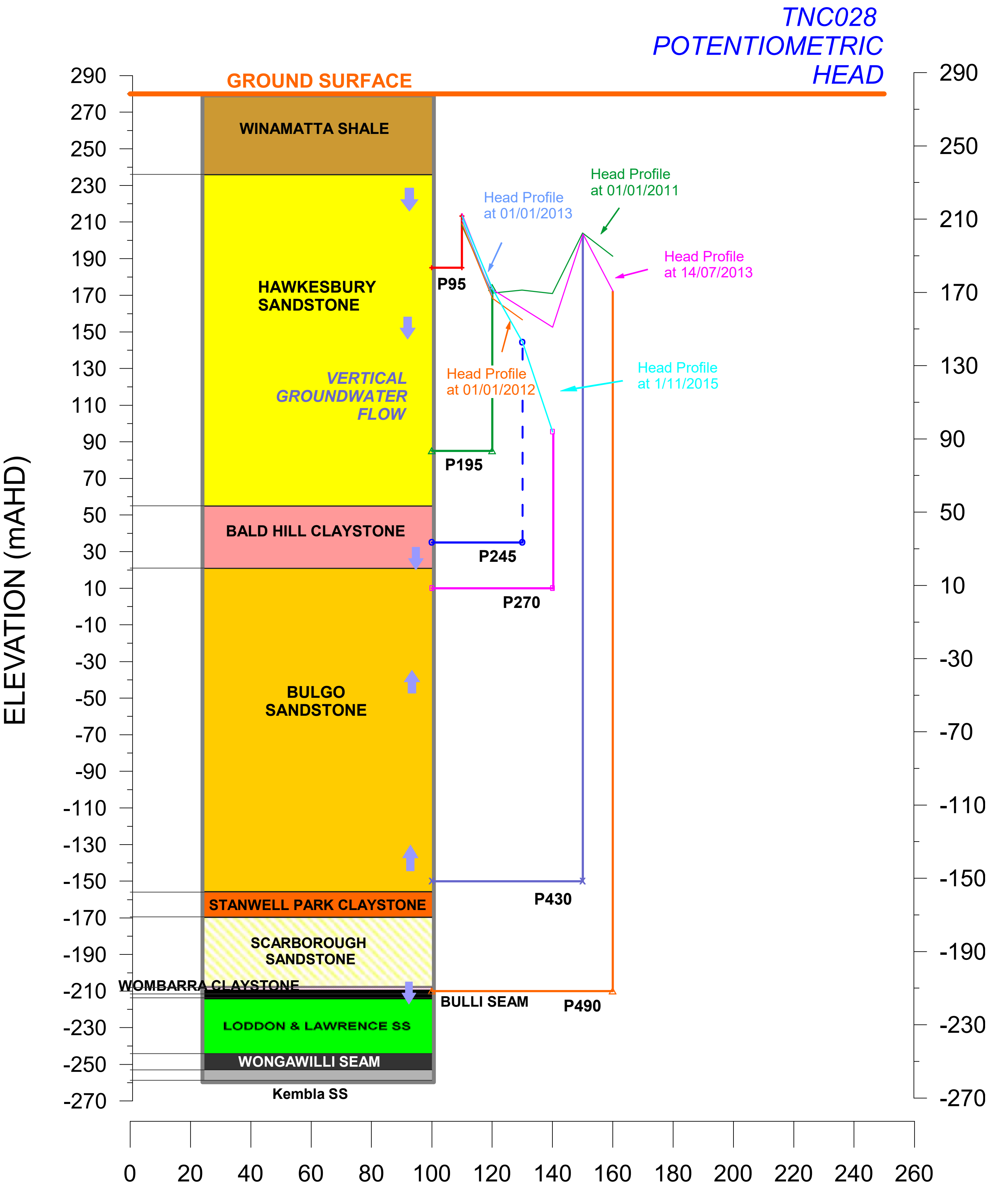


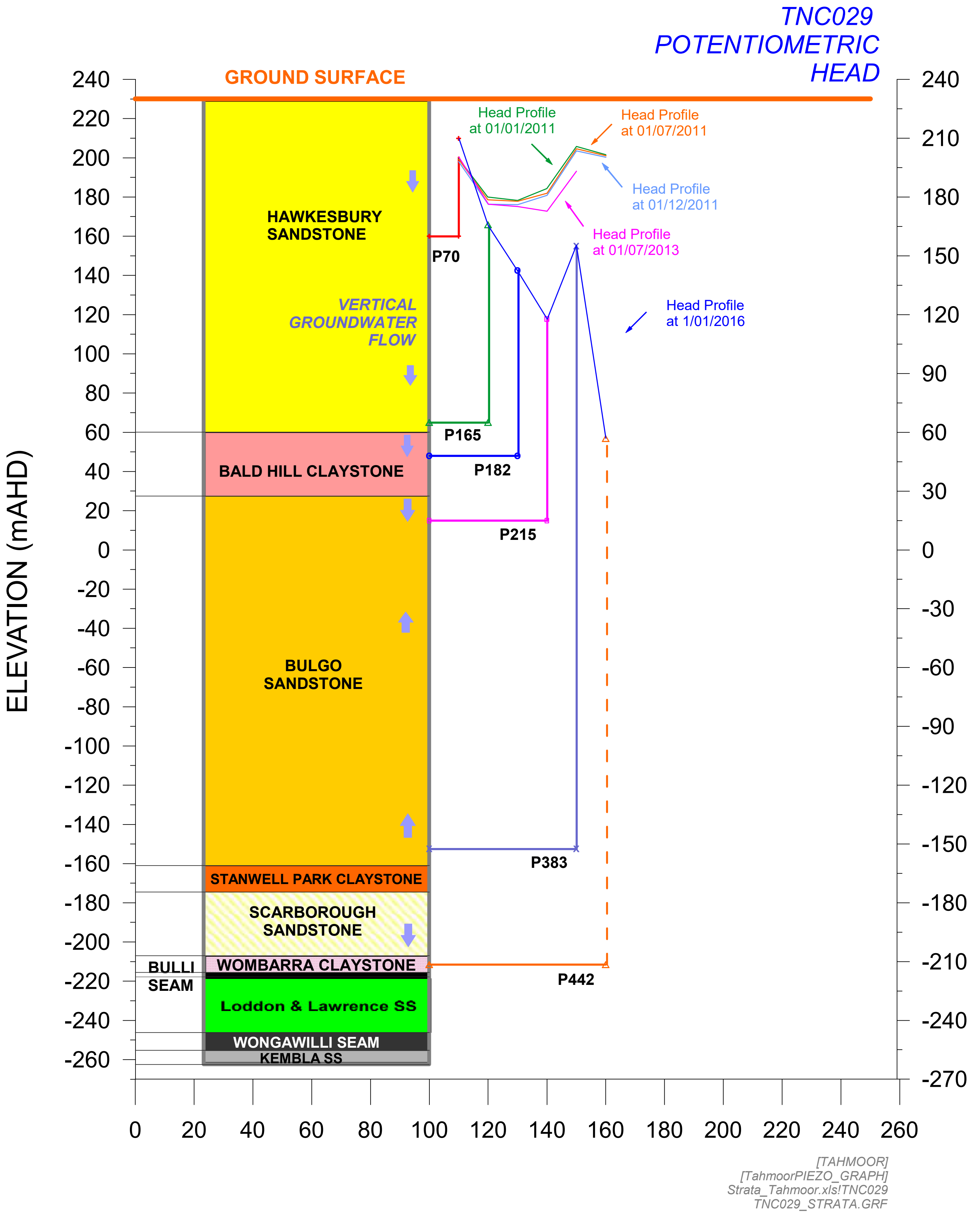

**Figure B2.17:** TBC038 Hydrograph. (out of service)

# APPENDIX C

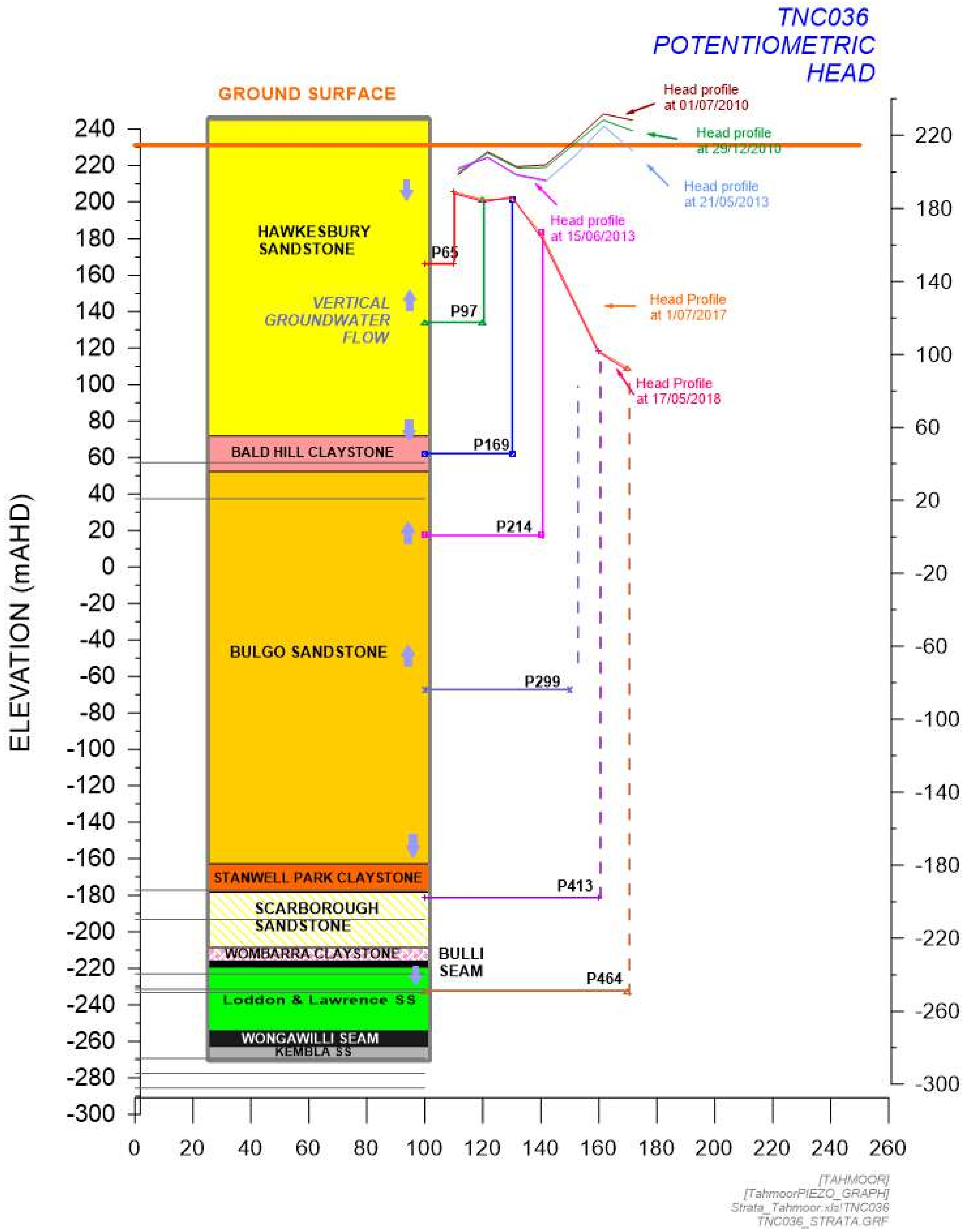
## Vertical head profiles

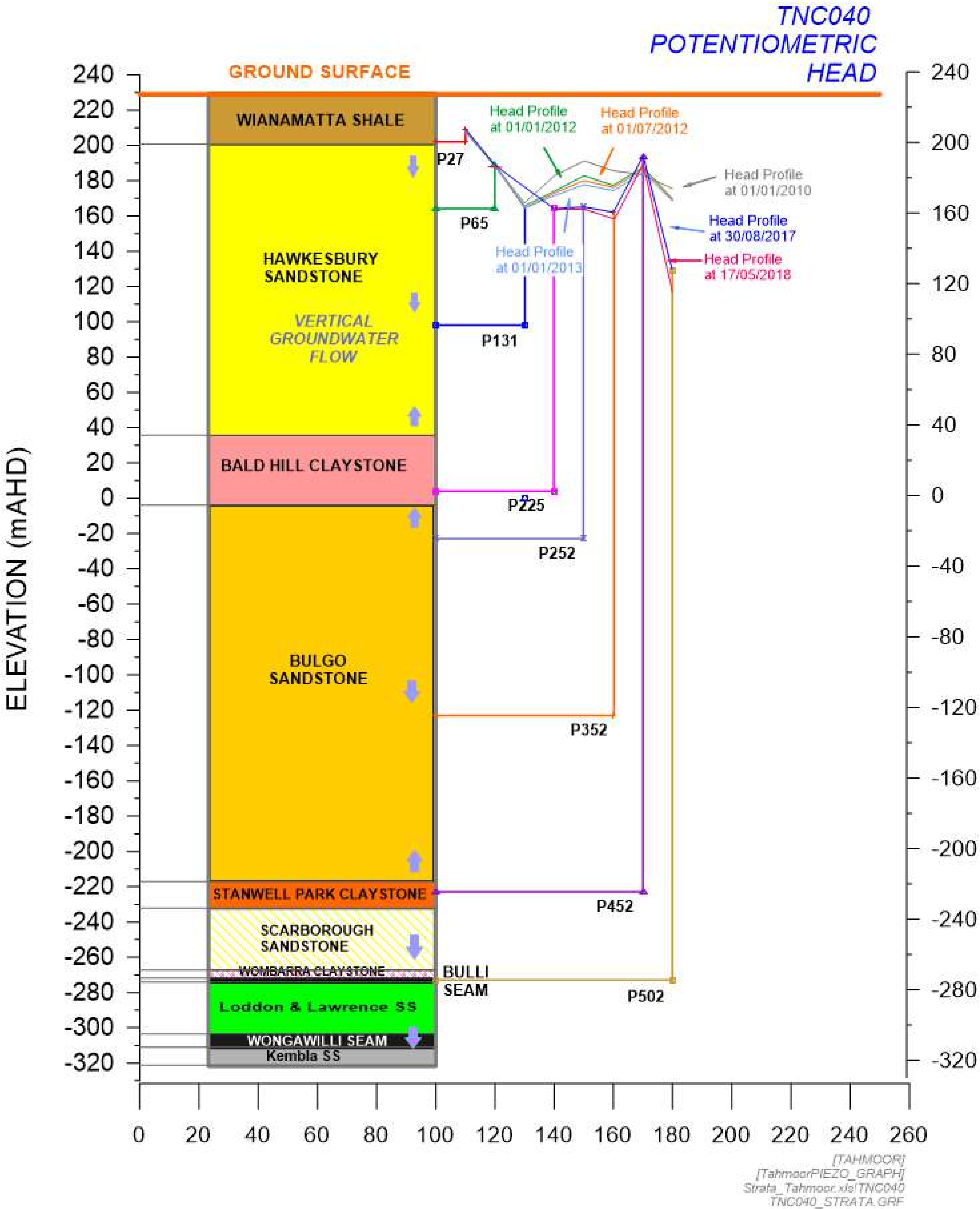



[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TNC028
TNC028_STRATA.GRF

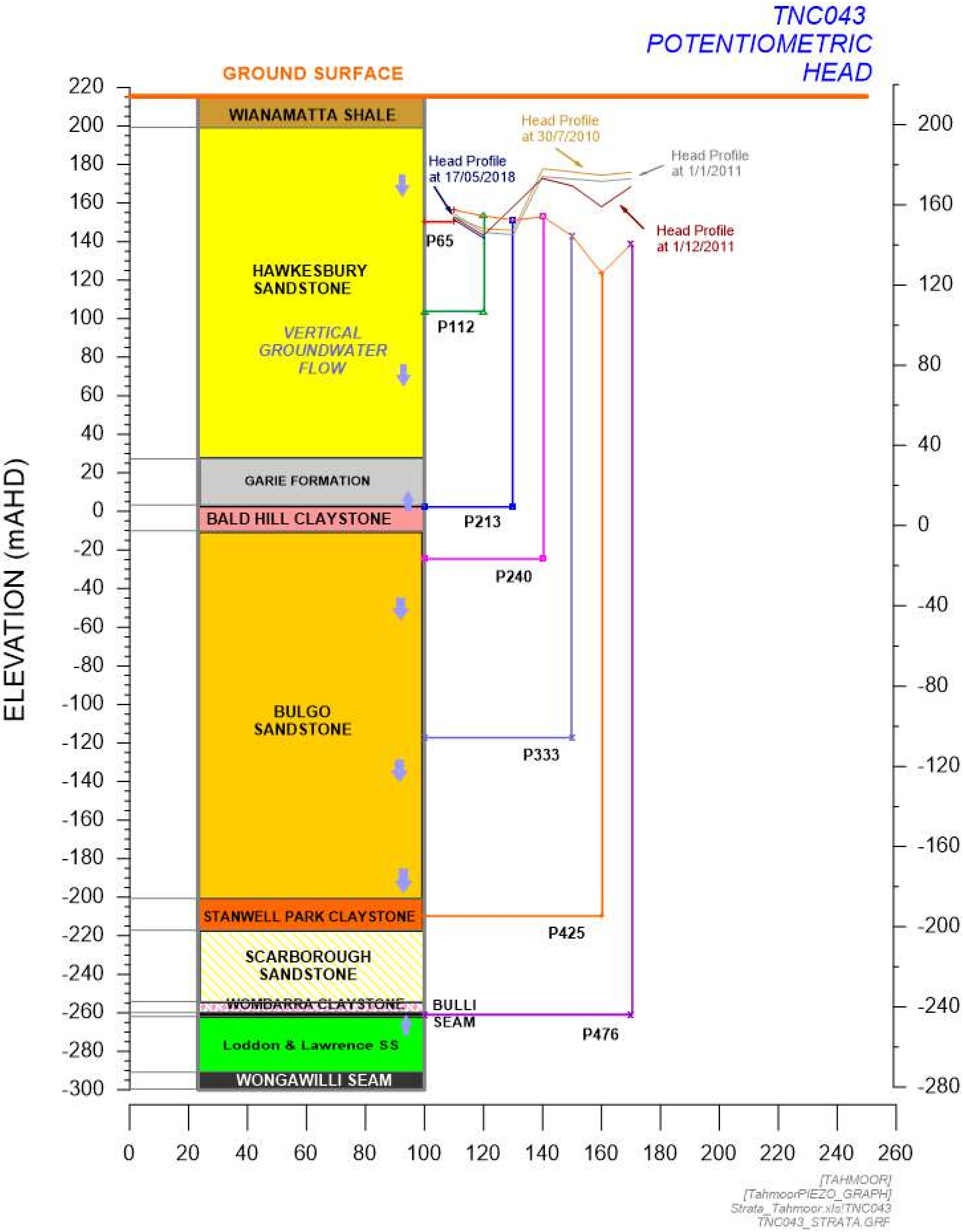


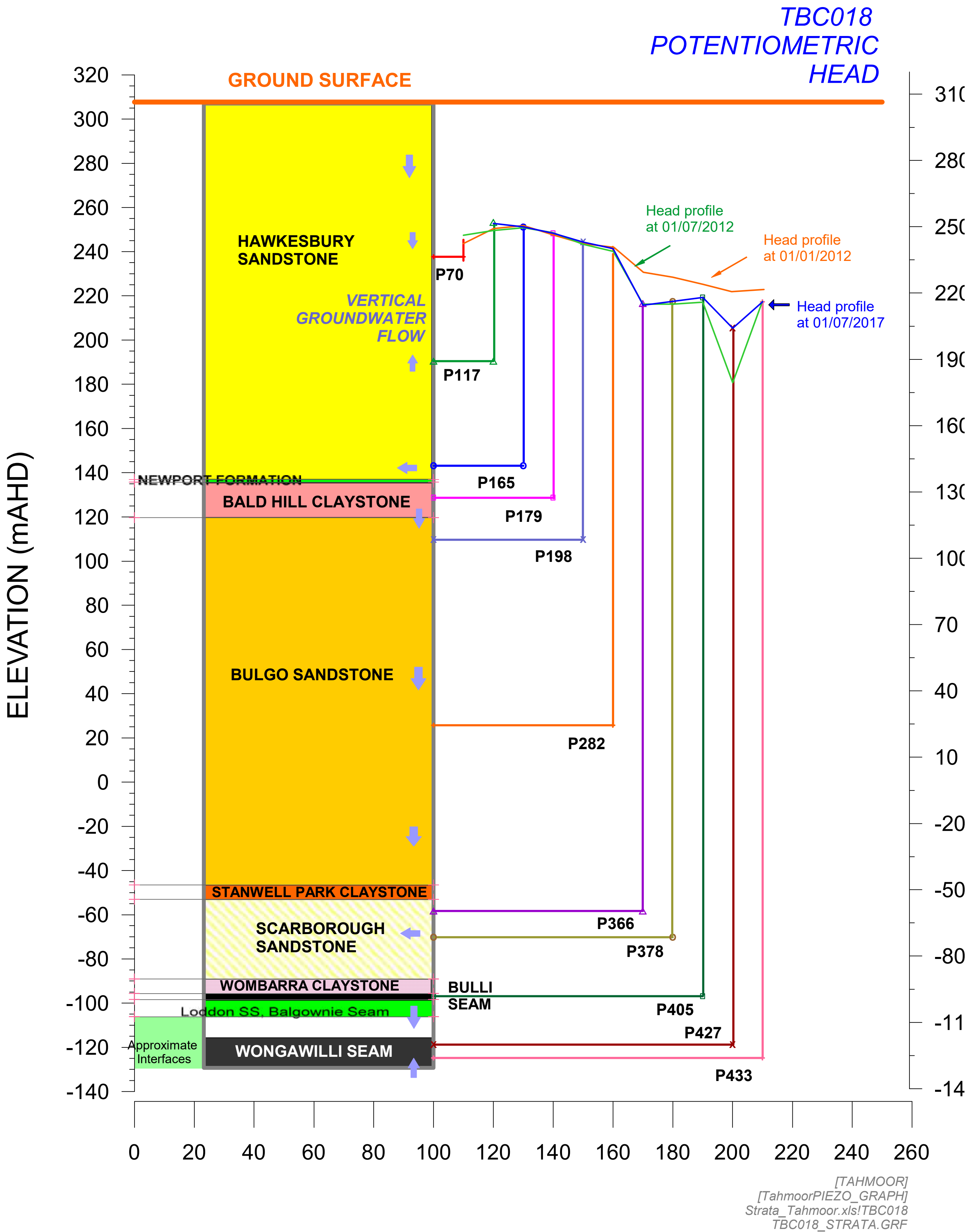
TNC029
POTENTIOMETRIC
HEAD
GROUND SURFACE
ELEVATION (mAHD)
HAWKESBURY SANDSTONE
VERTICAL GROUNDWATER FLOW
BALD HILL CLAYSTONE
BULGO SANDSTONE
STANWELL PARK CLAYSTONE
SCARBOROUGH SANDSTONE
WOMBARRA CLAYSTONE
BULLI SEAM
Loddon & Lawrence SS
WONGAWILLI SEAM
KEMBLA SS
P70
P165
P182
P215
P383
P442
Head Profile at 01/01/2011
Head Profile at 01/07/2011
Head Profile at 01/12/2011
Head Profile at 01/07/2013
Head Profile at 1/01/2016
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
240
210
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
-210
-240
-270
0
20
40
60
80
100
120
140
160
180
200
220
240
260
[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TNC029
TNC029_STRATA.GRF


TNC036
POTENTIOMETRIC
HEAD
GROUND SURFACE
Head profile at 01/07/2010
Head profile at 29/12/2010
Head profile at 21/05/2013
Head profile at 15/06/2013
Head Profile at 1/07/2017
Head Profile at 17/05/2018
HAWKESBURY SANDSTONE
VERTICAL GROUNDWATER FLOW
BALD HILL CLAYSTONE
BULGO SANDSTONE
STANWELL PARK CLAYSTONE
SCARBOROUGH SANDSTONE
WOMBARRA CLAYSTONE
BULLI SEAM
Loddon & Lawrence SS
WONGAWILLI SEAM
KEMBLA SS
P65
P97
P169
P214
P299
P413
P464
ELEVATION (mAHD)
[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TNC036
TNC036_STRATA.GRF



TNC040
POTENTIOMETRIC
HEAD
GROUND SURFACE
WIANAMATTA SHALE
HAWKESBURY SANDSTONE
VERTICAL GROUNDWATER FLOW
BALD HILL CLAYSTONE
BULGO SANDSTONE
STANWELL PARK CLAYSTONE
SCARBOROUGH SANDSTONE
WOMBARRA CLAYSTONE
BULLI SEAM
Loddon & Lawrence SS
WONGAWILLI SEAM
Kembla SS
P27
P65
P131
P225
P252
P352
P452
P502
Head Profile at 01/01/2012
Head Profile at 01/07/2012
Head Profile at 01/01/2010
Head Profile at 30/08/2017
Head Profile at 01/01/2013
Head Profile at 17/05/2018
ELEVATION (mAHD)
[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TNC040
TNC040_STRATA.GRF

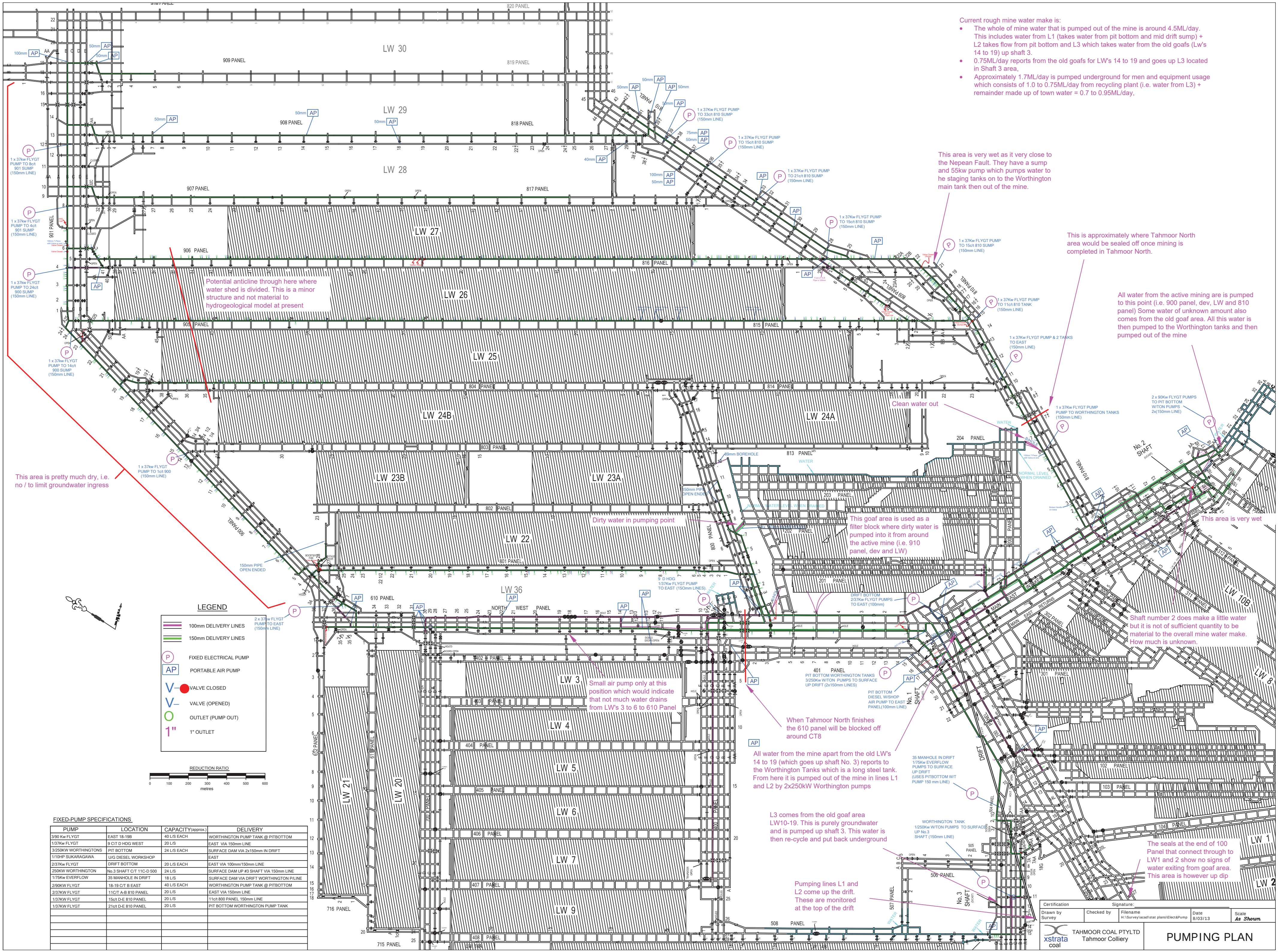

TNC043
POTENTIOMETRIC
HEAD
GROUND SURFACE
WIANAMATTA SHALE
HAWKESBURY SANDSTONE
VERTICAL GROUNDWATER FLOW
GARIE FORMATION
BALD HILL CLAYSTONE
BULGO SANDSTONE
STANWELL PARK CLAYSTONE
SCARBOROUGH SANDSTONE
WOMBARRA CLAYSTONE
BULLI SEAM
Loddon & Lawrence SS
WONGAWILLI SEAM
Head Profile at 30/7/2010
Head Profile at 17/05/2018
Head Profile at 1/1/2011
Head Profile at 1/12/2011
P65
P112
P213
P240
P333
P425
P476
ELEVATION (mAHD)
[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TNC043
TNC043_STRATA.GRF



TBC018
POTENTIOMETRIC
HEAD
GROUND SURFACE
HAWKESBURY SANDSTONE
VERTICAL GROUNDWATER FLOW
NEWPORT FORMATION
BALD HILL CLAYSTONE
BULGO SANDSTONE
STANWELL PARK CLAYSTONE
SCARBOROUGH SANDSTONE
WOMBARRA CLAYSTONE
BULLI SEAM
Loddon SS, Balgownie Seam
WONGAWILLI SEAM
Approximate Interfaces
P70
P117
P165
P179
P198
P282
P366
P378
P405
P427
P433
Head profile at 01/07/2012
Head profile at 01/01/2012
Head profile at 01/07/2017
ELEVATION (mAHD)
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
0
20
40
60
80
100
120
140
160
180
200
220
240
260
[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TBC018
TBC018_STRATA.GRF

# APPENDIX D

Tahmoor underground mine drainage plan (provided by Tahmoor Coal)




FIXED-PUMP SPECIFICATIONS

| PUMP | LOCATION | CAPACITY(approx.) | DELIVERY |
|---|---|---|---|
| 3/90 Kw FLYGT | EAST 18-19B | 40 L/S EACH | WORTHINGTON PUMP TANK @ PITBOTTOM |
| 1/37Kw FLYGT | 9 C\T D HDG WEST | 20 L/S | EAST VIA 150mm LINE |
| 3/250KW WORTHINGTONS | PIT BOTTOM | 24 L/S EACH | SURFACE DAM VIA 2x150mm IN DRIFT |
| 1/10HP SUKARAGAWA | U/G DIESEL WORKSHOP | | EAST |
| 2/37Kw FLYGT | DRIFT BOTTOM | 20 L/S EACH | EAST VIA 100mm/150mm LINE |
| 250KW WORTHINGTON | No.3 SHAFT C/T 11C-D 500 | 24 L/S | SURFACE DAM UP #3 SHAFT VIA 150mm LINE |
| 1/75Kw EVERFLOW | 35 MANHOLE IN DRIFT | 18 L/S | SURFACE DAM VIA DRIFT WORTHINGTON P/LINE |
| 2/90KW FLYGT | 18-19 C/T B EAST | 40 L/S EACH | WORTHINGTON PUMP TANK @ PITBOTTOM |
| 2/37KW FLYGT | 11C/T A-B 810 PANEL | 20 L/S | EAST VIA 150mm LINE |
| 1/37KW FLYGT | 15c/t D-E 810 PANEL | 20 L/S | 11c/t 800 PANEL 150mm LINE |
| 1/37KW FLYGT | 21c/t D-E 810 PANEL | 20 L/S | PIT BOTTOM WORTHINGTON PUMP TANK |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

# APPENDIX E

## Assessment of groundwater model confidence (using Barnett *et al*, 2012)

**Tahmoor South – Groundwater Model:**
**Model Confidence Assessment** based on 2012 Modelling Guidelines (SKM & CSIRO, 2012)

Table 2-1: Model confidence level classification—characteristics and indicators

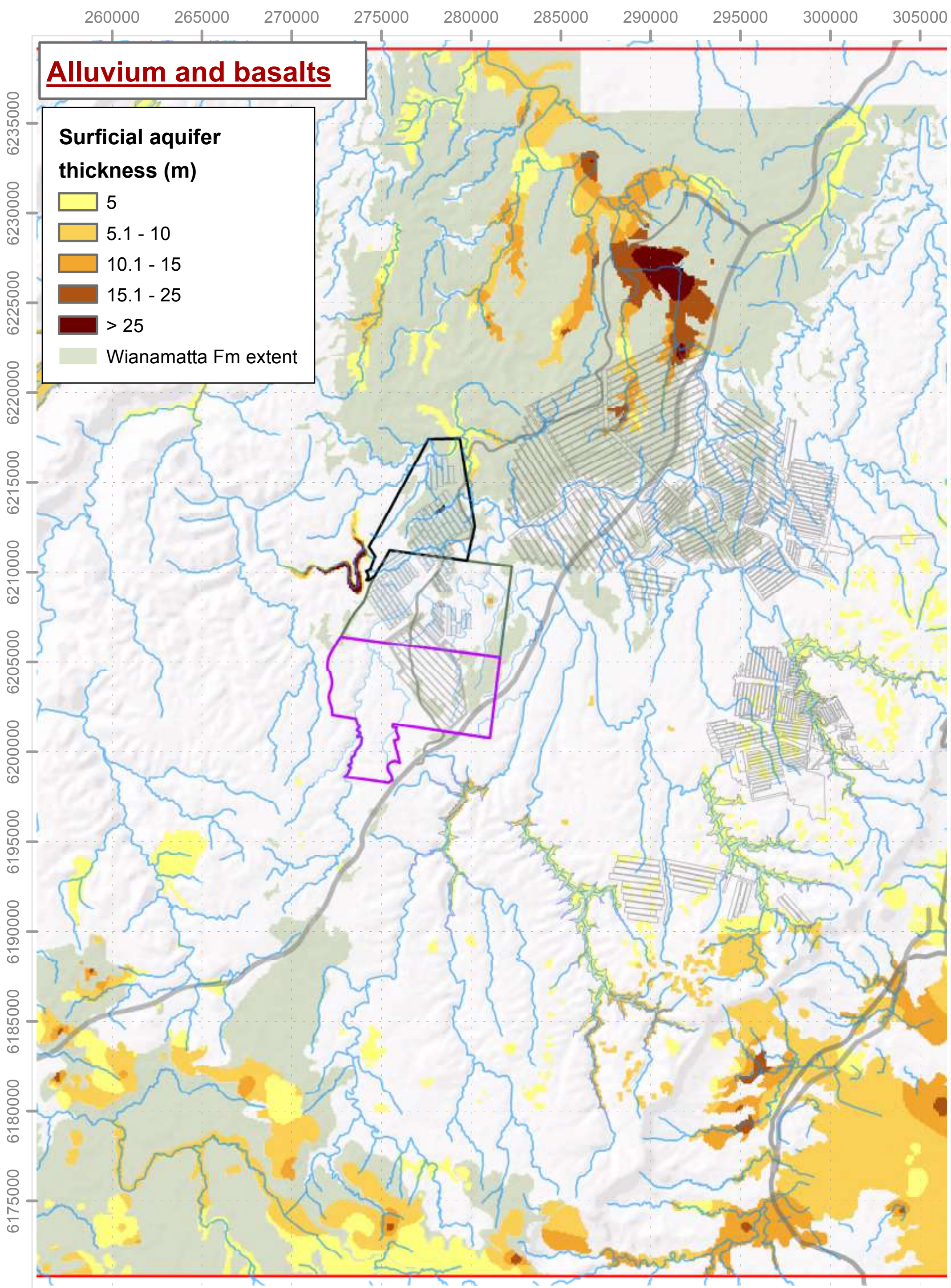
| *Confidence level classification* | *Data* | *Calibration* | *Prediction* | *Key indicator* | *Examples of specific uses* |
|---|---|---|---|---|---|
| **Class 3** | • Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported.<br>• Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry.<br>• Reliable metered groundwater extraction and injection data is available.<br>• Rainfall and evaporation data is available.<br>• Aquifer-testing data to define key parameters.<br>• Streamflow and stage measurements are available with reliable baseflow estimates at a number of points.<br>• Reliable land-use and soil-mapping data available.<br>• Reliable irrigation application data (where relevant) is available.<br>• Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation. | • Adequate validation* is demonstrated.<br>• Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable.<br>• Long-term trends are adequately replicated where these are important.<br>• Seasonal fluctuations are adequately replicated where these are important.<br>• Transient calibration is current, i.e. uses recent data.<br>• Model is calibrated to heads and fluxes.<br>• Observations of the key modelling outcomes dataset is used in calibration. | • Length of predictive model is not excessive compared to length of calibration period.<br>• Temporal discretisation used in the predictive model is consistent with the transient calibration.<br>• Level and type of stresses included in the predictive model are within the range of those used in the transient calibration.<br>• Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model.<br>• Steady-state predictions used when the model is calibrated in steady-state only. | • Key calibration statistics are acceptable and meet agreed targets.<br>• Model predictive time frame is less than 3 times the duration of transient calibration.<br>• Stresses are not more than 2 times greater than those included in calibration.<br>• Temporal discretisation in predictive model is the same as that used in calibration.<br>• Mass balance closure error is less than 0.5% of total.<br>• Model parameters consistent with conceptualisation.<br>• Appropriate computational methods used with appropriate spatial discretisation to model the problem.<br>• The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience. | • Suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain.<br>• Provide information for sustainable yield assessments for high-value regional aquifer systems.<br>• Evaluation and management of potentially high-risk impacts.<br>• Can be used to design complex mine-dewatering schemes, salt-interception schemes or water-allocation plans.<br>• Simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models.<br>• Assessment of complex, large-scale solute transport processes. |
| **Class 2**<br><br>*Cont'd overleaf* | • Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain. | • Validation* is either not undertaken or is not demonstrated for the full model domain.<br>• Calibration statistics are generally reasonable but may suggest significant errors in parts of the | • Transient calibration over a short time frame compared to that of prediction.<br>• Temporal discretisation used in the predictive model is different from that used in transient | • Key calibration statistics suggest poor calibration in parts of the model domain.<br>• Model predictive time frame is between 3 and 10 times the duration of transient calibration.<br>• Stresses are between 2 and 5 times greater than those | • Prediction of impacts of proposed developments in medium value aquifers.<br>• Evaluation and management of medium risk impacts. |

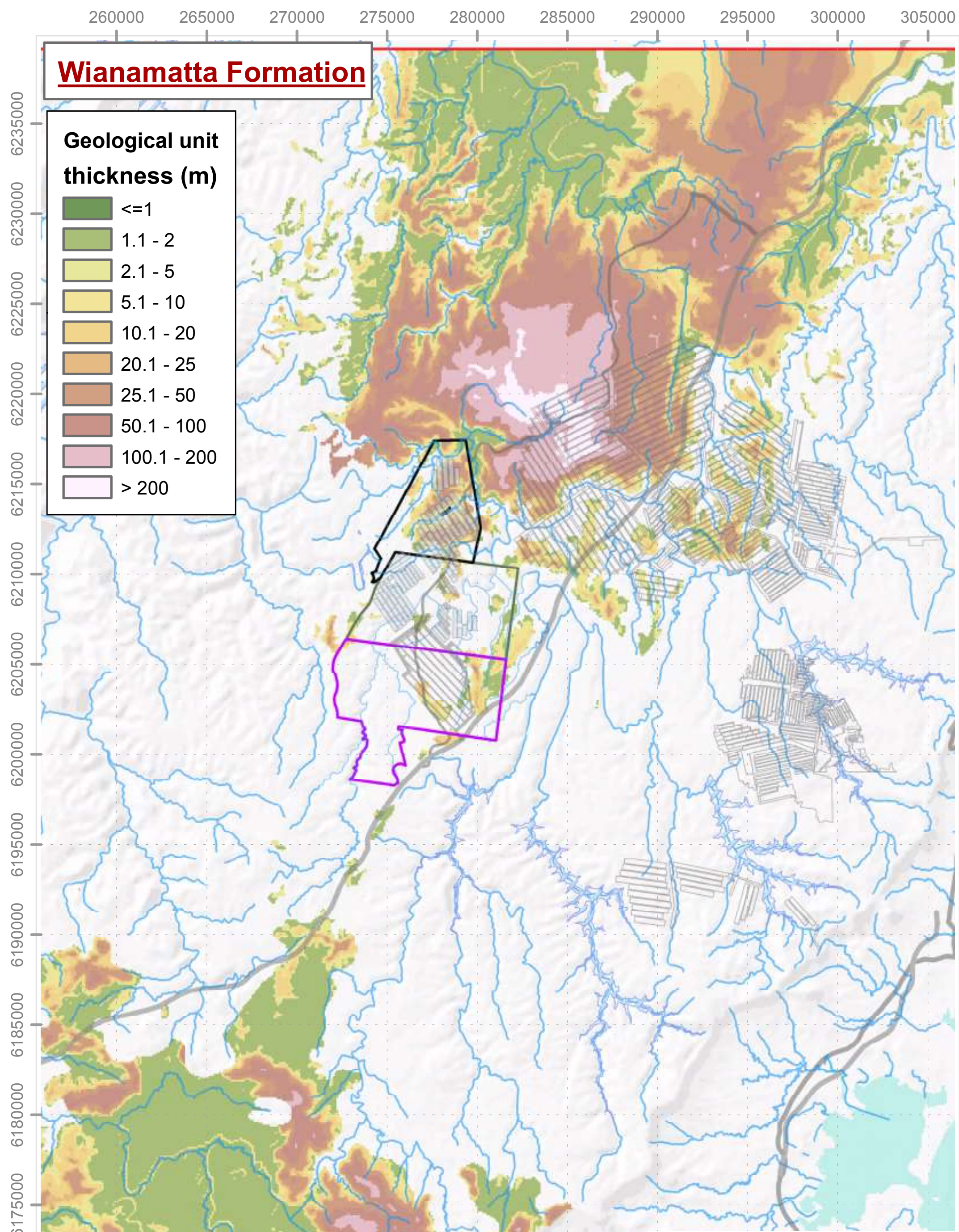
| *Confidence level classification* | *Data* | *Calibration* | *Prediction* | *Key indicator* | *Examples of specific uses* |
|---|---|---|---|---|---|
| **Class 2** *Cont'd* | • Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive.<br>• Streamflow data and baseflow estimates available at a few points.<br>• Reliable irrigation-application data available in part of the area or for part of the model duration. | model domain(s).<br>• Long-term trends not replicated in all parts of the model domain.<br>• Transient calibration to historic data but not extending to the present day.<br>• Seasonal fluctuations not adequately replicated in all parts of the model domain.<br>• Observations of the key modelling outcome data set are not used in calibration. | calibration.<br>• Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration.<br>• Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space. | included in calibration.<br>• Temporal discretisation in predictive model is not the same as that used in calibration.<br>• Mass balance closure error is less than 1% of total.<br>• Not all model parameters consistent with conceptualisation.<br>• Spatial refinement too coarse in key parts of the model domain.<br>• The model has been reviewed and deemed fit for purpose by an independent hydrogeologist. | • Providing estimates of dewatering requirements for mines and excavations and the associated impacts.<br>• Designing groundwater management schemes such as managed aquifer recharge, salinity management schemes and infiltration basins.<br>• Estimating distance of travel of contamination through particle-tracking methods. Defining water source protection zones. |
| **Class 1** | • Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information.<br>• Observations and measurements unavailable or sparsely distributed in areas of greatest interest.<br>• No available records of metered groundwater extraction or injection.<br>• Climate data only available from relatively remote locations.<br>• Little or no useful data on land-use, soils or river flows and stage elevations. | • No calibration is possible.<br>• Calibration illustrates unacceptable levels of error especially in key areas.<br>• Calibration is based on an inadequate distribution of data.<br>• Calibration only to datasets other than that required for prediction. | • Predictive model time frame far exceeds that of calibration.<br>• Temporal discretisation is different to that of calibration.<br>• Transient predictions are made when calibration is in steady state only.<br>• Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space. | • Model is uncalibrated or key calibration statistics do not meet agreed targets.<br>• Model predictive time frame is more than 10 times longer than transient calibration period.<br>• Stresses in predictions are more than 5 times higher than those in calibration.<br>• Stress period or calculation interval is different from that used in calibration.<br>• Transient predictions made but calibration in steady state only.<br>• Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time.<br>• Model parameters outside the range expected by the conceptualisation with no further justification.<br>• Unsuitable spatial or temporal discretisation.<br>• The model has not been reviewed. | • Design observation bore array for pumping tests.<br>• Predicting long-term impacts of proposed developments in low-value aquifers.<br>• Estimating impacts of low-risk developments.<br>• Understanding groundwater flow processes under various hypothetical conditions.<br>• Provide first-pass estimates of extraction volumes and rates required for mine dewatering.<br>• Developing coarse relationships between groundwater extraction locations and rates and associated impacts.<br>• As a starting point on which to develop higher class models as more data is collected and used. |

(*Refer Chapter 5 for discussion around validation as part of the calibration process.)

# APPENDIX F

## Isopachs from regional geological model




Tahmoor Coal
Tahmoor South Project

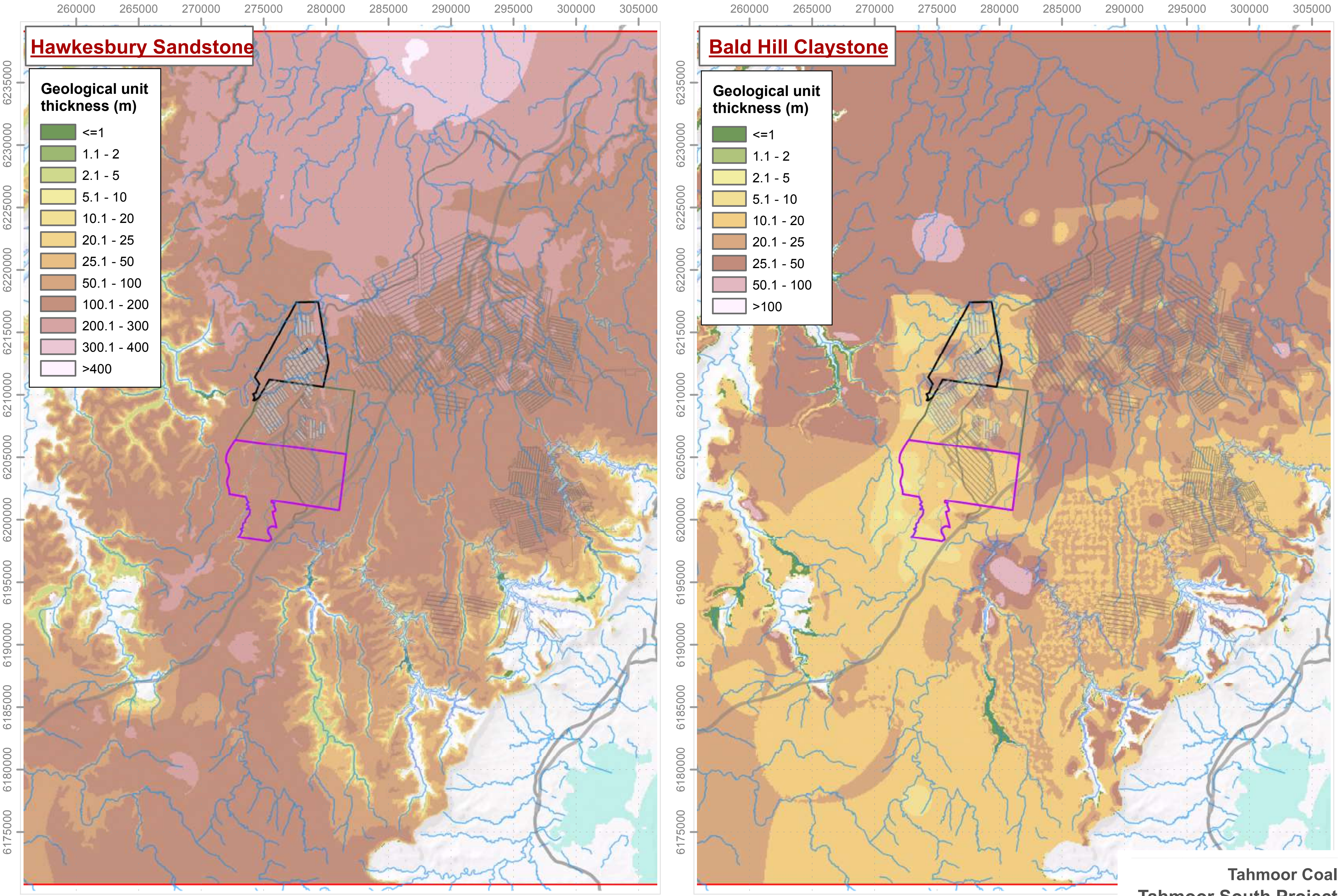
Scale: 375,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

**Geological Model: Surficial aquifers and Wianamatta Formation isopachs**

**Figure F-1**

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX1_Superfical&WMFMisopachs_A4L.mxd Rev: A - 1/11/2018 | by: BWhite




Tahmoor Coal
Tahmoor South Project

Scale: 375,000
GDA 1994 MGA Zone 56

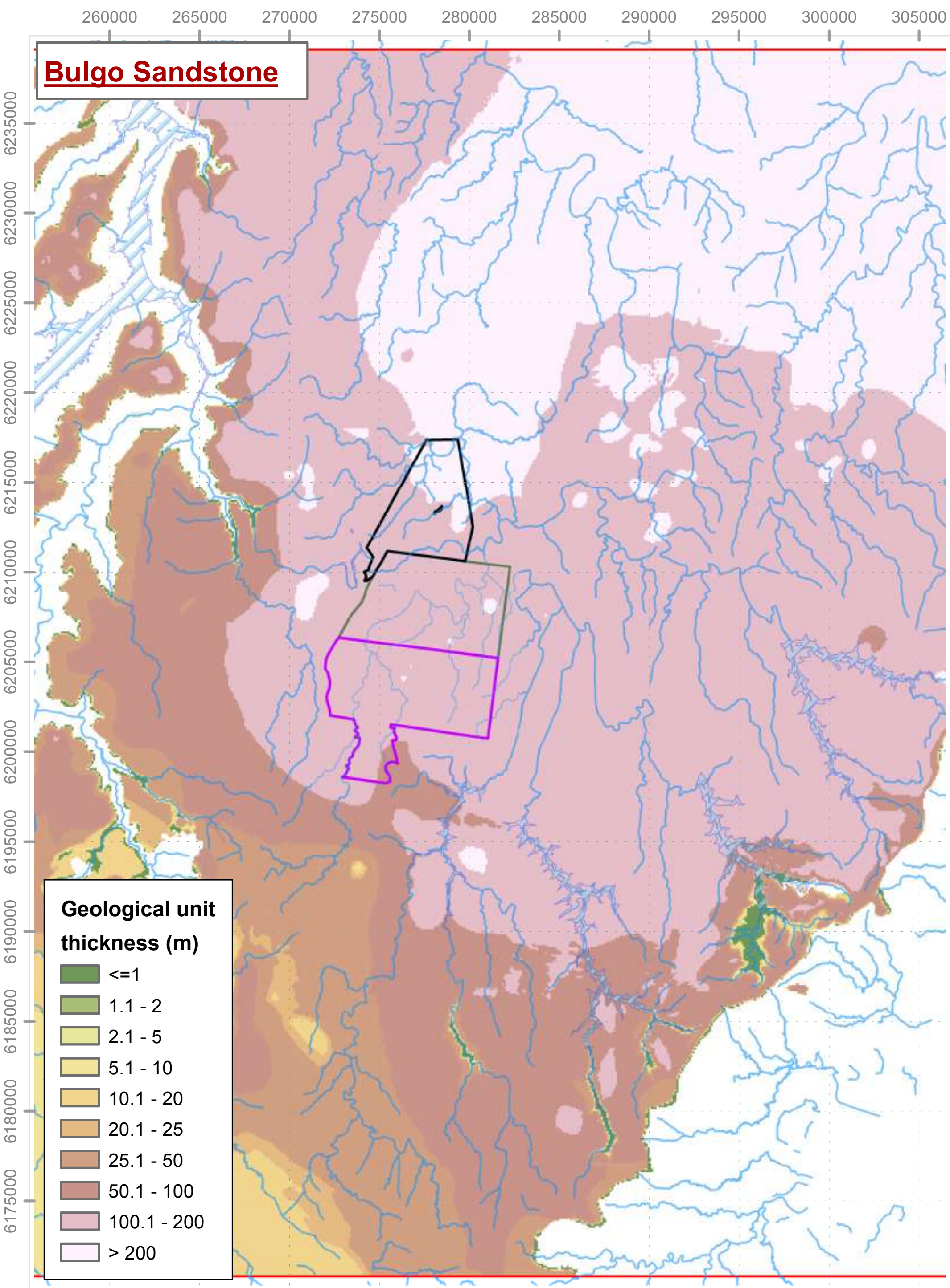
HYDROSIMULATIONS

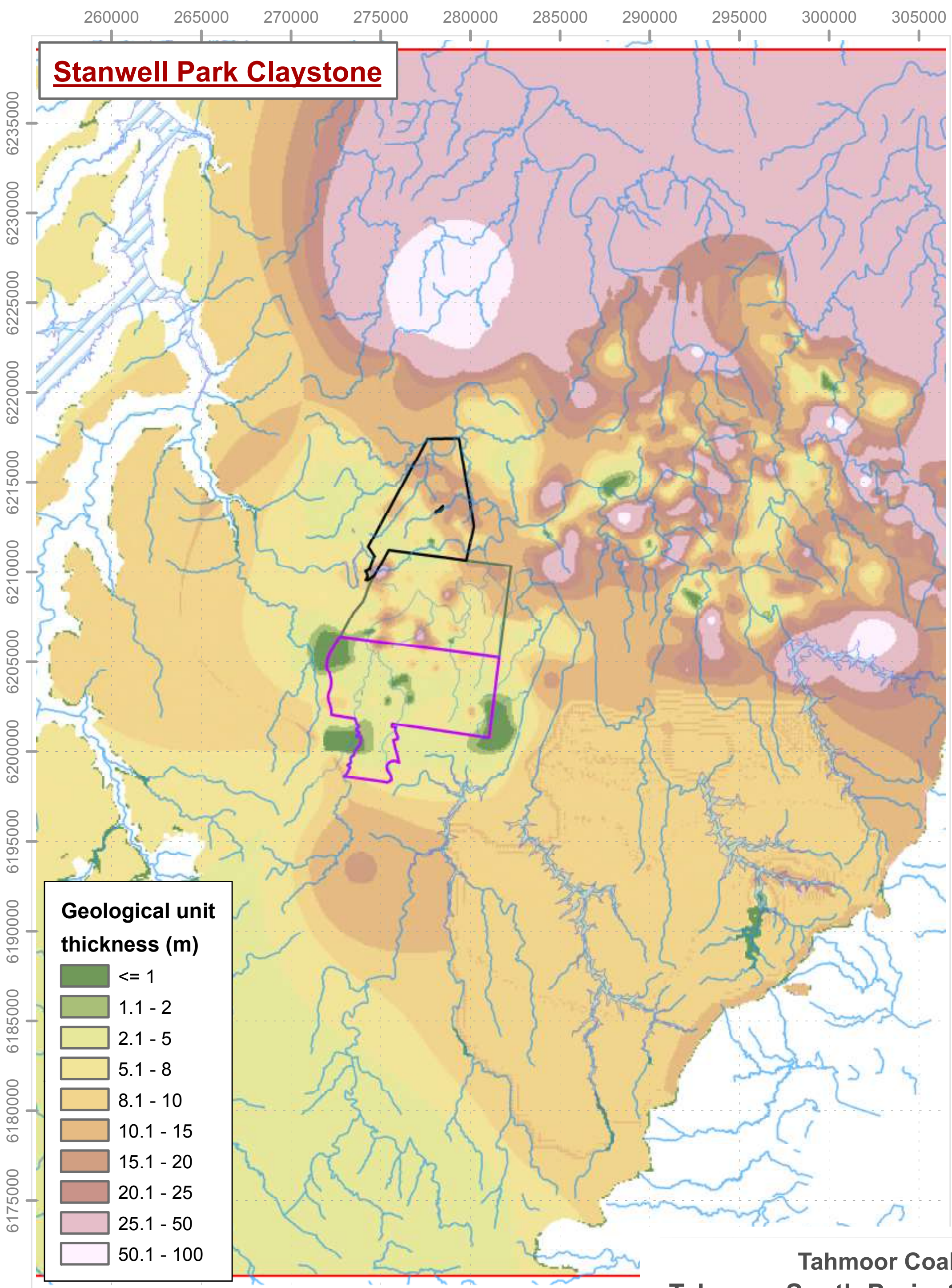
**Geological Model: Hawkesbury Sandstone and Bald Hill Claystone isopachs**

**Figure F-2**

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX2_HBSS&BHCSisopachs_A4L.mxd

Rev: A - 1/11/2018 | by: BWhite




Scale: 375,000
GDA 1994 MGA Zone 56

HYDRO SIMULATIONS

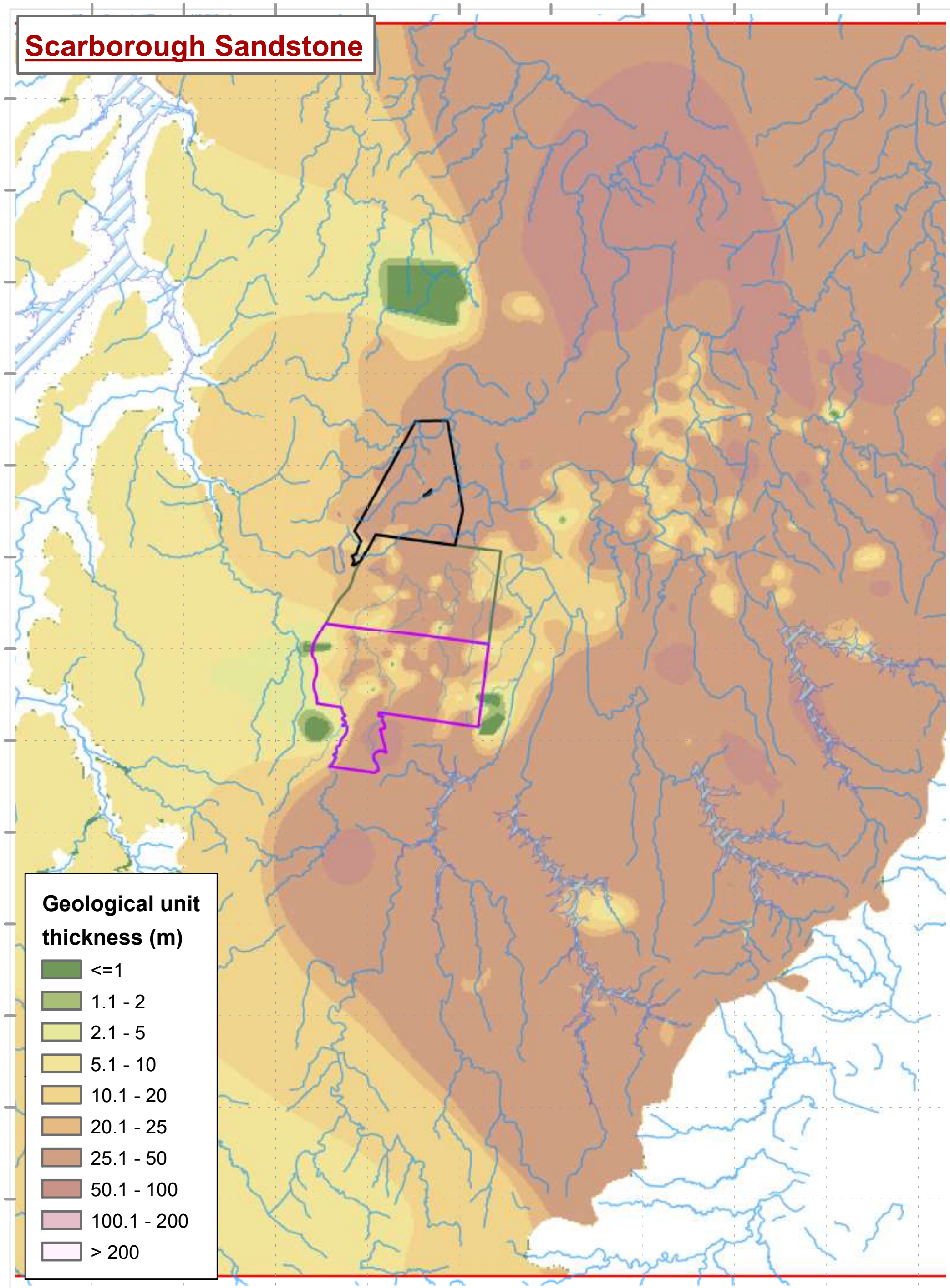
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX3_BUSS&SPCSisopachs_A4L.mxd

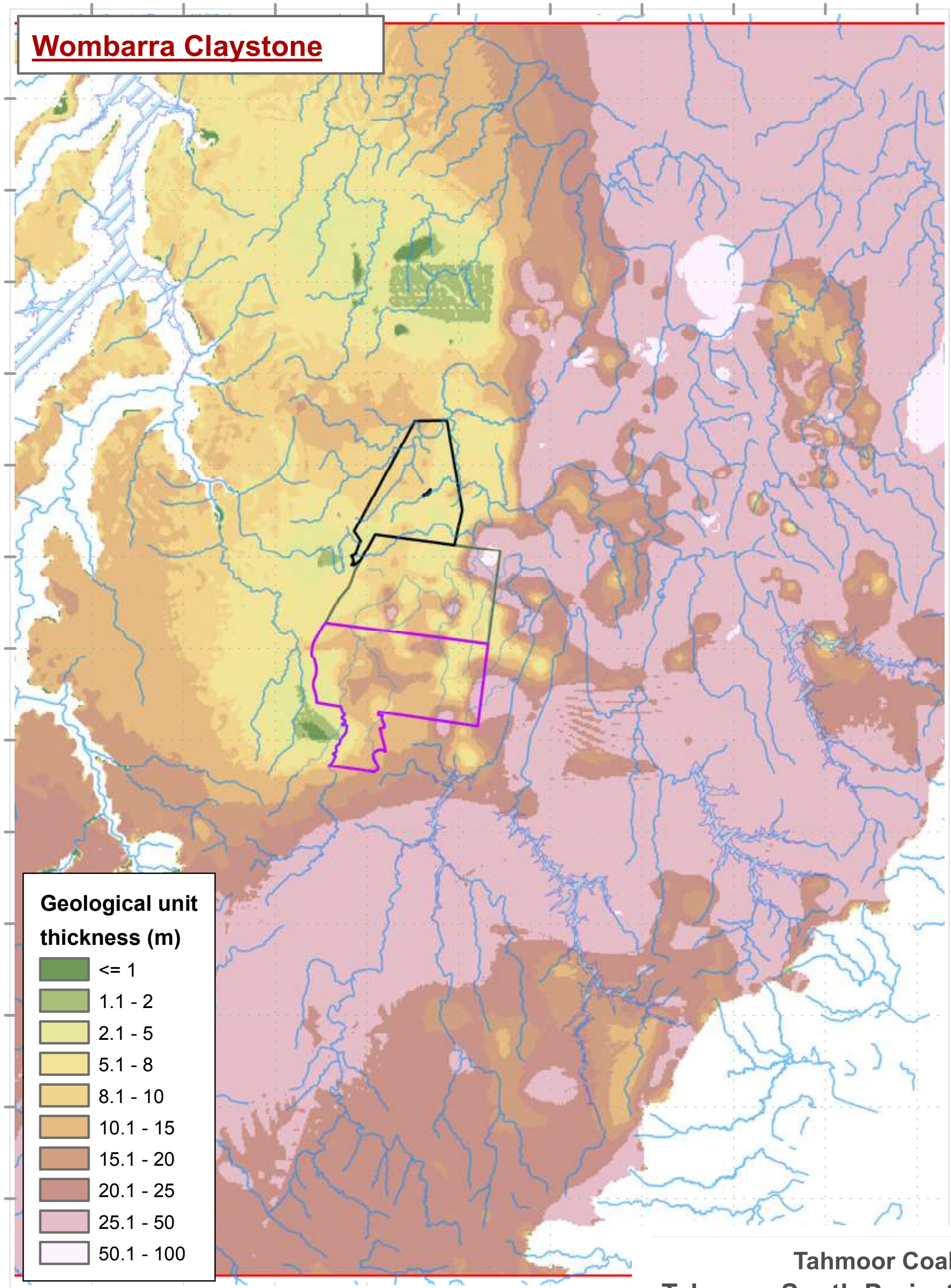
Rev: A - 1/11/2018 | by: BWhite

**Geological Model: Bulgo Sandstone and Stanwell Park Claystone isopachs**

Tahmoor Coal
Tahmoor South Project

**Figure F-3**




Scale: 375,000
GDA 1994 MGA Zone 56

HYDRO SIMULATIONS

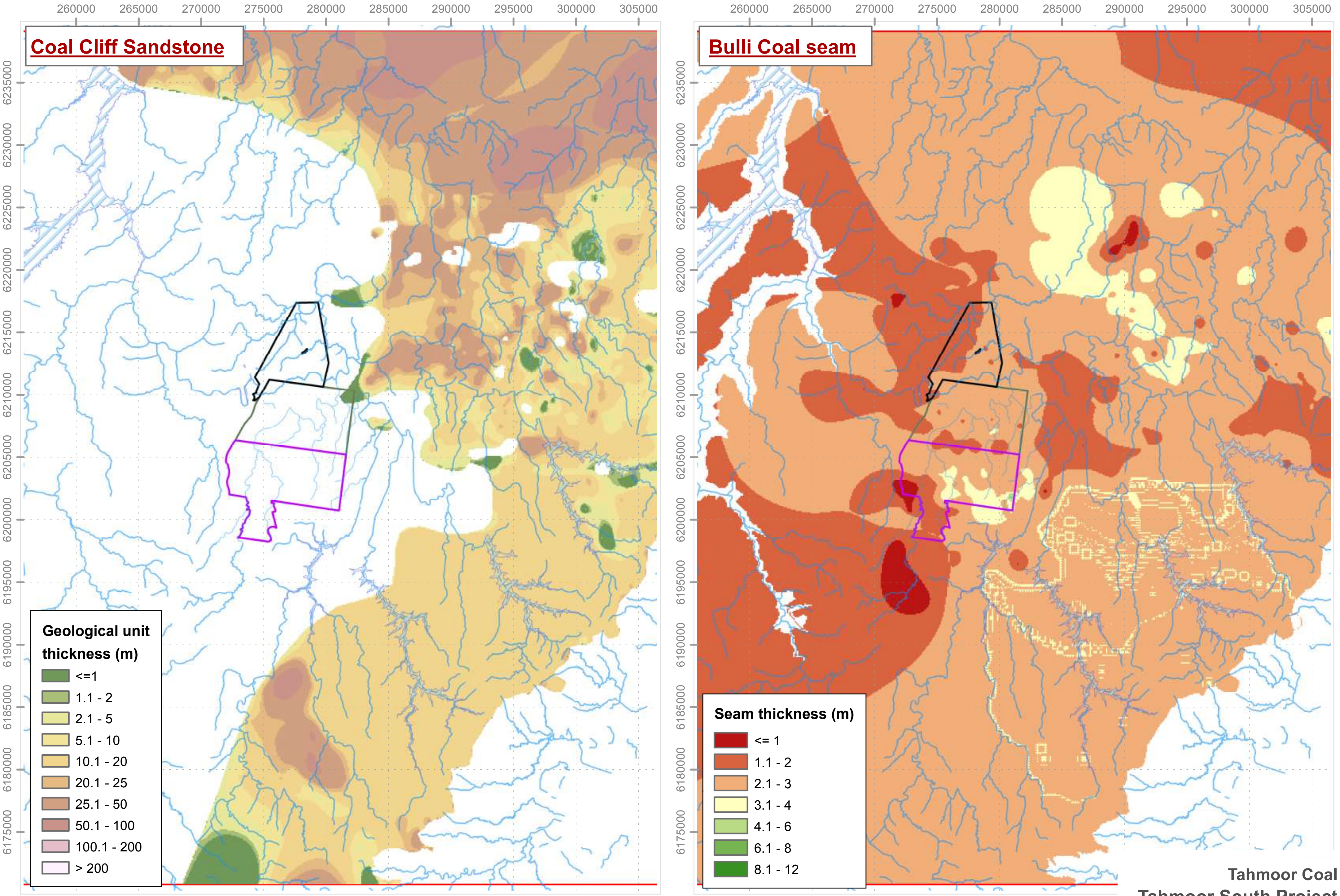
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX4_SBSS&WBCSisopachs_A4L.mxd

Rev: A - 1/11/2018| by: BWhite

**Geological Model: Scarborough Sandstone and Wombarra Claystone isopachs**

Tahmoor Coal
Tahmoor South Project

**Figure F-4**




Scale: 375,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

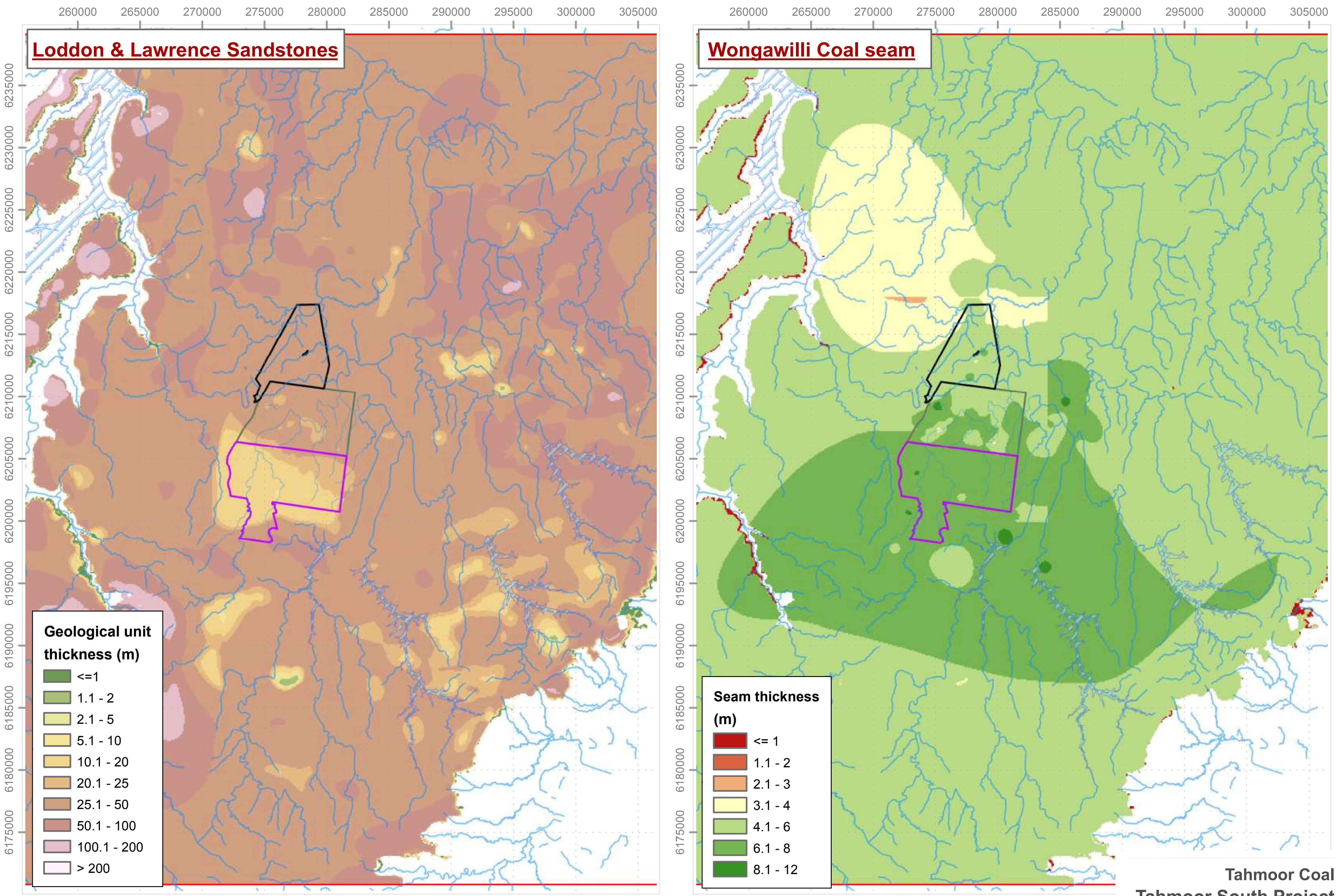
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX5_CCSS&BUSMisopachs_A4L.mxd

Rev: A - 1/11/2018 | by: BWhite

**Geological Model: Coal Cliff Sandstone and Bulli Coal seam isopachs**

Tahmoor Coal
Tahmoor South Project

**Figure F-5**




Scale: 375,000
GDA 1994 MGA Zone 56

HYDRO SIMULATIONS

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX6_LRSS&WWSMisopachs_A4L.mxd

Rev: A - 1/11/2018 | by: BWhite

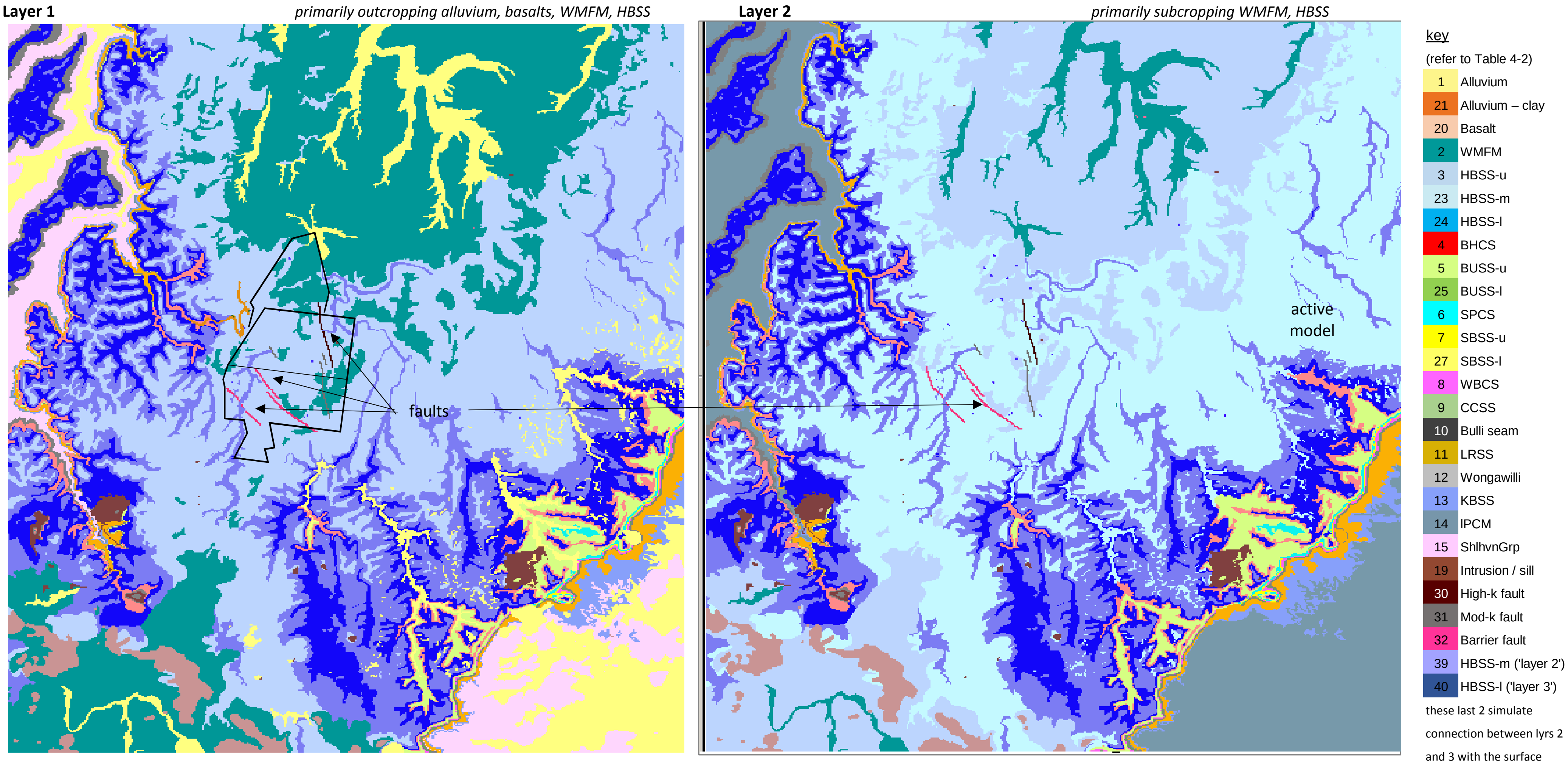
**Geological Model: Loddon & Lawrence Sandstones and Wongawilli Coal seam isopachs**

Tahmoor Coal
Tahmoor South Project

**Figure F-6**

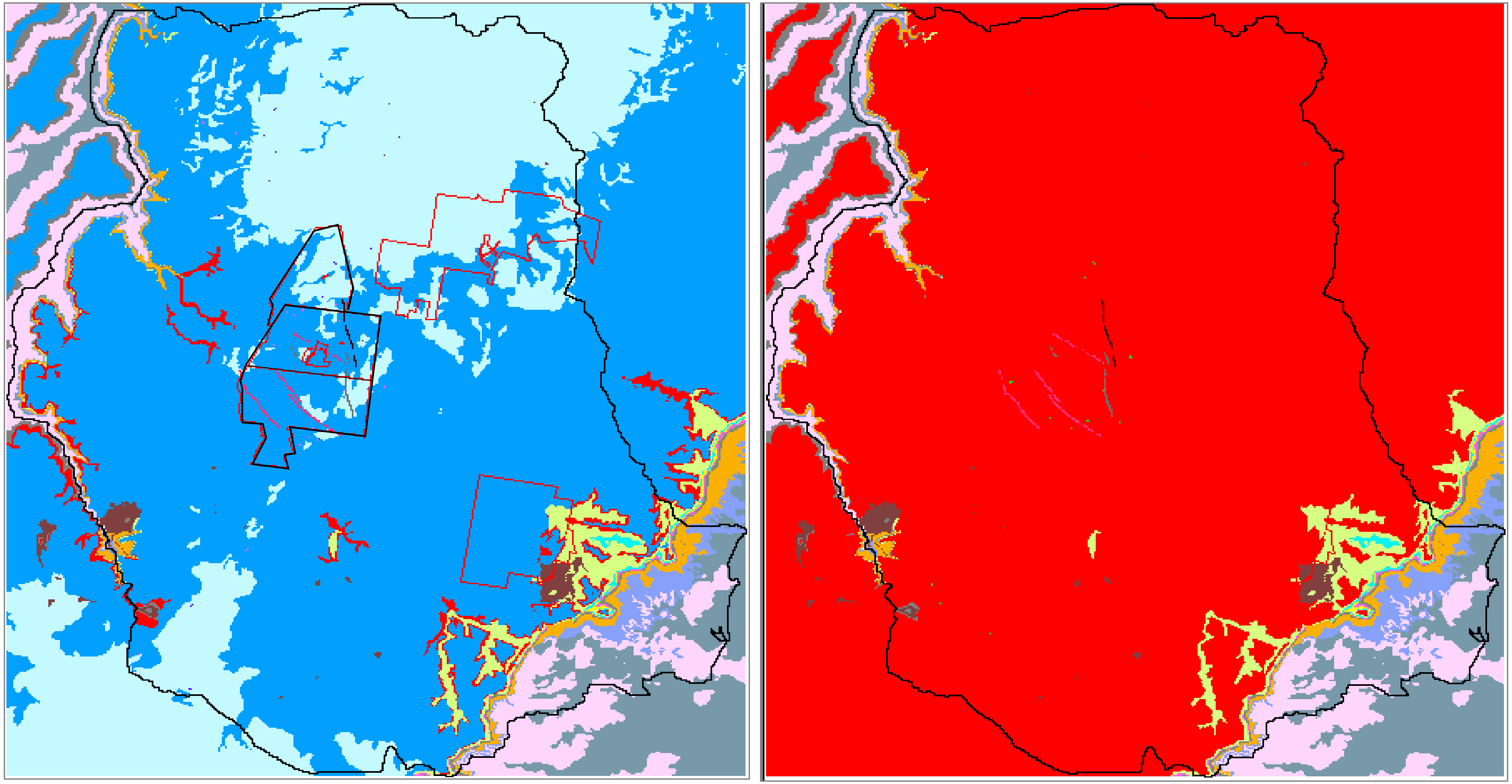
# APPENDIX G

Hydraulic conductivity zones used in the groundwater flow model




**Groundwater model hydraulic property zones:
Layer 1 and Layer 2**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx



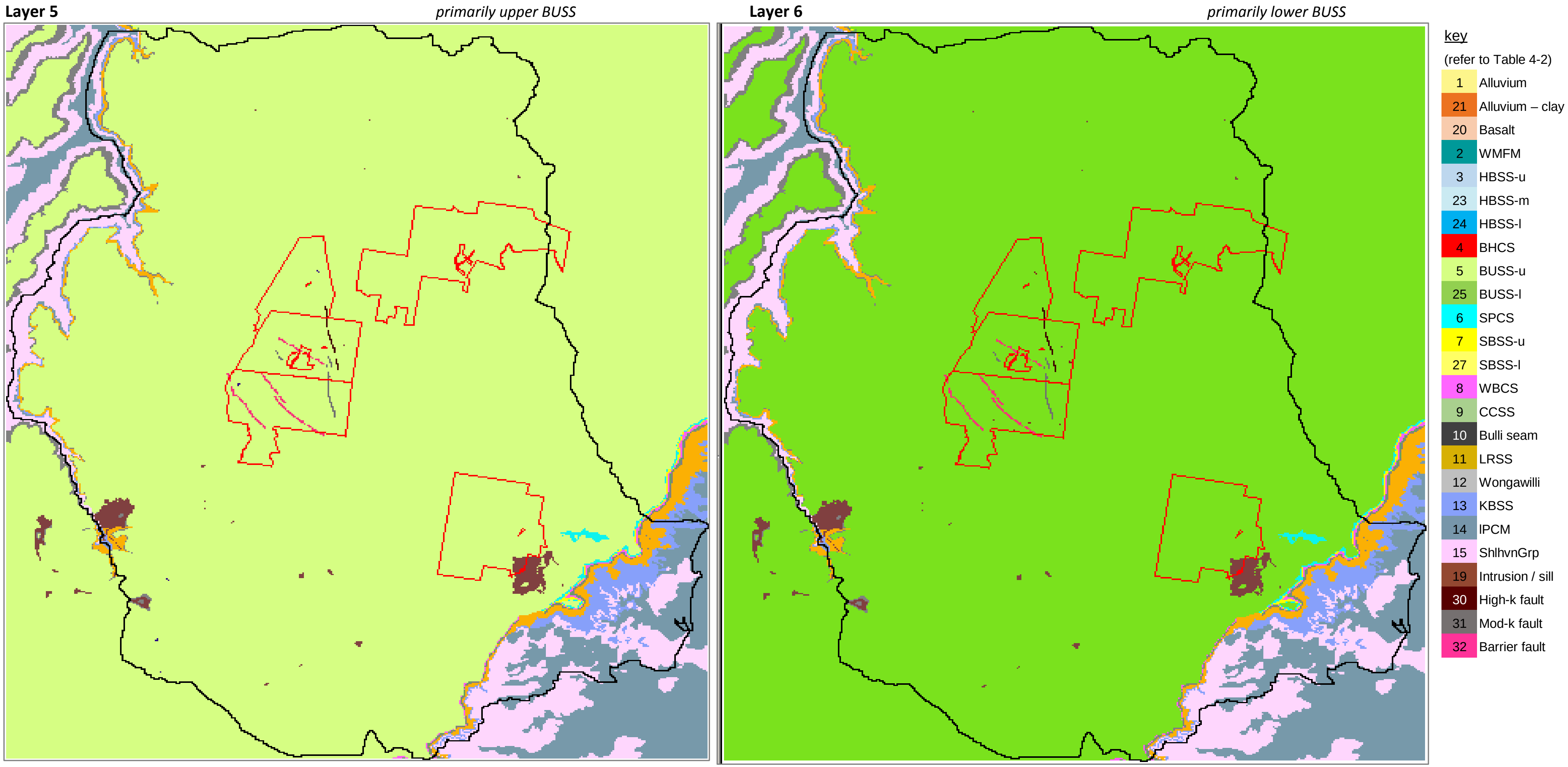

key
(refer to Table 4-2)

| | |
|---|---|
| 1 | Alluvium |
| 21 | Alluvium – clay |
| 20 | Basalt |
| 2 | WMFM |
| 3 | HBSS-u |
| 23 | HBSS-m |
| 24 | HBSS-l |
| 4 | BHCS |
| 5 | BUSS-u |
| 25 | BUSS-l |
| 6 | SPCS |
| 7 | SBSS-u |
| 27 | SBSS-l |
| 8 | WBCS |
| 9 | CCSS |
| 10 | Bulli seam |
| 11 | LRSS |
| 12 | Wongawilli |
| 13 | KBSS |
| 14 | IPCM |
| 15 | ShlhvnGrp |
| 19 | Intrusion / sill |
| 30 | High-k fault |
| 31 | Mod-k fault |
| 32 | Barrier fault |
| 39 | HBSS-m ('layer 2') |
| 40 | HBSS-l ('layer 3') |

these last 2 simulate connection between lyrs 2 and 3 with the surface

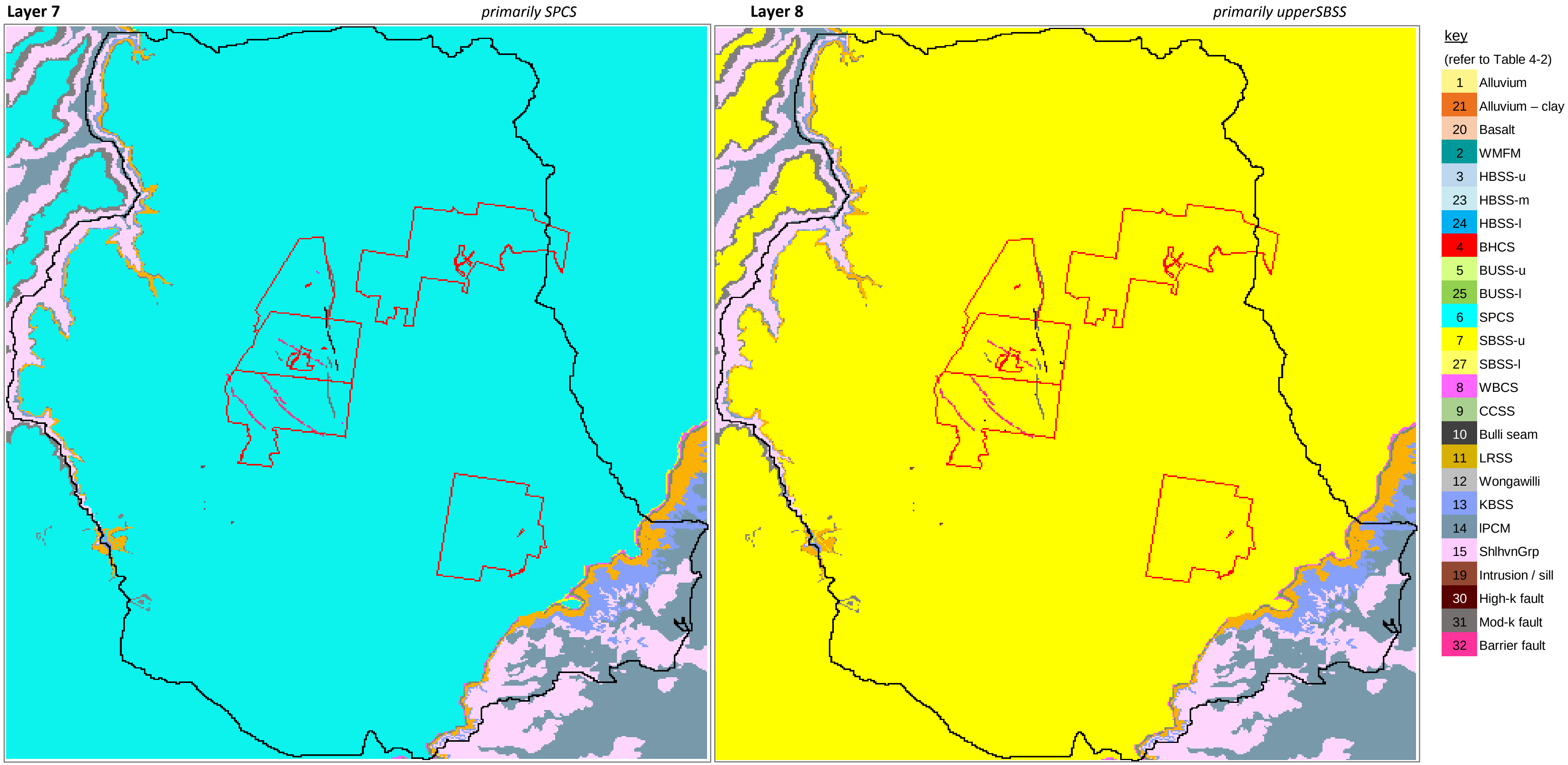
**Groundwater model hydraulic property zones: Layer 3 and Layer 4**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx



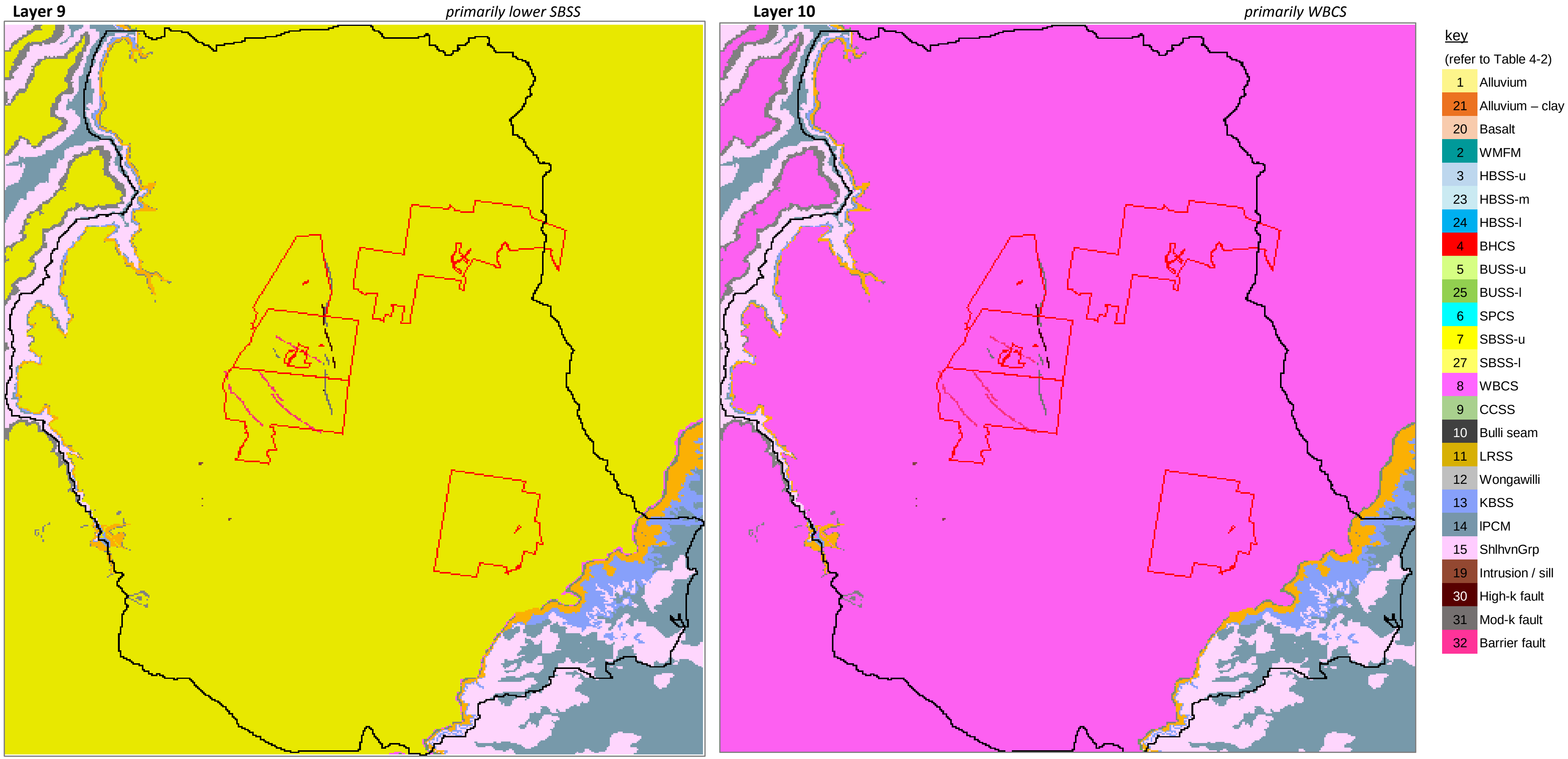

**Groundwater model hydraulic property zones: Layer 5 and Layer 6**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx




**Groundwater model hydraulic property zones:**
**Layer 7 and Layer 8**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx

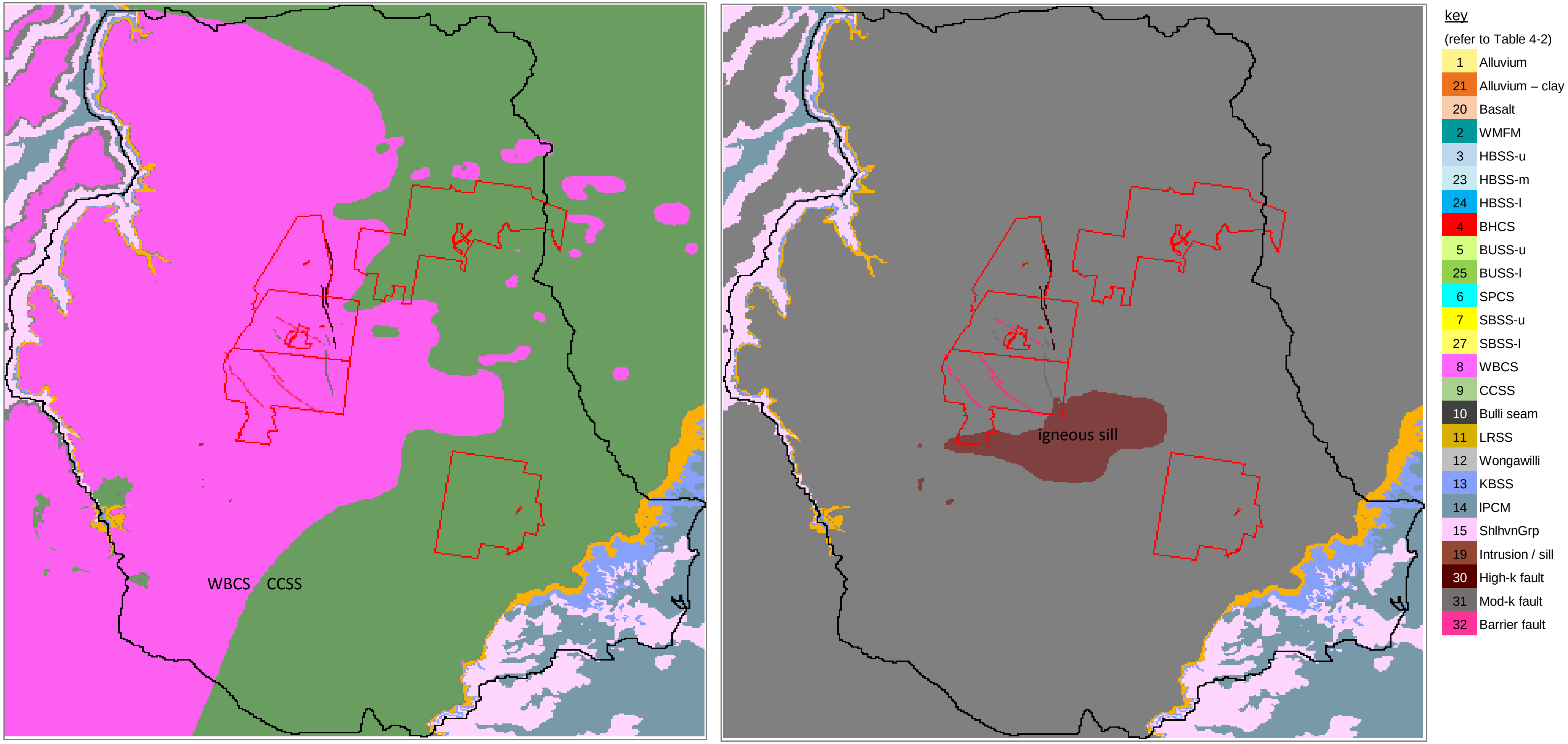



**Groundwater model hydraulic property zones: Layer 9 and Layer 10**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx

**Layer 11** *primarily CCSS, or lower part of WBCS*

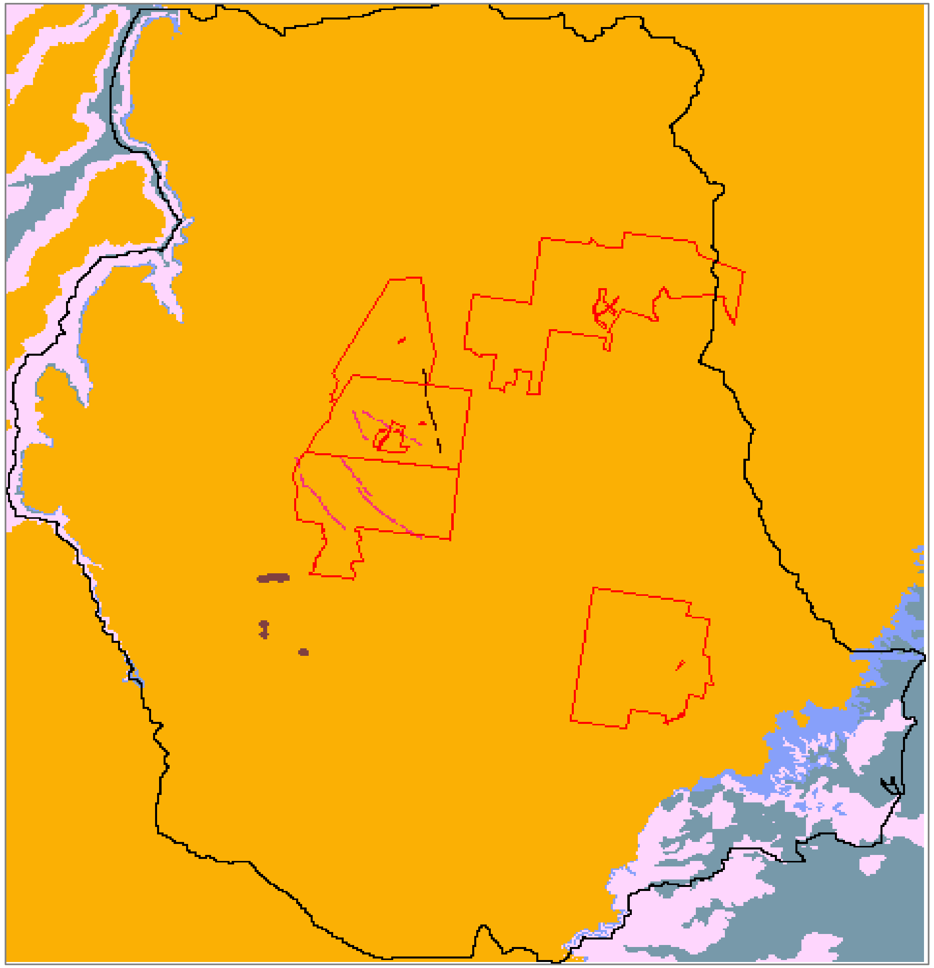
**Layer 12** *primarily Bulli Coal seam*



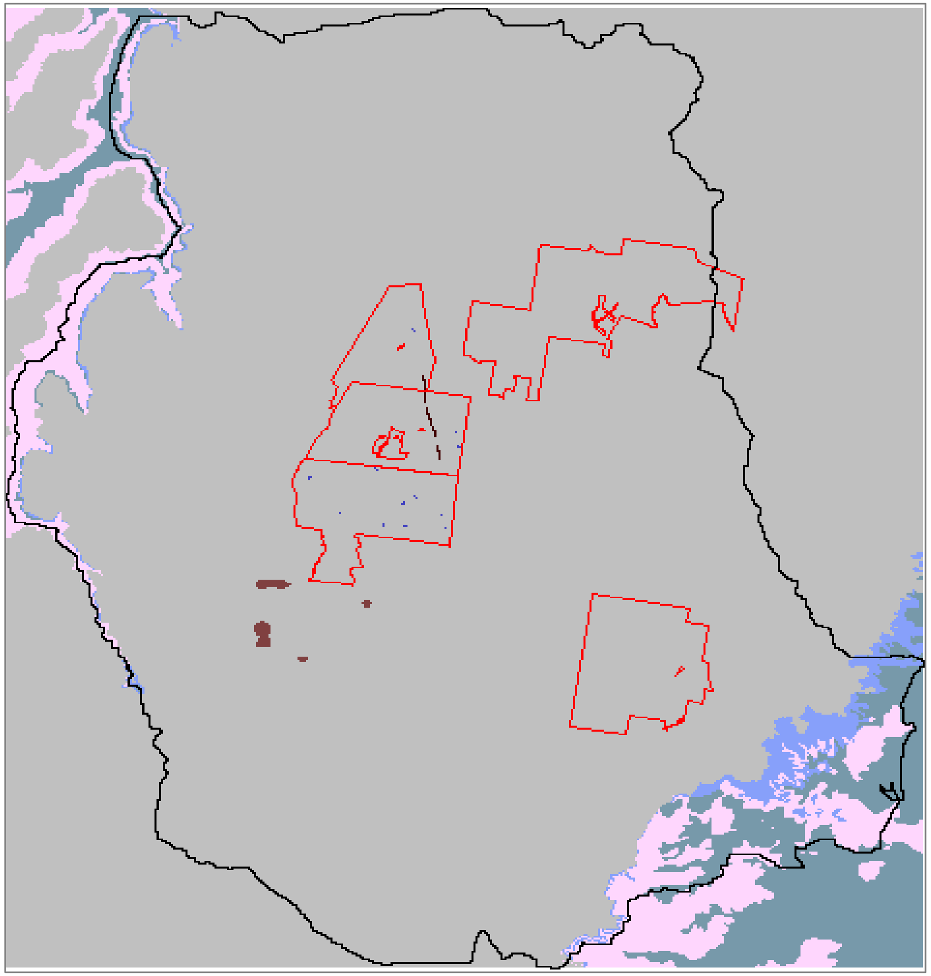

**Groundwater model hydraulic property zones:**
**Layer 11 and Layer 12**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx

**Layer 13** *primarily LRSS*



**Layer 14** *primarily Wongawilli Coal seam*



key

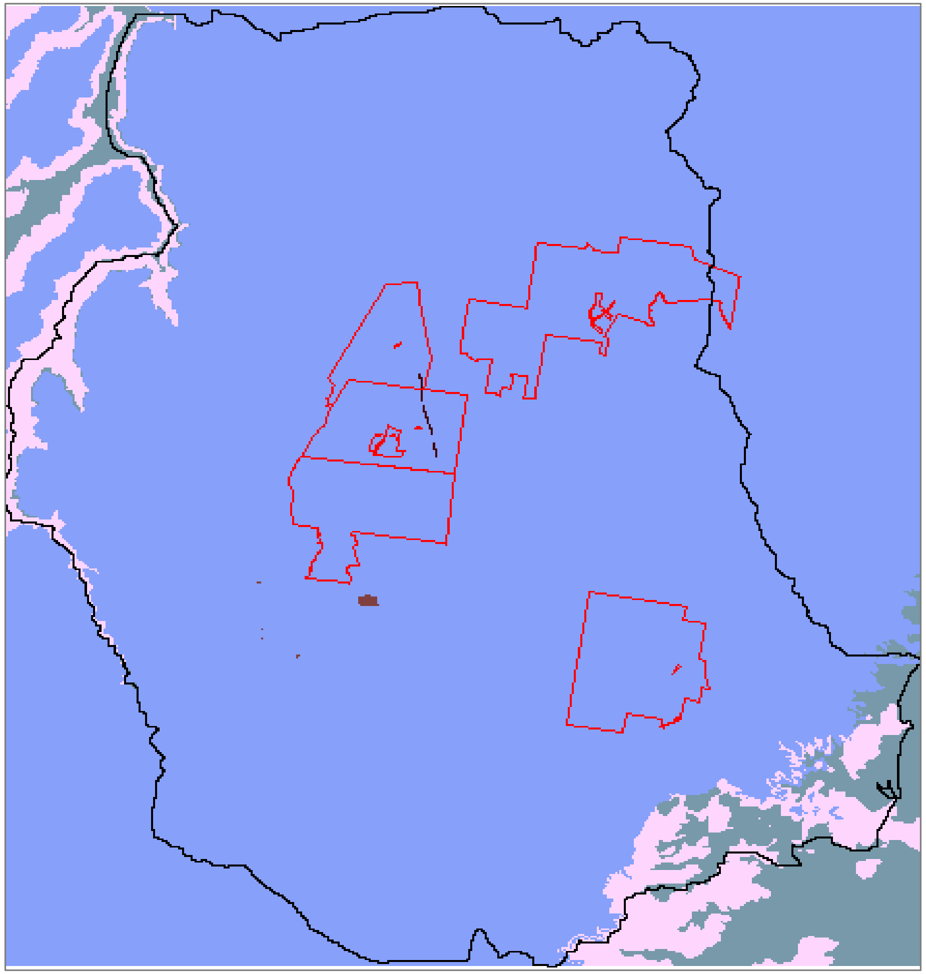
(refer to Table 4-2)

| | |
|---|---|
| 1 | Alluvium |
| 21 | Alluvium – clay |
| 20 | Basalt |
| 2 | WMFM |
| 3 | HBSS-u |
| 23 | HBSS-m |
| 24 | HBSS-l |
| 4 | BHCS |
| 5 | BUSS-u |
| 25 | BUSS-l |
| 6 | SPCS |
| 7 | SBSS-u |
| 27 | SBSS-l |
| 8 | WBCS |
| 9 | CCSS |
| 10 | Bulli seam |
| 11 | LRSS |
| 12 | Wongawilli |
| 13 | KBSS |
| 14 | IPCM |
| 15 | ShlhvnGrp |
| 19 | Intrusion / sill |
| 30 | High-k fault |
| 31 | Mod-k fault |
| 32 | Barrier fault |

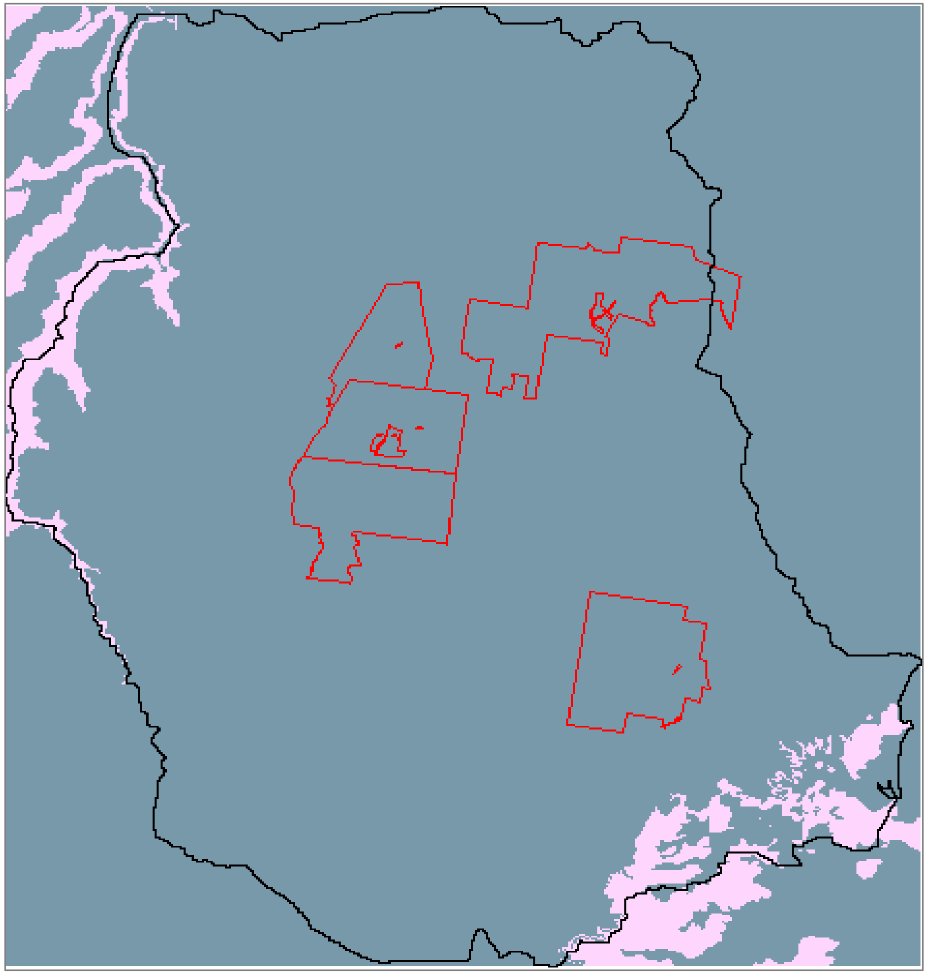
**Groundwater model hydraulic property zones: Layer 13 and Layer 14**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx

**Layer 15** *primarily KBSS*



**Layer 16** *primarily lower Permian Coal Measures and Shoalhaven Grp*



key

(refer to Table 4-2)

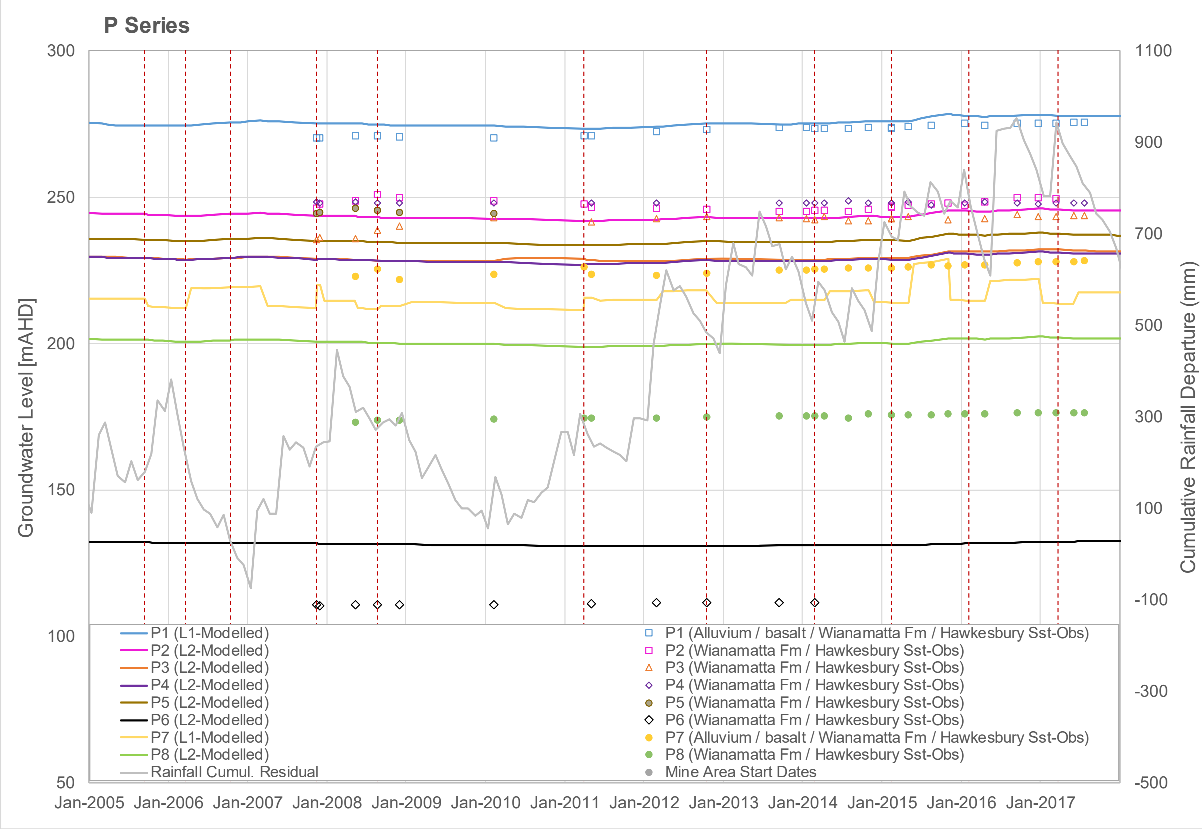
- 1 Alluvium
- 21 Alluvium – clay
- 20 Basalt
- 2 WMFM
- 3 HBSS-u
- 23 HBSS-m
- 24 HBSS-l
- 4 BHCS
- 5 BUSS-u
- 25 BUSS-l
- 6 SPCS
- 7 SBSS-u
- 27 SBSS-l
- 8 WBCS
- 9 CCSS
- 10 Bulli seam
- 11 LRSS
- 12 Wongawilli
- 13 KBSS
- 14 lPCM
- 15 ShlhvnGrp
- 19 Intrusion / sill
- 30 High-k fault
- 31 Mod-k fault
- 32 Barrier fault

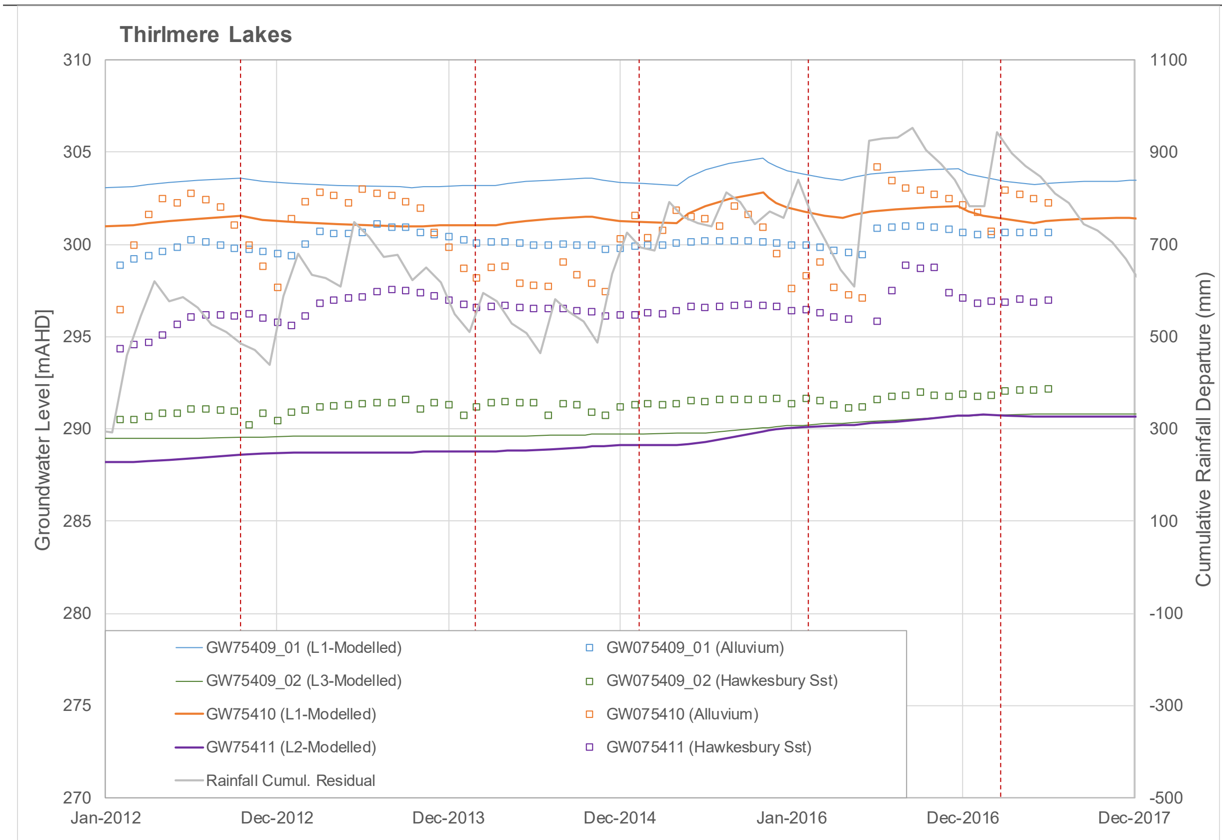
C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx

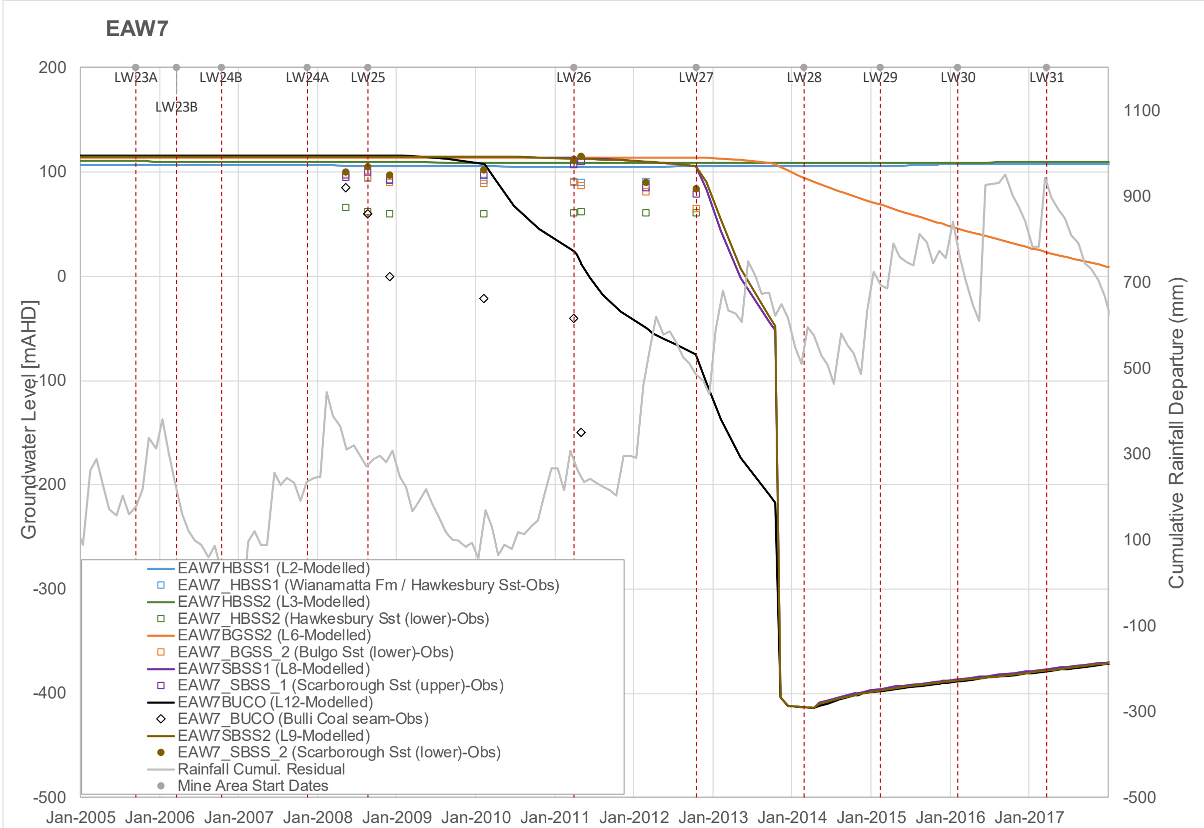
**Groundwater model hydraulic property zones: Layer 15 and Layer 16**

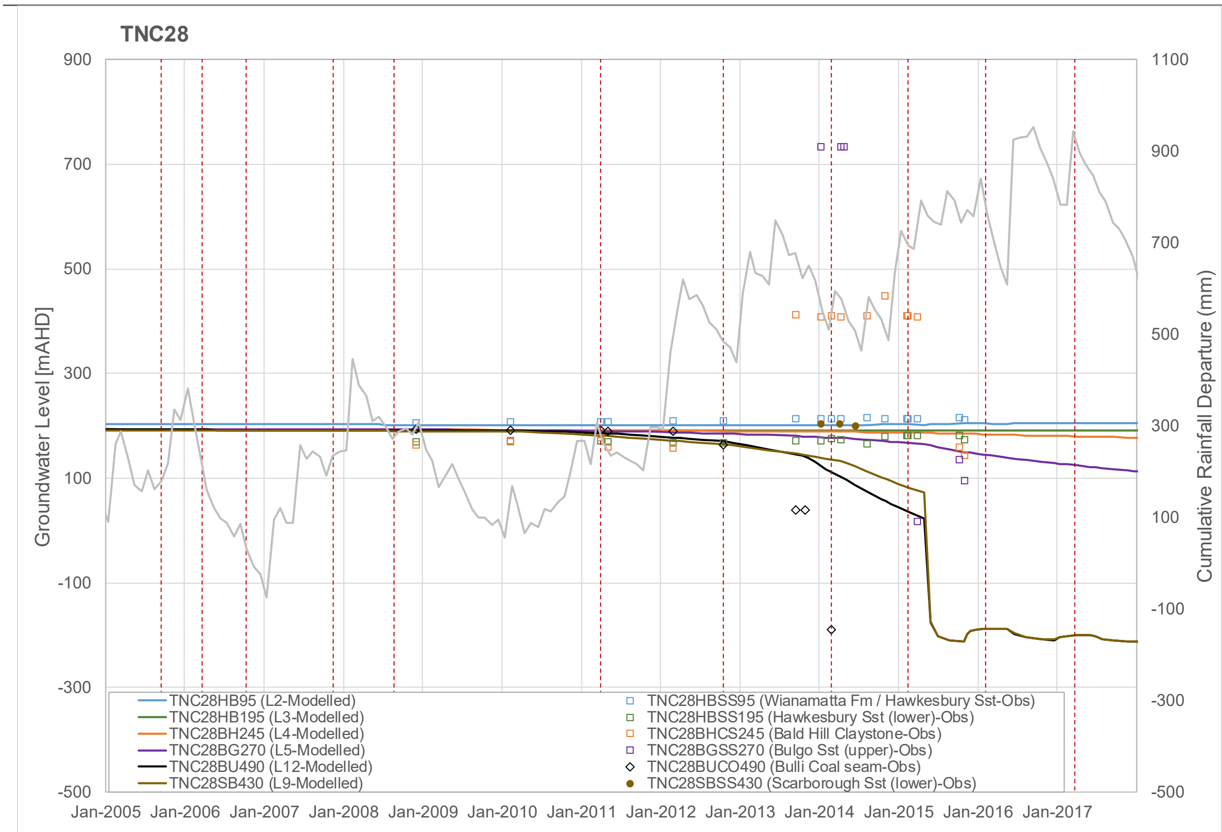
## APPENDIX H

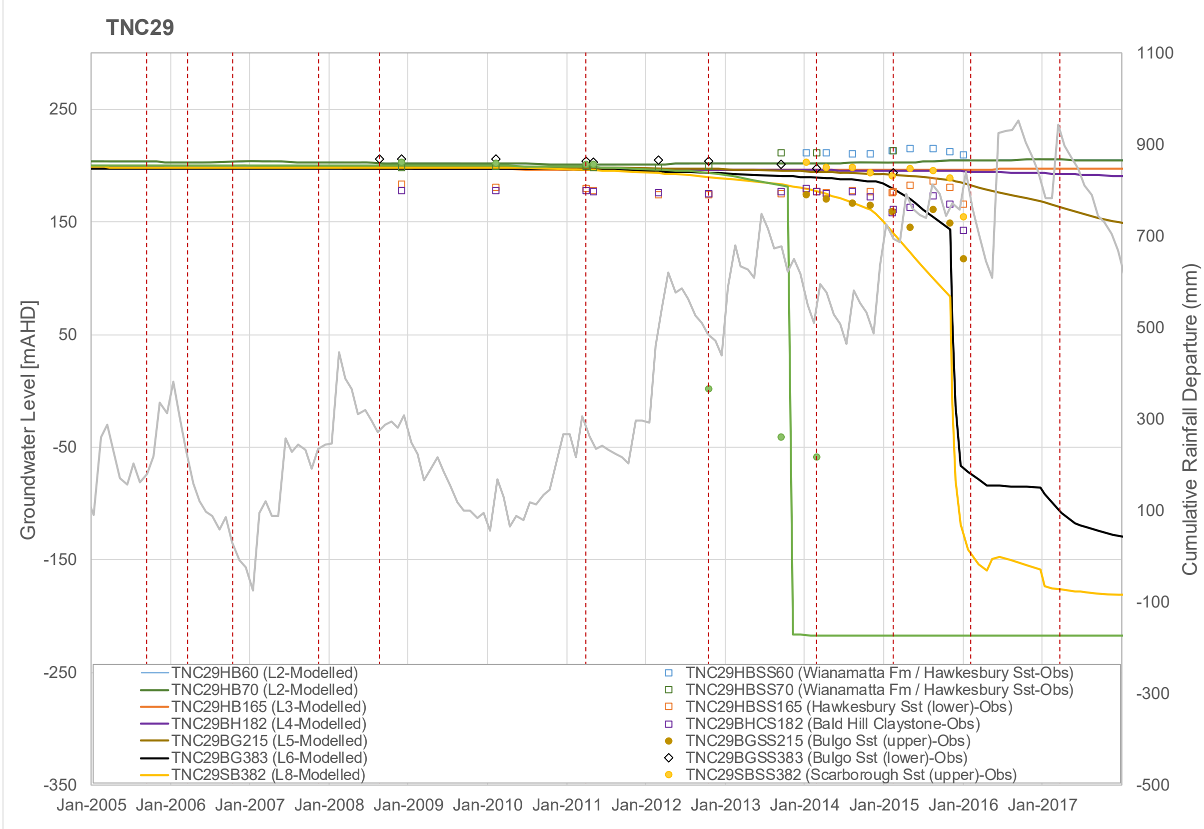
Modelled groundwater level hydrographs

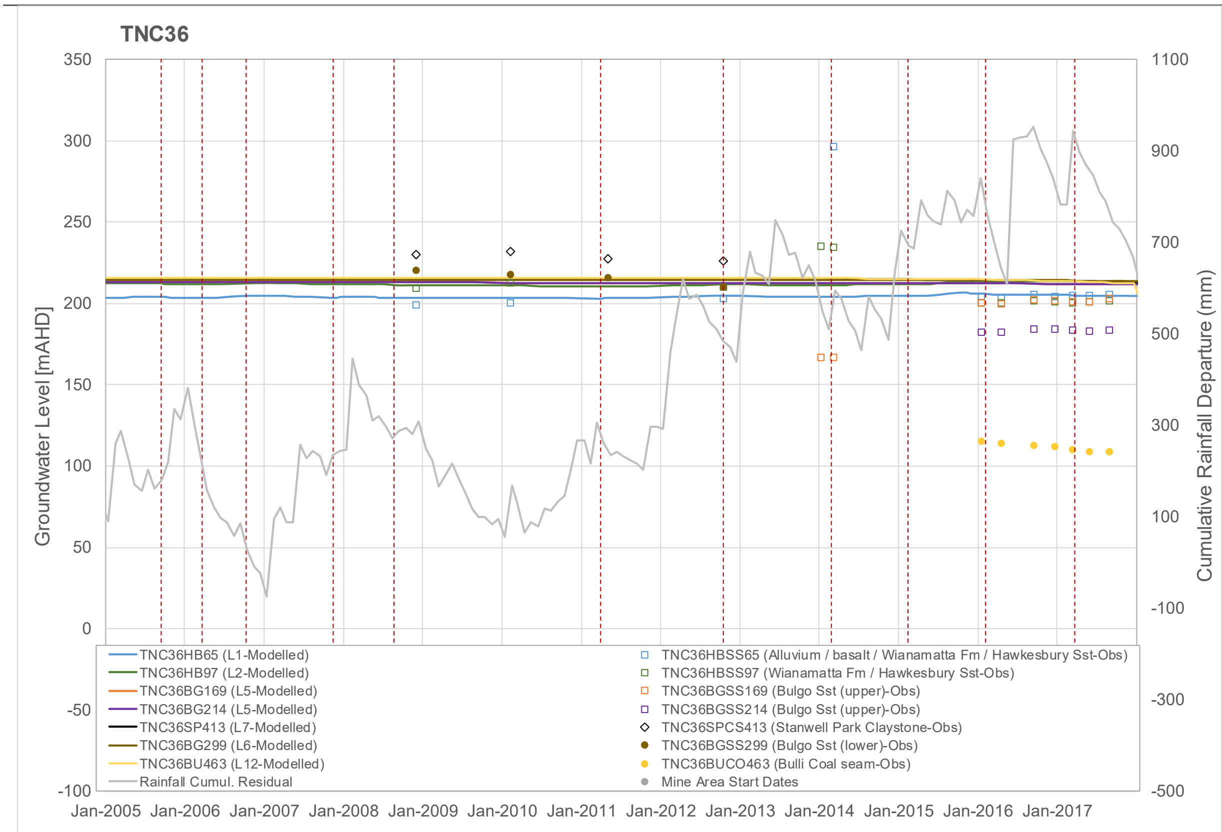

P Series
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
300
250
200
150
100
50
1100
900
700
500
300
100
-100
-300
-500
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017
P1 (L1-Modelled)
P2 (L2-Modelled)
P3 (L2-Modelled)
P4 (L2-Modelled)
P5 (L2-Modelled)
P6 (L2-Modelled)
P7 (L1-Modelled)
P8 (L2-Modelled)
Rainfall Cumul. Residual
P1 (Alluvium / basalt / Wianamatta Fm / Hawkesbury Sst-Obs)
P2 (Wianamatta Fm / Hawkesbury Sst-Obs)
P3 (Wianamatta Fm / Hawkesbury Sst-Obs)
P4 (Wianamatta Fm / Hawkesbury Sst-Obs)
P5 (Wianamatta Fm / Hawkesbury Sst-Obs)
P6 (Wianamatta Fm / Hawkesbury Sst-Obs)
P7 (Alluvium / basalt / Wianamatta Fm / Hawkesbury Sst-Obs)
P8 (Wianamatta Fm / Hawkesbury Sst-Obs)
Mine Area Start Dates

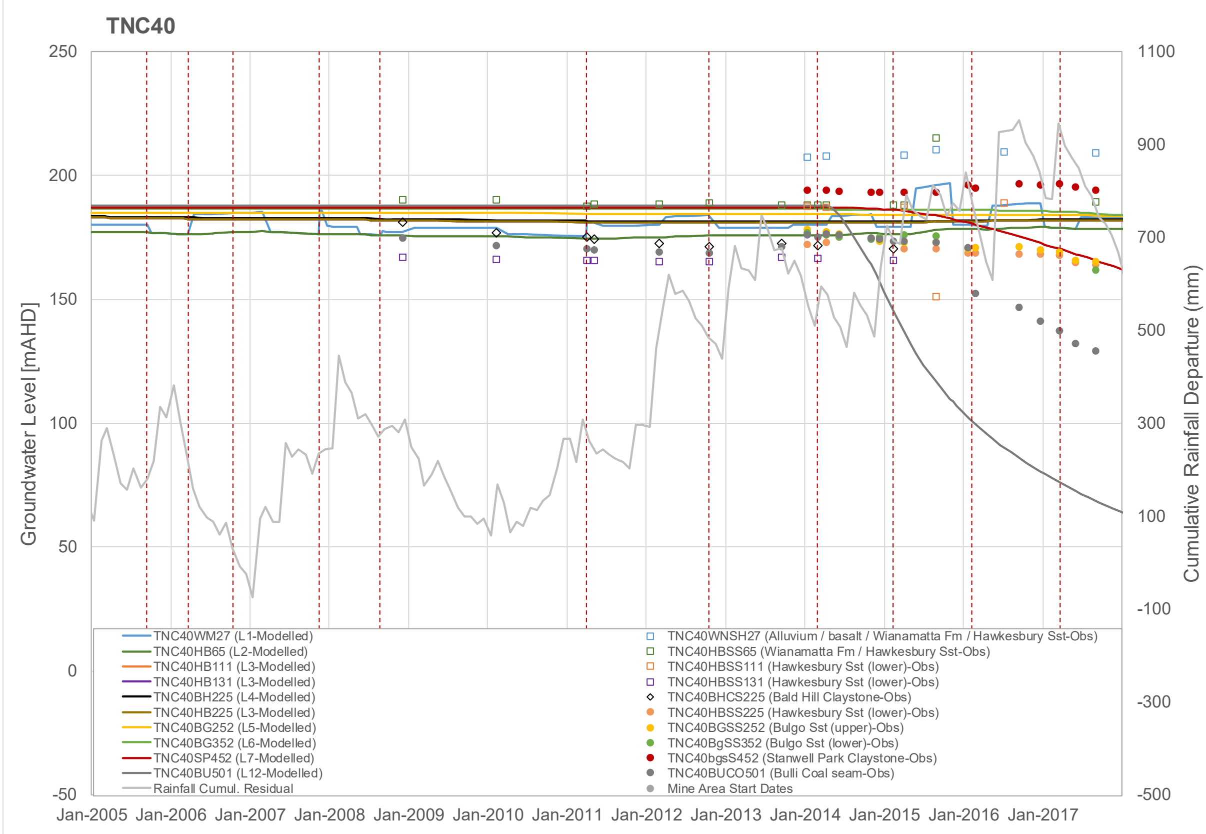

Thirlmere Lakes
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
310
305
300
295
290
285
280
275
270
1100
900
700
500
300
100
-100
-300
-500
Jan-2012 Dec-2012 Dec-2013 Dec-2014 Jan-2016 Dec-2016 Dec-2017
GW75409_01 (L1-Modelled)
GW75409_02 (L3-Modelled)
GW75410 (L1-Modelled)
GW75411 (L2-Modelled)
Rainfall Cumul. Residual
GW075409_01 (Alluvium)
GW075409_02 (Hawkesbury Sst)
GW075410 (Alluvium)
GW075411 (Hawkesbury Sst)

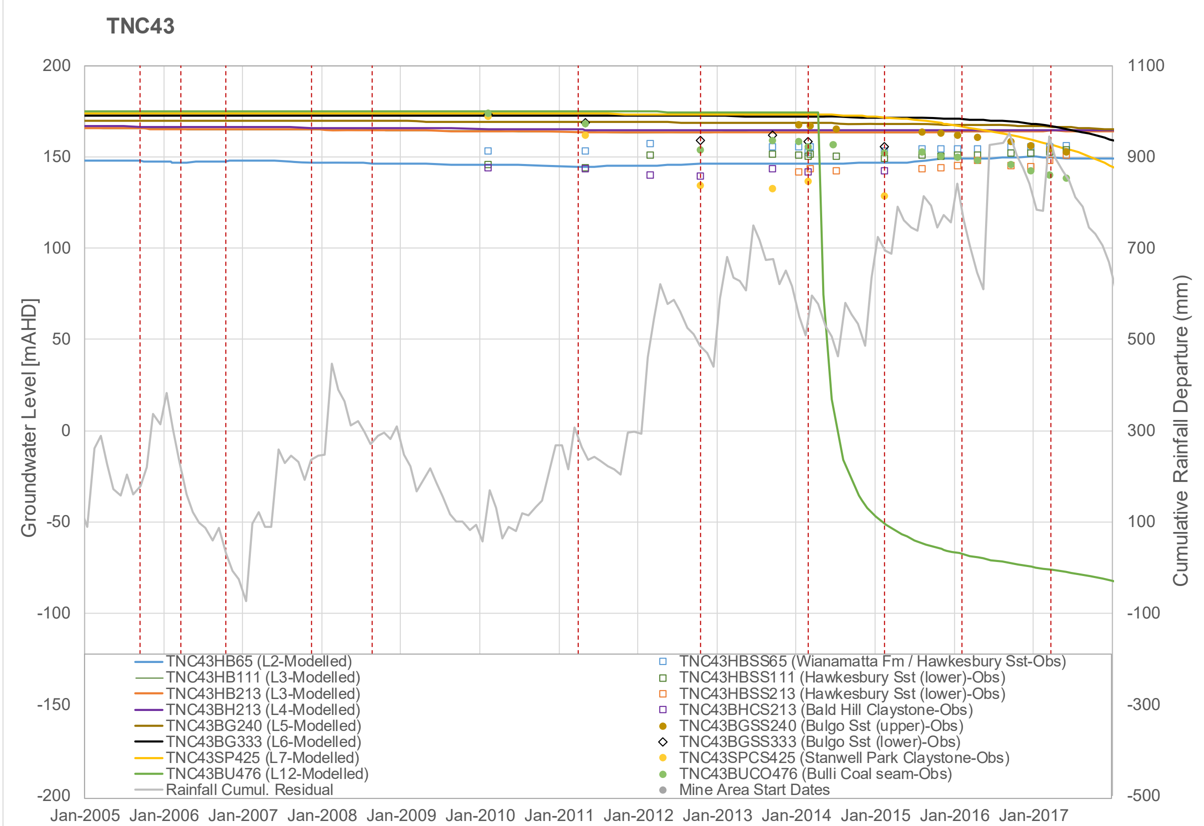

EAW7
LW23A
LW23B
LW24B
LW24A
LW25
LW26
LW27
LW28
LW29
LW30
LW31
Groundwater Level [mAHD]
200
100
0
-100
-200
-300
-400
-500
Cumulative Rainfall Departure (mm)
1100
900
700
500
300
100
-100
-300
-500
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017
EAW7HBSS1 (L2-Modelled)
EAW7_HBSS1 (Wianamatta Fm / Hawkesbury Sst-Obs)
EAW7HBSS2 (L3-Modelled)
EAW7_HBSS2 (Hawkesbury Sst (lower)-Obs)
EAW7BGSS2 (L6-Modelled)
EAW7_BGSS_2 (Bulgo Sst (lower)-Obs)
EAW7SBSS1 (L8-Modelled)
EAW7_SBSS_1 (Scarborough Sst (upper)-Obs)
EAW7BUCO (L12-Modelled)
EAW7_BUCO (Bulli Coal seam-Obs)
EAW7SBSS2 (L9-Modelled)
EAW7_SBSS_2 (Scarborough Sst (lower)-Obs)
Rainfall Cumul. Residual
Mine Area Start Dates

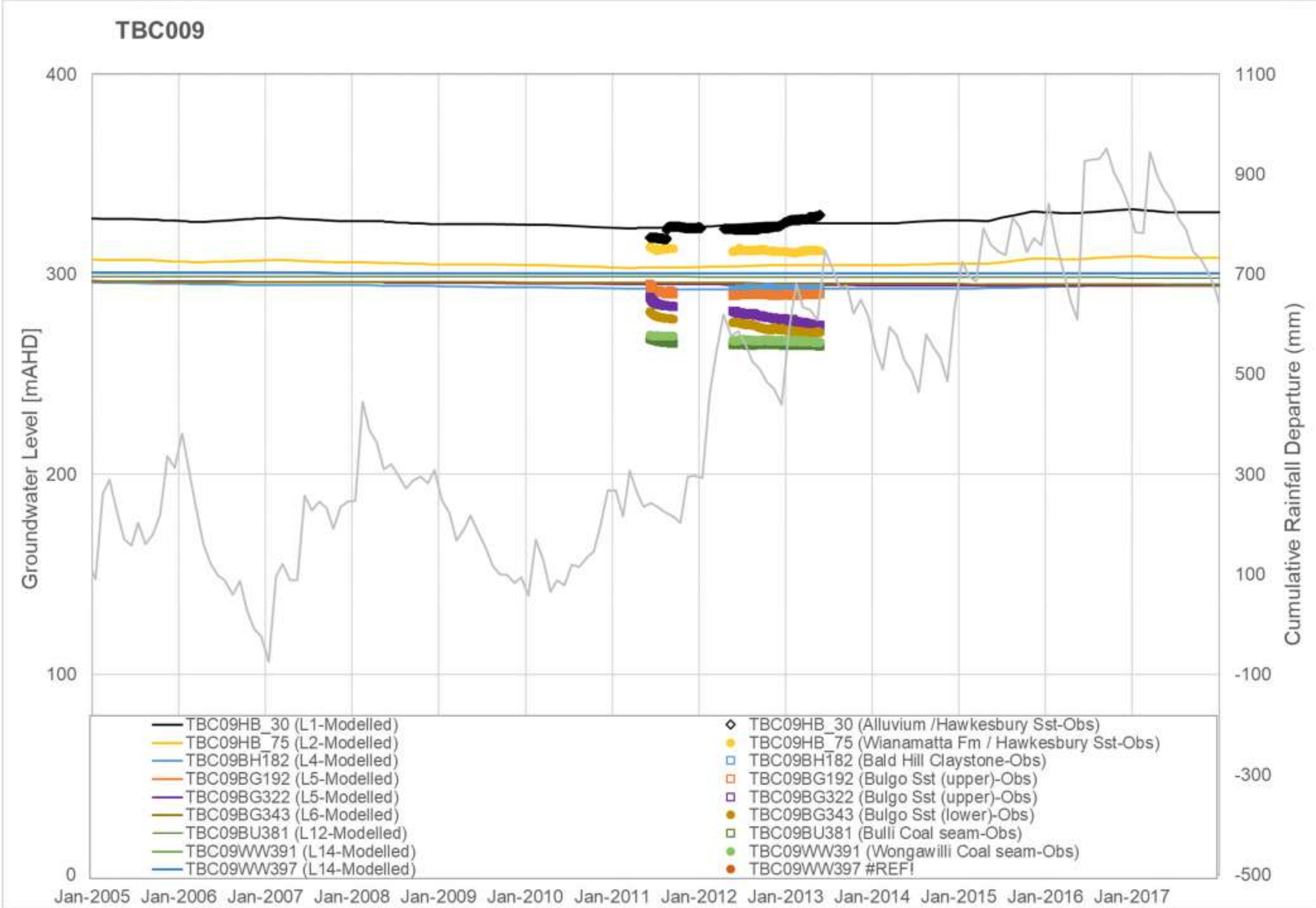

TNC28
Groundwater Level [mAHD]
900
700
500
300
100
-100
-300
-500
Cumulative Rainfall Departure (mm)
1100
900
700
500
300
100
-100
-300
-500
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017
TNC28HB95 (L2-Modelled)
TNC28HB195 (L3-Modelled)
TNC28BH245 (L4-Modelled)
TNC28BG270 (L5-Modelled)
TNC28BU490 (L12-Modelled)
TNC28SB430 (L9-Modelled)
TNC28HBSS95 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC28HBSS195 (Hawkesbury Sst (lower)-Obs)
TNC28BHCS245 (Bald Hill Claystone-Obs)
TNC28BGSS270 (Bulgo Sst (upper)-Obs)
TNC28BUCO490 (Bulli Coal seam-Obs)
TNC28SBSS430 (Scarborough Sst (lower)-Obs)

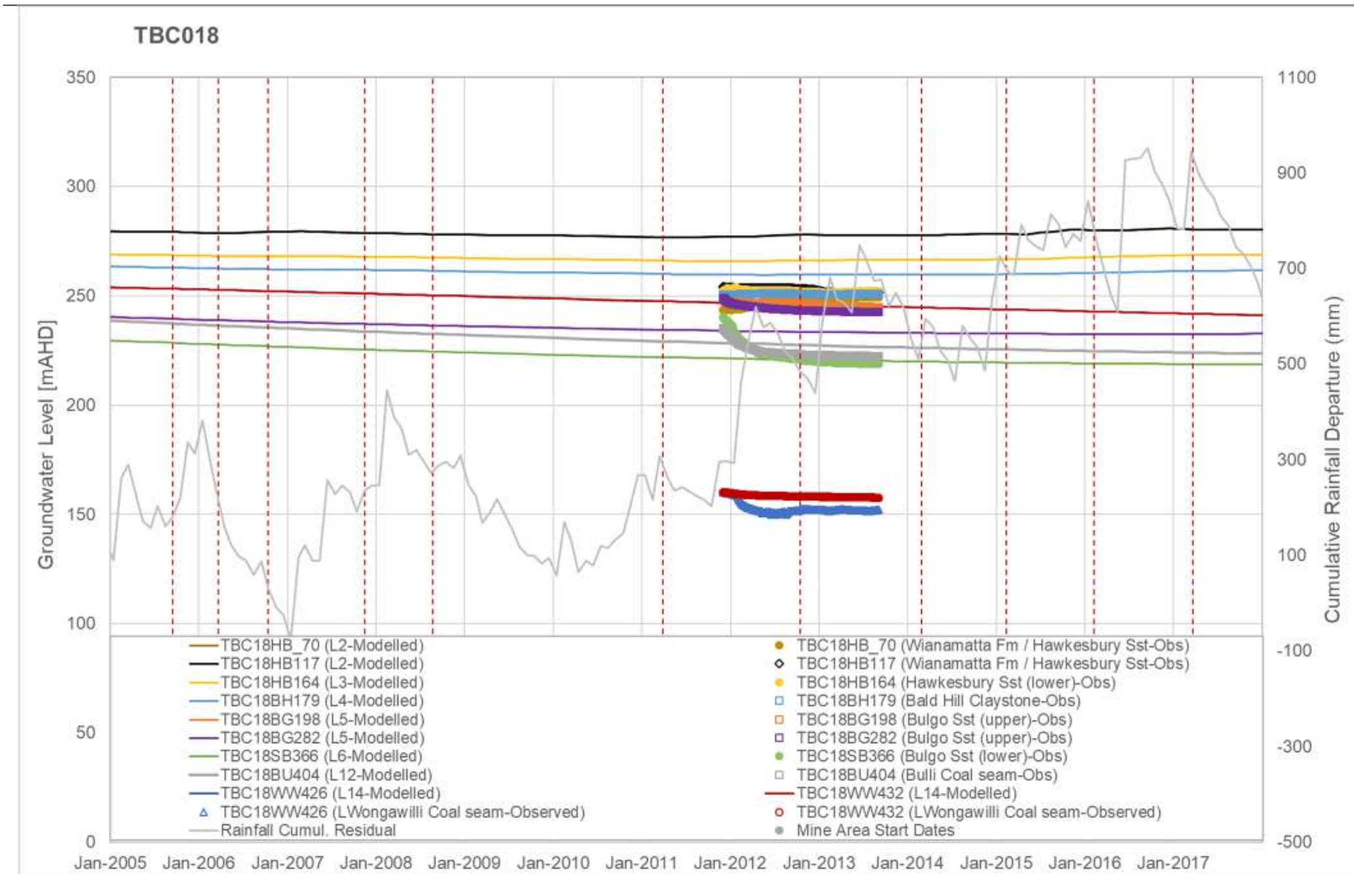

TNC29
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
250
150
50
-50
-150
-250
-350
1100
900
700
500
300
100
-100
-300
-500
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017
TNC29HB60 (L2-Modelled)
TNC29HB70 (L2-Modelled)
TNC29HB165 (L3-Modelled)
TNC29BH182 (L4-Modelled)
TNC29BG215 (L5-Modelled)
TNC29BG383 (L6-Modelled)
TNC29SB382 (L8-Modelled)
TNC29HBSS60 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC29HBSS70 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC29HBSS165 (Hawkesbury Sst (lower)-Obs)
TNC29BHCS182 (Bald Hill Claystone-Obs)
TNC29BGSS215 (Bulgo Sst (upper)-Obs)
TNC29BGSS383 (Bulgo Sst (lower)-Obs)
TNC29SBSS382 (Scarborough Sst (upper)-Obs)

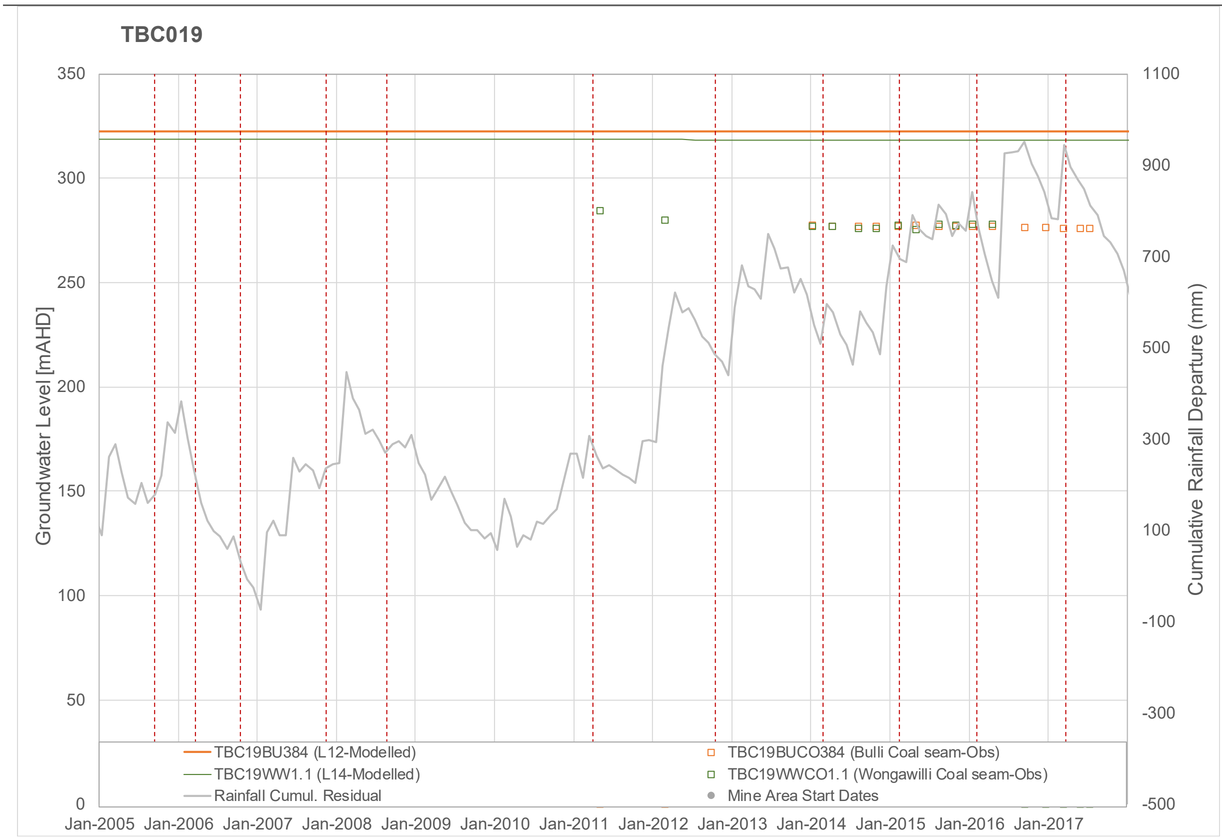

TNC36
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
350
300
250
200
150
100
50
0
-50
-100
1100
900
700
500
300
100
-100
-300
-500
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017
TNC36HB65 (L1-Modelled)
TNC36HB97 (L2-Modelled)
TNC36BG169 (L5-Modelled)
TNC36BG214 (L5-Modelled)
TNC36SP413 (L7-Modelled)
TNC36BG299 (L6-Modelled)
TNC36BU463 (L12-Modelled)
Rainfall Cumul. Residual
TNC36HBSS65 (Alluvium / basalt / Wianamatta Fm / Hawkesbury Sst-Obs)
TNC36HBSS97 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC36BGSS169 (Bulgo Sst (upper)-Obs)
TNC36BGSS214 (Bulgo Sst (upper)-Obs)
TNC36SPCS413 (Stanwell Park Claystone-Obs)
TNC36BGSS299 (Bulgo Sst (lower)-Obs)
TNC36BUCO463 (Bulli Coal seam-Obs)
Mine Area Start Dates


TNC40
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
250
200
150
100
50
0
-50
1100
900
700
500
300
100
-100
-300
-500
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017
TNC40WM27 (L1-Modelled)
TNC40HB65 (L2-Modelled)
TNC40HB111 (L3-Modelled)
TNC40HB131 (L3-Modelled)
TNC40BH225 (L4-Modelled)
TNC40HB225 (L3-Modelled)
TNC40BG252 (L5-Modelled)
TNC40BG352 (L6-Modelled)
TNC40SP452 (L7-Modelled)
TNC40BU501 (L12-Modelled)
Rainfall Cumul. Residual
TNC40WNSH27 (Alluvium / basalt / Wianamatta Fm / Hawkesbury Sst-Obs)
TNC40HBSS65 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC40HBSS111 (Hawkesbury Sst (lower)-Obs)
TNC40HBSS131 (Hawkesbury Sst (lower)-Obs)
TNC40BHCS225 (Bald Hill Claystone-Obs)
TNC40HBSS225 (Hawkesbury Sst (lower)-Obs)
TNC40BGSS252 (Bulgo Sst (upper)-Obs)
TNC40BgSS352 (Bulgo Sst (lower)-Obs)
TNC40bgsS452 (Stanwell Park Claystone-Obs)
TNC40BUCO501 (Bulli Coal seam-Obs)
Mine Area Start Dates


TNC43
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
200
150
100
50
0
-50
-100
-150
-200
1100
900
700
500
300
100
-100
-300
-500
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017
TNC43HB65 (L2-Modelled)
TNC43HB111 (L3-Modelled)
TNC43HB213 (L3-Modelled)
TNC43BH213 (L4-Modelled)
TNC43BG240 (L5-Modelled)
TNC43BG333 (L6-Modelled)
TNC43SP425 (L7-Modelled)
TNC43BU476 (L12-Modelled)
Rainfall Cumul. Residual
TNC43HBSS65 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC43HBSS111 (Hawkesbury Sst (lower)-Obs)
TNC43HBSS213 (Hawkesbury Sst (lower)-Obs)
TNC43BHCS213 (Bald Hill Claystone-Obs)
TNC43BGSS240 (Bulgo Sst (upper)-Obs)
TNC43BGSS333 (Bulgo Sst (lower)-Obs)
TNC43SPCS425 (Stanwell Park Claystone-Obs)
TNC43BUCO476 (Bulli Coal seam-Obs)
Mine Area Start Dates


TBC009
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
400
300
200
100
0
1100
900
700
500
300
100
-100
-300
-500
TBC09HB_30 (L1-Modelled)
TBC09HB_75 (L2-Modelled)
TBC09BH182 (L4-Modelled)
TBC09BG192 (L5-Modelled)
TBC09BG322 (L5-Modelled)
TBC09BG343 (L6-Modelled)
TBC09BU381 (L12-Modelled)
TBC09WW391 (L14-Modelled)
TBC09WW397 (L14-Modelled)
TBC09HB_30 (Alluvium /Hawkesbury Sst-Obs)
TBC09HB_75 (Wianamatta Fm / Hawkesbury Sst-Obs)
TBC09BH182 (Bald Hill Claystone-Obs)
TBC09BG192 (Bulgo Sst (upper)-Obs)
TBC09BG322 (Bulgo Sst (upper)-Obs)
TBC09BG343 (Bulgo Sst (lower)-Obs)
TBC09BU381 (Bulli Coal seam-Obs)
TBC09WW391 (Wongawilli Coal seam-Obs)
TBC09WW397 #REF!
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017


TBC018
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
350
300
250
200
150
100
50
0
1100
900
700
500
300
100
-100
-300
-500
TBC18HB_70 (L2-Modelled)
TBC18HB117 (L2-Modelled)
TBC18HB164 (L3-Modelled)
TBC18BH179 (L4-Modelled)
TBC18BG198 (L5-Modelled)
TBC18BG282 (L5-Modelled)
TBC18SB366 (L6-Modelled)
TBC18BU404 (L12-Modelled)
TBC18WW426 (L14-Modelled)
TBC18WW426 (LWongawilli Coal seam-Observed)
Rainfall Cumul. Residual
TBC18HB_70 (Wianamatta Fm / Hawkesbury Sst-Obs)
TBC18HB117 (Wianamatta Fm / Hawkesbury Sst-Obs)
TBC18HB164 (Hawkesbury Sst (lower)-Obs)
TBC18BH179 (Bald Hill Claystone-Obs)
TBC18BG198 (Bulgo Sst (upper)-Obs)
TBC18BG282 (Bulgo Sst (upper)-Obs)
TBC18SB366 (Bulgo Sst (lower)-Obs)
TBC18BU404 (Bulli Coal seam-Obs)
TBC18WW432 (L14-Modelled)
TBC18WW432 (LWongawilli Coal seam-Observed)
Mine Area Start Dates
Jan-2005 Jan-2006 Jan-2007 Jan-2008 Jan-2009 Jan-2010 Jan-2011 Jan-2012 Jan-2013 Jan-2014 Jan-2015 Jan-2016 Jan-2017




T:\TAHMOOR\Model\Processing\CalibrationHydrographs\CalibrationHydrographs_TAHv4TR045_StackedPlots.xlsx
E:\HYDROSIM\TAHMOOR\Reports\TAH004\Appendices\Appendix H ModelHydrographs\CalibrationHydrographs_TAHv4TR045_StackedPlots.xlsx

# APPENDIX I

## Impact assessment (predicted drawdown) at registered bores

## Bore impact assessment - Bores/works registered with NSW government (CL&W)

Tahmoor South Project

T:\TAHMOOR\Model\Processing\mod2smp\MOD2SMP_Sept2018\BoreDDN\Bores for Drawdown Assessment_v4TR045-047_&_senstivity_V2.xlsx

| work_no | Easting | Northing | Assumed Aquifer unit | Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW032179 | 268826 | 6227671 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW037285 | 268464 | 6190481 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW037289 | 275015 | 6209232 | HBSS | 1 | 1.7 | 3.8 | 2.6 | 4.8 |
| GW037302 | 274014 | 6224252 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW037425 | 273673 | 6225631 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW037426 | 273747 | 6225725 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.4 |
| GW037496 | 273263 | 6227717 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW034351 | 291132 | 6228223 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW034425 | 289184 | 6215603 | HBSS | 1 | 0.1 | 0.1 | 2.6 | 2.7 |
| GW034450 | 291372 | 6228968 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW034518 | 274860 | 6209289 | HBSS | 1 | 1.6 | 3.5 | 2.5 | 4.5 |
| GW013634 | 274304 | 6216428 | HBSS | 1 | 0.2 | 0.1 | 0.3 | 0.3 |
| GW017627 | 269765 | 6223902 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW017628 | 270156 | 6221538 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW018080 | 268562 | 6187554 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW018800 | 271658 | 6214576 | HBSS | 1 | 0.1 | 0.5 | 1.9 | 2.3 |
| GW019590 | 282131 | 6207118 | HBSS | 1 | 1.2 | 1.9 | 1.9 | 2.6 |
| GW019702 | 282859 | 6228775 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW022245 | 273516 | 6207685 | HBSS | 1 | 0.6 | 1.3 | 1.3 | 2.0 |
| GW023161 | 268579 | 6228343 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW023189 | 272087 | 6228645 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW023213 | 281313 | 6234628 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW023412 | 285720 | 6232725 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW023588 | 284629 | 6227676 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW023685 | 275677 | 6226542 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW024351 | 291921 | 6223863 | WMFM | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW024353 | 291479 | 6224161 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW024356 | 286692 | 6232870 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW024417 | 276063 | 6200748 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW024565 | 275680 | 6215660 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW024623 | 271717 | 6206901 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.4 |
| GW024644 | 286479 | 6209500 | HBSS | 1 | 0.1 | 0.0 | 1.6 | 1.6 |
| GW024750 | 277098 | 6216403 | WMFM | 1 | 0.1 | 1.6 | 1.2 | 2.8 |
| GW025598 | 274369 | 6196730 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.3 |
| GW025600 | 270454 | 6220898 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072229 | 282175 | 6230510 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW072296 | 273297 | 6227738 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072309 | 285170 | 6227902 | WMFM | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW026239 | 289192 | 6226669 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW026400 | 275566 | 6226909 | HBSS | 1 | 0.2 | 0.1 | 0.4 | 0.4 |
| GW026469 | 292182 | 6222513 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW026471 | 292243 | 6222082 | Alluvium | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW026472 | 291403 | 6226410 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW026474 | 291428 | 6226472 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW026516 | 289037 | 6220994 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW026529 | 286629 | 6223190 | WMFM | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW026533 | 289089 | 6226667 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW026551 | 291127 | 6223845 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW026557 | 291625 | 6222192 | Alluvium | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW064083 | 276977 | 6201016 | HBSS | 1 | 0.1 | 0.2 | 0.8 | 0.9 |
| GW064330 | 282333 | 6234898 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW072343 | 276313 | 6228521 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072344 | 285164 | 6223323 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW072391 | 272497 | 6202284 | BUSS | 5 | 0.9 | 4.9 | 1.4 | 5.4 |
| GW026934 | 268546 | 6226524 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW064813 | 276015 | 6231760 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW064815 | 294355 | 6222776 | HBSS | 1 | 0.1 | 0.0 | 1.0 | 1.0 |
| GW072473 | 273553 | 6223607 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW072623 | 276593 | 6199905 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.9 |
| GW072630 | 274371 | 6225855 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |

| work_no | Easting | Northing | Assumed Aquifer unit | Assumed Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW028270 | 282471 | 6207897 | HBSS | 1 | 0.9 | 1.4 | 1.5 | 2.0 |
| GW064932 | 290387 | 6207615 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW065022 | 271310 | 6188023 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW065042 | 282074 | 6229436 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW065084 | 271317 | 6227578 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072887 | 276590 | 6200387 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.9 |
| GW072928 | 282257 | 6229911 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW028859 | 274601 | 6211534 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW029020 | 283614 | 6231660 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW065516 | 271720 | 6217322 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW065725 | 263157 | 6201231 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW066043 | 271210 | 6199983 | HBSS | 1 | 0.1 | 0.0 | 0.7 | 0.7 |
| GW073018 | 279979 | 6206567 | HBSS | 1 | 0.5 | 1.2 | 2.0 | 2.7 |
| GW073364 | 282891 | 6228574 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW073406 | 275272 | 6209445 | HBSS | 1 | 0.4 | 0.3 | 0.8 | 0.8 |
| GW029382 | 271648 | 6218183 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.6 |
| GW066786 | 270381 | 6198760 | HBSS | 1 | 0.0 | 0.0 | 0.7 | 0.7 |
| GW042695 | 271883 | 6230705 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW042788 | 280417 | 6210315 | HBSS | 1 | 0.2 | 0.7 | 0.7 | 1.2 |
| GW042825 | 273088 | 6207366 | HBSS | 1 | 0.4 | 0.8 | 0.9 | 1.4 |
| GW042944 | 276631 | 6229617 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW043154 | 275295 | 6211427 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.5 |
| GW043276 | 272491 | 6223202 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW043278 | 273865 | 6222953 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW060205 | 275109 | 6212779 | HBSS | 1 | 0.2 | 0.1 | 0.5 | 0.5 |
| GW067309 | 276400 | 6200540 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.7 |
| GW067310 | 276347 | 6200631 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.7 |
| GW060286 | 272476 | 6200970 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW060375 | 271666 | 6224812 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW060778 | 280050 | 6224950 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW060886 | 294622 | 6215261 | SBSS | 7 | 8.5 | 8.5 | >50 | >50 |
| GW060888 | 294664 | 6215693 | SBSS | 7 | 8.4 | 8.6 | >50 | >50 |
| GW060889 | 294135 | 6215281 | BUSS | 5 | 3.7 | 3.6 | >50 | >50 |
| GW067380 | 270536 | 6220677 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW043690 | 290290 | 6210819 | HBSS | 1 | 0.0 | 0.0 | 2.5 | 2.5 |
| GW043728 | 273581 | 6194430 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW043863 | 292422 | 6211668 | HBSS | 1 | 0.1 | 0.1 | 3.1 | 3.1 |
| GW061532 | 282868 | 6230625 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW061547 | 273911 | 6219964 | ShoalhavenGrp | 16 | 0.1 | 1.1 | 6.0 | 7.1 |
| GW061588 | 266395 | 6189412 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW061592 | 271912 | 6190566 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW067570 | 277164 | 6213708 | HBSS | 1 | 0.2 | 0.8 | 5.3 | 6.0 |
| GW068323 | 275003 | 6219829 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW062068 | 276597 | 6209616 | HBSS | 1 | 2.2 | 9.8 | 4.1 | 11.7 |
| GW062169 | 294743 | 6215572 | HBSS | 1 | 0.1 | 0.0 | 1.0 | 1.0 |
| GW045404 | 282217 | 6206689 | HBSS | 1 | 1.4 | 2.2 | 2.0 | 2.8 |
| GW062661 | 282609 | 6207469 | HBSS | 1 | 1.0 | 1.6 | 1.6 | 2.2 |
| GW062945 | 287960 | 6221031 | HBSS | 1 | 0.0 | 0.0 | 2.2 | 2.2 |
| GW063525 | 276635 | 6214326 | HBSS | 1 | 0.3 | 0.3 | 0.6 | 0.7 |
| GW069174 | 267175 | 6189437 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW070245 | 280090 | 6205714 | HBSS | 1 | 0.9 | 1.7 | 1.5 | 2.3 |
| GW042537 | 274310 | 6209770 | HBSS | 1 | 1.0 | 2.6 | 2.0 | 3.6 |
| GW042647 | 277115 | 6230830 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW063732 | 272117 | 6205215 | HBSS | 1 | 0.2 | 0.7 | 0.8 | 1.3 |
| GW064073 | 279303 | 6233841 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW064080 | 277508 | 6201276 | HBSS | 1 | 0.2 | 0.3 | 0.6 | 0.7 |
| GW072168 | 276751 | 6199455 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.9 |
| GW035033 | 288045 | 6214961 | HBSS | 1 | 0.1 | 0.1 | 2.3 | 2.3 |
| GW035431 | 274319 | 6226510 | BUSS | 5 | 0.0 | 0.0 | 0.2 | 0.3 |
| GW035753 | 276668 | 6209703 | HBSS | 1 | 2.0 | 9.1 | 4.0 | 11.1 |
| GW037742 | 274479 | 6210236 | HBSS | 1 | 0.8 | 2.4 | 1.9 | 3.6 |
| GW037744 | 282374 | 6228703 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |

| work_no | Easting | Northing | Assumed Aquifer unit | Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW037745 | 271753 | 6226509 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW037747 | 276246 | 6199519 | HBSS | 1 | 0.1 | 0.1 | 0.9 | 0.9 |
| GW032724 | 289510 | 6229666 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW037860 | 275178 | 6209914 | HBSS | 1 | 1.3 | 7.8 | 2.5 | 9.0 |
| GW037932 | 272853 | 6211419 | HBSS | 1 | 0.2 | 0.6 | 0.7 | 1.2 |
| GW037952 | 273251 | 6226083 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW034615 | 272328 | 6225013 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW034636 | 278188 | 6234339 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW034702 | 271327 | 6186297 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW034941 | 275859 | 6226454 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.5 |
| GW013826 | 274330 | 6216429 | HBSS | 1 | 0.2 | 0.1 | 0.3 | 0.3 |
| GW013855 | 278126 | 6218431 | HBSS | 1 | 0.5 | 0.5 | 0.1 | 0.1 |
| GW014253 | 275724 | 6232154 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW014273 | 275713 | 6217510 | WMFM | 1 | 0.2 | 0.1 | 0.2 | 0.2 |
| GW035844 | 277150 | 6215294 | HBSS | 1 | 0.3 | 0.2 | 0.6 | 0.6 |
| GW038040 | 273444 | 6228739 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW038059 | 289959 | 6213000 | BUSS | 5 | 3.5 | 3.5 | >50 | >50 |
| GW038074 | 278216 | 6209215 | HBSS | 1 | 2.4 | 8.8 | 4.7 | 11.2 |
| GW038451 | 274667 | 6196059 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW005316 | 295345 | 6219715 | HBSS | 1 | 0.1 | 0.1 | 2.5 | 2.5 |
| GW007445 | 277454 | 6204323 | HBSS | 1 | 0.3 | 0.4 | 1.5 | 1.7 |
| GW008548 | 277099 | 6209867 | HBSS | 1 | 1.9 | 8.0 | 4.1 | 10.2 |
| GW010062 | 270809 | 6217885 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW010459 | 274240 | 6213745 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW010460 | 274760 | 6214497 | HBSS | 1 | 0.1 | 0.1 | 0.2 | 0.2 |
| GW010584 | 275340 | 6209548 | HBSS | 1 | 0.4 | 0.3 | 1.2 | 1.2 |
| GW010654 | 274949 | 6211974 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.6 |
| GW010968 | 276062 | 6214682 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.4 |
| GW011200 | 275607 | 6210735 | HBSS | 1 | 0.3 | 0.2 | 0.7 | 0.7 |
| GW011234 | 275883 | 6209314 | HBSS | 1 | 0.3 | 0.4 | 1.0 | 1.1 |
| GW011634 | 275622 | 6232090 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW015069 | 276226 | 6200351 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW015789 | 273581 | 6194430 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW031353 | 273003 | 6225738 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW031438 | 289830 | 6229088 | WMFM | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW038551 | 272484 | 6226003 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW033846 | 270058 | 6221351 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW033872 | 269326 | 6226111 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.4 |
| GW033916 | 273200 | 6206968 | HBSS | 1 | 0.3 | 0.7 | 0.9 | 1.3 |
| GW033932 | 272422 | 6217955 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW011930 | 268753 | 6192215 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW012577 | 269836 | 6187709 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW012611 | 275711 | 6210081 | HBSS | 1 | 0.4 | 0.7 | 1.9 | 2.3 |
| GW012612 | 275398 | 6210320 | HBSS | 1 | 0.4 | 0.3 | 1.1 | 1.1 |
| GW013282 | 276627 | 6209270 | HBSS | 1 | 0.2 | 0.8 | 2.3 | 2.9 |
| GW013326 | 269820 | 6189374 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW013336 | 268274 | 6190939 | HBSS | 1 | 0.0 | 0.0 | 0.7 | 0.7 |
| GW016553 | 274592 | 6195996 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW017315 | 286642 | 6220354 | WMFM | 1 | 0.0 | 0.0 | 0.7 | 0.8 |
| GW050408 | 276435 | 6200140 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW050754 | 282127 | 6228265 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW051118 | 270145 | 6217777 | HBSS | 1 | 0.2 | 0.1 | 0.6 | 0.6 |
| GW054316 | 272712 | 6224005 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW055146 | 276094 | 6200502 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW055147 | 276191 | 6200720 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW055149 | 276168 | 6200627 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW055154 | 276653 | 6199621 | HBSS | 1 | 0.1 | 0.1 | 0.9 | 0.9 |
| GW058431 | 271428 | 6226162 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW100173 | 265546 | 6201818 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW100289 | 288686 | 6218937 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW068452 | 278299 | 6232551 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072249 | 288091 | 6215538 | HBSS | 1 | 0.6 | 0.6 | 2.8 | 2.8 |

| work_no | Easting | Northing | Assumed Aquifer unit | Assumed Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW072619 | 272657 | 6216612 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW072402 | 277685 | 6216905 | HBSS | 1 | 0.4 | 0.4 | 0.1 | 0.1 |
| GW067412 | 272300 | 6188657 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072458 | 269917 | 6189739 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW072432 | 273364 | 6212851 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW047129 | 271904 | 6229843 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW047144 | 271250 | 6217680 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW047148 | 272508 | 6216539 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW047217 | 271932 | 6203361 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.7 |
| GW047330 | 273076 | 6221640 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW051877 | 281673 | 6205875 | HBSS | 1 | 1.9 | 3.2 | 2.6 | 3.9 |
| GW052016 | 280259 | 6203604 | HBSS | 1 | 7.3 | 12.2 | 8.4 | 13.4 |
| GW052126 | 285424 | 6223193 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW052159 | 284124 | 6228435 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW058634 | 279479 | 6203419 | HBSS | 1 | 9.4 | 22.6 | 10.3 | 23.5 |
| GW058832 | 289897 | 6206618 | BUSS | 5 | 0.6 | 0.5 | 8.9 | 8.9 |
| GW059075 | 269838 | 6229330 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.6 |
| GW059090 | 281573 | 6226711 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW059106 | 282268 | 6207800 | HBSS | 1 | 0.4 | 0.5 | 0.7 | 0.9 |
| GW047416 | 274634 | 6211226 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.6 |
| GW047444 | 282445 | 6227841 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW047446 | 272822 | 6223699 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW047596 | 274332 | 6223828 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW047600 | 272200 | 6223961 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW047684 | 274575 | 6225437 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW047710 | 270967 | 6228248 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW052540 | 276719 | 6200055 | HBSS | 1 | 0.1 | 0.1 | 0.9 | 0.9 |
| GW052657 | 281585 | 6228407 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW053002 | 281755 | 6228842 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW056632 | 277202 | 6201580 | HBSS | 1 | 0.4 | 0.4 | 0.3 | 0.4 |
| GW059152 | 271506 | 6219783 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW059325 | 281663 | 6229457 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW059326 | 281864 | 6228568 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW059401 | 281488 | 6228158 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW059446 | 294627 | 6212672 | HBSS | 1 | 0.1 | 0.1 | 3.1 | 3.1 |
| GW059481 | 275024 | 6222765 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.5 |
| GW059618 | 281587 | 6204277 | HBSS | 1 | 2.3 | 3.9 | 2.9 | 4.5 |
| GW059626 | 281382 | 6229420 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW059692 | 279572 | 6227836 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW059695 | 274794 | 6230220 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW059773 | 286102 | 6227216 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW047817 | 274029 | 6215096 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW047933 | 269634 | 6224022 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW047998 | 275028 | 6231181 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW048301 | 281997 | 6230574 | Alluvium | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW053070 | 270256 | 6194503 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW053288 | 289756 | 6207231 | HBSS | 1 | 0.0 | 0.0 | 0.9 | 0.9 |
| GW053294 | 277445 | 6200719 | HBSS | 1 | 0.2 | 0.2 | 0.8 | 1.0 |
| GW053449 | 280369 | 6205813 | HBSS | 1 | 5.2 | 9.2 | 7.4 | 11.4 |
| GW053450 | 282303 | 6205837 | HBSS | 1 | 2.5 | 3.9 | 3.5 | 5.0 |
| GW100056 | 285251 | 6226420 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW053808 | 266539 | 6189785 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW053980 | 282104 | 6217075 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.5 |
| GW054008 | 271254 | 6217526 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW054010 | 274687 | 6223990 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW054146 | 279886 | 6204676 | HBSS | 1 | 12.4 | 25.2 | 14.9 | 27.7 |
| GW054182 | 271523 | 6186641 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW057806 | 270478 | 6219912 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW057829 | 290335 | 6206504 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW057886 | 277468 | 6228000 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW057907 | 269564 | 6222664 | HBSS | 1 | 0.0 | 0.0 | 0.9 | 0.9 |
| GW057969 | 281350 | 6206116 | HBSS | 1 | 3.3 | 5.3 | 4.7 | 6.8 |

| work_no | Easting | Northing | Assumed | | Modelled Maximum Drawdown (at any time); [m] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Aquifer unit | Model layer | Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
| GW100088 | 287015 | 6223396 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW100116 | 269068 | 6197063 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW100130 | 270330 | 6186235 | HBSS | 1 | 0.3 | 0.2 | 0.2 | 0.2 |
| GW049292 | 276242 | 6200752 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW049516 | 276335 | 6200076 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW049796 | 275127 | 6210961 | HBSS | 1 | 0.2 | 0.1 | 0.5 | 0.5 |
| GW108538 | 281155 | 6205941 | HBSS | 1 | 2.1 | 3.5 | 2.9 | 4.3 |
| GW108524 | 273663 | 6193472 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW100710 | 272072 | 6218208 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW100721 | 276240 | 6200043 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.8 |
| GW100733 | 284956 | 6223259 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW100753 | 279647 | 6227755 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW100428 | 274087 | 6223959 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW100433 | 278540 | 6202588 | HBSS | 1 | 31.6 | 68.1 | 33.0 | >50 |
| GW100455 | 281877 | 6207020 | HBSS | 1 | 0.6 | 0.8 | 0.9 | 1.2 |
| GW100480 | 287377 | 6209419 | HBSS | 1 | 0.1 | 0.0 | 0.7 | 0.7 |
| GW100802 | 276182 | 6200277 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.6 |
| GW100816 | 281482 | 6217311 | HBSS | 1 | 0.2 | 0.2 | 0.2 | 0.2 |
| GW100817 | 271412 | 6228042 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW100519 | 275345 | 6215766 | HBSS | 1 | 0.2 | 0.2 | 0.3 | 0.3 |
| GW101106 | 293207 | 6225747 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW100959 | 278299 | 6232550 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW101175 | 271429 | 6226132 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW101247 | 272151 | 6210333 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW100562 | 277747 | 6201653 | HBSS | 1 | 0.8 | 3.4 | 0.8 | 3.5 |
| GW100605 | 287015 | 6223397 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW101010 | 281704 | 6234930 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW101031 | 287016 | 6223397 | WMFM | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW101066 | 285162 | 6226122 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW067391 | 269494 | 6191369 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW067392 | 269494 | 6191368 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW100673 | 286235 | 6216160 | HBSS | 1 | 0.1 | 0.2 | 2.4 | 2.6 |
| GW100688 | 289519 | 6211122 | WMFM | 1 | 0.1 | 0.1 | 2.5 | 2.5 |
| GW100691 | 294187 | 6213824 | HBSS | 1 | 0.1 | 0.2 | 2.3 | 2.4 |
| GW100692 | 294187 | 6213824 | HBSS | 1 | 0.1 | 0.2 | 2.3 | 2.4 |
| GW101314 | 286912 | 6223222 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW101530 | 282549 | 6228892 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW101554 | 277200 | 6200244 | HBSS | 1 | 0.2 | 0.2 | 0.9 | 1.0 |
| GW101575 | 270949 | 6188236 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW101654 | 274473 | 6219794 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW101727 | 285754 | 6226898 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW101867 | 271129 | 6186374 | HBSS | 1 | 0.1 | 0.1 | 0.0 | 0.0 |
| GW101881 | 267723 | 6190740 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW101936 | 280604 | 6202851 | HBSS | 1 | 0.6 | 0.9 | 0.8 | 1.2 |
| GW101939 | 269153 | 6189903 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW101942 | 295075 | 6210925 | BUSS | 5 | 1.4 | 1.4 | 48.5 | 48.5 |
| GW102048 | 268832 | 6196950 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW102144 | 285921 | 6220466 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW102153 | 271774 | 6218248 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102167 | 272091 | 6217651 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102177 | 281535 | 6228375 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW102179 | 280953 | 6203826 | HBSS | 1 | 5.7 | 9.3 | 6.7 | 10.4 |
| GW102231 | 272116 | 6217744 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102258 | 272616 | 6192094 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW102292 | 274895 | 6231290 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW102295 | 275512 | 6217351 | WMFM | 1 | 0.0 | 0.2 | 0.5 | 0.7 |
| GW102338 | 271504 | 6216731 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102738 | 270618 | 6187050 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW102412 | 280833 | 6225461 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW102418 | 278015 | 6201504 | HBSS | 1 | 0.8 | 3.5 | 0.9 | 3.6 |
| GW102507 | 285091 | 6222045 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW102528 | 289222 | 6204784 | HBSS | 1 | 0.0 | 0.0 | 0.9 | 0.9 |

| | | | Assumed | | Modelled Maximum Drawdown (at any time); [m] | | | |
|---|---|---|---|---|---|---|---|---|
| work_no | Easting | Northing | Aquifer unit | Model layer | Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
| GW102439 | 274477 | 6210080 | HBSS | 1 | 1.7 | 5.8 | 6.5 | 10.6 |
| GW102440 | 277778 | 6220149 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102581 | 280514 | 6223727 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW102585 | 271283 | 6218421 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW102619 | 287887 | 6220525 | HBSS | 1 | 0.0 | 0.0 | 6.1 | 6.1 |
| GW102765 | 271550 | 6216948 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102770 | 276132 | 6231177 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW102452 | 277234 | 6200992 | HBSS | 1 | 0.2 | 0.2 | 0.8 | 0.9 |
| GW102465 | 278687 | 6228370 | HBSS | 1 | 0.1 | -1.5 | 2.0 | 0.4 |
| GW102630 | 273332 | 6211914 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW102468 | 274822 | 6198098 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW102794 | 276601 | 6200303 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.9 |
| GW102796 | 276633 | 6200167 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.9 |
| GW102798 | 289990 | 6214783 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW102696 | 271589 | 6216363 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102478 | 276810 | 6200083 | HBSS | 1 | 0.1 | 0.2 | 0.9 | 0.9 |
| GW102481 | 281032 | 6213597 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.5 |
| GW102482 | 281217 | 6212276 | HBSS | 1 | 0.1 | 0.9 | 0.9 | 1.8 |
| GW102483 | 280297 | 6212193 | HBSS | 1 | 0.0 | 1.3 | 2.6 | 3.9 |
| GW102484 | 287975 | 6223775 | WMFM | 1 | 0.1 | 0.1 | 0.4 | 0.4 |
| GW102485 | 288863 | 6224196 | WMFM | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW102486 | 291012 | 6226710 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW102498 | 271545 | 6217132 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102704 | 277448 | 6200596 | HBSS | 1 | 0.2 | 0.2 | 0.9 | 1.0 |
| GW102706 | 271245 | 6213073 | HBSS | 1 | 0.0 | 0.0 | 0.7 | 0.7 |
| GW102721 | 271242 | 6187682 | HBSS | 1 | 0.1 | 0.0 | 0.1 | 0.1 |
| GW102722 | 271438 | 6188026 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW101414 | 273402 | 6221956 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW101517 | 278839 | 6232844 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW101520 | 273196 | 6193791 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW101430 | 270857 | 6187735 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW101437 | 291642 | 6216361 | HBSS | 1 | 0.1 | 0.2 | 3.3 | 3.3 |
| GW103023 | 277261 | 6200993 | HBSS | 1 | 0.2 | 0.2 | 0.8 | 0.9 |
| GW102910 | 269341 | 6228796 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW102912 | 271019 | 6219771 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW103036 | 276840 | 6200964 | HBSS | 1 | 0.1 | 0.2 | 0.8 | 0.9 |
| GW103037 | 271495 | 6227690 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW103202 | 266246 | 6190132 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW102927 | 271838 | 6226906 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102928 | 271566 | 6200461 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW103235 | 281482 | 6208754 | HBSS | 1 | 1.1 | 2.4 | 3.0 | 4.3 |
| GW102951 | 275244 | 6224562 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW103125 | 271607 | 6189629 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW103140 | 283731 | 6224662 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW103320 | 283769 | 6210457 | HBSS | 1 | 0.0 | 0.0 | 0.9 | 1.0 |
| GW103341 | 272667 | 6227246 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW103010 | 276077 | 6216106 | HBSS | 1 | 0.1 | 0.5 | 0.7 | 1.3 |
| GW103011 | 267052 | 6189173 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102891 | 282081 | 6228890 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW110550 | 283788 | 6218949 | HBSS | 1 | 0.1 | 0.1 | 7.7 | 7.7 |
| GW103625 | 272697 | 6216892 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW103532 | 275198 | 6219185 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW103535 | 272520 | 6201995 | HBSS | 1 | 0.2 | 0.1 | 0.8 | 0.8 |
| GW103536 | 284144 | 6220887 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW103457 | 276438 | 6200258 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.8 |
| GW103704 | 271634 | 6200721 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW103479 | 272278 | 6200069 | BUSS | 5 | 0.4 | 1.4 | 0.5 | 1.6 |
| GW103783 | 272300 | 6188657 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW103611 | 273880 | 6216628 | HBSS | 1 | 0.0 | 0.1 | 0.5 | 0.6 |
| GW103614 | 271252 | 6228244 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW103615 | 279720 | 6204034 | HBSS | 1 | 8.9 | 21.2 | 9.9 | 22.2 |
| GW104008 | 280368 | 6205982 | HBSS | 1 | 2.6 | 4.6 | 3.6 | 5.7 |

| work_no | Easting | Northing | Assumed Aquifer unit | Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW104024 | 271665 | 6215201 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW104025 | 286999 | 6222389 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW104068 | 289519 | 6214530 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW104077 | 275333 | 6211928 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW104092 | 280223 | 6225062 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW104121 | 276840 | 6233538 | HBSS | 1 | 0.0 | 0.0 | 2.4 | 2.3 |
| GW104146 | 271549 | 6218470 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW104154 | 291233 | 6216088 | HBSS | 1 | 0.1 | 0.1 | 2.5 | 2.5 |
| GW104155 | 269218 | 6228436 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW104159 | 285845 | 6222764 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW104183 | 274448 | 6198075 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW104194 | 281646 | 6226802 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW104202 | 271720 | 6201698 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW104211 | 273505 | 6231339 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW104224 | 283963 | 6222859 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW104323 | 279259 | 6203318 | HBSS | 1 | 25.4 | 51.4 | 27.0 | >50 |
| GW104326 | 276542 | 6200749 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW104370 | 285503 | 6226299 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW104347 | 284012 | 6217884 | HBSS | 1 | 0.1 | 0.1 | 2.6 | 2.7 |
| GW103989 | 271345 | 6200643 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.7 |
| GW104965 | 281462 | 6222697 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW075051 | 293652 | 6230668 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW075054 | 294159 | 6230165 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW075058 | 292667 | 6231729 | HBSS | 1 | 0.1 | 0.0 | 0.1 | 0.1 |
| GW105042 | 277491 | 6218561 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.4 |
| GW105043 | 280730 | 6234965 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW105053 | 272897 | 6218371 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW105296 | 270731 | 6221290 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW105301 | 270172 | 6201071 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW105145 | 275872 | 6210499 | HBSS | 1 | 0.3 | 0.7 | 1.2 | 1.6 |
| GW102405 | 280631 | 6225302 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW102355 | 274565 | 6196026 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW105228 | 278451 | 6216837 | HBSS | 1 | 0.1 | 0.1 | 0.1 | 0.1 |
| GW102344 | 280248 | 6206553 | HBSS | 1 | 0.7 | 1.5 | 1.0 | 1.8 |
| GW102337 | 272135 | 6216068 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW105236 | 275487 | 6211099 | HBSS | 1 | 0.8 | 2.9 | 2.1 | 4.4 |
| GW105244 | 280805 | 6224206 | HBSS | 1 | 0.1 | 0.0 | 0.1 | 0.1 |
| GW105246 | 274934 | 6211237 | HBSS | 1 | 0.1 | 0.2 | 0.5 | 0.5 |
| GW105196 | 271703 | 6215976 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW105197 | 271857 | 6217075 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW105251 | 284660 | 6229667 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW105254 | 278246 | 6211856 | HBSS | 1 | 0.6 | 3.3 | 10.2 | 12.9 |
| GW105260 | 272932 | 6223837 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW105262 | 278609 | 6200731 | HBSS | 1 | 1.0 | 4.6 | 1.0 | 4.7 |
| GW105203 | 277180 | 6230661 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW105271 | 279104 | 6233701 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW105205 | 283689 | 6230724 | HBSS | 1 | 0.9 | 0.9 | 0.4 | 0.4 |
| GW105207 | 285148 | 6223080 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW104978 | 271198 | 6190788 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW102549 | 281301 | 6222975 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW104959 | 281388 | 6222659 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW104986 | 272662 | 6227723 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW104466 | 277332 | 6217528 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.5 |
| GW104560 | 281795 | 6227548 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW104565 | 271943 | 6203049 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.8 |
| GW104612 | 274193 | 6224293 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW104616 | 272327 | 6201844 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.7 |
| GW104620 | 284099 | 6227949 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW104628 | 271777 | 6200195 | HBSS | 1 | 0.2 | 0.1 | 0.8 | 0.8 |
| GW104630 | 269351 | 6190968 | HBSS | 1 | 0.0 | 0.0 | 0.9 | 0.9 |
| GW104633 | 295351 | 6215109 | HBSS | 1 | 0.0 | 0.1 | 3.3 | 3.3 |
| GW104649 | 265663 | 6190029 | SBSS | 7 | 0.0 | 0.0 | 0.1 | 0.0 |

| work_no | Easting | Northing | Assumed Aquifer unit | Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW104659 | 276617 | 6207391 | HBSS | 1 | 9.0 | 13.6 | 10.5 | 15.2 |
| GW104793 | 268021 | 6191728 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW104720 | 274451 | 6211918 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW104722 | 282777 | 6234686 | HBSS | 1 | 0.0 | 0.0 | 1.0 | 1.0 |
| GW100148 | 267949 | 6190622 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW100047 | 274375 | 6216677 | HBSS | 1 | 0.2 | 0.1 | 0.4 | 0.4 |
| GW104689 | 276279 | 6201756 | HBSS | 1 | 0.6 | 2.2 | 0.6 | 2.3 |
| GW104690 | 275761 | 6214988 | HBSS | 1 | 0.2 | 0.1 | 0.3 | 0.3 |
| GW104700 | 272262 | 6218000 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW104756 | 269737 | 6222831 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.9 |
| GW104860 | 282745 | 6206178 | HBSS | 1 | 1.3 | 2.0 | 1.8 | 2.5 |
| GW104383 | 283414 | 6223610 | HBSS | 1 | 0.1 | 0.1 | 0.3 | 0.3 |
| GW104402 | 273579 | 6228066 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW104499 | 289920 | 6206816 | HBSS | 1 | 0.2 | 0.1 | 0.9 | 0.9 |
| GW104412 | 271648 | 6200536 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW104515 | 275487 | 6222733 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW104577 | 275482 | 6215322 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW104446 | 273751 | 6229005 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW104454 | 281410 | 6204568 | HBSS | 1 | 2.4 | 4.1 | 2.9 | 4.7 |
| GW104531 | 277188 | 6200159 | HBSS | 1 | 0.5 | 1.6 | 0.5 | 1.7 |
| GW104385 | 286784 | 6233581 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW104546 | 283573 | 6212241 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW104547 | 274936 | 6221982 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW104590 | 274714 | 6215475 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW104593 | 277373 | 6219823 | WMFM | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW104602 | 289054 | 6216338 | HBSS | 1 | 0.1 | 0.1 | 2.2 | 2.2 |
| GW104603 | 271842 | 6190262 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW015549 | 274027 | 6193978 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW015816 | 272063 | 6217977 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW018568 | 274881 | 6210554 | HBSS | 1 | 0.2 | 0.2 | 0.5 | 0.5 |
| GW023483 | 271717 | 6226940 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW024354 | 291866 | 6224047 | WMFM | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW026470 | 292880 | 6222220 | Alluvium | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW026473 | 291651 | 6222193 | Alluvium | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW026545 | 291137 | 6222243 | Alluvium | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW027792 | 285386 | 6230498 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW028935 | 270372 | 6226353 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW029143 | 274796 | 6210860 | HBSS | 1 | 0.2 | 0.2 | 0.5 | 0.6 |
| GW060238 | 274508 | 6211159 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.6 |
| GW061111 | 273911 | 6219964 | ShoalhavenGrp | 16 | 0.1 | 1.1 | 6.0 | 7.1 |
| GW063557 | 277107 | 6225000 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW064081 | 277795 | 6201036 | HBSS | 1 | 0.2 | 0.2 | 0.8 | 0.8 |
| GW064084 | 276850 | 6200983 | HBSS | 1 | 0.1 | 0.2 | 0.8 | 0.9 |
| GW064284 | 281519 | 6234601 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW064420 | 267017 | 6192141 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW064469 | 277346 | 6215669 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW064814 | 294354 | 6222807 | WMFM | 1 | 0.1 | 0.0 | 1.0 | 1.0 |
| GW064952 | 281750 | 6234576 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW067393 | 266139 | 6190514 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW067682 | 276859 | 6216739 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW070979 | 275315 | 6211674 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW072197 | 285108 | 6224185 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW072329 | 290560 | 6223453 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW072377 | 277252 | 6228131 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW072444 | 274606 | 6229969 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072474 | 279644 | 6233727 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072482 | 281952 | 6206909 | HBSS | 1 | 0.6 | 0.8 | 0.9 | 1.2 |
| GW072962 | 272913 | 6192088 | HBSS | 1 | 0.0 | 0.0 | 0.7 | 0.7 |
| GW042644 | 265560 | 6189113 | SBSS | 7 | 0.0 | 0.0 | 0.1 | 0.0 |
| GW043277 | 273802 | 6223445 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW043876 | 272471 | 6189655 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW044208 | 282266 | 6234495 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |

| work_no | Easting | Northing | Assumed Aquifer unit | Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW047037 | 272445 | 6213856 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW047054 | 271710 | 6199841 | HBSS | 1 | 0.2 | 0.1 | 0.8 | 0.8 |
| GW047128 | 282267 | 6229995 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW047903 | 275698 | 6213496 | HBSS | 1 | 0.2 | 0.1 | 0.5 | 0.5 |
| GW050397 | 270482 | 6186369 | HBSS | 1 | 0.1 | 0.0 | 0.1 | 0.1 |
| GW051668 | 270268 | 6217995 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.2 |
| GW052125 | 281891 | 6227397 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW053195 | 283822 | 6229291 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW053306 | 276492 | 6199926 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.9 |
| GW055510 | 279377 | 6233966 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW055918 | 277154 | 6200065 | HBSS | 1 | 0.5 | 1.5 | 0.5 | 1.6 |
| GW056708 | 278469 | 6231109 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW056750 | 283210 | 6206928 | HBSS | 1 | 0.2 | 0.2 | 0.6 | 0.7 |
| GW057797 | 284062 | 6211047 | HBSS | 1 | 0.1 | 0.1 | 1.4 | 1.5 |
| GW057837 | 282733 | 6227570 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW031294 | 279732 | 6205706 | HBSS | 1 | 1.8 | 3.6 | 2.1 | 3.9 |
| GW037294 | 272114 | 6213755 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW037428 | 273321 | 6227472 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW032426 | 272857 | 6225426 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW032443 | 276415 | 6206336 | HBSS | 1 | 7.0 | 13.5 | 7.9 | 14.5 |
| GW037743 | 282609 | 6229602 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW037746 | 271926 | 6229966 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW038060 | 274680 | 6210364 | HBSS | 1 | 0.9 | 2.6 | 2.0 | 3.8 |
| GW038191 | 271382 | 6219626 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW034687 | 278221 | 6209000 | HBSS | 1 | 2.7 | 10.2 | 5.3 | 12.9 |
| GW008537 | 277989 | 6211214 | HBSS | 1 | 0.1 | 0.6 | 3.9 | 4.5 |
| GW010301 | 271591 | 6216301 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW010496 | 276413 | 6211793 | HBSS | 1 | 0.1 | 0.0 | 0.9 | 0.9 |
| GW010604 | 276637 | 6214234 | HBSS | 1 | 0.3 | 0.3 | 0.6 | 0.7 |
| GW011042 | 289617 | 6208862 | HBSS | 1 | 0.1 | 0.0 | 2.1 | 2.1 |
| GW011299 | 275291 | 6209454 | HBSS | 1 | 0.4 | 0.3 | 0.8 | 0.8 |
| GW012613 | 282909 | 6231058 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW101174 | 274478 | 6215569 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW102152 | 266955 | 6189518 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW102390 | 274006 | 6212845 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.7 |
| GW102584 | 289626 | 6216445 | HBSS | 1 | 0.1 | 0.0 | 1.6 | 1.7 |
| GW103559 | 276499 | 6201858 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW102045 | 281266 | 6203733 | HBSS | 1 | 2.5 | 4.3 | 3.0 | 4.8 |
| GW102084 | 273727 | 6195361 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW102223 | 297881 | 6204297 | BUSS | 5 | 0.7 | 0.6 | 15.6 | 15.6 |
| GW102369 | 271745 | 6217369 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW104090 | 278208 | 6215913 | HBSS | 1 | 0.2 | 0.4 | 4.7 | 5.0 |
| GW067606 | 282421 | 6212095 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.7 |
| GW042941 | 272266 | 6216996 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW047576 | 274720 | 6223652 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW052628 | 276308 | 6200137 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.8 |
| GW100687 | 282621 | 6229816 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW100690 | 289519 | 6211122 | WMFM | 1 | 0.1 | 0.1 | 2.5 | 2.5 |
| GW100694 | 294187 | 6213824 | HBSS | 1 | 0.1 | 0.2 | 2.3 | 2.4 |
| GW072465 | 278298 | 6232551 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW072469 | 278299 | 6232550 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW014262 | 276764 | 6204587 | HBSS | 1 | 0.3 | 0.4 | 1.8 | 1.9 |
| GW023343 | 270096 | 6220858 | HBSS | 1 | 0.0 | 0.0 | 0.7 | 0.7 |
| GW101026 | 279751 | 6207946 | HBSS | 1 | 0.1 | 0.2 | 0.3 | 0.5 |
| GW101133 | 289443 | 6214100 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW101656 | 272030 | 6200896 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.7 |
| GW024355 | 286513 | 6232835 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW025594 | 270318 | 6225396 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW060887 | 293987 | 6215031 | BUSS | 5 | 3.7 | 3.6 | >50 | >50 |
| GW104223 | 284889 | 6223027 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW104461 | 270011 | 6218143 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW104513 | 272694 | 6231110 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |

| work_no | Easting | Northing | Assumed | | Modelled Maximum Drawdown (at any time); [m] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Aquifer unit | Model layer | Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
| GW104558 | 282447 | 6211841 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.8 |
| GW105148 | 278006 | 6209733 | HBSS | 1 | 1.9 | 7.1 | 4.1 | 9.4 |
| GW105306 | 272139 | 6220699 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW105309 | 269368 | 6229896 | BUSS | 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW104661 | 289118 | 6216661 | HBSS | 1 | 0.1 | 0.1 | 2.3 | 2.4 |
| GW075056 | 294312 | 6229788 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW075053 | 293868 | 6230837 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW075052 | 293786 | 6230791 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW075055 | 294445 | 6230226 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW104763 | 276430 | 6229649 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW105679 | 274382 | 6215472 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW105704 | 272682 | 6191424 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW105705 | 271172 | 6191283 | HBSS | 1 | 0.1 | 0.0 | 0.9 | 0.9 |
| GW105710 | 278010 | 6225931 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW105735 | 276814 | 6199660 | HBSS | 1 | 0.4 | 1.1 | 0.4 | 1.2 |
| GW105737 | 283351 | 6227384 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW105751 | 281818 | 6227257 | HBSS | 1 | 0.1 | 0.0 | 0.1 | 0.1 |
| GW105785 | 283181 | 6227139 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW105787 | 282092 | 6209593 | HBSS | 1 | 0.0 | 0.1 | 0.5 | 0.7 |
| GW105789 | 285485 | 6231633 | HBSS | 1 | 0.1 | 0.0 | 5.1 | 5.1 |
| GW105802 | 280547 | 6207174 | HBSS | 1 | 1.5 | 3.3 | 2.6 | 4.4 |
| GW105803 | 282278 | 6204644 | HBSS | 1 | 0.4 | 0.5 | 0.6 | 0.7 |
| GW105813 | 279408 | 6213106 | HBSS | 1 | 0.3 | 2.8 | 3.6 | 6.2 |
| GW105821 | 275351 | 6213650 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW105827 | 276889 | 6200247 | HBSS | 1 | 0.1 | 0.2 | 0.9 | 0.9 |
| GW105847 | 277020 | 6204404 | HBSS | 1 | 0.5 | 1.3 | 1.7 | 2.5 |
| GW105860 | 282520 | 6208359 | HBSS | 1 | 0.2 | 0.3 | 0.6 | 0.7 |
| GW105863 | 274208 | 6214937 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW105869 | 269245 | 6189636 | WMFM | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW106250 | 286336 | 6209811 | HBSS | 1 | 0.1 | 0.1 | 1.0 | 1.0 |
| GW105876 | 271871 | 6214700 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW105883 | 277040 | 6204629 | HBSS | 1 | 0.2 | 0.3 | 1.6 | 1.8 |
| GW105884 | 281588 | 6210112 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW106281 | 277018 | 6210748 | HBSS | 1 | 0.2 | 0.7 | 1.6 | 2.1 |
| GW105927 | 272574 | 6224638 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW105933 | 277845 | 6225998 | WMFM | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW105942 | 282545 | 6218791 | WMFM | 1 | 0.1 | 0.2 | 1.4 | 1.6 |
| GW105944 | 282182 | 6209287 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW105958 | 269552 | 6189600 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW106147 | 271672 | 6229163 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW106157 | 274034 | 6221680 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW106174 | 286816 | 6233726 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW106205 | 282759 | 6230599 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW106008 | 272038 | 6188416 | HBSS | 1 | 0.0 | 0.0 | 4.6 | 4.5 |
| GW105467 | 277279 | 6215251 | HBSS | 1 | 0.3 | 0.2 | 0.7 | 0.7 |
| GW105562 | 272154 | 6217892 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW105563 | 272836 | 6215463 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW105483 | 284916 | 6231684 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW105484 | 272509 | 6191356 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW105574 | 289656 | 6218908 | HBSS | 1 | 0.0 | 0.0 | 4.5 | 4.5 |
| GW105577 | 280728 | 6207041 | HBSS | 1 | 0.4 | 1.2 | 0.8 | 1.7 |
| GW105506 | 275834 | 6221753 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW105531 | 287664 | 6218430 | HBSS | 1 | 0.2 | 0.2 | 1.1 | 1.1 |
| GW105534 | 288655 | 6217297 | HBSS | 1 | 0.1 | 0.1 | 2.2 | 2.3 |
| GW105536 | 277011 | 6216893 | HBSS | 1 | 0.2 | 0.1 | 0.1 | 0.1 |
| GW105546 | 276997 | 6215723 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW100117 | 277320 | 6232706 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW105325 | 287685 | 6221474 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW105336 | 279817 | 6216879 | HBSS | 1 | 0.7 | 0.7 | 0.1 | 0.1 |
| GW105339 | 291802 | 6218287 | HBSS | 1 | 0.1 | 0.1 | 2.8 | 2.8 |
| GW105376 | 289443 | 6218380 | HBSS | 1 | 0.1 | 0.0 | 2.0 | 2.0 |
| GW105356 | 277217 | 6200741 | HBSS | 1 | 0.1 | 0.2 | 0.9 | 1.0 |

| work_no | Easting | Northing | Assumed Aquifer unit | Assumed Model layer | Modelled Maximum Drawdown (at any time); [m] Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
|---|---|---|---|---|---|---|---|---|
| GW105388 | 289888 | 6217892 | HBSS | 1 | 0.1 | 0.1 | 2.3 | 2.3 |
| GW105395 | 278543 | 6203037 | HBSS | 1 | 0.4 | 0.6 | 1.0 | 1.2 |
| GW104760 | 274627 | 6230551 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW104766 | 287663 | 6220995 | HBSS | 1 | 0.0 | 0.0 | 3.2 | 3.2 |
| GW072874 | 288601 | 6217630 | HBSS | 1 | 0.1 | 0.0 | 1.8 | 1.8 |
| GW104967 | 280717 | 6222856 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW102609 | 270478 | 6221144 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW075057 | 292003 | 6230933 | WMFM | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW105243 | 280629 | 6225123 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW057274 | 272074 | 6211164 | HBSS | 1 | 0.1 | 0.2 | 0.3 | 0.5 |
| GW058644 | 274910 | 6196589 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW059311 | 273294 | 6212643 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW100089 | 274890 | 6196609 | BUSS | 5 | 0.2 | 0.3 | 0.2 | 0.4 |
| GW106997 | 271508 | 6200375 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW107011 | 277410 | 6200688 | HBSS | 1 | 0.2 | 0.2 | 0.9 | 1.0 |
| GW107116 | 294895 | 6211394 | WMFM | 1 | 0.1 | 0.1 | 2.3 | 2.3 |
| GW107117 | 295107 | 6211331 | WMFM | 1 | 0.1 | 0.0 | 2.1 | 2.2 |
| GW107140 | 283491 | 6224497 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW107200 | 272934 | 6190150 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW107608 | 282854 | 6226596 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW107616 | 273360 | 6226061 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW107457 | 272895 | 6224377 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW107470 | 282069 | 6208057 | HBSS | 1 | 0.9 | 1.5 | 1.5 | 2.2 |
| GW072196 | 288911 | 6218867 | Alluvium | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW107718 | 284938 | 6223729 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW107721 | 286368 | 6222728 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW107363 | 267786 | 6190585 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW107517 | 274004 | 6223869 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW107421 | 286003 | 6222692 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW107525 | 274856 | 6211080 | HBSS | 1 | 0.2 | 0.2 | 0.5 | 0.5 |
| GW107546 | 278627 | 6204519 | HBSS | 1 | 1.0 | 3.8 | 1.2 | 4.0 |
| GW107547 | 278789 | 6204644 | HBSS | 1 | 2.1 | 2.1 | 2.3 | 2.3 |
| GW107570 | 272219 | 6231143 | HBSS | 1 | 0.1 | 0.0 | 0.6 | 0.6 |
| GW107687 | 272584 | 6215864 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW107692 | 283455 | 6208096 | HBSS | 1 | 0.2 | 0.2 | 0.6 | 0.7 |
| GW107696 | 281158 | 6234413 | HBSS | 1 | 0.0 | 1.4 | 0.2 | 1.6 |
| GW106979 | 276811 | 6230433 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.5 |
| GW106901 | 276780 | 6231030 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW106490 | 281131 | 6225637 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW106546 | 282785 | 6206765 | HBSS | 1 | 1.2 | 1.8 | 1.7 | 2.4 |
| GW106566 | 276213 | 6200551 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW106574 | 290123 | 6218350 | HBSS | 1 | 0.1 | 0.1 | 1.8 | 1.8 |
| GW106590 | 280442 | 6206344 | HBSS | 1 | 4.8 | 7.9 | 7.6 | 10.8 |
| GW106593 | 276442 | 6234253 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW106606 | 276860 | 6226795 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW106612 | 273834 | 6215981 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW106613 | 276660 | 6201037 | HBSS | 1 | 0.1 | 0.1 | 0.7 | 0.8 |
| GW106673 | 275940 | 6216040 | HBSS | 1 | 0.1 | 0.6 | 0.7 | 1.3 |
| GW106675 | 288797 | 6218642 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW106620 | 282046 | 6229023 | HBSS | 1 | 0.1 | 0.1 | 0.0 | 0.0 |
| GW106690 | 270342 | 6218375 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW106702 | 278569 | 6227335 | HBSS | 1 | 0.2 | 0.2 | 0.4 | 0.4 |
| GW106648 | 274728 | 6228099 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW106663 | 270369 | 6200065 | BUSS | 5 | 0.1 | 0.4 | 0.2 | 0.5 |
| GW106669 | 278629 | 6227609 | HBSS | 1 | 1.0 | 4.2 | 0.4 | 3.6 |
| GW106406 | 275580 | 6216195 | HBSS | 1 | 0.1 | 0.6 | 0.7 | 1.3 |
| GW106334 | 271054 | 6224453 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.7 |
| GW106412 | 280922 | 6217038 | HBSS | 1 | 0.0 | 0.2 | 0.6 | 0.8 |
| GW106290 | 271617 | 6222779 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.6 |
| GW106292 | 276654 | 6200100 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.9 |
| GW106446 | 288570 | 6228846 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW107886 | 281276 | 6207377 | HBSS | 1 | 0.2 | 0.9 | 0.8 | 1.6 |

| work_no | Easting | Northing | Assumed | | Modelled Maximum Drawdown (at any time); [m] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Tahmoor South Impact estimate | Max Impact, Sensitivity | Cumulative Impact - Mining | Max Impact, Sensitivity Runs |
| | | | Aquifer unit | Model layer | | Tahmoor South | | Cumulative - All |
| GW108155 | 279212 | 6217250 | HBSS | 1 | 0.2 | 0.1 | 0.1 | 0.1 |
| GW108186 | 274296 | 6197951 | BUSS | 5 | 0.3 | 0.7 | 0.4 | 0.8 |
| GW108192 | 272015 | 6200536 | BUSS | 5 | 0.5 | 1.7 | 0.6 | 1.9 |
| GW108193 | 282555 | 6218724 | WMFM | 1 | 0.1 | 0.2 | 1.4 | 1.6 |
| GW108208 | 286175 | 6227656 | HBSS | 1 | 0.2 | 0.1 | 0.1 | 0.1 |
| GW108242 | 263166 | 6201260 | BUSS | 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW040946 | 279950 | 6199980 | BUSS | 5 | 14.4 | 18.4 | 14.8 | 18.8 |
| GW108389 | 268657 | 6187413 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW108276 | 271905 | 6224809 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW040953 | 293280 | 6216510 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW040954 | 293340 | 6216720 | HBSS | 1 | 0.0 | 0.0 | 1.4 | 1.4 |
| GW108312 | 291534 | 6217750 | HBSS | 1 | 0.1 | 0.1 | 2.8 | 2.9 |
| GW108055 | 284640 | 6225734 | WMFM | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW108318 | 272930 | 6190480 | HBSS | 1 | 0.1 | 0.0 | 0.8 | 0.8 |
| GW040989 | 274200 | 6184769 | HBSS | 1 | 0.2 | 0.2 | 0.9 | 0.9 |
| GW040945 | 281350 | 6196350 | BUSS | 5 | 0.4 | 0.4 | 0.6 | 0.7 |
| GW040952 | 279950 | 6199570 | HBSS | 1 | 0.2 | 0.2 | 0.9 | 0.9 |
| GW108414 | 267201 | 6189096 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW108415 | 277750 | 6200567 | HBSS | 1 | 0.2 | 0.2 | 0.8 | 1.0 |
| GW107781 | 267492 | 6188859 | BUSS | 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW107786 | 271920 | 6215301 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW107791 | 289415 | 6220392 | HBSS | 1 | 0.1 | 0.0 | 1.6 | 1.6 |
| GW108022 | 278460 | 6228280 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW107811 | 272792 | 6190886 | HBSS | 1 | 0.1 | 0.0 | 0.9 | 0.9 |
| GW107915 | 269530 | 6194354 | HBSS | 1 | 0.0 | 0.0 | 0.7 | 0.7 |
| GW107918 | 279629 | 6211559 | HBSS | 1 | 0.1 | 0.8 | 1.1 | 1.8 |
| GW107925 | 276613 | 6199968 | HBSS | 1 | 0.1 | 0.1 | 0.9 | 0.9 |
| GW107818 | 287244 | 6225291 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW107988 | 276795 | 6229253 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW107995 | 273973 | 6220230 | ShoalhavenGrp | 16 | 0.1 | 1.1 | 5.3 | 6.4 |
| GW107853 | 277467 | 6233084 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW109010 | 278173 | 6211781 | HBSS | 1 | 0.6 | 3.4 | 9.1 | 11.9 |
| GW109012 | 270596 | 6218276 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW108629 | 274456 | 6215006 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW100806 | 279525 | 6234363 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW108842 | 282500 | 6204716 | HBSS | 1 | 0.3 | 0.3 | 0.6 | 0.6 |
| GW072226 | 280704 | 6206868 | HBSS | 1 | 0.4 | 1.2 | 0.9 | 1.7 |
| GW072388 | 269494 | 6191368 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW100283 | 279768 | 6218698 | HBSS | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW100329 | 289288 | 6227553 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW108542 | 267804 | 6187586 | BUSS | 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW101986 | 288223 | 6217328 | HBSS | 1 | 0.1 | 0.1 | 2.0 | 2.1 |
| GW108451 | 271400 | 6185153 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.1 |
| GW108863 | 293738 | 6222478 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW108667 | 276603 | 6229529 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW108826 | 271577 | 6187194 | HBSS | 1 | 0.1 | 0.0 | 0.0 | 0.0 |
| GW108908 | 275336 | 6233491 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW108916 | 265450 | 6200528 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW102043 | 289777 | 6214659 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW108765 | 267838 | 6190765 | HBSS | 1 | 0.0 | 0.0 | 0.6 | 0.6 |
| GW108981 | 276641 | 6210801 | HBSS | 1 | 0.2 | 0.7 | 1.4 | 1.9 |
| GW108990 | 290347 | 6219588 | HBSS | 1 | 0.2 | 0.1 | 2.0 | 2.0 |
| GW108930 | 272663 | 6191760 | HBSS | 1 | 0.1 | 0.0 | 0.7 | 0.7 |
| GW103095 | 279684 | 6220398 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW109153 | 272074 | 6207558 | HBSS | 1 | 0.2 | 0.3 | 0.5 | 0.8 |
| GW109159 | 280600 | 6211398 | HBSS | 1 | 0.2 | 1.4 | 1.3 | 2.5 |
| GW109163 | 273788 | 6224577 | HBSS | 1 | 0.1 | 0.0 | 0.3 | 0.3 |
| GW100390 | 272165 | 6216867 | WMFM | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW108907 | 288602 | 6218547 | HBSS | 1 | 0.1 | 0.1 | 0.5 | 0.5 |
| GW109203 | 274797 | 6212250 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW109032 | 271824 | 6206636 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.5 |
| GW108606 | 275988 | 6217019 | HBSS | 1 | 0.0 | 0.0 | 0.0 | 0.0 |

| work_no | Easting | Northing | Assumed | | Modelled Maximum Drawdown (at any time); [m] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Aquifer unit | Model layer | Tahmoor South Impact estimate | Max Impact, Sensitivity Tahmoor South | Cumulative Impact - Mining | Max Impact, Sensitivity Runs Cumulative - All |
| GW108615 | 273015 | 6222473 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW108621 | 265957 | 6191841 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW108624 | 288024 | 6226703 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW100611 | 272190 | 6217022 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW108786 | 269560 | 6225662 | HBSS | 1 | 0.0 | 0.0 | 0.8 | 0.8 |
| GW100689 | 289518 | 6211121 | WMFM | 1 | 0.1 | 0.1 | 2.5 | 2.5 |
| GW100693 | 294187 | 6213824 | HBSS | 1 | 0.1 | 0.2 | 2.3 | 2.4 |
| GW109630 | 276049 | 6210284 | HBSS | 1 | 1.4 | 8.0 | 3.0 | 9.6 |
| GW110436 | 279363 | 6209869 | HBSS | 1 | 0.1 | 0.3 | 0.6 | 0.8 |
| GW110613 | 281442 | 6215610 | HBSS | 1 | 0.0 | 0.3 | 1.0 | 1.3 |
| GW109901 | 282443 | 6231511 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW109902 | 282989 | 6233307 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW109903 | 283455 | 6232799 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW109904 | 283284 | 6232173 | HBSS | 1 | 0.2 | 0.2 | 0.7 | 0.7 |
| GW109905 | 284986 | 6232516 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW109906 | 282829 | 6231600 | HBSS | 1 | 0.1 | 0.0 | 0.4 | 0.4 |
| GW109279 | 286688 | 6210293 | HBSS | 1 | 0.1 | 0.0 | 1.8 | 1.8 |
| GW110073 | 282402 | 6203851 | HBSS | 1 | 0.4 | 0.5 | 0.6 | 0.8 |
| GW110074 | 282350 | 6203875 | HBSS | 1 | 0.4 | 0.6 | 0.6 | 0.8 |
| GW109224 | 279140 | 6211222 | HBSS | 1 | 0.2 | 2.3 | 1.0 | 3.0 |
| GW110075 | 282295 | 6204007 | HBSS | 1 | 0.5 | 0.6 | 0.6 | 0.8 |
| GW110076 | 282402 | 6204055 | HBSS | 1 | 0.4 | 0.5 | 0.6 | 0.8 |
| GW110077 | 282331 | 6203769 | HBSS | 1 | 0.4 | 0.6 | 0.6 | 0.8 |
| GW110586 | 288755 | 6226962 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW110587 | 288139 | 6227101 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW110300 | 274632 | 6223345 | HBSS | 1 | 0.0 | 0.0 | 6.2 | 6.2 |
| GW110185 | 274345 | 6221032 | HBSS | 1 | 0.0 | 0.0 | 0.5 | 0.5 |
| GW110215 | 276066 | 6200472 | HBSS | 1 | 0.0 | 0.0 | 0.2 | 0.3 |
| GW110523 | 274807 | 6212696 | HBSS | 1 | 0.1 | 0.1 | 0.6 | 0.6 |
| GW109700 | 290978 | 6222235 | Alluvium | 1 | 0.0 | 0.0 | 0.2 | 0.2 |
| GW109701 | 288488 | 6222454 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW109702 | 288285 | 6223941 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW109703 | 288718 | 6225231 | Alluvium | 1 | 0.1 | 0.0 | 0.1 | 0.1 |
| GW109704 | 289591 | 6226370 | Alluvium | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW110669 | 274565 | 6207896 | HBSS | 1 | 0.4 | 0.2 | 3.0 | 2.8 |
| GW110413 | 291837 | 6224389 | HBSS | 1 | 0.0 | 0.0 | 0.3 | 0.3 |
| GW109315 | 292422 | 6224028 | WMFM | 1 | 0.1 | 0.0 | 0.5 | 0.5 |
| GW109950 | 276471 | 6200106 | HBSS | 1 | 0.1 | 0.1 | 0.8 | 0.8 |
| GW109257 | 276603 | 6205052 | HBSS | 1 | 6.6 | 17.7 | 7.7 | 18.9 |
| GW109560 | 280724 | 6224373 | HBSS | 1 | 0.0 | 0.0 | 0.1 | 0.1 |
| GW110435 | 279215 | 6209715 | HBSS | 1 | 0.1 | 0.1 | 0.4 | 0.6 |
| GW110491 | 288745 | 6229609 | HBSS | 1 | 0.1 | 0.0 | 0.2 | 0.2 |
| GW110230 | 267317 | 6189032 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |
| GW110231 | 267574 | 6188751 | BUSS | 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| GW110562 | 274626 | 6226744 | HBSS | 1 | 0.0 | 0.0 | 4.2 | 4.2 |
| GW109548 | 284593 | 6232869 | HBSS | 1 | 0.0 | 0.0 | 0.7 | 0.7 |
| GW109278 | 286012 | 6210468 | HBSS | 1 | 0.1 | 0.1 | 1.8 | 1.9 |
| GW110671 | 288717 | 6216340 | HBSS | 1 | 0.1 | 0.1 | 2.5 | 2.6 |
| GW110708 | 284529 | 6227139 | HBSS | 1 | 0.0 | 0.0 | 0.4 | 0.4 |

HYDRO SIMULATIONS

# FIGURES TO ACCOMPANY REPORT

# TAHMOOR SOUTH PROJECT EIS:

# GROUNDWATER ASSESSMENT

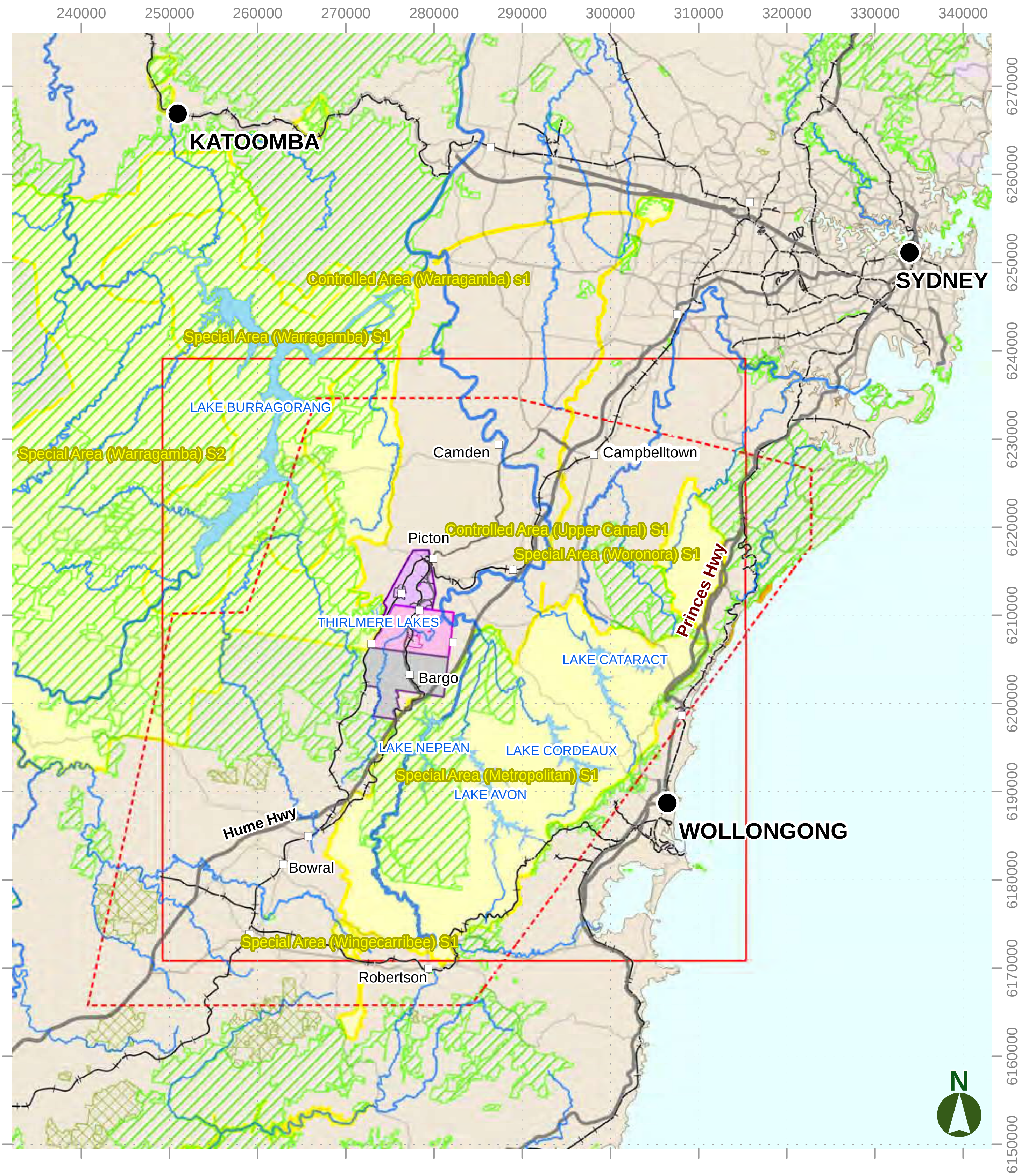
FOR

TAHMOOR COAL PTY LTD

Report: HS2018-052

Date: December 2018

LIST OF FIGURES




Major Town
Minor Town
Railway
Lake
Watercourse

SCA Special Area (2013)
National Park
NSW State Forest
Southern Coalfield (approx)

**Tahmoor Coal titles**

MLs 1308, 1376, 1539
CCL 716
CCL 747
Study area for Groundwater Assessment

Scale: 600,000 at A4
GDA 1994 MGA Zone 56

0 2.5 5 10 15 20 25 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH001a_ProjLocation_A4P.mxd

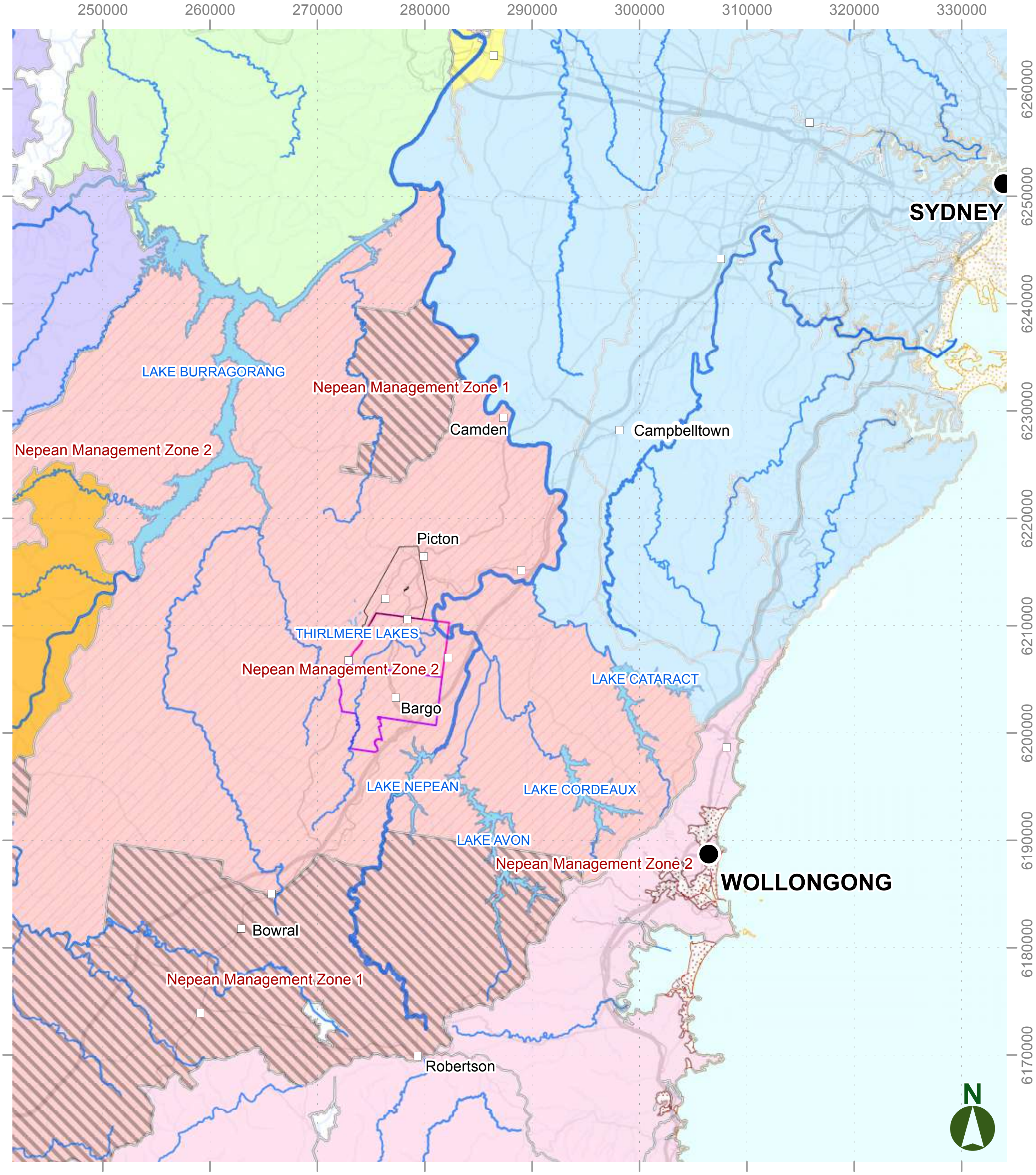
DrawingNo: TAH-004 | Rev: A | Created by: B.White | Date: 25/09/2018

HYDROSIMULATIONS

**Tahmoor Coal**
**Tahmoor South Project**

# Figure 1-1

**Project Location**




**Management Zone**

- Nepean Management Zone 1
- Nepean Management Zone 2

**GMA**

- Sydney Basin - Nepean Sandstone
- Botany Sandbeds
- Metropolitan Coastal Sands
- Hawkesbury Alluvium
- Coxs River Fractured Rock
- Goulburn Fractured Rock
- Sydney Basin - Blue Mtns Sandstone
- Sydney Basin - South
- Sydney Basin Central

- Major Town
- Minor Town
- Railway
- MLs 1308, 1376, 1539
- CCL 716
- CCL 747
- Lake
- Watercourse

Scale: 500,000
GDA 1994 MGA Zone 56

0 2 4 8 12 16 20 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH002a_WaterRegulation_A4P.mxd

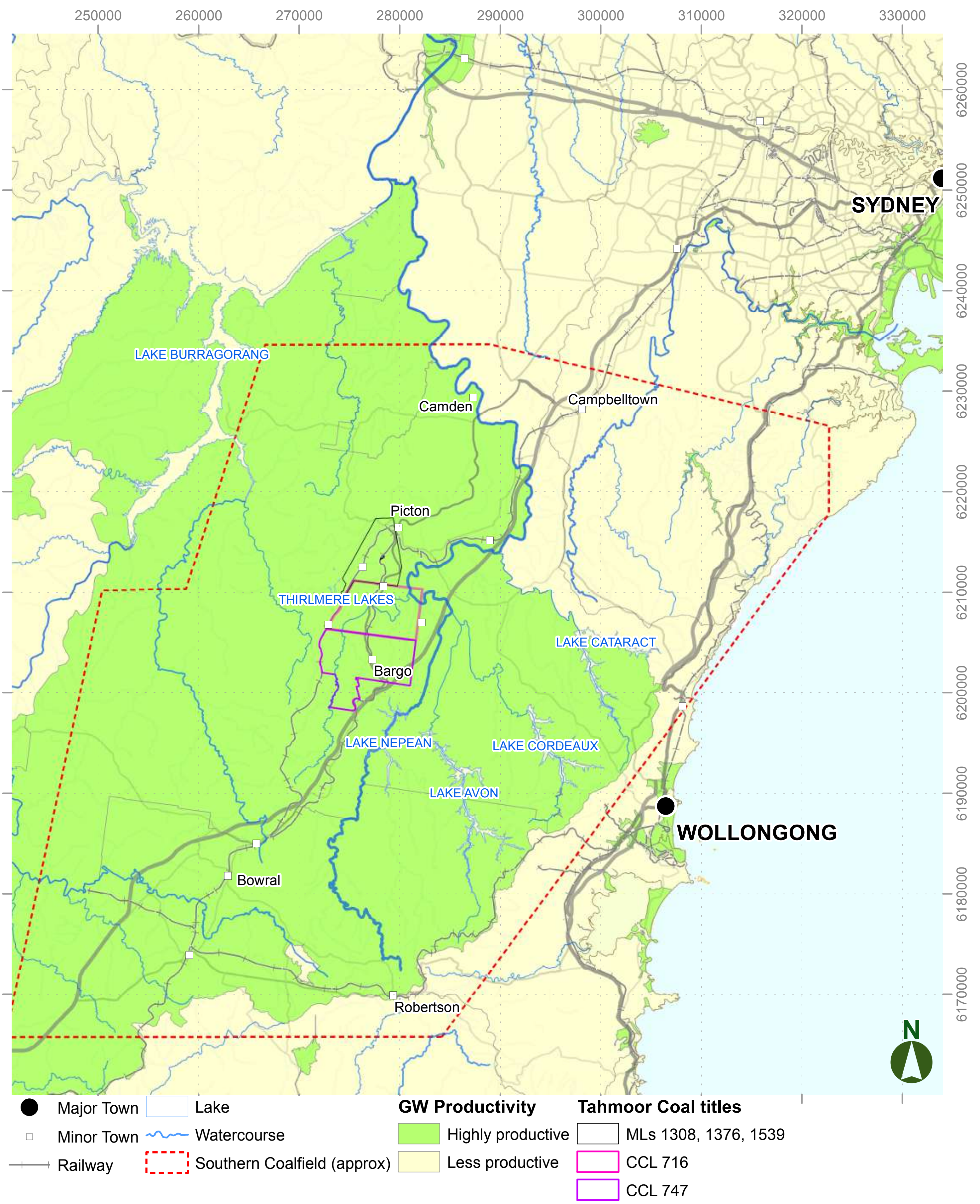
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HYDROSIMULATIONS

**Tahmoor Coal**
**Tahmoor South Project**

# Figure 1-2

## Water Management and Regulatory boundaries




Scale: 500,000
GDA 1994 MGA Zone 56

0 2 4 8 12 16 20 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH003a_GWproductivity_A4P.mxd

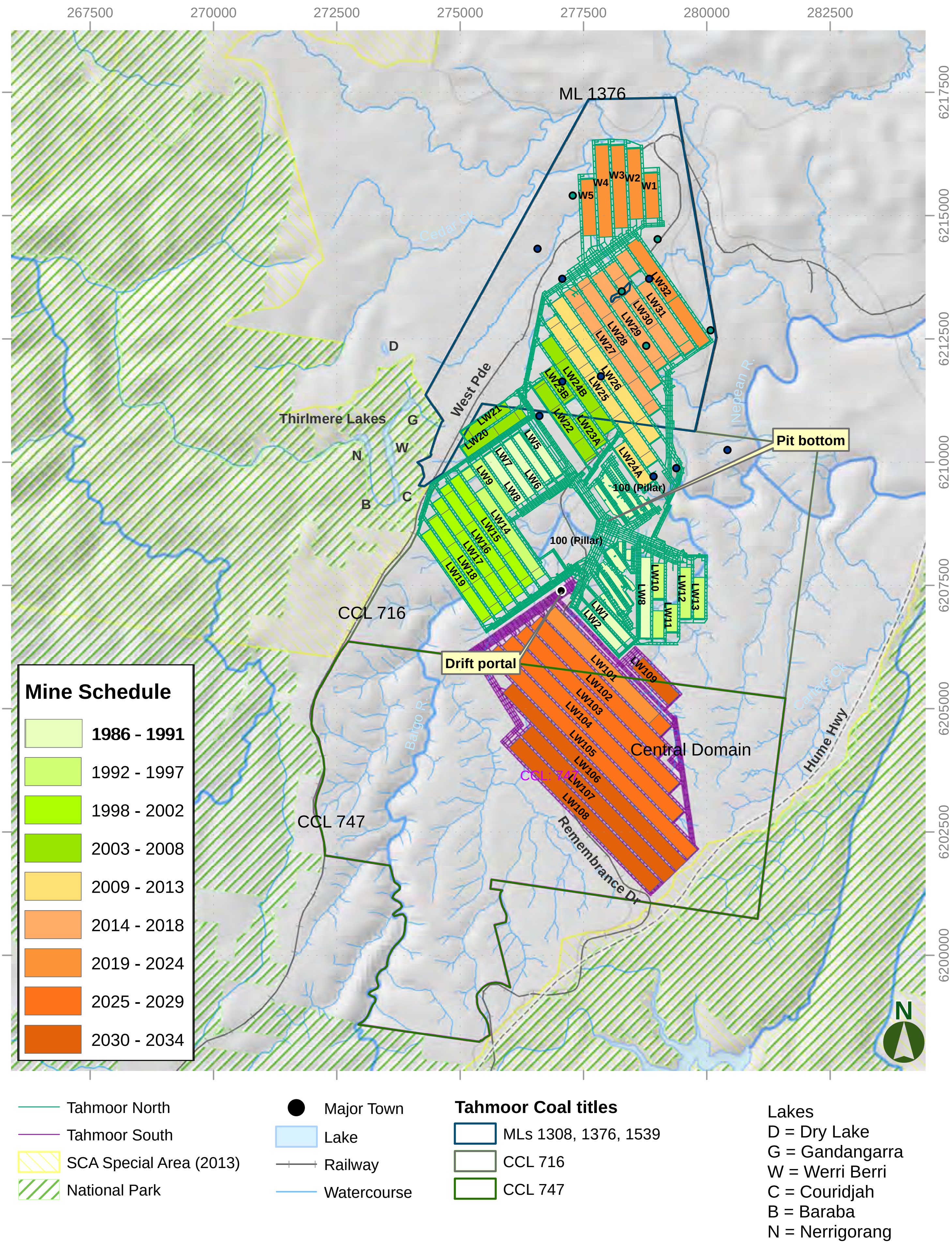
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

Tahmoor Coal
Tahmoor South Project

**Figure 1-3**

**Groundwater Productivity**




Scale: 100,000
GDA 1994 MGA Zone 56

0 0.5 1 2 3 4 kilometres

While Heritage/HydroSims has taken care to ensure the accuracy of this product, Heritage/HydroSims and DATA CUSTODIAN(S), make no representations or warranties about its accuracy, completeness or suitability for any particular purpose and cannot accept liability of any kind (whether in contract, tort or otherwise) for any expenses, losses,

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH003_MinePlan_A4P.mxd

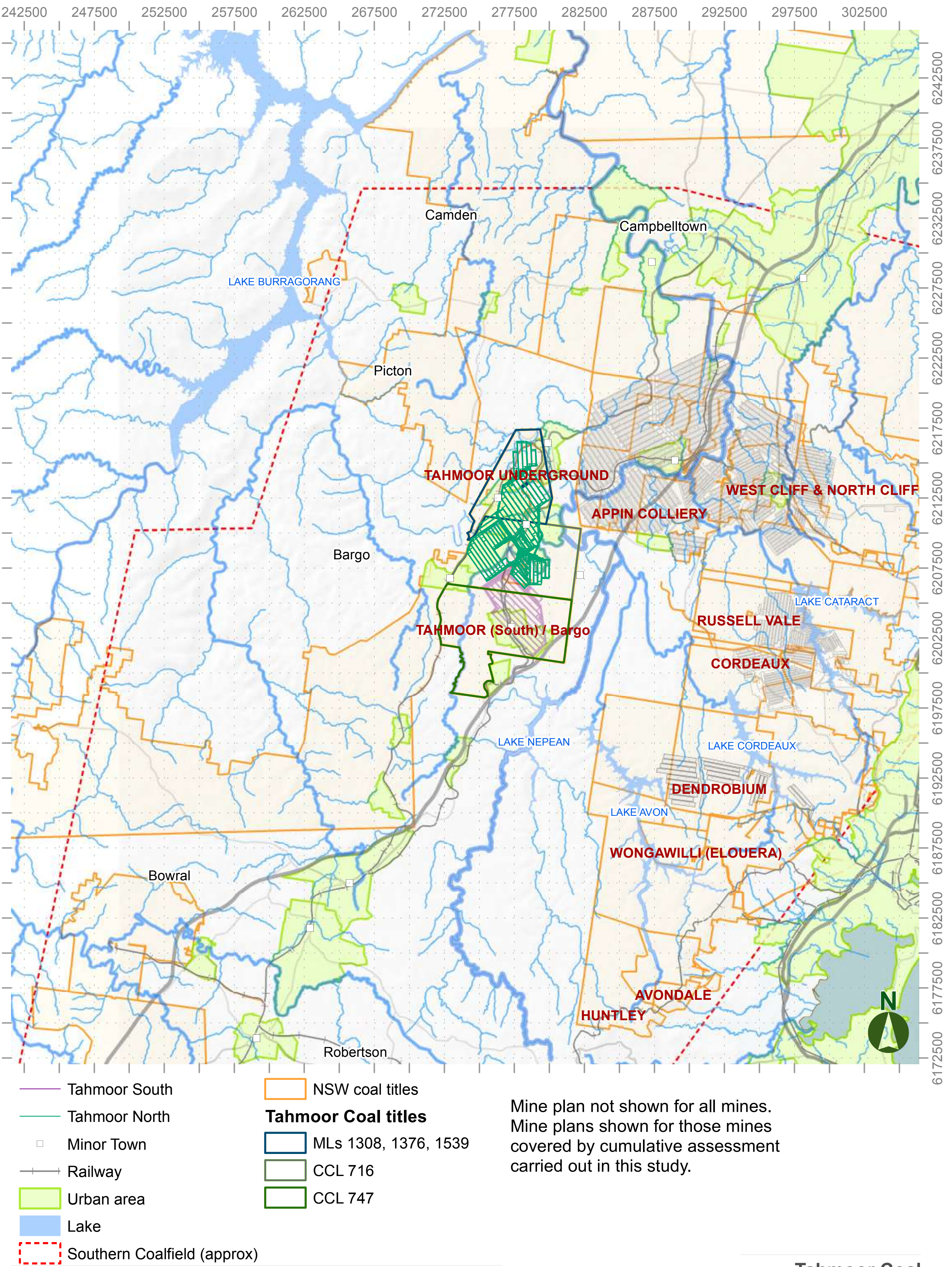
Project: TAH-004 | Rev: A | Created by: B.White | Date: 07/09/2018

HydroSimulations

**Tahmoor Coal**
**Tahmoor South Project**

# Figure 2-1

**Mine plan and schedule for Tahmoor Mine**




Mine plan not shown for all mines. Mine plans shown for those mines covered by cumulative assessment carried out in this study.

Scale: 350,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH005a_SurroundingMines_A4P.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

Tahmoor Coal
Tahmoor South Project

**Figure 2-2**

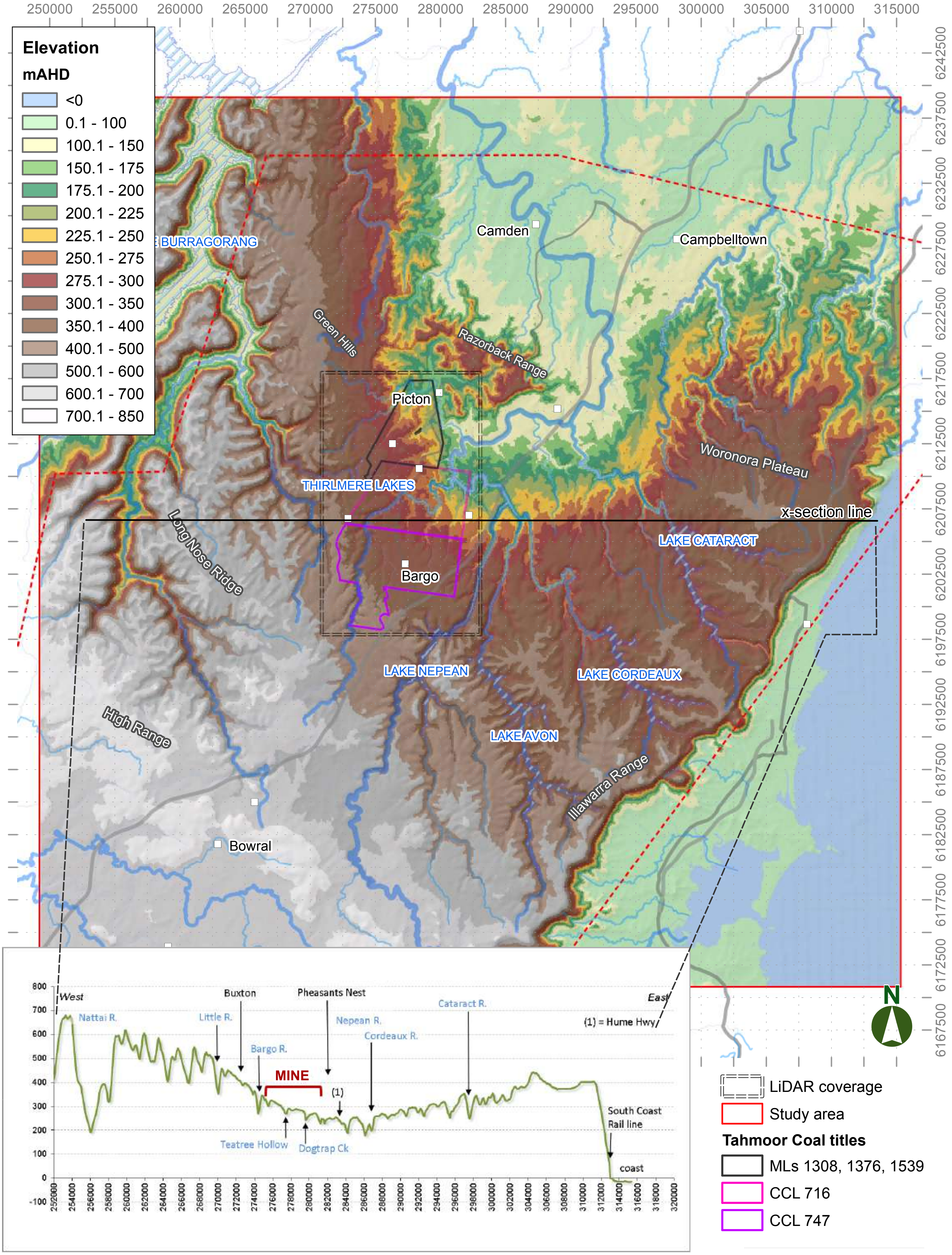
**Coal mining activity in the Southern Coalfield**

| | | | | | MINING AREAS ("LW" = longwall) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SP** | **Purpose** | **Start** | **End** | **DAYS** | Tahmoor Nth | Tah.Sth - Development | Tahmoor Sth | Appin | West Cliff | Tower | Bellambi | Cordeaux | Dendrobium |
| 1 | Initialise (SS) | | | 1 | | | | | | | | | |
| 2 | HISTORIC | Jan-80 | Dec-81 | 701 | 100 (pillar) | | | | | | | | |
| 3 | HISTORIC | Dec-81 | Oct-86 | 1795 | 100, 200, 300 (pillar) | | | LW12 | LW6 | | | | |
| 4 | HISTORIC | Nov-86 | Mar-87 | 121 | no longwall mining | | | LW14 | LW7 | | | | |
| 5 | HISTORIC | Mar-87 | Aug-87 | 168 | LW1 | | | LW14, LW15 | LW7, LW8 | | | | |
| 6 | HISTORIC | Aug-87 | Nov-87 | 102 | LW2 | | | LW15 | | | | | |
| 7 | HISTORIC | Nov-87 | Mar-88 | 115 | | | | | LW9 | | | | |
| 8 | HISTORIC | Mar-88 | Nov-88 | 241 | LW3 | | | LW15, LW16 | LW10, LW11 | LW1 | | | |
| 9 | HISTORIC | Nov-88 | Feb-89 | 80 | | | | LW16 | LW11 | | | | |
| 10 | HISTORIC | Feb-89 | Jun-89 | 120 | LW4 | | | LW17 | LW11, LW12 | | | | |
| 11 | HISTORIC | Jun-89 | Dec-89 | 182 | LW5 | | | | LW12, LW13, LW14 | LW2 | | | |
| 12 | HISTORIC | Dec-89 | Apr-90 | 139 | LW6 | | | LW18 | LW14, LW15 | LW2, LW3 | | | |
| 13 | HISTORIC | Apr-90 | Jul-90 | 85 | | | | LW18, LW20A | | LW3 | | | |
| 14 | HISTORIC | Jul-90 | Jan-91 | 197 | LW7 | | | LW20A, LW21A | | LW4A, LW4B | | | |
| 15 | HISTORIC | Jan-91 | Apr-91 | 78 | | | | LW21A, LW21B | LW16 | LW4B | | | |
| 16 | HISTORIC | Apr-91 | Dec-91 | 233 | LW8 | | | LW21B, LW22A | LW17 | LW5A, LW5B | | | |
| 17 | HISTORIC | Dec-91 | Jul-92 | 234 | LW9 | | | LW22A, LW22B, LW23 | LW17, LW18 | LW6 | | | |
| 18 | HISTORIC | Jul-92 | Dec-92 | 130 | LW10A | | | LW23 | LW18 | | | | |
| 19 | HISTORIC | Dec-92 | May-93 | 164 | LW10B | | | LW23, LW24 | LW18, LW19 | LW7 | | | |
| 20 | HISTORIC | May-93 | Sep-93 | 116 | LW11 | | | LW24 | LW19, LW20 | LW7, LW8 | | | |
| 21 | HISTORIC | Sep-93 | Jan-94 | 134 | | | | LW24 | | LW8, LW9 | | | |
| 22 | HISTORIC | Jan-94 | Jul-94 | 167 | LW12 | | | LW25 | | LW9 | | | |
| 23 | HISTORIC | Jul-94 | Nov-94 | 127 | LW13 | | | | LW20 | LW10 | | | |
| 24 | HISTORIC | Nov-94 | Jan-95 | 80 | | | | | | | | | |
| 25 | HISTORIC | Jan-95 | Jun-95 | 136 | LW14A | | | LW26 | | LW10, LW11 | | | |
| 26 | HISTORIC | Jun-95 | Oct-95 | 127 | LW14B | | | | LW21 | LW11, LW12 | | | |
| 27 | HISTORIC | Oct-95 | Jun-96 | 250 | | | | LW27 | LW21, LW22 | LW12, LW13 | | | |
| 28 | HISTORIC | Jun-96 | Feb-97 | 226 | | | | LW 28A | | LW13, LW14 | | | |
| 29 | HISTORIC | Feb-97 | Jun-97 | 134 | LW15 | | | LW 28B | LW22 | LW14 | | | |
| 30 | HISTORIC | Jun-97 | Sep-97 | 78 | | | | LW29 | | | | | |
| 31 | HISTORIC | Sep-97 | May-98 | 250 | | | | | LW23 | LW14, LW15 | | | |
| 32 | HISTORIC | May-98 | Oct-98 | 155 | LW16 | | | LW 401 | | LW15 | | | |
| 33 | HISTORIC | Oct-98 | Feb-99 | 121 | | | | LW 402 | LW24 | LW16 | | | |
| 34 | HISTORIC | Feb-99 | Oct-99 | 229 | LW17 | | | | LW24, LW25 | LW16, LW17 | | | |
| 35 | HISTORIC | Oct-99 | Jun-00 | 263 | | | | LW 403 | LW25, LW26 | LW17 | | | |
| 36 | HISTORIC | Jun-00 | Nov-00 | 149 | LW18 | | | | LW26 | LW18 | | | |
| 37 | HISTORIC | Nov-00 | Oct-01 | 319 | | | | LW 404 | LW27 | LW18, LW19 | | | |
| 38 | HISTORIC | Oct-01 | Feb-02 | 145 | LW19 | | | | LW27, LW28 | LW19 | | | |
| 39 | HISTORIC | Feb-02 | Sep-02 | 217 | | | | LW 405 | LW28 | LW19, LW20 | | | |
| 40 | HISTORIC | Sep-02 | May-03 | 239 | LW20 | | | | LW28, LW29 | LW20 | | | |
| 41 | HISTORIC | May-03 | Sep-03 | 108 | | | | LW405, LW406 | | | | | |
| 42 | HISTORIC | Sep-03 | May-04 | 262 | LW21 | | | LW406 | LW29 | | | | |
| 43 | HISTORIC | May-04 | Aug-04 | 65 | | | | | LW29, LW30 | | | | |
| 44 | HISTORIC | Aug-04 | Feb-05 | 209 | LW22 | | | LW407 | LW30 | | | | |
| 45 | HISTORIC | Mar-05 | Sep-05 | 197 | | | | | LW30, LW31 | | | | LW1 |
| 46 | HISTORIC | Sep-05 | Jan-06 | 140 | LW23A | | | | | | | | |
| 47 | HISTORIC | Feb-06 | Mar-06 | 49 | | | | LW408 | LW31 | | | | |
| 48 | HISTORIC | Mar-06 | Oct-06 | 205 | LW23B | | | | LW31, LW31A | | | | LW2 |
| 49 | HISTORIC | Oct-06 | Feb-07 | 139 | LW24B | | | LW 301 | LW31A, LW32 | | | | |
| 50 | HISTORIC | Mar-07 | Nov-07 | 259 | | | | LW 302 and Appin West LW701 | | | | | LW3 |
| 51 | HISTORIC | Nov-07 | Nov-07 | 16 | | | | Appin West LW701 | | | | | |
| 52 | HISTORIC | Dec-07 | May-08 | 161 | LW24A | | | | | | | | |
| 53 | HISTORIC | May-08 | Aug-08 | 104 | | | | | LW32 | | | | LW4 |
| 54 | HISTORIC | Aug-08 | Nov-08 | 101 | | | | | | | | | |
| 55 | HISTORIC | Dec-08 | Feb-10 | 435 | LW25 | | | Appin Area7 | West Cliff Area5 | | | | LW5 |
| 56 | HISTORIC | Feb-10 | Mar-11 | 414 | | | | Appin Area7 | West Cliff Area5 - LW34 | | | | LW6 |
| 57 | HISTORIC | Mar-11 | May-11 | 35 | | | | Appin Area7 | West Cliff Area5 - LW34 | | | | no longwall mining |
| 58 | HISTORIC | May-11 | Feb-12 | 301 | LW26 | | | Appin Area7 - LW704 | West Cliff Area5 - LW34 | | | | LW7 |
| 59 | HISTORIC | Feb-12 | Oct-12 | 229 | | | | Appin Area7 - LW704 | West Cliff Area5 - LW35 | | | | LW8 |
| 60 | HISTORIC | Oct-12 | Oct-13 | 365 | LW27 | | | Appin Area7 | West Cliff Area5 - LW36 | | | | LW8 |
| 61 | HISTORIC | Oct-13 | Apr-14 | 178 | | | | Appin Area7, Appin Area9 | | | | | LW9 |
| 62 | HISTORIC | Apr-14 | Nov-14 | 205 | LW28 | | | Appin Area7, Appin Area9 | | | | | |
| 63 | HISTORIC | Nov-14 | May-15 | 181 | LW28 | | | Appin Area7, Appin Area9 | | | | | LW10 |
| 64 | HISTORIC | May-15 | Nov-15 | 184 | LW29 | | | Appin Area7, Appin Area9 | | | | | |
| 65 | HISTORIC | Nov-15 | Apr-16 | 169 | LW29 | | | Appin Area7, Appin Area9 | | | | | LW11 |
| 66 | HISTORIC | Apr-16 | Dec-16 | 246 | LW30 | | | Appin Area7, Appin Area9 | | | | | |
| 67 | HISTORIC | Dec-16 | Jun-17 | 163 | LW30 | | | Appin Area7, Appin Area9 | | | | | LW12 |
| 68 | HISTORIC | Jun-17 | Dec-17 | 202 | LW31 | | | Appin Area7, Appin Area9 | | | | | |
| 69 | HISTORIC | Dec-17 | Jun-18 | 163 | LW31 | | | Appin Area7, Appin Area9 | | | | | LW13 |
| 70 | PREDICTIVE | Jun-18 | Sep-18 | 92 | LW32 | | | Appin Area7, Appin Area9 | | | | | |
| 71 | PREDICTIVE | Sep-18 | Mar-19 | 183 | LW32 | | | Appin Area7, Appin Area9 | | | | | LW14 |
| 72 | PREDICTIVE | Mar-19 | Aug-19 | 151 | W1,W2 | TG101 | | Appin Area7, Appin Area9 | | | | | |
| 73 | PREDICTIVE | Aug-19 | Feb-20 | 184 | W1,W2 | TG101 | | Appin Area7, Appin Area9 | | | | | LW15 |
| 74 | PREDICTIVE | Feb-20 | Aug-20 | 182 | W3 | MG101, MG102 | | Appin Area7, Appin Area9 | | | | | |
| 75 | PREDICTIVE | Aug-20 | Jan-21 | 154 | W3 | MG101, MG102 | | Appin Area7, Appin Area9 | | | | | LW16 |
| 76 | PREDICTIVE | Jan-21 | Jun-21 | 164 | W4 | MG102 | | Appin Area7, Appin Area9 | | | | | |
| 77 | PREDICTIVE | Jun-21 | Dec-21 | 177 | W4 | MG102 | | Appin Area7, Appin Area9 | | | | | LW17 |
| 78 | PREDICTIVE | Dec-21 | May-22 | 143 | W5 | MG102 | | Appin Area7, Appin Area9 | | | | | |
| 79 | PREDICTIVE | May-22 | Oct-22 | 155 | W5 | MG102 | | Appin Area7, Appin Area9 | | | | | LW18 |
| 80 | PREDICTIVE | Oct-22 | Jan-23 | 120 | | MG102, MG103 | | Appin Area7, Appin Area9 | | | | | LW19 |
| 81 | PREDICTIVE | Feb-23 | Aug-23 | 211 | | MG102, MG103 | LW101 | Appin Area7, Appin Area9 | | | | | LW19 |
| 82 | PREDICTIVE | Aug-23 | Jan-24 | 136 | | MG103, MG104 | LW101 | Appin Area7, Appin Area9 | | | | | |
| 83 | PREDICTIVE | Jan-24 | Jun-24 | 140 | | MG103, MG104, MG105 | LW102 | Appin Area7, Area9, Area8 | | | | | |
| 84 | PREDICTIVE | Jun-24 | Jan-25 | 233 | | MG103, MG104, MG105 | LW102 | Appin Area7, Area9, Area8 | | | | | |
| 85 | PREDICTIVE | Jan-25 | Oct-25 | 254 | | MG104, MG105, MG106 | LW103 | Appin Area7, Appin Area8 | | | | | |
| 86 | PREDICTIVE | Oct-25 | Jun-26 | 251 | | MG104, MG105, MG106 | LW103 | Appin Area7, Appin Area8 | | | | | |
| 87 | PREDICTIVE | Jun-26 | Mar-27 | 265 | | MG105, MG106, MG107 | LW104 | Appin Area7, Appin Area8 | | | | | |
| 88 | PREDICTIVE | Mar-27 | Jan-28 | 325 | | MG105, MG106, MG107 | LW104 | Appin Area7, Appin Area8 | | | | | |
| 89 | PREDICTIVE | Jan-28 | Jun-28 | 133 | | MG106, MG107, MG108 | LW105 | Appin Area7, Appin Area8 | | | | | |
| 90 | PREDICTIVE | Jun-28 | Jan-29 | 228 | | MG106, MG107, MG108 | LW105 | Appin Area7, Appin Area8 | | | | | |
| 91 | PREDICTIVE | Jan-29 | Jan-30 | 351 | | MG108, MG109, TG109 | LW106 | Appin Area8 | | | | | |
| 92 | PREDICTIVE | Jan-30 | Jan-31 | 365 | | MG108, MG109, TG109 | LW106 | Appin Area8 | | | | | |
| 93 | PREDICTIVE | Jan-31 | Jun-31 | 180 | | TG109 | LW107 | Appin Area8 | | | | | |
| 94 | PREDICTIVE | Jul-31 | Jan-32 | 194 | | TG109 | LW107 | Appin Area8 | | | | | |
| 95 | PREDICTIVE | Jan-32 | Jun-33 | 537 | | | LW108 | Appin Area8 | | | | | |
| 96 | PREDICTIVE | Jul-33 | Jan-34 | 194 | | | LW108 | Appin Area8 | | | | | |
| 97 | PREDICTIVE | Jan-34 | Jun-34 | 171 | | | LW109 | Appin Area8 | | | | | |
| 98 | RECOVERY | Jul-34 | Jan-35 | 214 | | | | Appin Area8 | | | | | |
| 99 | RECOVERY | Jan-35 | Jun-35 | 151 | | | | Appin Area8 | | | | | |
| 100 | RECOVERY | Jul-35 | Dec-35 | 184 | | | | Appin Area8 | | | | | |
| 101 | RECOVERY | Jan-36 | Jun-36 | 182 | | | | Appin Area8 | | | | | |
| 102 | RECOVERY | Jul-36 | Dec-36 | 184 | | | | Appin Area8 | | | | | |
| 103 | RECOVERY | Jan-37 | Jun-37 | 181 | | | | Appin Area8 | | | | | |
| 104 | RECOVERY | Jul-37 | Dec-37 | 184 | | | | Appin Area8 | | | | | |
| 105 | RECOVERY | Jan-38 | Jun-38 | 181 | | | | Appin Area8 | | | | | |
| 106 | RECOVERY | Jul-38 | Dec-38 | 184 | | | | Appin Area8 | | | | | |
| 107 | RECOVERY | Jan-39 | Jun-39 | 181 | | | | Appin Area8 | | | | | |
| 108 | RECOVERY | Jul-39 | Dec-39 | 184 | | | | Appin Area8, Appin Area3 Ext. | | | | | |
| 109 | RECOVERY | Jan-40 | Jun-40 | 182 | | | | Appin Area8, Appin Area3 Ext. | | | | | |
| 110 | RECOVERY | Jul-40 | Dec-40 | 184 | | | | Appin Area3 Ext. | | | | | |
| 111 | RECOVERY | Jan-41 | Dec-41 | 365 | | | | | | | | | |
| 112 | RECOVERY | Jan-42 | Dec-42 | 365 | | | | | | | | | |
| | | continued.... | | | | | | | | | | | |
| 132 | RECOVERY | Jan-2300 | 2500 | 73050 | | | | | | | | | |

E:\HYDROSIM\TAHMOOR\Model\Construction\Time\[Model Timing_20180910v4_Report.xlsx]Model Timing

(note this has been produced with modelling in mind, so dates/longwall/areas are not always 100% accurate. It is produced for impact assessment (inc cumulative impact), and considered accurate enough for that purpose)

**Comparative mine schedule for cumulative impact assessment** **Figure 2-3**




Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH007a_Topo_A4P.mxd

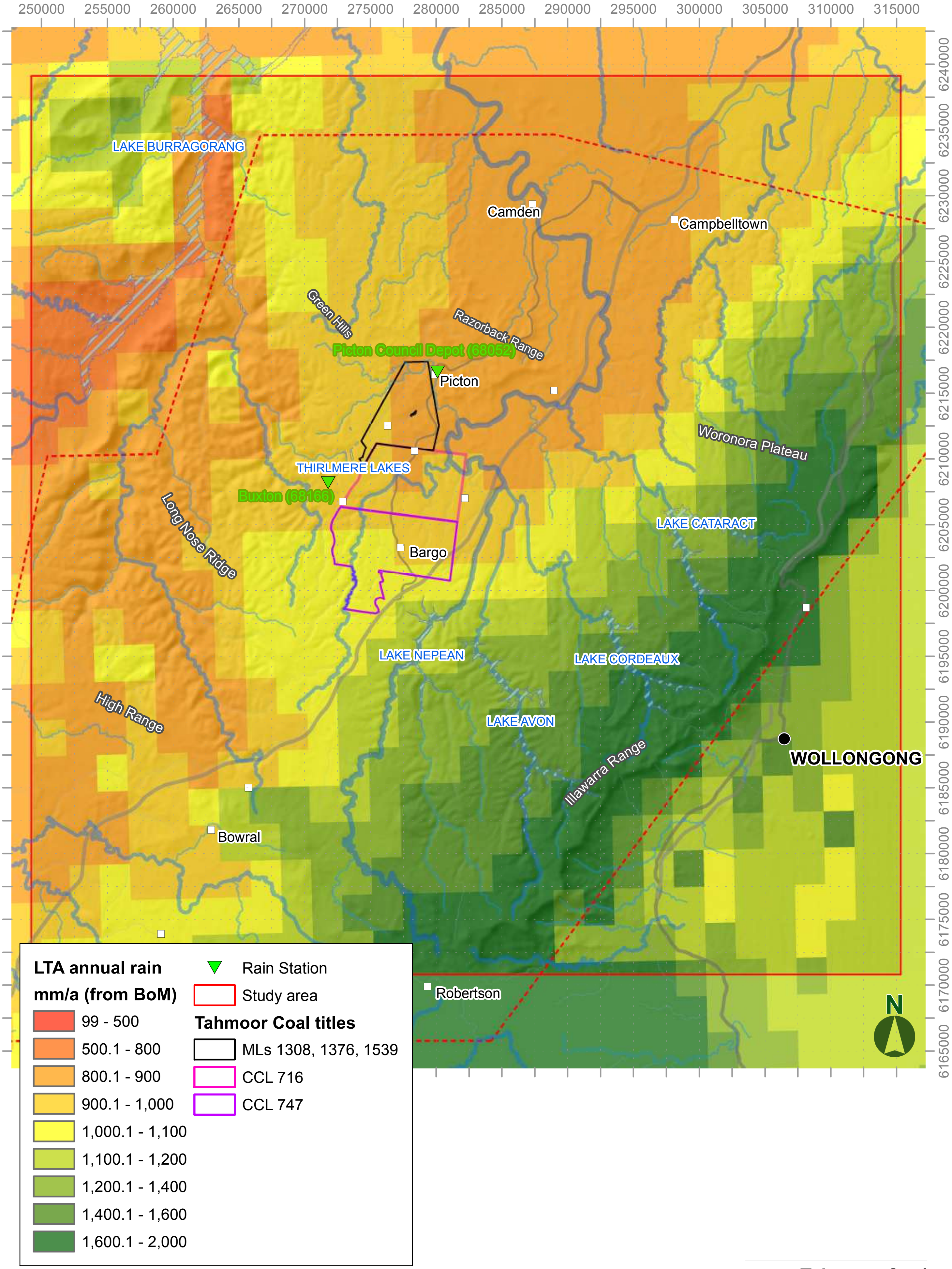
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HYDROSIMULATIONS

**Tahmoor Coal**
**Tahmoor South Project**

# Figure 3-1

**Topography of the Tahmoor area**




Tahmoor Coal
Tahmoor South Project

**Figure 3-2**

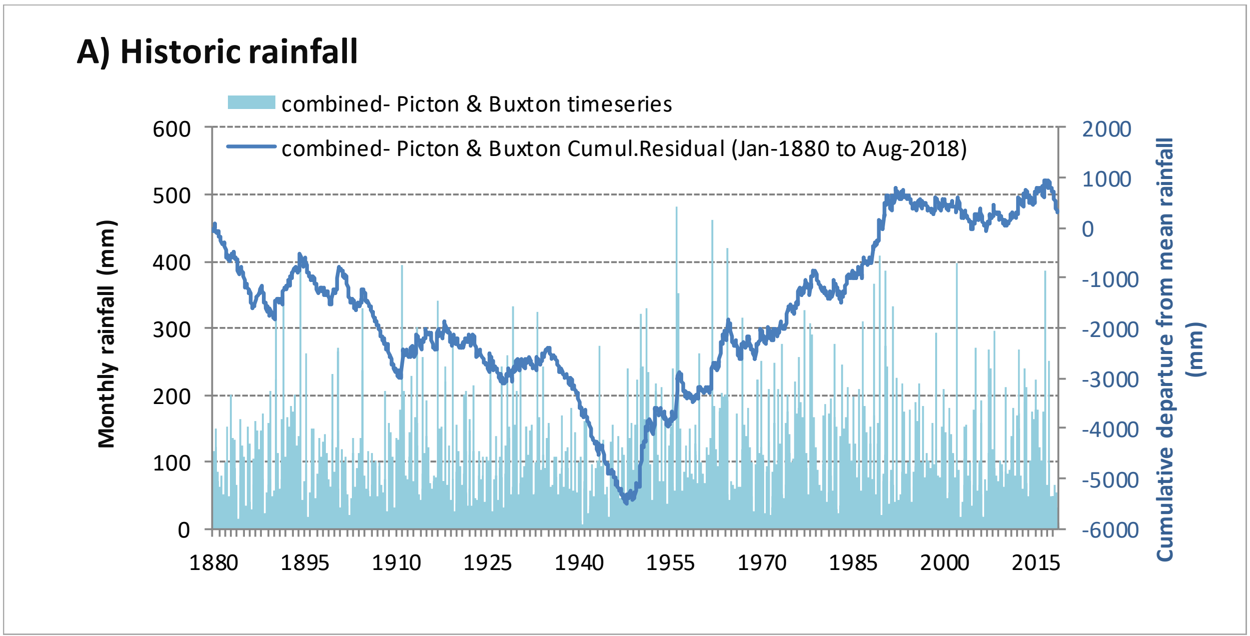


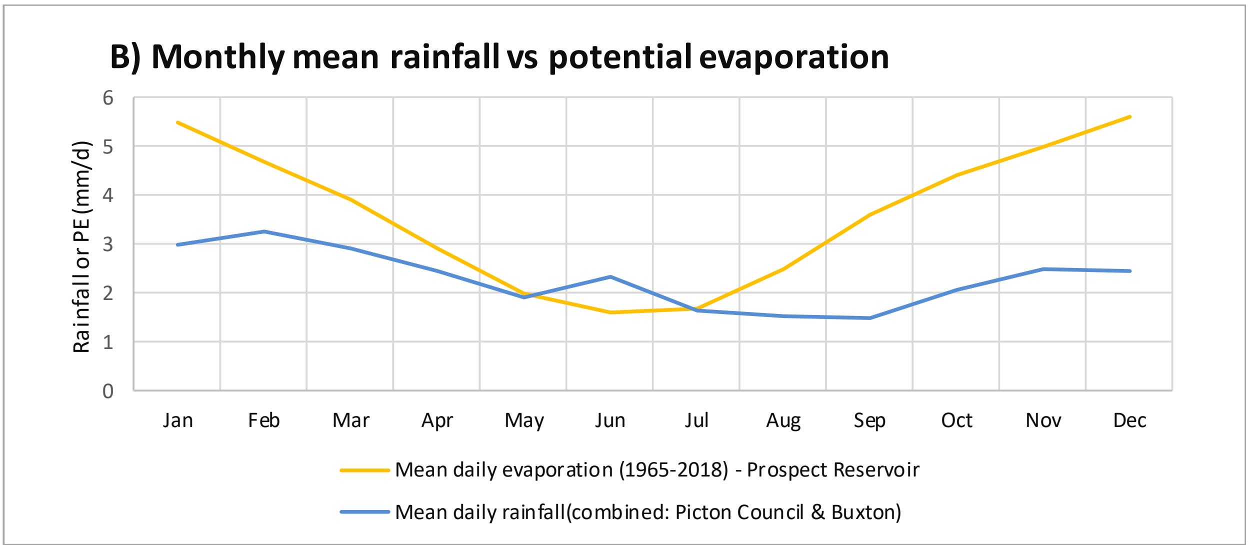
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH008a_Rainfall_A4P.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

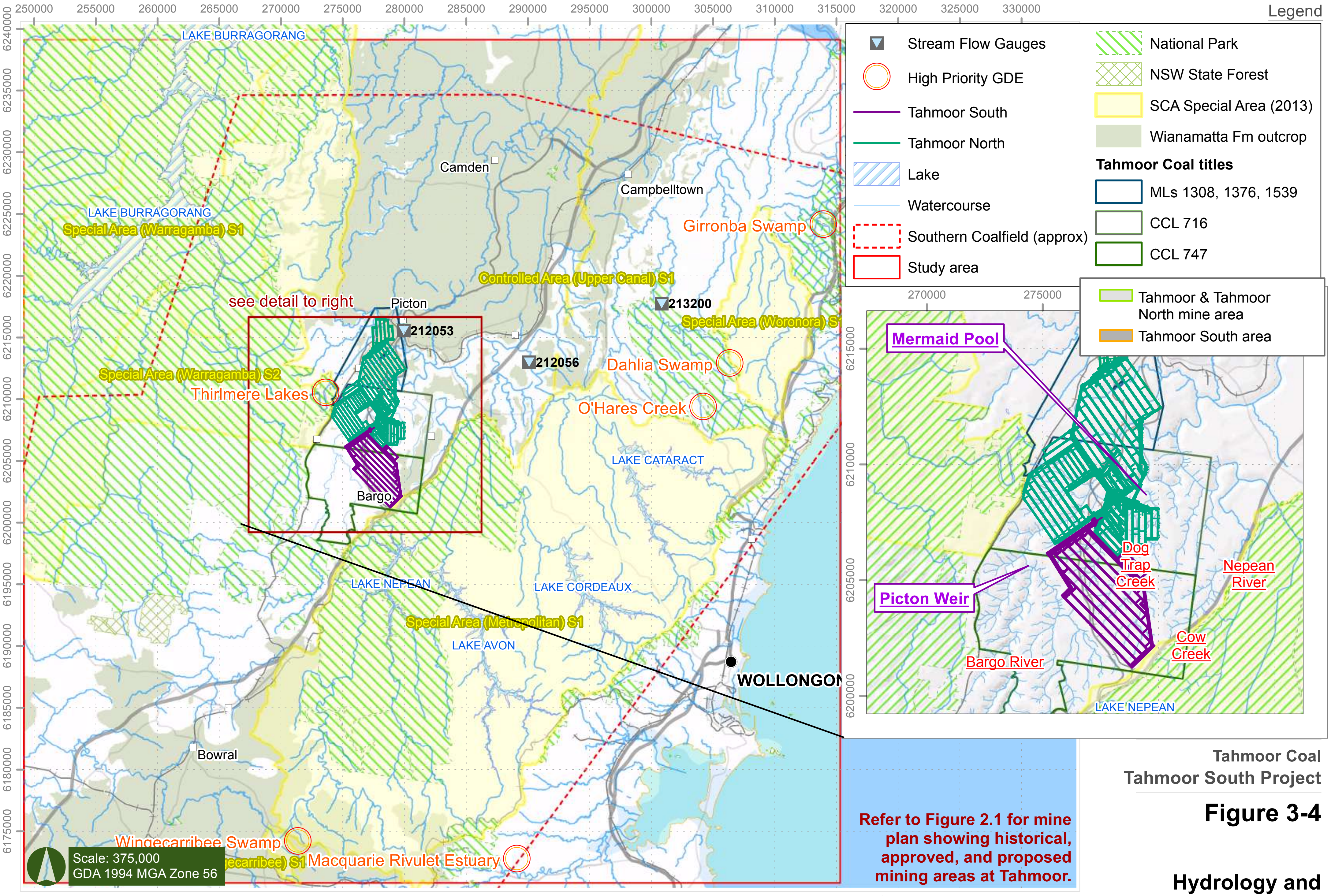
**Mean annual rainfall**




T:\TAHMOOR\Model\Construction\Boundaries\Recharge\[Rainfall&Recharge.xlsx]PotEvap

**Figure 3-3 A) Historical Rainfall. B) Monthly rainfall and potential evaporation**




Refer to Figure 2.1 for mine plan showing historical, approved, and proposed mining areas at Tahmoor.

Tahmoor Coal
Tahmoor South Project

# Figure 3-4

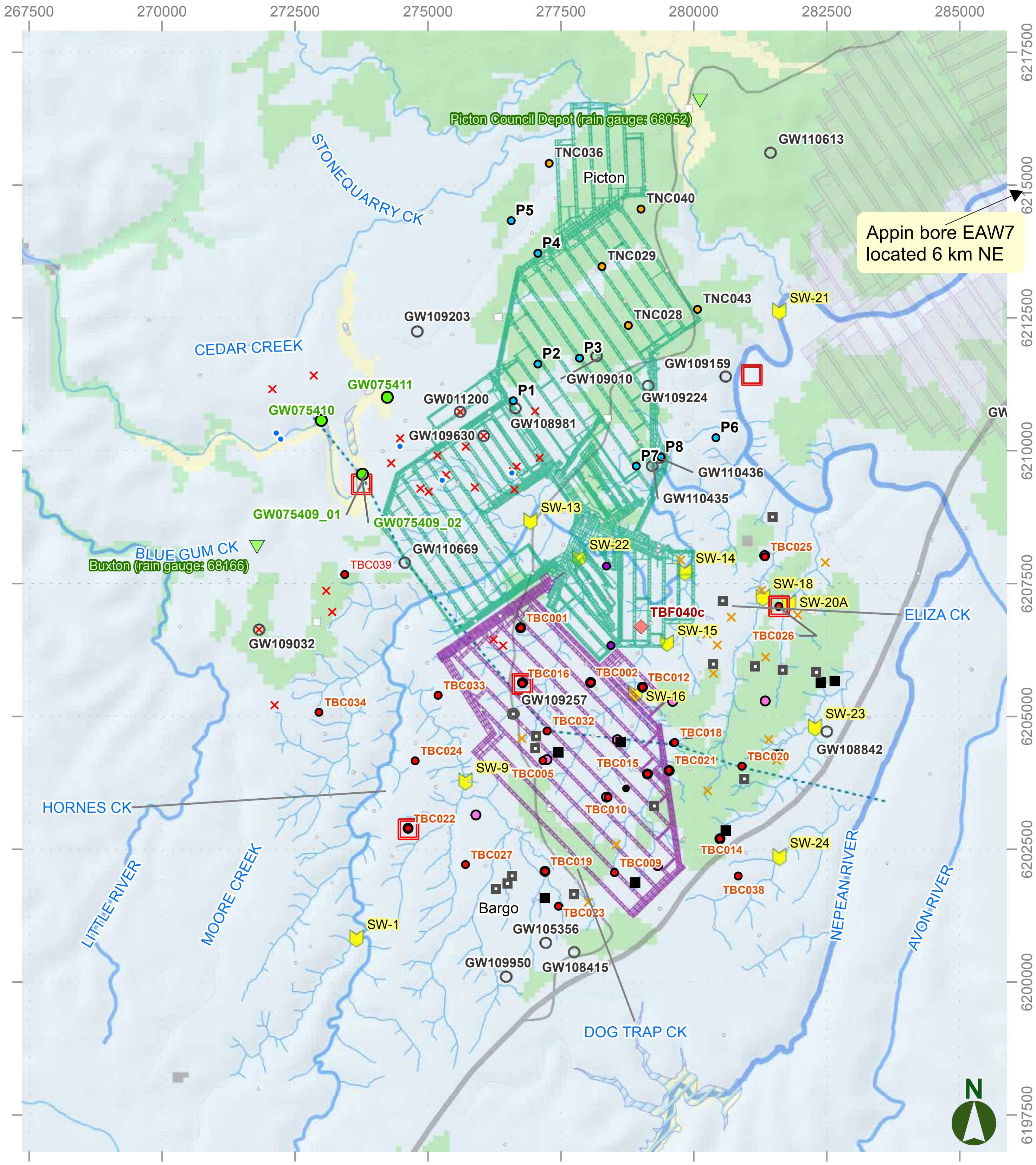
## Hydrology and environmental sites around Tahmoor



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH009a_Hydrology_A4Lv4.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HYDROSIMULATIONS




- Tahmoor North VWP
- Tahmoor South VWP
- Time of drilling (GW works)
- local shallow standpipe piezo
- other monitoring bores (NoW)
- Bargo bore census - chemistry only
- Bargo bore census - level & chem
- Bargo (private) - no access
- Tahmoor South - dual piezo
- Thirlmere Bore census - standpipe
- Thirlmere (private) - no access
- REA Piezometer
- TBF040c ('HoF hole')
- Bore (various, e.g. exploration)
- Project surface water monitoring site
- Cross-section line (Figure 3-25)
- (refer to Section 5.6 of the text)
- Tahmoor South workings
- Tahmoor North workings
- MLs 1308, 1376, 1539
- CCL 716
- CCL 747

Scale: 100,000 at A4
GDA 1994 MGA Zone 56

0 0.5 1 2 3 4 5 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH012a_MonitoringLocations_A4P.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 29/10/2018

HydroSimulations

**Tahmoor Coal**
**Tahmoor South Project**

**Figure 3-5**

**Monitoring locations**

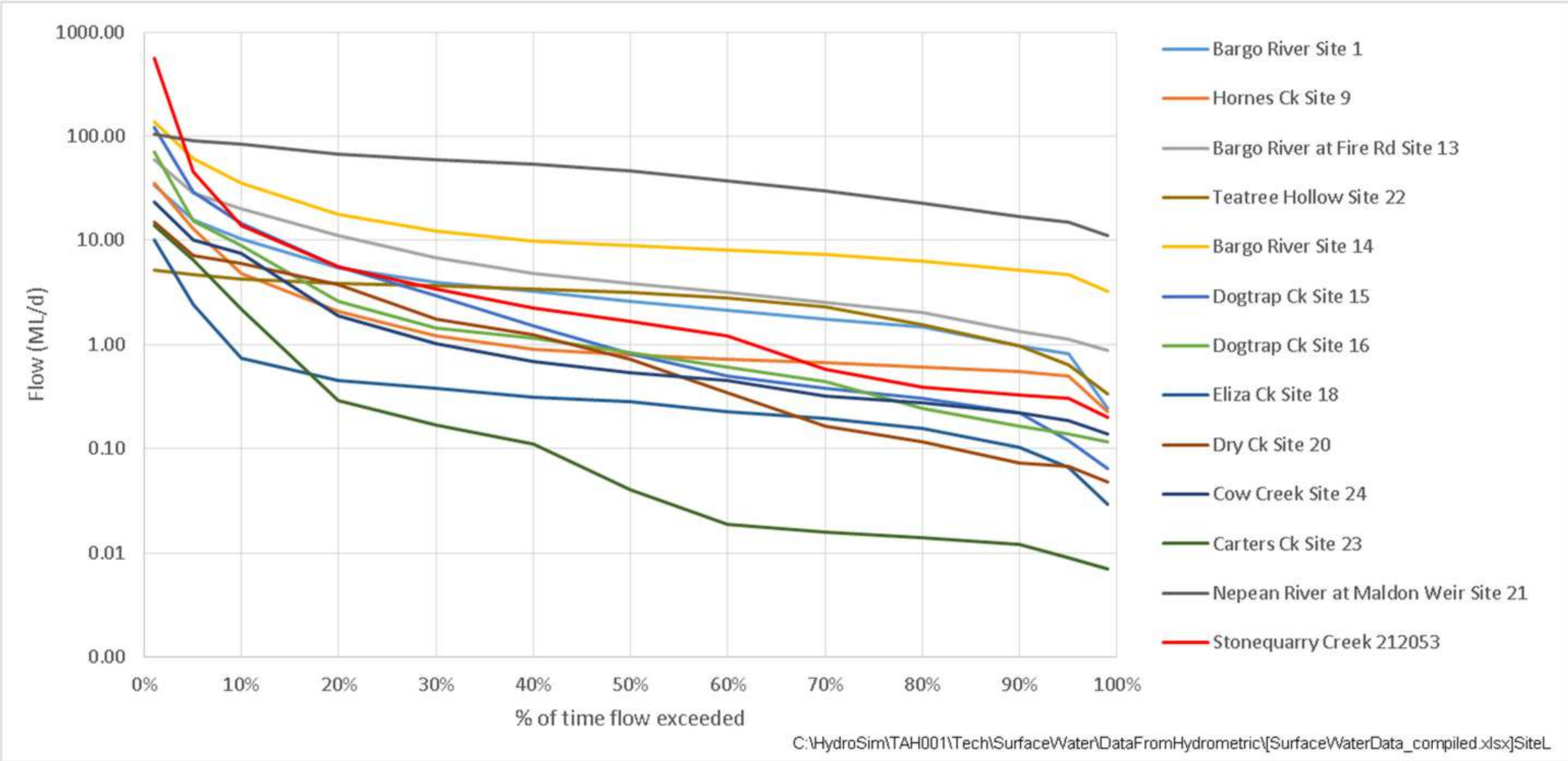
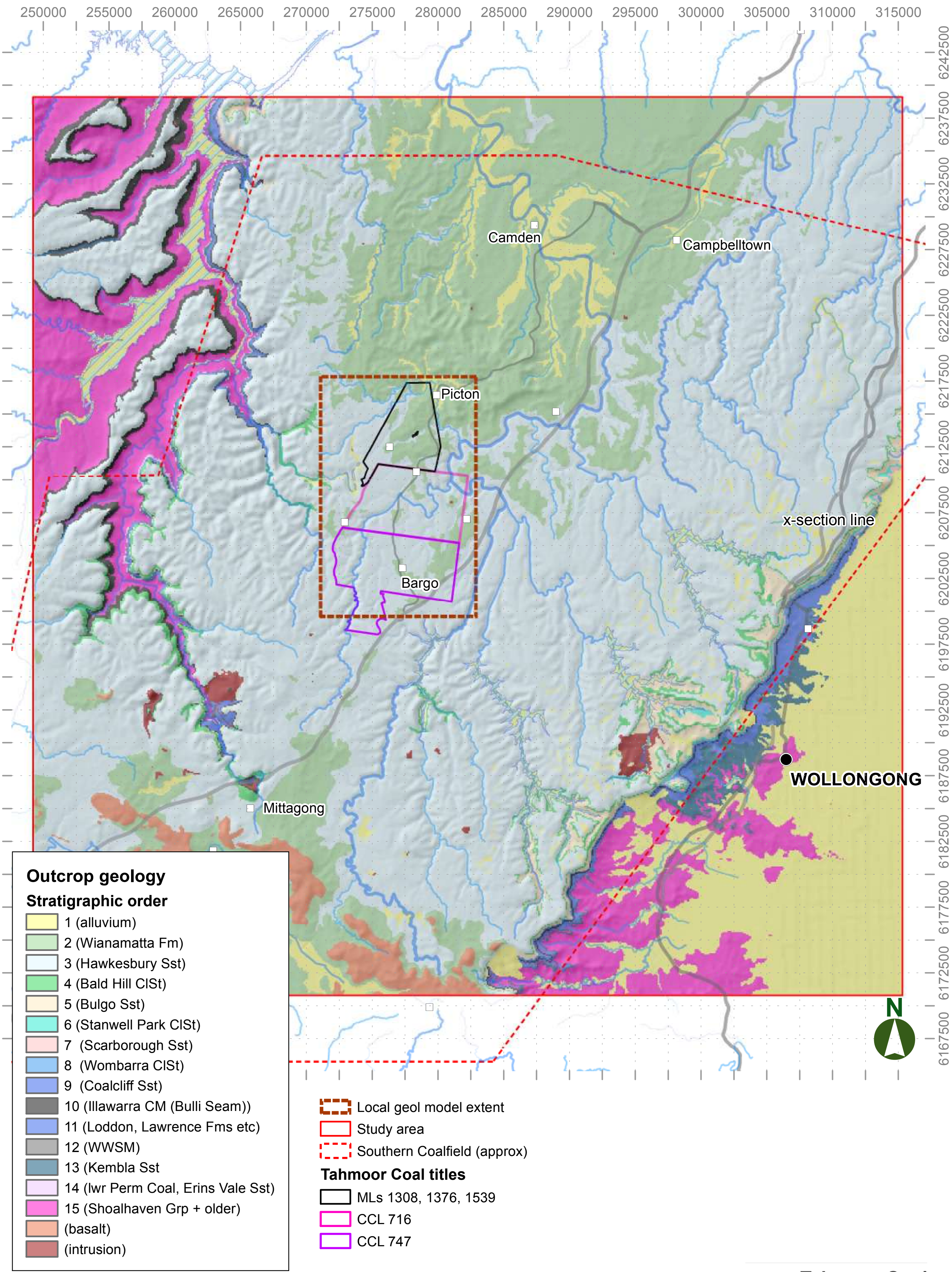



**Figure 3-6 Flow duration curves for local watercourses**




Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH010a_Geology_A4P.mxd

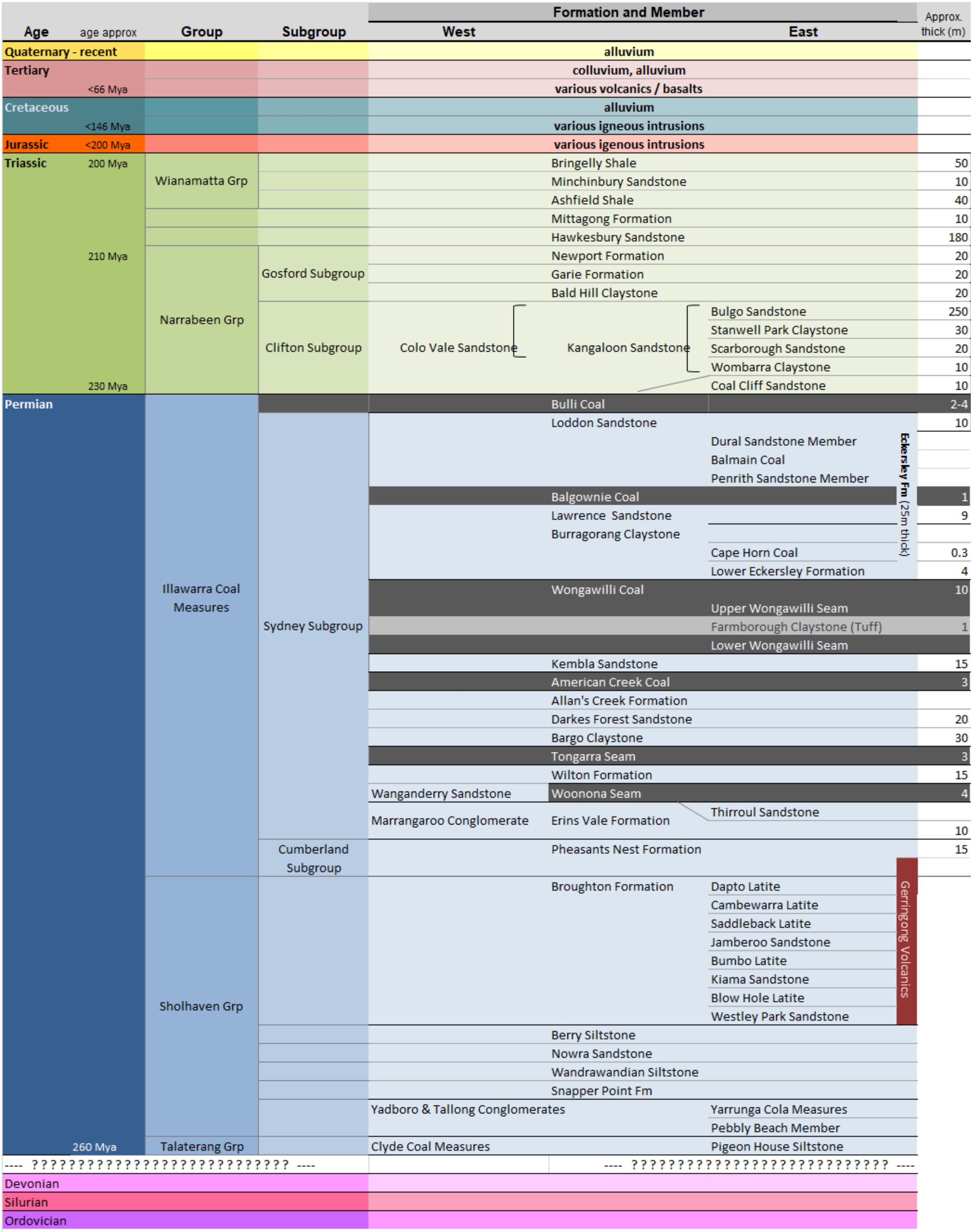
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

Tahmoor Coal
Tahmoor South Project

**Figure 3-7**

**Outcrop geology (Southern Coalfield 100k)**

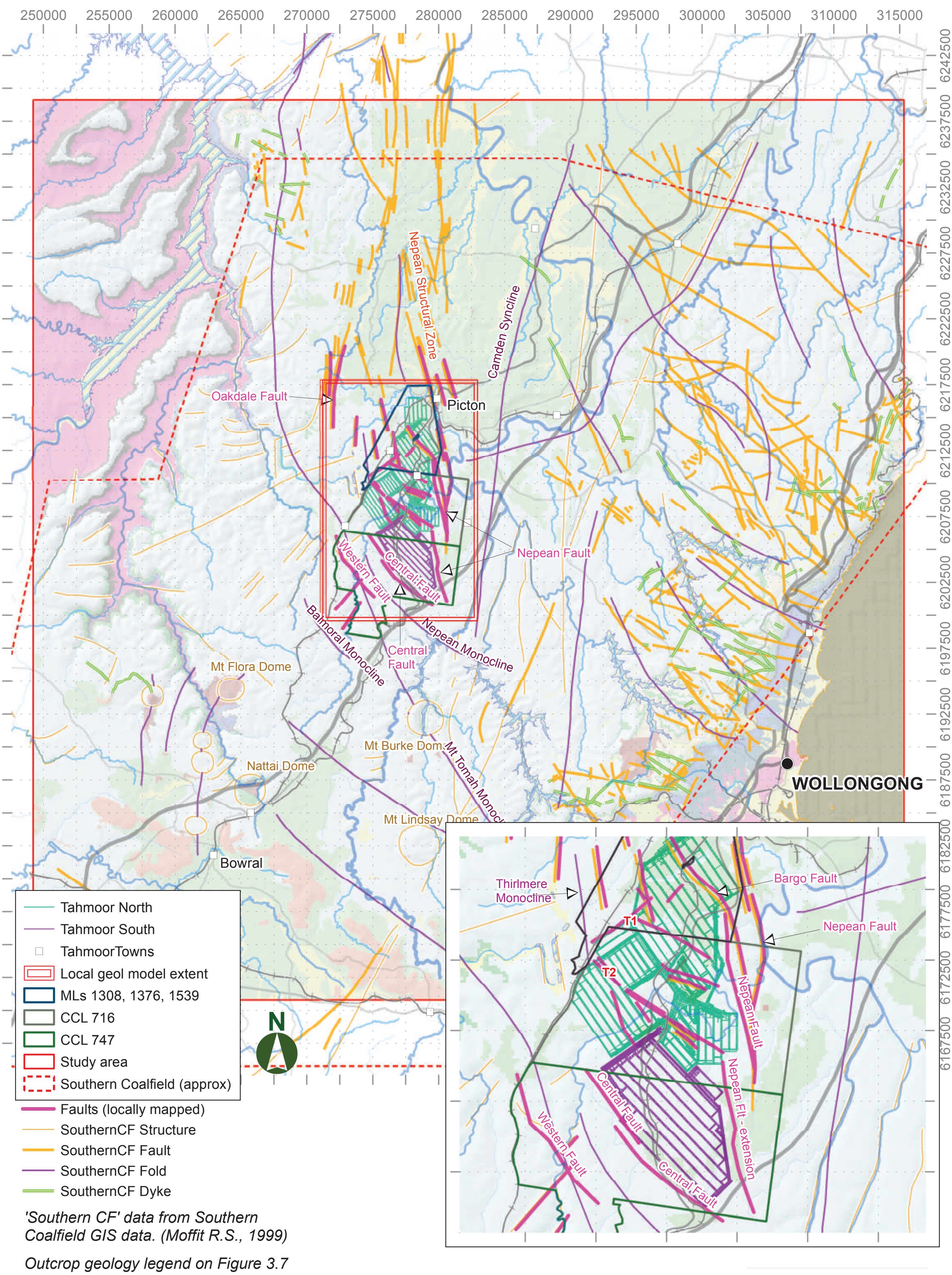



*adapted from:*

| | |
|---|---|
| SCA 2007 | *Design of a Hydrological and Hydrogeological Monitoring Program to Assess the Impact of Longwall Mining in SCA Catchments, App5 (Inquiry Southern Coalfield)* |
| GHD 2007 | *Hydrogeology Report for Dendrobium Coal (Appendix A)*, GHD doc 21/11716/03/AY116.doc |
| Uni Wollongong 2012 | *Bioregional Assessment: Sydney Metropolitan, Southern Rivers and Hawkesbury-Nepean Catchments* |

E:\HYDROSIM\TAHMOOR\Tech\Geology\[TahmoorSouth_GeologicalFramework.xlsx]StratColumn_report

## Figure 3-8 Southern Coalfield stratigraphic column




Scale: 375,000 at A4
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres

Tahmoor Coal
Tahmoor South Project

**Figure 3-9**

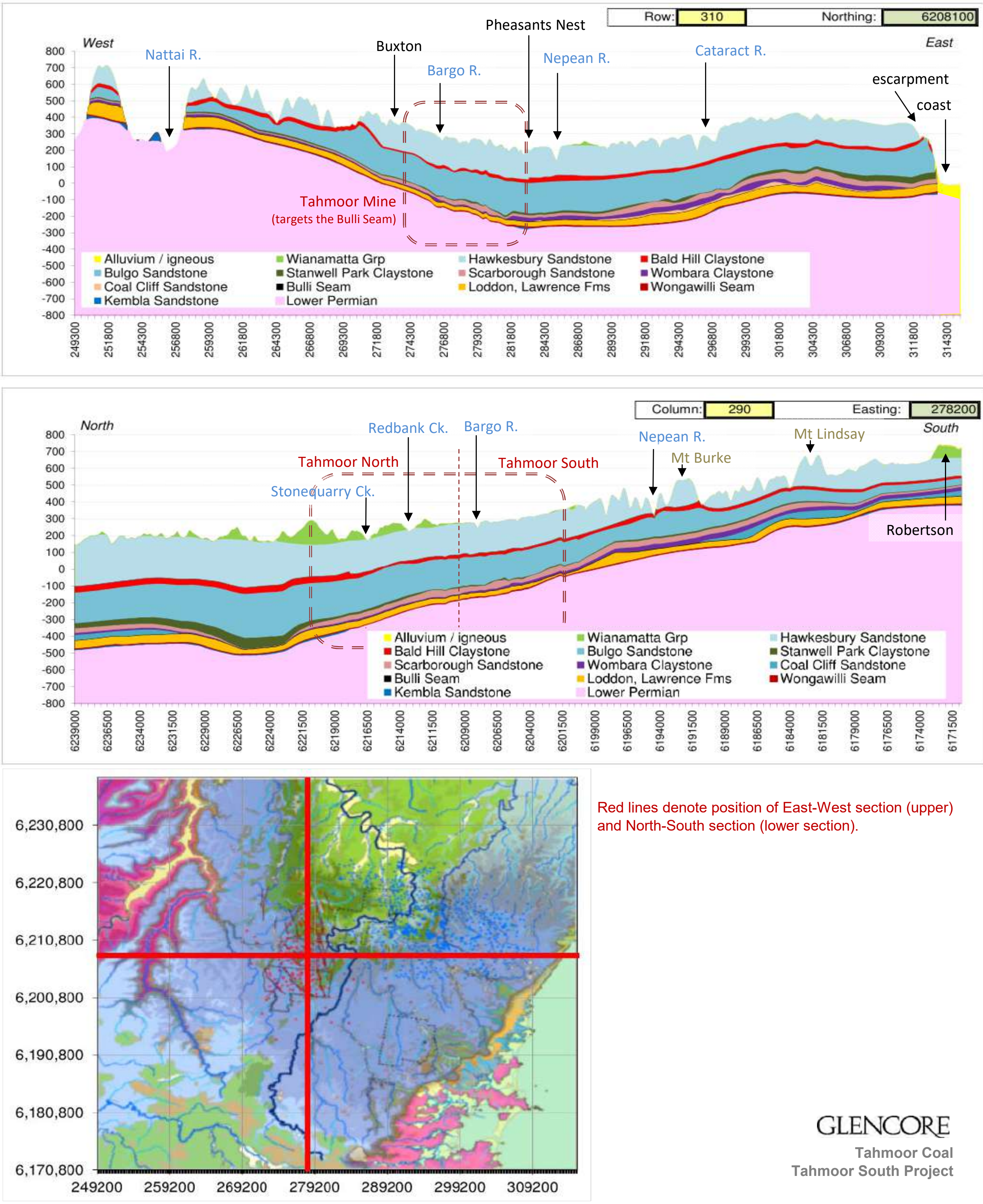


T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH013a_GeologicalStructure.mxd

DrawingNo: TAH-004 | Rev: B | Created by: B. White | Date: 07/09/2018

HydroSimulations

**Geological structure**




Red lines denote position of East-West section (upper) and North-South section (lower section).

GLENCORE

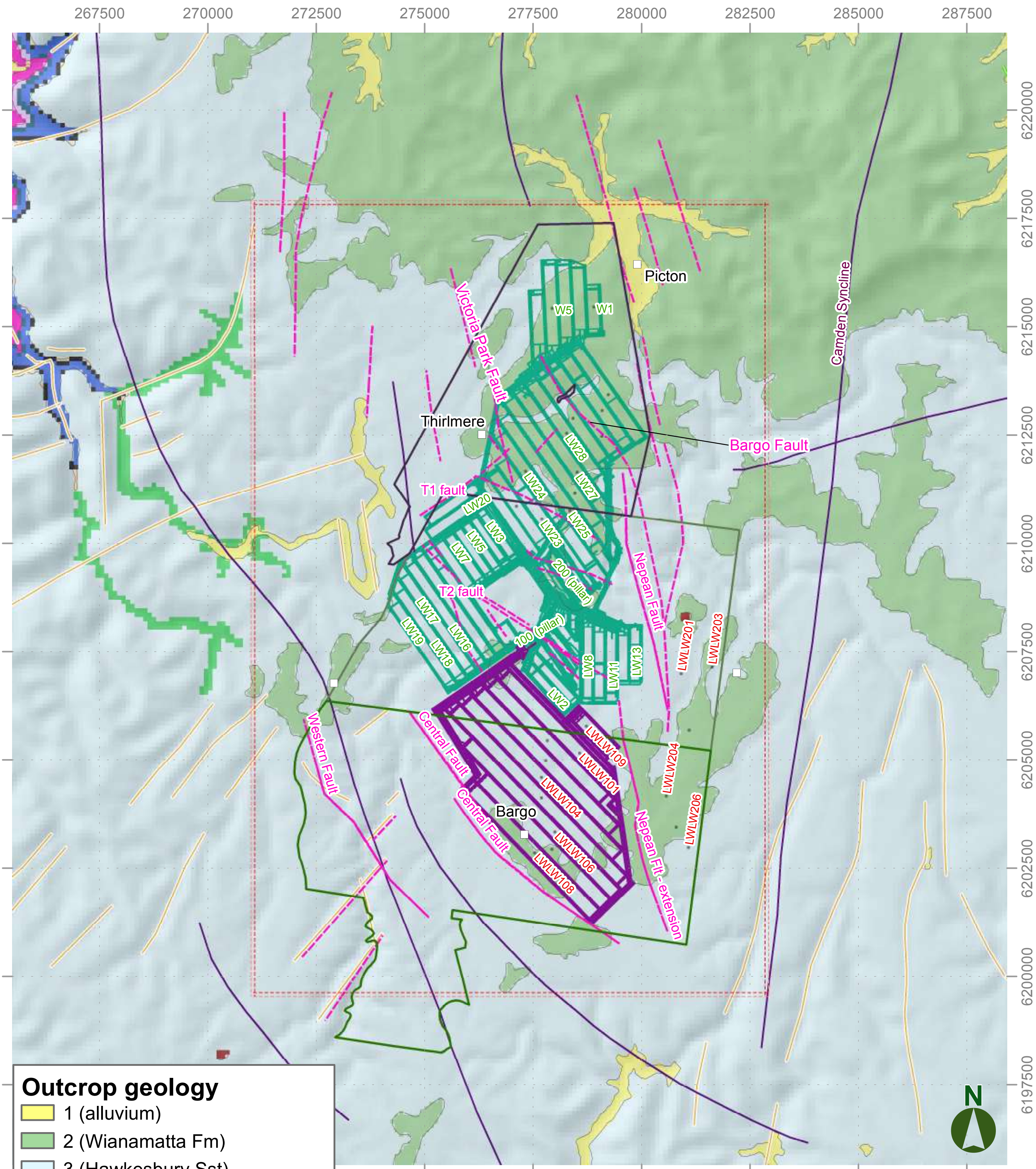
Tahmoor Coal

Tahmoor South Project

E:\HYDROSIM\TAHMOOR\Tech\Geology\GeolModel\[TahmoorSouth_2013_Geological_Cross-SectionCheck_V3.xlsm]Xsection_report

HydroSimulations

**Cross-sections through regional geological model** **Figure 3-10**




## Outcrop geology

- 1 (alluvium)
- 2 (Wianamatta Fm)
- 3 (Hawkesbury Sst)
- 4 (Bald Hill ClSt)
- 10 (Illawarra CM (Bulli Seam))
- 11 (Loddon, Lawrence Fms etc)
- 13 (Kembla Sst
- 15 (Shoalhaven Grp + older)

*Complete outcrop geology legend shown on Figure 3.7*

*'Southern CF' data from Southern Coalfield GIS data. (Moffit, 1999)*

- Faults (locally mapped)
- SouthernCF Structure
- SouthernCF Fault
- SouthernCF Fold
- SouthernCF Dyke

**Tahmoor Coal titles**

- MLs 1308, 1376, 1539
- CCL 716
- CCL 747
- Local geol model extent

- Tahmoor South
- Tahmoor North

Scale: 123,833
GDA 1994 MGA Zone 56

0 0.5 1 2 3 4 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH015a_SiteGeology.mxd

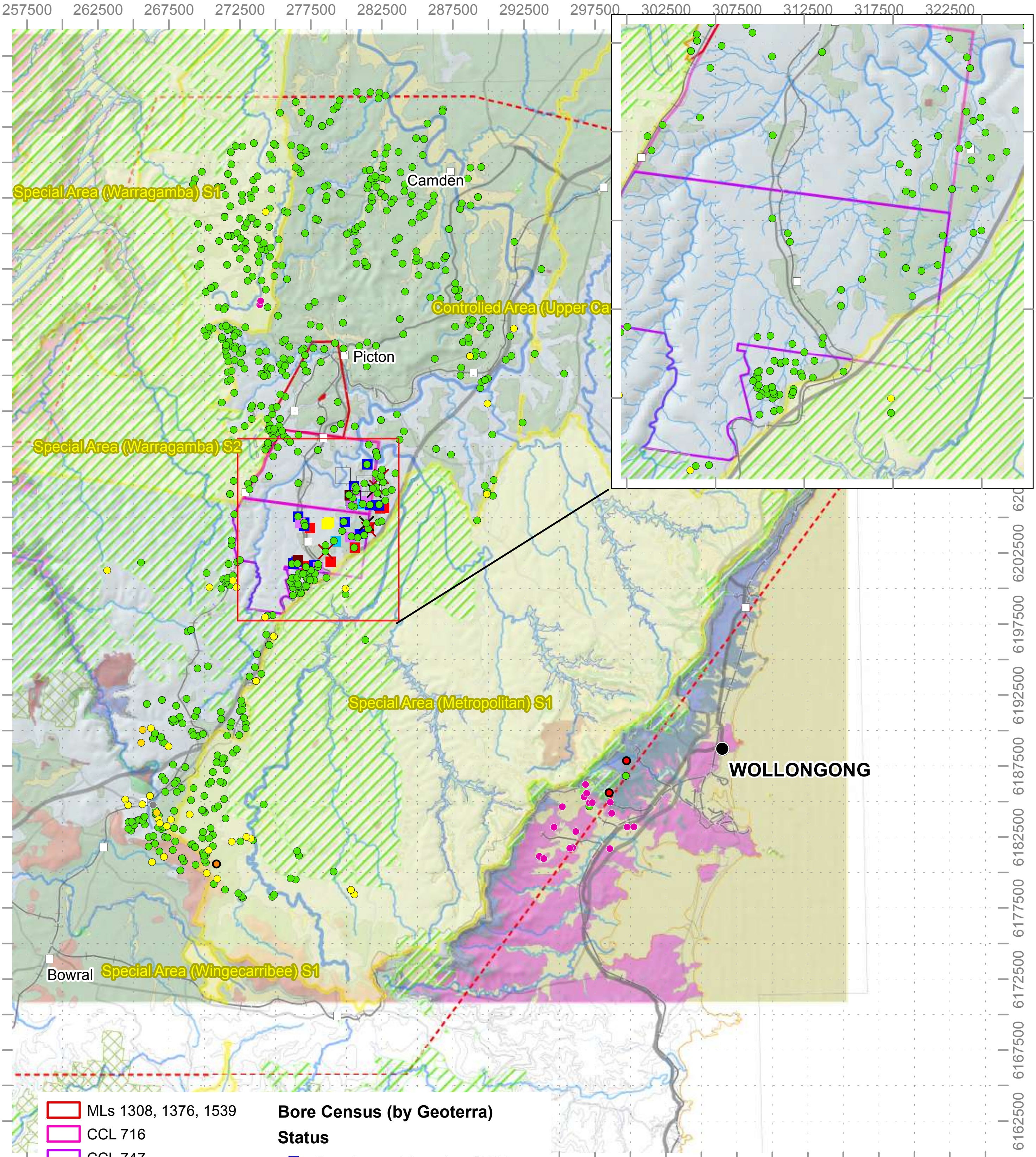
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HYDROSIMULATIONS

**Tahmoor Coal**
**Tahmoor South Project**

# Figure 3-11

**Site geology**




MLs 1308, 1376, 1539
CCL 716
CCL 747
NSW_coal_titles
Southern Coalfield (approx)
SCA Special Area (2013)
National Park

**Bore Census (by Geoterra)**

**Status**

- Bore in use (chem / no SWL)
- Bore in use (chem / swl available)
- Piezometer
- Bore present (swl / chem n/a)
- Bore not used
- Bore not used / no current access
- No bore on site
- No contact made
- Site access rejected

**Groundwater extractions**

- Shallow / HBSS
- Bulgo Sst
- Scarborough Sst
- Illawarra Coal Measures / Bulli Coal
- Illawarra Coal Measures / Loddon Sst
- Illawarra Coal Measures / Kembla Sst
- Shoalhaven Grp?

N

Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH016a_GroundwaterUsers_A4P.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. Whtite | Date: 07/09/2018

HydroSimulations

Tahmoor Coal
Tahmoor South Project

**Figure 3-12**

**Groundwater extraction bores and Tahmoor bore census results**

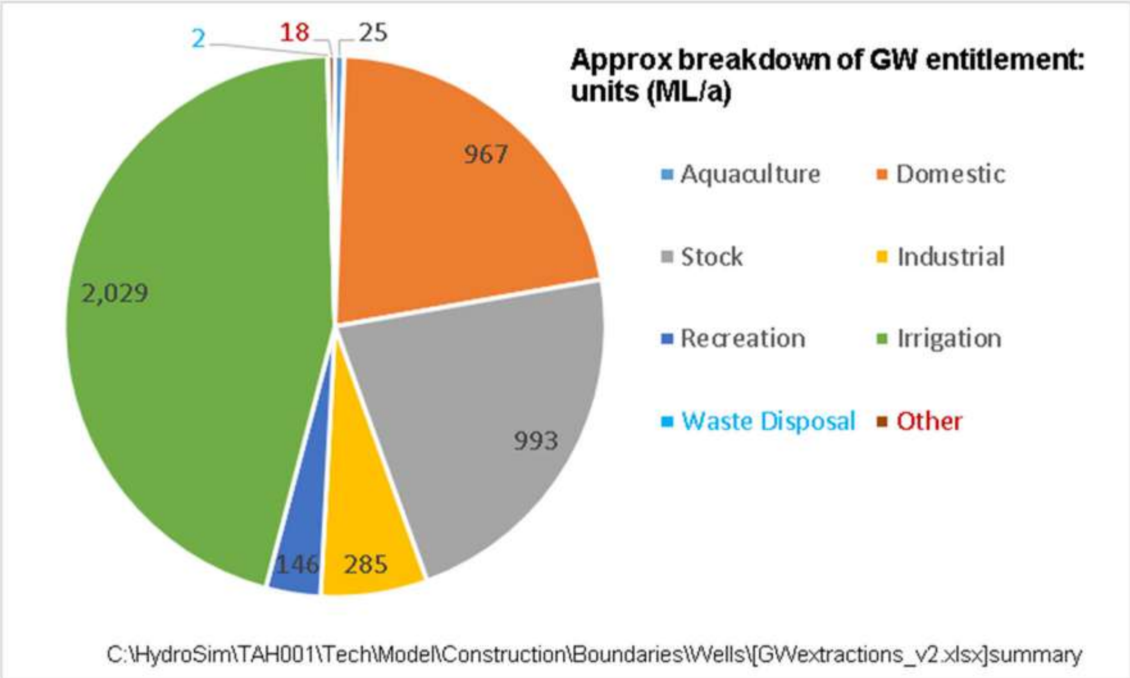
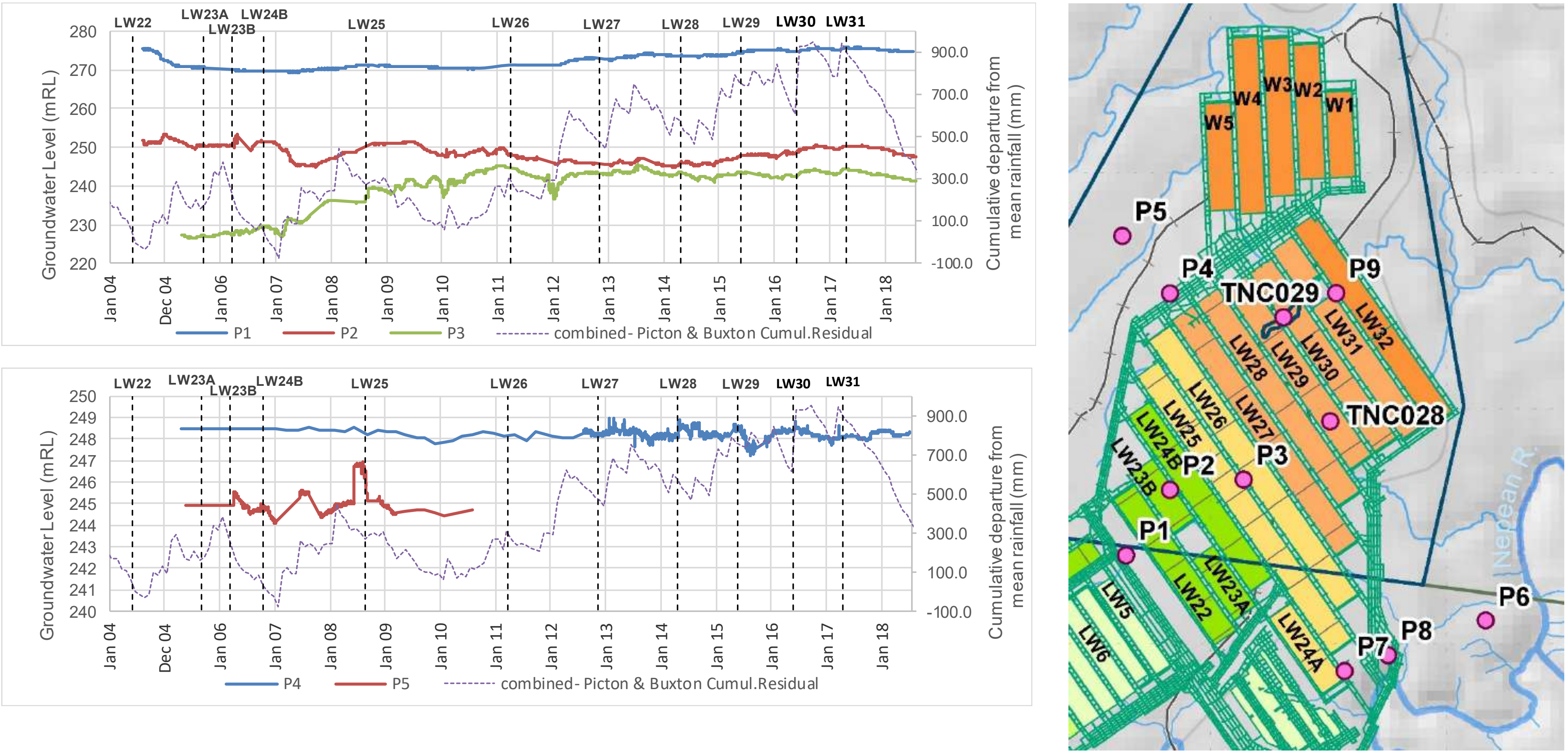
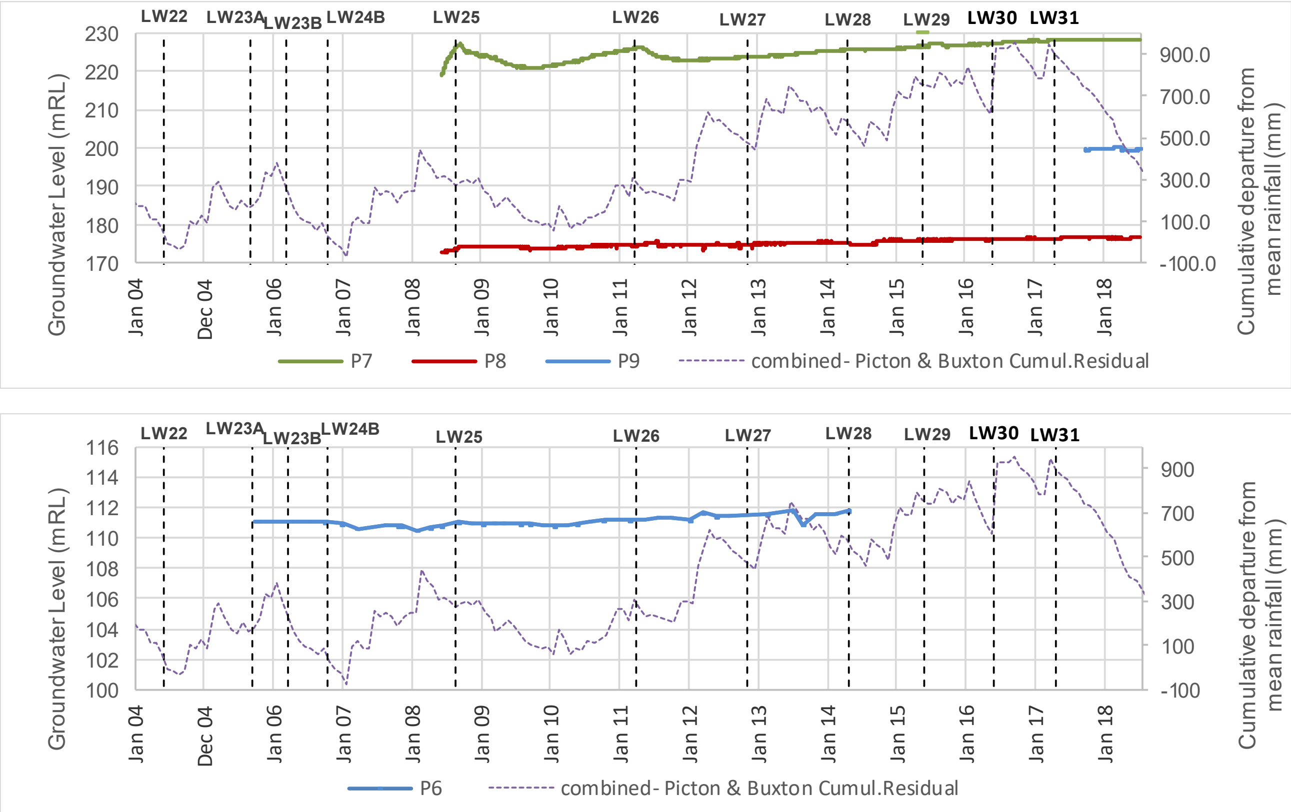


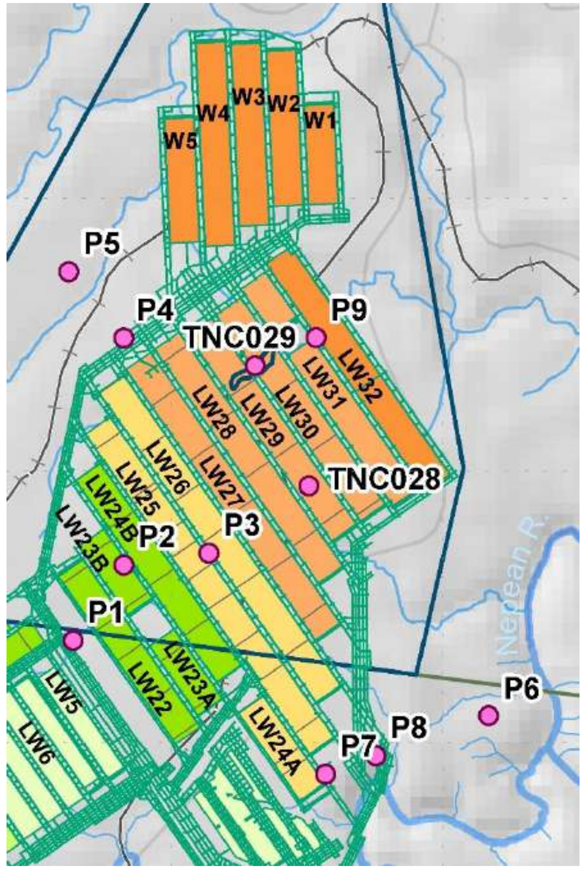

**Figure 3-13 Breakdown of groundwater entitlement and use**

(data from 2014)



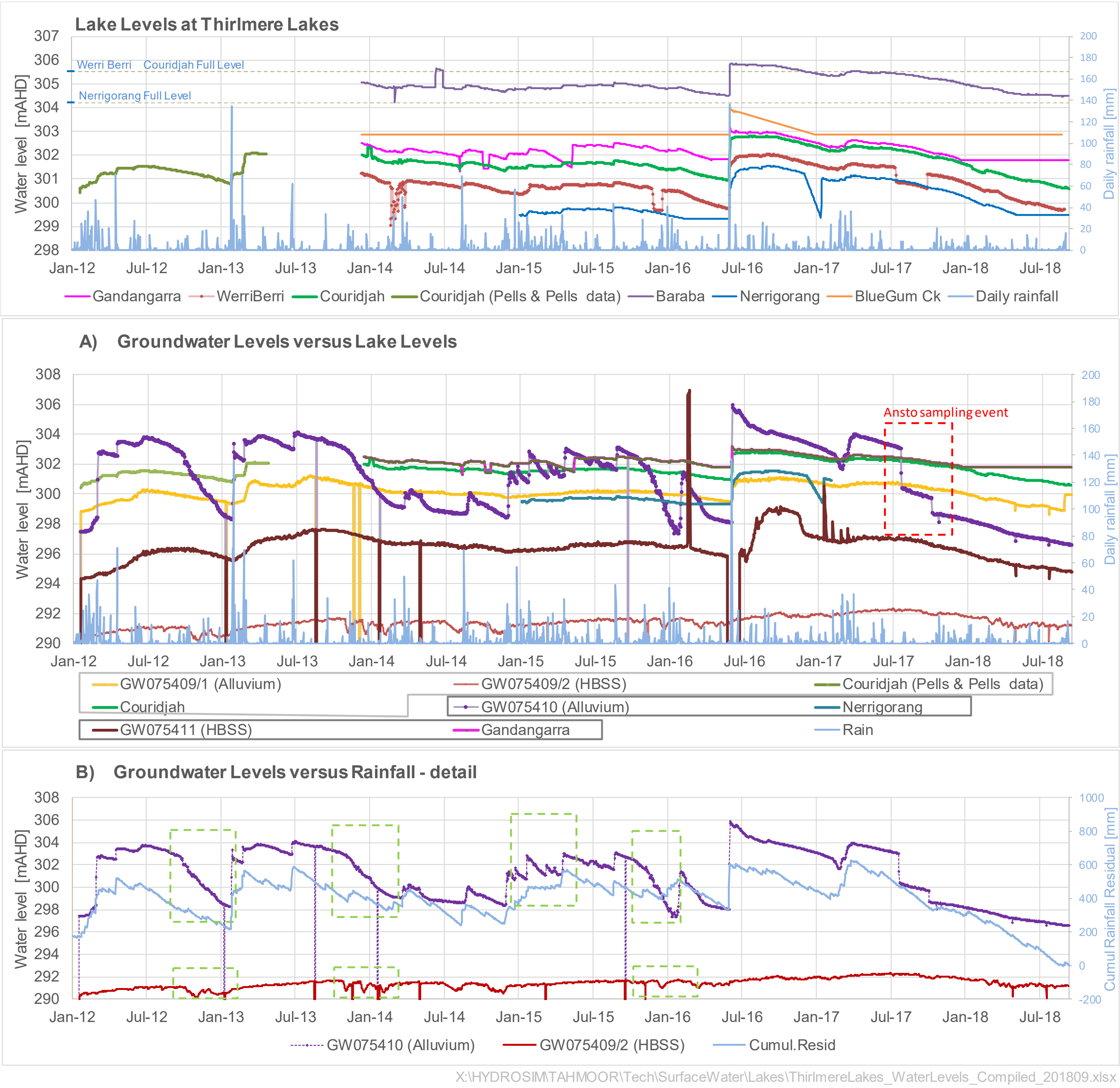

## Figure 3-14 Water level trends – shallow aquifer (P1-P5)



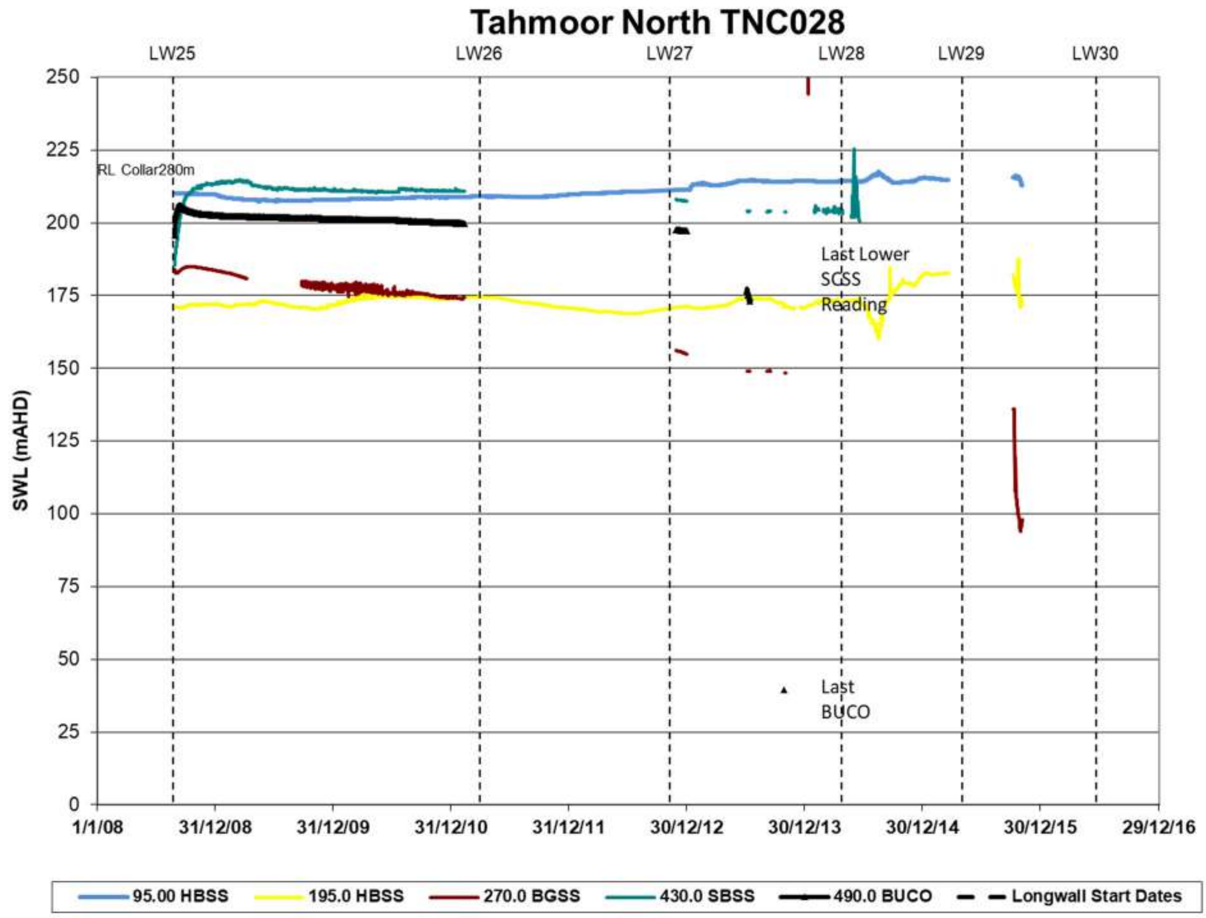



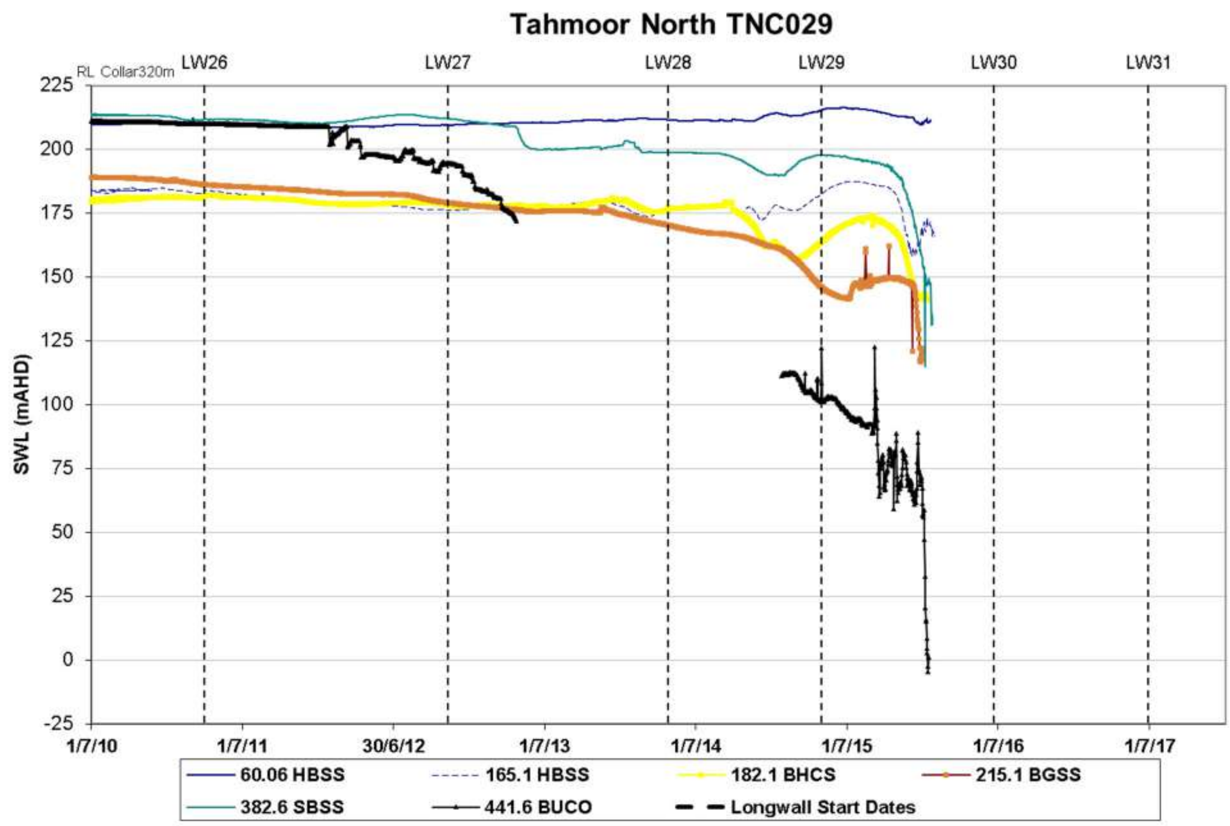

T:\TAHMOOR\Tech\Groundw ater Level\Shallow bores P series\[Tahmoor shallow bores (P1-P9) 201809.xlsx]graphs

## Figure 3-15 Water level trends – shallow aquifer (P6-P9)

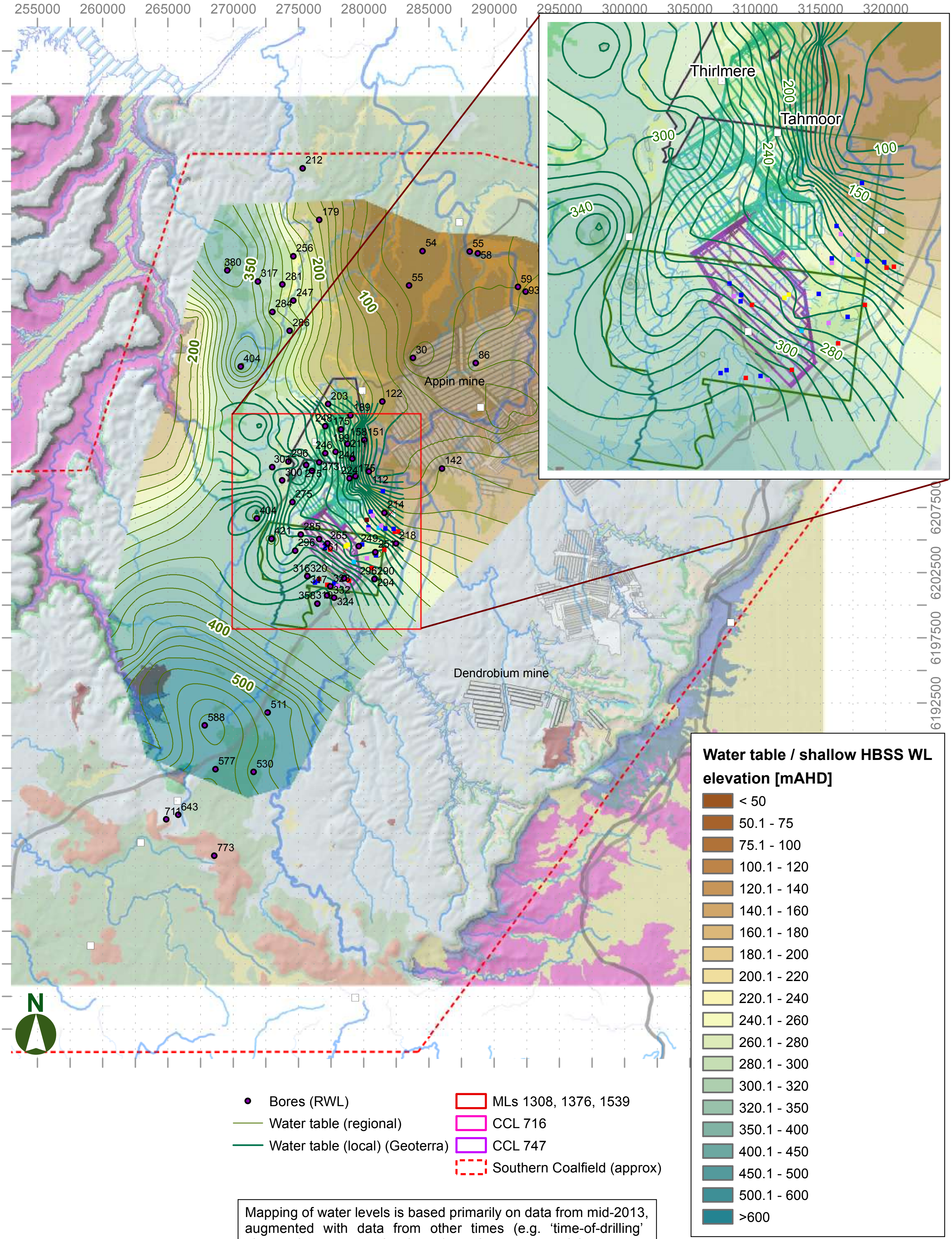



## Figure 3-16 Thirlmere Lakes: lake and groundwater levels




## Figure 3-17 Water level trends – deeper units




Mapping of water levels is based primarily on data from mid-2013, augmented with data from other times (e.g. 'time-of-drilling' observations at nearby bores) to increase spatial coverage.

Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH017a_WaterTableHBSS_A4P.mxd

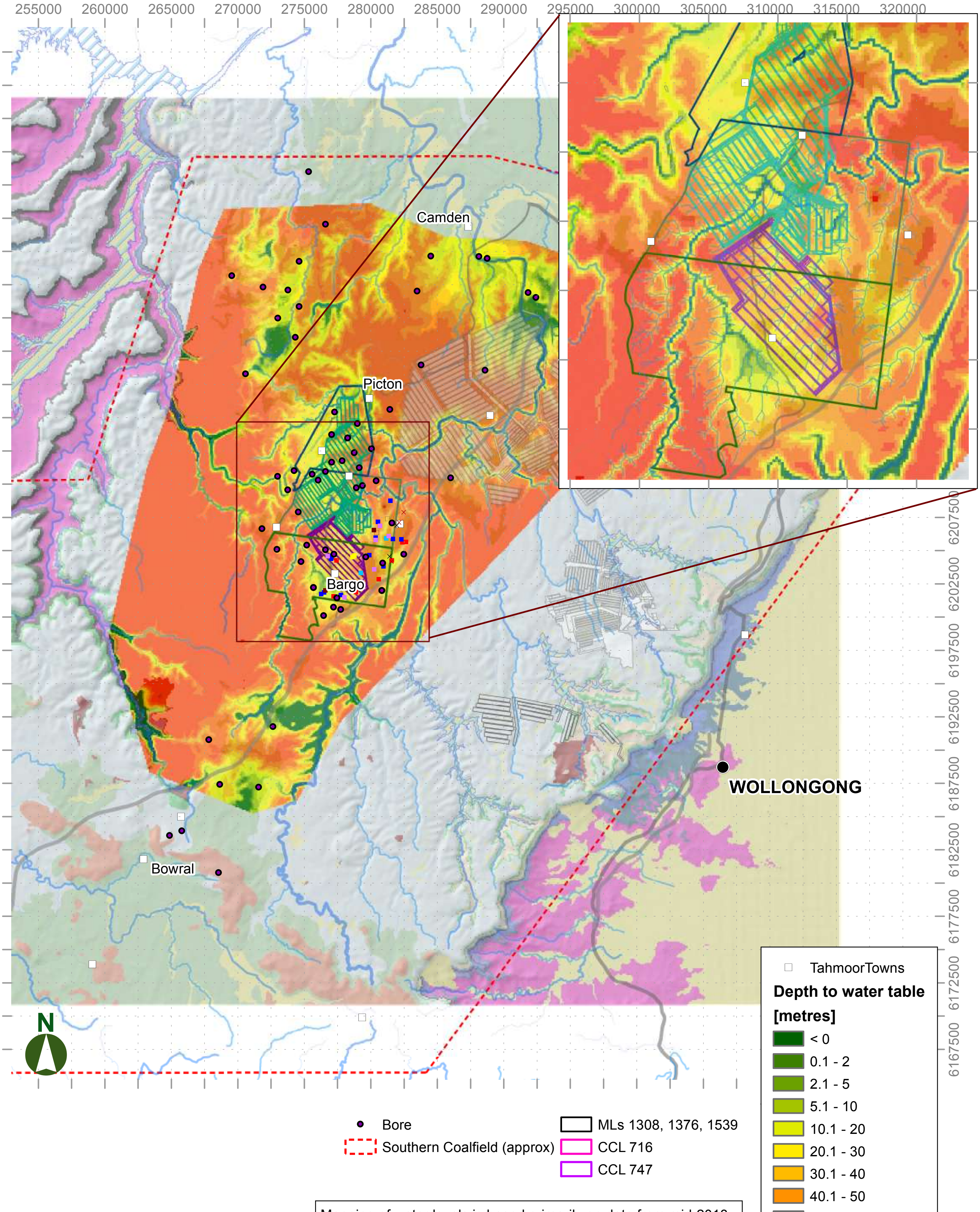
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

Tahmoor Coal
Tahmoor South Project

**Figure 3-18**

**Interpreted water table / Hawkesbury Sandstone water levels**





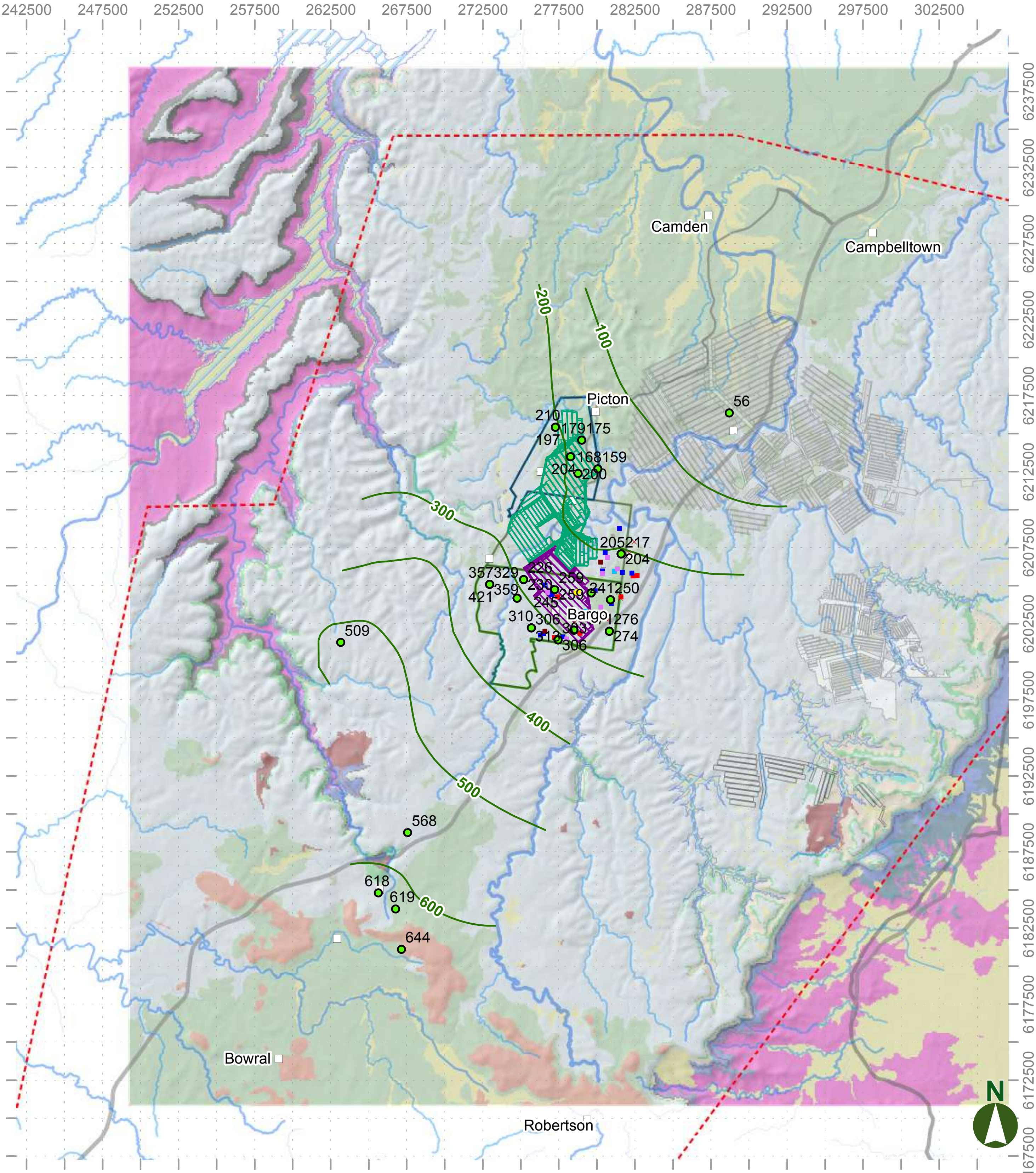

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH018a_UnsaturatedDepth_A4P.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

**Tahmoor Coal**
**Tahmoor South Project**

**Figure 3-19**
**Interpreted depth to water table (Hawkesbury Sandstone water levels)**




- Bore (Bulgo Sst RWL)
- Tahmoor North
- Tahmoor South
- Bulgo Sst water level
- Southern Coalfield (approx)
- MLs 1308, 1376, 1539
- CCL 716
- CCL 747
- MLs 1308, 1376, 1539
- CCL 716
- CCL 747

Mapping of water levels is based primarily on data from mid-2013, augmented with data from other times (e.g. 'time-of-drilling' observations at nearby bores) to increase spatial coverage.

Scale: 352,221
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH019a_BulgoSstWLs_A4P.mxd

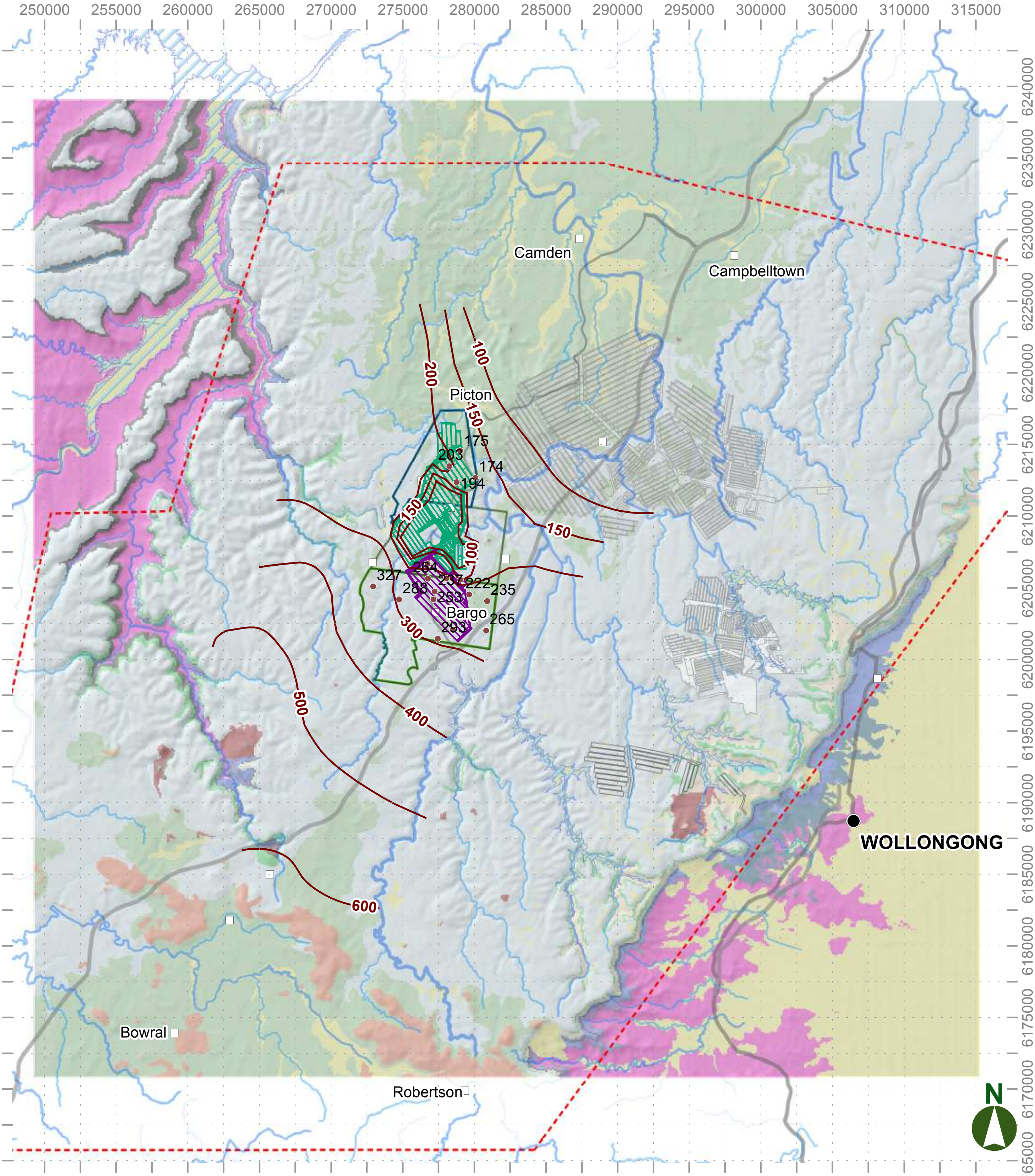
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

Tahmoor Coal
Tahmoor South Project

**Figure 3-20**

**Water levels in the Bulgo Sandstone**




Bore (Bulli Seam RWL)
Tahmoor South
Tahmoor North
Bulli seam water level
Southern Coalfield (approx)
MLs 1308, 1376, 1539
CCL 716
CCL 747

Mapping of water levels is based primarily on data from mid-2013, augmented with data from other times (e.g. 'time-of-drilling' observations at nearby bores) to increase spatial coverage.

Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH020a_BulliSeamWLs_A4P.mxd

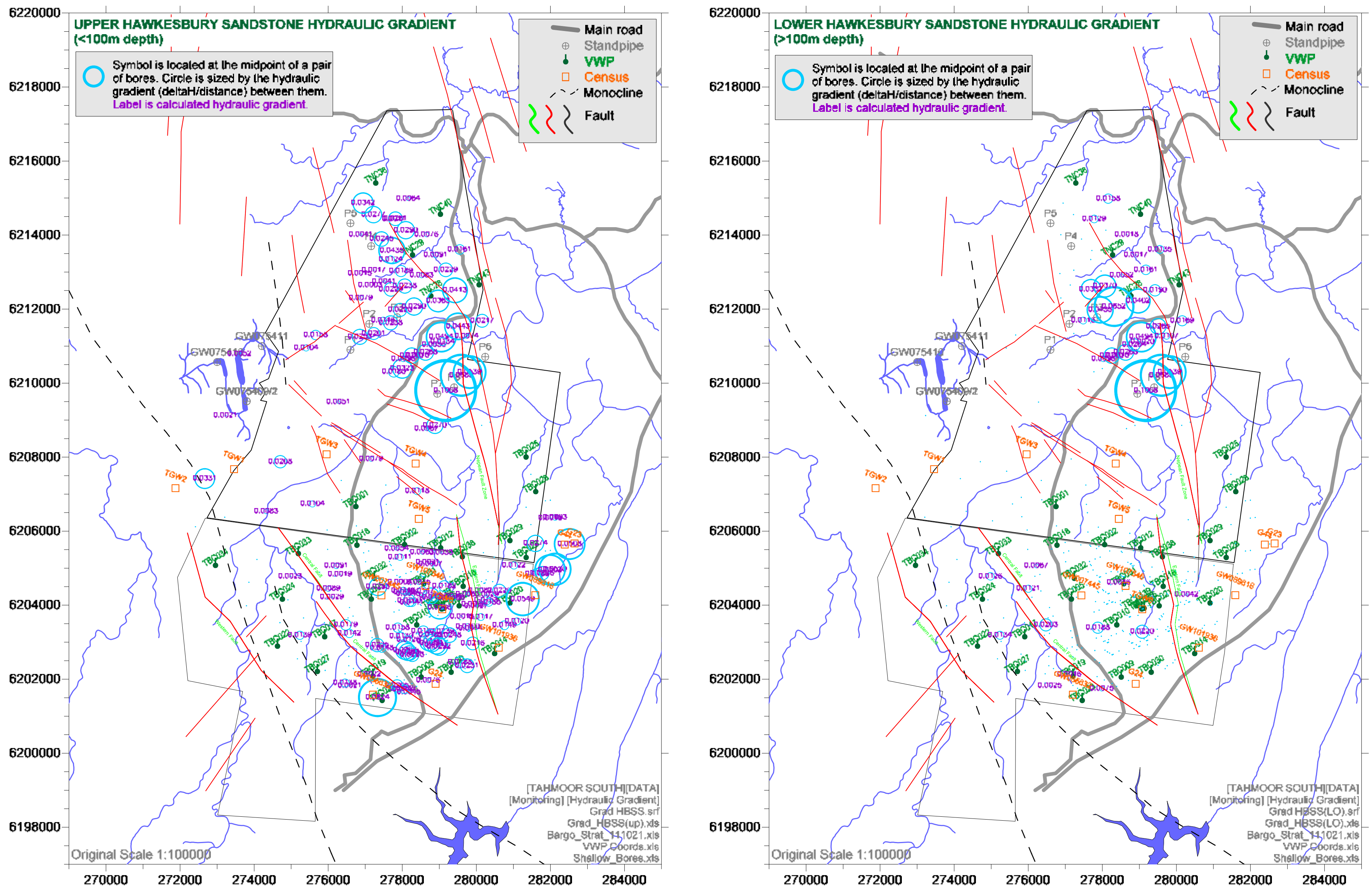
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HYDROSIMULATIONS

**Tahmoor Coal**
**Tahmoor South Project**

## Figure 3-21

**Water levels in the Bulli Coal Seam**




## Figure 3-22 Hydraulic gradient analysis: Hawkesbury Sandstone upper and lower

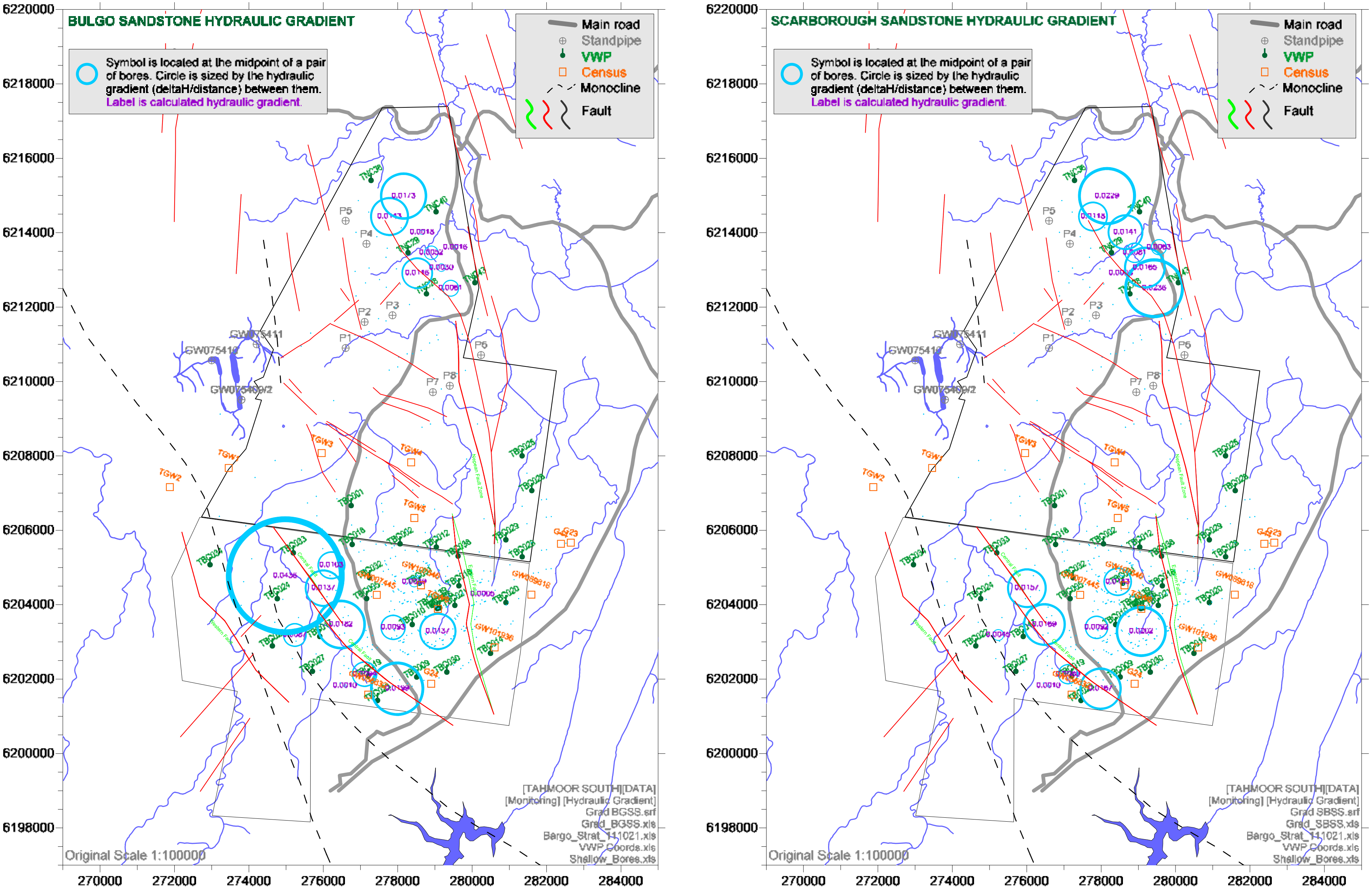



**Figure 3-23 Hydraulic gradient analysis: Bulgo and Scarborough Sandstones**

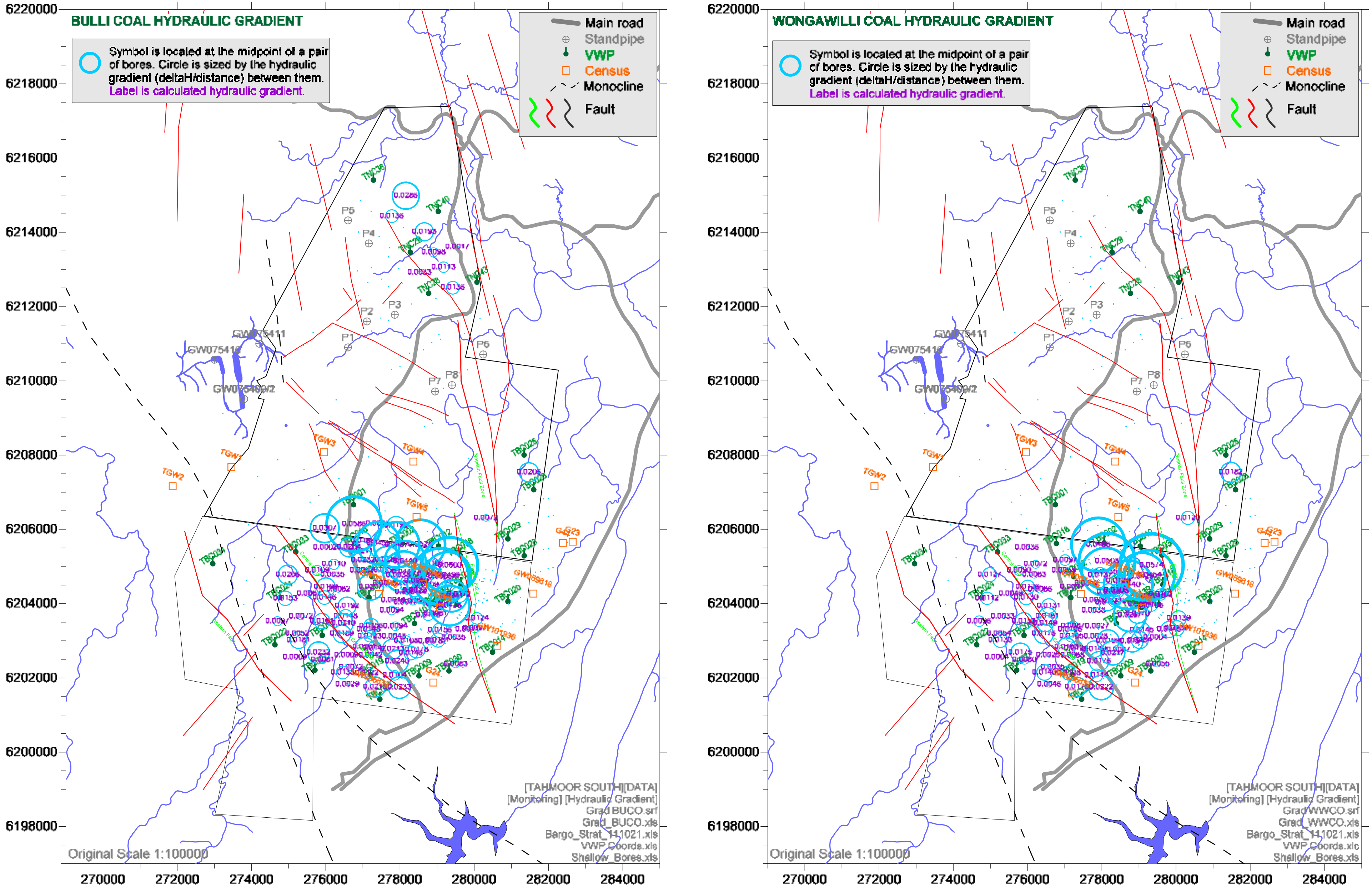



**Figure 3-24 Hydraulic gradient analysis: Bulli and Wongawilli coal seams**

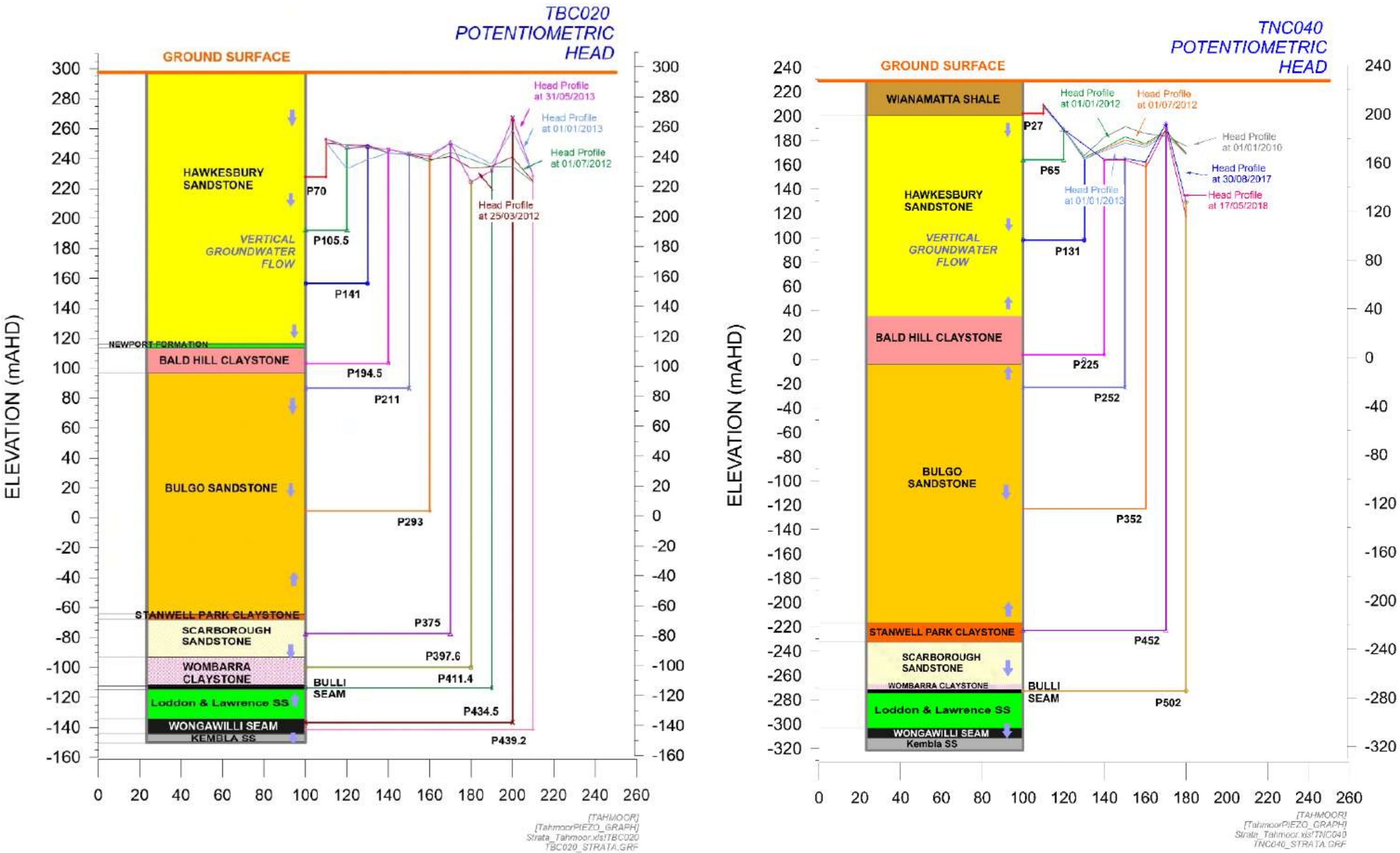
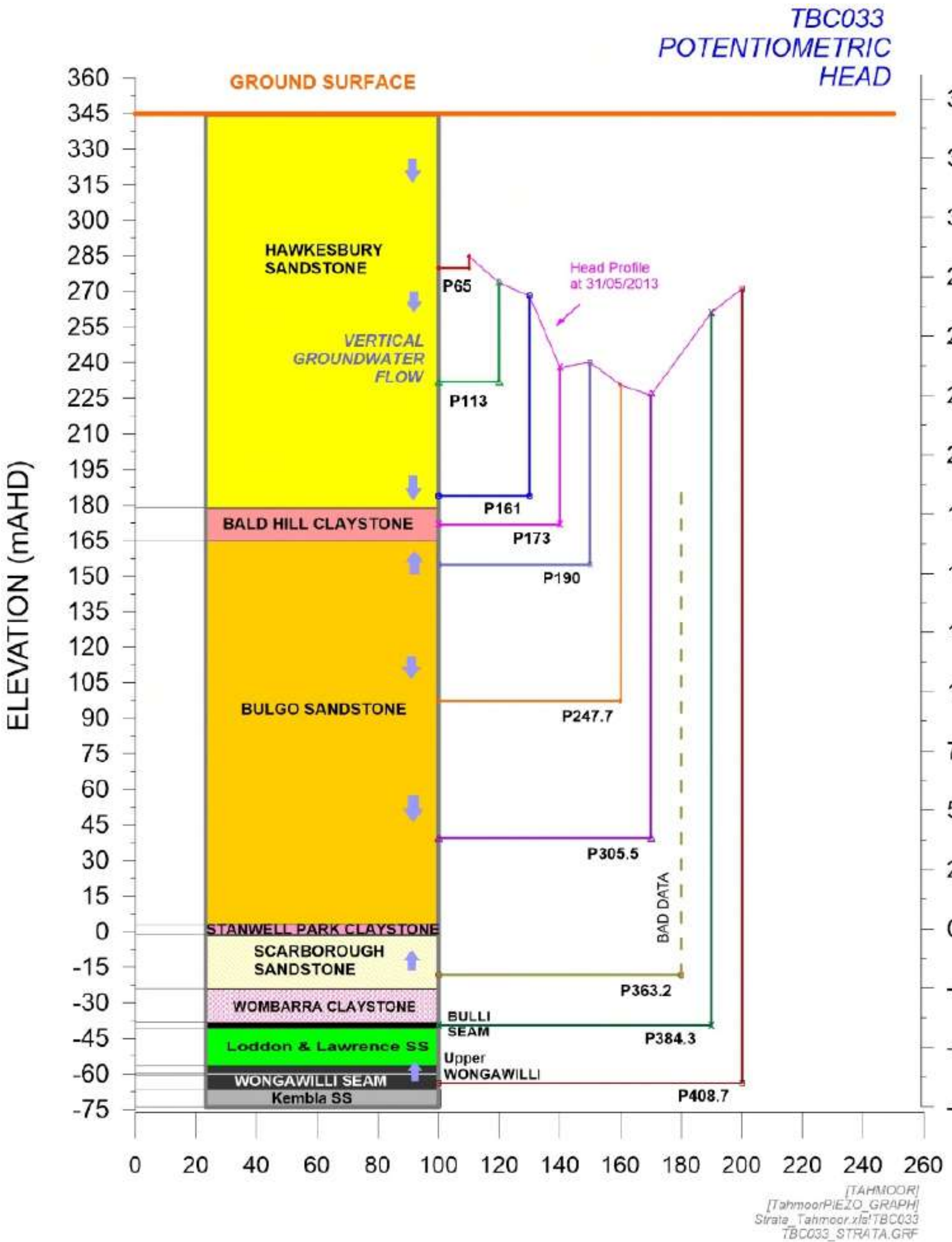



**Figure 3-25 Vertical head profiles: TBC020 and TNC040**



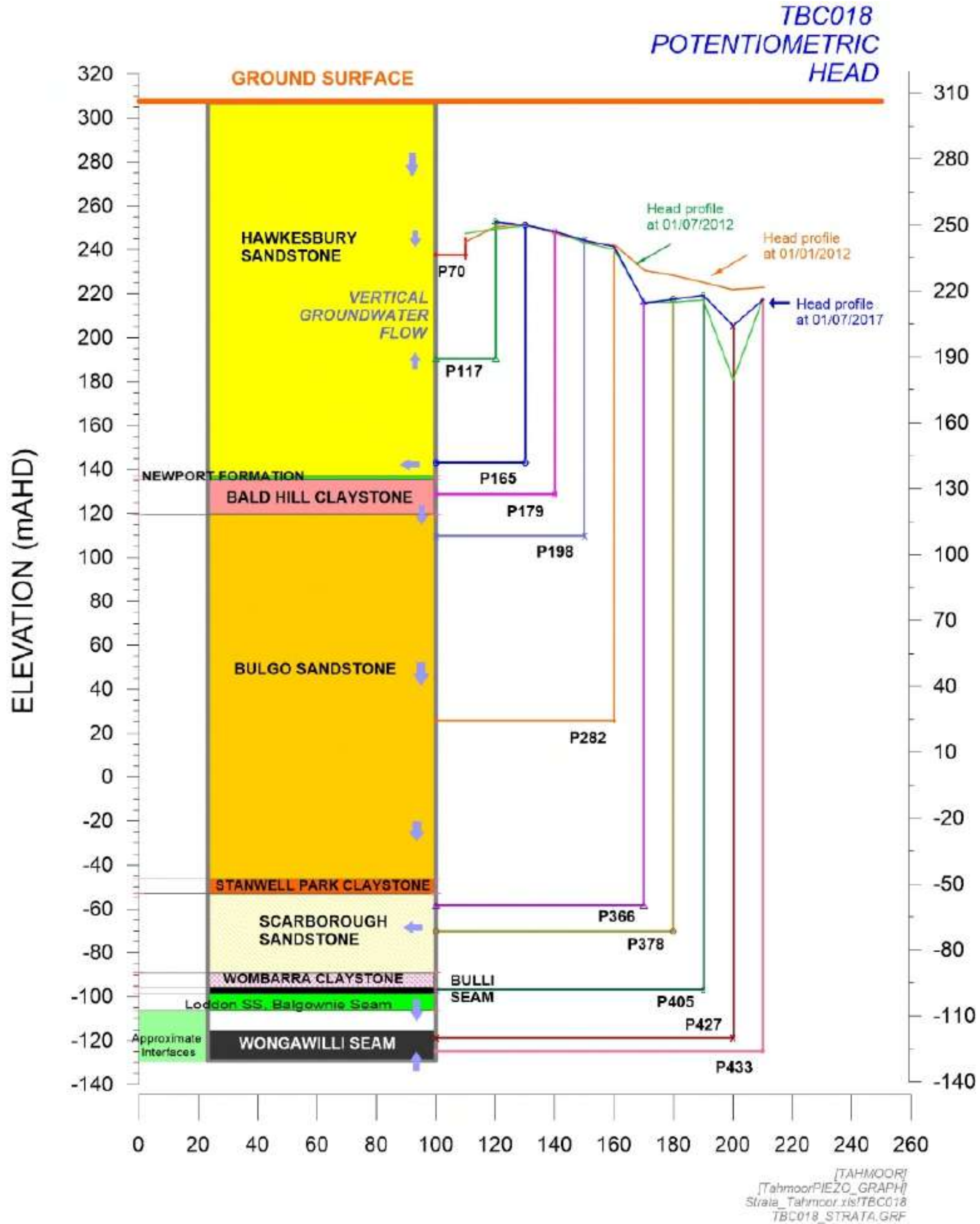
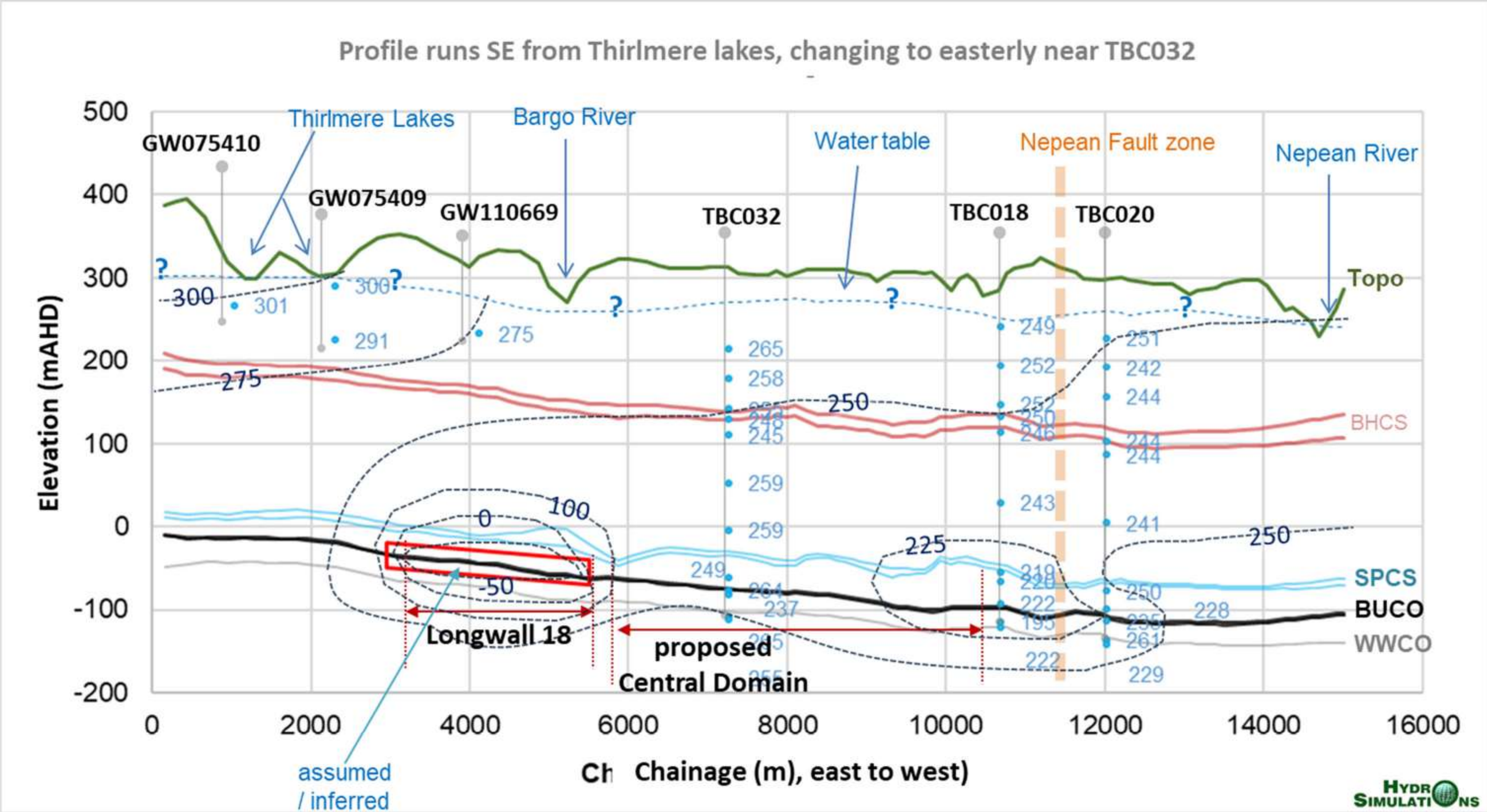
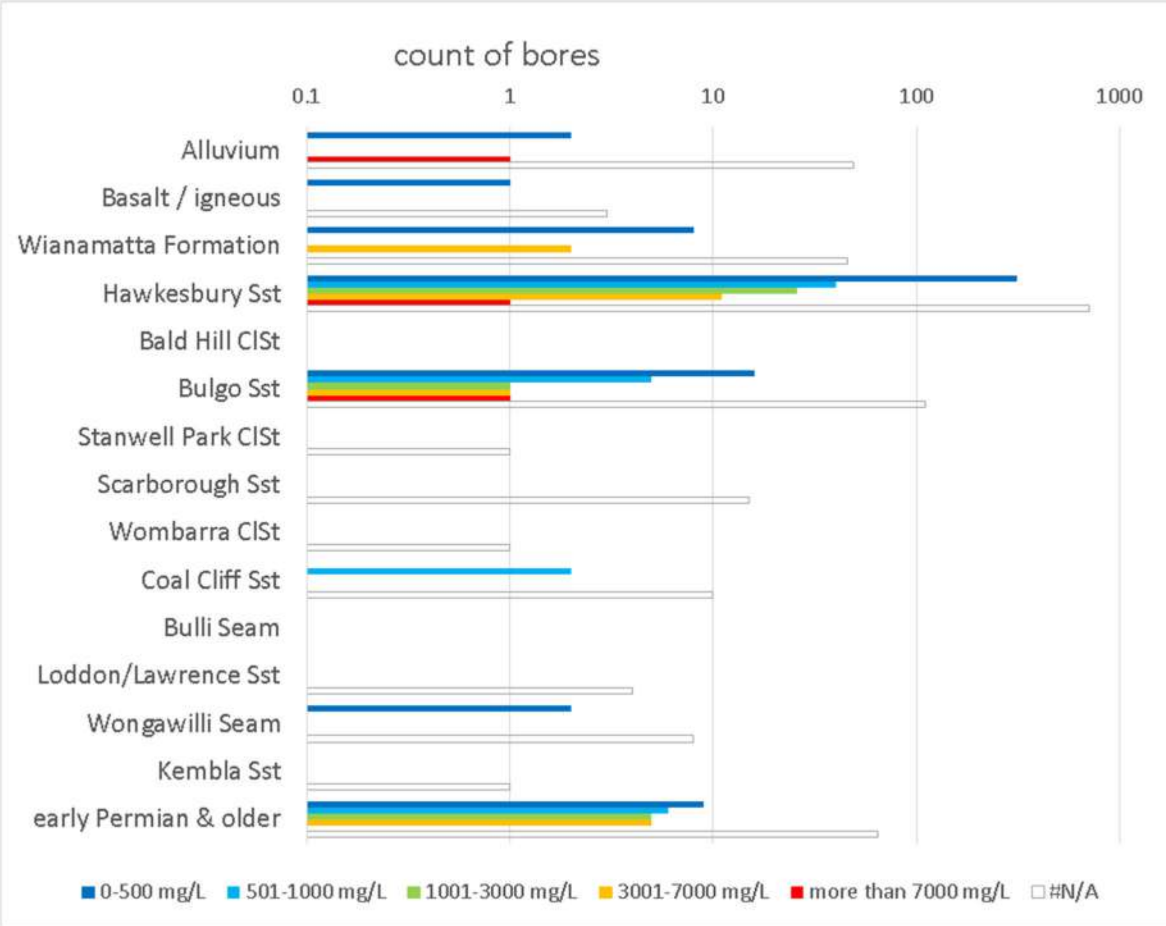




**Figure 3-26 Vertical head profiles: TBC033 and TBC018**




C:\HydroSim\TAH001\Tech\WaterLevels\WaterLevel_Xsection\WaterLevel_X-section.pptx
and WaterLevel_Xsection_TahmoorSouthCentral.xlsx

**Figure 3-27 Hydraulic head profile through Tahmoor South**




C:\HydroSim\TAH001\Tech\GroundwaterUse\NSW_GroundwaterWorks_Bores.xlsx

**Figure 3-28 Summary of groundwater salinity data**

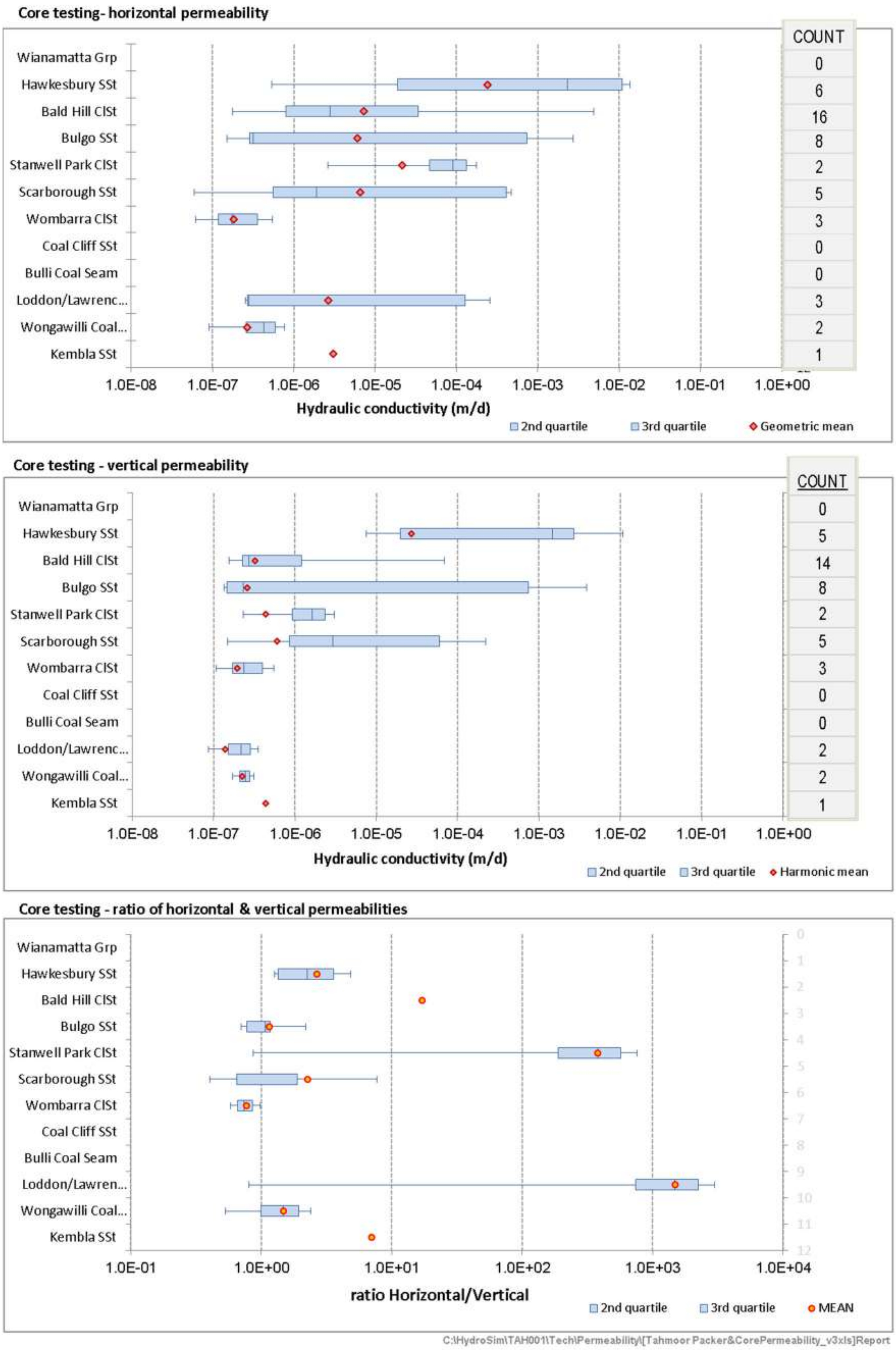
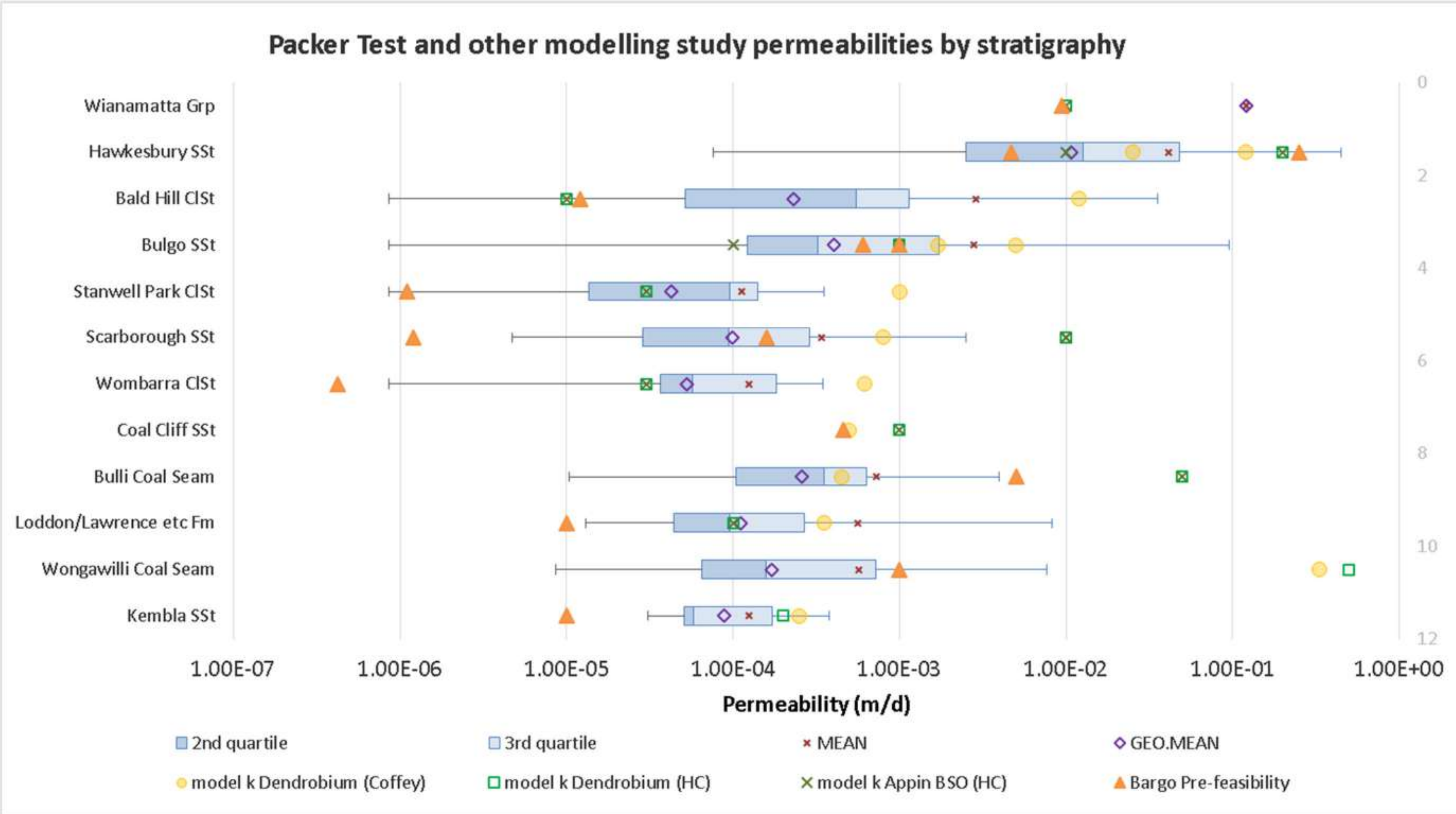



**Figure 3-29 Summary of Hydraulic Conductivity data from core testing**




C:\HydroSim\TAH001\Tech\Permeability\[Tahmoor Packer&CorePermeability_v2.xls]

**Figure 3-30 Summary of Hydraulic Conductivity data from packer testing and neighbouring modelling studies**

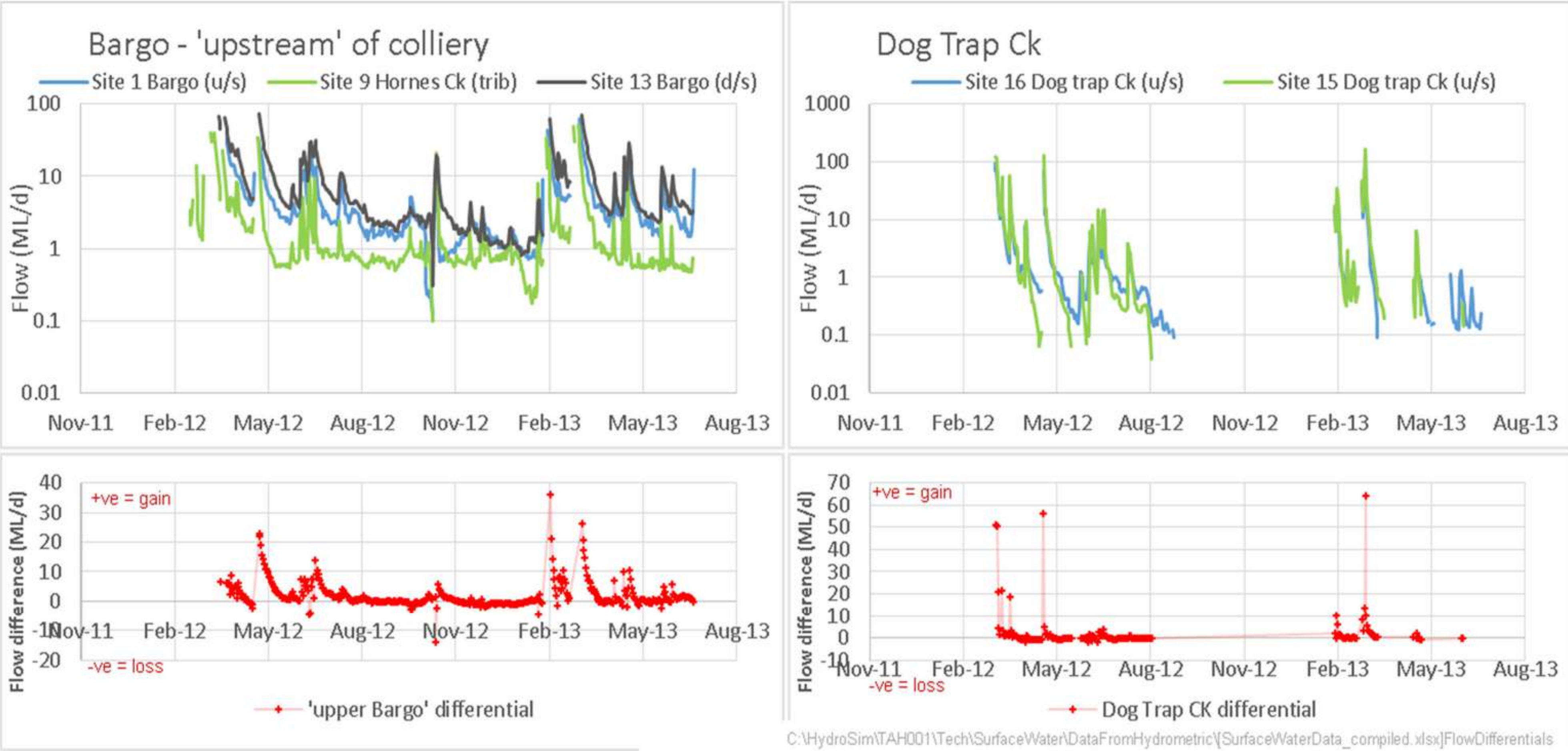
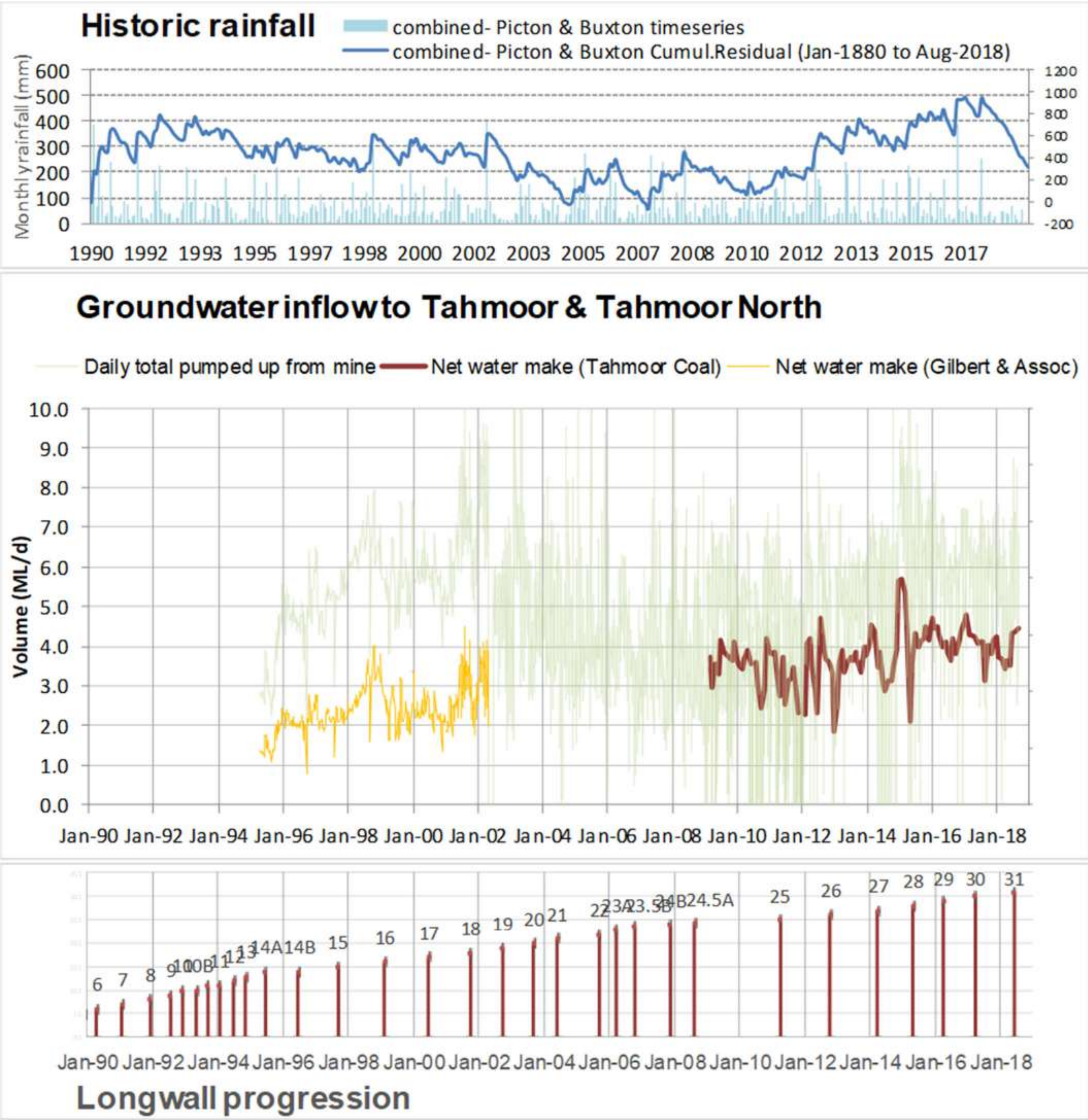


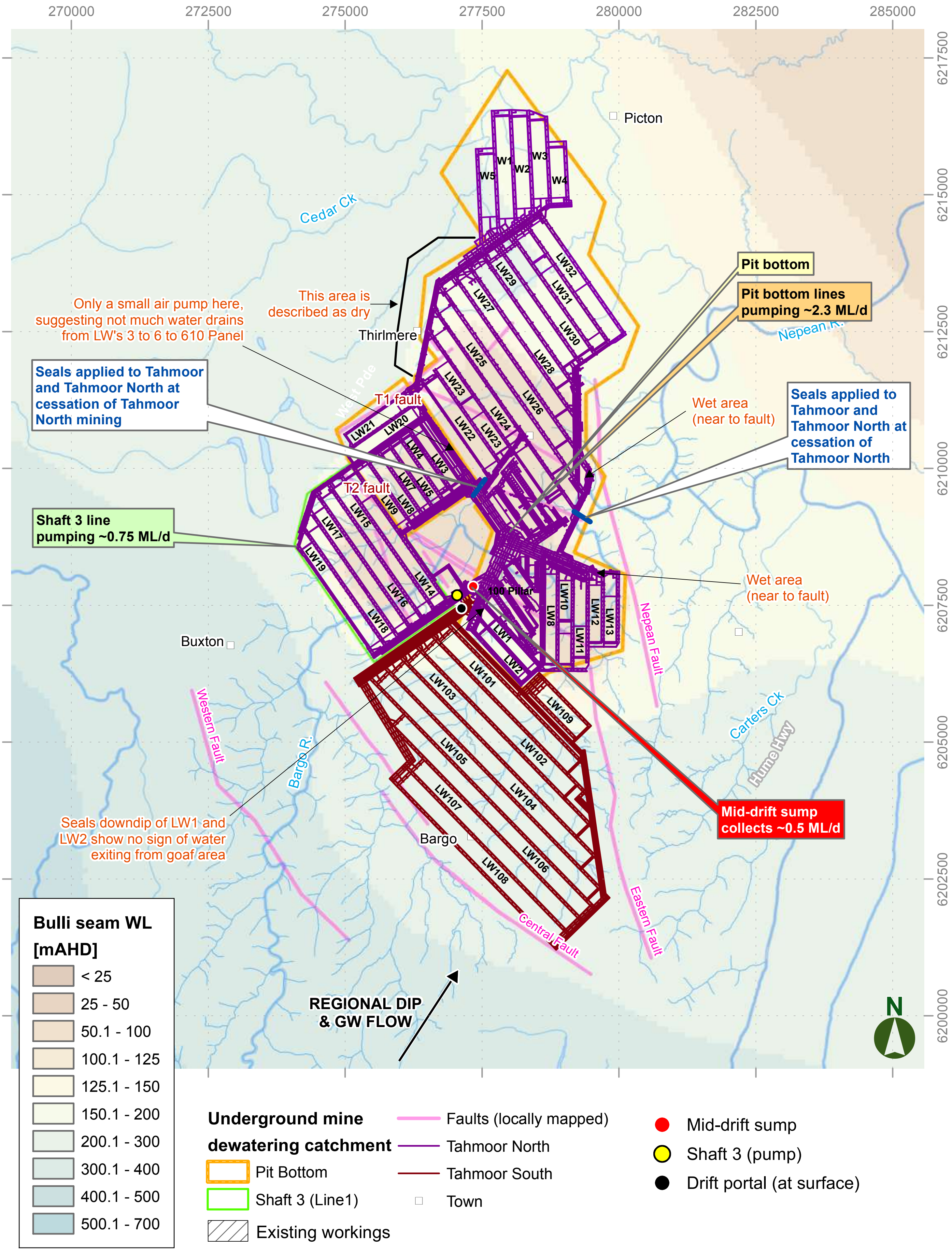

**Figure 3-31 Flow differentials along the Bargo River and Dog Trap Creek**

(refer to site locations on Figure 3-5)




T:\TAHMOOR\Tech\MineInflow\UpdateSeptOct18\[Tahmoor (Nth) Colliery Inflow_HS_Sept2017.xlsx]DewaterSummary_Glencore30Aug13

**Figure 3-32 Historical record of inflows at Tahmoor North**






T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH021a_MineInflows&Drainage_A4P.mxd

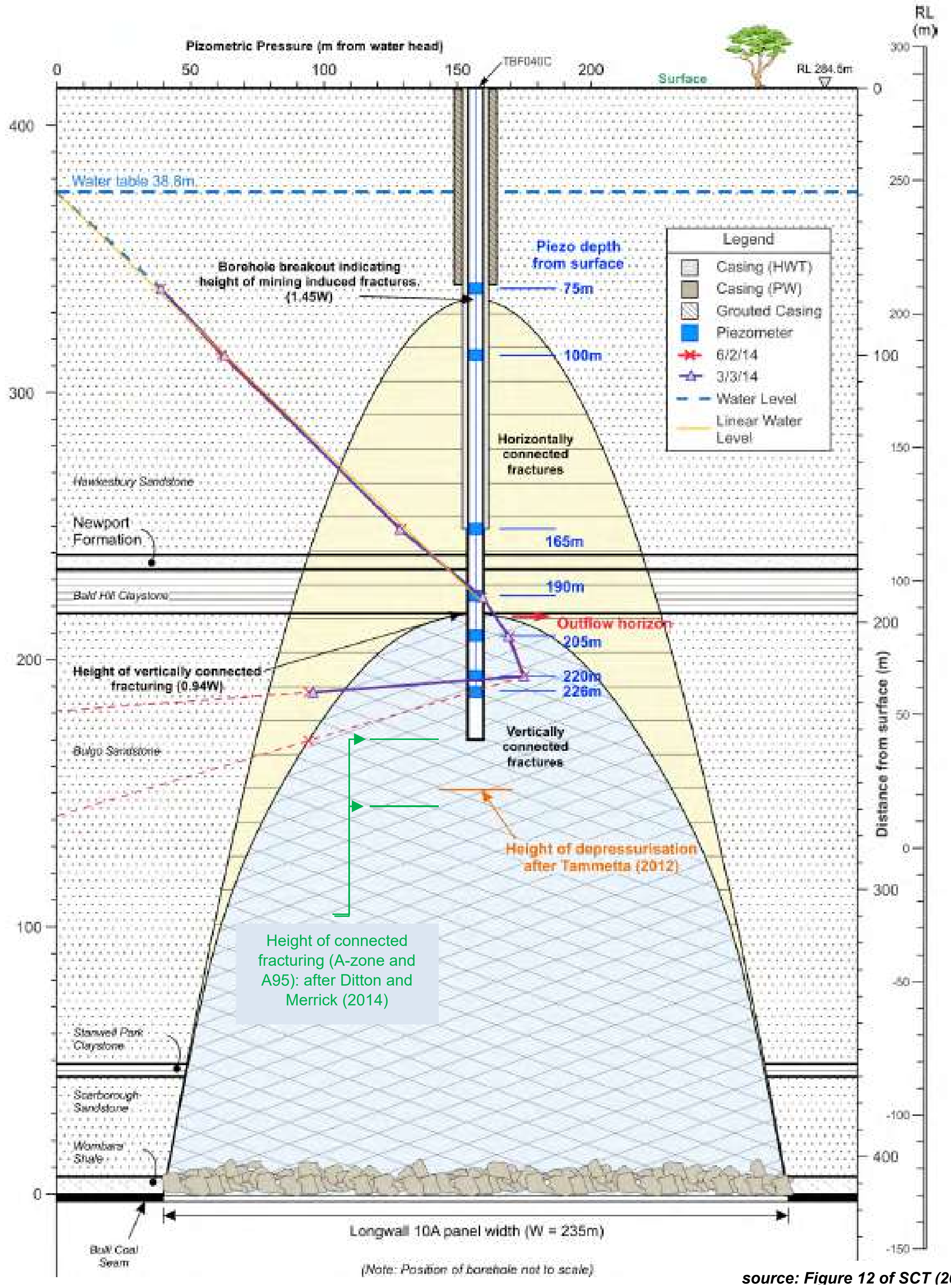
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 10/09/2018

HYDROSIMULATIONS

Tahmoor Coal
Tahmoor South Project

**Figure 3-33**

**Record of observations of inflow and drainage plan**




*source: Figure 12 of SCT (2014)*

## Figure 3-34 Profile with piezometric and geotechnical observations from TBF040

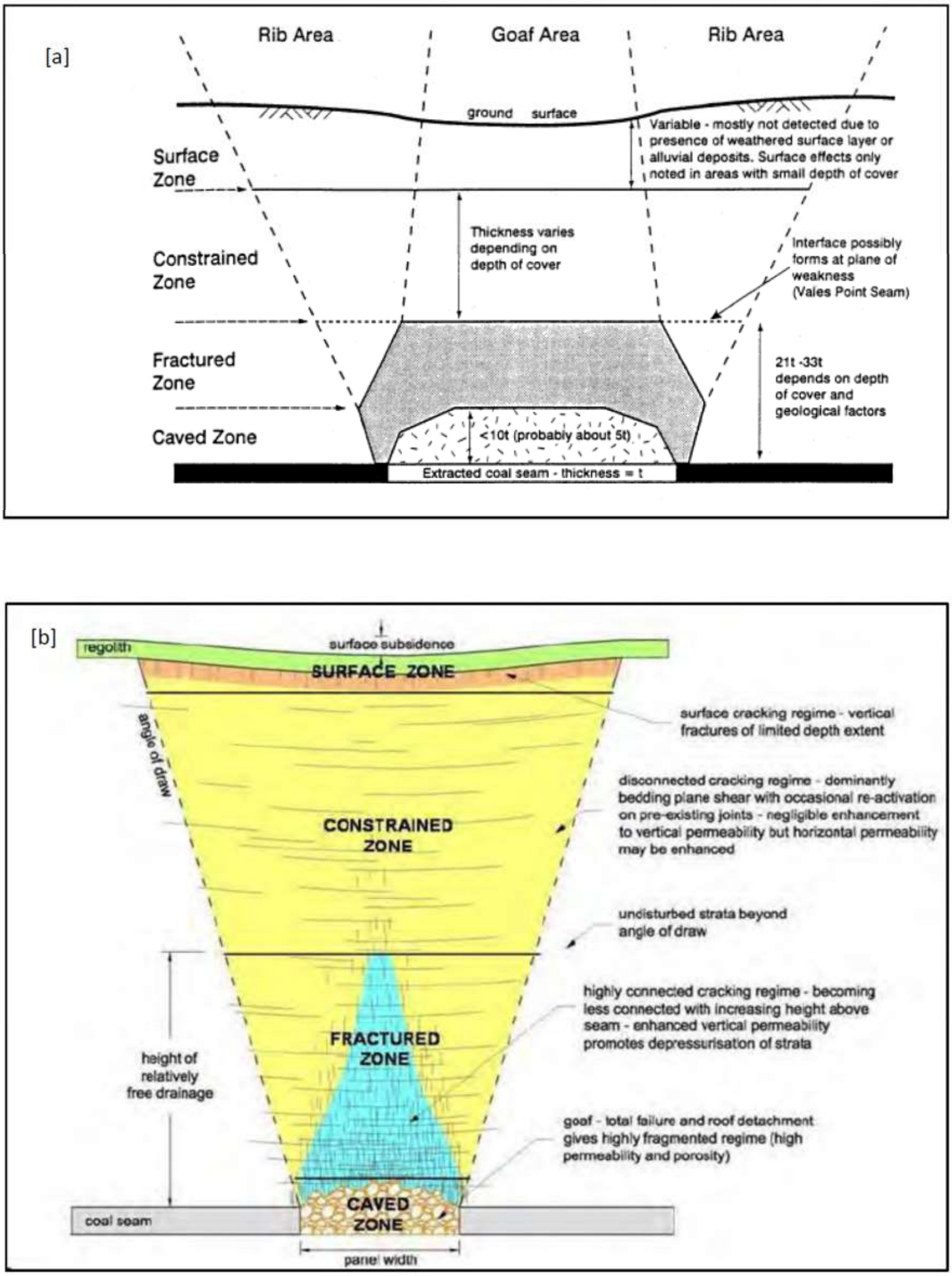
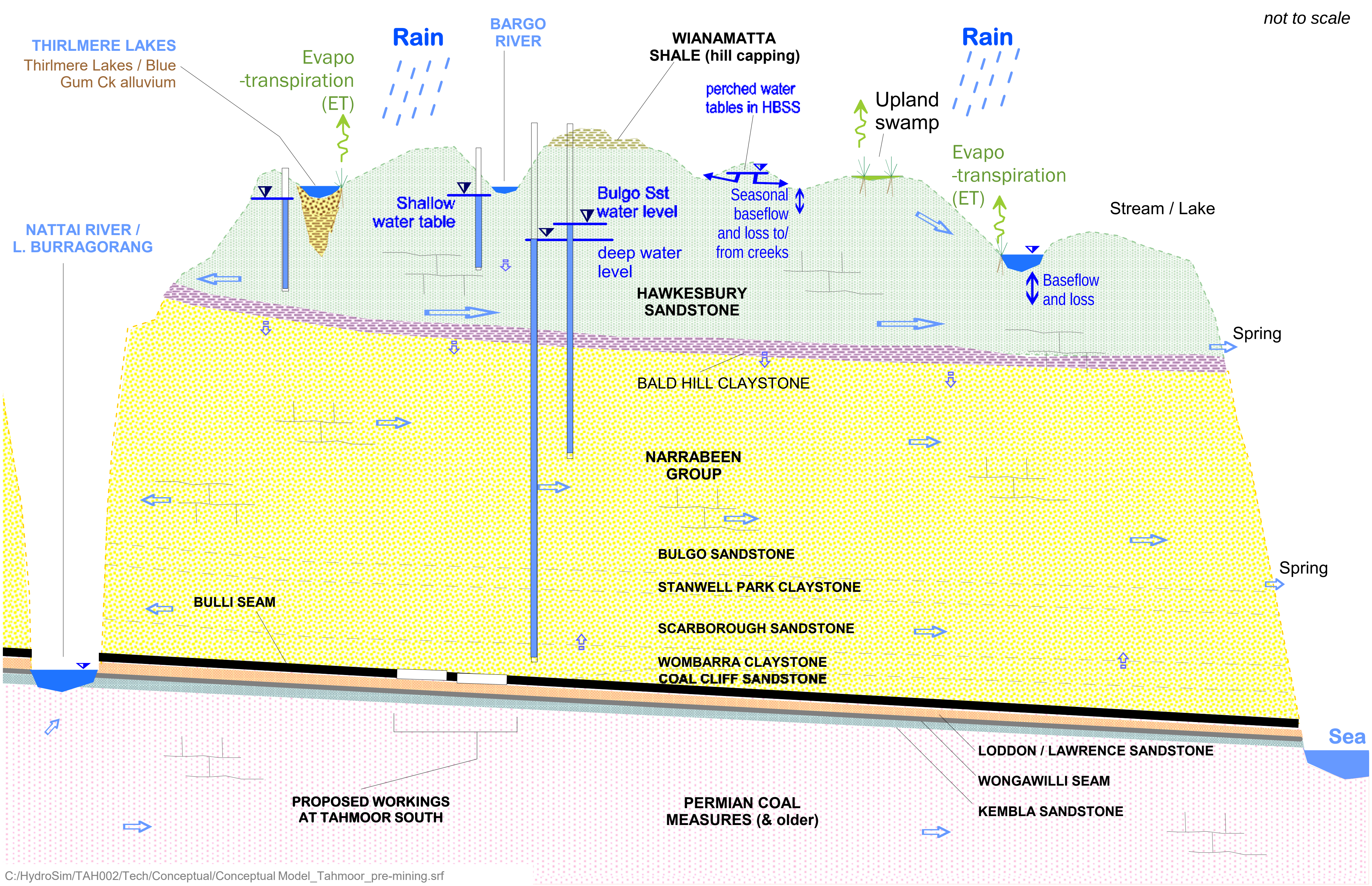
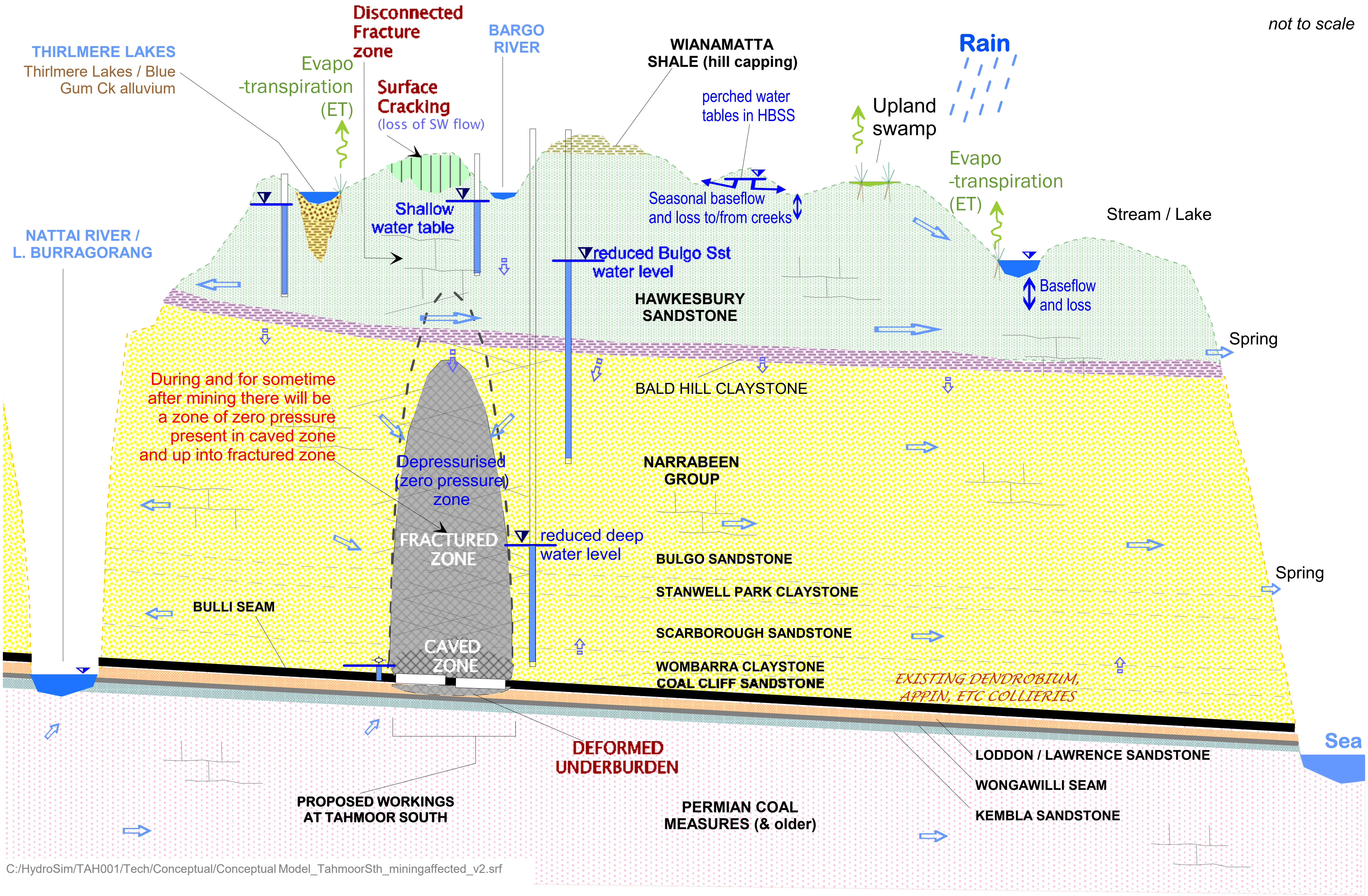



**Figure 3-35 Conceptual Model of Longwall Mining-Induced Rock Deformation**

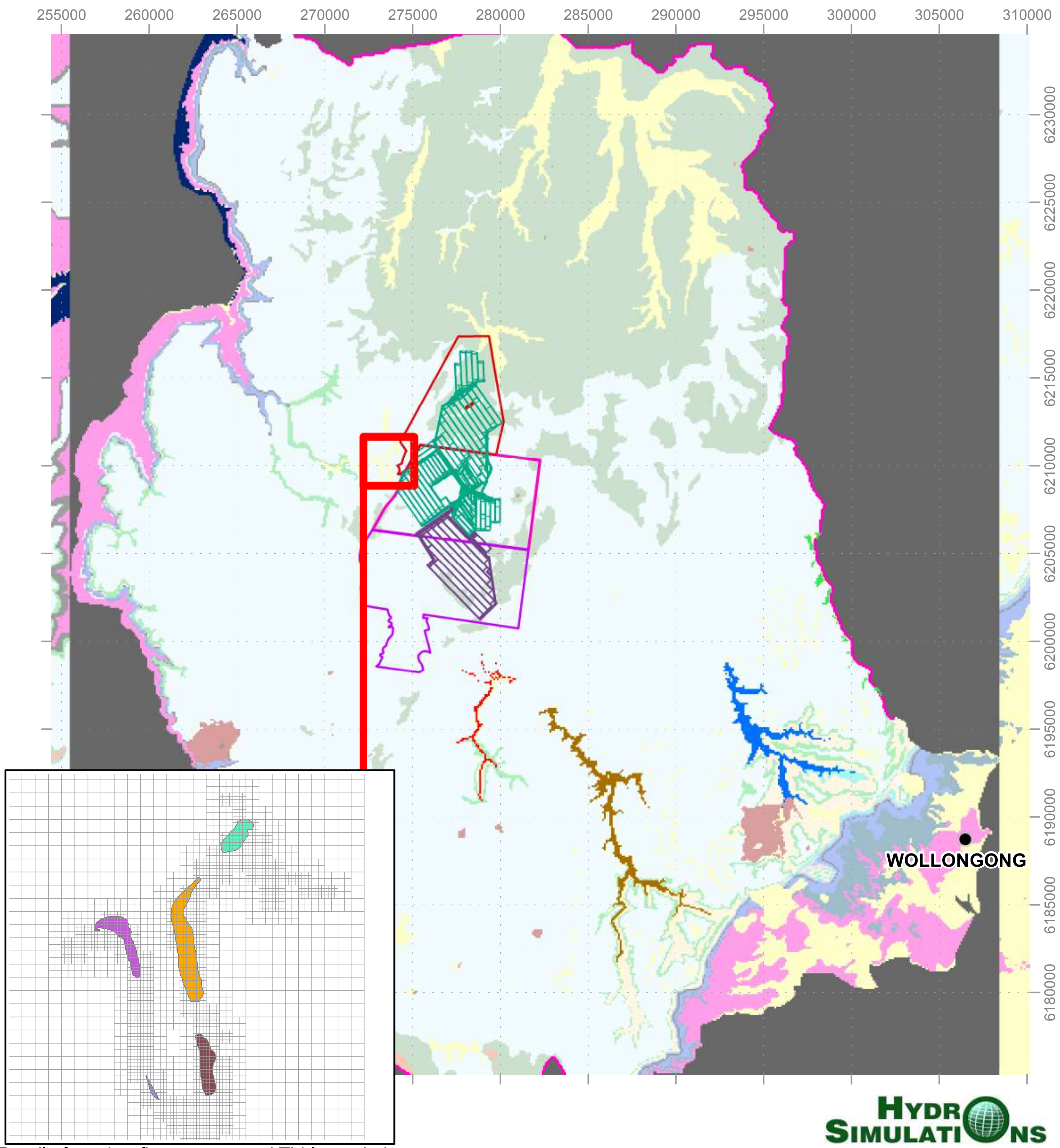
(source Forster & Enever, 1992 and Department of Planning, 2008)




Hydrogeological Conceptual Model: Pre-mining Figure 3-36




**Hydrogeological Conceptual Model: Post-mining** **Figure 3-37**




Detail of mesh refinement around Thirlmere Lakes

**MODFLOW River**

- 110mAHD (Burragorang)
- 284mAHD (Cataract)
- 298mAHD (Cordeaux)
- 308mAHD (Nepean)
- 312mAHD (Avon)

MODFLOW General Head Boundary

**MODFLOW IBOUND**

- 0 (inactive area)

Study area

**Tahmoor Coal titles**

- MLs 1308, 1376, 1539
- CCL 716
- CCL 747

**Lakes**

- LAKE BARABA
- LAKE COURIDJAH
- LAKE GANDANGARRA
- LAKE NERRIGORANG
- LAKE WERRI BERRI

Scale: 300,000
GDA 1994 MGA Zone 56

0 1.25 2.5 5 7.5 10 12.5 kilometres

N



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH0XXa_ModelDomain_A4P.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 10/09/2018

**Tahmoor Coal**
**Tahmoor South Project**

**Figure 4-1**

**Groundwater flow model domain and boundary conditions**

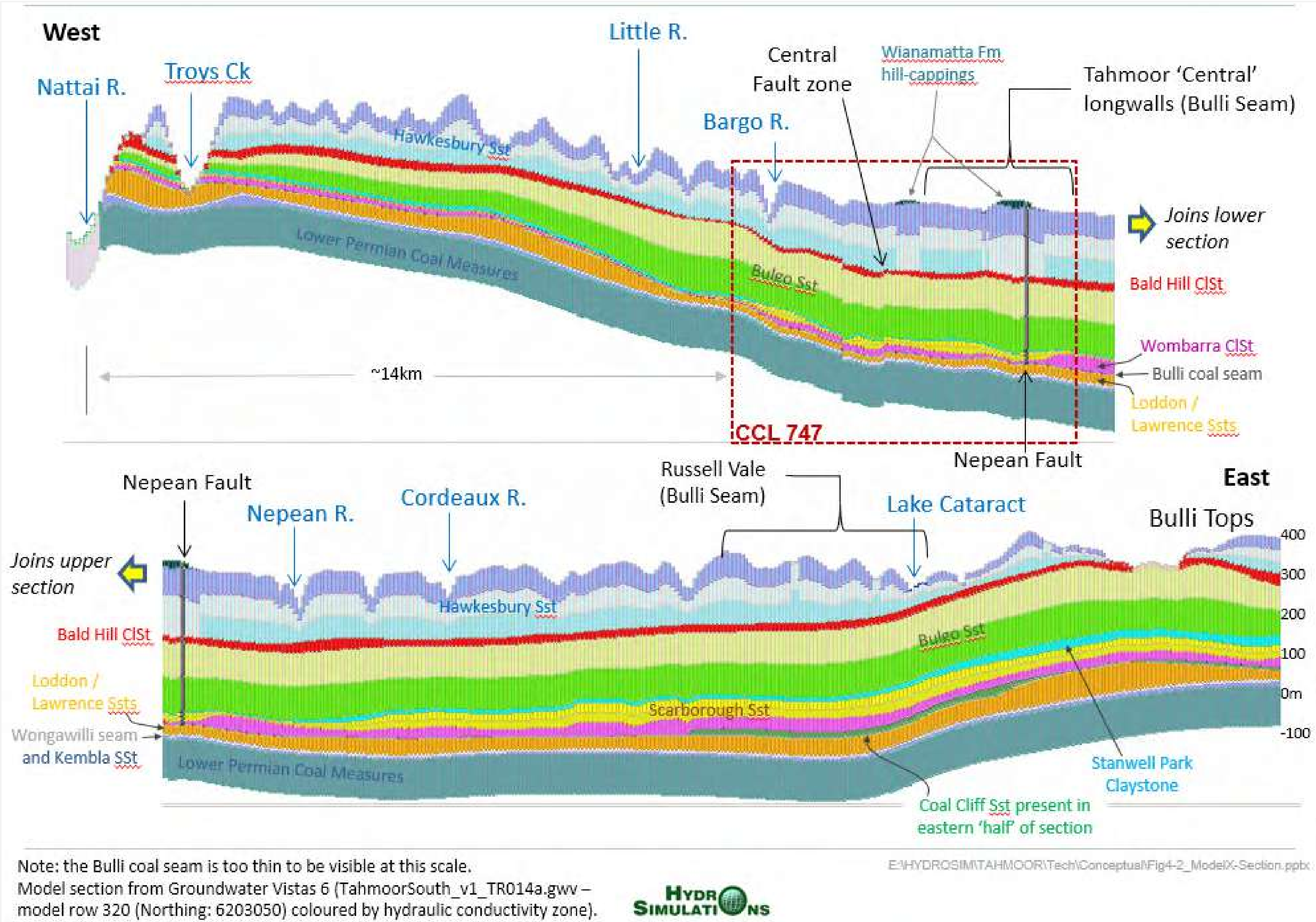
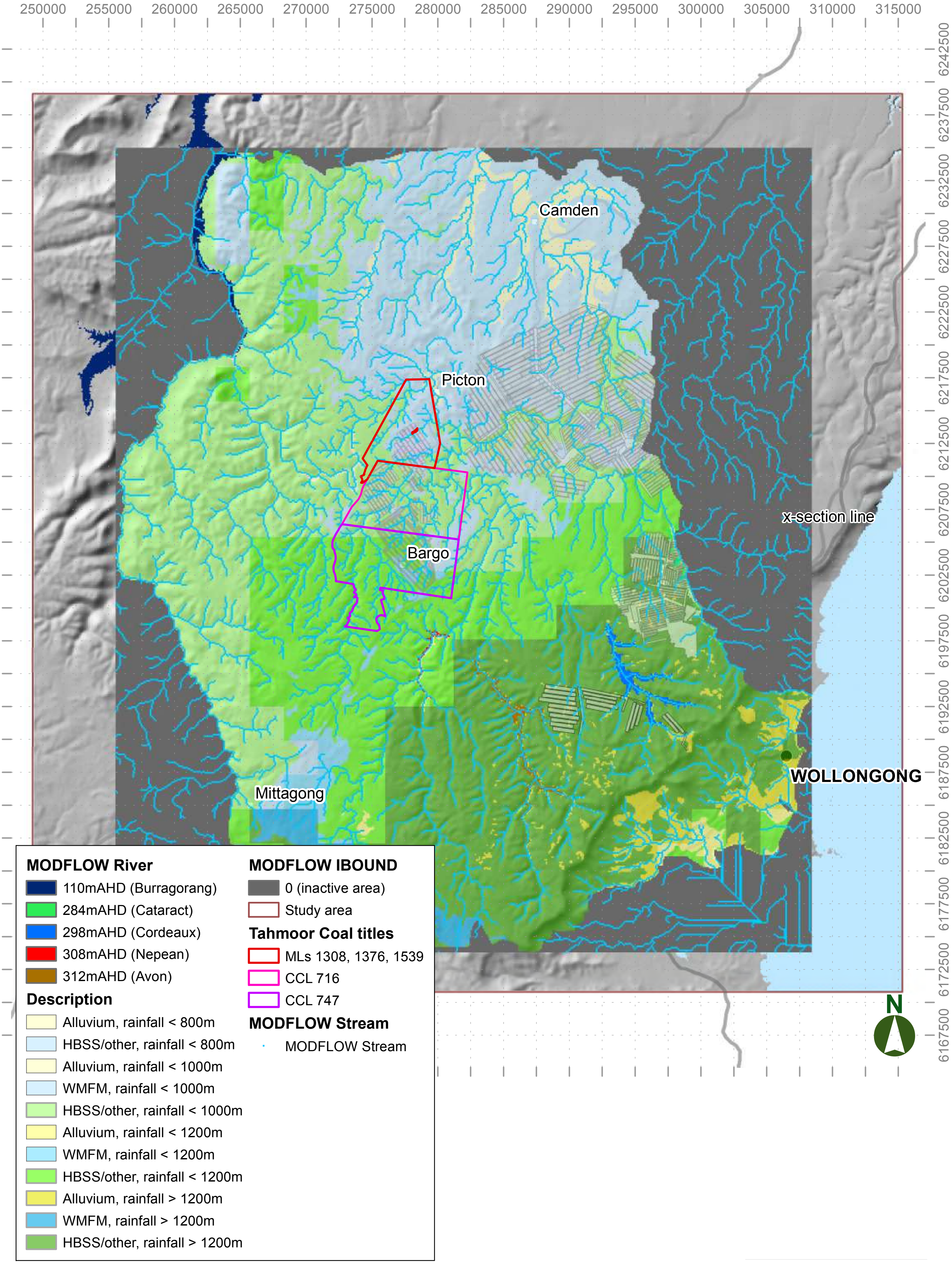



**Figure 4-2 Representative Model Cross-section**




Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres



T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH0XXa_ModelRechargeZones_A4P.mxd

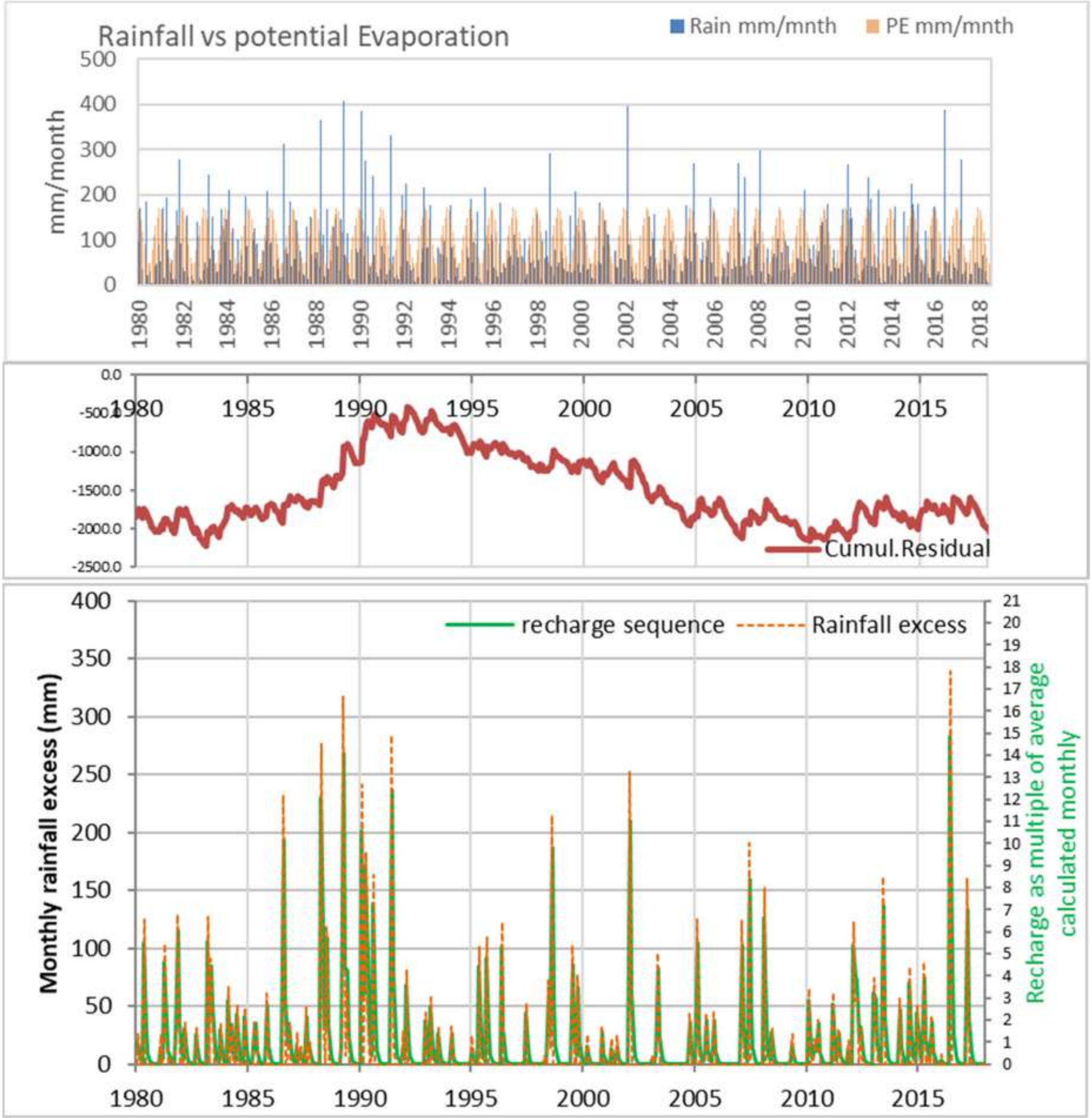
DrawingNo: TAH-0XX | Rev: A | Created by: WMinchin | Date: 25/11/2013

HydroSimulations

Tahmoor Coal
Tahmoor South Project

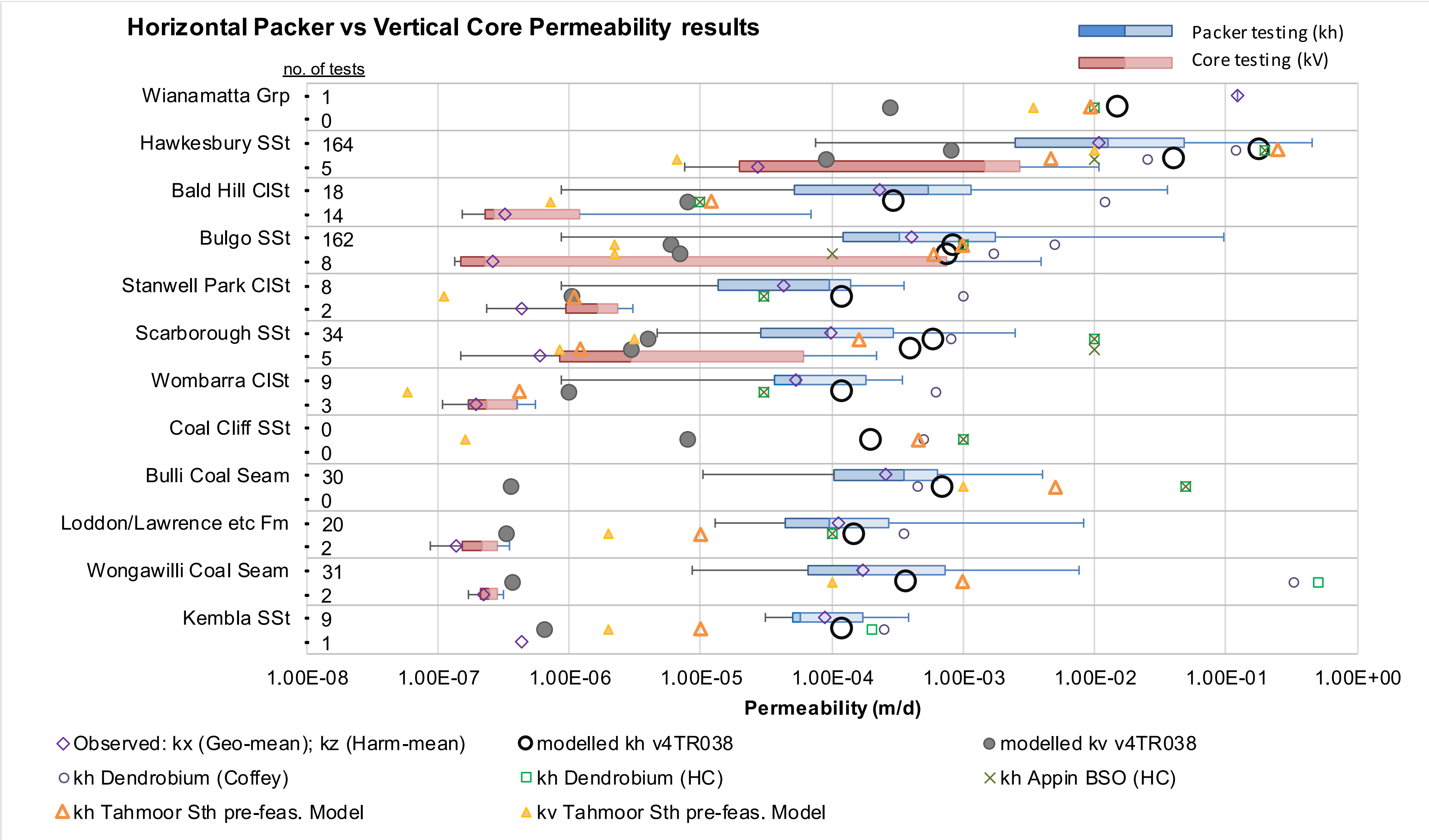
**Figure 4-3**

**Recharge zonation in the groundater model**




C:\HydroSim\TAH001\Tech\Model\Construction\Boundaries\Recharge\Rainfall&Recharge_2018.xlsx

**Figure 4-4 Modelled recharge sequence (monthly)**




E:\HYDROSIM\TAHMOOR\Tech\HydraulicProperties\Tahmoor Packer&CorePermeability_v5.xls

**Figure 4-5 Comparison of modelled hydraulic conductivity and measured data**

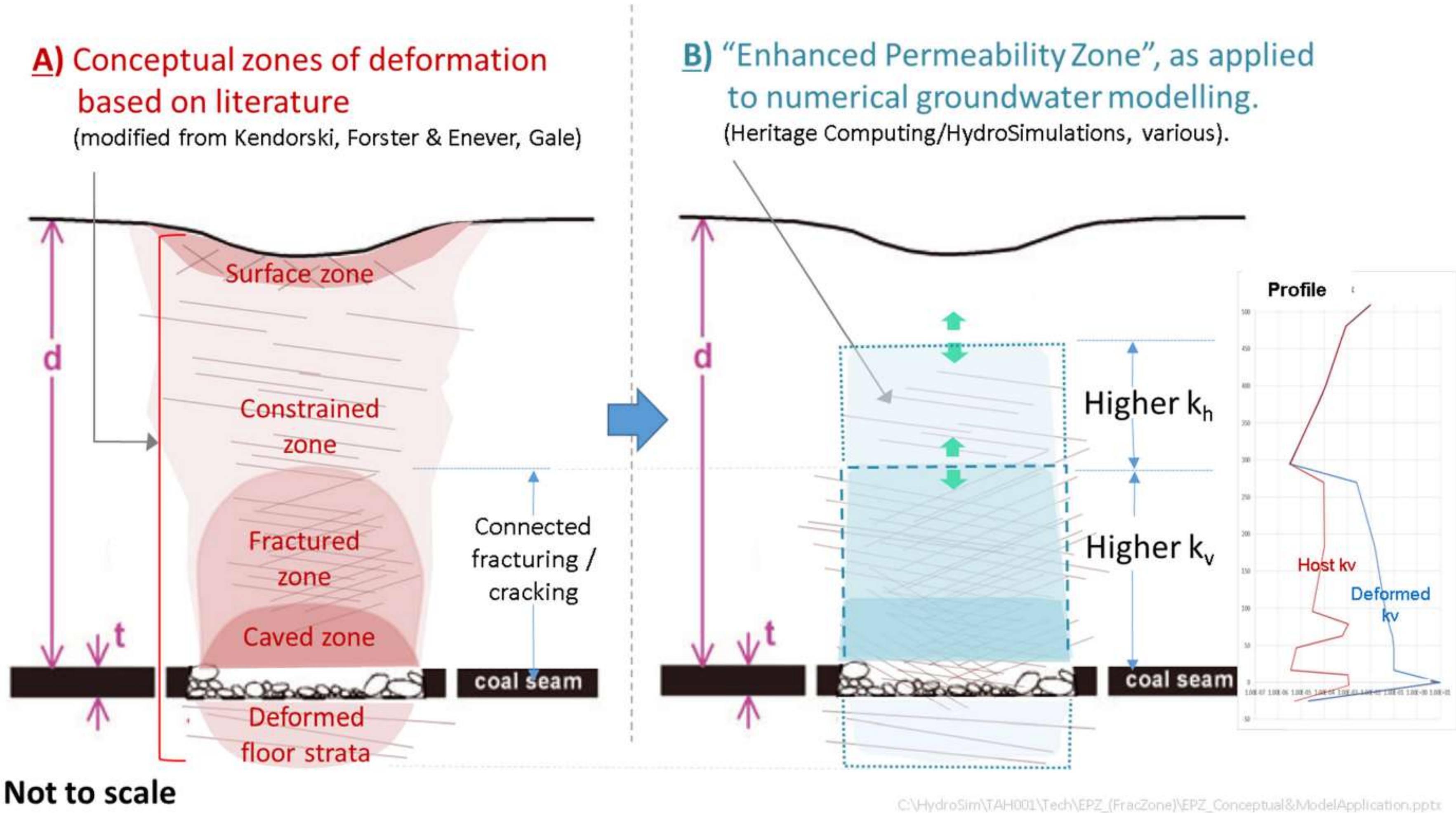



**Figure 4-6 Application of enhanced permeability within the groundwater model**

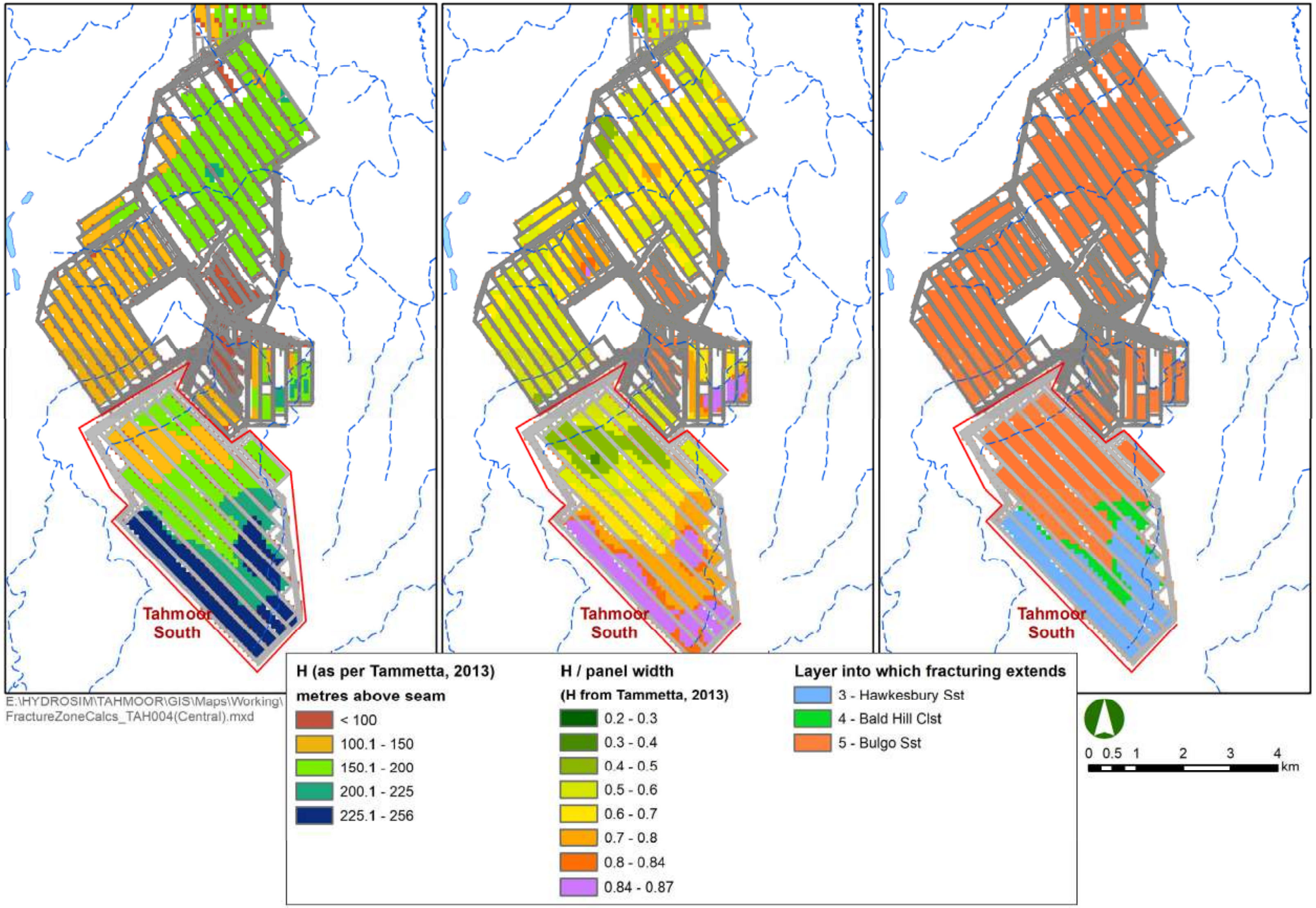



**Figure 4-7 Spatial distribution of the modelled Height of Connected Fracturing**

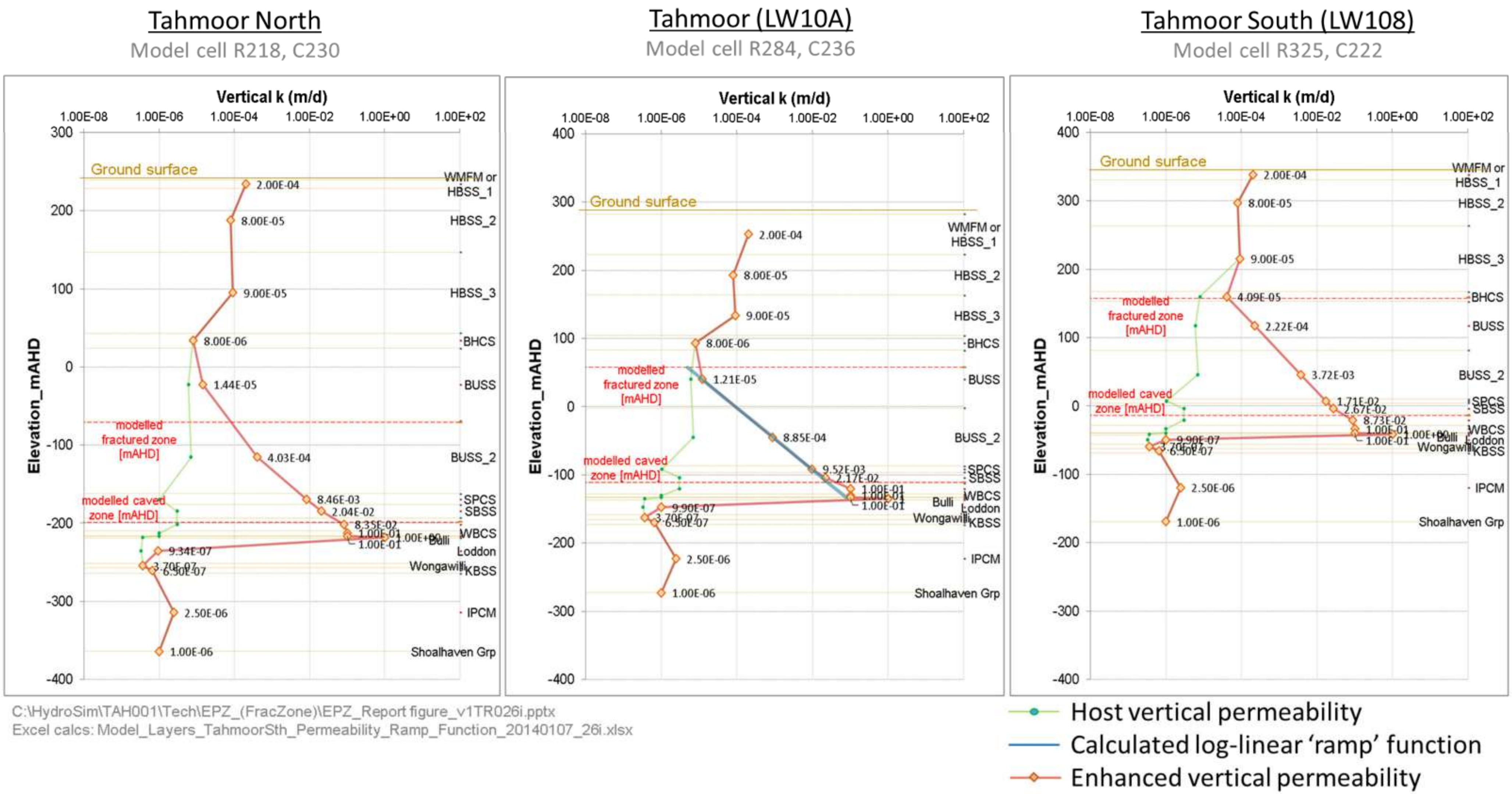
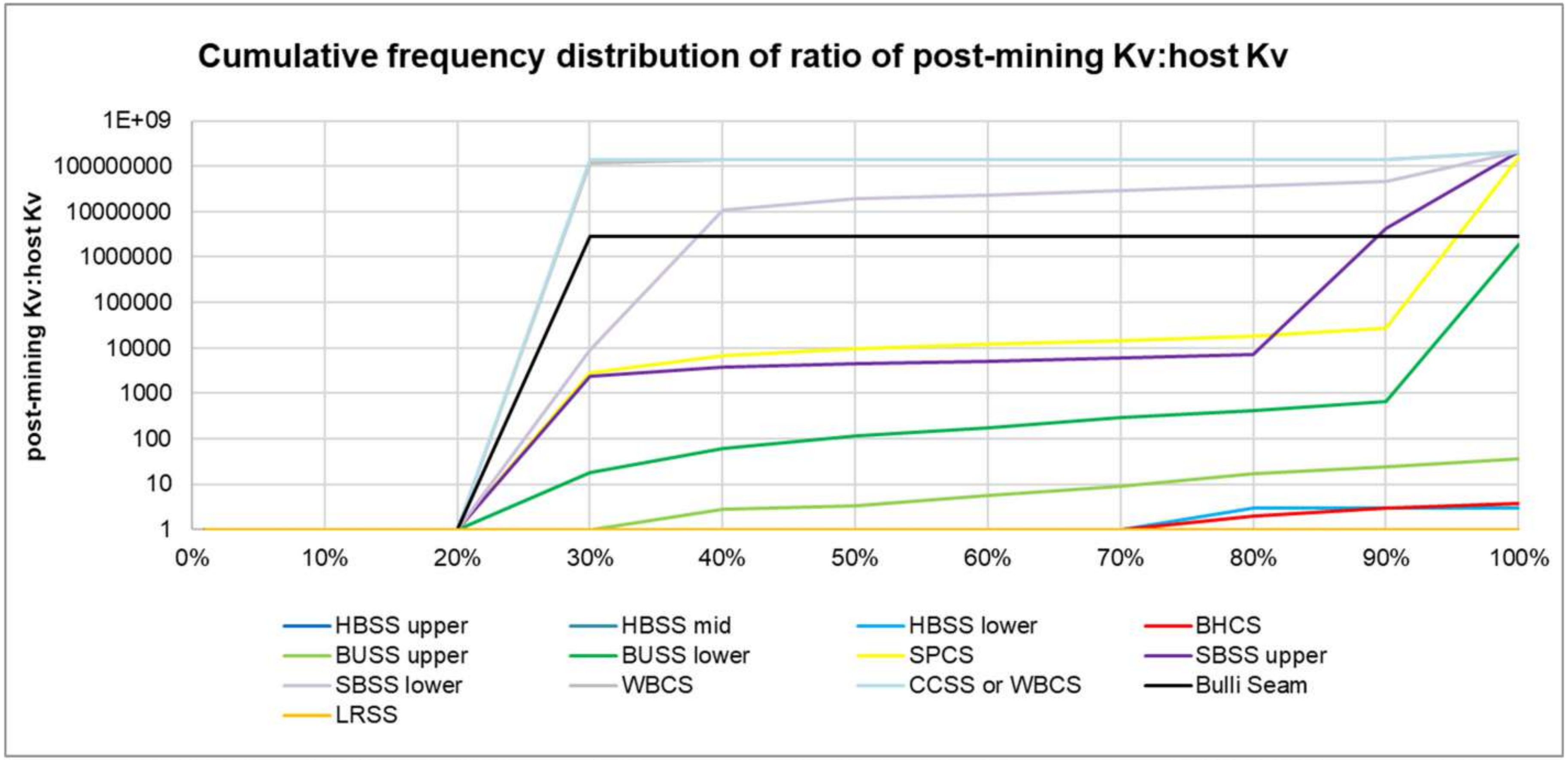
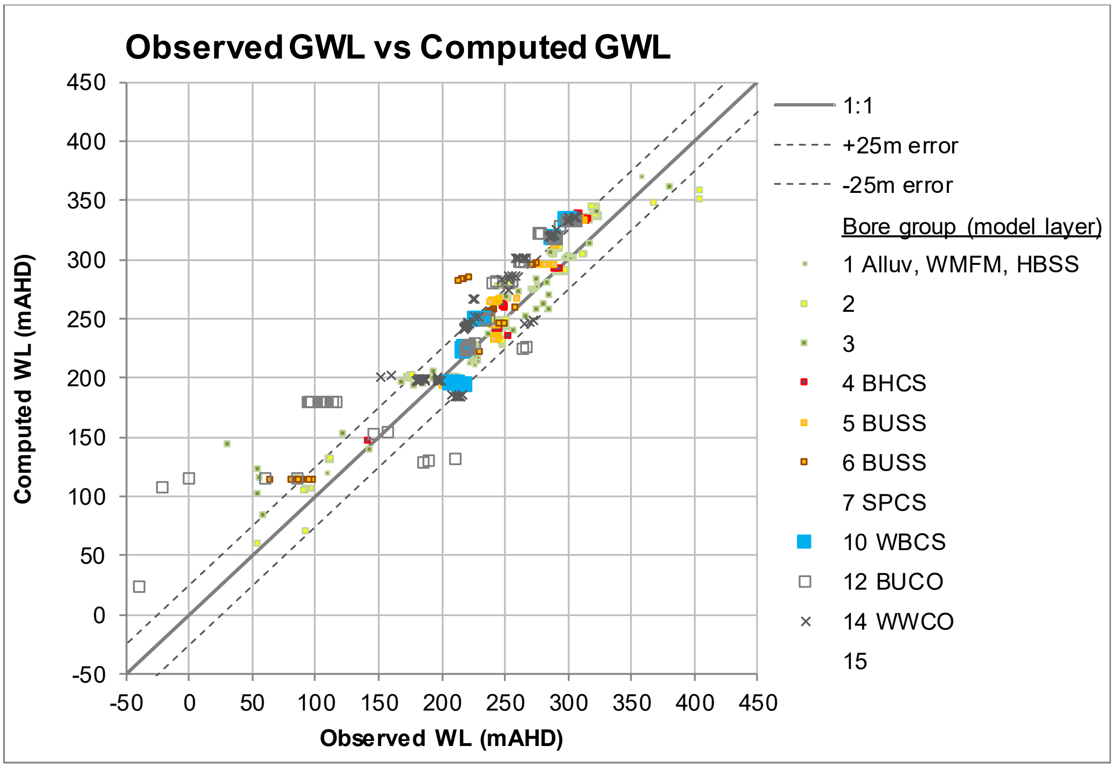


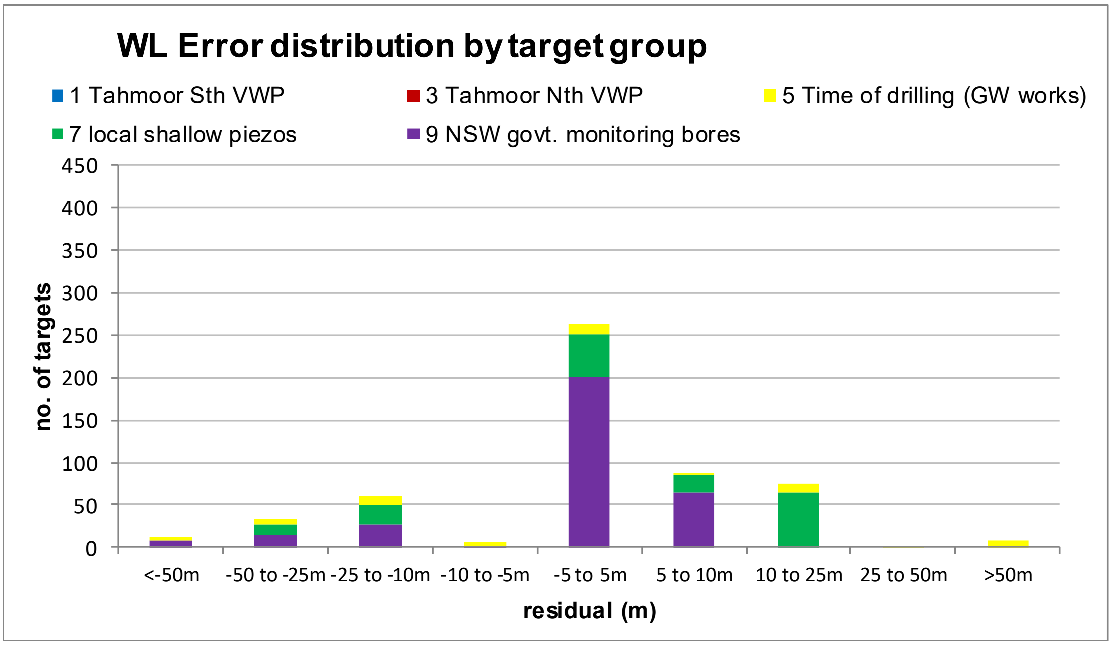

**Figure 4-8 Vertical profiles illustrating modelled permeability in the Fractured Zone**




E:\HYDROSIM\TAHMOOR\Model\Construction\Properties\TMP_TVM\FracZoneHeightv1_TahmoorV4TR045v3_Tammetta_TVM.xlsm

**Figure 4-9 Modelled enhancement of Vertical Hydraulic Conductivity in Deformed Overburden: Tahmoor South**




T:\TAHMOOR\Model\Processing\CalibrationHydrographs\[TahmSthv04Run045_calibration_v4_Report.xlsx]CHART_calib

## Figure 4-10 Summary of transient calibration to water levels

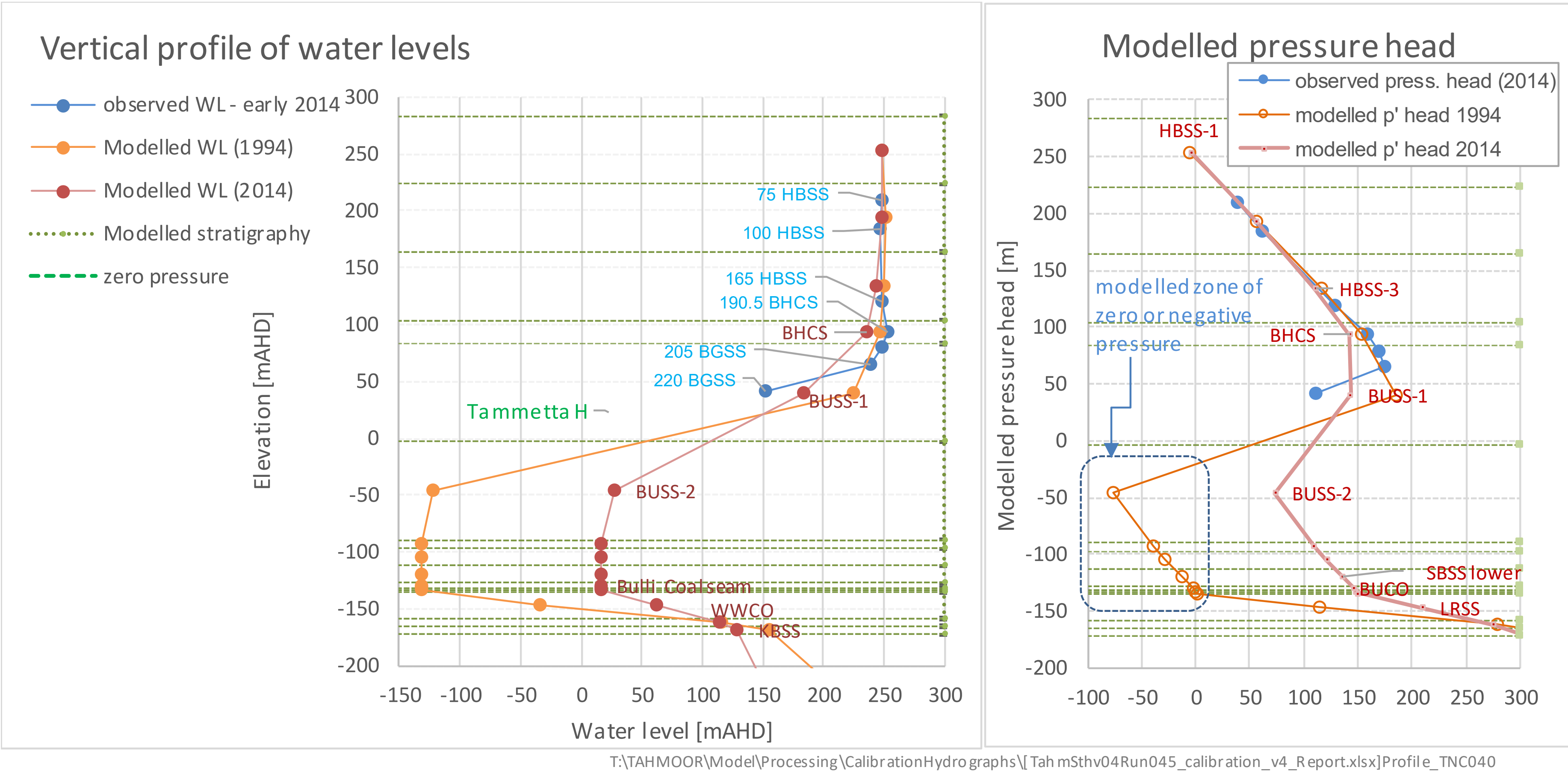
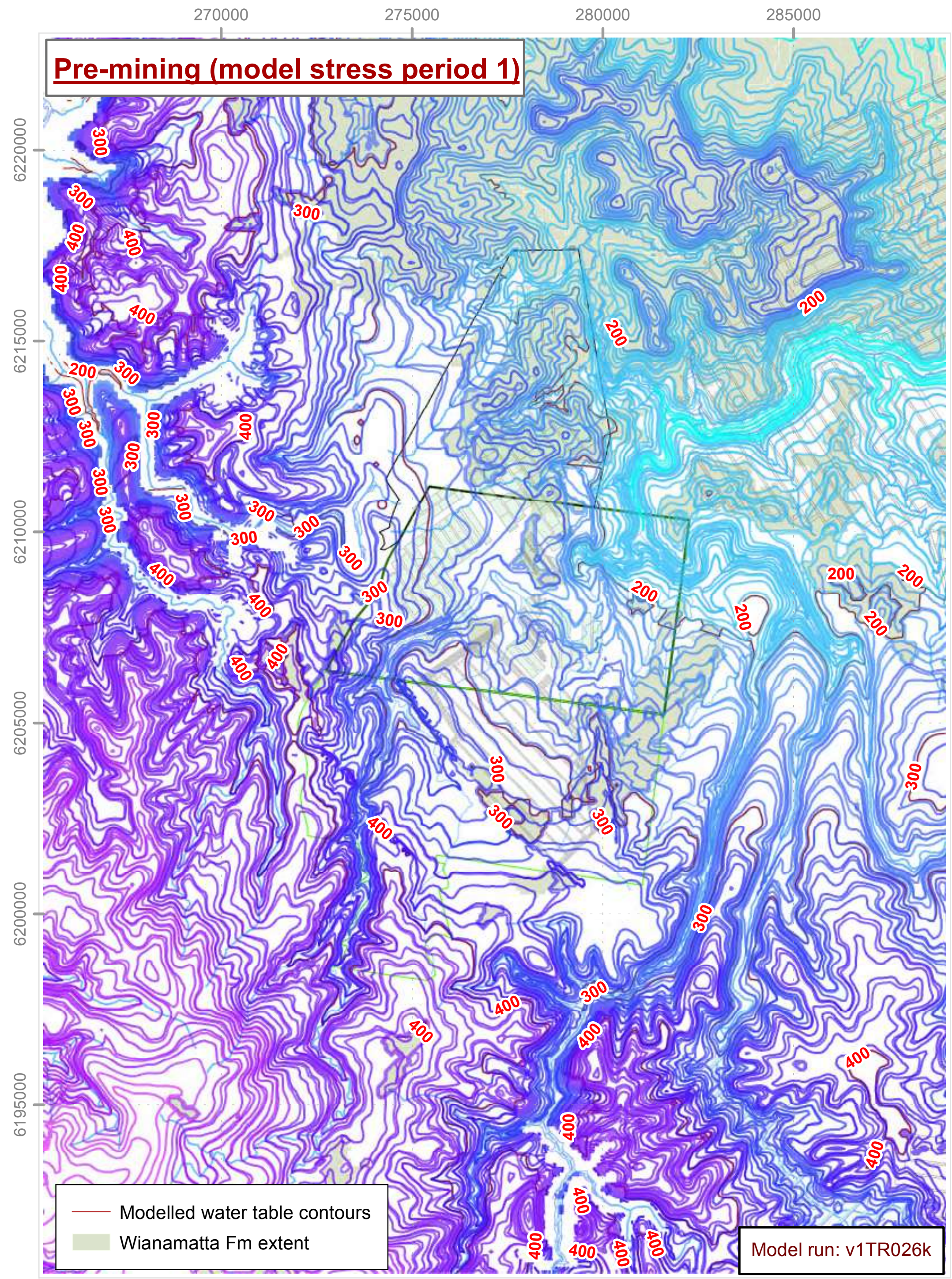
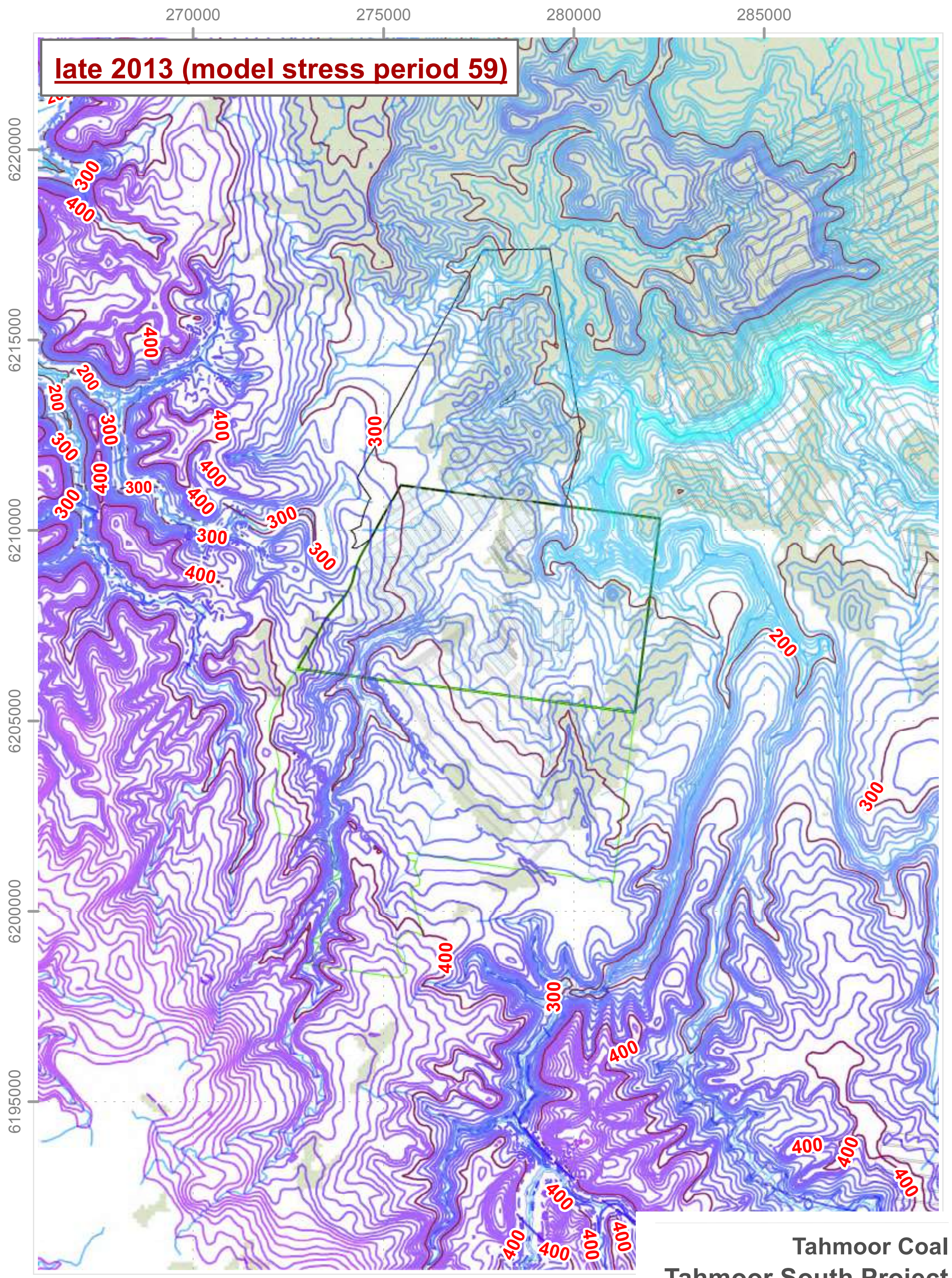



**Figure 4-11 Simulation of water levels in TBF040c ('HoF') borehole**




Scale: 175,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

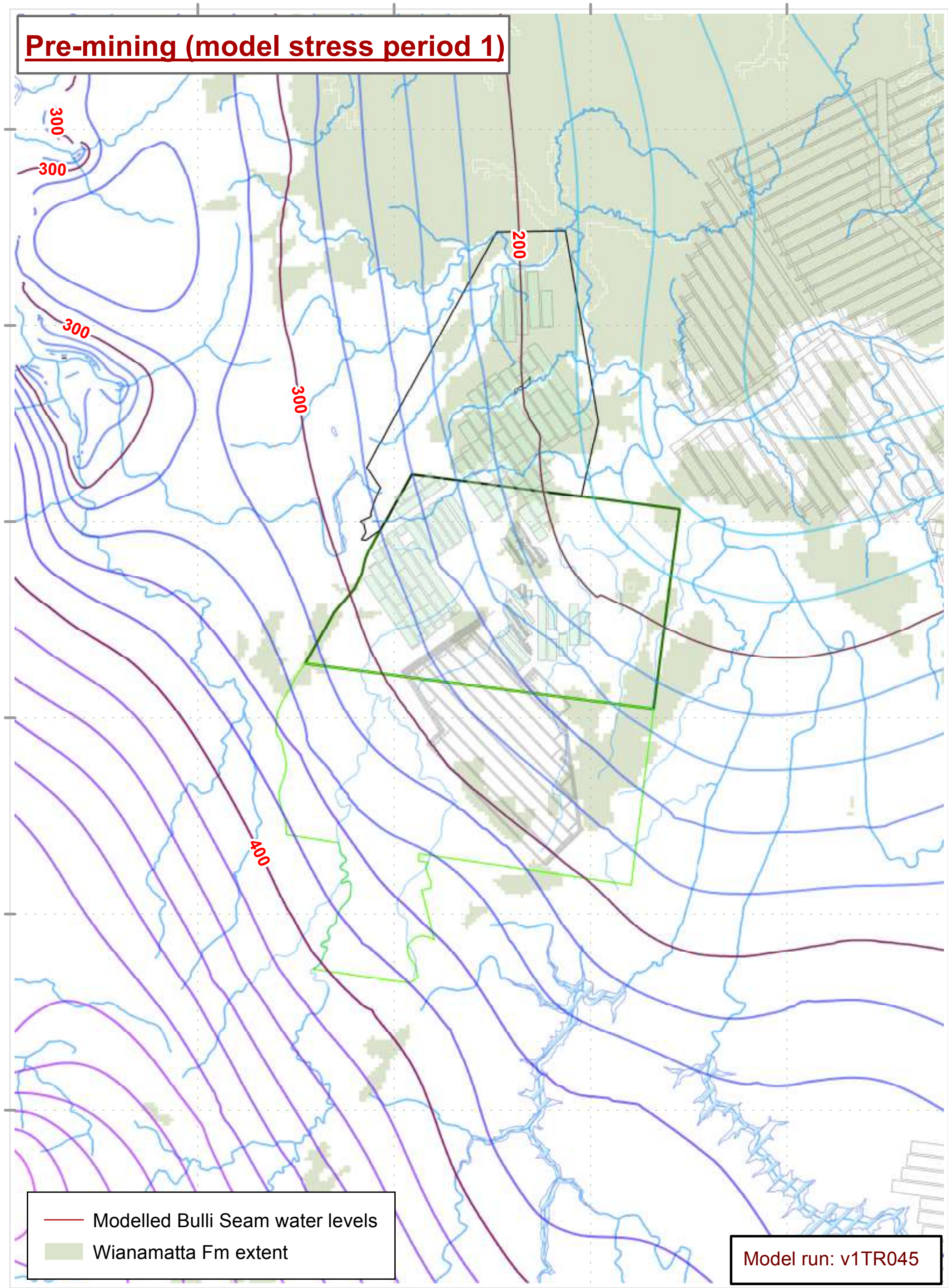
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_ModelledWatertable_A4L.mxd

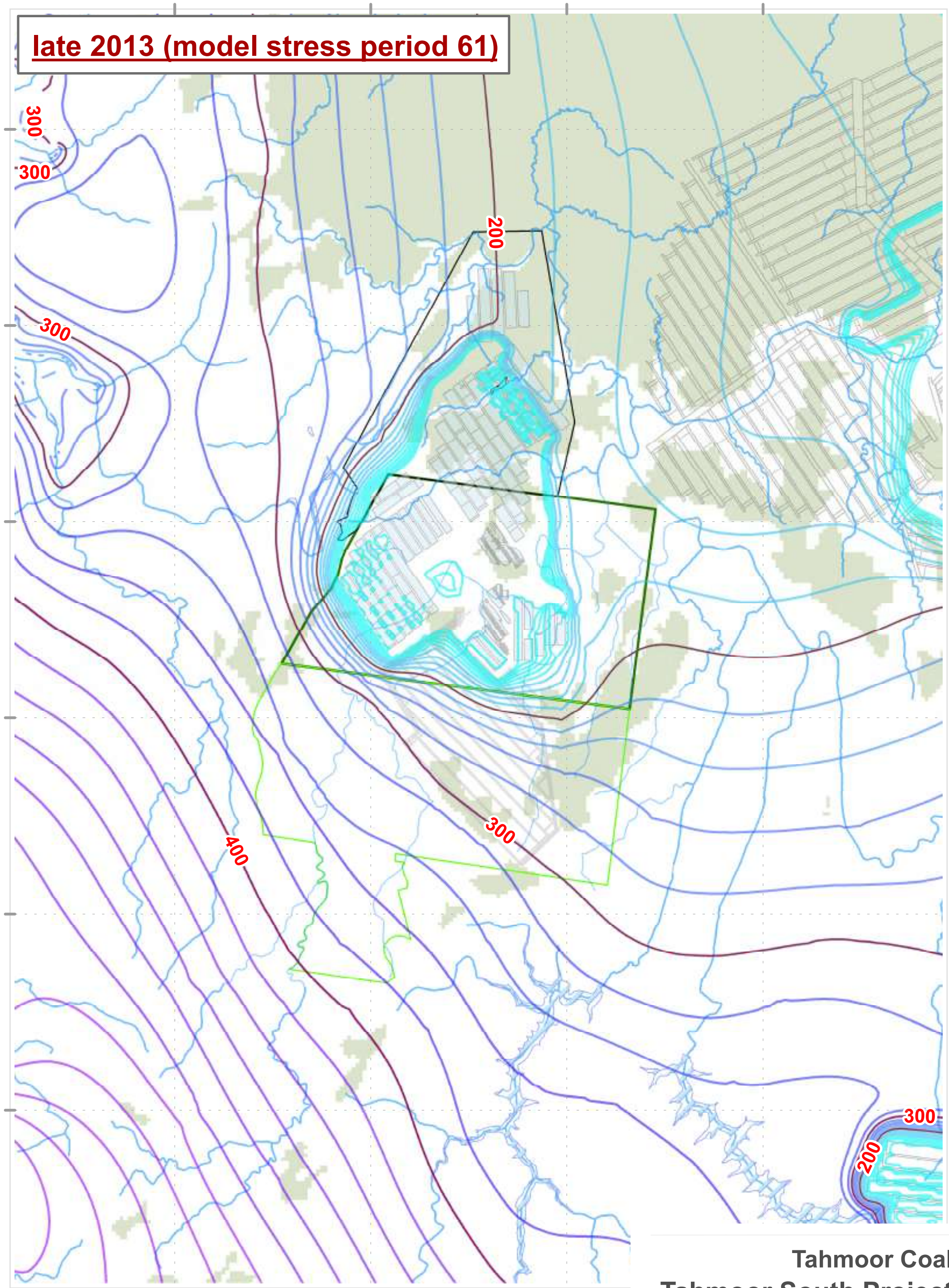
Rev: A - 10/09/2018 | by: B.White

**Modelled water table: pre-mining (i.e. ~1980) and late 2013 levels**

Tahmoor Coal
Tahmoor South Project

**Figure 4-12**




Scale: 175,000
GDA 1994 MGA Zone 56

HYDRO SIMULATIONS

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH0022_ModelledBulliWLs_A4L.mxd

Rev: A - 05/10/2018 | by: B.White

**Modelled water levels in the Bulli Seam: pre-mining (i.e. ~1980) and late 2013 levels**

Tahmoor Coal
Tahmoor South Project

**Figure 4-13**

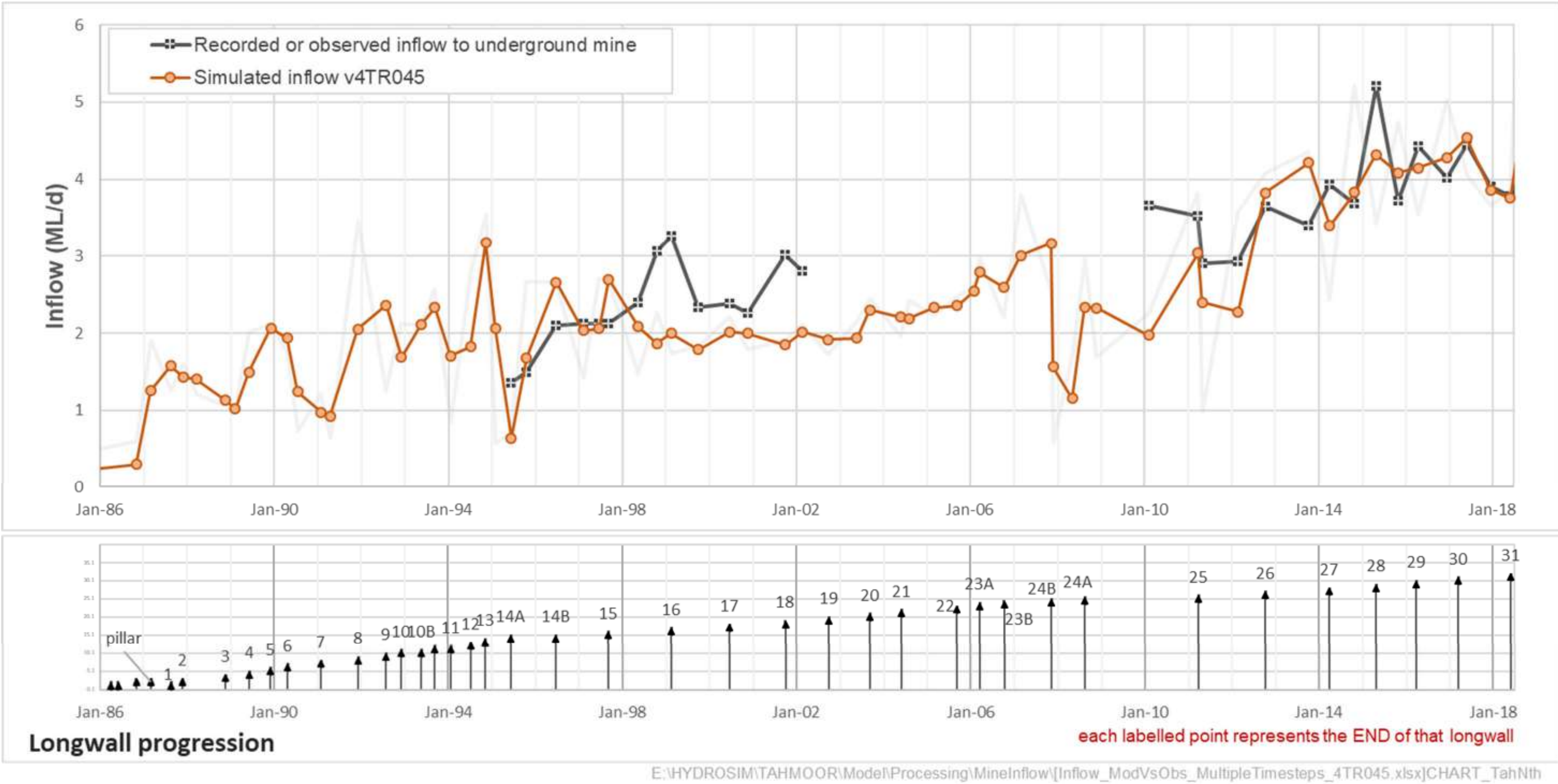
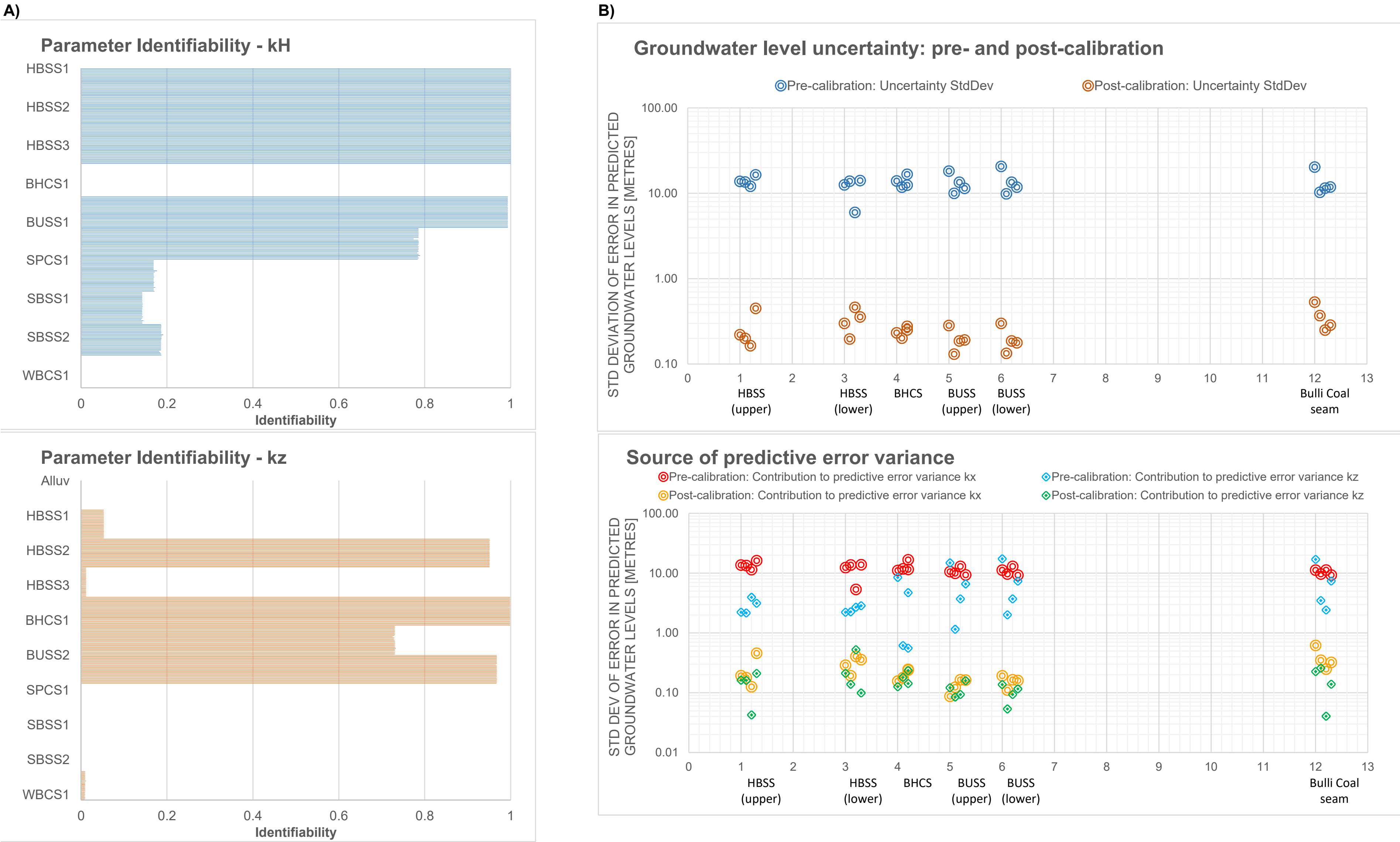



**Figure 4-14 Comparison of observed and modelled inflow at Tahmoor**




E:\HYDROSIM\TAHMOOR\Model\Runs_SLAVES\MASTER\GENLINPRED\[GENLINPRED_output_SS012_Feb2018.xlsx]REPORT

**Summary of Uncertainty Analysis of Groundwater Levels** **Figure 4-15**

## Figure 4-15 Summary of Uncertainty Analysis of Modelled Groundwater Levels

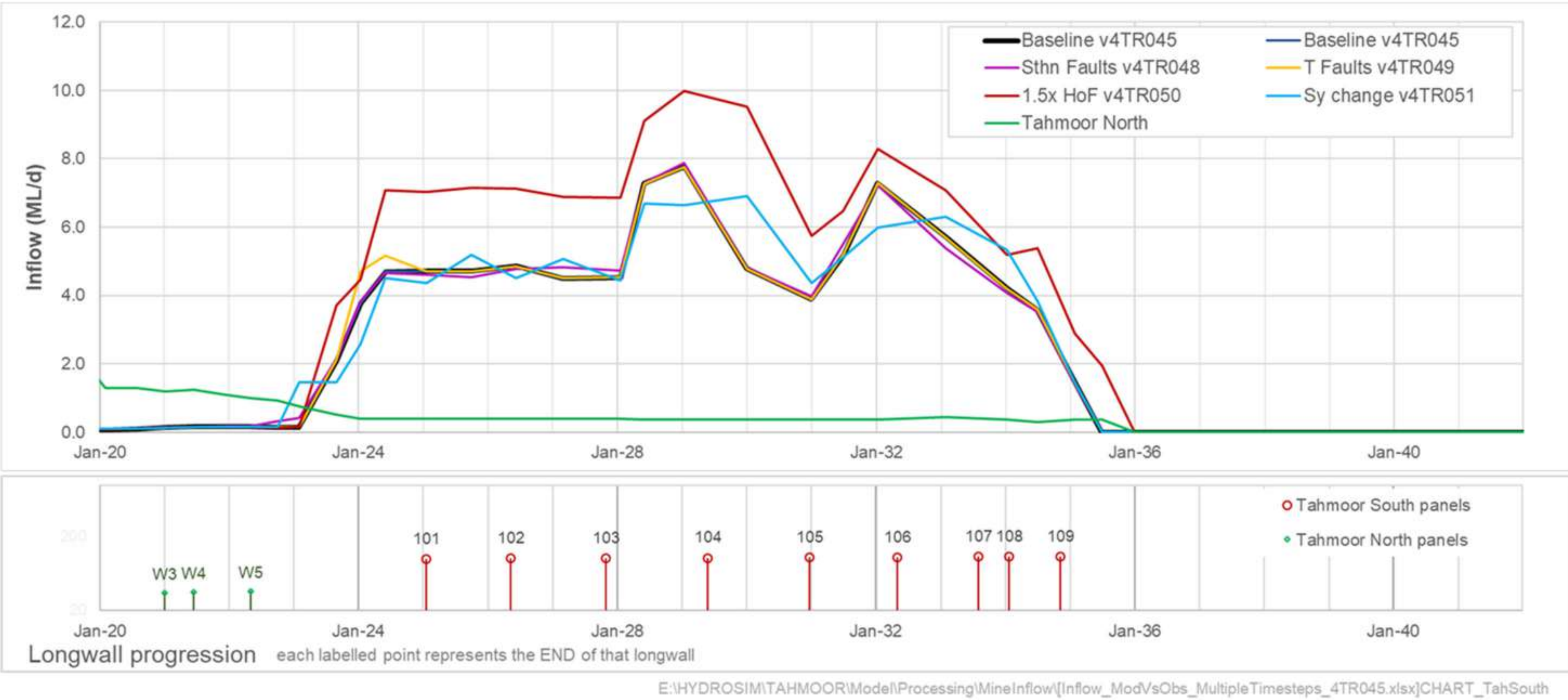
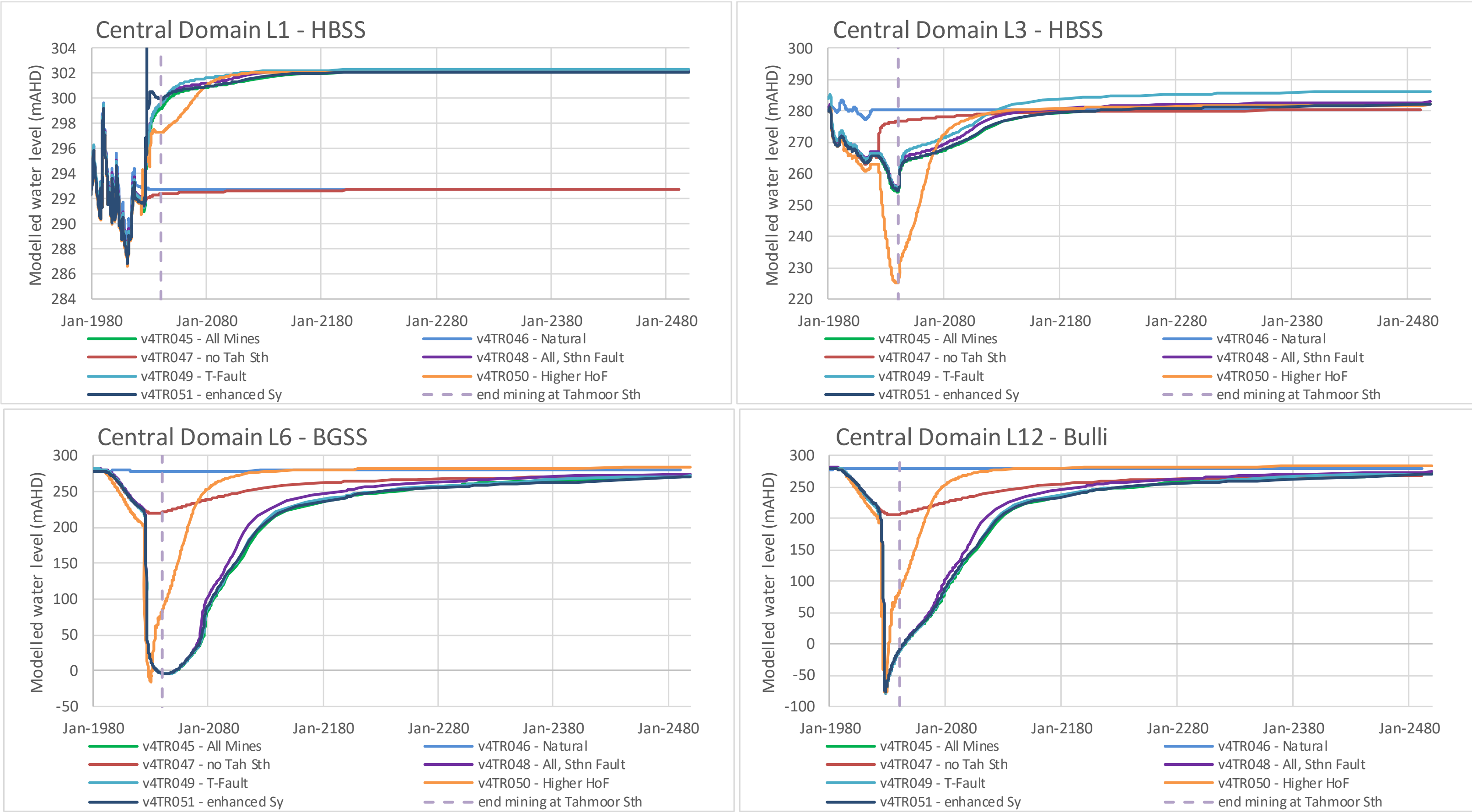



**Figure 5-1 Modelled Tahmoor South Mine Groundwater Inflows and Uncertainty**

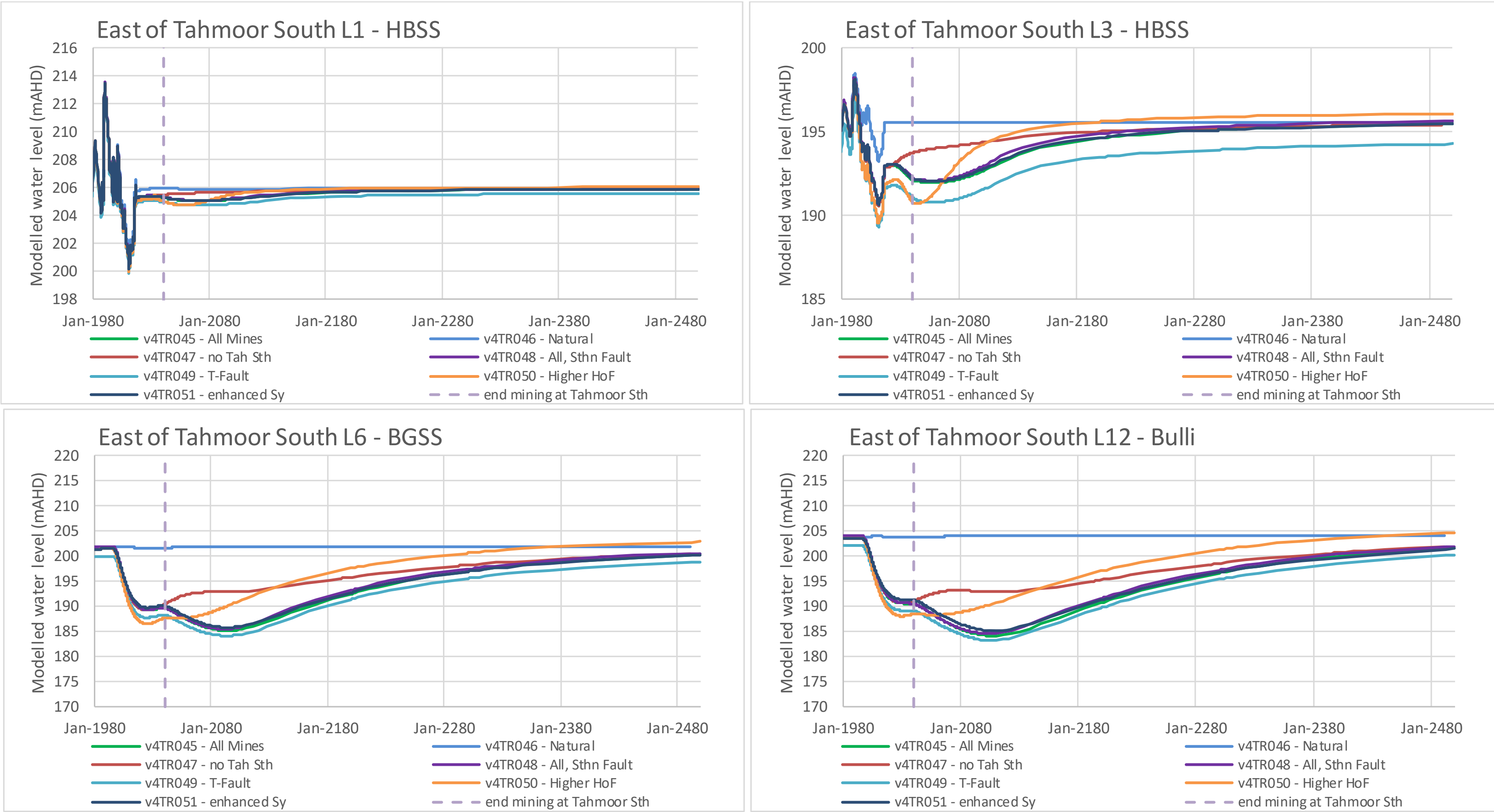
*The bore chosen here does not necessarily intersect or even monitor all the stratigraphic units indicated here. The location was chosen to provide a guide to water levels around the Tahmoor South Project. Refer to Figure 3-5 for locations.* *This location is at TBC026.*




T:\TAHMOOR\Model\Processing\mod2smp\predictiveHydrographs\[PredictiveHydrographs_V4TR045-TR051.xlsx]CHARTS_CentralDomain

## Figure 5-2 Modelled groundwater levels: Tahmoor South - Central Domain

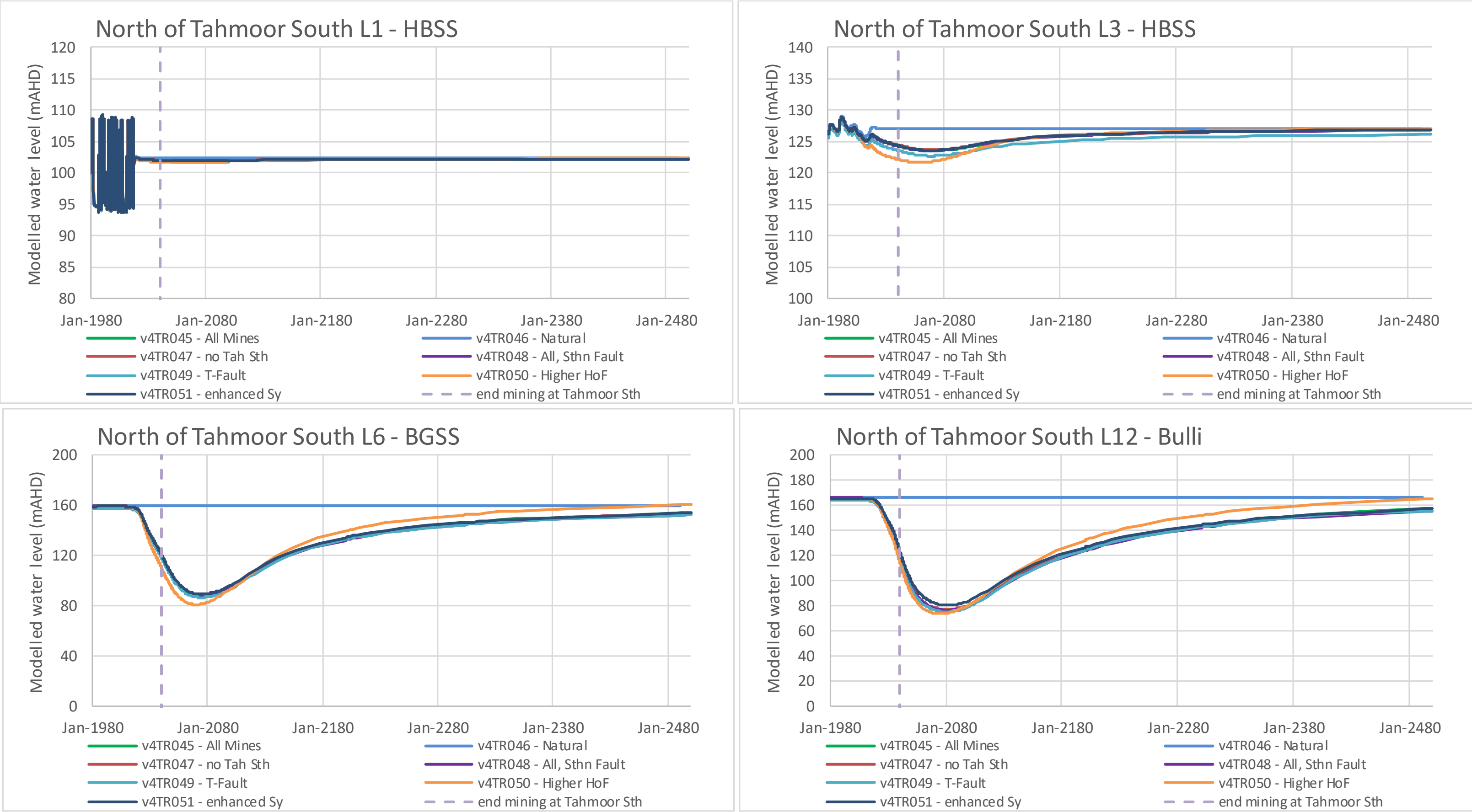
*The bore chosen here does not necessarily intersect or even monitor all the stratigraphic units indicated here. The location was chosen to provide a guide to water levels around the Tahmoor South Project. Refer to Figure 3-5 for locations.* *This location is at TBC016.*




T:\TAHMOOR\Model\Processing\mod2smp\predictiveHydrographs\[PredictiveHydrographs_V4TR045-TR051.xlsx]CHARTS_CentralDomain

## Figure 5-3 Modelled groundwater levels: East of Tahmoor South

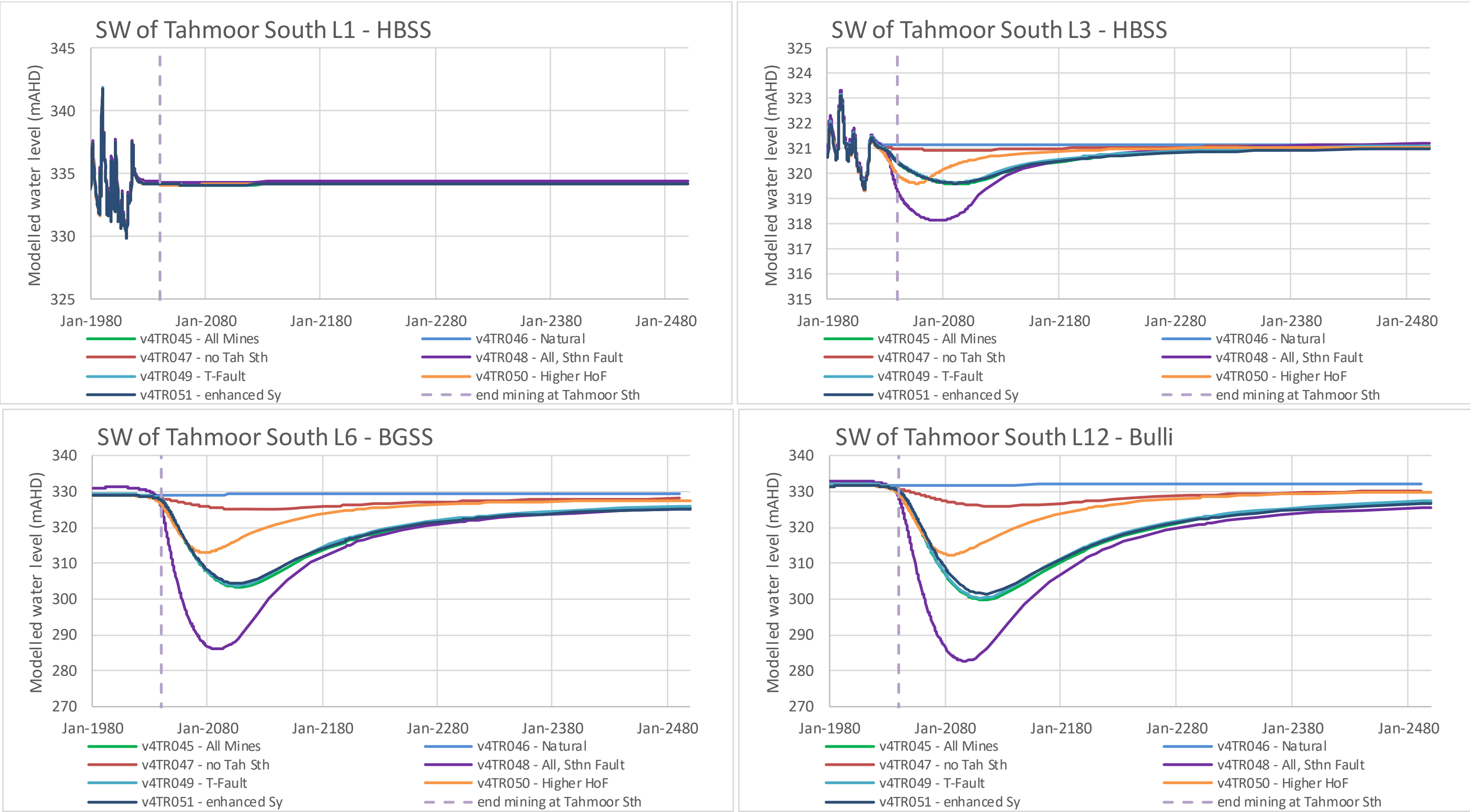
*The bore chosen here does not necessarily intersect or even monitor all the stratigraphic units indicated here. The location was chosen to provide a guide to water levels around the Tahmoor South Project. Refer to Figure 3-5 for locations. This location is at GW109159.*




T:\TAHMOOR\Model\Processing\mod2smp\predictiveHydrographs\[PredictiveHydrographs_V4TR045-TR051.xlsx]CHARTS_NorthOfTahSth

## Figure 5-4 Modelled groundwater levels: GW109159 (north of Project)

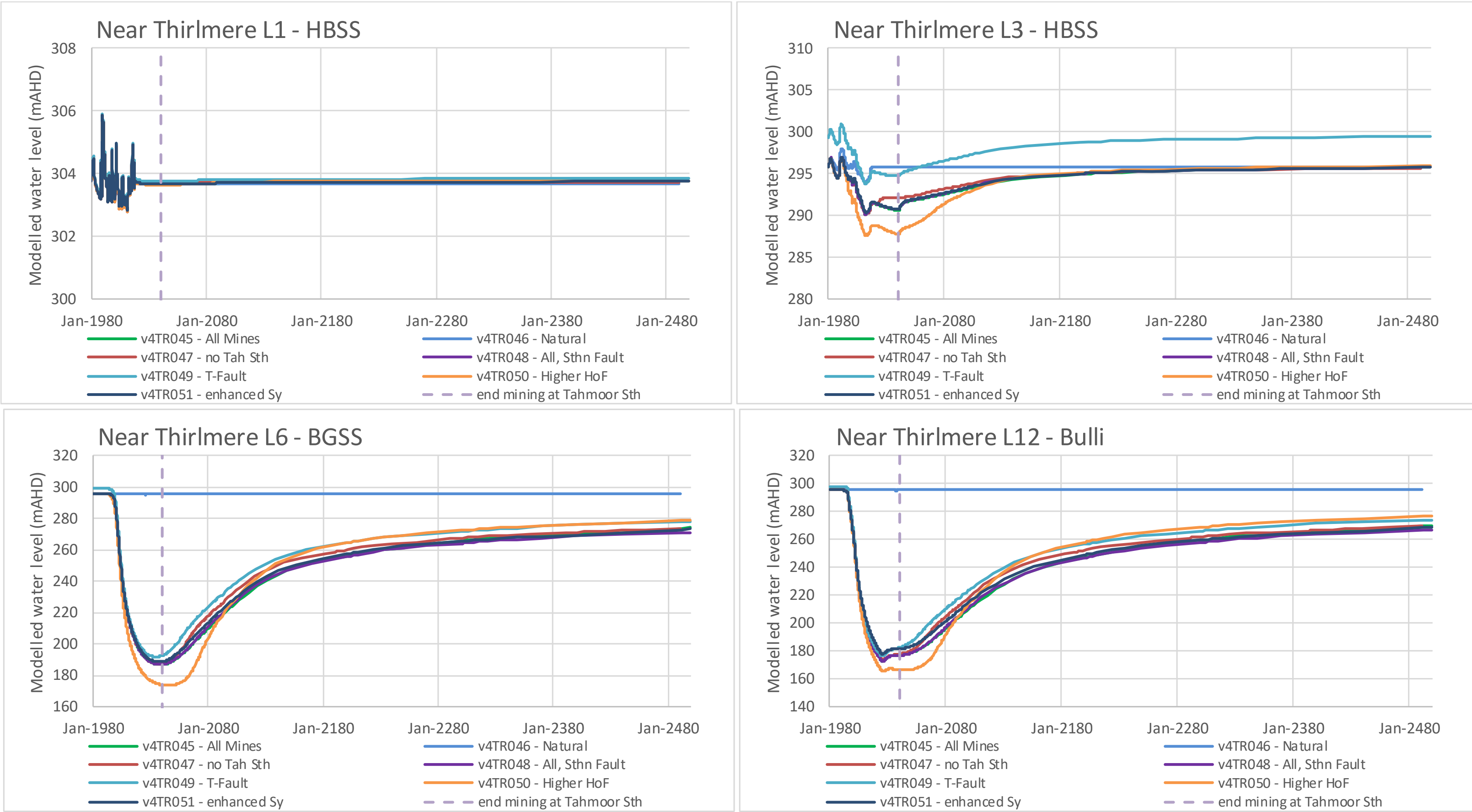
*The bore chosen here does not necessarily intersect or even monitor all the stratigraphic units indicated here. The location was chosen to provide a guide to water levels around the Tahmoor South Project. Refer to Figure 3-5 for locations. This location is at TBC022.*




T:\TAHMOOR\Model\Processing\mod2smp\predictiveHydrographs\[PredictiveHydrographs_V4TR045-TR051.xlsx]CHARTS_NorthOfTahSth

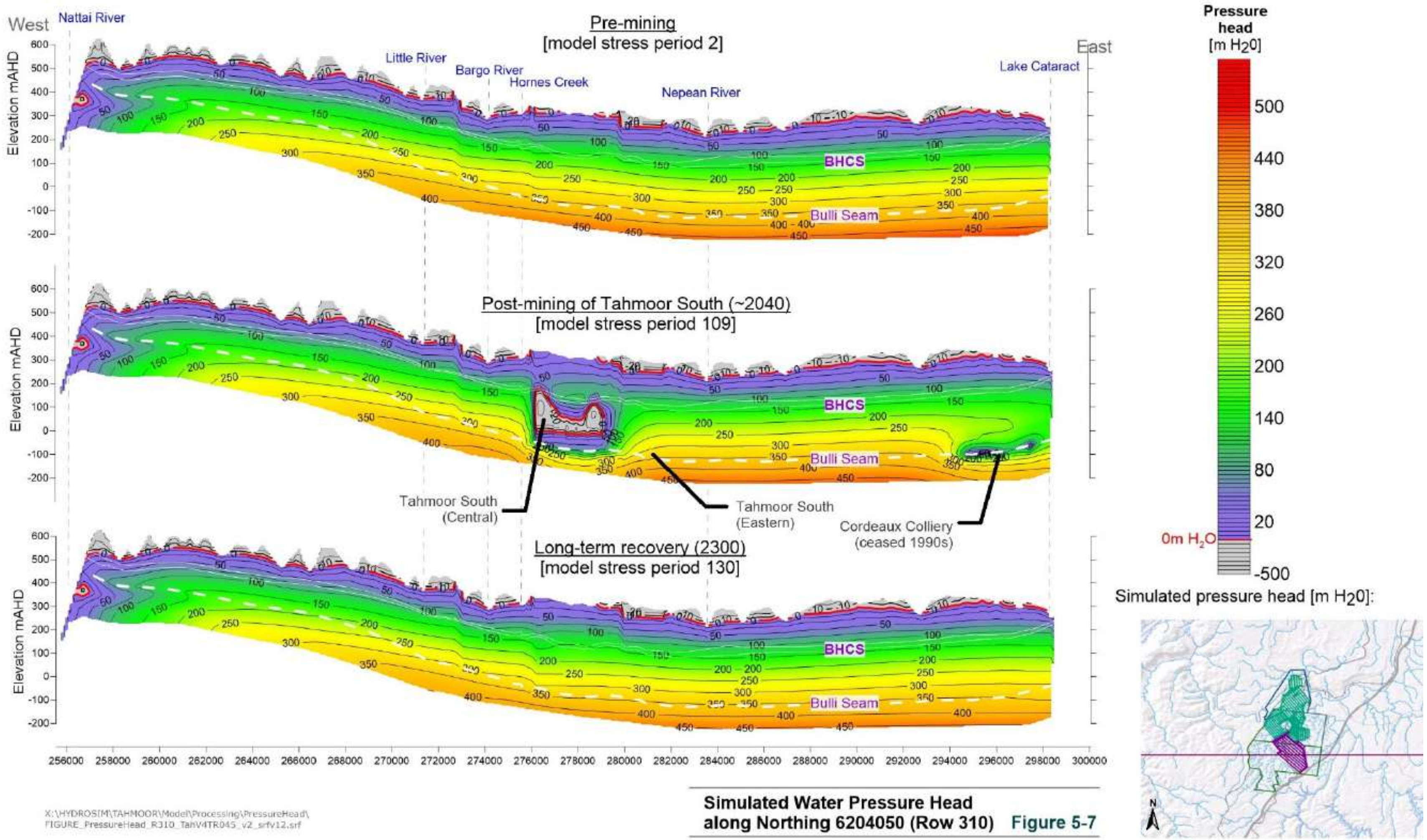
## Figure 5-5 Modelled groundwater levels: TBC026 (southwest of Project).

*The bore chosen here does not necessarily intersect or even monitor all the stratigraphic units indicated here. The location was chosen to provide a guide to water levels around the Tahmoor South Project. Refer to Figure 3-5 for locations.* *This location is at GW075409 (Couridjah).*

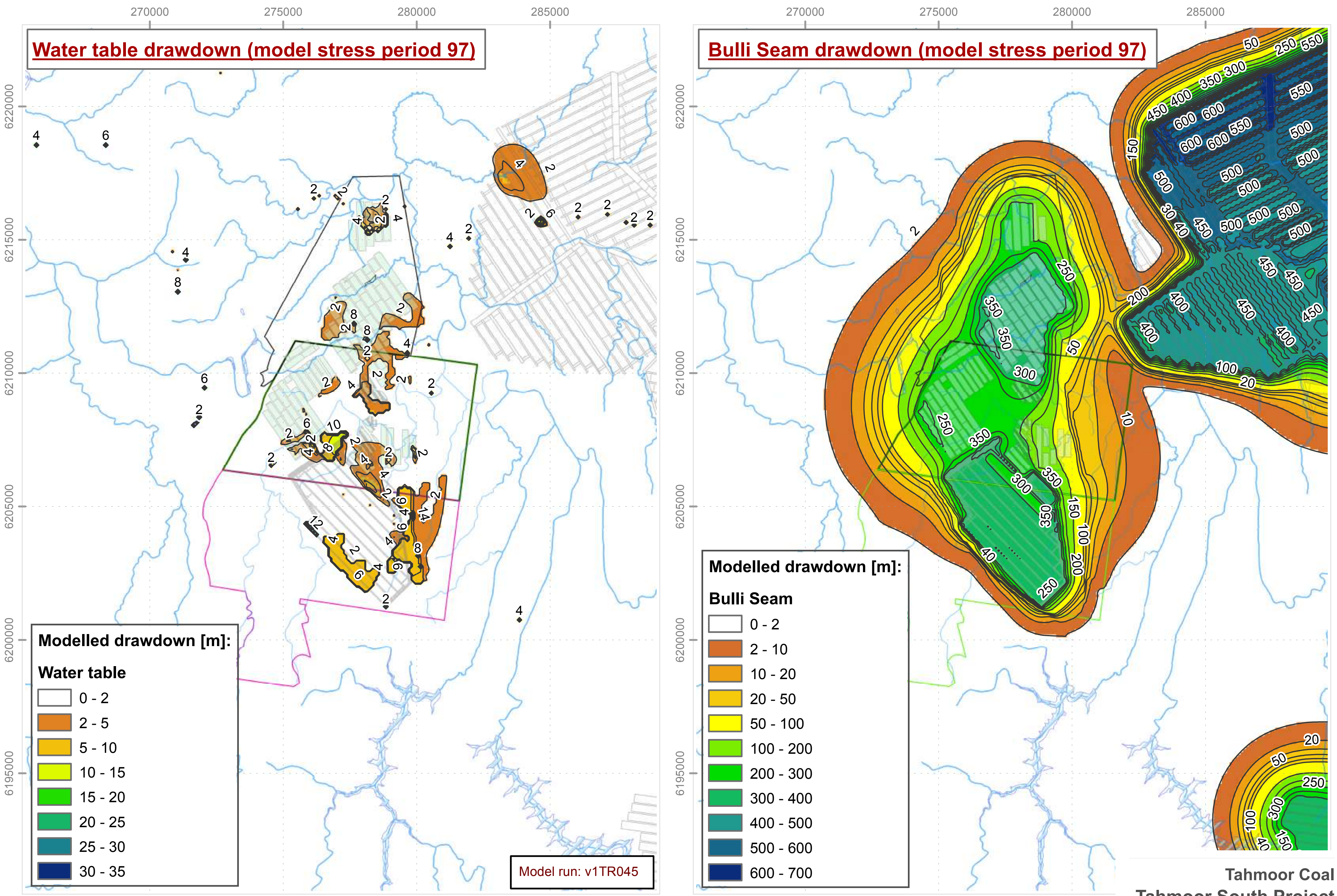



T:\TAHMOOR\Model\Processing\mod2smp\predictiveHydrographs\[PredictiveHydrographs_V4TR045-TR051.xlsx]CHARTS_NorthOfTahSth

## Figure 5-6 Modelled groundwater levels near Thirlmere Lakes




## Figure 5-7 Modelled pressure head cross-section




Scale: 175,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

**Modelled drawdown in the water table and Bulli Seam: during stress period 97 (June 2034 - end of mining Tahmoor South)**

Tahmoor Coal
Tahmoor South Project

**Figure 5-8**

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH004_BulliSeamDDN_A4P.mxd
Rev: A - 1/11/2018 | by: B.White

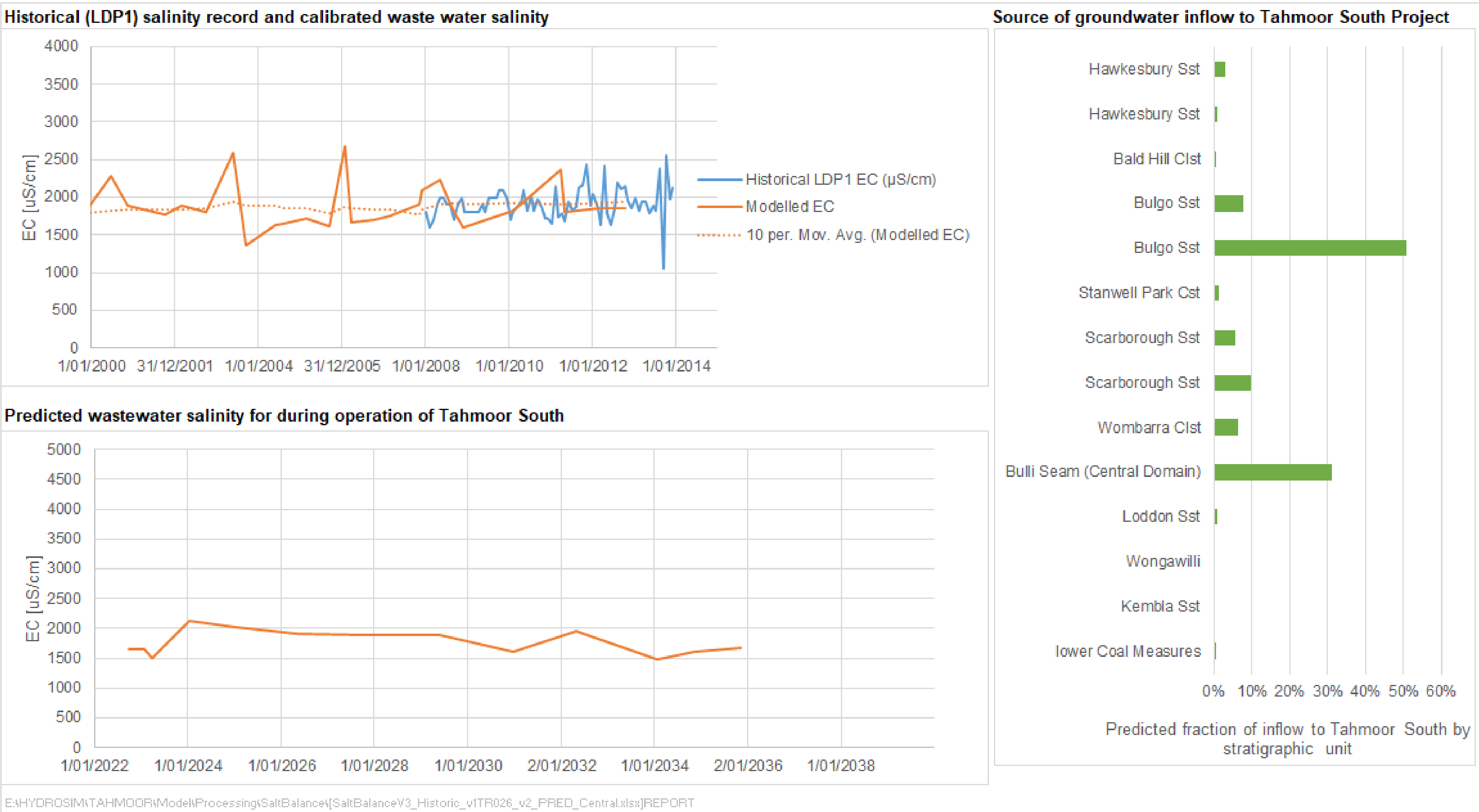
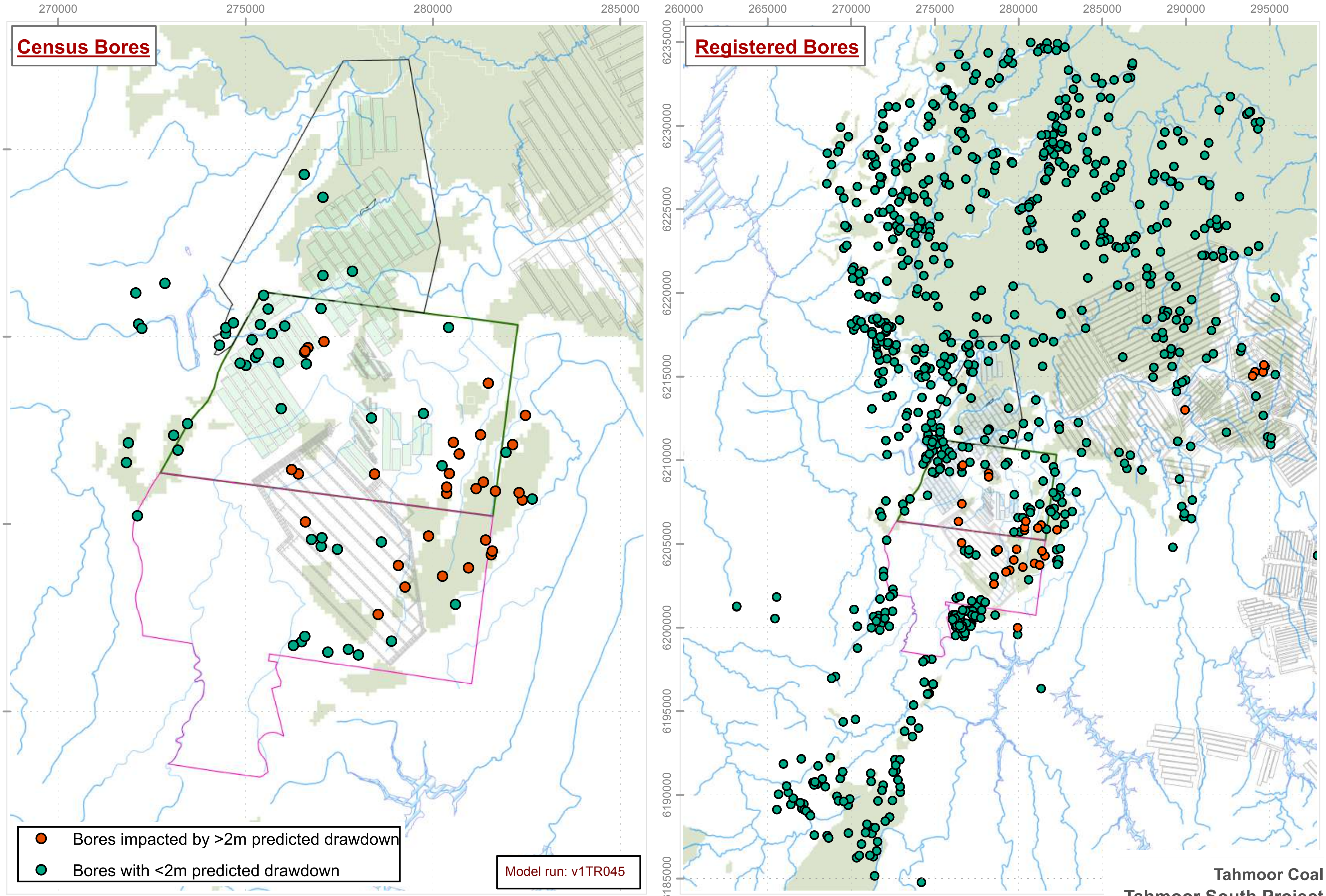



**Figure 5-9 Historical and Predicted Salinity of Mine Inflow**




Tahmoor Coal
Tahmoor South Project

Scale: 125,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

## Distribution of Drawdown Impacts on Groundwater Users

**Figure 6-1**

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH004_BoreDDN_A4P_version2.mxd
Rev: A - 12/10/2018 | by: B.White

This page has been left blank intentionally.

# Tahmoor South Project EIS

# Review of the Numerical Groundwater Model

By
Dr. S.A. Prathapar
NSP Pty Ltd Trading as Prathapar & Associates
5 Yaralla Place, Baulkham Hills, NSW 2153
ABN 34 096 467 711
November 2018

## Executive Summary

HydroSimulations (HS), developed a numerical groundwater model to provide the groundwater assessment for the Environmental Impact Statement (EIS) for the Tahmoor South Coal Project ("the Project"), targeting the Bulli Seam Coal resource within Consolidated Coal Leases 716 and 747.

An Independent Peer Review of this model is provided in this report. The review initially assessed whether the model is developed as per the Australian Groundwater Modelling Guidelines (Barnett et al. 2012). Subsequently the review assessed the impacts predicted by the model against the Aquifer Interference Policy of NSW.

The reviewer considers that HS has utilised all data available to develop the conceptual model and have used the state-of-the-art software to model the impact of proposed mining at Tahmoor South. The model development and calibration meet the Australian Groundwater Modelling Guidelines, and the scenarios are selected to provide guidance to key issues. The uncertainty analysis is very informative to show the limitations of what a model can do; but also, to show how a model calibration helps better estimates of parameters estimated by point-based direct methods.

The groundwater impact assessment sections adequately meet the requirements of the NSW AIP. The calibrated model is considered to have Class 2 level of confidence and fit-for-purpose to predict impacts.

Appropriate recommendations to address potential impact of proposed mining against NSW AIP are also provided by HS.

## Compliance checklist

***1. Are the model objectives and model confidence level classification clearly stated?***
Although the model objectives are not explicitly stated, they are deducible from section 1.1, that is to assess potential impact of proposed mining against SEARS (1.1.1), NSW AIP (1.1.2) and DoE (Section 1.1.3). The Scope of Work in section 1.2 includes a good summary of objectives. The Section 7 also summarises the objectives adequately.

The reviewer agrees with HS that the confidence level of this model is Class 2. It is also noted that several key indicators of Class 3 confidence level have been met by HydroSimulations.

***2. Are the objectives satisfied?***

Assessing against the summary in Section 1.2

- A 3D regional scale numerical groundwater model based on available data has been developed. The conceptual model adequately represents the data available and the major impacts to be assessed. Although, an assessment of impact on O'Hares Creek and Macquarie Rivulet was desired, the model domain does not include them. A satisfactory explanation, that the far field impacts from mining do not reach the boundaries of the modelling and hence are not anticipated to reach beyond the model to these GDEs, has been provided.
- Steady-state and transient model calibration to observed groundwater level data, mine in-flows and base flows had been completed. Calibration statistics (SRMS 3.7 for the model), for observed groundwater level data is acceptable.
- Transient simulation period well exceeds the required minimum 100 year simulation, and covers 'full recovery' of groundwater levels.
- The groundwater impact assessment sections adequately meet the requirements of the NSW AIP.

***3. Is the conceptual model consistent with objectives and confidence level classification?***

Yes.

***4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?***
Not sure whether another independent reviewer had previously reviewed the conceptual model. I am not a geologist, but I note that all necessary – spatially and temporally varying data to conceptualise the model - data had been accessed. Sources include Tahmoor Coal's geological database. The conceptualisation is consistent with the geological model for Tahmoor North.

***5. Does the model design conform to best practice?***
Yes. The design considers the geology, stress periods, boundary conditions, surface hydrologic features, rainfall and evaporation adequately.

The use of Quad-tree discretisation around the Thirlmere lakes may not have helped model performance and assessment against NSW AIP requirements. It is noted that the hydrogeological process affected mining is a vertical one – fracture induced connectivity and changes to vertical fluxes. Quad-Tree discretisation may have added unnecessary computing burden. However, it will not diminish model's credibility. CVFD size of 100 m near the project area is appropriate as the long walls are of 200-300 m width.

The use of DRAIN package to model long walls is appropriate. The DRAIN package will set the head to atmospheric pressure (zero), and it is possible that CVFDs adjacent to DRAIN cells may have very high head value, resulting in convergence issues. Hence a high HCLOSE is accepted, noting that it has not contributed to high mass balance error.

Equating stress periods to longwalls activating or ceasing, is true to the definition of the term 'stress period'.

***6. Is the model calibration satisfactory?***
Yes. SRMS for each stratigraphic in Table 4-3 is very useful. The Average Residual column does not add value.

***7. Are the calibrated parameter values and estimated fluxes plausible?***
Yes. Necessary evidence for hydraulic conductivity is presented in Fig-5. Storage parameters and recharge rates selected are within the range reported in literature.

***8. Do the model predictions conform to best practice?***
Yes.

***9. Is the uncertainty associated with the predictions reported?***
HS acknowledges that there is uncertainty associated with the choice or calibration of enhanced permeability within the vertical column above and below the longwall areas that constitutes the EPZ.

The Uncertainty of the parameters used in the model had been carried out using GENLINPRED, is commendable. I have not seen this done by other Groundwater EIS models. Discussion on 'identifiability' is very good.

***10. Is the model fit for purpose?***
Yes, as a model with Class 2 confidence level. Further improvements to the model, as listed in Section 7.1 are supported. Furthermore, reconsider the size of CVFD and take advantage of MODFLOW USG in 'full'.

# Review checklist

## 1. Planning

1.1. Are the project objectives stated? Yes.
1.2. Are the model objectives stated? Yes.
1.3. Is it clear how the model will contribute to meeting the project objectives? Yes.
1.4. Is ~~a groundwater~~a groundwater model the best option to address the project and model objectives? Yes. A groundwater model is the only option for this task. Data, information and knowledge, should be parsed carefully and linked to governing physical laws is the only way we could get an impression of what may happen due to stressing (pumping) a natural system.
1.5. Is the target model confidence-level classification stated and justified? Yes.
1.6. Are the planned limitations and exclusions of the model stated? Yes.

## 2. Conceptualisation

2.1. Has a literature review been completed, including examination of prior investigations? Yes. In Sections 2 and 3.

2.2. Is the aquifer system adequately described? Yes. Consistent with previous models.

2.3. Hydrostratigraphy including aquifer type (porous, fractured rock ...):

- 2.3.1. Lateral extent, boundaries and significant internal features such as faults and regional folds: Yes. Faults are included.
- 2.3.2. Aquifer geometry including layer elevations and thicknesses: Yes.
- 2.3.3. Confined or unconfined flow and the variation of these conditions in space and time? Yes.

2.4. Have data on groundwater stresses been collected and analysed?

- 2.4.1. Recharge from rainfall, irrigation, floods, lakes: Yes.
- 2.4.2. River or lake stage heights; Rivers and Dams had been noted. A very credible analysis of surface water processes, is presented.
- 2.4.3. Groundwater usage (pumping, returns, etc.):
- 2.4.4. Evapotranspiration; Yes.
- 2.4.5. Other?

2.5. Have groundwater level observations been collected and analysed?

- 2.5.1. Selection of representative bore hydrographs Yes. .
- 2.5.2. Comparison of hydrographs Yes to demonstrate vertical gradients as well as horizontal gradients.
- 2.5.3. Effect of stresses on hydrographs: Satisfactory.
- 2.5.4. Watertable maps/piezometric surfaces? Yes
- 2.5.5. If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data? Not relevant.

2.6. Have flow observations been collected and analysed?

- 2.6.1. Base flow in rivers; Yes.
- 2.6.2. Discharge in springs;
- 2.6.3. Location of diffuse discharge areas? No. May not be present within the model domain.

2.7. Is the measurement error or data uncertainty reported?

- 2.7.1. Measurement error for directly measured quantities (e.g. piezometric level, concentration, flows); Yes.
- 2.7.2. Spatial variability/heterogeneity of parameters: Yes. We believe all available details has been provided.
- 2.7.3. Interpolation algorithm(s) and uncertainty of gridded data? Not applicable.

2.8. Have consistent data units and geometric datum been used? Yes.

2.9. Is there a clear description of the conceptual model?

- 2.9.1. Is there a graphical representation of the conceptual model? Yes.
- 2.9.2. Is the conceptual model based on all available, relevant data? Yes.

2.10. Is the conceptual model consistent with the model objectives and target model confidence level classification? Yes.

- 2.10.1. Are the relevant processes identified? Yes.
- 2.10.2. Is justification provided for omission or simplification of processes? Yes, when required.

2.11. Have alternative conceptual models been investigated? No

## 3. Design and construction

3.1. Is the design consistent with the conceptual model? Yes.

3.2. Is the choice of numerical method and software appropriate?: Yes.

3.2.1. Are the numerical and discretization methods appropriate? Yes.

3.2.2. Is the software reputable? Yes. MODFLOW-USG.

3.2.3. Is the software included in the archive or are references to the software provided? Yes.

3.3. Are the spatial domain and discretization appropriate?

3.3.1. 1D/2D/3D. This is a 3D model, as necessary to meet modelling objectives.

3.3.2. Lateral extent : Yes, for most part. Model boundaries are chosen far away from the project site. Hence errors associated with assumptions will not any impact on the model performance and results.

3.3.3. Layer geometry? Yes.

3.3.4. Is the horizontal discretization appropriate for the objectives, problem set, conceptual model and target confidence level classification? A compromise has been made considering data availability, processing time and desired accuracy of results in deciding the discretisation. See comments in the previous section.

3.3.5. Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction? Yes.

3.4. Are the temporal domain and discretisation appropriate?

3.4.1. Steady state or transient: Steady state followed by transient,

3.4.2. Stress periods: Yes. Wisely defined!

3.4.3. Time steps? Yes.

3.5. Are the boundary conditions plausible and sufficiently unrestrictive? Yes.

3.5.1. Is the implementation of boundary conditions consistent with the conceptual model? Yes.

3.5.2. Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained? Yes. Based on initial water levels, water courses, lakes etc.

3.5.3. Is the calculation of diffuse recharge consistent with model objectives and confidence level? Yes.

3.5.4. Are lateral boundaries time-invariant? No.

3.6. Are the initial conditions appropriate?

3.6.1. Are the initial heads based on interpolation or on groundwater modelling? Yes.

3.6.2. Is the effect of initial conditions on key model outcomes assessed? No.

3.6.3. How is the initial concentration of solutes obtained (when relevant)? Not applicable.

3.7. Is the numerical solution of the model adequate?

3.7.1. Solution method/solver: Yes.

3.7.2. Convergence criteria: Reported. Higher than normally used in models. But as a % of the noise in VWP readings, acceptable.

3.7.3. Numerical precision: Satisfactory

## 4. Calibration and sensitivity

4.1. Are all available types of observations used for calibration? Yes. It is innovative to calibrate against four variables simultaneously.

4.1.1. Groundwater head data : Yes

4.1.2. Flux observations : Yes

4.1.3. Other: Hydraulic Conductivity

4.2. Does the calibration methodology conform to best practice? Yes.

4.2.1. Parameterisation

4.2.2. Objective function

4.2.3. Identifiability of parameters

4.2.4. Which methodology is used for model calibration? Inversion to improve initial estimates, followed by trial & error to improve calibration.

4.3. Is a sensitivity of key model outcomes assessed against?

4.3.1. Parameters – Yes. Especially sensitivity to Fracture zones and faults

4.3.2. Boundary conditions. No.

4.3.3. Initial conditions: No.

4.3.4. Stresses: Yes. Null, all mines except Tahmoor South, and all mines.

4.3.5. Other: Yes.

4.4. Have the calibration results been adequately reported? Yes.

4.4.1. Are there graphs showing modelled and observed hydrographs at an appropriate scale? Yes

4.4.2. Is it clear whether observed or assumed vertical head gradients have been replicated by the model? Yes.

4.4.3. Are calibration statistics reported and illustrated in a reasonable manner? Yes.

4.5. Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated? Model is sufficiently calibrated.

4.5.1. Spatially:

4.5.2. temporally : Yes.

*4.6.* Are the calibrated parameters plausible? Yes. K values, stream flows and discharge to voids are all in plausible range.

4.7. Are the water volumes and fluxes in the water balance realistic? Yes.

4.8. Has the model been verified? No. Reason for not doing so is acceptable

## 5. Prediction

5.1. Are the model predictions designed in a manner that meets the model objectives? Yes.

5.2. Is predictive uncertainty acknowledged and addressed? No.

5.3. Are the assumed climatic stresses appropriate? Yes.

5.4. Is a null scenario defined? Yes.

5.5. Are the scenarios defined in accordance with the model objectives and confidence level classification? Yes.

5.5.1. Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence? Not applicable

5.5.2. Are well losses accounted for when estimating maximum pumping rates per well? Not relevant.

5.5.3. Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence? Not relevant.

5.5.4. Are the assumed stresses and timescale appropriate for the stated objectives? Yes.

5.6. Do the prediction results meet the stated objectives? Yes.

5.7. Are the components of the predicted mass balance realistic?

5.7.1. Are the pumping rates assigned in the input files equal to the modelled pumping rates?

5.7.2. Does predicted seepage to or from a river exceed measured or expected river flow? N/A.

5.7.3. Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)? No

5.7.4. Is diffuse recharge from rainfall smaller than rainfall? Yes.

5.7.5. Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge? No.

5.8. Has particle tracking been considered as an alternative to solute transport modelling? Not applicable.

## 6. Uncertainty

6.1. Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction? Yes. GENLINPRED analysis.

6.2. Is the model with minimum prediction-error variance chosen for each prediction? Not relevant.

6.3. Are the sources of uncertainty discussed?

6.3.1. measurement of uncertainty of observations and parameters Yes.

6.3.2. structural or model uncertainty Yes.

6.4. Is the approach to estimation of uncertainty described and appropriate? Not relevant because a stochastic approach to uncertainty analysis was not undertaken.

6.5. Are there useful depictions of uncertainty? Not relevant.

## 7. Solute transport (Not Applicable).

7.1. Has all available data on the solute distributions, sources and transport processes been collected and analysed?

7.2. Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?

7.3. Is the choice of numerical method and software appropriate?

7.4. Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?

7.5. Is there sufficient basis for the description and parameterisation of the solute transport processes?

7.6. Are the solver and its parameters appropriate for the problem under consideration?

7.7. Has the relative importance of advection, dispersion and diffusion been assessed?

7.8. Has an assessment been made of the need to consider variable density conditions?

7.9. Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?

7.10. Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?

7.11. Is the calibration based on meaningful metrics?

7.12. Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis?

7.13. Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?

7.14. Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings?

7.15. Does the report address the role of geologic heterogeneity on solute concentration distributions?

## 8. Surface water–groundwater interaction

8.1. Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives? Yes.

8.2. Is the implementation of surface water–groundwater interaction appropriate? Yes.

8.3. Is the groundwater model coupled with a surface water model? No. But the results are discussed together with results from a surface water model.

8.3.1. Is the adopted approach appropriate?? Yes, very sound analysis of surface water groundwater interactions.

8.3.2. Have appropriate time steps and stress periods been adopted? Not applicable

8.3.3. Are the interface fluxes consistent between the groundwater and surface water models? Not applicable

# Assessment In terms of NSW AIP (Section 6.10)

The reviewer considers that the assessment presented in Section 6.10 is consistent with the AIP of NSW.

# Tahmoor South Project EIS

# Review of the Numerical Groundwater Model

## Assessment Against IESC Check List

By
Dr. S.A. Prathapar
NSP Pty Ltd Trading as Prathapar & Associates
5 Yaralla Place, Baulkham Hills, NSW 2153
ABN 34 096 467 711
November 2018

### *Description of the proposal*

☐ A regional overview of the proposed project area including a description of the geological basin, coal resource, surface water catchments, groundwater systems, water-related assets, and past, current and reasonably foreseeable coal mining and CSG developments.

☐ A description of the statutory context, including information on the proposal's status within the regulatory assessment process and on any water management policies or regulations applicable to the proposal.

☐ A description of the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-related assets.

☐ A description of how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions.

### *Groundwater*

*Context and conceptualisation*

✓ Descriptions and mapping of geology at an appropriate level of horizontal and vertical resolution including:
- definition of the geological sequence/s in the area, with names and descriptions of the formations with accompanying surface geology and cross-sections.
- definitions of any significant geological structures (e.g. faults) in the area and their influence on groundwater, in particular, groundwater flow, discharge or recharge.

✓ Values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and storage characteristics) for each hydrogeological unit.

✓ Data to demonstrate the varying depths to the hydrogeological units and associated standing water levels or potentiometric heads, including direction of groundwater flow, contour maps, hydrographs and hydro-chemical characteristics (e.g. acidity/alkalinity, electrical conductivity, metals, major ions). Time series data representative of seasonal and climatic cycles.

✓ Description of the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.

✓ Assessment of the frequency, location, volume and direction of interactions between water resources, including surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.

*Analytical and numerical modelling*

- ✓ A detailed description of all analytical and/or numerical models used, and any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.
- ✓ Undertaken in accordance with the Australian Groundwater Modelling Guidelines[8], including peer review.
- ✓ Identification of the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.
- ✓ An explanation of the model conceptualisation of the hydrogeological system or systems, including key assumptions and model limitations, with any consequences described.
- ✓ Calibration with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow).
- ✓ Consideration of a variety of boundary conditions across the model domain, including constant head or general head boundaries, river cells and drains, to enable a comparison of groundwater model outputs to seasonal field observations.
- ✓ Representations of each hydrogeological unit, the thickness, storage and hydraulic characteristics of each unit, and linkages between units, if any.
- ✓ Sensitivity analysis of boundary conditions and hydraulic and storage parameters, and justification for the conditions applied in the final groundwater model.
- ✓ Representation of the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the development activities.
- ✓ An assessment of the quality of, and risks and uncertainty inherent in, the data used to establish baseline conditions and in modelling, particularly with respect to predicted potential impact scenarios.
- ✓ Incorporation of the various stages of the proposed development (construction, operation and rehabilitation) with predictions of water level and/or pressure declines and recovery in each hydrogeological unit for the life of the project and beyond, including surface contour maps.
- ☐ A programme for review and update of the models as more data and information become available, including reporting requirements.
- ✓ Information on the time for maximum drawdown and post-development drawdown equilibrium to be reached.

*Impacts to water resources and water-related assets*

- ✓ An assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts:
  - Description of any hydrogeological units that will be directly or indirectly dewatered or depressurised, including the extent of impact on hydrological interactions between water resources, surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with
- ✓ Description of the water resources and water-related assets that will be directly impacted by mining or CSG operations, including hydrogeological units that will be exposed/partially removed by open cut mining and/or underground mining.
- ✓ For each potentially impacted water resource, a clear description of the impact to the resource, the resultant impact to any water- related assets dependent on the resource, and the consequence or significance of the impact.

sea water.

- The effects of dewatering and depressurisation (including lateral effects) on water resources, water-related assets, groundwater, flow direction and surface topography, including resultant impacts on the groundwater balance.
- Description of potential impacts on hydraulic and storage properties of hydrogeological units, including changes in storage, potential for physical transmission of water within and between units, and estimates of likelihood of leakage of contaminants through hydrogeological units.
- Consideration of possible fracturing of and other damage to confining layers.
- For each relevant hydrogeological unit, the proportional increase in groundwater use and impacts as a consequence of the development proposal, including an assessment of any consequential increase in demand for groundwater from towns or other industries resulting from associated population or economic growth due to the proposal.

☐ Description of existing water quality guidelines and targets, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.

✓ An assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.

✓ Proposed mitigation and management actions for each significant impact identified, including any proposed mitigation or offset measures for long-term impacts post mining.

☐ Description and assessment of the adequacy of proposed measures to prevent/minimise impacts on water resources and water-related assets.

*Data and monitoring*

✓ Sufficient physical aquifer parameters and hydrogeochemical data to establish pre-development conditions, including fluctuations in groundwater levels at time intervals relevant to aquifer processes.

✓ A robust groundwater monitoring programme, utilising dedicated groundwater monitoring wells and targeting specific aquifers, providing an understanding of the groundwater regime, recharge and discharge processes and identifying changes over time.

☐ Long-term groundwater monitoring, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.

☐ Water quality monitoring complying with relevant National Water Quality Management Strategy (NWQMS) guidelines[9] and relevant legislated state protocols[10].

***Surface water***

*Context and conceptualisation*

☐ A description of the hydrological regime of all watercourses, standing waters and springs across the site including:

- Geomorphology, including drainage patterns, sediment regime and floodplain features.
- Spatial, temporal and seasonal trends in streamflow and/or standing water levels.

☐ A description of the existing flood regime, including flood volume, depth, duration, extent and velocity for a range of annual exceedance probabilities, and flood hydrographs and maps identifying peak flood extent, depth and velocity.

☐ Assessments of the frequency, volume and

- Spatial, temporal and seasonal trends in water quality data (such as turbidity, acidity, salinity, relevant organic chemicals, metals and metalloids and radionuclides).
- Current stressors on watercourses, including impacts from any currently approved projects.

direction of interactions between water resources, including surface water/ groundwater connectivity and connectivity with sea water.

*Analytical and numerical modelling*

- ☐ Conceptual models at an appropriate scale, including water quality, stores, flows and use of water by ecosystems.
- ☐ Methods in accordance with the most recent publication of Australian Rainfall and Runoff.
- ☐ A programme for review and update of the models as more data and information becomes available.
- ☐ Description and justification of model assumptions and limitations, and calibration with appropriate surface water monitoring data.
- ☐ An assessment of the risks and uncertainty inherent in the data used in the modelling, particularly with respect to predicted scenarios.
- ☐ A detailed description of any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.

*Impacts to water resources and water-related assets*

- ☐ Description of all potential impacts of the proposed project on surface waters, including a clear description of the impact to the resource, the resultant impact to any water-related assets dependent on the resource, and the consequence or significance of the impact, including:
  - Impacts on streamflow under different flow conditions.
  - Impacts associated with surface water diversions.
  - Impacts to water quality, including consideration of mixing zones.
  - Estimates of the quality, quantity and ecotoxicological effects of operational discharges of water (including saline water), including potential emergency discharges, and the likely impacts on water resources and water-related assets
  - Identification and consideration of landscape modifications, for example,
- ☐ Existing water quality guidelines and targets, environmental flow objectives and requirements for the surface water catchment(s) within which the development proposal is based.
- ☐ Identified processes to determine surface water quality and quantity triggers which incorporate seasonal variation but provide early indication of potential impacts to assets.
- ☐ Proposed mitigation actions for each trigger and identified significant impact.
- ☐ Description and adequacy of proposed measures to prevent/minimise impacts on water resources and water-related assets.
- ☐ Description of the cumulative impact of the proposal on surface water resources and water-related assets when all developments (past, present and/or reasonably foreseeable) are considered in combination.

subsidence, voids, onsite earthworks including disturbance of acid-forming or sodic soils, roadway and pipeline networks through effects on surface water flow, surface water quality, erosion and habitat fragmentation of water-dependent species and communities.

- ☐ An assessment of the risks of flooding, including channel form and stability, water level, depth, extent, velocity, shear stress and stream power, and impacts to ecosystems, project infrastructure and the final project landform.

*Data and monitoring*

- ☐ Water quality monitoring complying with relevant National Water Quality Management Strategy (NWQMS) guidelines[5] and relevant legislated state protocols[8].
- ☐ Monitoring sites representative of the diversity of potentially affected water-related assets and the nature and scale of potential impacts, and matched with suitable replicated control and reference sites (i.e. BACI design) to enable detection and monitoring of potential impacts.
- ☐ A surface water monitoring programme collecting sufficient data to detect and identify the cause of any changes from established baseline conditions, and assessing the effectiveness of mitigation and management measures.
- ☐ The rationale for selected monitoring variables, duration, frequency and methods, including the use of satellite or aerial imagery to identify and monitor large-scale impacts.
- ☐ Identification of dedicated sites to monitor hydrology, water quality, and channel and floodplain geomorphology throughout the life of the development proposal and beyond.
- ☐ Ongoing ecotoxicological monitoring, including direct toxicity assessment of discharges to surface waters where appropriate.
- ☐ Specified data sources, including streamflow data, proximity to rainfall stations, data record duration and a description of data methods, including whether missing data has been patched.

***Water-related assets***

*Context and conceptualisation*

- ☐ Identification of water-related assets, including:
  - Water-dependent fauna and flora supported by habitat, flora and fauna (including stygofauna) surveys.
  - Public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource.
- ☐ Identification of GDEs in accordance with the method outlined by Eamus et al. (2006)[11]. Information from the GDE Toolbox[12] and GDE Atlas[13] may assist in identification of GDEs.
- ☐ Identification of the hydrogeological units on which any identified GDEs are dependent.
- ☐ An estimation of the ecological water requirements of identified GDEs and other water-dependent assets.
- ☐ An outline of the water-related assets and associated environmental objectives and the modelling approach to assess impacts to the assets.
- ☐ Conceptualisation and rationale for likely water-dependence, impact pathways, tolerance and resilience of water-related assets. Examples of ecological conceptual models can be found in Commonwealth of

Australia (2015)[2].

- ☐ A description of the process employed to determine water quality and quantity triggers and impact thresholds for water-related assets (e.g. threshold at which a significant impact on an asset may occur).

*Impacts, risk assessment and management of risks*

- ✓ An assessment of direct and indirect impacts on water-related assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs.
- ☐ Estimates of the impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-related assets and ecological processes.
- ☐ Indication of the vulnerability to contamination (for example, from salt production and salinity) and the likely impacts of contamination on the identified water-related assets and ecological processes.
- ☐ Identification and consideration of landscape modifications (for example, voids, onsite earthworks, roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.
- ✓ A description of the potential range of drawdown at each affected bore, and a clear articulation of the scale of impacts to other water users.
- ☐ An assessment of the overall level of risk to water-related assets that combines probability of occurrence with severity of impact.
- ✓ The proposed acceptable level of impact for each water-related asset based on the best available science and site-specific data, and ideally developed in conjunction with stakeholders.
- ☐ Proposed mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed.

*Data and monitoring*

- ☐ Ecological monitoring complying with relevant state or national monitoring guidelines.
- ☐ Sampling sites at an appropriate frequency and spatial coverage to establish pre-development (baseline) conditions, and test hypothesised responses to impacts of the proposal.
- ☐ Concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design).
- ✓ Monitoring that identifies impacts, evaluates the effectiveness of impact prevention or mitigation strategies, measures trends in ecological responses and detects whether ecological responses are within identified thresholds of acceptable change.
- ☐ Regular reporting, review and revisions to the monitoring programme.

***Water and salt balance and water management strategy***

- ☐ Quantitative site water balance model
- ☐ Estimates of the quality and quantity of

describing the total water supply and demand under a range of rainfall conditions and allocation of water for mining activities (e.g. dust suppression, coal washing etc), including all sources and uses.

- ☐ Description of water requirements and onsite water management infrastructure, including modelling to demonstrate adequacy under a range of potential climatic conditions.

operational discharges under dry, median and wet conditions, potential emergency discharges due to unusual events and the likely impacts on water-related assets.

- ☐ Salt balance modelling, including stores and the movement of salt between stores taking into account seasonal and long-term variation.

### *Subsidence – underground coal mines and coal seam gas*

- ☐ Consideration of geological layers and their properties (strength/hardness/fracture propagation) in subsidence modelling.
- ☐ Predictions of subsidence impact on surface topography, water-related assets, groundwater (including enhanced connectivity between aquifers) and movement of water across the landscape[14,15]
- ☐ Description of subsidence monitoring methods, including use of remote or on-ground techniques and explanation of predicted accuracy of such techniques.

### *Final landform and voids – coal mines*

- ☐ Identification and consideration of landscape modifications (for example, voids, onsite earthworks, roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities.
- ✓ An assessment of the adequacy of modelling, including surface water and groundwater quantity and quality, lake behaviour, timeframes and calibration.
- ☐ An assessment of the long-term impacts to water resources posed by various options for the final landform design, including complete or partial backfilling of mining voids, which considers:
  - Groundwater behaviour – sink or lateral flow from void.
  - Water level recovery – rate, depth, and stabilisation point (e.g. timeframe and level in relation to existing groundwater level, surface elevation).
  - Seepage – geochemistry and potential impacts.
  - Long-term water quality, including salinity, pH, metals and toxicity.
  - Measures to prevent migration of void water off-site.

### *Acid-forming materials and other contaminants of concern*

- ☐ Identification of the presence and potential exposure of acid-sulphate soils (including oxidation from groundwater drawdown).
- ☐ Identification of the presence and volume of potentially acid-forming waste rock and coal reject/tailings material and exposure pathways.
- ☐ Handling and storage plans for acid-forming material (co-disposal, tailings dam, encapsulation).
- ☐ Assessment of the potential impact to water-related assets, taking into account dilution factors, and including solute transport modelling where relevant, representative and statistically valid sampling, and appropriate

analytical techniques.

☐ Identification of other sources of contaminants, such as high metal concentrations in groundwater, leachate generation potential and seepage paths.

☐ Description of proposed measures to prevent/minimise impacts on water resources, water users and water-dependent ecosystems and species.

***Hydraulic stimulation – coal seam gas projects***

☐ A description of the scale of fracturing (number of wells, number of fracturing events per well), types of wells to be stimulated (vertical versus horizontal), and other forms of well stimulation (cavitation, acid flushing).

☐ Measuring and monitoring of fracture propagation.

☐ A description of the water source for hydraulic stimulation, volume of fluid and mass balance (quantities/volumes).

☐ A description of the rules (e.g. water sharing plans) covering access to each water source for hydraulic stimulation and how the project proposes to comply with them.

☐ Quantification of flowback water and a description of how it will be managed.

☐ Potential for inter-aquifer leakage or contamination.

☐ A list of chemicals proposed for use in hydraulic fracturing including:
- names of the companies producing fracturing fluids and associated products
- proprietary names (trade names) of compounds (fracturing fluid additives) being produced
- chemical names of each additive used in each of the fluids
- Chemical Abstract Service (CAS) numbers of each of the chemical components used in each of the fluids
- general purpose and function of each of the chemicals used
- mass or volume proposed for use
- maximum concentration (mg / L or g / kg) of the chemicals used
- chemical half-life data, partitioning data, and volatilisation data
- excotoxicology
- any material safety data sheets for the chemicals or chemical products used.

☐ Chemicals for use in hydraulic fracturing must be identified as being approved for import, manufacture or use in Australia (that is, confirmed by NICNAS as being listed in the Australian Inventory of Chemical Substances[16]).

☐ The use of chemicals should be informed by appropriately tiered deterministic and/or probabilistic hazard and risk assessments, based on ecotoxicological testing consistent with Australian Government testing guidelines[5, 17, 18].

***Cumulative Impacts***

*Context and conceptualisation*

✓ Cumulative impact analysis with sufficient geographic and time boundaries to include all potentially significant water-related impacts.

✓ Cumulative impact analysis identifies all past, present, and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern.

*Impacts*

✓ An assessment of the condition of affected water resources which includes:
- Identification of all water resources likely to be cumulatively impacted by the proposed development.
- A description of the current condition and quality of water resources and information on condition trends.
- Identification of ecological characteristics, processes, conditions, trends and values of water resources.
- Adequate water and salt balances.
- Identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown).

*Mitigation, monitoring and management*

☐ Identification of modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts

☐ Identification of measures to detect and monitor cumulative impacts, pre and post development, and assess the success of mitigation strategies

☐ Proposed adaptive management measures and management responses

☐ An assessment of cumulative impacts to water resources which considers:
- The full extent of potential impacts from the proposed development, including alternatives, and encompassing all linkages include both direct and indirect links, operating upstream, downstream, vertically and laterally.
- An assessment of impacts considered at all stages of the development, including exploration, operations and post closure / decommissioning.
- An assessment of impacts, utilising appropriately robust, repeatable and transparent methods.
- Identification of the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts.
- Identification of opportunities to work with others to avoid, minimise or mitigate potential cumulative impacts.

✓ Identification of cumulative impact environmental objectives

☐ Appropriate reporting mechanisms