APPENDIX C

Groundwater Assessment

TAHMOOR SOUTH AMENDED PROJECT REPORT:

Groundwater Assessment

FOR

Tahmoor Coal Pty Ltd

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EXECUTIVE SUMMARY

The ‘Tahmoor South’ Project (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. Tahmoor Coal Pty Ltd (“Tahmoor Coal”) is seeking development consent for the continuation of mining at Tahmoor Mine, extending underground operations and associated infrastructure south, within the Bargo area. The proposed development seeks to extend the life of underground mining at Tahmoor Mine for an additional 13 years until approximately 2035.

In accordance with the requirements of the *Environmental Planning and Assessment Act 1979* (EP&A Act), the *Environmental Planning & Assessment Regulation 2000* (Regulation) and the Secretary’s Environmental Assessment Requirements (SEARs), an Environmental Impact Statement (EIS) was prepared to assess the potential environmental, economic and social impacts of the Project. The EIS for the Project, including the groundwater assessment (HS, 2018) was placed on public exhibition by the Department of Planning, Industry and Environment (DPIE) (formerly the Department of Planning and Environment [DPE]) from 23 January 2019 to 5 March 2019.

Key issues raised in submissions included concerns relating to the proposed extent of longwall mining, the magnitude of subsidence impacts and the extent of vegetation clearing required for the expansion of the reject emplacement area (REA). In response to these and other issues raised in Government agency, local Council, stakeholder and community submissions, and as a result of ongoing mine planning, several amendments have been made to the proposed development, so as to also further reduce the predicted environmental impacts of the Tahmoor South Project.

Full details of the Amended Project are presented in AECOM (2020a). The key amendments to the Project since public exhibition of the EIS are:

- A revised mine plan, including:
  - an amended longwall panel layout and the removal of LW109;
  - a reduction in the height of extraction within the longwall panels from up to 2.85 metres (m) to up to 2.6 m; and
  - a reduction in the proposed longwall width, from up to 305 m to approximately 285 m.
- A reduction in the total amount of Run-of-Mine (ROM) coal to be extracted over the Project life, from approximately 48 million tonnes (Mt) to approximately 43 Mt of ROM coal, comprising;
  - 30 Mt of coking coal product (reduced from 35 Mt);
  - 2 Mt of thermal coal product (reduced from 3.5 Mt)
- A revised extended REA; including:
  - a reduction in the additional capacity required to accommodate the Project;
  - a reduction in the REA extension footprint, from 43 ha to 11 ha;
  - an increase in the final height of the REA (from RL 305 m to RL 310 m).

This groundwater assessment has been prepared for Tahmoor Coal to assess the impacts of the Amended Project at Tahmoor South. The assessment considers and outlines the differences in impacts compared to the original project as presented in the EIS. In this way, it serves as an update to the groundwater assessment (HS, 2018) (Appendix I of the Tahmoor South EIS).

The groundwater 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 *Australian Groundwater Modelling Guidelines*, sponsored by the National Water Commission (Barnett *et al*., 2012). Submissions by agencies and the community have been considered during the preparation of the Amended Project Report (APR). The conceptual and numerical models incorporate key amended changes made to the Project and try to address as much as possible the submissions on the original EIS.

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 proposed Tahmoor South Amended Project 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, despite there being some limited groundwater drawdown predicted in this area, 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 being minor.

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

Aquifer	Sydney Basin Porous Rock (Nepean Groundwater Source, Management Zone 2)
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water Table 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: • high priority groundwater dependent ecosystem; or • high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR 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). There are no High Priority Culturally Significant Sites in the Study Area listed in the WSP. There are several High Priority Groundwater Dependent Ecosystems (GDEs) in the Study Area: Thirlmere Lakes - There is a possibility of groundwater drawdown of approximately 0.02 m from Tahmoor South Project or <1% of water table fluctuation. This represents a negligible effect. There is a risk of peak drawdown of 0.13 and 0.48 m peak drawdown from cumulative mining in the alluvium underlying the lakes. The cumulative impact groundwater drawdown is less than the 10% criterion at three of the lakes and close to or above the 10% criterion at two of the lakes (9% and 12%). Predicted drawdown due to local groundwater pumping is assessed to be a similar order of magnitude to cumulative mining, noting that pumping rates are uncertain. *More detail on the effects on surface water levels within the lakes is presented in the Surface Water Assessment (HEC, 2020b).* 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. Water supply works: There is likely risk of drawdown in excess of the water supply work drawdown criterion within the Permo-Triassic strata. **Level 2 minimal impact consideration classification.**
Water pressure 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. **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. **Level 1 minimal impact consideration classification.**

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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, West Cliff)
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 Department of Environment and Energy
DPIE	NSW Department of Planning, Industry and Environment (formerly DPE)
DPIE Water	Water division within DPIE
	(formerly DoI Water, Crown Lands and Water, Office of Water)
EC	electrical conductivity
EIS	environmental impact statement
EPA	Environment Protection Authority
EPBC	Environment Protection and Biodiversity Conservation Act 1999
EPL	Environment Protection Licence
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 or HoCF	height of (connected) 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
MODFLOW-USG	UnStructured Grid version of MODFLOW, an industry-standard modelling software package
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 Project is an underground coal project targeting the Bulli Seam coal resource within CCL 716 and CCL 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. 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 EIS for the "Amended Project", which is State Significant Development pursuant to the provisions of Part 4, Division 4.7 of the *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 1.5, 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, 2020c).
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, 2020d).

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 1.5.1, 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 DPIE WATER REQUIREMENTS

DPIE Water also supplied requirements to be addressed 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: ▪ Water Sharing Plan for the Greater Metropolitan Regional Groundwater Sources 2011 (‘WSPGMRGWS’); and ▪ Water Sharing Plan for the Greater Metropolitan Unregulated River Water Sources 2011).	Section 6.3 and Surface Water Assessment (HEC, 2020b).
Compliance with the rules of any relevant legislation;	Sections 1.5 and 0.
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, 2020a).
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 6.11

Additional 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 1.5, 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 0.
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, 2.2.2, and Surface Water Assessment (HEC, 2020b).
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 addressed 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 ENVIRONMENT PROTECTION AUTHORITY (EPA) REQUIREMENTS

The EPA submitted requirements in a letter dated 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 EPBC Act, and the assessment must meet the requirements of the Act and the DoEE. Following the declaration of the Project as 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 1.5.1 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. In addition to the issued SEARs, this may include a great consideration of cumulative impacts and on-going monitoring regimes.	Sections 5 and 6. Cumulative impacts in Section 5, and Section 6. 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 SUBMISSIONS FOLLOWING EIS EXHIBITION

The original EIS for the Project was placed on public exhibition by DPE/DPIE between 23 January and 5 March 2019, and submissions accepted thereafter. Submissions relevant to groundwater were received from IESC, DOI Water (now DPIE Water) and NRAR, Wollondilly Shire and Wingecarribee Shire Councils, OEH, and other agencies, as well as the public.

Further to the submissions, a meeting was held between DPE, DoI Water, NRAR, and DPE's Independent Reviewer in April 2019. Following that meeting the Independent Reviewer requested some clarification on a number of points before issuing a final review (HydroGeoLogic, 2019). Following that, DPIE issued a 'Preliminary Issues' report.

The submissions and review identified a number of aspects to be considered in the APR. A detailed response to individual submissions is presented in the separate 'Response to Submissions' document (AECOM, 2020b). However, a summary of those most relevant to the Groundwater Assessment is presented in **Table 1-1**, including where these have been addressed in this revised Groundwater Assessment.

Table 1-1 Significant issues raised in submissions following the EIS

ISSUE RAISED IN SUBMISSIONS	WHERE ADDRESSED
Incorporation of surface cracking in the groundwater model.	Sections 3.10.4 and 4.6.
Revision of watercourse representation to allow more watercourses to 'leak' water from surface to groundwater.	Section 4.4.4.
Revise the representation of Thirlmere Lakes bed and lake stage elevations, and potentially improve groundwater level calibration in this area.	Section 4.4.5.
Improve groundwater level calibration generally, if possible.	Section 4.8.
Concerns over treatment of geological structures, such as the Nepean Fault zone, but also between Tahmoor mine workings and Thirlmere Lakes.	Section 4.9.1 and 5.2.1
Inclusion of groundwater pumping within the model for calibration and impact assessment purposes.	Sections 3.8.1, 4.4.7 and 5.2.1.
Incorporation of findings from the Thirlmere Lakes Research Program	Section 3.6.1 and 7.2.
Limited uncertainty analysis	Sections 4.10, 5.2.1 and 7.2 and HydroGeoLogic, 2019.

1.3 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 in HS (2018) as carried out for the EIS, including data analysis conceptualisation and modelling, was Peer Reviewed by Dr Prathapar Sanmugan of Prathapar and Associates. The assessment has been subsequently reviewed by agencies and DPIE’s Independent Reviewer (HydroGeoLogic, 2019) as part of the EIS process.

1.4 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 2022 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 m high. Plans and longwall geometry for the Amended 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.

1.5 WATER REGULATION

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

1.5.1 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, and this plan commenced in 2011. This WSP comprises several Groundwater Sources, of which those in the study area 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 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 an annualised limit on entitlement (LTAAEL) of 99,568 ML (NOW, 2011), while the current entitlement is 28,841 ML (based on the WaterNSW *Water Register*). The volume of 'Unassigned Water' is not publicly available and requires confirmation with government.

The Greater Metropolitan Region Unregulated Water Sources WSP 2011 is the relevant plan for surface waters for the Project. Within this WSP the *Upper Nepean and Upstream Warragamba Water Source* is the relevant Water Source, of which the following MZ cover the project site:

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

1.5.2 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 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 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.

1.5.3 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.

1.6 REPORT STRUCTURE

The remainder of this report is structured as follows:

Section 2 describes the background to the 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 the 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 Project, the history of coal mining at Tahmoor and in the Southern Coalfield in general, the water licences held by Tahmoor Coal, as well as 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 2022-2035. 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

2.2.1.1 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 32 was completed on 26/09/2019, and Longwall W1 had just commenced at the time of writing this report. Details of the historical and approved longwalls are presented in **Table 2-1**.

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.

Table 2-1 Tahmoor / Tahmoor North and Western Domain longwall details

Long-wall	Date Start	Date End	Void Width (m)	LW length (m)	Elevation of BUSM (mAHD)	Ground Elevation (mAHD)	Cutting height (m)		Depth of Cover (m)			Ratio Width/Depth			HoCF - Tammetta *H* (mAHD)	Depth to HoCF (m)
Tahmoor / Tahmoor North							**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**		
1	2/03/1987	16/08/1987	190	1050	-127	285.4	2.1	2.6	381	401	419	0.5	0.47	0.45	-18.7	303.3
2	17/08/1987	26/11/1987	190	1050	-119	281.7	2.1	2.1	380	402	408	0.5	0.47	0.47	-14.3	291.7
3	21/03/1988	16/11/1988	180	1120	-129.2	293.9	2.5	2.6	414	423	431	0.46	0.45	0.44	-14.0	307.9
4	5/02/1989	4/06/1989	170	1130	-123	294.4	2.6	2.7	412	421	427	0.46	0.45	0.44	-19.4	308.3
5	5/06/1989	3/12/1989	180	1200	-115.8	297.5	2.5	2.8	402	414	423	0.47	0.46	0.45	9.3	290.9
6	4/12/1989	21/04/1990	180	1200	-110.1	297.4	2.4	2.7	399	408	417	0.48	0.47	0.46	14.7	286.6
7	16/07/1990	28/01/1991	180	1200	-105.4	296.3	2.3	2.5	386	401	412	0.49	0.47	0.46	8.3	289.8
8	17/04/1991	5/12/1991	200	1640	-140.8	273.9	2.5	2.7	386	412	426	0.49	0.46	0.45	2.7	271.9
9	6/12/1991	26/07/1992	180	1220	-94.5	300.1	2.2	2.3	383	395	403	0.5	0.48	0.47	11.3	291.2
10A	27/07/1992	3/12/1992	230	770	-134.7	262	2.7	2.9	400	412	416	0.47	0.46	0.46	21.9	247.4
10B	4/12/1992	16/05/1993	230	710	-150.2	262	2.4	2.5	382	398	418	0.5	0.48	0.45	21.9	247.4
11	17/05/1993	21/01/1994	235	560	-142.5	265.7	2.8	2.9	381	409	417	0.5	0.46	0.46	55.2	238.1
12	22/01/1994	7/07/1994	230	1030	-166.1	247.3	2.6	2.9	393	410	434	0.48	0.46	0.44	7	242.6
13	8/07/1994	11/11/1994	230	830	-170.6	242.5	2.7	2.9	398	411	421	0.48	0.46	0.45	13.8	233.2
14A	31/01/1995	15/06/1995	235	215	-75.3	292.5	2	2.1	388	389	390	0.49	0.49	0.49	31.4	270
14B	16/06/1995	26/06/1996	235	2150	-91.9	292.5	2.2	2.2	373	387	393	0.51	0.49	0.48	31.4	270
15	27/06/1996	7/09/1997	235	2650	-87.4	299.2	2.1	2.3	357	385	402	0.53	0.49	0.47	45.4	271.2
16	8/09/1997	15/02/1999	235	2675	-74.1	306.1	2.1	2.2	340	378	392	0.56	0.5	0.48	54.6	272.8
17	16/02/1999	21/06/2000	235	2555	-63.3	313.3	2.1	2.3	327	375	389	0.58	0.51	0.49	64.5	269.4
18	22/06/2000	2/10/2001	235	2360	-52.6	316.1	2.1	2.3	319	369	387	0.59	0.52	0.49	75.3	264.2

Long-wall	Date Start	Date End	Void Width (m)	LW length (m)	Elevation of BUSM (mAHD)	Ground Elevation (mAHD)	Cutting height (m)		Depth of Cover (m)			Ratio Width/Depth			HoCF - Tammetta *H* (mAHD)	Depth to HoCF (m)
19	3/10/2001	29/09/2002	235	2175	-44.3	317.2	2.1	2.3	306	361	410	0.62	0.53	0.46	84.1	258.6
20	30/09/2002	11/09/2003	235	1445	-103.9	302.7	2.2	2.4	393	407	435	0.48	0.47	0.44	10.6	293.5
21	12/09/2003	30/05/2004	235	1080	-97.4	308.1	2.2	2.3	400	405	409	0.47	0.47	0.46	17.2	293.4
22	2/06/2004	11/07/2005	283	1875	-142.8	283	2.2	2.3	414	425	441	0.46	0.45	0.43	-11	292
23A	7/09/2005	20/02/2006	283	775	-156.7	279.4	2.2	2.2	428	435	449	0.44	0.44	0.42	13	269
23B	15/03/2006	21/08/2006	283	770	-141.8	288.1	2	2.1	415	431	451	0.46	0.44	0.42	8	283
24B	15/10/2006	26/08/2007	283	2260	-153.2	286.2	2.1	2.3	420	440	457	0.45	0.43	0.42	-1	287
24A	15/11/2007	19/07/2008	283	980	-166.4	270.9	2.2	2.3	428	438	462	0.44	0.43	0.41	-49	317
25	22/08/2008	27/02/2011	283	3580	-164.8	278.5	2.2	2.5	422	443	462	0.45	0.43	0.41	-11	286
26	30/03/2011	11/10/2012	283	3480	-175.3	275.5	2.2	2.5	422	450	474	0.45	0.42	0.4	-17	287
27	8/11/2012	22/03/2014	283	3030	-183.3	273	2.2	2.5	424	456	491	0.45	0.42	0.39	-14	282
28	24/04/2014	17/05/2015	283	2620	-196.7	263.3	2.2	2.3	421	460	513	0.45	0.41	0.37	-35	291
29	29/05/2015	13/04/2016	283	2310	-209.5	256.7	2.2	2.3	424	465	498	0.45	0.41	0.38	-45	292
30	26/05/2016	13/04/2017	283	2310	-221.9	250	2.2	2.3	430	473	506	0.44	0.4	0.38	-59	296
31	20/04/2017	17/08/2018	283	2340	-234.1	241.9	2.1	2.2	434	474	512	0.44	0.4	0.37	-83	305
32	28/11/2018	26/09/2019	283	2376	-252	231.1	2.2	2.5	474	487	502	0.4	0.39	0.38	-92	300
Western Domain							**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**		
W1	14/11/2019	1/08/2020	283	1870	-283	226	2	2.1	474	518	547	0.4	0.37	0.35	-117	307
W2	1/08/2020	1/04/2021	283	1675	-283	226	2	2.1	474	518	547	0.4	0.37	0.35	-119	311
W3*	1/05/2021	1/12/2021	283	1425	-267	204	2	2.1	472	503	531	0.4	0.38	0.36	-129	226
W4*	1/12/2021	1/05/2022	283	915	-254	204	1.9	2	455	484	516	0.42	0.39	0.37	-91	256

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2.2.1.2 Tahmoor South

The 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.

2.2.2 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 Dewatering (groundwater)	1642 units

Tahmoor Mine holds a 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) 1389. The discharge points and conditions governing these are dealt with in the Surface Water Impact Assessment (HEC, 2020b).

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

2.3.1.1 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.

Extraction at proposed ‘Western Domain’ panels LW W1-W4 began in September 2019 and is anticipated to finish in June 2022. Proposed LW W1-W4 are oriented north to south, with LW W1 being the longest (Figure 1-2). These panels have all a maximum extraction height of approximately 2.1 m and are 283 m wide.

2.3.1.2 Tahmoor South

The Amended Project consists of 14 longwalls, separated into the ‘A’ and ‘B’ blocks. The panels are numbered 101A-106A and 101B – 108B. These are shown and labelled on **Figure 2-1**. As shown in **Table 2-2**, panel void widths have been revised and are proposed to be 285 m reduced from 305 m in the original EIS mine plan. By comparison, historical panel widths at Tahmoor were 170-235 m (Longwalls 1-21), while the more recent panels (Longwalls 22-onward) were also up to 285 m (**Table 2-1**). Longwall cutting heights at Tahmoor South have also been reduced with a maximum longwall cutting to be up to 2.6 m instead of the 2.9 m proposed in the original EIS.

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. It is proposed that each panel will commence at the south-eastern end, with extraction progressing to the northwest.

Table 2-2 Tahmoor South Amended Project longwall details

Long-wall	Date Start	Date End	Void Width (m)	LW length (m)	Elevation of BUSM (mAHD)	Ground Elevation (mAHD)	Cutting height (m)		Depth of Cover (m)			Ratio Width/Depth			HoCF - Tammetta H (mAHD)	Depth to HoCF (m)
Tahmoor South APR mine plan							Mean	Max	Min	Mean	Max	Min	Mean	Max		
101A	5/07/2022	9/01/2023	285	1720	-103.7	289	2	2.6	372	393	405	0.77	0.73	0.7	58	231
102A	12/02/2023	25/08/2023	285	1730	-93.2	295	2	2.6	373	389	400	0.76	0.73	0.71	71	224
103A	28/09/2023	14/04/2024	285	1740	-81.1	303	2	2.2	373	384	392	0.76	0.74	0.73	77	226
101B	18/05/2024	14/11/2024	285	1440	-105	288	2	2.6	375	393	407	0.76	0.73	0.7	86	202
102B	6/01/2025	15/08/2025	285	1875	-96	301	2	2.6	382	397	407	0.75	0.72	0.7	99	202
103B	29/09/2025	11/08/2026	285	2530	-86.7	307	2	2.6	366	394	404	0.78	0.72	0.71	108	199
104B	14/09/2026	1/09/2027	285	3020	-77.6	312	2	2.6	366	390	400	0.78	0.73	0.71	120	193
105B	6/10/2027	13/11/2028	285	3500	-70.2	317	2	2.6	372	387	400	0.77	0.74	0.71	129	189
106B	20/12/2028	15/04/2030	285	3760	-63	324	3	2.6	373	387	398	0.76	0.74	0.72	144	180
107B	18/05/2030	2/10/2031	285	3790	-55.9	331	3	2.6	374	387	401	0.76	0.74	0.71	154	178
108B	5/11/2031	29/03/2033	285	3820	-47.9	340	3	2.6	366	388	406	0.78	0.73	0.7	162	179
104A	5/05/2033	9/11/2033	285	1760	-73.1	310	2	2.6	374	383	390	0.76	0.74	0.73	85	225
105A	13/12/2033	26/06/2034	285	1800	-62.1	319	2	2.6	365	381	389	0.78	0.75	0.73	96	223
106A	30/07/2034	20/02/2035	285	1820	-53.5	328	2	2.6	373	381	386	0.76	0.75	0.74	108	220
101A	5/07/2022	9/01/2023	285	1720	-103.7	289	2	2.6	372	393	405	0.77	0.73	0.7	58	231

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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).
- proposed Dendrobium Area 5 and Area 6 (South32 / Illawarra Coal) (7 km south east and 11 km east respectively).
- 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 bord and 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 southeast, beyond the Illawarra Escarpment in the east, and into the suburbs of Sydney in the north and northeast. 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 is 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 the nearest Bureau of Meteorology (BoM) stations as well as from two local Data Drill records produced by SILO (**Table 3-1**). 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.

Because of the gaps in the data series at each of the Picton Council Depot and Buxton stations, the SILO records have been used in this study, however we have compared all these datasets for common periods to determine that they are representative (given earlier criticism by DoI Water, this comparison was presented to DoI Water in a meeting in April 2019 to confirm that the data was appropriate).

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

STATION NAME	STATION NUMBER	Easting (zone56)	Northing (zone56)	Mean Rainfall (mm/a)	Elevation (mAHD)
Picton Council Depot	068052	280100	6216600	805	165
Buxton	068166	271750	6208200	858	420
SILO-Picton	0.05degree tile	150.60 deg	-34.15 deg	757	195
SILO-Bargo	0.05degree tile	150.60 deg	-35.25 deg	823	318

mm/a = mm/annum

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, whereas rainfall is 750-800 mm/a at Lake Burragorang.

The long-term record and cumulative residual trend from the ‘Bargo’ SILO tile 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 in the period 1900-1950, 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 1997-2010), as well as the current dry conditions (2017-onwards).

3.3 EVAPORATION

The closest climate station with available pan evaporation (PE) data is Prospect Reservoir (Station 067019[1]), located about 40 km to the northeast of the Project at elevation 61 mAHD. Mean annual PE at Prospect is 1,314 mm/a. The SILO Data Drill records described above indicate that mean annual pan evaporation for the area is 1430-1480 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[2] 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.

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[1] http://www.bom.gov.au/climate/averages/tables/cw_067019_All.shtml#other

[2] http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp

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 Project, and the 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 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 of Little River, and this in turn is a tributary of 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 Gandangarra, 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 sites around the Thirlmere Lakes (**Table 3-2**, **Figure 3-5**), while the approximate lowest lake-bed elevations were provided by HEC (2020). These are revised slightly from those reported in HS (2018).

Table 3-2 Thirlmere Lakes gauging sites

SITE	Waterbody	Easting	Northing	Zero Gauge (mAHD)	Lowest lake bed elevation (mAHD)
212067	Werri Berri	273500	6210300	299.74	299.5
212068	Gandangarra	273700	6210950	301.47	301.0
212066	Couridjah	273630	6209350	300.26	300.0
212065	Baraba	273030	6209470	303.94	303.25
212063	Nerrigorang	272870	6210380	299.33	297.97
212064	Blue Gum Ck	272200	6210100	302.87	N/A

3.4.2 RESERVOIRS

The Tahmoor Mine and the proposed Tahmoor South Project are situated between water supply catchments (‘Special Areas’) managed by WaterNSW. **Table 3-3** lists the five major water storage reservoirs in the Study Area, each within one of the Special Areas, 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**.

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. The surface water monitoring network commenced in 2012 along watercourses surrounding the Project area. Surface water monitoring stopped at Eliza Creek (between November 2015-July 2018) before stopping again from September 2018 and along Dog Trap Creek with a gap in data from November 2015-to February 2019. Other surface monitoring sites were active in 2019, recording flow (ML/d) and levels (mAHD). Refer to the Surface Water Assessment (HEC, 2020a) for more details regarding the monitoring site status around the Project area.

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
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, 2020b).

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 Pell's 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 assessing 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).

3.6.1.1 Thirlmere Lakes Inquiry

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.*

3.6.1.2 OEH Thirlmere Lakes Research Program

In consideration of the on-going research coordinated by NSW OEH, some draft outputs (as presented at a public information day in early 2019) have been reviewed for this groundwater assessment. A number of key points from that are identified below, however, research findings are only preliminary at this stage, and we assume will be integrated by the researchers.

- ANSTO indicate that inputs to the lakes, even during the relatively dry period on which the preliminary findings are based, were rainfall-dominated.
- Preliminary findings by ANSTO indicate that groundwater in the piezometer GW75409/1 is connected to lake water, albeit with a delayed response, while the deep piezometer GW75409/2 shows no connection to lake water.
- ANSTO indicated that evaporation is the main process of water loss at the lakes, with Gandangarra being the lake with greatest evaporative losses, then Nerrigorang, Werri berry, Couridjah and Baraba the least. Associated with this, as-yet “unexplained losses” (e.g. loss to groundwater system, pumping, other?) are apparent in four of the lakes but not at Gandangarra.

It is acknowledged that future assessments may need to be revised to consider relevant findings from the Research Program[3].

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);

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[3] Available: https://www.environment.nsw.gov.au/research-and-publications/our-science-and-research/our-research/water/freshwater-and-wetlands/thirlmere-lakes-research

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 (2018), 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.

3.6.2 WIRRIMBIRRA SANCTUARY

The Heritage Council of NSW's submission stated concern regarding effects on watercourses and natural features within the Wirrimbirra Sanctuary (although this might be regarded as a cultural site, rather than strictly a GDE). This property is situated on Tea Tree Hollow and one of its main tributaries and within the footprint of proposed panels 101A-104A (**Figure 3-4**).

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**. The geology around Tahmoor 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, and the Shoalhaven Group.

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.

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

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

the Thirlmere Lakes, and is recorded as Cretaceous age 'laterised alluvium' (Moffit, 1999). Based on the logs in **Table 3-6** the Thirlmere Lakes may reach a thickness of 50-60 m.

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 the alluvial sequence is thinner (~6 m) 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

The alluvium around Thirlmere lakes is shown to consist primarily of sandy clays and clayey sands between 1-9 m thick, with some peats/organics interspersed, sometimes with a thin layer of sandier alluvium at surface. These bore logs were sourced from the NSW government bore database and from Vorst (1974) and Pells (2011).

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 – noting that recent UNSW drilling conducted as part of the OEH Research Program intersected the Bald Hill Claystone at a depth of 102 m near 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 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

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

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 seismic surveys of the site (Velseis, 2013). As discussed with the IESC at a workshop between the IESC and Southern and Western Coalfield operators in March 2019, the data available on structures at the EIS phase is limited. Mine operators investigate structures in greater detail as mine planning proceeds, with more horizontal drilling and other resources committed to understanding how geology and structure may constrain or effect the development of the mine.

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 to be 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 potentially 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.

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

3.7.4 COAL RESOURCES

Proposed mining operations at Tahmoor South will 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 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**. Many of the bores captured in the census are also registered.

Based on a search of the Water Register, Pinneena and BoM Groundwater Explorer information was obtained, 791 bores within the Study Area returned matches with Water Access Licences (WAL). Based on data supplied by WaterNSW in 2019, there is a licensed groundwater entitlement of approximately 4,060 ML/a for private or small scale government use. There are There is some additional 987,000 ML/a associated with licences held by government agencies (these may be groundwater and surface water licences). 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 by purpose is presented in **Figure 3-13**. These estimates exclude groundwater licences held by mines, including Tahmoor (Section 2.2.2), for groundwater entering mine workings.

Within the registered bore and census datasets, average bore depth is 95 m, median depth is 85 m, and ranging from 3-650 m, with a few that are suspected to be exploration bores over 1000 m). 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.

A number of submissions requested that groundwater usage be simulated in the groundwater model. A review of the NSW Water Register for records of actual usage (compared to licensed entitlement) for the whole *Nepean Sandstone Groundwater Source* returned:

- '0' ML of actual usage for the 13 water years from 2004/2005 to 2016/2017;
- 2969.3 ML for 2017/2018 (usage equal to approximately 12% of all entitlement in the Groundwater Source)
- 2853.8 ML for the water year 2018/2019 (11% entitlement), and
- 20.4 ML for 2019/2020 (year to date).

The records of zero usage are considered by HS to be 'false' zeroes, i.e. simply a lack of metering and estimated use. The lack of records indicates a high degree of uncertainty with estimating historical groundwater usage for this study.

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 Project area is more than adequate for both baseline monitoring and to facilitate operational monitoring, although communication with GES (who carry out some groundwater monitoring at Tahmoor) confirms that over time there have been a number of piezometers in the Tahmoor South network that have failed (see also the Data Quality Assessment at the end of Section 3.8.3).

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. NSW government requirements are that baseline monitoring should 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 Project is planned to commence in 2022, so there will be a sufficient baseline dataset before operations begin. However, HS recommend that this network be re-assessed and new or replacement bores/piezometers be installed, pending project approval.

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 (VWP) 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.

There are five shallow bores (P12-P17) that have been installed recently at Tahmoor Western Domain, monitoring the shallow Hawkesbury Sandstones and regolith. Groundwater level data for P12-P17 started being collected in May-June 2019. Note that P15 has not been drilled yet due to a land access issue. Their locations are shown in **Figure 3-5**.

Further bore installations have been conducted along Redbank Creek (P10-P11, P19) and Myrtle Creek (P18, P20-P25) at Tahmoor North. The data loggers in these shallow bores have been recording groundwater levels since mid-2019 and June-September 2019 respectively. Logger data at P20, P24, P25 and P26 is not available yet.

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

Group	Bore	2008		2009		2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		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	X	X	X	X	■	sub-daily
	TNC040				X	X	X	X	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	X	X	X	X	X	■	sub-daily
LW10A	TBF040c													X												monthly
local shallow piezos / bores	P1	X	X	X	X	X	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	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	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	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	X	X	X	X	■	Daily
	P8		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	■	Daily
	P9																				X	X	X	X	X	Daily
	P10																							X	X	Daily
	P11																							X	X	Daily
	P12																								X	Daily
	P13																							X	X	Daily
	P14																								X	Daily
	P16																							X	X	Daily
	P17																								X	Daily
	P18																								X	Daily
	P19																								X	Daily
	P21																								X	Daily
	P22																								X	Daily
	P23																								X	Daily
Pit Area	PT1																								X	Monthly
	PT2																								X	Monthly
	PT4																								X	Monthly
NOW obs. bores	GW075409/1								X	X	X	X	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	X	X	X	X	■	Monthly, then daily
	GW075410								X	X	X	X	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	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	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	X	X	X	X	X	X	X	X	X	X	■	sub-daily
(multi)	TBC024										X	X	X	X	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	X	X	X	X	■	sub-daily
(multi)	TBC027											X	X	X	X	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	X	X	X	X	■	sub-daily
(multi)	TBC033											X	X	X	X	X	X	X	X	X	X	X	X	X	■	sub-daily
(multi)	TBC034											X	X	X	X	X	X	X	X	X	X	X	X	X	■	sub-daily
(dual)	TBC036											X	X	X	X	X	X	X	X	X	X	X	X	X	■	sub-daily
(multi)	TBC037																									sub-daily
(multi)	TBC038											X	X	X	X	X	X	X	X	X	X	X	X	X	■	sub-daily
(multi)	TBC039												X	X	X	X	X	X	X	X	X	X	X	X	■	sub-daily

There are 30 monitoring bores installed around the 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.

There are seven bores monitoring groundwater levels within the Reject Emplacement Area (REA1-REA7) at Tahmoor Mine. Groundwater level data was collected at REA1-REA2 from July 2013 to mid 2019 and commenced at RE3-REA7 since August 2019. Further recommendations regarding water quality sampling are provided in Section 7.2.

Monitoring bore (PT1-PT4) located at Tahmoor North (early historical workings area) have two single measurements in September 2019. Note that PT3 collapsed on drilling and no piezometers was installed. 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. In future, more monitoring bores and groundwater level information may be available as part of the OEH Research Program.

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 (Section 6.11).

Water quality sampling has been carried out at 29 local bores since early 2013, six 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, 2020a).

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.

3.8.3.1 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 drawdown of 6 m from 276 mAHD as LW22 is extracted, 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, before declining gradually by about 3 m due to on-going dry conditions;
- 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. Water levels have declined by 5 m since then in response to on-going dry conditions;
- 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 late 2019 water levels declined from 244 to 240 mAHD due to lack of rainfall;
- 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, and water levels have oscillated between 248-249 mAHD since then, even in spite of dry conditions since early 2017.;
- 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 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 consistently followed a rising trend, and have steadied in 2018-19;
- 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, possibly as a more permeable zone that allows increased recharge through this area;
- Bore P9A is an open standpipe installed to 24 m depth in September 2017, so no long-term trend information is available (**Figure 3-15**). The bore is located along Redbank Creek between Longwalls 31 and 32 (the most recently extracted panels), while VWPs were installed in nearby bore P9 (see **Appendix B Figure B1.6**). The base level for P9A bore is around 4 m lower than P4 (closest shallow monitoring bore, 1.7 km away) but similar to levels recorded at P5 (2.3 km away). For the period of data available for P9A, water levels were stable through Longwall 31, even increasing slightly up to early 2019, but have since declined by 10 m to 190 mAHD with the passing of Longwall 32. Based on the VWP sensors (**Figure B1.6**), the shallower two sensors decline 3 and 6 m during the passing of Longwall 31 before failing, Water levels in the 60 m piezometer showed similar drawdown (6 m) during Longwall 31, and then recovered to pre-Longwall 32 levels, suggesting that a change in aquifer storage was the primary mechanism for the drawdown. With the passing of Longwall 32, the 60 m piezometer has responded similarly to P9A, declining by about 7 m.

3.8.3.2 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 groundwater levels from the nested site GW075409/1 and /2 with Lake Couridjah levels indicates that Couridjah is a losing system. GW075409/1 is screened at 3-13 mBG across 3 m of alluvium and 7 m of Hawkesbury Sandstone while GW075409/2 is screened at 72-84 mBG in the Hawkesbury Sandstone. Water levels from the shallow bore 075409/1 are consistently about 2 m below lake stage and just below the alluvium (i.e. within weathered rock), while Hawkesbury Sandstone (HBSS) levels from the deeper monitoring bore are a further 8-10 m below. Shallow groundwater levels in GW075409/1 are observed to range from 298.9 mAHD(ignoring suspect data in early 2019) to 301.2 mAHD, a range of 2.3 m.

Comparison of GW075410 groundwater levels and Nerrigorang lake levels indicates that the relationship is variable, i.e. there are both periods ‘gaining’ behaviour (e.g. most of 2015, second half of 2016) with groundwater levels up to 3-4 m higher than lake stage, as well as ’losing’ behaviour (e.g. first half of 2016) where groundwater levels are 1-2 m lower than lake stage. Overall, alluvial groundwater levels in GW075410 are observed to vary 10 m from 296 to 306 mAHD across the period 2012-2019, with annual variation observed to be up to 6 m (e.g. late 2012, late 2015).

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). These 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 is aware, the pumping is not metered, so the temporal pattern and magnitude of local pumping would be unknown, other than being estimated from the owner’s entitlement.

3.8.3.3 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. The actual levels recorded by piezometers in this bore are considered suspect given the unexplained step-changes in some piezometer records (GES, pers. comm) however some of the trends may be representative of stresses. 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.
- **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 accelerated in 2016-2018 before sudden depressurisation by 70 m in mid-2018 and VWP failure at that time. More subdued decline in Bulgo Sandstone and Bald Hill Claystone has occurred since 2016-2019, with the signs of compression in the Bald Hill Claystone in late 2018, followed by further decline to 160 mAHD in mid-2019. Water levels in the Hawkesbury Sandstone piezometers appear unaffected by the approach of mining.
- **TNC043** is located at the south-eastern corner of Longwall 32 approximately 1050 m north east of Longwall 29. Some of 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 (GES, pers comm). 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 ~35 m, and the Bulgo Sandstone exhibits a similar decline of 25-35 mover all piezometers. The gradient of this decline has become steeper since July 2015, as mine works approach this location from the south, 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. The sudden decline and recovery in HBSS water levels is possibly related to an increase in aquifer storage due to the extraction and subsidence effects of nearby Longwall 32.

3.8.3.4 Water level mapping

This subsection presents mapping of water levels for the water table/Hawkesbury Sandstone, the Bulgo Sandstone and Bulli Coal. Most 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 mining 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 mine 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).

3.8.3.5 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.

3.8.3.6 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.

3.8.3.7 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 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 reliable 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 and again more recently).

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).

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%-7%	primarily Hawkesbury Sst around Dendrobium Mine	Dendrobium (regional)	HydroSimulations (2016 and 2019)

* not stated explicitly – calculated by HydroSimulations

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.

3.8.4.1 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.

Table 3-10 Recharge estimation using WTF method

BORE	PIEZO	PERIOD		WL RISE	GEOLOGY	Sy (estimated)			RECHARGE (mm/a)		
				(m)		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

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).

3.8.4.2 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.

3.8.4.3 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:

$$
\begin{aligned}
Recharge &= Discharge \\
&= Baseflow\ (BF) + Evapotranspiration\ (ET) + GWabs + GW\ flow\ out
\end{aligned}
$$

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.

3.8.4.4 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

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[6] http://mapconnect.ga.gov.au/MapConnect/ [Groundwater] [accessed 204, but now defunct]

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.

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.

Available data from AGL’s Camden Gas Project indicated an average groundwater TDS of about 380 mg/L for the Hawkesbury Sandstone and 11,000 mg/L (range 3,200-27,500 mg/L) in the Illawarra Coal Measures, including the Bulli Coal seam (Parsons Brinckerhoff, 2013). The apparently fresher conditions are likely due to the higher rainfall (**Figure 3-2**) and lower evaporation at Dendrobium than inland at Tahmoor or Camden. A general trend for increasing salinity with depth is expected at Tahmoor.

Table 3-11 summarises surface water sampling from Tahmoor. Surface water is shown to be fresher, less saline, than local groundwater.

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

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[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.

SITE		SALINITY (mg/L)		
		MINIMUM	MEAN	MAXIMUM
Site 20A	Dry Creek	99	163	283
Site 21	Nepean River - Maldon Weir	15	115	218
Site 23	Carter Creek	132	282	408
Site 24	Cow Creek	60	83	131

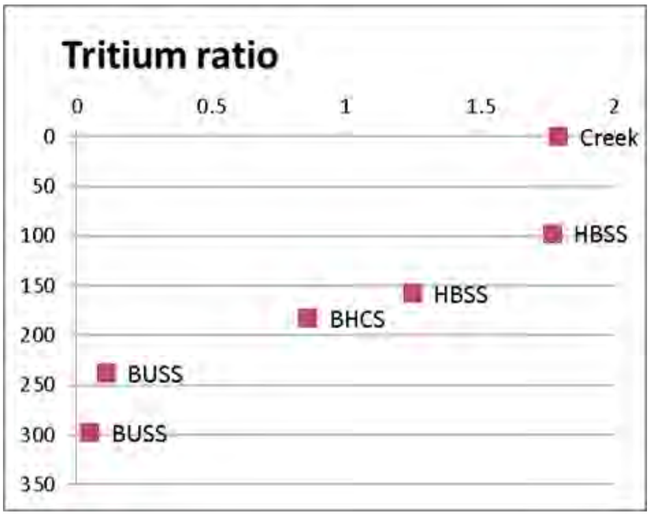
* influenced by wastewater discharge from mine.

** 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 existing 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 exceedances 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 within 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.

3.8.6.1 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 (4.5E-1) 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. From packer tests conducted at Tahmoor, coal permeability tends to lie between 1E-4 and 1E-3 m/d.
- Based on core testing, horizontal hydraulic 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.
- To support the later modelling of the Hawkesbury Sandstone using multiple model layers (Section 4.3), calculations on the packer test data were made based on 50 m depth intervals. As a results, the Hawkesbury Sandstone Kh can be characterised by depth as in

Table 3-13 Tahmoor packer test Kh by depth in the Hawkesbury Sandstone

Depth interval [mBG]	Arithmetic mean Kh [m/d]	Min to Max range
0-50	7.4E-2	1.0E-3 to 4.5E-1
50-100	3.8E-2	7.6E-5 to 2.6E-1
100-150	3.9E-2	4.0E-4 to 1.7E-1
150-200	1.3E-2	8.5E-5 to 7.2 E-2
all intervals:	4.2E-2	7.6E-5 to 4.5E-1

- 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

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[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).

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.
  - 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.

3.8.6.2 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 to 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.

3.8.6.3 *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%.

3.8.6.4 *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, although modified during calibration in line with 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

3.8.7.1 *Baseflow separation and chloride mass balance*

Baseflow estimates from Tahmoor Coal's monitoring sites at Hornes Creek and Bargo River are presented in **Table 3-14**. The government gauging station on Stonequarry Creek (gauge 212053) was not analysed because of the lack of river EC in the Pinneena database.

Table 3-14 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 (2020a) 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 are consistent with independent estimates by HEC (2020a) noted in the footer of **Table 3-14**, and with the conclusions of Advisian (2016). This suggests that baseflows in the area will be in the order of 1-2% of rainfall.

3.8.7.2 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 compared to 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 3-15**, 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 being the water make (inflow) in the Bulli Seam mine workings, 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 structures 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 indicates 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 3-15 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 3-15 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 1.6 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 190 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.

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[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'.

The implication of this is that while fracturing 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 changes 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 postulates that the Bald Hill Claystone is not the reason for the head separation observed between the fractured Bulgo Sandstone and the shallow Hawkesbury Sandstone. They claim that the Bald Hill Claystone is simply approximately 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).

SCT (2014) state that the observed and inferred drawdown in this borehole "are consistent with the approach forwarded by Tammetta". HS notes 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 in 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. On a regional scale, it is likely that discharge via baseflow will be larger than recharge from river leakage.

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. According to available WaterNSW records from 2017, but noting the lack of historical estimates or records of actual usage prior to that (Section 3.8.1), recent actual use is approximately 11-12% of entitlement, but could be higher (say 30%) but possibly lower. This means that groundwater bore use is probably about 1-4% 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;
- an upper zone of disconnected-cracking;
- the constrained zone; and
- the surface cracking zone.

HS also considers 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 "Height of Fracture" (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 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 (2020), 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). Effects of mining-induced subsidence have been reported as occurring at Redbank Creek (e.g. Geoterra, 2019). An assessment conducted by Morrison *et al*. (2019) found that the quality of surface waters was degraded in the direct vicinity of surface cracking features along Redbank Creek, with higher salinity and metal concentrations measured compared to an unaffected reference site. In order to assess future impacts of subsidence, monitoring and analysis of both ground and surface water quality is essential to determine whether subsidence has occurred.

Surface water impacts of the project are discussed and assessed in HEC (2020b).

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 (as per the original EIS mine plan), a 2.4 m mined seam thickness and a 400 m depth of cover, the height to which the fractured zone would 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 into 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 HydroGeoLogic [HGL] Inc.), however given the desire to add local-scale mesh refinement around Thirlmere Lakes, HS moved to using 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 has not used the full capability of the flexible mesh functionality (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-2019. 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 72 stress periods in the calibration model (the initial steady state period plus 71 transient stress periods), and 62 in the predictive period.

Of the 134 transient stress periods, 116 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 sufficient 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, and 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 areas where layer 1 is used to represent alluvium, and in these areas the layer 1 cells were assigned a minimum thickness of 5 m. Some further comments regarding specific layers are as follows:

- 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 combination of the upper Hawkesbury Sandstone with alluvium and Wianamatta Formation units (where present) within one layer was implemented in the original MODFLOW-SURFACT model as a result of the requirement that model layers must be fully extensive. This was employed to reduce the number of model cells. This means that flow between these units (within layer 1) is governed by horizontal hydraulic conductivity (Kh) and not vertical hydraulic conductivity (Kv). Kh is much higher in the consolidated formations than Kv. This means that groundwater level variations can be transmitted more easily between the Hawkesbury Sandstone and alluvium or Wianamatta Formation than would occur in reality. This simplification may mean more conservative assessment of drawdown and baseflow losses within alluvial features located away from the mine footprint.
- 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.

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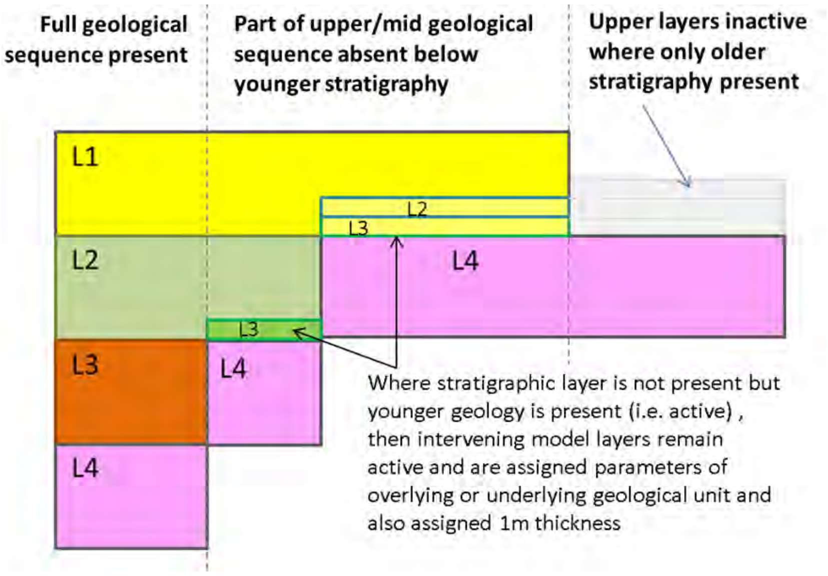
[10] A ply is a thickness or layer within a sequence of laminated material (e.g. a coal seam, or timber plyboard). The Wongawilli Seam consists of multiple thin coal layers or plies.

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.



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. The steady state model was calibrated to match a selection of water level records that were considered to be unaffected or minimally affected by historical records.

4.4.2 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 NOW (2011a) (see Section 3.8.4). Later the evidence from steady state calibration and the analysis of 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. 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, and so on, decaying over time. 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 some methods of rainfall-runoff-recharge estimates results in a reflection of transient soil moisture deficit through comparison of rain and PE. The monthly totals were then aggregated into the model stress periods, as per the timing discussed in Section 4.2.

4.4.3 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.

4.4.4 WATERCOURSES

Creeks and rivers throughout the model domain were modelled using MODFLOW's River (RIV) package. 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 bed elevations were parameterised as the value of the 100 m DEM, which was built specifically for this model considering the minimum observed elevation in each cell. This DEM 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.

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.

In response to comments by DoI Water and DPIE Independent Review, the model has been modified for the Amended Project Report to better capture seasonal river flow and stage variations around Tahmoor and to allow the watercourses to 'leak' water back int o the aquifer as a results of declining water levels. In order to do this, the RIV package was updated to include transient stages for the key watercourses around the Tahmoor North and South mine areas (**Table 4-2**).

Table 4-2 River stage multipliers for transient watercourse stage simulation

WATERCOURSE NAME	MODEL REACH NUMBER	STAGE MULTIPLIER	MEDIAN SIMULATED STAGE HEIGHT
Stonequarry Creek	29	1*	0.36
Nepean River	25	3	
Bargo River	26	2	
Avon River	27	2	
Cordeaux River	28	2	
Cedar Creek	30	4.5	1.62
Redbank Creek	31	2.1	0.76
Matthews Creek	32	3.9	1.40
Eliza Creek	36	0.8	
Dogtrap Creek	37	0.8	
Cow Creek	38	0.8	
Hornes Creek	39	0.8	
TeaTree Hollow	40	0.8	
Carters Creek	41	0.8	
Dry Creek	42	0.8	

* Multipliers for watercourses developed in relation to Stonequarry Ck stage (station 212053)

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

Transient river stages were estimated from observed data from the NSW Government monitoring station on Stonequarry Creek (212053) and data collected by Tahmoor Mine at several monitoring locations along Redbank, Cedar, Matthews and Stonequarry Creeks. The government data comprised monthly readings collected from 1990 to April 2019, whereas the data received from Tahmoor only covered the six months preceding and including April 2019. Additional historic water level data for Redbank Creek for the period December 2009-July 2013 to provide an indication of stage prior to undermining (as described in SCT, 2018b).

Due to the longer period of data available for station 212053 on Stonequarry Creek, stages for each model stress period were calculated using that record as the basis. Average stage levels were calculated for model periods that correlated with dates of available data. For those model periods where no data was available, a long-term average was applied. This is not considered to be a significant weakness given that the historical data extends back to 1990. The monitoring data collected by Tahmoor Coal for the four specific creeks was then used to estimate an appropriate multiplier of the Stonequarry Creek data for the other watercourses, which have been classed according to their size (catchment area). The relevant stage multiplier and median simulated stage heights for each watercourse is provided in **Table 4-2** and **Figure 4-5** presents the representative stage heights for these watercourses based on the method outlined above.

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

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).

4.4.5 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. In the original EIS (HydroSimulations, 2018) lake stages were set at a constant stage height. In order to better capture variation of lake level, the RIV package was updated to include transient stages for the five freshwater lakes. The short record of the gauging stations around the Thirlmere Lakes (Table 3-2) were used for the period end 2013 to August 2019. Simulated lake levels from HEC, 2020 were used to build the transient lake stages at Couridjah and Werri Berri lakes (period 1990 to 2011). Data from Pell and Pells (2016) and Schädler and Kingsford (2016) were also used to complete the gaps lake level records for Couridjah and Werri Berri lakes.
- Lake stages were set at constant levels for the predictive period. These were set at an estimated ‘median levels’ as follows: Gandangarra (304.6 mAHD), Werri Berri

(302.0 mAHD), Couridjah (302.5 mAHD), Baraba (304.5 mAHD), and Nerrigorang (301 mAHD).

- The bed conductance was modified based on the maximum loss rate (to groundwater) as estimated from the surface water model (HEC, 2020b), 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.

4.4.6 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 the NSW government (currently DPIE Water and WaterNSW) and those of the Tahmoor bore census (Section 3.8.1; Geoterra, 2013a), as shown in **Figure 3-12**, were not included in the base case model. This is because of the uncertainty around the actual extraction (rather than the entitlement), as noted in Section 3.8.1. The focus of this study is to simulate the effects of mining in the 'cumulative impact' scenarios, and does not account for bore pumping effects, on features like GDEs and watercourses.

However, in response to submissions following the EIS, groundwater bore pumping has been included in one model scenario (Section 5.2.1).

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 North 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 was unsure of the detail required for cumulative impact assessment requirements and adopted a conservative approach by including more detail. The implication of the model size and long run times meant that uncertainty analysis had to be limited (Section 4.10). Relevant recommendations are made in Section 7.2.

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;
- Dendrobium Areas 1, 2, 3A, 3B; and
- Dendrobium Areas 5 and 6, as well as Area 3C. Dendrobium Area 5, which is nearest to Tahmoor South, would extract from the Bulli Coal seam (proposed to operate from 2024 to 2040), while Areas 3C and 6 would extract from the Wongawilli Coal seam (operations from 2039 to 2042 and 2043 to 2048 respectively). These areas were simulated in the groundwater model using the proposed mine plan and longwall geometry outlined in the Dendrobium Expansion Project EIS (South32, 2019)

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 10 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 2.2 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/BSO 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. We understand that recent mining at Appin/BSO deviates from the mine plan originally used to represent mining in this Tahmoor groundwater model. A recommendation (Section 7.2) is made to update this when/if further modelling is required at Tahmoor.

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 4-3**.

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 4-3**).

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 4-3** 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 4-6**. This figure shows that the modelled parameter values are well constrained by the observed dataset.

Some of the hydraulic conductivity values have been modified during re-calibration of this revised model (i.e. changed from HS, 2018). This includes a slight increase to the Kh of the Bulli Coal seam, as well as a reduction in Kh for Hawkesbury Sandstone, to better match the arithmetic mean calculated from packer tests (Section 3.8 and **Table 3-13**), based on depth intervals that approximately correspond to ‘upper’, ‘mid’ and ‘lower’ HBSS).

Table 4-3 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	5.00E-3	2.80E-4	1.02E-6	1.06E-2
1	Hawkesbury Sandstone - upper	3	7.40E-2	8.00E-4	6.00E-6	1.60E-2
2	Hawkesbury Sandstone - mid	23	4.00E-2	8.00E-5	6.00E-6	1.10E-2
3	Hawkesbury Sandstone - lower	24	2.00E-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	1.70E-3	6.00E-6	6.00E-6	1.00E-2
6	Bulgo Sandstone - lower	25	1.5E-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	2.00E-3	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	8.00E-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	1.00E-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	3.00E-3	2.00E-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: V4TR069C
(LPF: TR076)

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.

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 4-7.**

4.6.1 MODEL SIMULATION

We note the ‘zones’ discussed below are likely to exist as a continuum of effects in reality, rather than neat or discrete zones. However, the need to simulate the effects requires some classification into simplified zones.

4.6.1.1 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 the following subsections in Section 4.6.1.

4.6.1.2 Zone of connected fracturing

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 connected fracture zone extending upward from the mined panel 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. The amended Tahmoor South mine longwall panels are proposed to be 285 m wide for both the A and B blocks (**Figure 2-1**). 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 4-8**), so that the variation in panel width and depth of overburden are accounted for. Although the IESC raised a criticism that this was the incorrect method of estimating the height of connected fracturing, the method employed is based on local data, geotechnical modelling, and is consistent with recommendations of IEPMC (2018). This point was also noted in the Independent Review of HydroGeoLogic (2019).

The top right-hand pane in **Figure 4-8** presents the estimated height of the connected fracture zone, presented as a height above the mined seam. The calculated height of the fractured zone above Tahmoor and Tahmoor North longwalls varies between 96 and 211 m, with an average and median of 165 m and 163 m respectively. The calculated height of the fractured zone above Tahmoor South APR mine plan longwalls varies between 156 and 211 m, with an average and median of 189 and 200 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 0.42 to 0.87 (see the middle pane in **Figure 4-8**), with a mean and median of 0.62 and 0.59 respectively. The ratio is greater in the southernmost 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 bottom right-hand pane in **Figure 4-8**, 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 (light green areas in the third pane of **Figure 4-8**) and, in a small area above Longwall 108B, into the lower Hawkesbury Sandstone (yellow areas). This suggests that there may be greater inflow when mining in those areas, and greater effects (i.e. drawdown) in the Hawkesbury Sandstone in those areas (i.e. around the upper parts of the Dog Trap Creek catchment).

Within the EPZ, the height of the various conceptual zones (**Figure 4-7**) 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 4-9**. Note that these are derived 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.

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 the 'Height of Fracture' (HoF) borehole above LW10A. 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 is merely coincidental.

4.6.1.3 Surface cracking zone

In response to comments by DoI Water, IESC and DPIE's review, the model has been revised to simulate the changes in hydraulic properties that occur in areas where surface cracking is likely to occur (Section 3.10.4). As discussed earlier in this section, the model utilises the time varying material (TVM) package to simulate changes in hydraulic conductivity and storage and is guided by the data and findings of SCT (2018). For the numerical model, surface cracking parameters were only calculated in areas overlying a longwall panel, i.e. within the panel footprint, and applied uniformly across this footprint (i.e. in valleys, on interfluves), even though some parts of the landscape might be more prone or less prone to surface cracking effects. We consider uniform distribution to be a conservative approach to this conceptualised zone of deformation.

The depth below the surface to where surface cracking extends was estimated as ten times the extraction height of a given longwall (based on the data presented in SCT (2018b). In areas estimated to be affected by surface cracking, the host horizontal and vertical hydraulic conductivity were both multiplied by 10 to represent the enhanced permeability of the fracture zone. The use of these multipliers is supported by a recent investigation into the changed hydraulic properties of sections of Redbank Creek that have experienced surface subsidence (SCT, 2018).

The estimated depth of the surface cracking across all parts of the Tahmoor Mine, including the Tahmoor South area, is presented in **Figure 4-8A**. The estimated depth of the SCZ over the mine does not exceed 30 m, with the estimated depth of cracking over Tahmoor South being from 20 m and 27 m. The bottom left panel of this figure presents the distance between the estimated SCZ and the height of connected fracture (HoCF). The vertical distance between the SCZ and HoCF over Tahmoor South averages 190 m (130 to 240 m). As a result, it is unlikely that surface to seam connectivity, which is a risk discussed in PSM (2017) and IEPMC (2018), would occur as a result of the extraction of the proposed Tahmoor South panels. A profile showing the change in Kv for areas affected by surface cracking is depicted in **Figure 4-9** for a number of representative locations.

4.6.1.4 Hydraulic conductivity

Hydraulic conductivities within the conceptual zones of the EPZ (see **Figure 4-7**) were simulated as follows. The changes to vertical hydraulic conductivity are illustrated on **Figure 4-9**.

In the surface cracking zone, horizontal and vertical hydraulic conductivity were multiplied by a factor of 10. This was weighted so that if only part of a layer is within the estimated surface cracking zone, the multiplier is thickness weighted by the fraction of the cell within the surface cracking zone.

The mined seam horizontal hydraulic conductivity was enhanced to 10 m/day and vertical hydraulic conductivity to 0.25 m/day. Caved zone horizontal hydraulic conductivity was enhanced to 5 m/day while vertical hydraulic conductivity was increased to 0.02 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.

4.6.1.5 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 (at Tahmoor Mine, mined thickness is typically up to 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.

4.6.1.6 Development headings

Development headings and roadways in the Tahmoor underground mine were simulated as having a horizontal hydraulic conductivity of 10 m/d. Vertical hydraulic conductivity for roadways changed to 0.2 m/d 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 0.15 on the basis that the roadway itself has a porosity of 1, but most of the roadways only cover a fraction of a 100 m wide model cell.

4.6.1.7 Other Southern Coalfield mines

Enhanced permeabilities were required to be included in the model in order to simulate operations at nearby mines. Height of fracture calculations were available from the following studies, or were based on the recommendations of IEPMC (2018):

- 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 IEPMC (2018); 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 possibly less 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 1980-2019). 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 (2022-2035), 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 in accordance with NWC guideline advice (Barnett *et al.*, 2012. 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 4.4.2, for the period 1980-2019. 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;
- Multi-piezometer boreholes EAW7–S1936 and S1941 (at Illawarra Coal’s Appin mine), which are 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

4.8.2.1 Model run time

The model takes about 12 hours to run the historical calibration period (i.e. to Stress Period 72), which while quicker than for the original EIS, it remains 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.

4.8.2.2 Groundwater Levels - Summary

A summary of the model's performance against target groundwater levels is presented in **Figure 4-10**. There is a total of 3856 groundwater level 'targets' from 282 bores/piezometers suitable for calibration over the period 1980-2019. 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. 2360 of the 3856 targets have a weighting of 1; 332 have a weighting of 0.5; 97 weighted between 0.1 and 0.5; and 735 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 2.8% Scaled Root Mean Square (SRMS) and an absolute residual mean of 10.7 m. Sources of errors are discussed below. These statistics indicate that the model is a reasonable match to historical data, and most of the statistical measures of calibration have improved since the EIS model (HS, 2018), especially the average residuals (whole of model average residual reduced from 21 m to 10.7 m). 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, residuals are distributed reasonably uniformly around the line of perfect fit;
- 39% of modelled heads lie within 10 m of the observed level (up from 31% in HS, 2018), and 74% within 20 m (similar to HS, 2018, which had 73%);
- The model tends to overestimate the extent, or possibly just the rate (see below) of drawdown, which is the reason for a number of the Layer 12 – Bulli Coal seam observations, and Layer 8 – Scarborough Sandstone 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 4-4**.

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

Stratigraphic unit	Count of observations	sRMS [%]	Average residual [m]	Average residual [m] from the EIS model (HS, 2018)
Upper HBSS, alluvium (Layer1)	460	5.6%	0.3	0.7
HBSS	568	4.2%	-0.3	4.7
lower HBSS	460	3.5%	-4.3	0.1
Bald Hill Claystone	101	4.9%	-3.3	0.9
Bulgo Sandstone	489	6.1%	-5.8	8.6
Scarborough Sandstone	49	16.7%	0.1	5.3
Wombarra Claystone	83	28.5%	-11.5	-5.6
Bulli Coal seam	309	12.8%	-6.2	21.8
Wongawilli Coal seam	205	14.8%	-15.1	-14.6

Source: E:\HYDROSIM\TAHMOOR\Model\Processing\Calibration\TahmSthv06Run069_CAL_calibration_v6_Report.xlsx

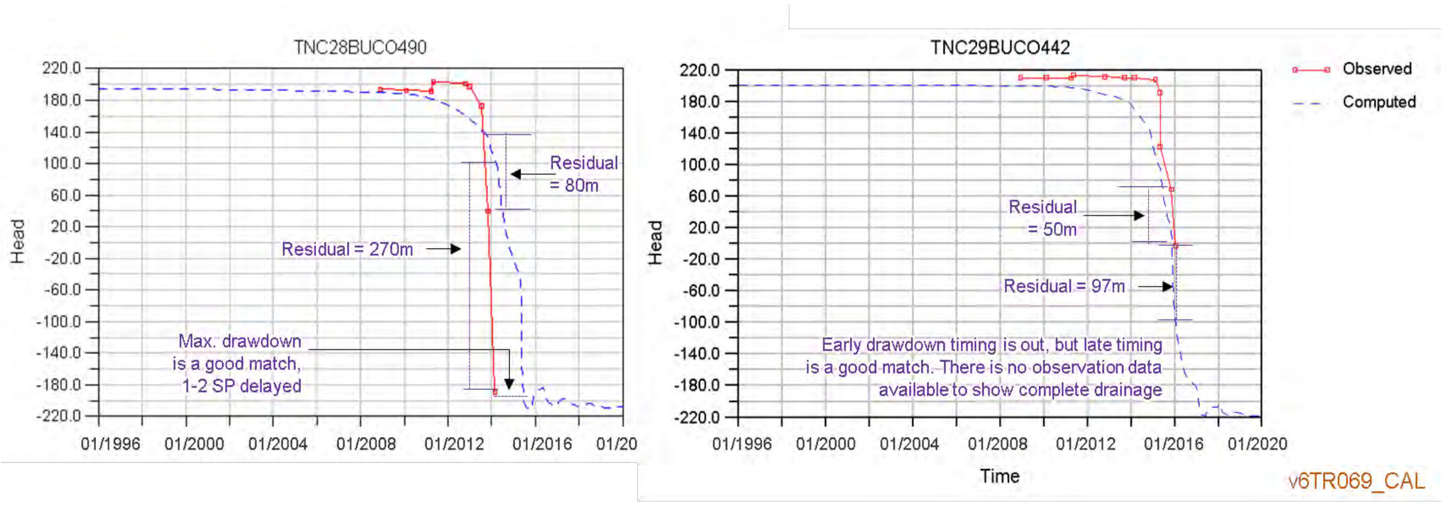
The residuals in this study area compared with those from the EIS model (HS, 2018), and while some layers have a worse statistical fit in the current study, on the whole there is an improvement, reflective of the whole-of-model residual reported above.

Table 4-4. 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.

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

- Imperfect simulation of mining operations, specifically roadway development and advanced gas drainage.
- 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. Examples are illustrated in the following sketch from the Bulli Coal seam piezometers in bores TNC028 and TNC029, which show large residuals 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.

4.8.2.3 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.

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 a 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.

4.8.2.4 Groundwater Levels – vertical head profile

Figure 4-11 presents water levels measured in the HoF hole TBF040c (aka 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.

4.8.2.5 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** to **Figure 3-21**). There is no discernible difference between 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.

4.8.2.6 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. This shows that while the model does not represent all peaks and troughs, it matches the magnitude of inflow and the general increasing trend, to an appropriate degree.

The historical average inflow to the Tahmoor underground mine is 3.2 ML/d, based on the years 1995-2002 and 2009-2019. For the same period the average of the modelled inflow to the mine is 3.05 ML/d – a variance of 4%. For the recent period 2009-2019, the modelled average is 3.7 ML/d compared to an observed average of 3.8 ML/d (a variance of 3%).

4.8.2.7 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 4-5**, 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 5%.
- Stonequarry Creek BFI <10%, and the model ratio is 12%.
- Bargo River BFI are up to 20% (approx.), modelled ratio is 20-28%.

Table 4-5 Comparison of modelled baseflow and observed flow

SITE	OBSERVED FLOW	MODELLED	OBSERVED	MODELLED
	Q99-Q01 RANGE	MIN-MAX RANGE	MEAN	MEAN
Hornes Ck (SW9)	0.2 to 35.4	0.1 to 0.5	2.7	0.14
Stonequarry Ck	0 to 560	0.9 to 6.1	15	1.8
Bargo R (SW1)	0.2 to 34.1	1.0 to 2.2	4.8	1.3
Bargo R (SW14)	3.3 to 137.4	2.1 to 5.8	16.8	3.1
Maldon Weir (SW21)	11.3 to 104.6	9.9 to 45.3	47.5	17.0

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. As expected, maximum modelled baseflows are considerably less than observed flows, 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 flow range, considering that the top end of the observed flows is runoff-dominated (not baseflow).

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.

4.8.2.8 Water balance

The mass balance reported by MODFLOW at the end of the historical calibration period (stress period 72) is <0.01%, and better than 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 4-6**.

Table 4-6 Calibrated transient model water balance (1980-2019)

COMPONENT	MODFLOW package	INFLOW (ML/d)	OUTFLOW (ML/d)
Rainfall recharge	Recharge	173.1	--
Evaporation from shallow groundwater	EVT and RSF (‘rejected	--	111.8
Leakage and baseflow at watercourses and lakes/reservoirs	Rivers	55.6	118.9
Regional groundwater throughflow	GHB	0.9	4.5
Mine inflow	Drains	--	5.9
Storage	Storage	64.0	52.5
Total		293.5	293.5

E:\HYDROSIM\TAHMOOR\Model\Processing\WaterBalance\v4TR038\TahSthv6TR069C_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. The revised model, including transient watercourse stages on major and significant watercourses, now simulates leakage from watercourses equal to approximately 15% of total inflow, and equivalent to about 45% of the simulated baseflow volume. 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 4-3** and **Figure 4-6**. 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 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 the “Type 2” method advocated by the IESC “Explanatory Note on Uncertainty Analysis” (Middlemis and Peeters, 2018), and is consistent with 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 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

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 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

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[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

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 based 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 per layer. 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. That is, the finite difference numerical method employed by MODFLOW only simulates the average head in a cell (averaged horizontally and vertically). Where cells are large and/or hydraulic gradients are steep, there should be no expectation that an observation of groundwater level will be exactly matched by the model.

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 proposed 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 development scenarios:

Scenario A:	The 'Null' Run (as described in Barnett *et al*, 2012) 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**.
Scenario D:	All mining activities are simulated, except for the Tahmoor Mine, being both the historical/approved Tahmoor North and the proposed Tahmoor South Project.
Scenario C + bore pumping	As noted earlier, groundwater extraction bores are not simulated in all predictive runs given the uncertainty around actual extraction versus entitlement, as well as due to the possible presence of unregistered bores. However, an additional development scenario was run to consider pumping at registered groundwater bores at a rate approximately equivalent to 20% of current entitlement, based on the uncertainty surrounding actual levels of usage.

- 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.
- When Scenarios D and C are compared, the differences between the two represents the effects of the Tahmoor Mine (approved and proposed).

These scenarios were all run using the calibrated 'base case' model.

Further to those scenarios, a selection of deterministic uncertainty scenario runs have been carried out to test the impacts of various hydrogeological features and behaviours. These sensitivity runs are primarily focused on 'conservative' runs that are anticipated to result in typically greater connection to the surface than anticipated (e.g. there is a run with a greater than estimated height of fracturing, but also a run with a lesser height of connected fracturing). The runs are as follows:

- 'Faults as conduits': A single run to test the possibility that the mapped faults were more permeable than simulated in the base case model. The faults in question are those around Tahmoor South, specifically the southern portion of the Nepean Fault, Western and Central Faults and the 'T' Faults –**Figure 3-11**). These were all simulated as more permeable features or zones than in the calibrated model, i.e.:

  - the southern Nepean Fault zone was simulated with Kh increased from 3E-4 to 3E-3 m/d and Kv increased from 2E-4 to 2E-3 m/d
  - The T-Faults, Central and Western Fault zones simulated with Kh increased from 5E-5 to 5E-4 m/d and Kv increased significantly from 7E-7 to 2E-4 m/d. In addition, the fault zone of the T2 Fault (oriented southeast to northwest to the south of Tahmoor South - **Figure 3-9**) was extended to the northwest to just beneath the Thirlmere Lakes alluvium for added conservatism. There is no indication whether or not this occurs in reality.

- 'High HoCF': A run to test a greater vertical extent or height of the connected fracture zone. The calibrated 'base case' model relies on the Tammetta (2012) estimate, as discussed in Section 3.10.4. This scenario considers the effects if this conceptual zone extends a further 30% higher above the mined seam (i.e. 130% of the Tammetta H).
- 'Low HoCF': A run to test a lower vertical extent or height of the connected fracture zone. This scenario considers the effects if this conceptual zone extends 70% of the 'base case' estimate above the mined seam (i.e. a 30% reduction in the vertical height).
- 'High Kh HBSS': A scenario to test if the bulk horizontal hydraulic conductivity of the Hawkesbury Sandstone (HBSS) was increased from the calibrated 'base case' model (from 0.074 to 0.4 m/d in the upper HBSS, from 0.04 to 0.14 m/d in the mid-HBSS and from 0.02 to 0.08 m/d in the lower HBSS). These changes are based on the packer test dataset presented in Section 3.8.6 and on **Figure 4-6**. These new parameters are close to the top of the range indicated by field data.
- A run using the hydraulic properties simulated in the original EIS (HS, 2018). These are not much different, but had a lower hydraulic conductivity in the Bulli Coal seam and Bulgo Sandstone, among a few other changes.

These sensitivity runs have been run once each with the activities of Scenario C, and some with Scenario A, B and D as necessary, as outlined in **Table 5-1**.

Table 5-1 Summary of deterministic scenarios for impact assessment

MODEL RUN	SCENARIO	DEVELOPMENT SCENARIOS	BORE PUMPING
v6TR069	**Base case**	A, B, C	None
v6TR070	**Original EIS**	A, B, C	None
v6TR071	**Low HoCF**	B, C	None
v6TR072	**High HoCF**	B, C	None
v6TR073	**Faults as conduits**	B, C	None
v6TR074	**High Kh HBSS**	A, B, C	None
v6TR075	**Base case with GW pumping**	D	Yes

Given the significance of the Thirlmere Lakes (even though they are 3-4 km from the proposed Tahmoor South Project), 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. 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, 2020b) 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/Western Domain. 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 (2019-2035)

COMPONENT	MODFLOW package	All Mines – v6TR069C		Null Run – v6TR069A	
		INFLOW	OUTFLOW	INFLOW	OUTFLOW
Rainfall recharge	Recharge	190.8		190.0	
Evap. from shallow groundwater	EVT and RSF		114.1		114.3
Leakage and baseflow at watercourses and lakes	Rivers	57.2	116.6	57.2	116.6
Regional GW throughflow	GHB	0.9	4.4	0.835	4.447
Mine inflow	Drains		18.1		0.0
Storage	Storage	57.4	53.2	32.7	45.3
Total		**306.3**	306.3	280.7	280.7

Units are ML/d. E:\HYDROSIM\TAHMOOR\Model\Processing\WaterBalance\v4TR069\TahSthv4TR069_C_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 18 ML/d of mine inflow (averaged 2018-2035) for all mines in the area, which now includes the proposed expansion to Dendrobium Mine.
- This is then met by changes to:
    - Groundwater storage, i.e. a decline in groundwater levels (approximately equivalent to 95% of the mines inflows);
    - Reduced surface water flows, approximately equivalent to 1% of total mine inflows (this is a regional estimate – specific sub-catchments will experience greater localised reductions – Section 5.7);
    - Reduced evapotranspiration (approximately equivalent to 3% of the inflow to mines);
    - A very minor reduction in groundwater throughflow OUT and increase in groundwater throughflow IN (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 – v6TR069C		Null Run – v6TR069A	
		INFLOW	OUTFLOW	INFLOW	OUTFLOW
Rainfall recharge	Recharge	190.8		189.8	
Evap. from shallow groundwater	EVT and RSF		120.5		120.6
Leakage and baseflow at watercourses and lakes	Rivers	57.4	122.8	57.3	122.7
Regional GW throughflow	GHB	0.9	4.6	0.8	4.7
Mine inflow ^	Drains		0.2		0.0
Storage	Storage	0.5	1.5	0.0	0.0
Total		249.6	249.6	248.0	248.0

Units are ML/d. ^ other than the proposed Dendrobium expansion, there are no mines simulated in this period.

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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 (1 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 0.1 ML/d) relative to the Natural scenario;
- evapotranspiration is reduced by about 0.1 ML/d; and
- there also remains some slight increase in induced groundwater inflow to the modelled catchment (<0.1 ML/d).

These simulated long-term reductions are now lower than in the modelling presented in the EIS (HS, 2018). Localised reductions in sub-catchments show appropriate rates of loss (Section 5.7), however on a regional basis the implementation of transient river stage in the MODFLOW Rivers requested is now able to provide additional recharge, reducing the apparent long-term reductions in regional groundwater-surface water interaction volumes.

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 ('v4TR069_C') represents the base case model inflow to the Tahmoor South workings during the operation of the Tahmoor South Project. 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 half 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 2028-29 and 2032-33, 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. Empirically, these inflows are higher than expected, given that the historical inflows are 3-5 ML/d and the proposed longwall geometry is similar to that in recent Tahmoor North longwalls.

Most of the scenario runs support the peak of 7.5-8 ML/d, except for run v6TR072, which simulated the inflow if a greater degree of vertical fracturing occurred above the mine. This model run suggested an overall average of approximately 11 ML/d through the life of Tahmoor South.

However due to the degree of correlation between the calibrated 'base case' model (run v6TR069C) 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, e.g. after the first one or two completed longwall panels.

Over the life of mining within the Tahmoor South Project, these simulated inflows total about 21 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 2,850 ML/d in 2029, and about 2,600 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 3.5 to 5.1 ML/d (1,600 to 1,900 ML/a); and
- Peak inflows occur during 2029 and 2032 in most of the scenario runs. Across a year, the predicted peak inflows are 2,800 ML/a, possibly up to 3,200 ML/a (excluding the High HOCF scenario, which is considered to produce unreasonably high inflow estimates).

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:

- TBC016 (**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).
- In response to Submissions to the EIS, results for an additional site or receptor have been extracted. This site is located in the centre of the Wirrimbirra Sanctuary property boundary (location on **Figure 3-4** and **Figure 3-5**), above Longwall 103A. The hydrograph is shown on **Figure 5-7**.

Referring initially to differences in modelled groundwater levels between the natural/Null run (v6TR069_A), the full impact model run (v6TR069_C) and the modelled effect without mining in the proposed Tahmoor South area (v6TR069_B), the points to note from these predicted water levels are:

- Results from the full impact model run (v6TR069_C) at the location of bore TBC016 show drawdown would be strongest in the mined coal seam. A peak drawdown of the Bulli Seam of 350 m (**Figure 5-2**) becomes less pronounced and severe in the overlying strata. In the Bulgo Sandstone drawdown is predicted to be approximately 300 m. The lower Hawkesbury is predicted to experience ~30 m of drawdown (80 m based on the most severe sensitivity run). The upper Hawkesbury is not predicted to experience as much drawdown, however the simulated near-surface effects mean that water levels are predicted to decline by 14 m below those in the natural run (v6TR069_A Null) and the simulation without Tahmoor South (v6TR069_B). However, once mining is completed at Tahmoor, water levels in the upper Hawkesbury at this location are simulated as remaining at ~10 m below those in the natural and ‘no Tahmoor South‘ or ‘no Tahmoor’ scenarios.
- Final recovery is predicted to be incomplete at TBC016 which is located immediately above proposed longwall panels. This is because enhanced hydraulic conductivity is simulated through much of the strata above the longwall, including in the near-surface.
- In the area to the east of Tahmoor South (**Figure 5-3**, bore TBC026) some similarities can be drawn to the water levels represented in **Figure 5-2**, 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. The greatest drawdown is predicted to occur in the mined seam (~25 m) with marginally less in the Bulgo Sandstone (~20 m) and 4-7 m in the lower Hawkesbury Sandstone. Modelled water levels in the upper Hawkesbury Sandstone in the full impact model are similar to the predictions for the natural and no Tahmoor South model runs, with only a slight (<1 m) drawdown predicted to occur in the period of the completion of Tahmoor South.
- Similar to the predictions for TBC016, at GW109159 (**Figure 5-4**) and TBC022 (**Figure 5-5**), depressurization 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 footprint (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.
- The results of the various sensitivity runs, as presented on **Figure 5-2** to **Figure 5-5**, indicate the following:
    - The scenario runs that modified the properties of the faults show little significant change in water levels within the Central Domain, but at the sites to the south and east of Tahmoor South, the results are more sensitive, due to these locations being closer to significant fault zones. The changes exhibited are 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 connected fractured ('HoCF') zone above the coal seam (refer to Section 5.2.1) typically show more sensitivity than the others. The increased fracture zone height ("Higher HoCF") 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 (2020b) with a short summary of that provided below. With respect to groundwater, key points are as follows:

Predicted incremental drawdown, due to the Project, of alluvial groundwater beneath 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 in the alluvium at Lake Werri Berri;
- 0.01 m peak and <0.01 m average in the alluvium at Lake Couridjah;
- 0.01 m peak and <0.01 m average in the alluvium at Lake Baraba;
- 0.02 m peak and <0.01 m average in the alluvium at Lake Nerrigorang.

It should be noted that all these estimates are on the same order or magnitude as the solver head close tolerance of 0.04 m (Section 4.2). This means that these drawdowns should be considered to be "in the range 0 to 0.04 m". The maximum drawdown at the lakes that is due to Tahmoor South is predicted to occur in 2070-2100.

The model predicts greater drawdowns in the Hawkesbury Sandstone (i.e. beneath the Thirlmere Lakes/Blue Gum Creek alluvium), peaking between 1-5 m, however given the hydraulics of sandstone-alluvium aquifers (Section 3.8.3, **Figure 3-16**) drawdown in the Hawkesbury Sandstone is not considered a key driver of water availability in Thirlmere Lakes (Section 3.6.1.6). The effects at Thirlmere Lakes are addressed further in Section 6.4.

The simulated groundwater drawdowns as a result of cumulative mining in this area, for the base case and deterministic scenarios, are summarised in **Table 5-4**. The revised APR estimates provided here are the mean and peak drawdowns from the ‘base case’ model.

Table 5-4 Predicted cumulative drawdown in the Thirlmere Lakes alluvium

Lake	Modelled maximum drawdown in alluvium [m]			Modelled average drawdown in alluvium [m]		
	Cumulative mining		Mining + GW bore pumping	Cumulative mining		Mining + GW bore pumping
	EIS (HS, 2018)	APR (this study)	APR (this study)	EIS (HS, 2018)	APR (this study)	APR (this study)
Gandangarra	0.05	0.2 to 0.48	2.35	0.03	0.19	0.97
Werri Berri	0.03	0.08 to 0.18	0.84	0.02	0.08	0.20
Couridjah	0.05	0.20 to 0.38	0.66	0.03	0.20	0.24
Baraba	0.05	0.07 to 0.16	0.66	0.02	0.07	0.11
Nerrigorang	0.05	0.08 to 0.13	0.51	0.02	0.08	0.17

All of the APR estimates are predicted to peak before 2019, i.e. due to a combination of drought conditions and mining at Tahmoor North. The reason for the significant difference in the two sets of results (the 2018 EIS compared to this current APR study) is the conservative assumption of surface cracking across the full longwall footprint, as well as the relatively conservative approach to connectivity between the Hawkesbury Sandstone and alluvium in this groundwater model (Section 4.3). The effect of this is shown in the maximum drawdown contour plots (**Figure 5-10**), where the predicted 2 m contour bounds the footprint of the longwall mine.

With this conservative representation of surface cracking, the revised APR model does not predict full recovery at the lakes, with the long-term drawdown being 80-90% of the average stated in **Table 5-4**.

The drawdown due to simulated groundwater extraction at local bores (Sections 3.8.1 and 5.2.1) is also stated in **Table 5-4**. These are uncertain due to the simulated level of groundwater extraction, however indicate the potential for local groundwater extraction to affect groundwater levels around Thirlmere Lakes, noting again that the drawdown effects due to bore pumping, like those from mining, may be overestimated due to the model layering (Section 4.3).

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. Assessment of the Project-related and cumulative drawdowns against the AIP ‘*minimal harm criteria*’ is presented in Section 6.4.

The predicted water table drawdown at Wirrimbirra Sanctuary was also calculated (**Figure 5-7**). This site is located along the middle of Tea Tree Hollow and above the proposed ‘A’ block of longwalls. The location above longwalls means that it will be subject to drawdown via depressurisation and also surface cracking effects (see also MSEC, 2020). Drawdown in the water table is likely to be on the order of 5-10 m, based on the modelling, a finding supported by comparison against recent observations from the P9 piezometers at Redbank Creek.

5.6.1 PREDICTED PRESSURE HEADS AND CONE OF DEPRESSION

Figure 5-8 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. The aim is to show the differences between pre-mining pressures [upper pane], pressure after the end of mining at Tahmoor South (in 2040) [middle pane], and then ~250-yearsafter mining [lower pane].

The key feature of **Figure 5-8** 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 pressures 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 5-8**).

In the lower pane of **Figure 5-8**, the model suggests that pressure heads would 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 5-9 shows the spatial distribution of modelled drawdown due to the Project in both the water table (**Figure 5-9A**) and in the lower Hawkesbury Sandstone (**Figure 5-9B**). The water table has been selected because it is the groundwater system that is connected to most environmental (surface) features, while the lower Hawkesbury Sandstone is the source of much of local groundwater extraction by bores. The maximum drawdown is calculated as the maximum drawdown between the 'base case' model scenarios at any point in time during those runs.

Generally, maximum water table drawdown is <2 m across much of the Tahmoor South footprint, with a lobe of predicted drawdown extending north or northeast beneath the Wianamatta Formation, and a lobe extending southwest toward Lake Nepean. The maximum extent of the 0.2 and 2 m drawdown contours has been extracted from the deterministic scenarios and is also presented on **Figure 5-9**. The 0.2 m contour has been presented as requested in the submission by the IESC. Note there is some 'noise' in the contouring, with isolated bulls-eyes apparent in the mapping.

Figure 5-9A shows that the 'base case' 2 m water table drawdown contour covers the longwall footprint, extending further east to near the Nepean River and halfway toward Lake Nepean. The maximum extent of the 2 m contour is quite consistent with the 'base case' contour. The maximum extent of the 0.2 m contour extends around the whole Tahmoor Mine footprint, which seems very conservative given historical and approved longwall mining in that area.

Figure 5-9B shows the maximum drawdown contours in the lower Hawkesbury Sandstone extend radially from the proposed longwall footprint. The 'base case' 2 m contour approaches Lake Nepean to the south, the Nepean River to the east, and to Lake Couridjah in the northwest. The 'base case' 0.2 m contour extends further, around the lower parts of Lake Nepean to the south, and around much of the Tahmoor/Tahmoor North Mine to the north, and around the Thirlmere Lakes to the northeast.

Figure 5-10 presents drawdown results in a similar manner, but this time for the maximum drawdown due to cumulative mining activities. The drawdown contours for the water table (**Figure 5-10A**) and lower Hawkesbury Sandstone (**Figure 5-10B**) show the simulated effects of Tahmoor North and South, BSO and Dendrobium.

Generally, 2 m water table drawdown extends across the footprint of the longwall mines, including all domains at Tahmoor. This is driven by the surface cracking mechanism now simulated in the revised model. The 0.2 m contours are also presented, again as requested in the submission by the IESC. The base case estimates of 0.2 m drawdown appear reasonable, however the relatively conservative assumptions tested in the deterministic scenarios produce drawdown of approximately 0.2 m in the water table across much of the model domain, and this seems extreme.

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. This effect can be amplified in areas above longwall panels, where surface cracking may increase the permeability of the stream bed and the near-surface strata, as is evident around Tahmoor North (e.g. Redbank Creek). 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). The effects of the surface water losses reported here are dealt with in HEC (2020b).

Based on simulated baseflow capture calculated to occur directly within a sub-catchment. The sub-catchments most affected by the Project would be Dog Trap Creek, Bargo River between SW-1 and SW-13 and Nepean River SW-21.

Table 5-5 presents a summary of the predicted baseflow capture accumulated along upstream watercourses to each assessment point, as simulated by the predictive models that use the calibrated or 'base case' model. Gauged sites are marked on **Figure 3-5**. 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.

Table 5-5 Baseflow capture in local watercourses

WATERCOURSE	SITE USED FOR ASSESSMENT	TAHMOOR SOUTH IMPACT	CUMULATIVE MINING
		Best estimate Max (ML/d)	Best estimate Max (ML/d)
Eliza Creek	SW-18	0.001	0.005
Carters Creek	SW-23	0.002	0.002
Blue Gum Creek		0.015	0.140
Dog Trap Creek	SW-15	0.101	0.133
Tea Tree Hollow	SW-22	0.027	0.088
Cow Creek	SW-24	0.018	0.019
Stonequarry Ck	212053	0.013	0.077
Bargo River	SW-1	0.002	0.002
Bargo River	SW-13	0.051	0.175
Bargo River	SW-14	0.083	0.303
Hornes Ck	SW-9	0.001	0.001
Nepean River	SW-21	0.340	1.181
Matthews Creek		0.001	0.020
Cedar Creek		0.005	0.056
Redbank Creek		0.002	0.030
Avon River		0.018	0.228

WATERCOURSE	SITE USED FOR ASSESSMENT	TAHMOOR SOUTH IMPACT	CUMULATIVE MINING
		Best estimate Max (ML/d)	Best estimate Max (ML/d)
Cordeaux River		0.028	0.422
Rumker Gully		0.000	0.000
Newlands Gully		0.000	0.000
Myrtle Creek		0.001	0.020
Dry Creek		0.001	0.002

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The predicted maximum baseflow depletion impact due to Tahmoor South on Blue Gum Creek is around 0.015 ML/d (this was 0.011 ML/d in the EIS - HS, 2018), while the mean impact of Tahmoor South is around 0.005 ML/d (same in this APR and the original EIS assessment).

Cumulative impacts due to mining are often 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. an early peak in 2023-24 and a slight recovery for a period before a new and more persistent effect peaking 2040-50 (Dog Trap Creek) and many later in the life or after the operational life of Tahmoor South, such as in 2033 (Bargo River, SW13) or 2070 (Cow Creek).

At the Wirrimbirra Sanctuary, located halfway along Tea Tree Hollow and one of its main tributaries, loss of surface water flow due to Tahmoor South is predicted to peak at 0.016 ML/d. The cumulative mining effect is predicted to be 0.021 ML/d. These losses are calculated as the upstream losses in the catchment of Tea Tree Hollow and the tributary to the northern (downstream) boundary of the Wirrimbirra Sanctuary property. Peak losses within this sub-catchment are predicted to occur from about 2026 (as the site is mined under), and persist into the future, due to combined drawdown and surface cracking effects.

5.8 CHANGE IN LAKE-AQUIFER INTERACTION AT THIRLMERE LAKES

In previous sections, estimates of drawdown in shallow groundwater have 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. Preliminary findings from the OEH Research program (Section 3.6.1) suggest that interaction with groundwater is relatively low, especially in the case of Lake Gandangarra.

Modelled changes in the groundwater-surface water interaction between the lake system and the local groundwater system may be due to predicted declines in groundwater levels at or beneath a lake, or a decline in water levels further up-gradient may result in a loss of baseflow or stream flow to that feature, although baseflow is not considered a significant input to the lakes. These combined effects could cause a decline in alluvial groundwater levels and potentially on surface water levels in a lake.

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. 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 their model to allow the effects of these to be calculated with respect to surface water behaviour (HEC, 2020b). The rates simulated by the groundwater model are summarised in **Table 5-6**, with rates in m^3/d.

Table 5-6 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
303.3	0	4	5	298	5	11	14
303.3	0	4	5	300	7	10	11
303.3	0	4	5	301	21	30	31
304	0.7	5	6	302	66	77	84
306	80	86	87	304	262	276	283

Leakage rates in m^3/d

Nat = modelled natural leakage rate

TN = leakage rate for Tahmoor/Tahmoor North

TN + TS = leakage rate with Tahmoor and Tahmoor South

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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 affects the ability of the model to accurately estimate very low leakage rates, however based on calibration of the lake water balance model by HEC (2020b) it is clear that losses from the lake must be low when the lake levels are low, and that the rates in the **Table 5-6** are of the correct order of magnitude (i.e. low rates of loss at low lake levels, which appear consistent with the preliminary findings of ANSTO, as noted above).

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 m$H_2$0). 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, while ANSTO also noted that there was no evidence of lake water in the nearby Hawkesbury Sandstone monitoring bore GW075409/2 (Section 3.6.1). 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. Two primary components of this mine-water stream that is returned to surface are:

- potable water that has been pumped down into the underground mine for use in various mining-related processes and operational use. Based on daily records since 2006, about 700-800 m^3/d of potable water is pumped into the mine; 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 1,500-2,500 uS/cm (average 1,900 uS/cm, equivalent to a TDS of about 1,150 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.

A salt balance was calculated by taking model results from the calibrated ‘base case’ 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, as in Section 3.8.5) and the modelled mine inflows and groundwater balance is shown on **Figure 5-11** (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 in each of the relevant hydrogeological unit were then applied to the predicted ‘base case’ inflows to the Tahmoor South Project. The predicted salinity time series is presented on the lower chart on **Figure 5-11**). This assumes that low salinity potable water will be required in a similar volume to as it has been historically.

This modelling suggests that inflows could be less saline as mining occurs in Tahmoor South, than for historical mining, with predicted average salinities of about 1,600 EC, with some spikes of 2,000 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, the salinity of the mine water entering Tahmoor South workings is unlikely to rise significantly.

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. DPIE Water licenses ‘take’ on the basis of Water Sources (Section 1.5). The Tahmoor Mine is within the *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 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).

Model predictions from the base case and deterministic scenarios (Section 5.5) are presented on **Figure 5-1**. A comparison of the inflow from the deterministic scenarios indicates that most of them are a similar match to the historical inflow record, with the exception of the High HOCF scenario, which is consistently too high. The Low HOCF scenario is often too low, but not consistently, and is closer to the long-term average than the High HOCF scenario.

Based on these modelling results, the peak groundwater inflow to the Tahmoor South project will likely be 2,300-2,900 ML/a. The base case model predicts 2,850 ML/a, equivalent to a peak annual inflow of 8 ML/d. Empirically, these inflows are higher than expected, given that the historical inflows are 3-5 ML/d and the proposed longwall geometry is similar to that in recent Tahmoor North longwalls. These peak inflows are expected to occur in the period 2028-29 and 2032-2033 during Longwalls 104B-105B and 107B-108B. The groundwater entitlement volume currently held by Tahmoor Coal is 1,642 ML/a (Section 2.2.2).

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:

- Nepean MZ2 (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. 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. These are unchanged from the estimates reported in the EIS (HS, 2018).

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

WATER SHARING PLAN	WATER SOURCE / MANAGEMENT ZONE	Predicted Annual Inflow Volumes requiring Licensing (ML/a)
Greater Metropolitan Region Groundwater Sources (*Water Management Act 2000*)	Nepean Groundwater Source / Management Zone 2 (Porous Rock aquifer)	**Avg. 1500-1900**, of which: ▪ **1400-1700** from depleted storage during mine operation, ▪ **100** from reduced evapotranspiration, ▪ **30-120** from baseflow depletion, ▪ **6** from reservoirs (L. Nepean, L. Avon etc), and ▪ **1** from other groundwater flow from other GMAs and MZs (see below) **Likely max = 2,850 ML/a**
		Tahmoor currently holds 1642 shares (**Section 2.2.2**).
	Nepean Groundwater Source / Management Zone 1 (Porous Rock aquifer)	**Average = <1; Max = 2.**
	Sydney Basin - Central Groundwater Source (Porous Rock aquifer)	**Average = <1; Max = 1.**
	Sydney Basin - South Groundwater Source (Porous Rock aquifer)	**Average = 0; Max = 0.**

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 DPIE Water.

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 surface water losses (baseflow depletion and additional leakage, combined as '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, 2020b).

Model results for baseflow depletion and enhanced leakage due to surface cracking effects for local watercourses are summarised in **Table 5-5**. That table shows the Tahmoor South Project and Cumulative impacts ('base case' estimate using the calibrated model configuration). More detailed assessment of the effects is provided in HEC (2020b).

The result of mining at Tahmoor South, and both mining and groundwater pumping as part of the cumulative impact assessment, is a reduction in available surface water in a number of management zones (MZs) in the Nepean River Water Sharing Plan:

- Maldon Weir MZ: maximum baseflow depletion is predicted to be approx. 0.19 ML/d (Tahmoor South), 0.49 (Tahmoor total) and 0.5 ML/d (cumulative mining effect).
- Upper Nepean Tributaries Headwaters MZ: 0.049 ML/d (Tahmoor South), 0.052 (Tahmoor total) and 0.5 ML/d (cumulative mining effect);
- Maguires Crossing MZ: 0.028 ML/d (Tahmoor South), 0.029 (Tahmoor total) and 0.032 ML/d (cumulative mining effect);
- Pheasants Nest Weir to Nepean Dam MZ: 0.014 ML/d (Tahmoor South), 0.015 (Tahmoor total) and 0.016 ML/d (cumulative mining);
- Little River MZ: 0.01 ML/d (Tahmoor South), 0.15 (Tahmoor total) and 0.15 ML/d (cumulative mining effect);
- Stonequarry Creek MZ: 0.008 ML/d (Tahmoor South), 0.044 (Tahmoor total) and 0.085 ML/d (cumulative mining effect).

More detail on these is provided in the Surface Water Assessment (HEC, 2020b). Specific recommendations for licensing have also been provided to Tahmoor Coal.

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 0.006 ML/d for the project (this is similar to the 0.007 ML/d predicted in HS (2018).

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.

6.3.3.1 Metropolitan Special Area

The south-eastern ends of the proposed longwall panels are deliberately planned to be set back from 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 approximately 0.1 ML/d (36 ML/a) in around 2100 before declining again. These volumes are similar to those predicted in HS (2018).

Cumulative impacts on the Metropolitan Special Area are mainly felt by reductions in baseflow and evapotranspiration from shallow groundwater, noting that the Tahmoor groundwater model does not fully cover the Metropolitan Special Area. Baseflow is predicted to decline by an average of approx. 0.25 ML/d, with peak losses of over 1 ML/d to occur in the period 2070-2110, before the impact on both lessens over the following period, although never fully recovers. This is due primarily to the cumulative impact of historical, current and proposed workings at Dendrobium, Russell Vale and Cordeaux mines.

6.3.3.2 Warragamba Special Area

Baseflow capture due to the Project is predicted to peak at approximately 0.01 ML/d (<30 ML/a). For context, inflows to Lake Burragorang (as a proxy for the resource within the Special Area) average at about 2,800 ML/d (since 1909) or 1,280 ML/d (since 2000). The predicted 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 0.15 ML/d (50 ML/a). The estimated 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**), and based on the scenario modelling (Section 5.2.1) could be in the order of 0.04 ML/d (average) to 0.07 ML/d, noting uncertainty in actual usage compared to entitlement.

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**).

The AIP specifies that the '*minimal harm criteria*' is "*Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from* … a High Priority GDE". With respect to Thirlmere Lakes, which are the closest High Priority GDEs to Tahmoor Mine, two monitoring bores provide relevant water level fluctuation information:

- GW075409/01, screened 3-13 m across alluvium and Hawkesbury Sandstone, and adjacent to Lake Couridjah. As described in Section 3.8.3, water levels in this bore actually reside below the alluvium and within the weathered rock, so may not be completely relevant to the GDE. Water level fluctuation in this bore is up to 2.3 m.

- GW075410, screened 2.5-14.5 m in alluvium, and adjacent to Lake Nerrigorang. Water level fluctuation in this bore is up to 6 m within a year, or up to 10 m over the historical record.

These records are used for subsequent the assessments against the AIP. HS consider that the record from GW075410 is most representative of groundwater levels within the alluvium, however, have used both the bores to assess the predicted drawdown against the AIP. The assessment of predicted drawdown compared to water level fluctuation is calculated as the percentage of each of the two bores, and presented as the average of the two (and the range) in **Table 6-2** and **Table 6-3**.

6.4.1 IMPACTS OF TAHMOOR SOUTH PROJECT

The predicted risks and impacts of mine development to High Priority GDEs are quantified in **Table 6-2**. **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 (2020b); the main findings from that are summarised in the text after **Table 6-2**.

Table 6-2 Project-specific Groundwater Drawdown and Baseflow Capture at Priority GDEs

GDE		PREDICTED MAX DRAWDOWN (m)	% OF ALLUVIAL WATER LEVEL FLUCTUATION	PREDICTED BASEFLOW CAPTURE	
Thirlmere Lakes	Gandangarra	0.02	0 to 1%	See **Table 5-6**	
	Werri Berri	0.01	0 to 1%		
	Couridjah	0.01	0 to 1%		
	Baraba	0.01	0 to 1%		
	Nerrigorang	0.02	0 to 1%		
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					

The assessment against the AIP criteria as a % of water level fluctuation highlights that the Tahmoor South Project would have negligible effect on groundwater levels at the Thirlmere Lakes. This is consistent with the distance between the Project and the lakes, and the position of the historical Tahmoor North longwall areas between the Project and the lakes.

With respect to the potential effects on surface water levels within lakes themselves, an assessment was undertaken by HEC (2020b) 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 (2020b) for more details.

6.4.2 CUMULATIVE IMPACTS

Predicted cumulative groundwater drawdown impacts at the significant GDEs are quantified in **Table 6-3**, summarising effects such as those shown on **Figure 5-6**. These are for the cumulative impacts of all mines. As noted earlier, these are estimates of groundwater drawdown within the alluvium, and not reductions in surface water (lake) level. Reduction in lake levels is assessed in HEC (2020b); the main findings from that are summarised in the text after **Table 6-3**.

Table 6-3 Cumulative Groundwater Drawdown and Baseflow Capture at Priority GDE

SITE		PREDICTED DRAWDOWN (m)	% OF ALLUVIAL WATER LEVEL FLUCTUATION	PREDICTED BASEFLOW CAPTURE
Thirlmere Lakes	Gandangarra	0.19 to 0.48	12% (8 to 21%)	see **Table 5-6**
	Werri Berri	0.08 to 0.18	4% (3 to 8%)	
	Couridjah	0.20 to 0.38	9% (6 to 17%)	
	Baraba	0.07 to 0.16	4% (3 to 7%)	
	Nerrigorang	0.08 to 0.13	3% (2 to 5%)	
North Pole Swamp	(upland swamp)	0	n/a	The nearest of the upland swamps to the Project

The assessment against the AIP criteria as a % of water level fluctuation indicates that at three of the lakes the predicted groundwater drawdown is consistently lower than the AIP threshold, while at Lakes Couridjah and Gandangarra (the two closest to historical longwalls at Tahmoor North), the simulated drawdown was greater, and at 9 and 12% of the shallow water table fluctuation, indicative of ‘Level 2’ under the AIP. This finding is consistent with that of the original EIS (HS, 2018), which also considered that the cumulative effects would be Level 2.

It is important to note that these effects are associated with the Tahmoor North operation, and as outlined in Section 6.4.1, are not associated with the proposed Tahmoor South operation. The effects outlined above are also for cumulative mining operations only, and do no consider the effects of local bore users, which as presented in **Table 5-4**, are likely to be greater but less persistent than those from mining.

6.5 CULTURALLY SIGNIFICANT SITES

There are no ‘High Priority’ Culturally Significant Sites listed in the relevant Water Sharing Plan.

Wirrimbirra Sanctuary is located above the Tahmoor South ‘A’ block of longwalls. This property is predicted to experience approx. 5-10 m of water table drawdown and a reduction in surface water flow within the Tea Tree Hollow sub-catchment of 0.016-0.02 ML/d.

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 in **Figure 5-2**, **Figure 5-3**, **Figure 5-8**, and **Figure 5-9**

In general, and with reference to the figures listed above, the maximum water table drawdown associated with the Tahmoor South mine would be around 10 m within and close to the footprint of the proposed Tahmoor South longwalls.

Recovery of the water table is likely to be incomplete across much of the footprint, given the presence of surface cracking above longwalls. There are no significant drawdowns in the Thirlmere Lakes alluvium in response to proposed 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). This bore census is currently being updated.

Table 6-5 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 6-4**, **Table 6-5** 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 6-4**, **Table 6-5** 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. A change to this assessment from that presented in the original EIS (HS, 2018), where depth information is available, but no other construction information (e.g. screen intervals), a bore is conservatively assigned to the deepest possible layer that the depth allows, even though this may not be the zone that is responsible for bore yield. Transmissivity-based weighting for bores potentially open across multiple model layers has been carried out. This conservative approach is for the purpose of identifying bores potentially affected by mining and allow Tahmoor Coal to consult with owners. 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 6-4** and the count of affected bores. However, for completeness, registered bores are included in **Table 6-5** where they were recorded as part of the project bore census.

Tahmoor Coal has committed to “make-good” provisions for any groundwater users shown to be adversely impacted by the Project. As far as HS is aware, there is no reference to specific ‘make-good’ measures in NSW, however QLD Department of Environment and Science

(2016) provides a useful reference. In summary, ‘make-good’ measures include lowering pumps within groundwater bores or providing an improved pump, deepening a bore or drilling a new bore, or providing an alternative water supply.

Tahmoor Coal has previously enacted ‘make-good’ provisions for two landowners affected by the Tahmoor North Mine. For context, the revised groundwater model predicts that the historical operation at Tahmoor North (32 longwalls extracted between the 1980s and 2019) and the few remaining Western Domain longwalls would have already affected, or would affect, 72 bores. This, when compared to the fact that only 2 bore users have previously required make-good assistance, supports the idea that this assessment method is conservative for the reasons that many users might be affected beyond 2 m drawdown but not notice the effect compared to available drawdown and natural variation in water levels, or are not affected due to the reasons described in Section 6.7.

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 criterion are listed in Appendix I.

6.7.1 IMPACTS OF TAHMOOR SOUTH PROJECT

The calibrated ‘base case’ model simulates a total of 52 registered bores (**Table 6-4**) and 4 census bores [which are unregistered] (**Table 6-5**) 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 6-5**). The number of bores impacted beyond 2 m rises to a possible 73 registered bores and 8 census bores respectively if the results of all deterministic scenarios are taken into account. Of the 52 registered bores predicted to be affected, 6 are already predicted to be affected beyond 2 m by mining at Tahmoor North.

Table 6-4 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 EFFECT	CUMULATIVE MINING	ADDITIONAL BORES: TAHMOOR STH	ADDITIONAL BORES: CUMULATIVE MINING
>2 metres	46 bores (+ a further 6 already affected by Tahmoor North) = 52	228	+21	+36
Total bores in model area	791			

E:\HYDROSIM\TAHMOOR\Model\Processing\MaxDDN\Bores for Drawdown Assessment_v6TR069-XXX_&_senstivity_v4.xlsx

Of the 46 bores predicted to be affected beyond 2 m due to the Project, 8 are predicted to experience 5-10 m maximum drawdown and 16 to experience greater than 10 m, meaning that 22, or 50%, are predicted to experience 2-5 m drawdown. This suggests that the former 24 are at higher risk of experiencing drawdown that may affect bore yield, while 22 have a lower risk.

A summary of the number of registered bores impacted and the degree of impact is presented in **Table 6-4**. 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**, both for the base case and for the maximum estimate from uncertainty scenarios.

The number of census bores predicted to be affected has declined from the EIS (HS, 2018), owing to revised method of assigning bores to layers and to a revision of the list of census bores that are registered. The number of registered bores predicted to be affected has risen owing to a change in bore assignment to layers, as discussed in Section 6.7.

6.7.2 CUMULATIVE IMPACTS FROM MINING ACTIVITY

Accounting for cumulative impacts of mining within the groundwater model area, the number of impacted bores increases to 228 registered bores potentially affected (**Table 6-4**) and 12 sites from the project bore census (**Table 6-5**)..

The deterministic scenarios indicate an even more conservative assessment of the number of bores that could be affected beyond the 2 m threshold by mining, with up to 264 registered bores and 12 census bores (the same as the base case) potentially affected.

A map showing the distribution of affected bores, both the base case and from the uncertainty scenarios, is presented on **Figure 6-2**. The distribution of potentially affected bores on **Figure 6-2** indicates that a number of mine areas (being Tahmoor South, Tahmoor North and the other mines, especially BSO/Appin) would be the cause of drawdown beyond 2 m.

Table 6-5 Modelled Impacts on Groundwater Bores from the Project Bore Census

BORE					MODELLED MAXIMUM DRAWDOWN (at any time); [m]				Registered bore?
GW WORKS # (or alias)	LOCATION DESCRIPTION	EASTING	NORTHING	MODEL LAYER	TAHMOOR SOUTH BASE CASE EFFECT	MAX IMPACT FROM SENSITIVITY RUNS	CUMULATIVE MINING BASE CASE EFFECT	MAX IMPACT FROM SENSITIVITY RUNS	
						TAHMOOR SOUTH		CUMULATIVE MINING	
Pulic	Thirlmere_Lakes	276581	6209581	1	<2	<2	2.1	4.5	N
SmythWell	Thirlmere_Lakes	272238	6210218	1	<2	<2	<2	<2	N
TGW005	TahSth_Standpipe_piezo	278446	6206332	1	<2	<2	7.6	6.7	N
TGW004	TahSth_Standpipe_piezo	278363	6207827	1	<2	<2	2.8	3.6	N
TGW006	TahSth_Standpipe_piezo	279079	6203890	1	5.7	11.2	5.0	11.5	N
TGW003	TahSth_Standpipe_piezo	275956	6208076	1	<2	<2	7.6	7.3	N
TGW001	TahSth_Standpipe_piezo	273456	6207677	1	<2	11.1	12.4	12.9	N
TGW002	TahSth_Standpipe_piezo	271875	6207163	1	<2	15.2	17.4	17.6	N
P2	Tahmoor_North_Standpipe_piezo	277070	6211630	1	<2	12.7	13.9	15.4	N
P3	Tahmoor_North_Standpipe_piezo	277854	6211740	1	<2	9.3	6.0	13.3	N
G8	Bargo_private_no_access	281559	6204177	1	5.1	11.1	10.8	12.9	N
G23	Bargo_bore_census_level_chem	282654	6205666	1	<2	<2	<2	<2	N
G24	Bargo_bore_census_level_chem	278899	6201873	1	27.7	30.3	27.4	28.5	N
G44	Bargo_bore_census_level_chem	282388	6205638	1	2.6	13.1	15.1	15.2	N
G53	Bargo_bore_census_chem_only	276585	6201999	1	<2	<2	<2	<2	N

source: E:\HYDROSIM\TAHMOOR\Model\Processing\MaxDDN\DDNcalc\BoreDrawdown Assessment_v6TR069-XXX_&_sensitivity_V4.xlsx [CensusTableForReport_noREG]

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 is considered in the Surface Water Assessment (HEC, 2020b).

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 likely that changes in salinity and specific nutrients (e.g. iron, manganese, barium and others, as noted in Morrison *et al*., 2019) would occur within the utilised groundwater systems in the Permo-Triassic rock aquifers in or around the mine lease. The risk of such impacts decreases with distance from longwall mine areas and associated rock mass deformation and fracturing. However, a reduction in the beneficial uses of the groundwater is unlikely. 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, 2020b).

6.9 SUMMARY OF ASSESSMENT IN TERMS OF THE AI POLICY

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

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

Aquifer	**Sydney Basin Porous Rock** **(Nepean Groundwater Source, Management Zone 2)**
Category	**Highly Productive Groundwater**
Level 1 Minimal Impact Consideration	**Assessment**
Water Table 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: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR 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). 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. There are three High Priority Groundwater Dependent Ecosystems (GDEs) in the Study Area: Thirlmere Lakes - There is a risk of groundwater drawdown of approximately 0.02 m from Tahmoor South Project or <1% of water table fluctuation. There is a risk of peak drawdown of 0.13 and 0.48 m drawdown from the cumulative effects of historical mining in the alluvium underlying the lakes, noting that lake level reductions are discussed in HEC (2020b). The cumulative impact groundwater drawdown is less than the 10% criterion at 3 of the lakes and close to or above the 10% criterion at two of the lakes (9% and 12%). Additional drawdown is likely due to local groundwater pumping in conjunction with the effects of mining and local groundwater pumping. Other GDEs (e.g. O’Hares Creek and Macquarie Rivulet) are beyond the boundaries of the impact assessment model. Water supply works: It is likely that drawdown at some bores will exceed the water supply work drawdown criterion within the Permo-Triassic strata. **Level 2 minimal impact consideration classification.**
Water pressure 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. **Level 2 minimal impact consideration classification.**
Water quality 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. **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.

6.10 OTHER IMPACTS OF MINING

6.10.1.1 Mining near/under alluvial Water Sources

The proposed underground mining at Tahmoor South will not take place beneath any 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 designated alluvial water sources.

6.10.1.2 Baseflow capture within WaterNSW Special Areas

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

6.11 MITIGATION AND MANAGEMENT

Based on the findings summarised in Section 6.10, the 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 and noted subsequently in communication with GES) that some monitoring sites, especially the TBC bores, might require repair/replacement/augmentation to improve confidence.

In 2018-19, Tahmoor Coal has installed a significant number of piezometers in and around Longwalls 31-32 and the Western Domain longwalls in the northern part of the mine. These have already, and will in future, provide useful information for future conceptualisation and model calibration/verification. 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, three recommendations regarding monitoring of groundwater levels are:

- 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.
- 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.
- 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 (101A), 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 continued.

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/Western Domain and then in the Tahmoor South ‘A’ and ‘B’ blocks. 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. As discussed with Tahmoor personnel, 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. This provides context to the number of bores simulated as experiencing or likely to experience >2 m drawdown due to Tahmoor Mine operations (Section 6.7).

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

7.1 SUMMARY OF CHANGES IN THIS AMENDED PROJECT ASSESSMENT

7.1.1 GROUNDWATER-RELATED CHANGES DUE TO THE AMENDED PROJECT MINE PLAN

The key changes to the revised mine plan are:

- the reduction in panel (void) width from 305 m to 285 m;
- a change in maximum cutting height from 2.9 m to 2.6 m; and
- the amended mine plan has now two distinctive sections of longwall panels ('A' and 'B' blocks) separated by central mains, with the removal of LW109.

These changes affect the height of the connected fracture zone, and have a slight change on depth to which surface cracking is inferred to extend down from ground surface. The change to the footprint of longwall panels will mean that there is a change to areas in which surface cracking would occur (i.e. it will not occur with the same intensity above the new central mains than it would directly above panels).

The overall Amended Project timing remains consistent with the mine plan proposed in the EIS, with mining operations starting in 2022 and ending in 2035.

7.1.2 SPECIFIC CHANGES TO THE AMENDED PROJECT GROUNDWATER ASSESSMENT

The numerical model presented in the EIS (HS, 2018) was updated to incorporate a number of items raised by IESC, local councils, DPIE/DPE, DPIE (DoI) Water and DPIE's Independent Reviewer following the public exhibition of the EIS and following a further meeting with these groups in early 2019.

The key changes of the Amended Project were implemented into the numerical model. The significant actions targeted are included in **Table 7-1**.

Table 7-1 Summary of changes to the assessment (model) in response to submissions

COMMENT	CHANGE
Incorporate a representation of surface cracking in the numerical modelling, relying on literature and recent investigation at Redbank Creek (e.g. SCT, 2018), and incorporating this effect in estimated surface water losses.	This has been incorporated in the model, based on literature and local monitoring data.
Account for transient river stages and river leakage in estimated surface water losses.	This has been incorporated in the model, based on available monitoring data.
Revise the representation of lake bed and stage elevations at Thirlmere Lakes. Improve calibration to groundwater levels in Thirlmere Lakes bores.	This has been revised based on data from HEC (2020b). Calibration to local groundwater levels at Thirlmere Lakes is much the same as in the EIS (HS, 2018).
Improve the overall model performance in matching historical groundwater levels and mine inflows at Tahmoor;	The history match to groundwater inflow is good, and overall calibration performance to groundwater levels has improved.
Include groundwater pumping from private bores in the modelling.	HS has obtained recent entitlement data from WaterNSW, however estimates of actual groundwater pumping data are limited, and considered potentially

	unreliable. As a result, a single predictive scenario incorporating an estimate of groundwater use at local bores has been run for assessment of selected impacts.

The changes to the assessment method and to the mine plan have resulted in the following predicted outcomes of the impact assessment.

Table 7-2 Summary of differences in Amended Project Report

GROUNDWATER-RELATED PROCESS	KEY METRIC IN ORIGINAL EIS	KEY METRIC IN AMENDED PROJECT	COMMENT
Mine Inflow (average)	4.7 ML/d	4.7 ML/d	Similar to EIS. Groundwater licensing requirements are similar to the EIS, including the very low likelihood of 'take' from Groundwater Sources other than the Nepean Sandstone Groundwater Source.
Mine Inflow (peak)	7.5-8 ML/d (2029-30 and 2032)	7.5-8 ML/d (2028-29 and 2032-3)	
Groundwater drawdown at High Priority GDEs	Thirlmere Lakes alluvium - Incremental: 0.03 m	Thirlmere Lakes alluvium -Incremental: 0.02 m	Similar magnitude of incremental drawdown at Thirlmere Lakes due to Tahmoor South.
	Thirlmere Lakes alluvium - Cumulative: 0.02 to 0.05 m	Thirlmere Lakes alluvium - Cumulative: 0.08 to 0.48 m.	Higher groundwater drawdown at Thirlmere Lakes. This is associated with the inclusion of surface cracking in the numerical model associated with the Tahmoor North area, rather than changes to the Tahmoor South mine plan in the APR. At three lakes, the drawdown is <10% of water table fluctuation, while at two it is close to just above the 10% criterion. Additional drawdown due to local groundwater users is predicted to be similar or greater than due to mining, but is uncertain due to understanding of actual groundwater use by non-mining users. For consideration of lake level drawdown, refer to HEC (2020b).
Drawdown at neighbouring bores	Registered: 31. Census: 6	Registered 46. Census 4	Greater number of bores predicted to be affected now. This is associated with a revised method of assessment, rather than changes to the mine plan in the APR.
Surface Water Take	Peak take (ML/d) of: • Pheasants Nest MZ: 0.04. • Stonequarry MZ: 0.06. • Maldon Weir MZ: 0.6.	Peak take (ML/d) of: • Pheasants Nest MZ: 0.014. • Stonequarry MZ: 0.01. • Maldon Weir MZ: 0.2.	Similar in overall magnitude to the EIS, but now considered to be more reliable as a result of revised modelling in line with submissions. This APR assessment also includes assessment of take from more Water Sources or zones than provided for in the EIS.
Effect on groundwater quality	No specific metrics.	See discussion in Section 6.8.	Similar to EIS. Surface cracking above panels will lead to similar effect on shallow groundwater and surface water as observed around Tahmoor North.

7.1.3 SUMMARY OF GROUNDWATER ASSESSMENT

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:

  - Subsidence (MSEC, 2020);
  - Surface water (HEC, 2020a,b,c,d);
  - Shallow Groundwater Baseline Monitoring (Geoterra, 2013a,b);
  - 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 APR 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 investigations carried out for Tahmoor Coal above Longwall 10A (SCT, 2014) and at Redbank Creek (SCT, 2018). 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 EIS for the Amended Project (AECOM, 2020a). 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 was conducted, but considering the good calibration to historical inflow records, the current best estimate for licensing to cover the predicted peak groundwater take by the Tahmoor South mine is 2,700-2,900 ML/a. Tahmoor Coal already holds 1,642 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 1,700-2,000 ML/a, with most via the depletion of aquifer storage, 120 and 100 ML/a each from reduced baseflow and evapotranspiration, and 1 ML/a from other groundwater sources (GMAs) as described above.
- Surface water take estimates have been provided for inclusion in the Surface Water Assessment (HEC, 2020b), and also passed to Tahmoor Coal for the operators to commenced inquiries into obtaining surface water licences.
- 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 <=0.02 m due to the operation of Tahmoor South Project, which is 3.5 km or more from the lakes. As per the AIP, this is less than 1% of observed water level fluctuation in the alluvium.
    - Cumulative mining effects are greater, with drawdown from 0.08 up to 0.48 m predicted in parts of the Thirlmere Lakes alluvium. The predicted drawdowns are 3 to 12% of observed water level fluctuation.
    - Effects on lake levels are addressed by HEC (2020b).
    - With the exception of 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 'High Priority' Culturally Significant sites are identified in the relevant Water Sharing Plan. Hence the proposal is not considered a risk to such sites.
- The Wirrimbirra Sanctuary, located along the middle of Tea Tree Hollow and above the proposed 'A' block of longwalls, was identified in Submissions by the Heritage Council. The position of this feature above longwalls means that it will be subject to drawdown via depressurisation and also surface cracking effects (see also MSEC, 2020). Drawdown in the water table is likely to be on the order of 5-10 m, based on the modelling and supported by comparison against recent observations from the P9 piezometers at Redbank Creek.
- 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 estimates that 46 registered bores would be affected by the proposed Tahmoor South mine in excess of the 2 m drawdown criterion of the AI Policy, as well as a further 6 registered bores that would be affected by Tahmoor South yet are already predicted to be affected by historical mining effects. Uncertainty analysis via deterministic scenarios, including conservative representations of the height of fracturing, transmissivity of fault zones and high horizontal permeability of the Hawkesbury Sandstone, suggests that up to 73 registered bores might be affected beyond the 2 m threshold. The base case model indicates that approximately 228 registered bores would be affected by the cumulative activity of all simulated mines, and this could be up to 264 registered bores when considering the results of the deterministic scenarios. A small number of unregistered bores, captured as part of the bore census, may also be affected (up to 4 such bores affected by Tahmoor South Project). The number of bores predicted as affected beyond 2 m drawdown needs to be considered in the context that Tahmoor has, historically, only been required to 'make-good' at 2 groundwater bores, despite over 70 being predicted to be affected by the operation of Tahmoor North.
- 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. This is the same finding as in the EIS (HS, 2018).
- 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 bore census was conducted in 2013 (Geoterra, 2013), and as requested in submissions following the EIS, this is currently being revised for Tahmoor Coal.
- A Groundwater Management Plan will require development and approval if this Project is approved. This will need to define groundwater level triggers, and Trigger, Action, Response Plans (TARP).

7.2 RECOMMENDATIONS FOR FUTURE WORK

Following approval of the 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, specifically the Western Domain, 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, as well as providing additional data on surface cracking effects.
- Some replacement of failed bores around Tahmoor North and Tahmoor South. The installation of new bores around the Tahmoor North Western Domain has been addressed in the recent version of the GWMP. However, pending approval of the Tahmoor South Project, additional works are required to improve the Tahmoor South monitoring network.
- Sampling and analysis of groundwater entering the workings. This would be beneficial to better understanding potential water quality effects. This should be implemented in a sump/collection point/pump location prior to treatment and discharge to LDP1. If such a sampling point is available and appropriate, then this should included in the GWMP, pending project approval.
- Review of findings from the on-going Thirlmere Lakes Research Programme (coordinated by the NSW government). Limited information has been available thus far (e.g. presentations from the Information Day in early 2019, updates on the programme website). Where necessary and possible, relevant findings should be represented within the groundwater conceptual and numerical models.
- 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. This was recommended in HydroSimulations (2018), and has occurred already with respect to Tahmoor operations. However, HydroSimulations is aware that the BSO (Appin) mine plan modelled here is not completely accurate to the actual development that has occurred in recent years, and this should be addressed in future model revisions.
- For future modelling, HS recommends that the groundwater model be rebuilt to take further advantage of the ‘unstructured mesh’ capability of MODFLOW-USG, to the model extent and reduce cell counts, all while preserving detail where necessary. Initial testing suggests that the cell count could be reduced to about 15% of the current count, with associated improvements in run times, memory requirements, and therefore the ability to carry out further automated calibration and uncertainty analysis, such as that in the following point.
- Following the previous point, 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.

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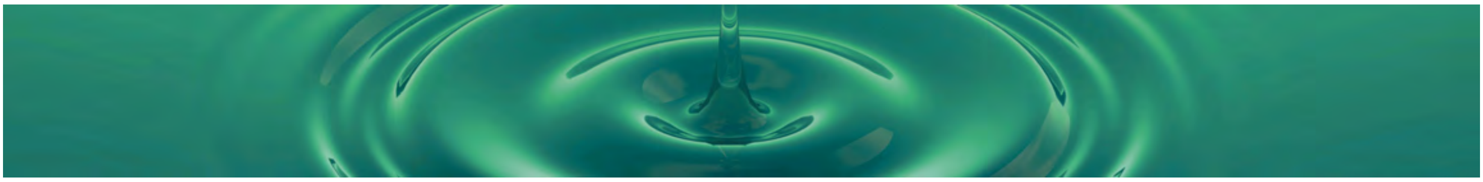
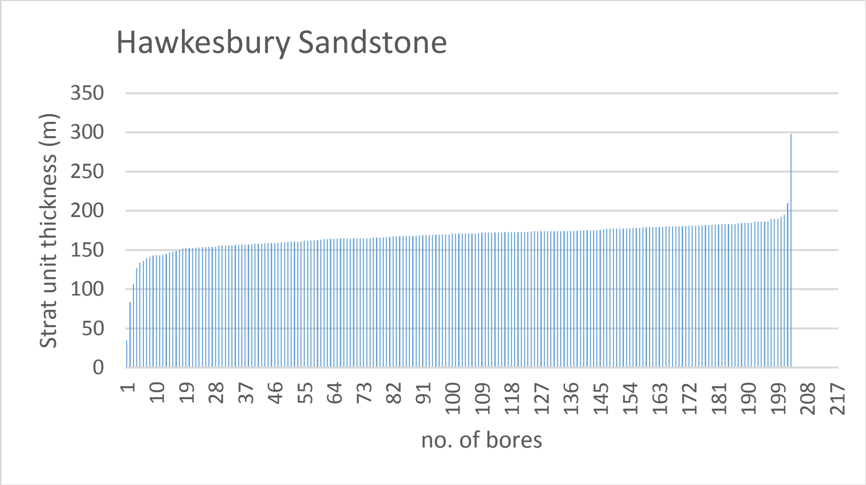
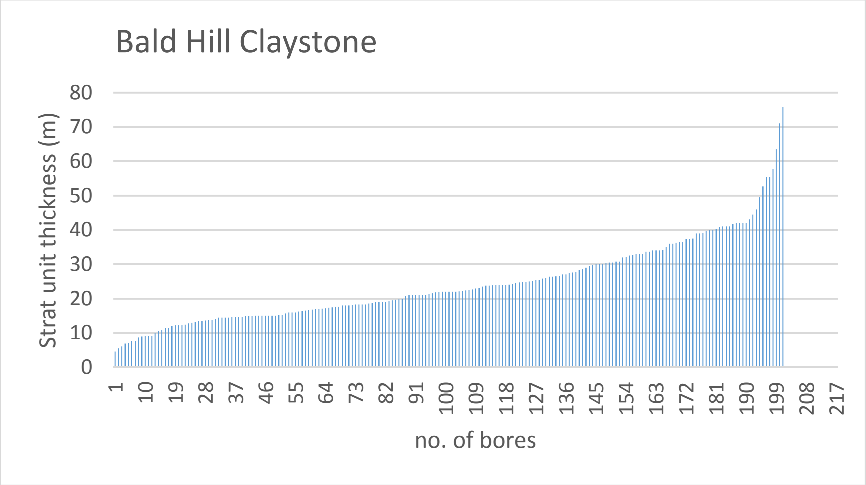
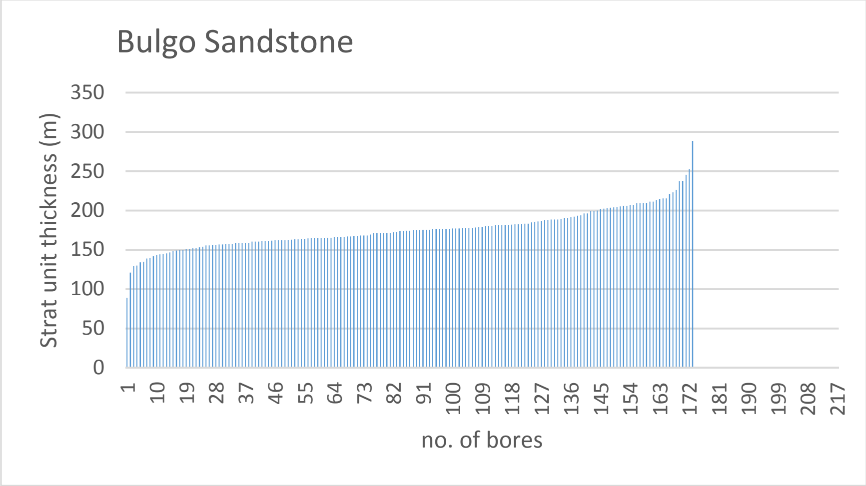


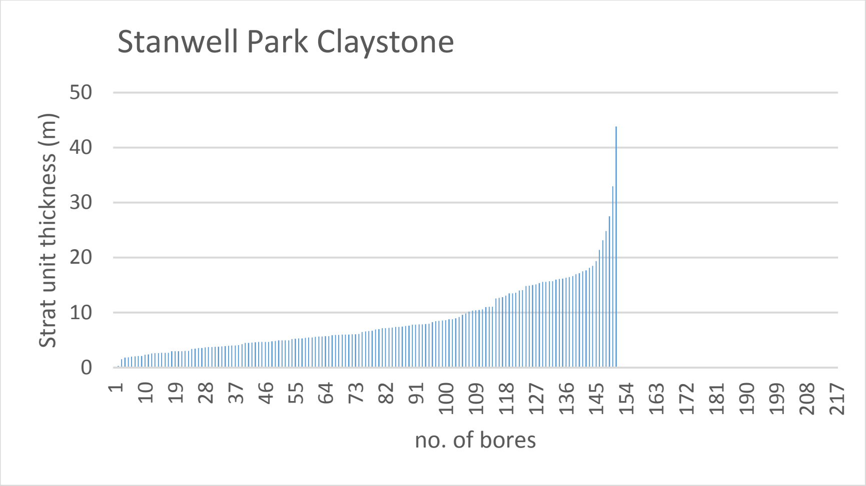
APPENDIX A Stratigraphic thickness from Tahmoor bore logs

Bore-by-bore stratigraphic interpretation









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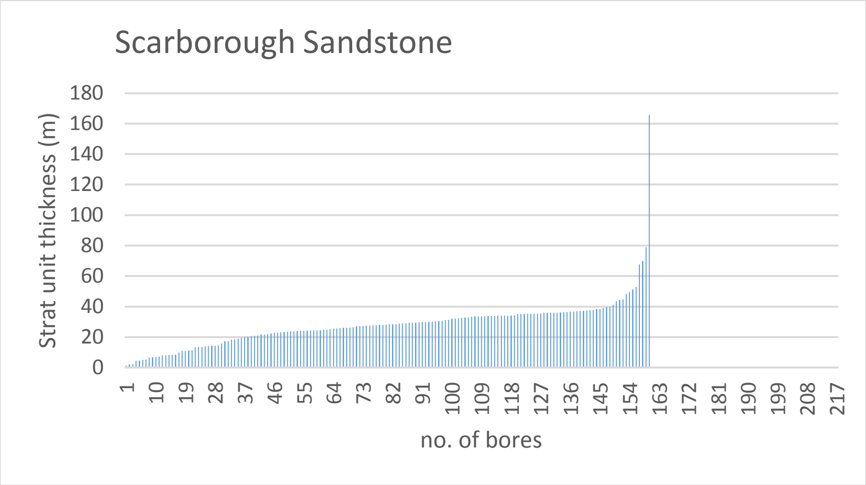
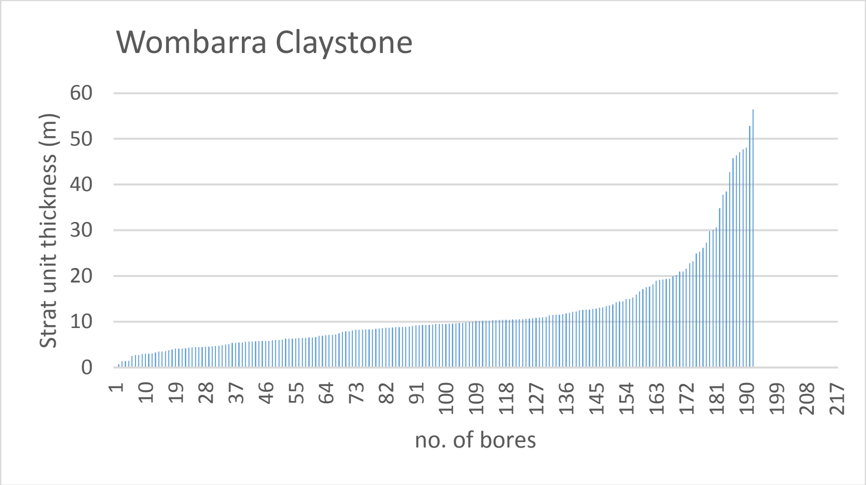
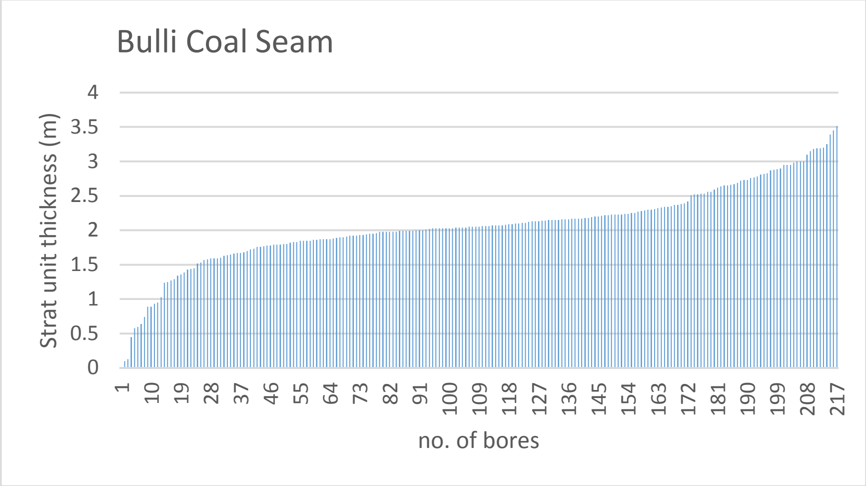
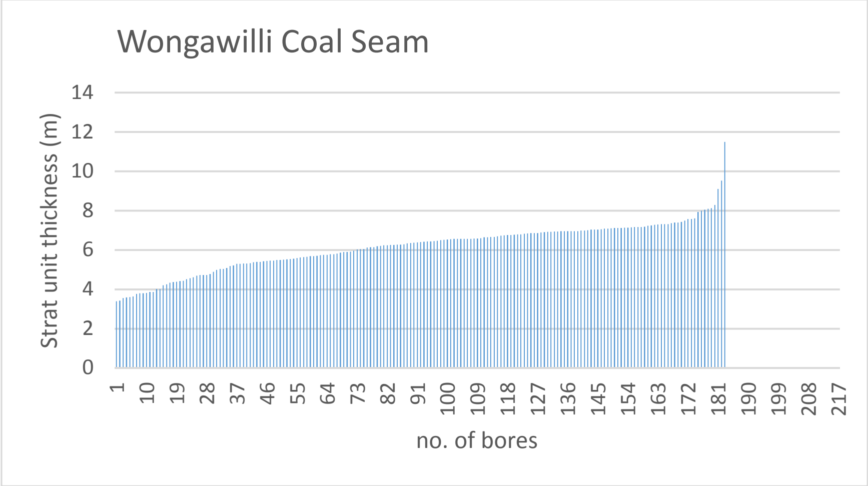
Bore-by-bore stratigraphic interpretation









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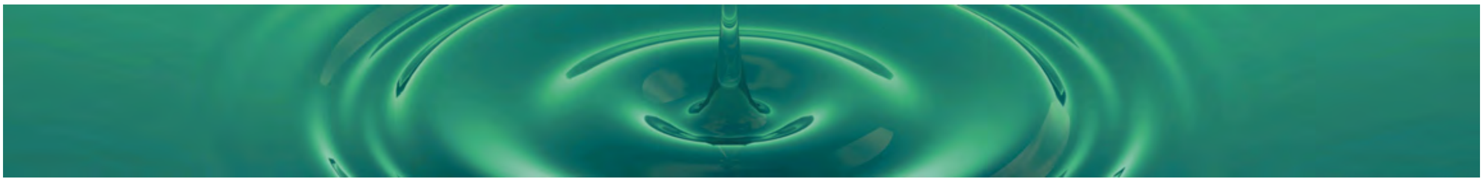
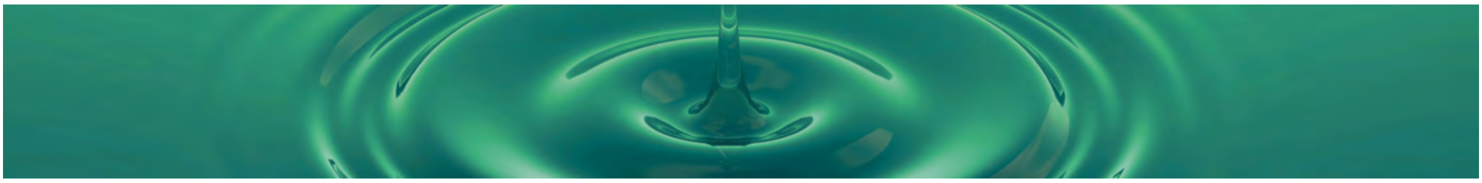


APPENDIX B Vibrating Wire Piezometer (VWP) hydrographs

(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

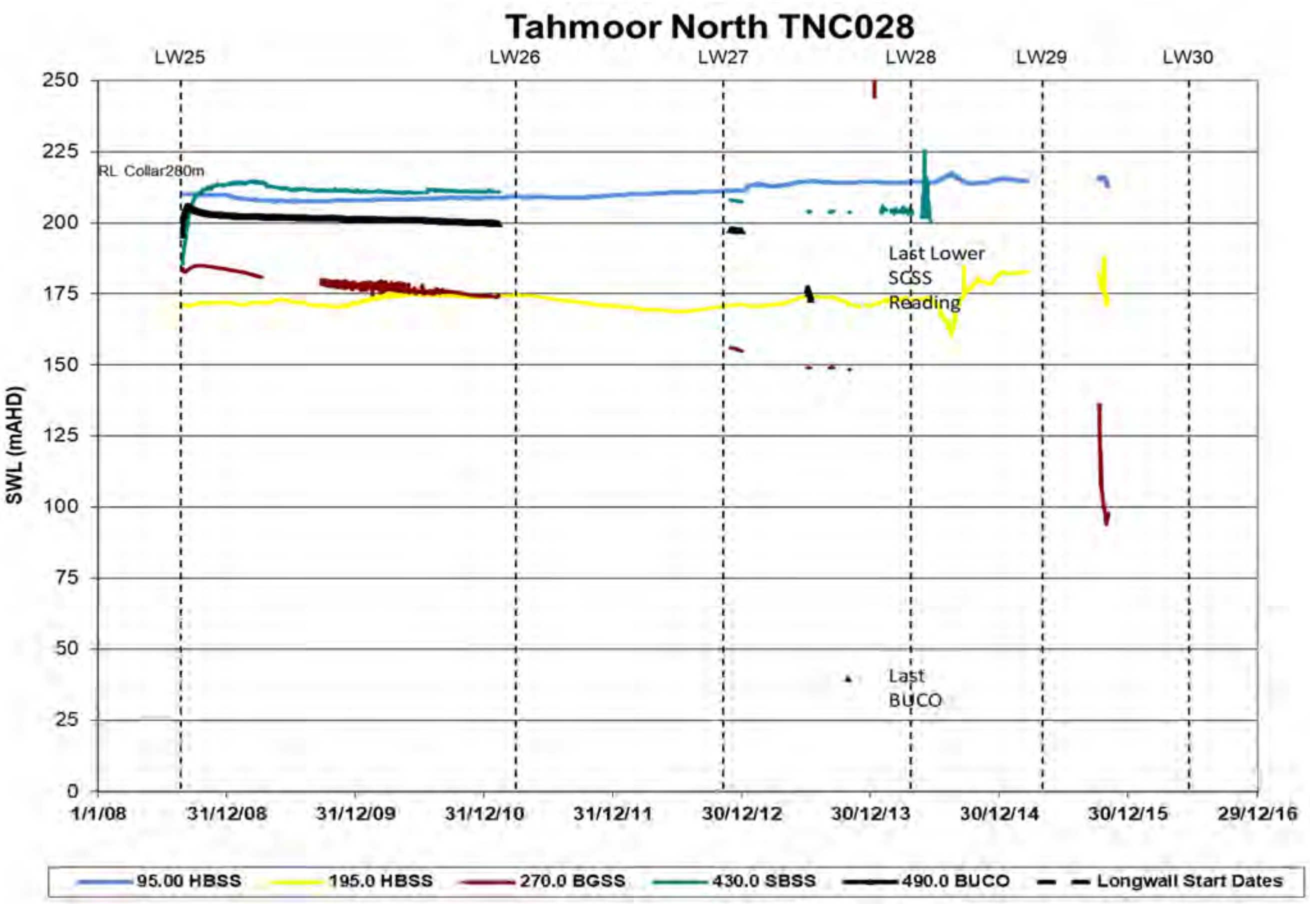


Figure B1.1: TNC028 Hydrograph (Decommissioned)

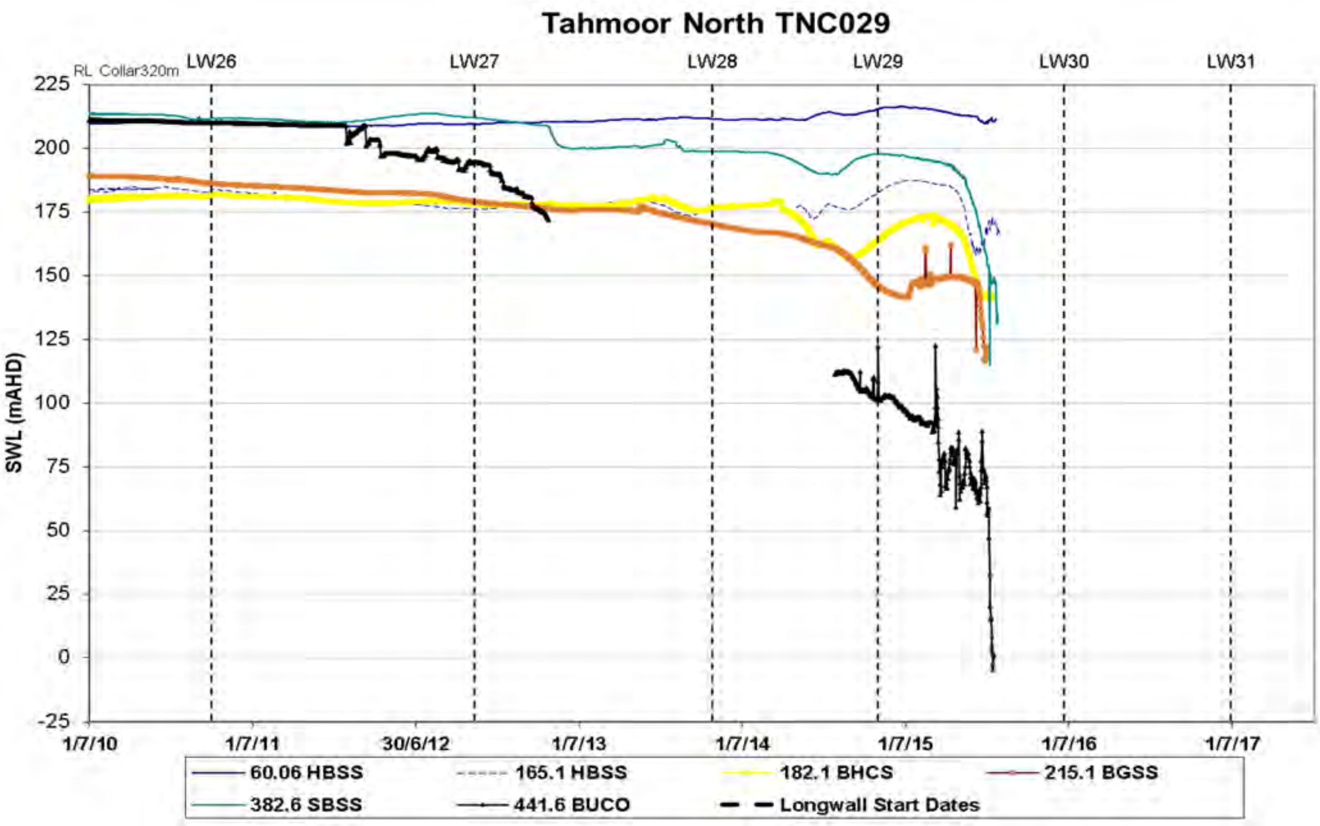


Figure B1.2: TNC029 Hydrograph (Decommissioned)

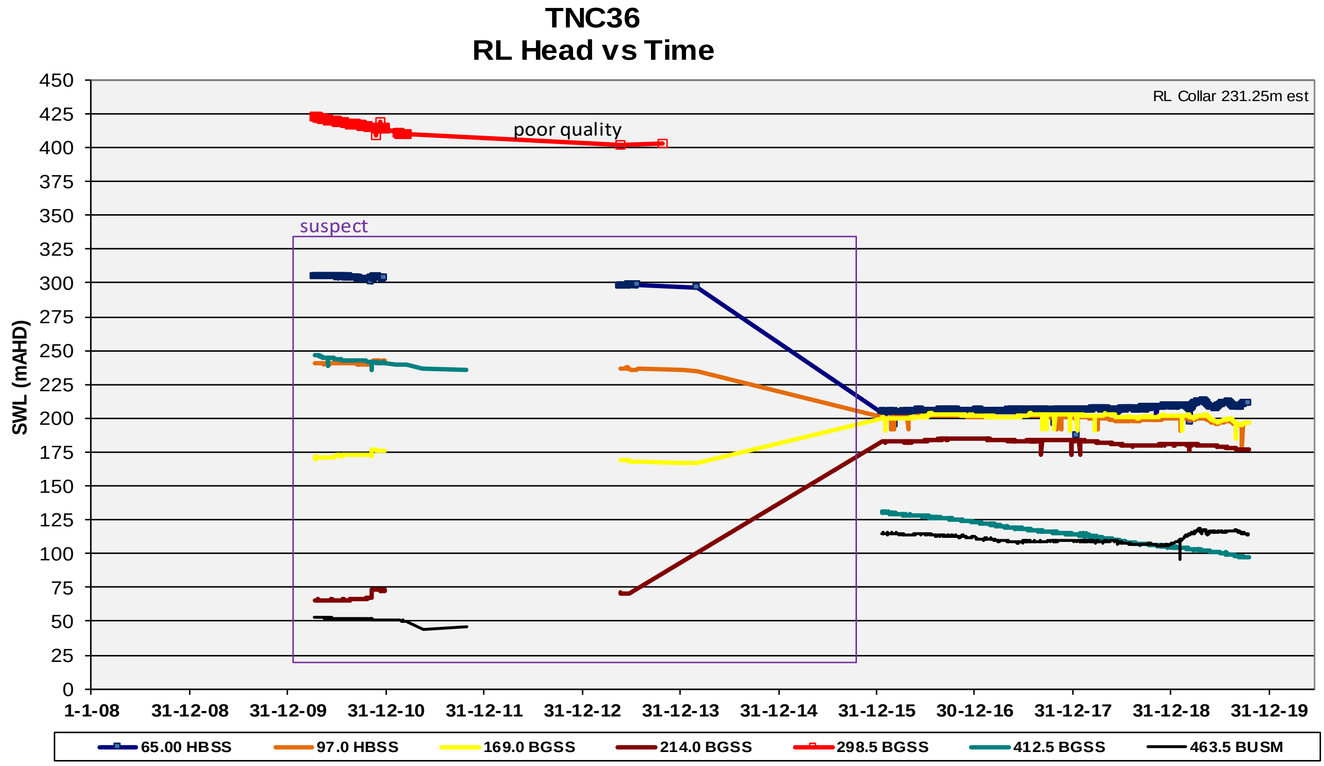


Figure B1.3: TNC036 Hydrograph

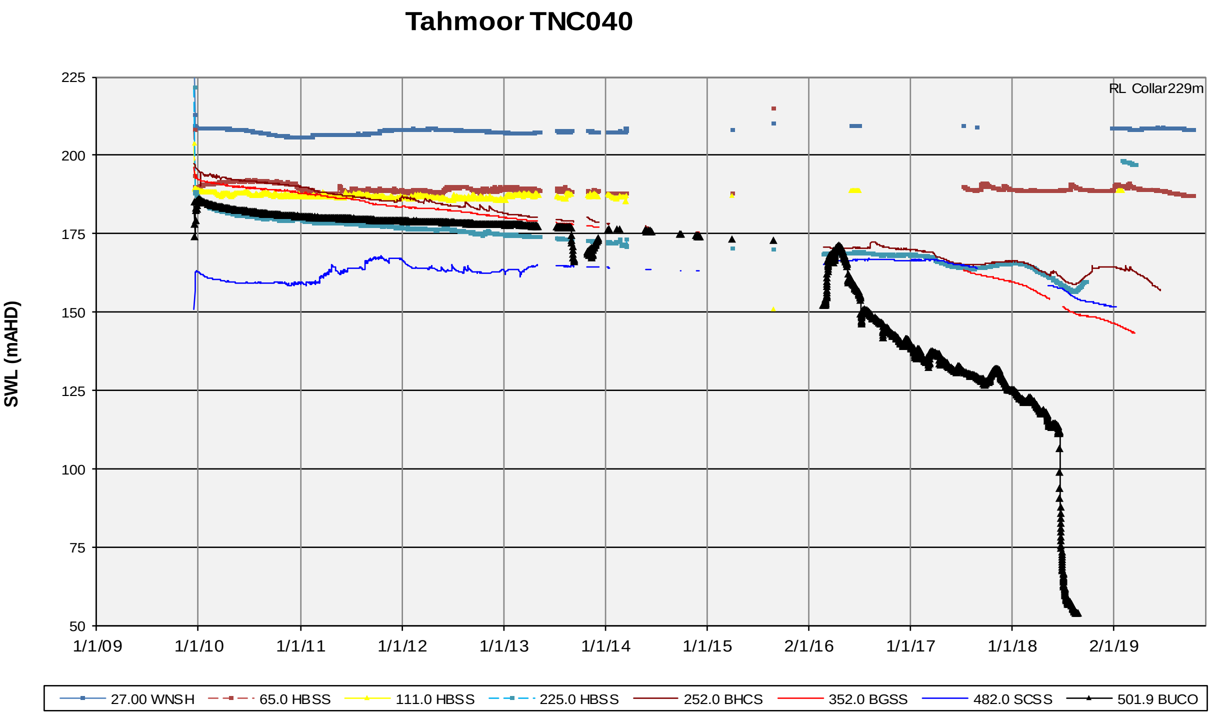


Figure B1.4: TNC040 Hydrograph

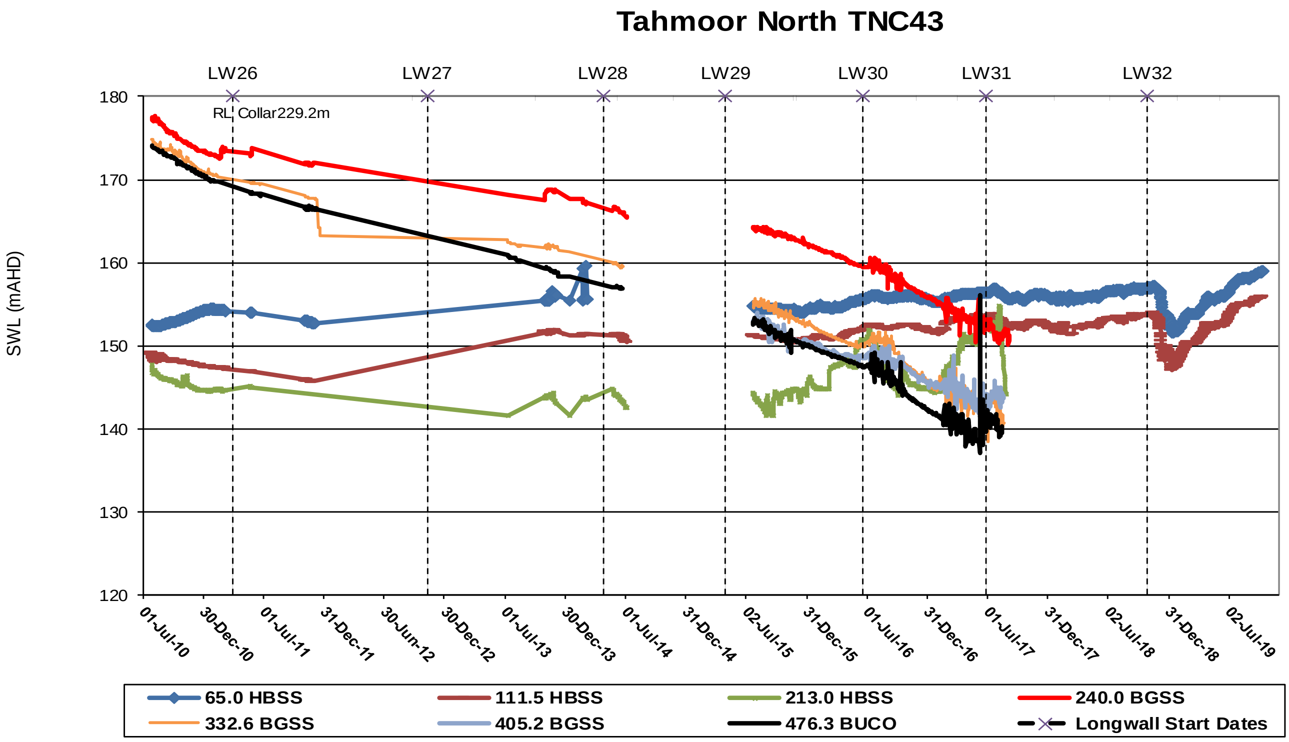
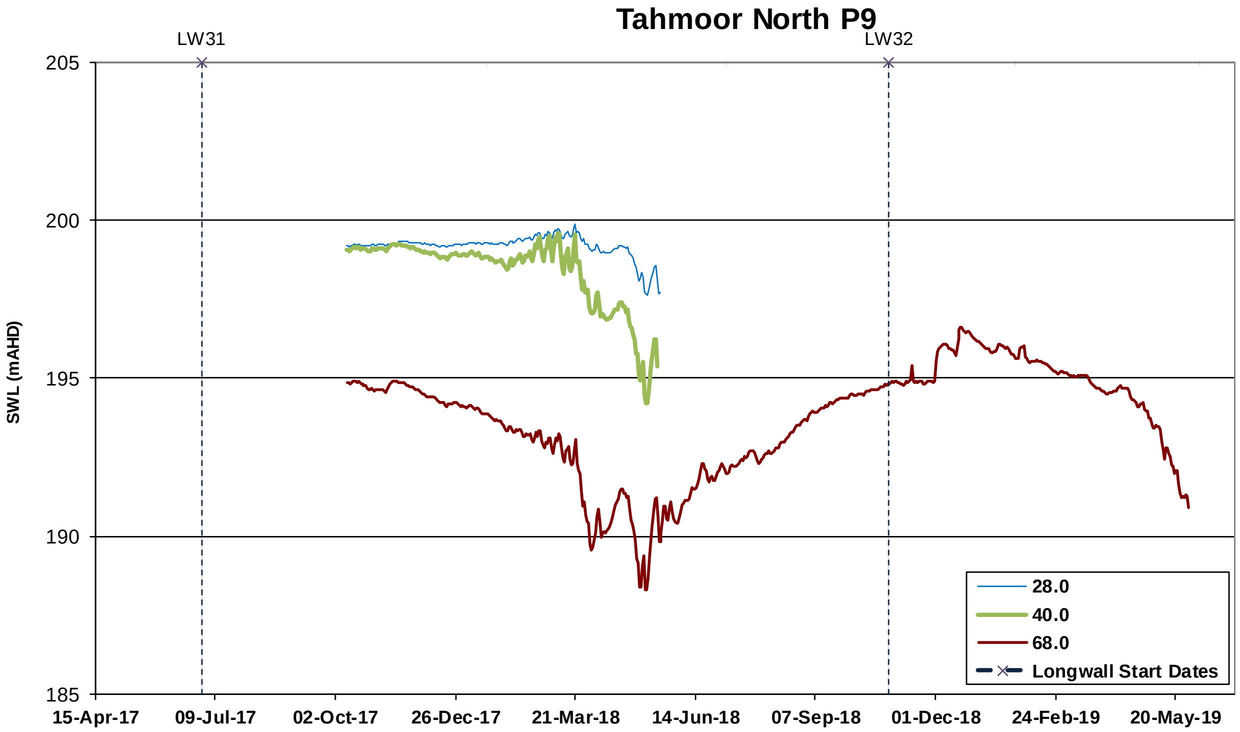


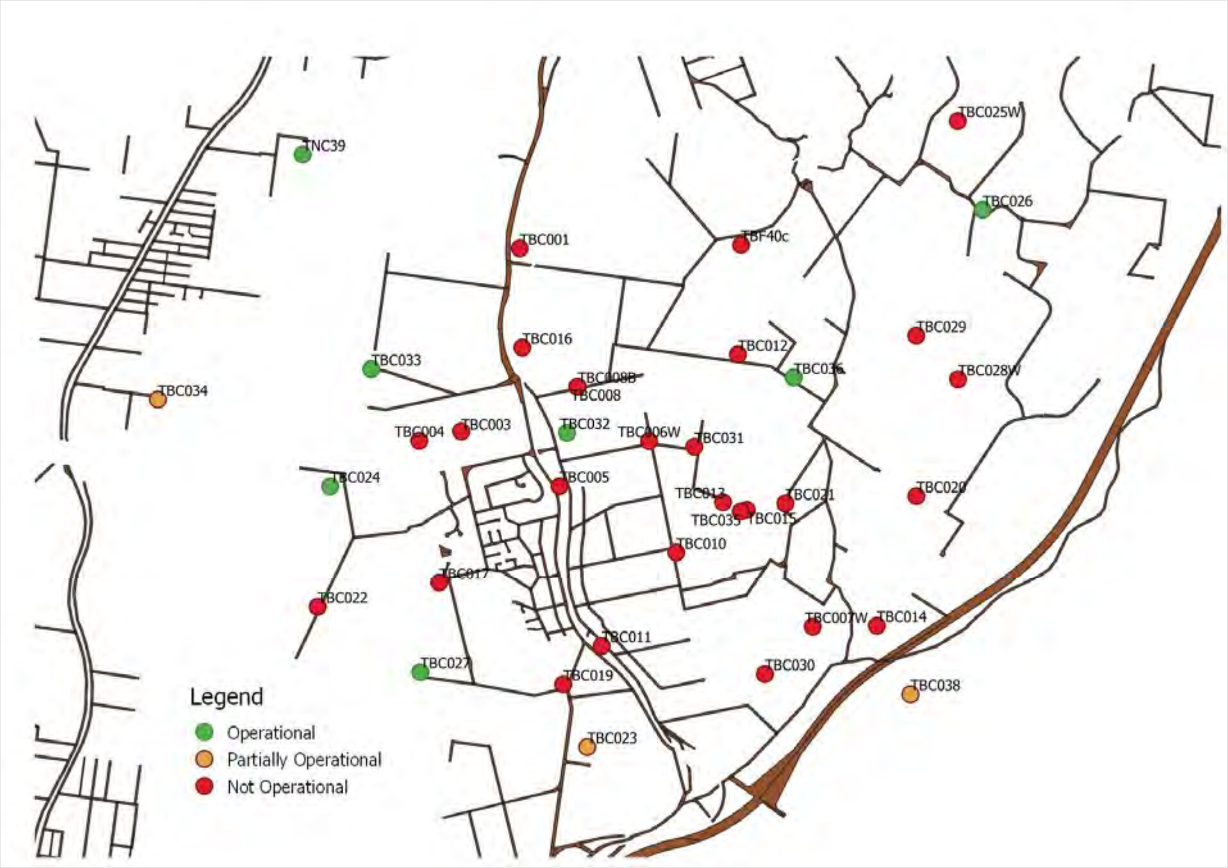
Figure B1.5: TNC043 Hydrograph



Piezometer	Piezo Depth	Lithology
P9B	28 m	Sandstone
P9C	40 m	Sandstone
P9D	68 m	Sandstone

Figure B1.6: P9 VWP Hydrograph

2 TAHMOOR / TAHMOOR SOUTH



(partially operational = some but not all piezometers functional at that location

(not operational = all piezometers at that location are out of action)

Figure B2.1: Summary of TBC VWP status

(updated and provided by GES 2019)

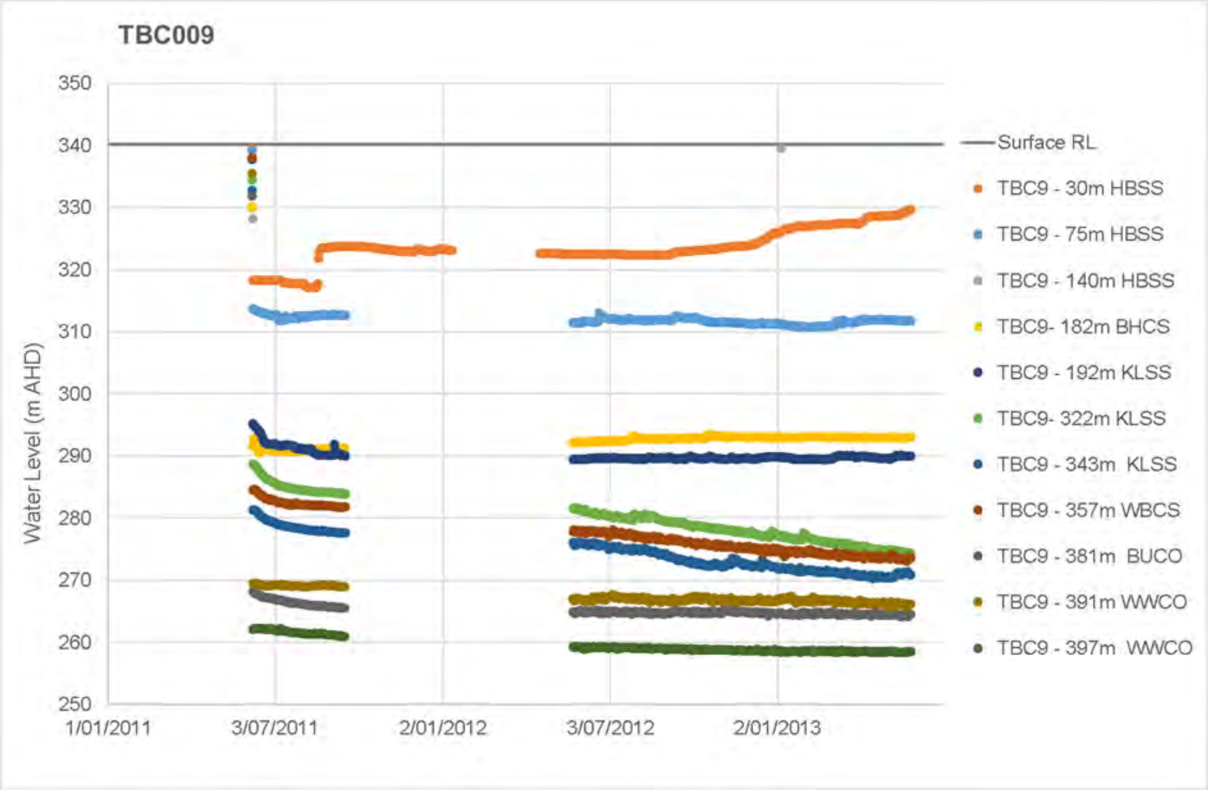


Figure B2.2: TBC009 Hydrograph. (out of service)

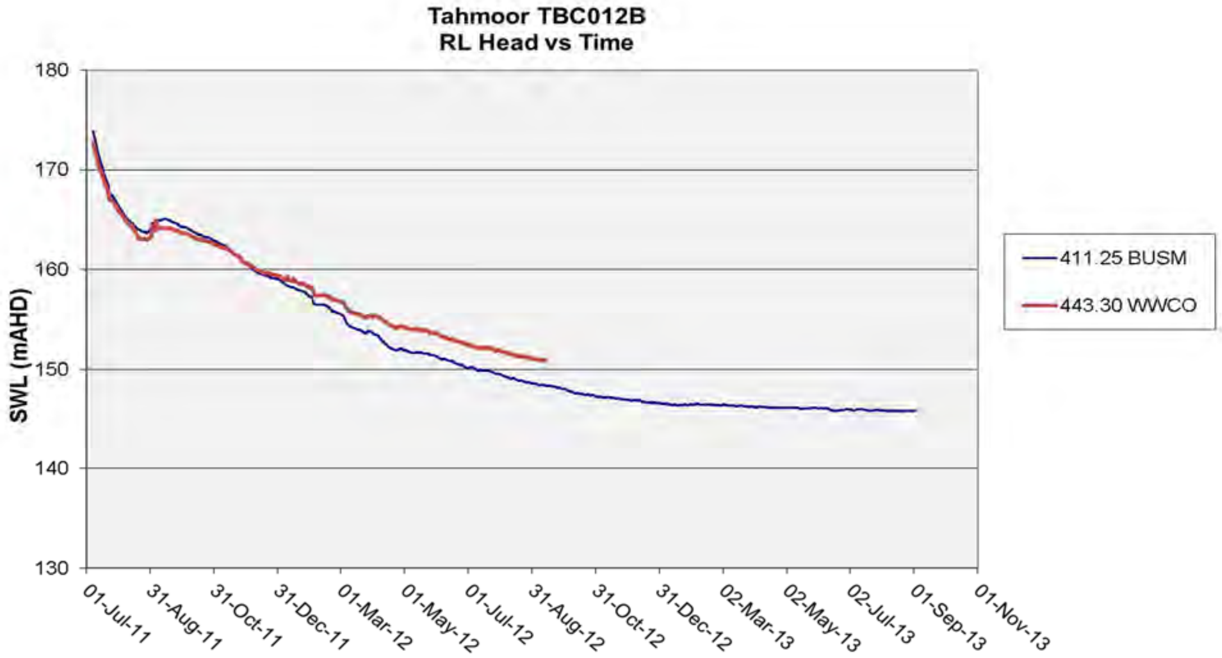


Figure B2.3: TBC012 Hydrograph. (out of service)

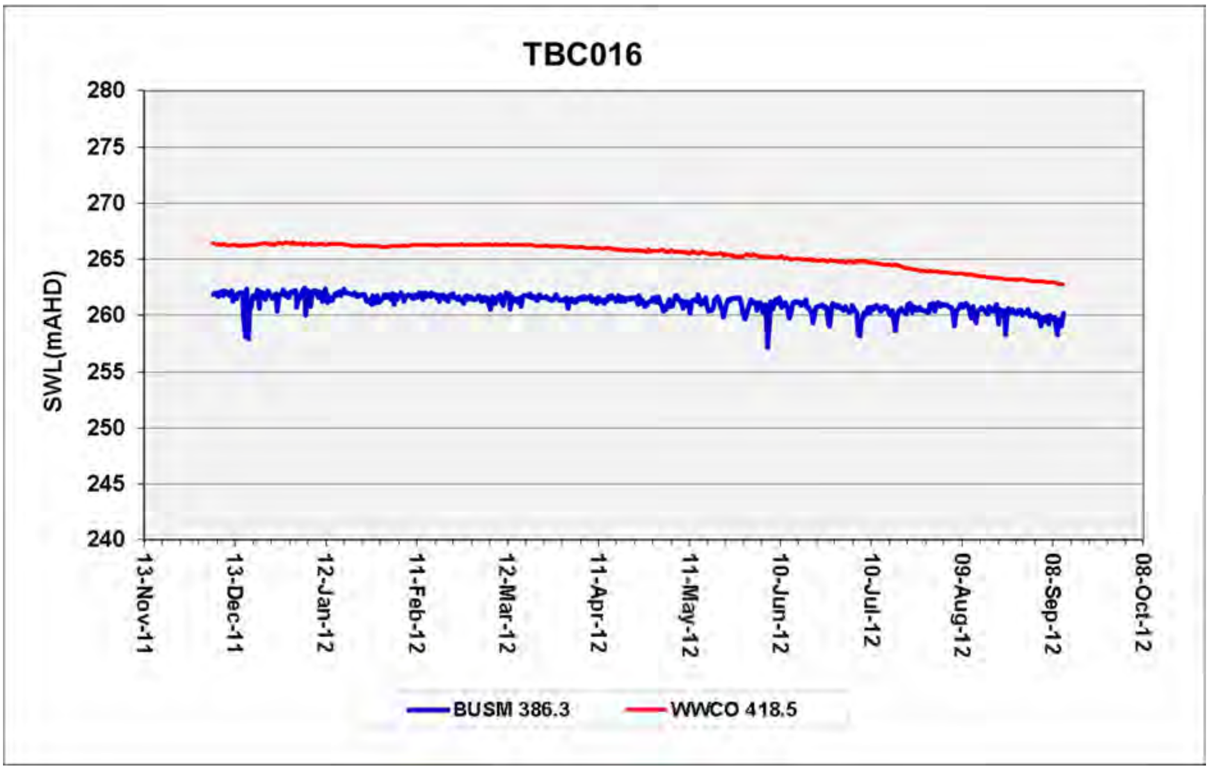


Figure B2.4: TBC016 Hydrograph. (out of service)

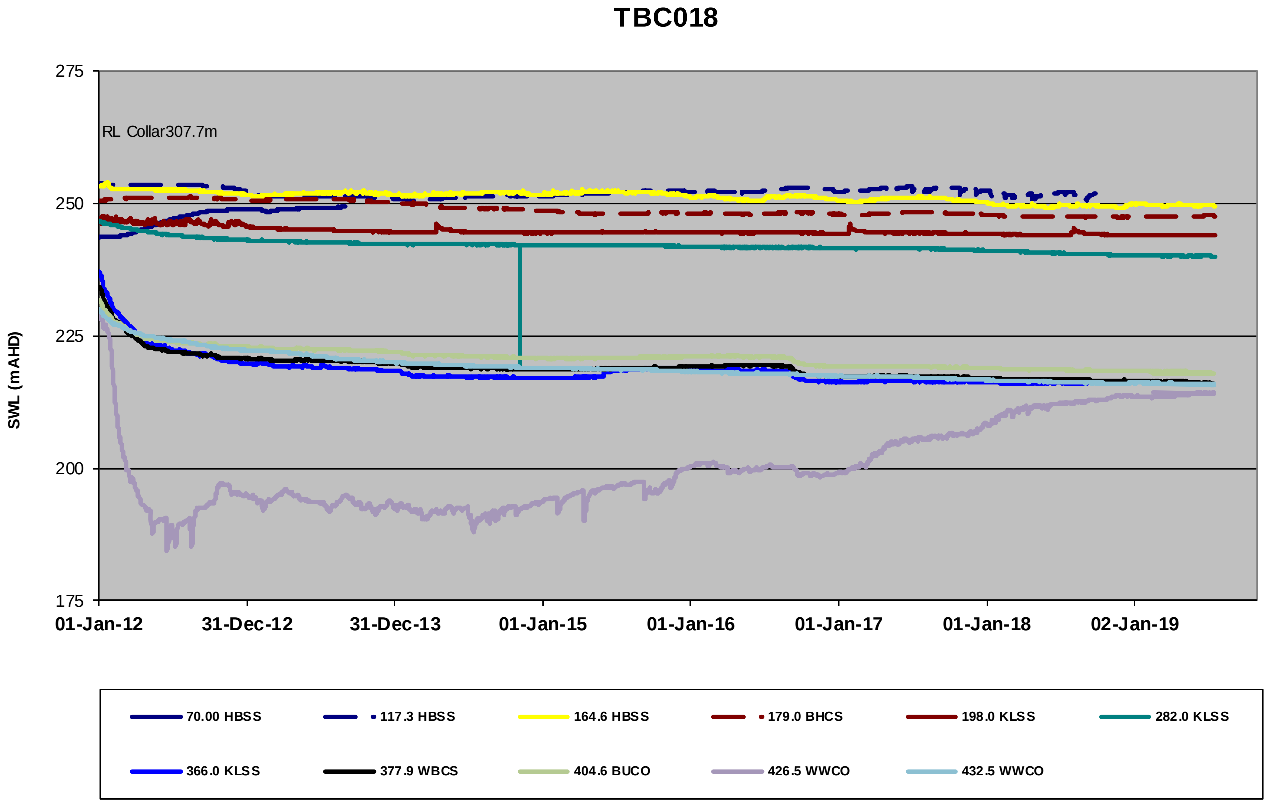


Figure B2.5: TBC018 Hydrograph

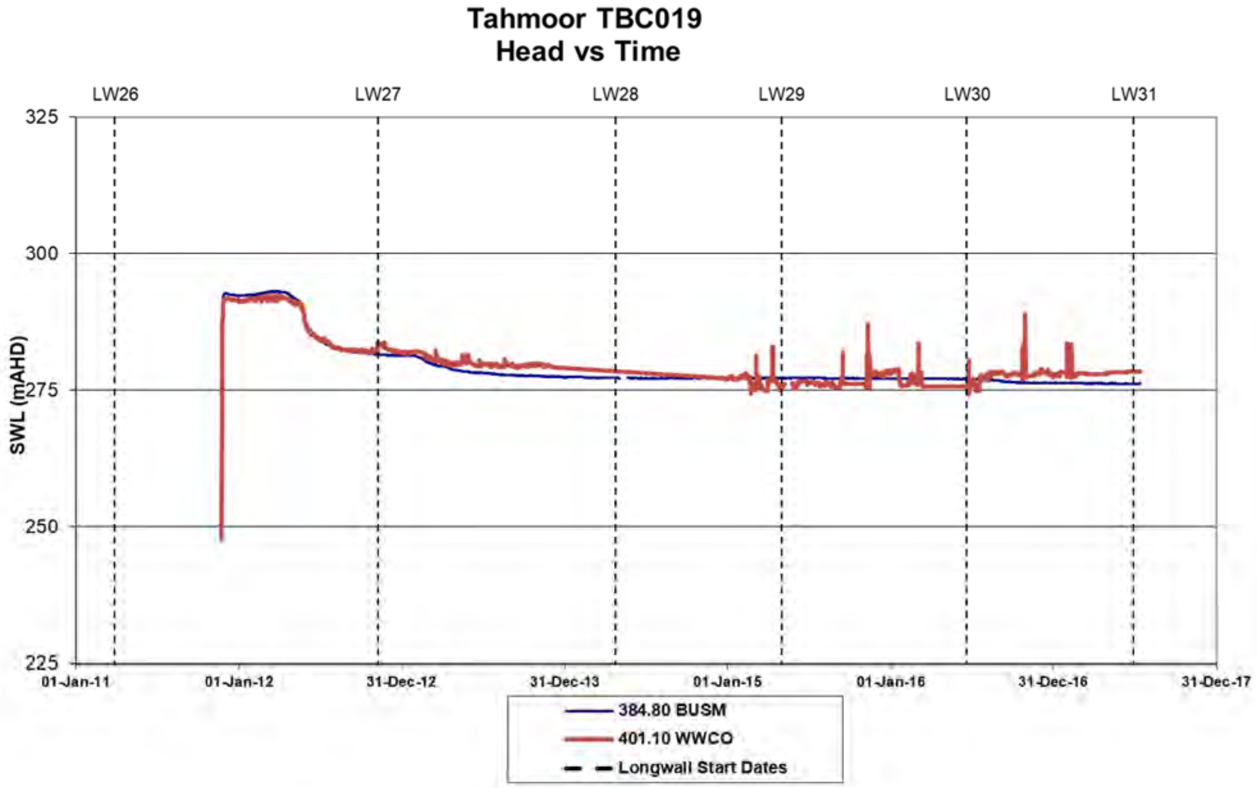


Figure B2.6: TBC019 Hydrograph

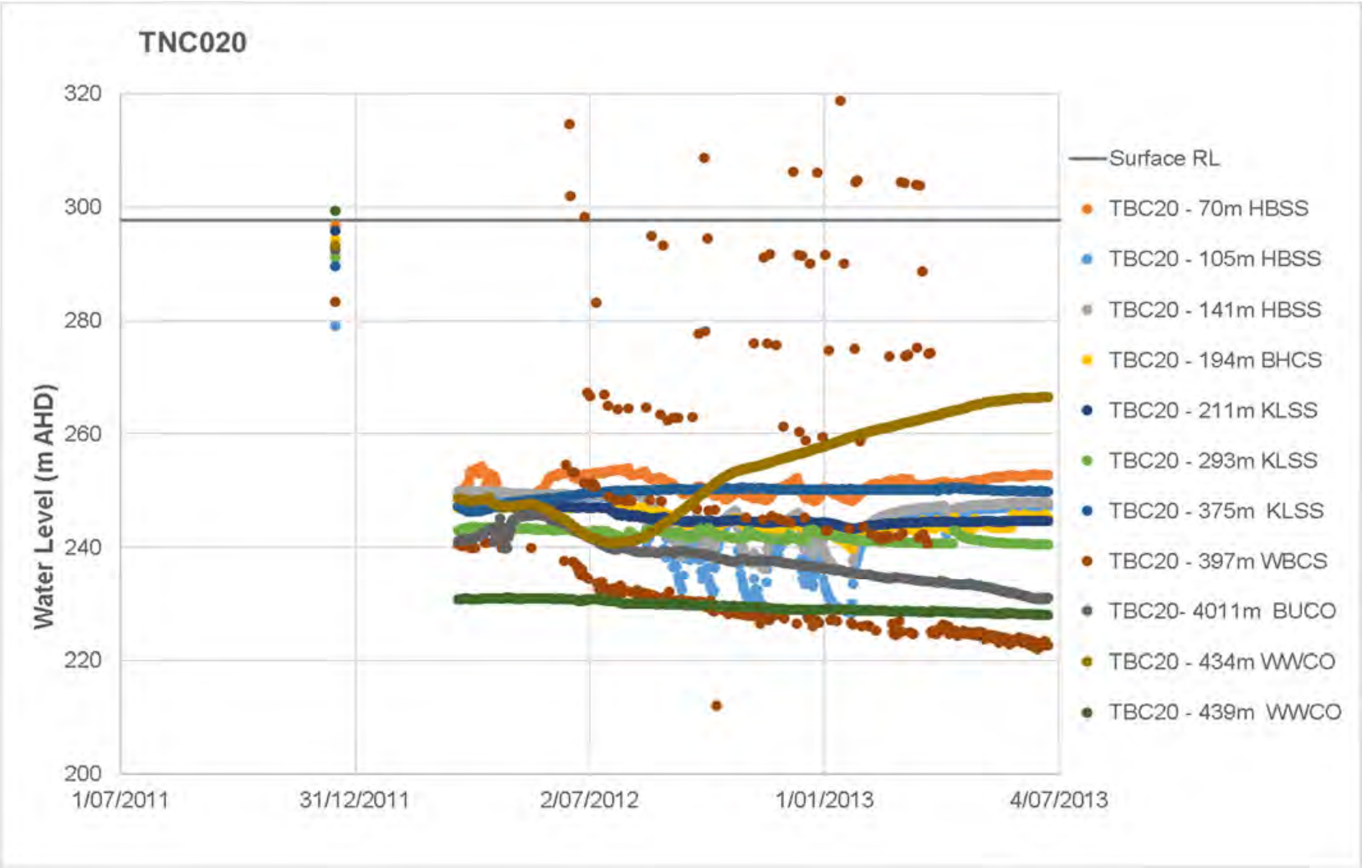


Figure B2.7: TBC020 Hydrograph. (out of service)

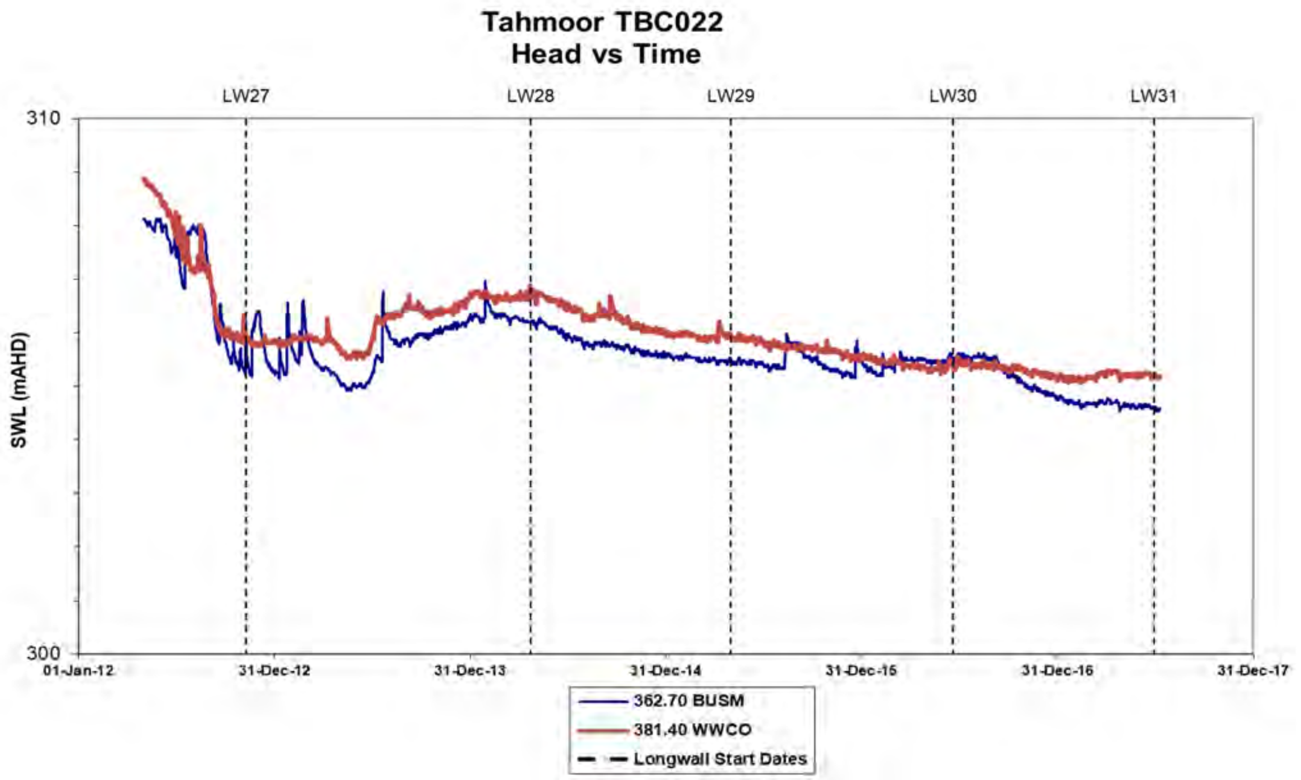


Figure B2.8: TBC022 Hydrograph

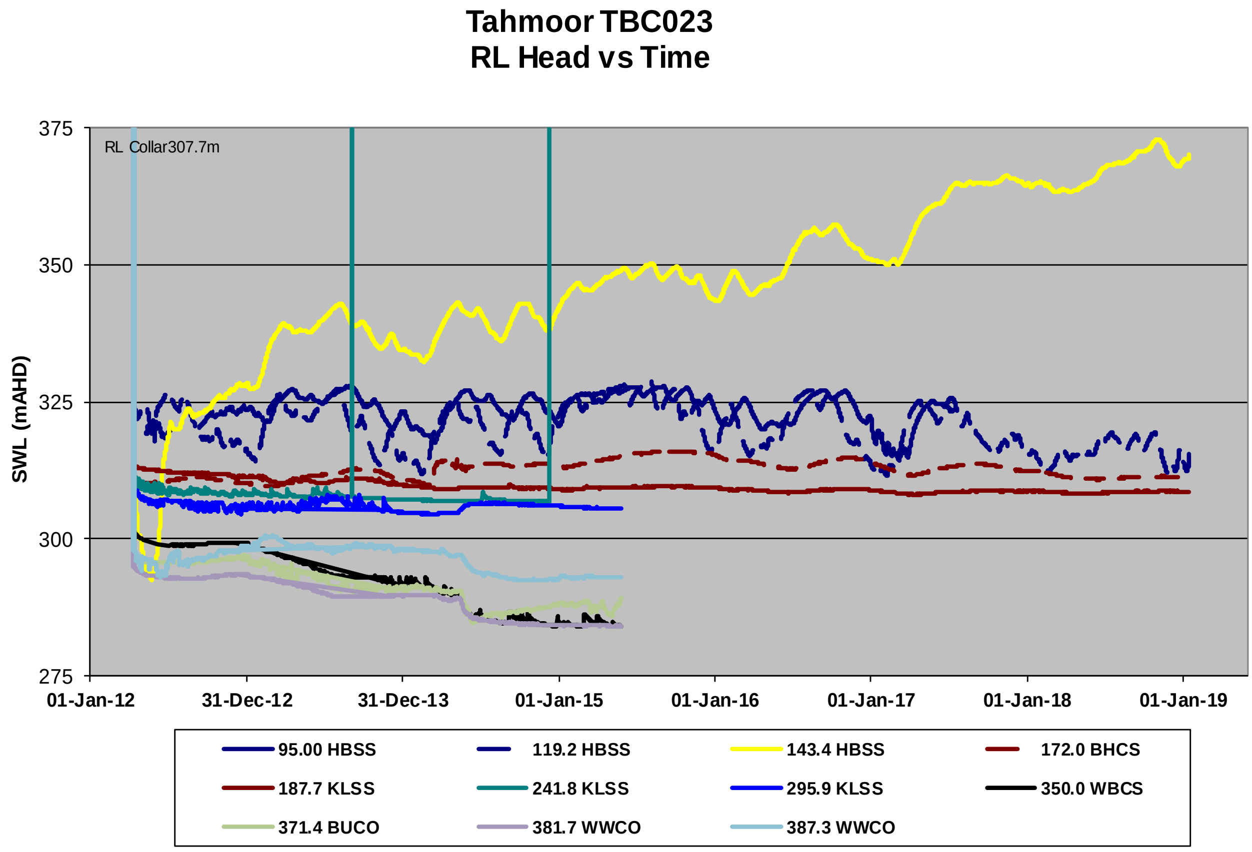


Figure B2.9: TBC023 Hydrograph (deeper piezos are out of service)

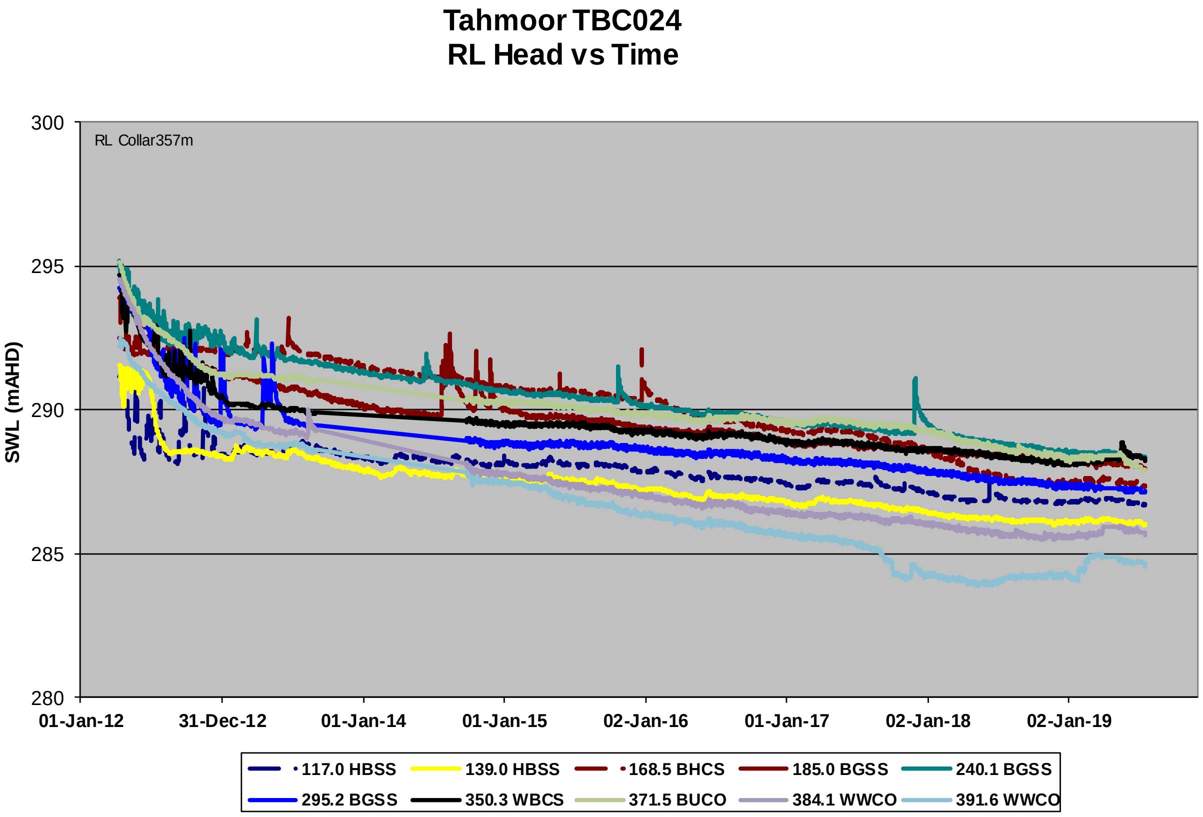


Figure B2.10: TBC024 Hydrograph

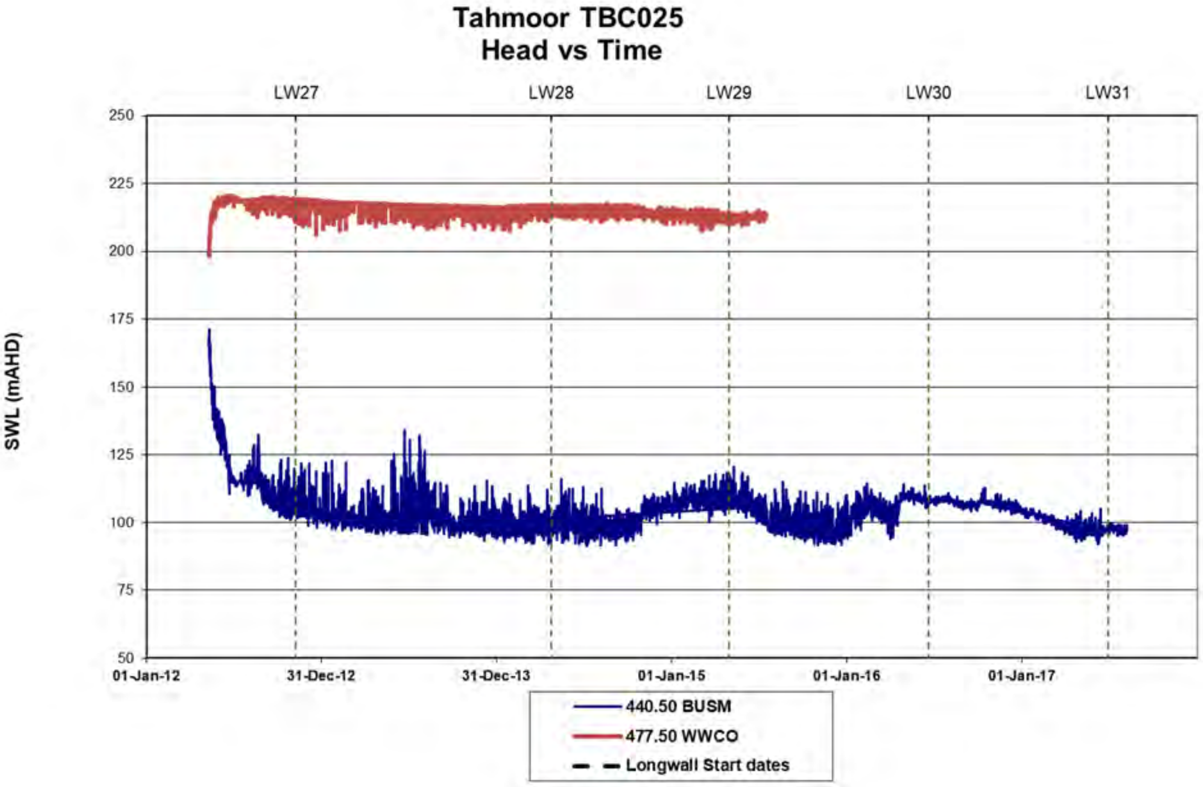


Figure B2.11: TBC025 Hydrograph (WWCO piezometer is out of service)

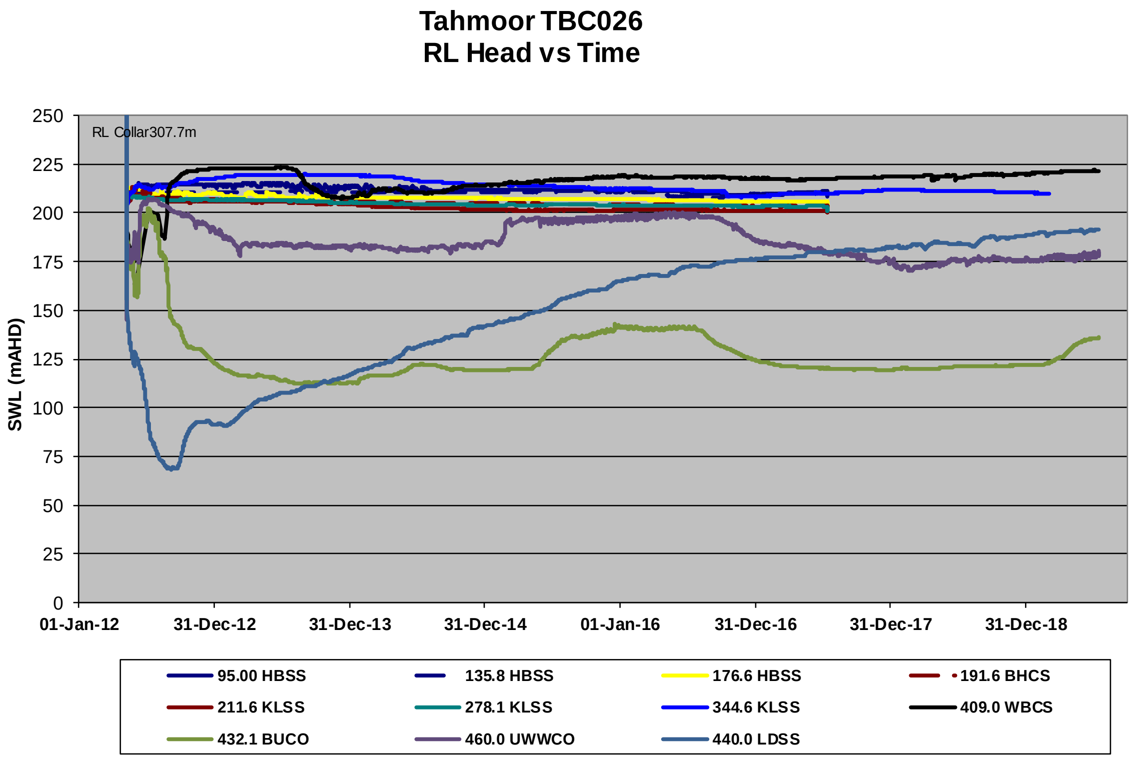


Figure B2.12: TBC026 Hydrograph

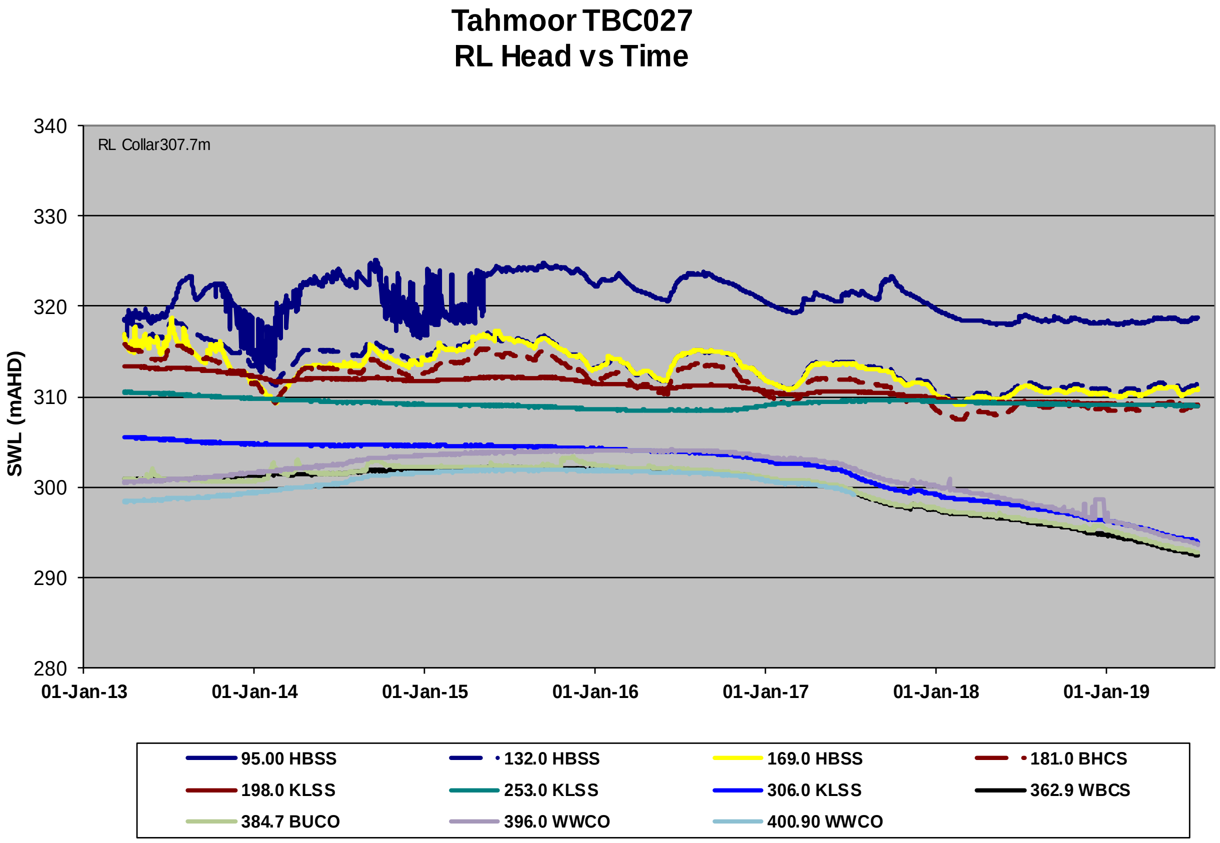


Figure B2.13: TBC027 Hydrograph

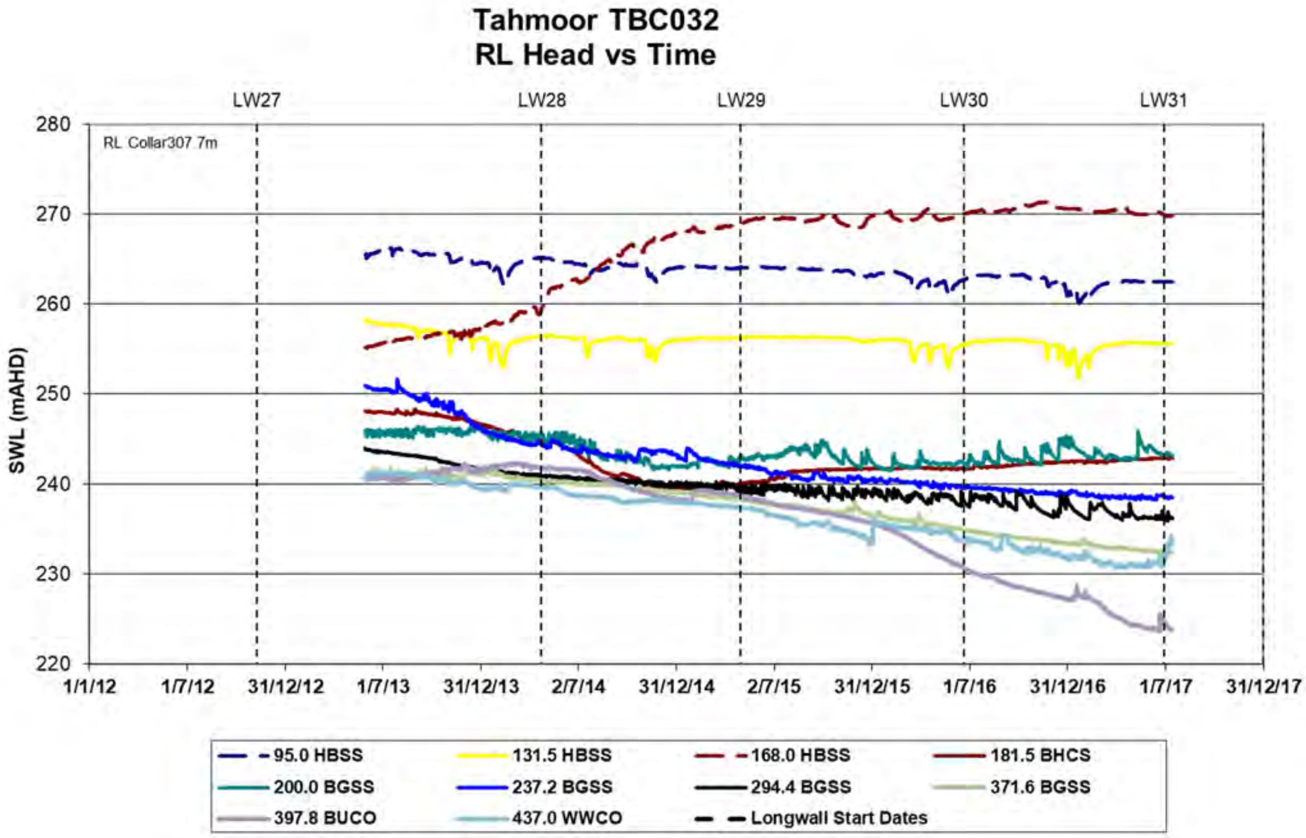


Figure B2.14: TBC032 Hydrograph

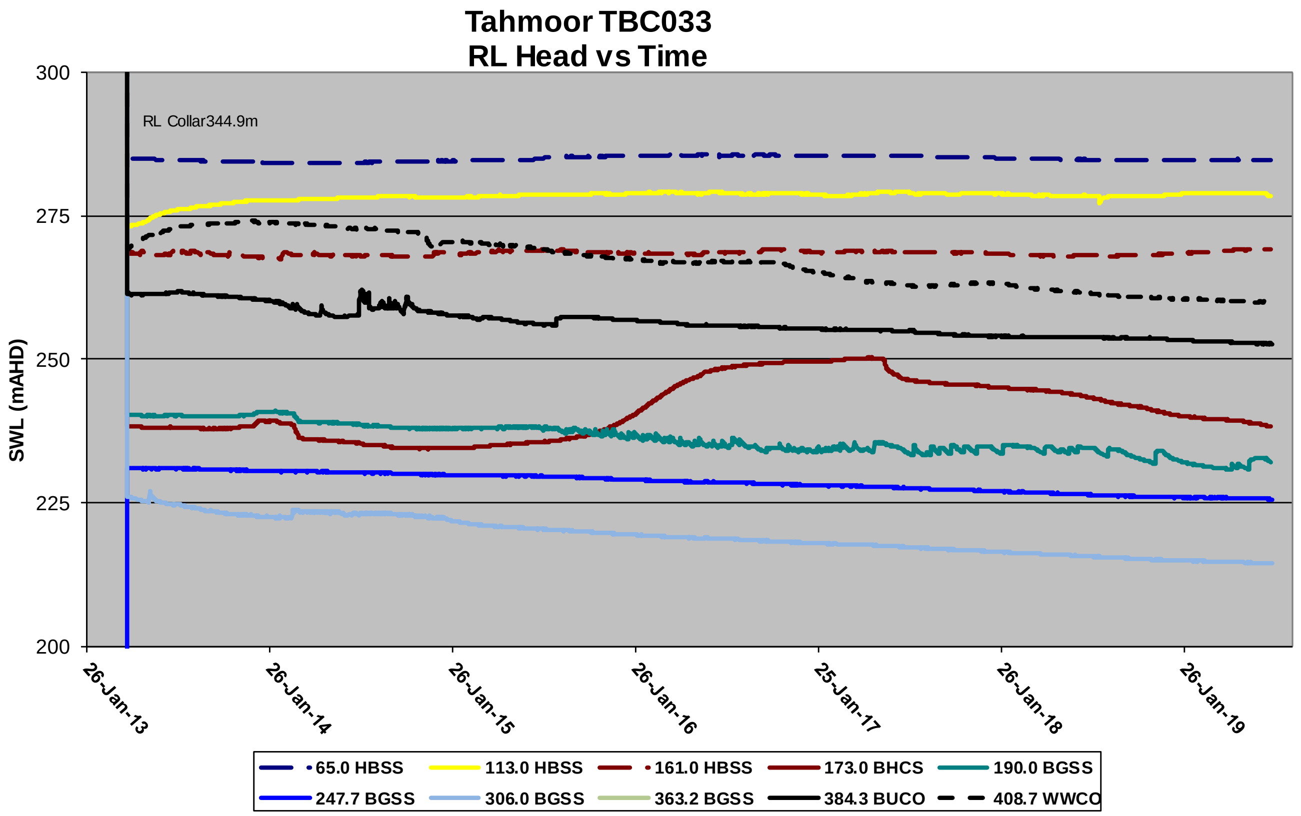


Figure B2.15: TBC033 Hydrograph.

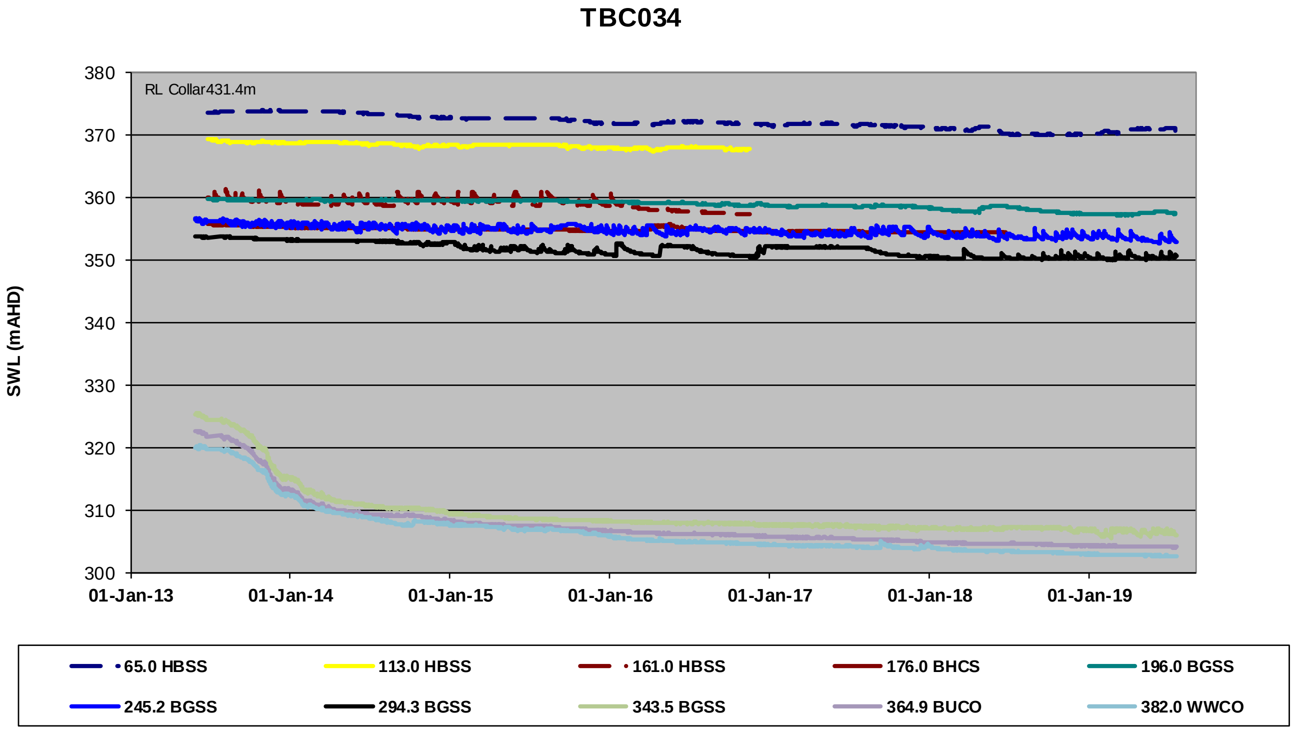


Figure B2.16: TBC034 Hydrograph.

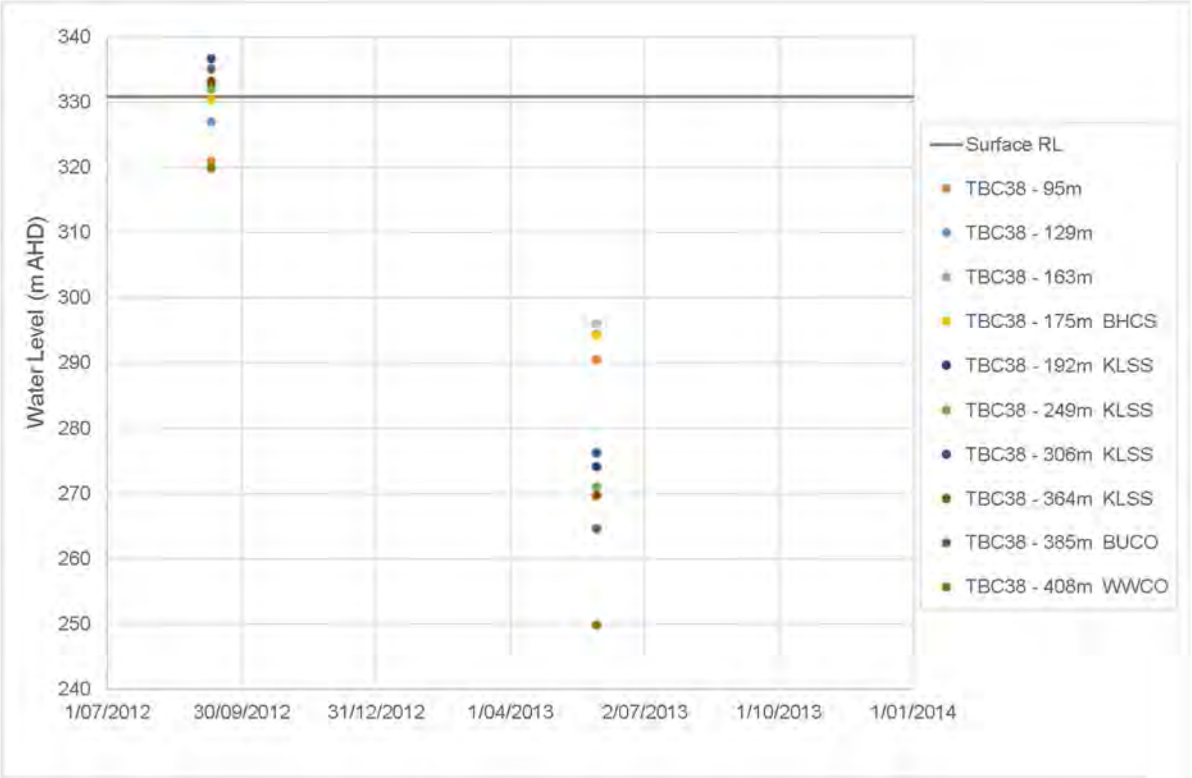


Figure B2.17: TBC038 Hydrograph. (out of service)

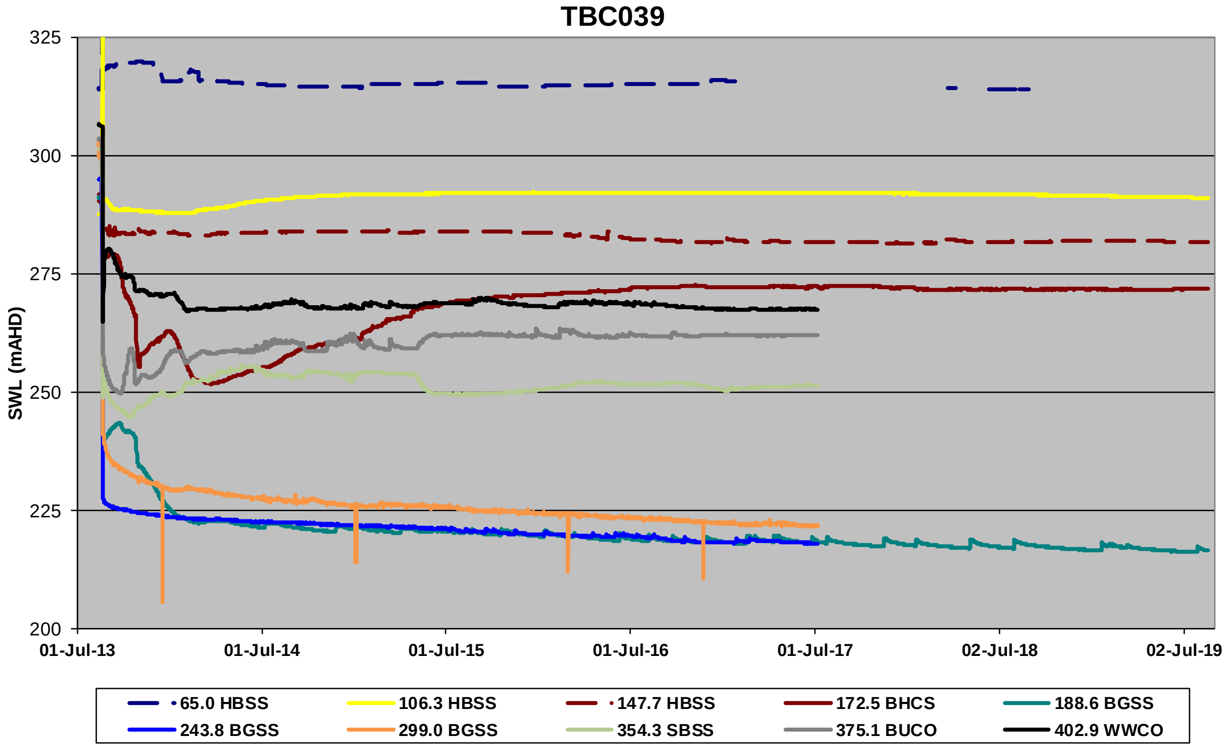
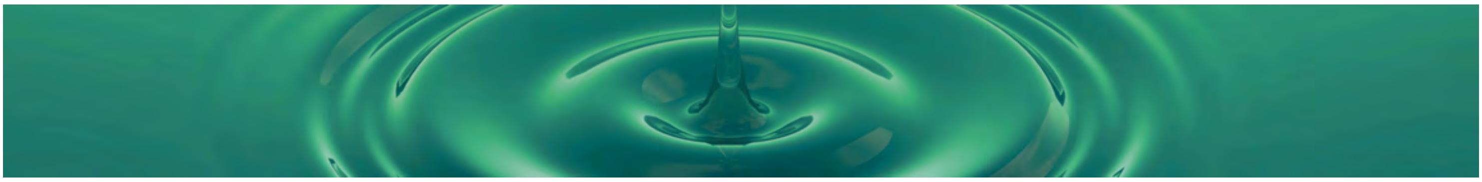
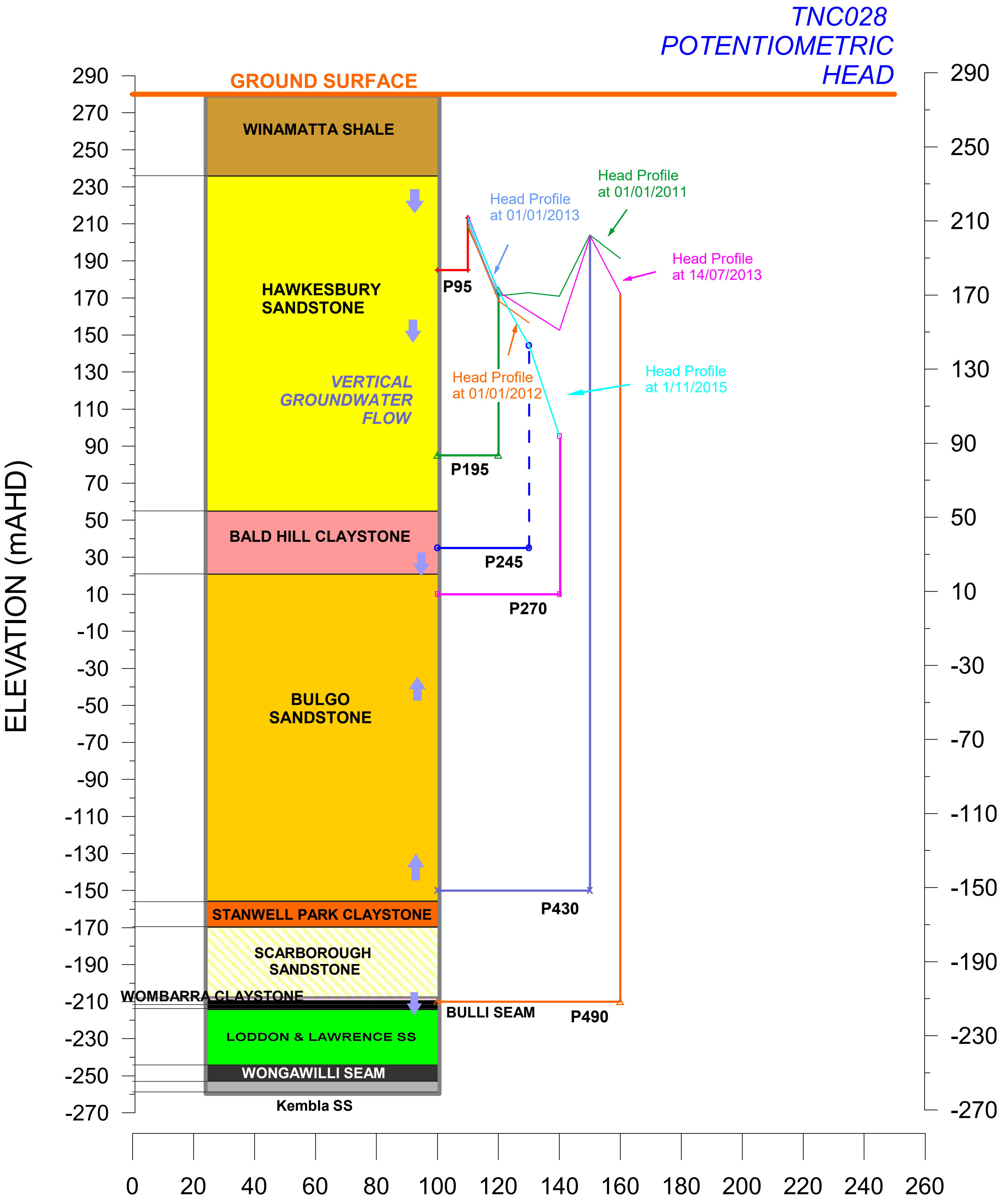


Figure B2.18: TBC039 Hydrograph.



APPENDIX C Vertical head profiles



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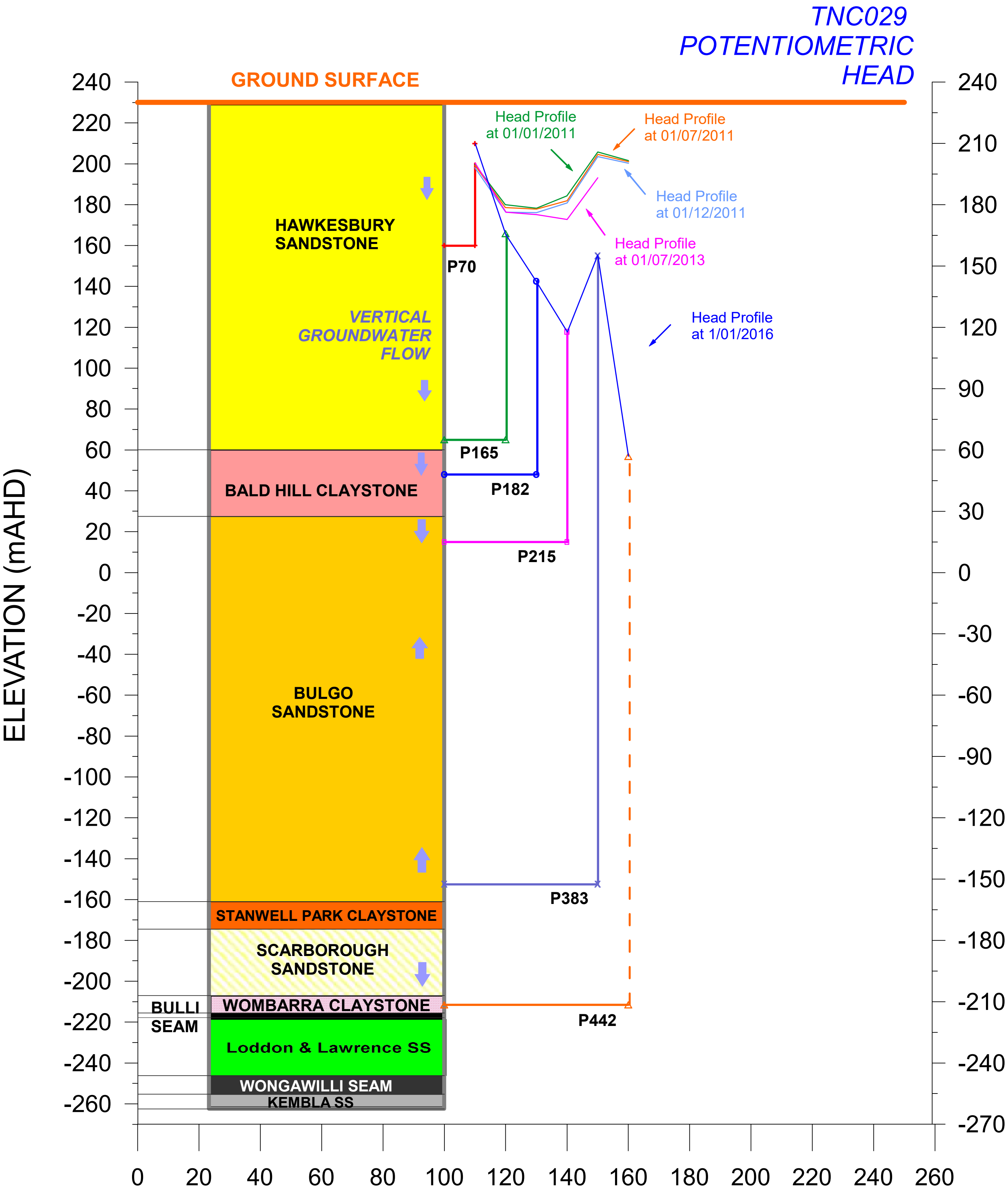

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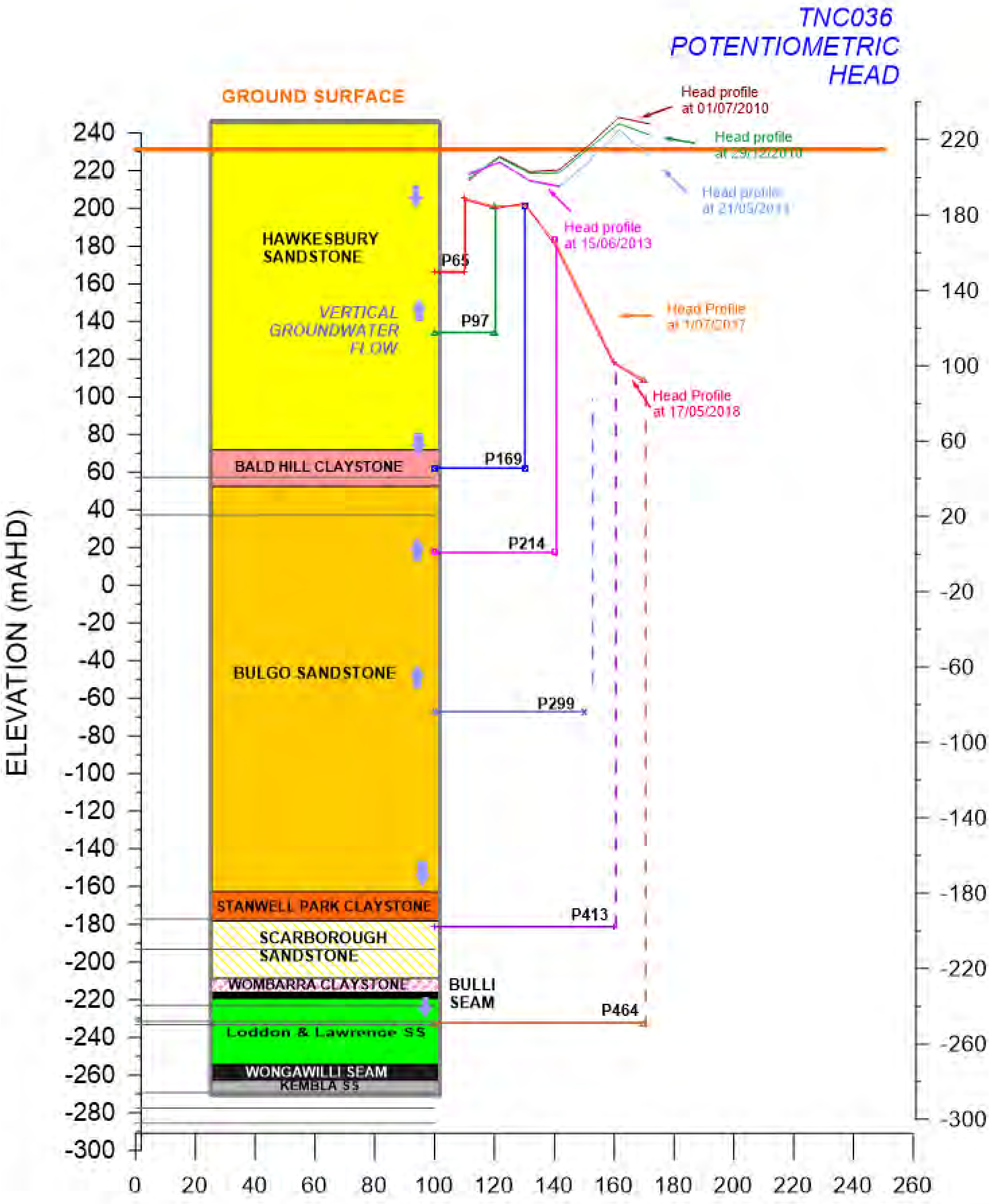

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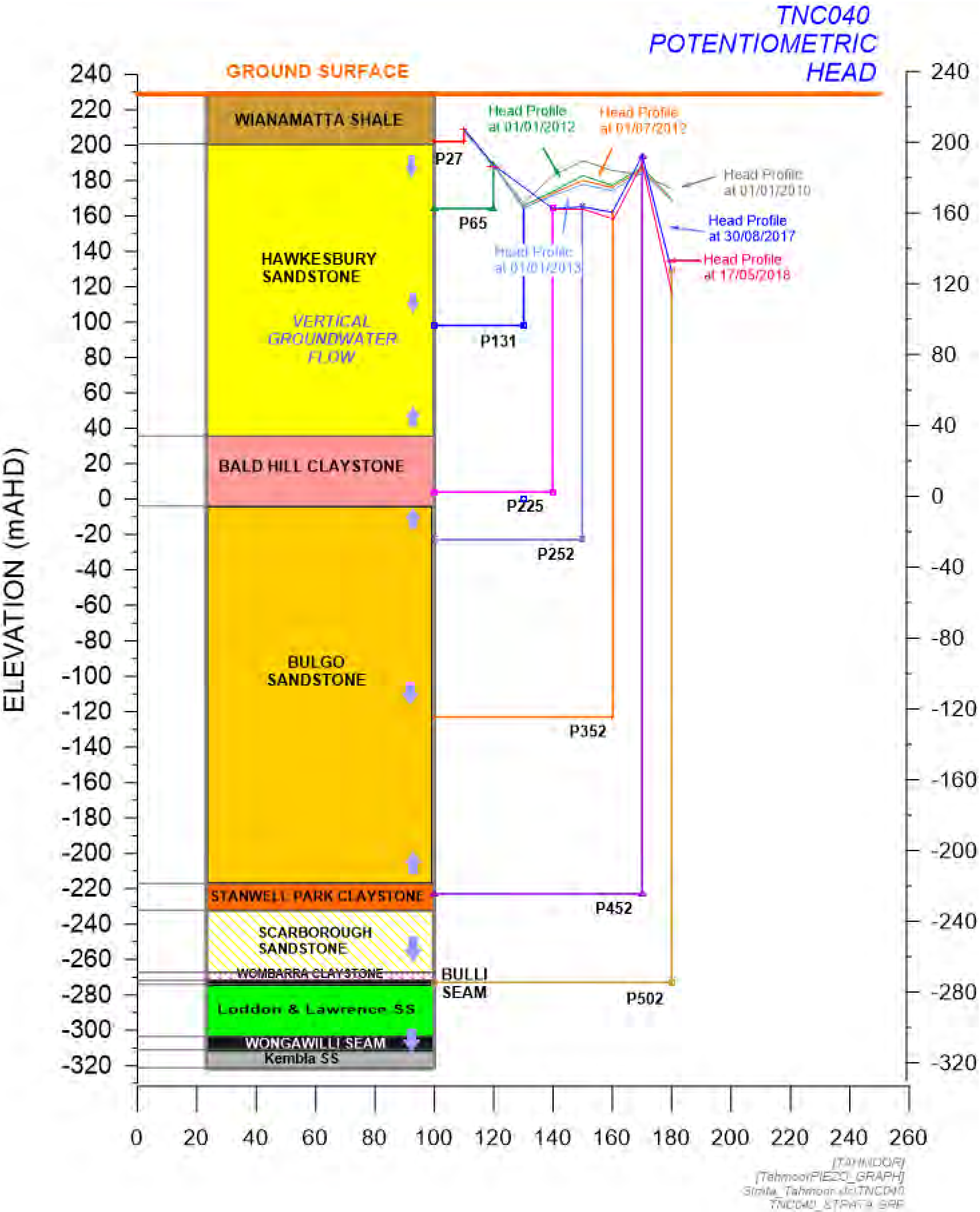TNC040
POTENTIOMETRIC
HEAD
GROUND SURFACE
ELEVATION (mAHD)
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
-280
-300
-320
0
20
40
60
80
100
120
140
160
180
200
220
240
260
WIANAMATTA SHALE
HAWKESBURY
SANDSTONE
VERTICAL
GROUNDWATER
FLOW
BALD HILL CLAYSTONE
BULGO
SANDSTONE
STANWELL PARK CLAYSTONE
SCARBOROUGH
SANDSTONE
WOMBARRA CLAYSTONE
BULLI
SEAM
Loddon & Lawrence SS
WONGAWILLI SEAM
Kembla SS
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
P27
P65
P131
P225
P252
P352
P452
P502
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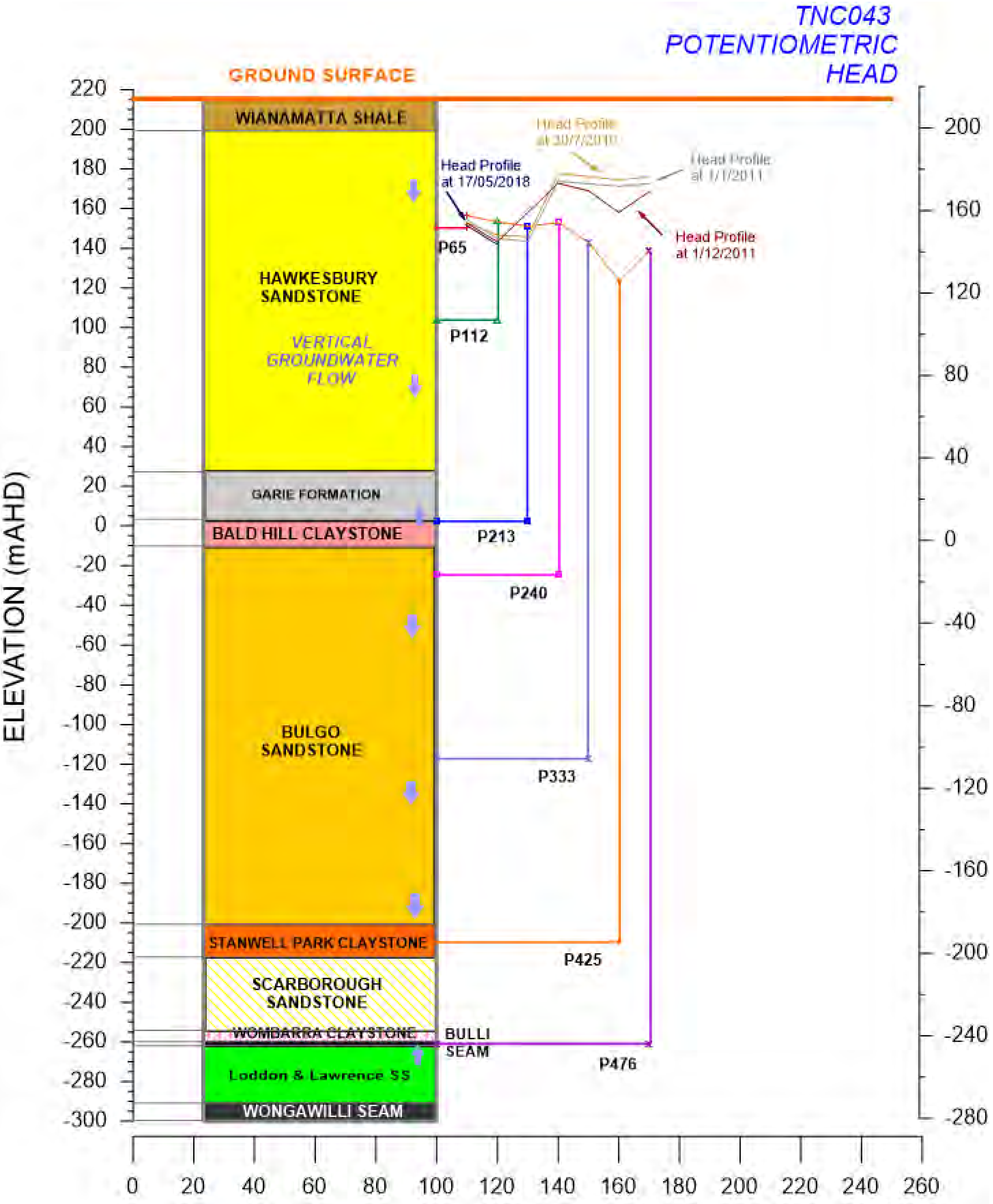

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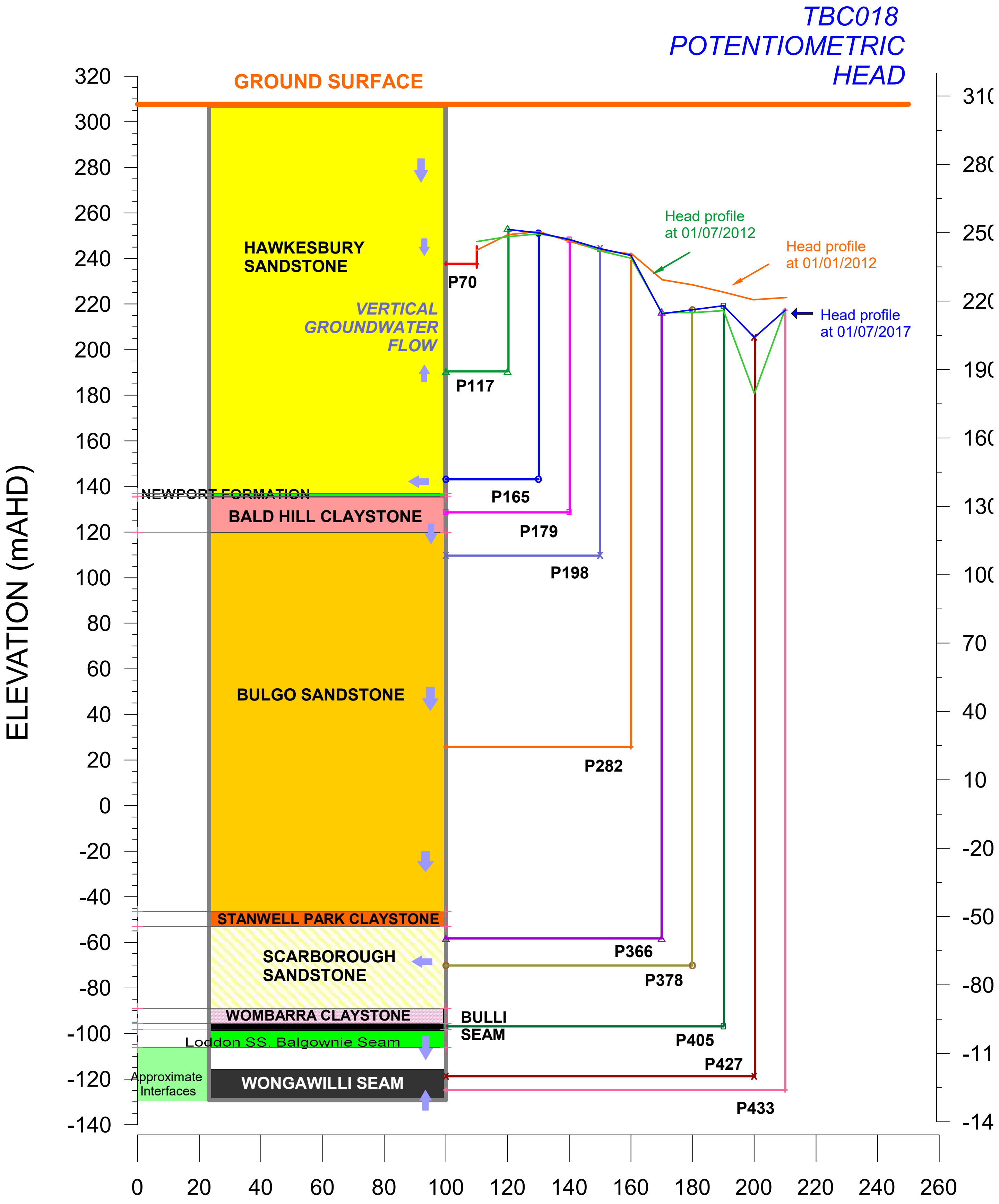

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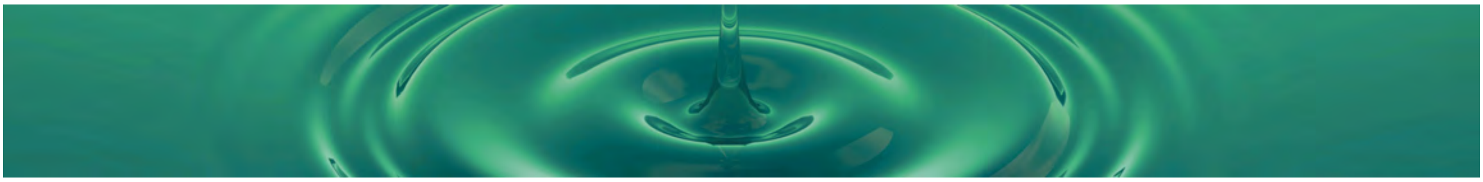
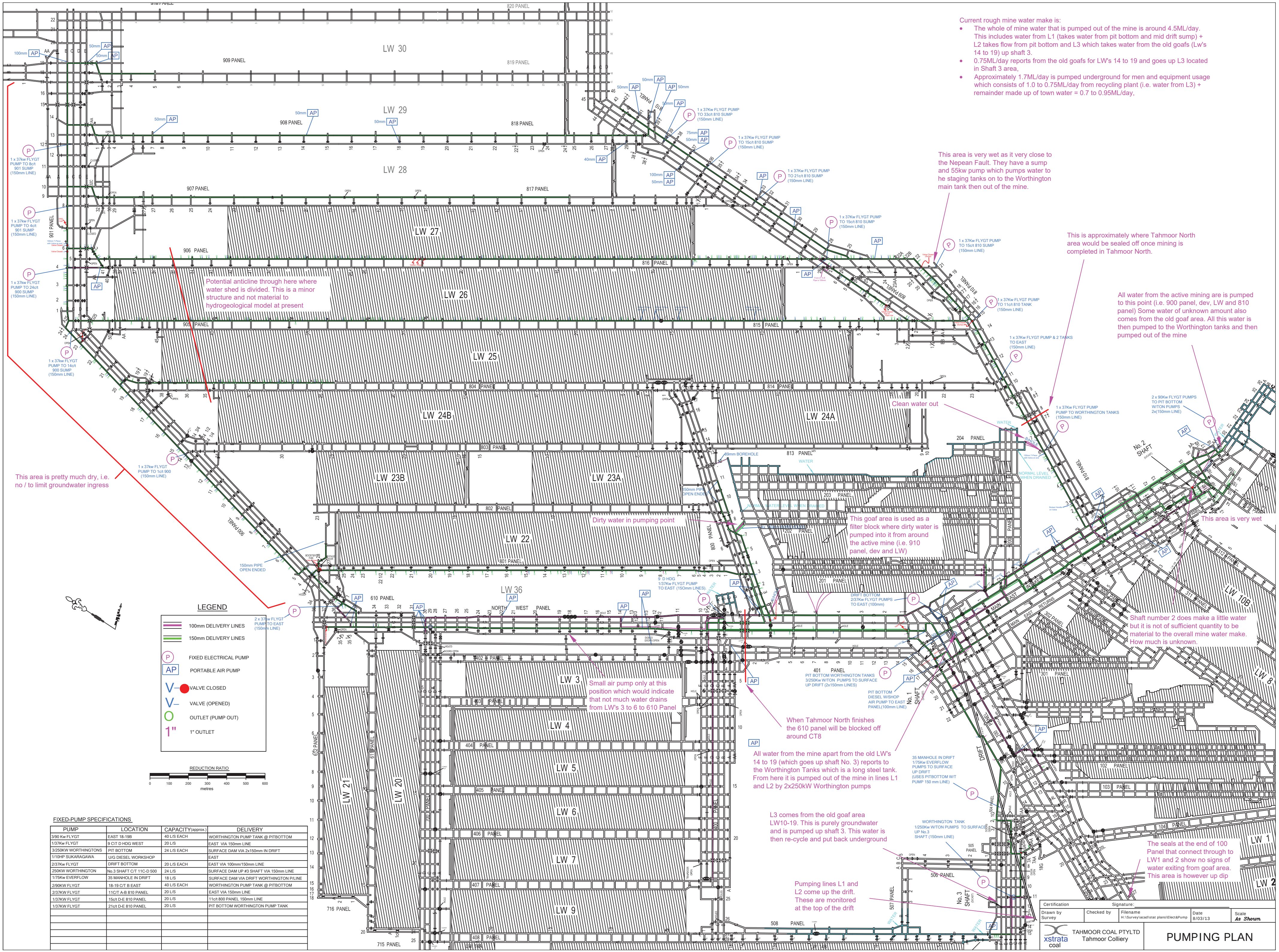


APPENDIX D Tahmoor underground mine drainage plan

(provided by Tahmoor Coal)



Current rough mine water make is:

- The whole of mine water that is pumped out of the mine is around 4.5ML/day. This includes water from L1 (takes water from pit bottom and mid drift sump) + L2 takes flow from pit bottom and L3 which takes water from the old goafs (Lw's 14 to 19) up shaft 3.
- 0.75ML/day reports from the old goafs for LW's 14 to 19 and goes up L3 located in Shaft 3 area,
- Approximately 1.7ML/day is pumped underground for men and equipment usage which consists of 1.0 to 0.75ML/day from recycling plant (i.e. water from L3) + remainder made up of town water = 0.7 to 0.95ML/day,

This area is very wet as it very close to the Nepean Fault. They have a sump and 55kw pump which pumps water to he staging tanks on to the Worthington main tank then out of the mine.

This is approximately where Tahmoor North area would be sealed off once mining is completed in Tahmoor North.

All water from the active mining are is pumped to this point (i.e. 900 panel, dev, LW and 810 panel) Some water of unknown amount also comes from the old goaf area. All this water is then pumped to the Worthington tanks and then pumped out of the mine

Potential anticline through here where water shed is divided. This is a minor structure and not material to hydrogeological model at present

Clean water out

This area is pretty much dry, i.e. no / to limit groundwater ingress

Dirty water in pumping point

This goaf area is used as a filter block where dirty water is pumped into it from around the active mine (i.e. 910 panel, dev and LW)

This area is very wet

Shaft number 2 does make a little water but it is not of sufficient quantity to be material to the overall mine water make. How much is unknown.

Small air pump only at this position which would indicate that not much water drains from LW's 3 to 6 to 610 Panel

When Tahmoor North finishes the 610 panel will be blocked off around CT8

All water from the mine apart from the old LW's 14 to 19 (which goes up shaft No. 3) reports to the Worthington Tanks which is a long steel tank. From here it is pumped out of the mine in lines L1 and L2 by 2x250kW Worthington pumps

L3 comes from the old goaf area LW10-19. This is purely groundwater and is pumped up shaft 3. This water is then re-cycle and put back underground

Pumping lines L1 and L2 come up the drift. These are monitored at the top of the drift

The seals at the end of 100 Panel that connect through to LW1 and 2 show no signs of water exiting from goaf area. This area is however up dip

LEGEND

🟪	100mm DELIVERY LINES
🟩	150mm DELIVERY LINES
P	FIXED ELECTRICAL PUMP
AP	PORTABLE AIR PUMP
V●	VALVE CLOSED
V	VALVE (OPENED)
O	OUTLET (PUMP OUT)
1"	1" OUTLET

REDUCTION RATIO

0 100 200 300 400 500 600
metres

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

Certification		Signature:		
Drawn by Survey	Checked by	Filename H:\Survey\acad\stat plans\Elect&Pump	Date 8/03/13	Scale As Shown

xstrata coal

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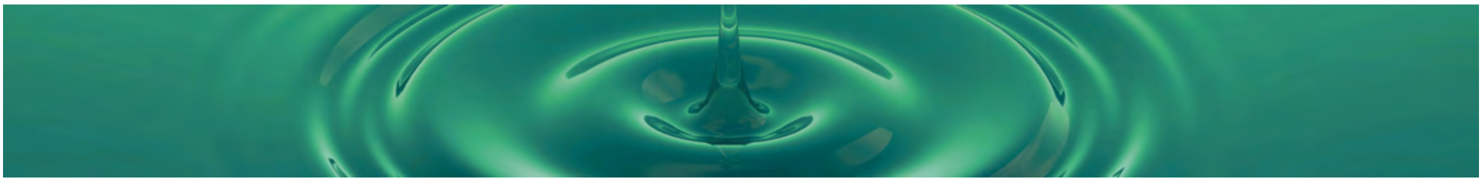
PUMPING PLAN



APPENDIX E Assessment of groundwater model confidence

(from Barnett *et al*, 2012)

Tahmoor South – Groundwater Model:
Model Confidence Assessment based on 2012 Modelling Guidelines (SKM & CSIRO, 2012)

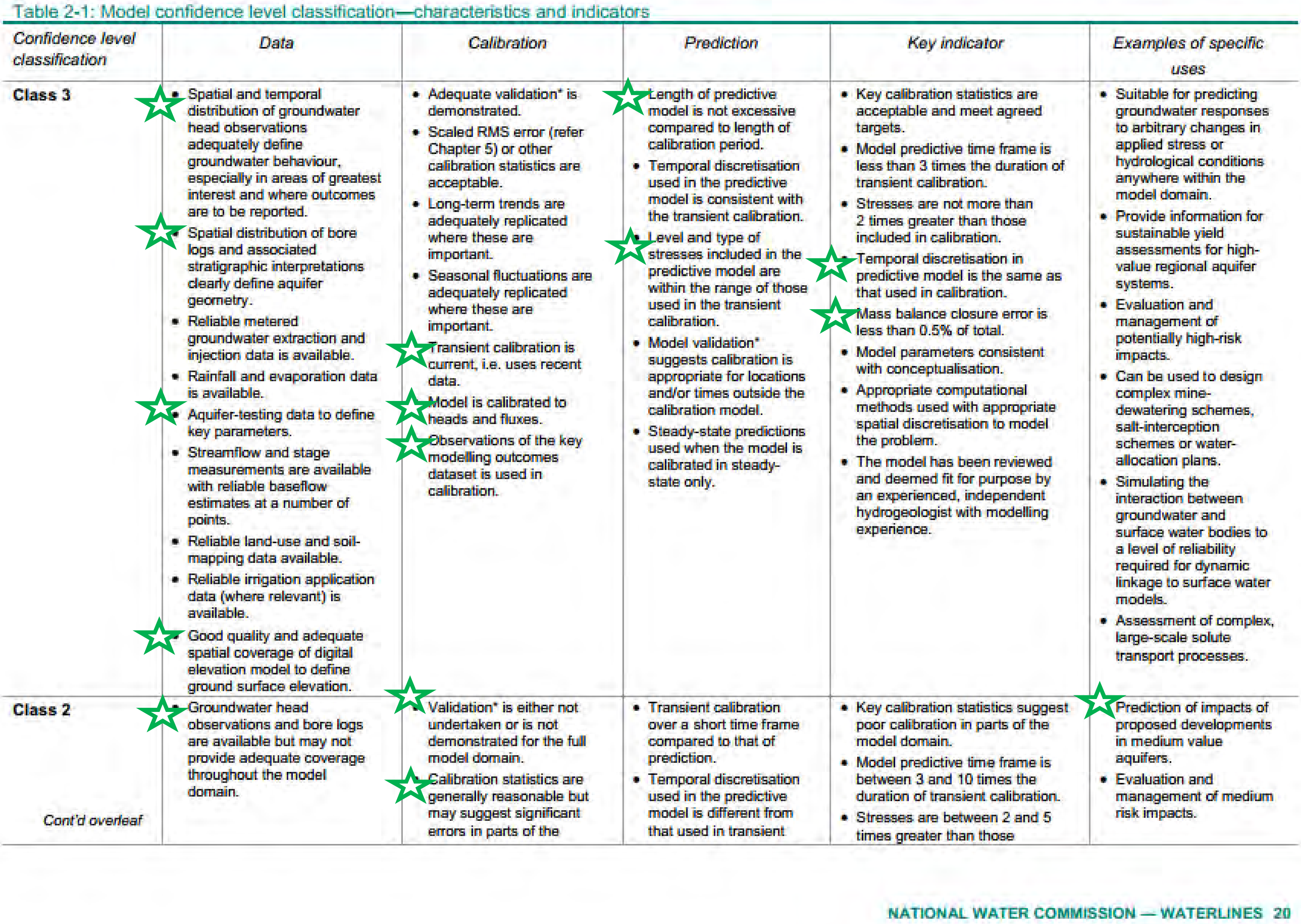


Table 2-1: Model confidence level classification—characteristics and indicators

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. ☆ Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. • Reliable metered groundwater extraction and injection data is available. • Rainfall and evaporation data is available. ☆ Aquifer-testing data to define key parameters. • Streamflow and stage measurements are available with reliable baseflow estimates at a number of points. • Reliable land-use and soil-mapping data available. • Reliable irrigation application data (where relevant) is available. ☆ Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	• Adequate validation* is demonstrated. • Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable. • Long-term trends are adequately replicated where these are important. • Seasonal fluctuations are adequately replicated where these are important. ☆ Transient calibration is current, i.e. uses recent data. ☆ Model is calibrated to heads and fluxes. ☆ Observations of the key modelling outcomes dataset is used in calibration.	☆ Length of predictive model is not excessive compared to length of calibration period. • Temporal discretisation used in the predictive model is consistent with the transient calibration. ☆ Level and type of stresses included in the predictive model are within the range of those used in the transient calibration. • Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model. • Steady-state predictions used when the model is calibrated in steady-state only.	• Key calibration statistics are acceptable and meet agreed targets. • Model predictive time frame is less than 3 times the duration of transient calibration. • Stresses are not more than 2 times greater than those included in calibration. ☆ Temporal discretisation in predictive model is the same as that used in calibration. ☆ Mass balance closure error is less than 0.5% of total. • Model parameters consistent with conceptualisation. • Appropriate computational methods used with appropriate spatial discretisation to model the problem. • 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. • Provide information for sustainable yield assessments for high-value regional aquifer systems. • Evaluation and management of potentially high-risk impacts. • Can be used to design complex mine-dewatering schemes, salt-interception schemes or water-allocation plans. • Simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models. • Assessment of complex, large-scale solute transport processes.
Class 2 *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. ☆ 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. • 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. • Model predictive time frame is between 3 and 10 times the duration of transient calibration. • Stresses are between 2 and 5 times greater than those	☆ Prediction of impacts of proposed developments in medium value aquifers. • Evaluation and management of medium risk impacts.

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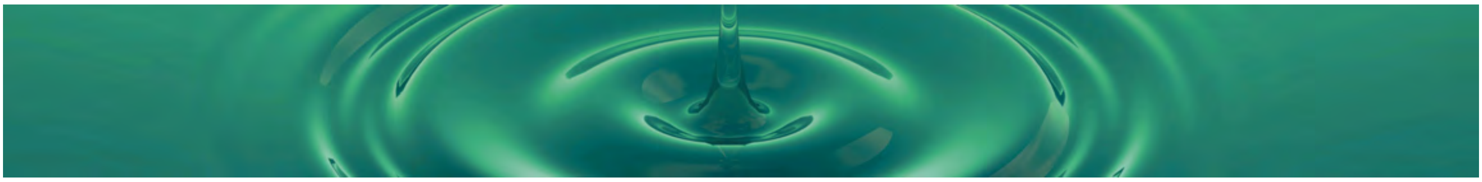
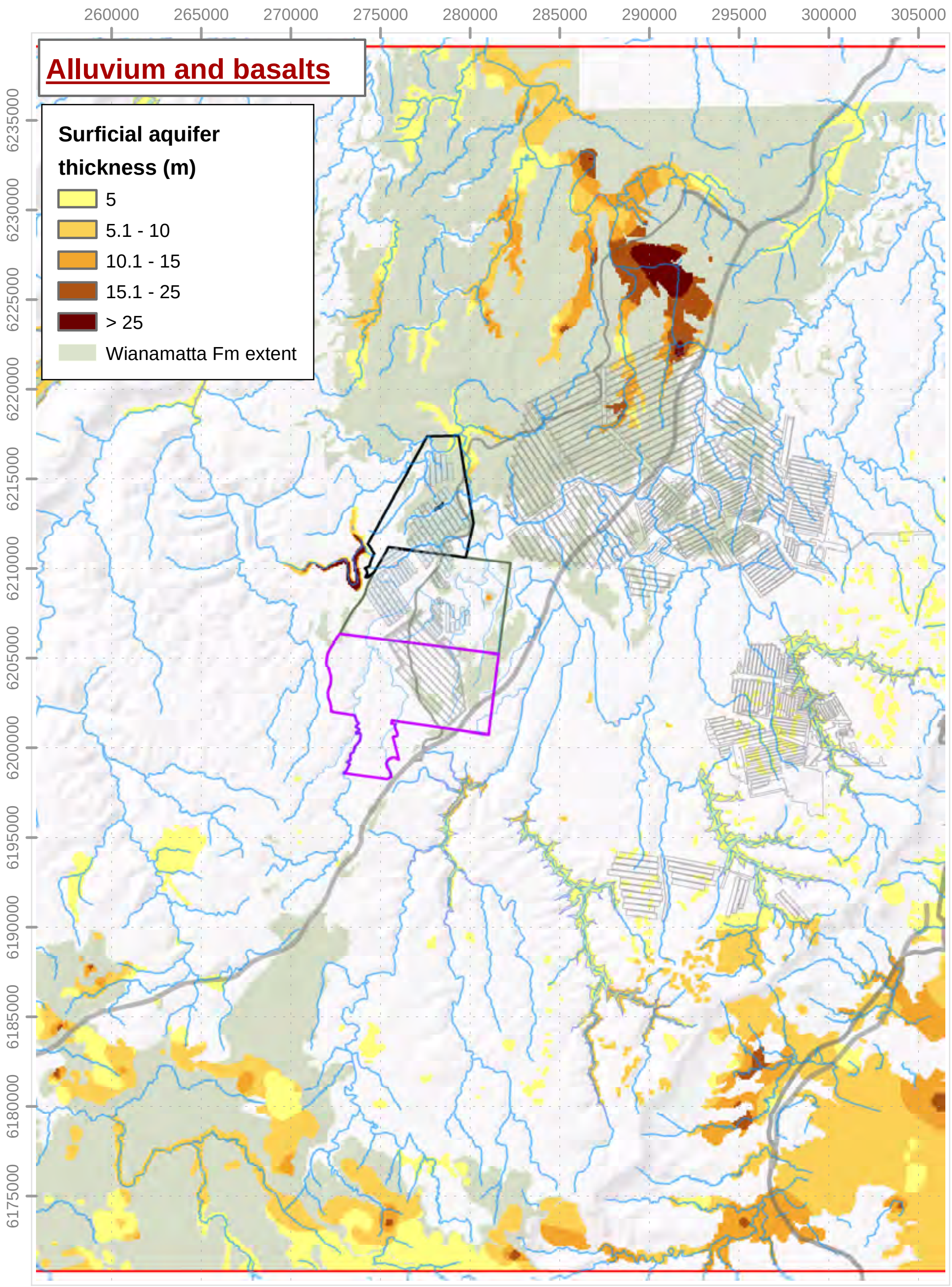
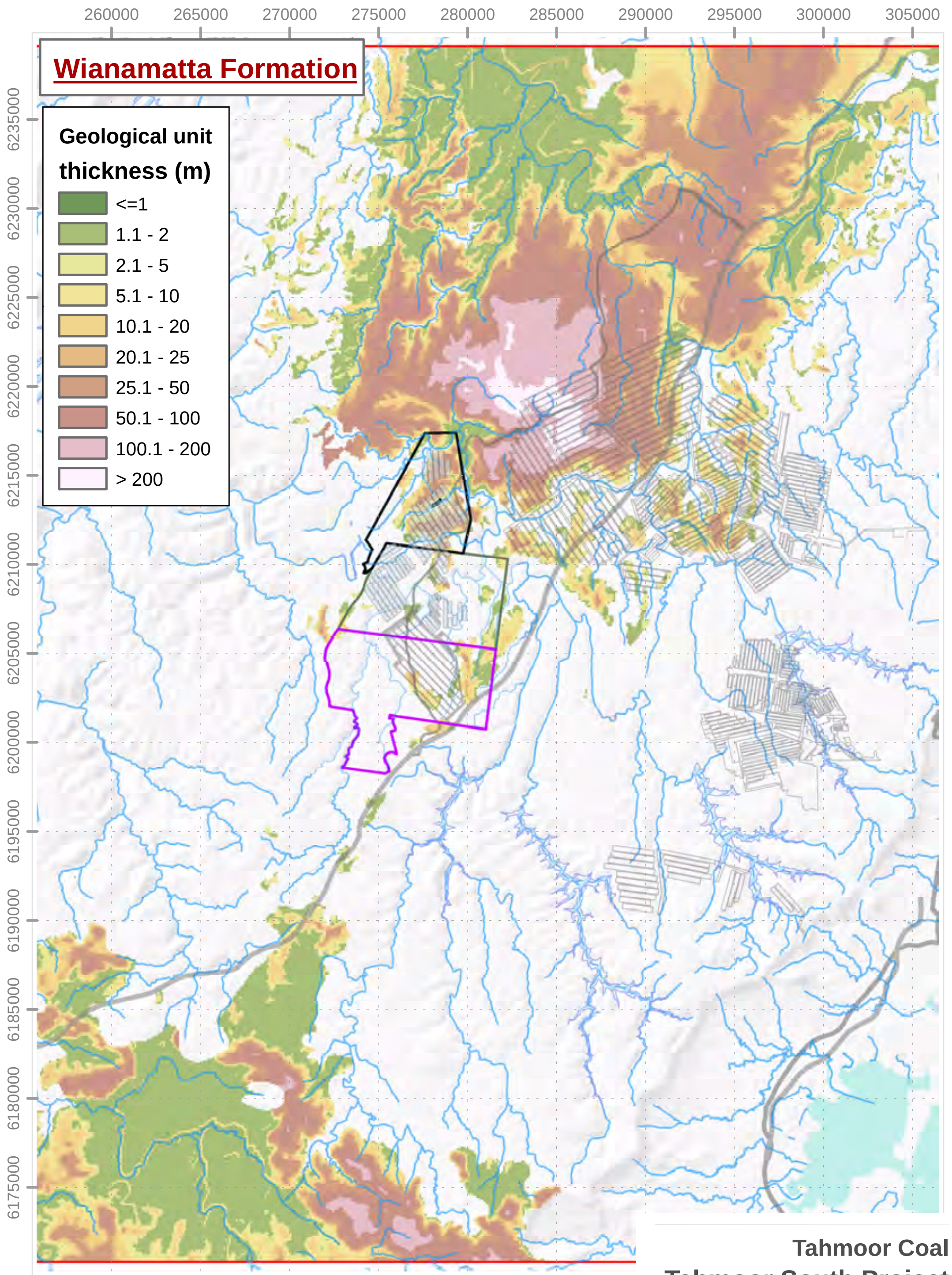
Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key Indicator*	*Examples of specific uses*
Class 2 *Cont'd*	- Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive. ☆ Streamflow data and baseflow estimates available at a few points. - Reliable irrigation-application data available in part of the area or for part of the model duration.	model domain(s). - Long-term trends not replicated in all parts of the model domain. - Transient calibration to historic data but not extending to the present day. ☆ Seasonal fluctuations not adequately replicated in all parts of the model domain. - Observations of the key modelling outcome data set are not used in calibration.	calibration. - Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. - Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.	included in calibration. - Temporal discretisation in predictive model is not the same as that used in calibration. ☆ Mass balance closure error is less than 1% of total. - Not all model parameters consistent with conceptualisation. - Spatial refinement too coarse in key parts of the model domain. - 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. - Designing groundwater management schemes such as managed aquifer recharge, salinity management schemes and infiltration basins. - 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. - Observations and measurements unavailable or sparsely distributed in areas of greatest interest. ☆ No available records of metered groundwater extraction or injection. - Climate data only available from relatively remote locations. - Little or no useful data on land-use, soils or river flows and stage elevations.	- No calibration is possible. - Calibration illustrates unacceptable levels of error especially in key areas. - Calibration is based on an inadequate distribution of data. - Calibration only to datasets other than that required for prediction.	- Predictive model time frame far exceeds that of calibration. - Temporal discretisation is different to that of calibration. - Transient predictions are made when calibration is in steady state only. - 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. - Model predictive time frame is more than 10 times longer than transient calibration period. - Stresses in predictions are more than 5 times higher than those in calibration. - Stress period or calculation interval is different from that used in calibration. - Transient predictions made but calibration in steady state only. - Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time. - Model parameters outside the range expected by the conceptualisation with no further justification. - Unsuitable spatial or temporal discretisation. - The model has not been reviewed.	- Design observation bore array for pumping tests. - Predicting long-term impacts of proposed developments in low-value aquifers. - Estimating impacts of low-risk developments. - Understanding groundwater flow processes under various hypothetical conditions. - Provide first-pass estimates of extraction volumes and rates required for mine dewatering. - Developing coarse relationships between groundwater extraction locations and rates and associated impacts. - 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





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GDA 1994 MGA Zone 56

HYDROSIMULATIONS

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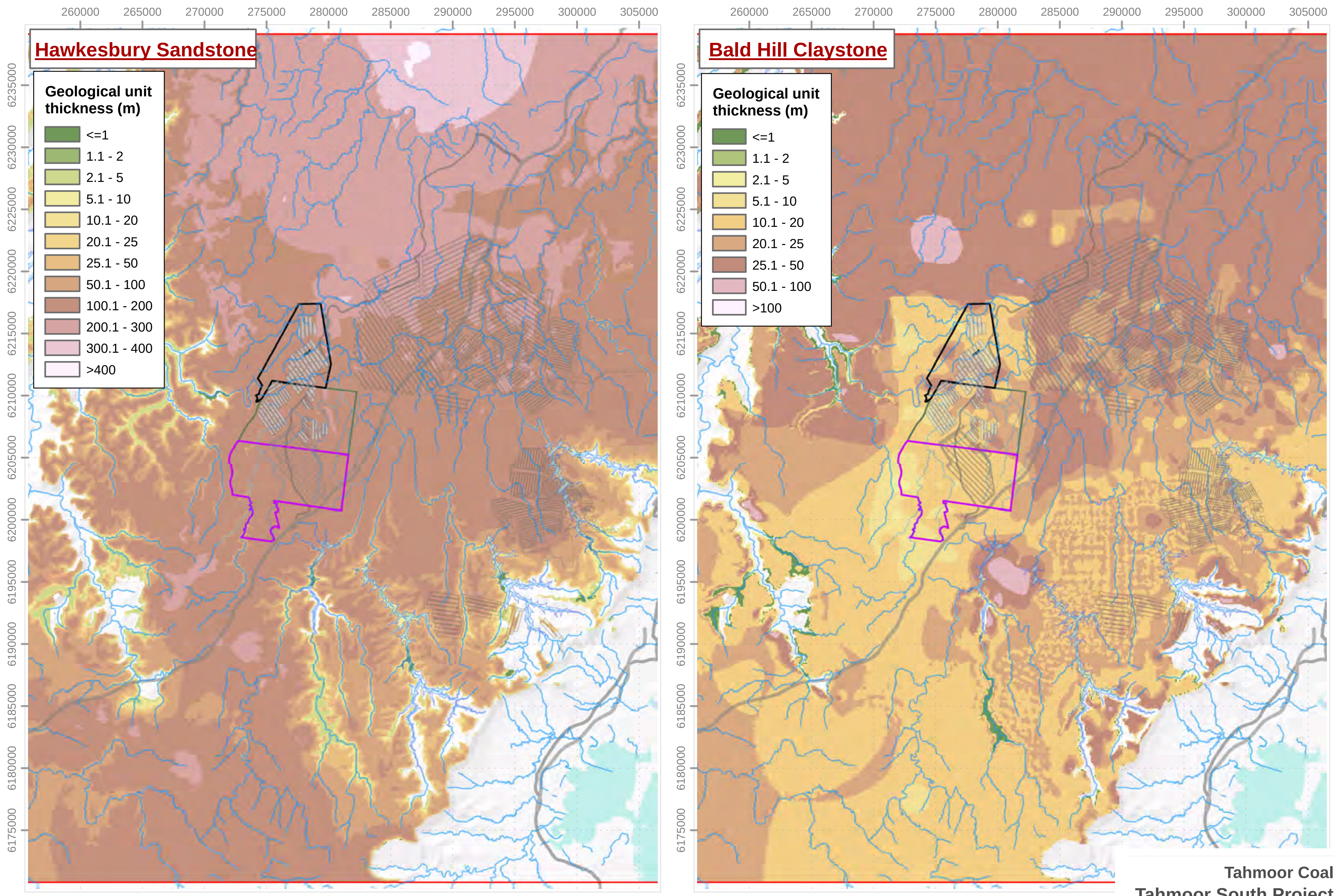
Tahmoor Coal
Tahmoor South Project

Geological Model: Surficial aquifers and Wianamatta Formation isopachs

Figure F-1



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HYDROSIMULATIONS

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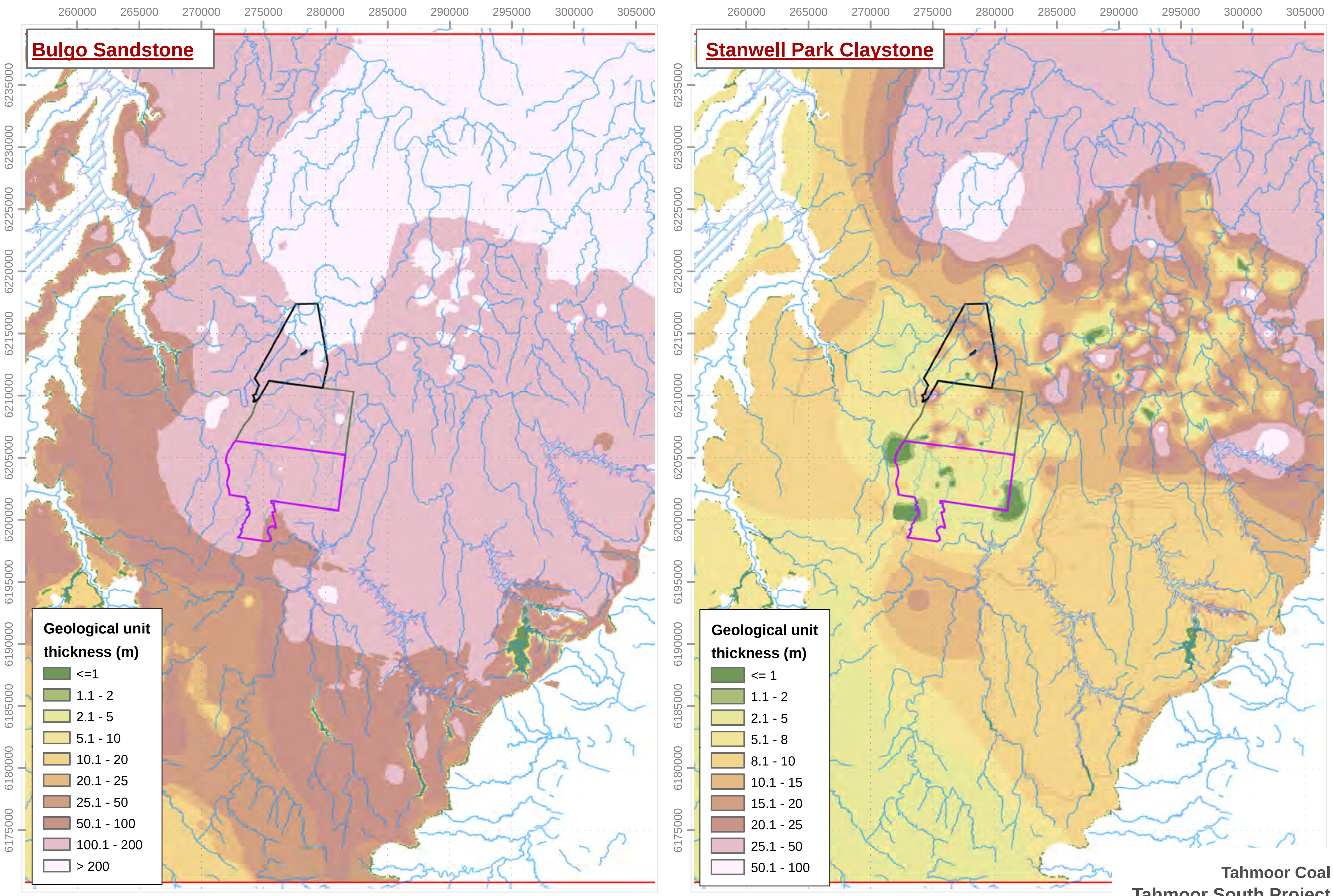
Rev: A - 1/11/2018 | by: BWhite

Geological Model: Hawkesbury Sandstone and Bald Hill Claystone isopachs

Tahmoor Coal
Tahmoor South Project

Figure F-2



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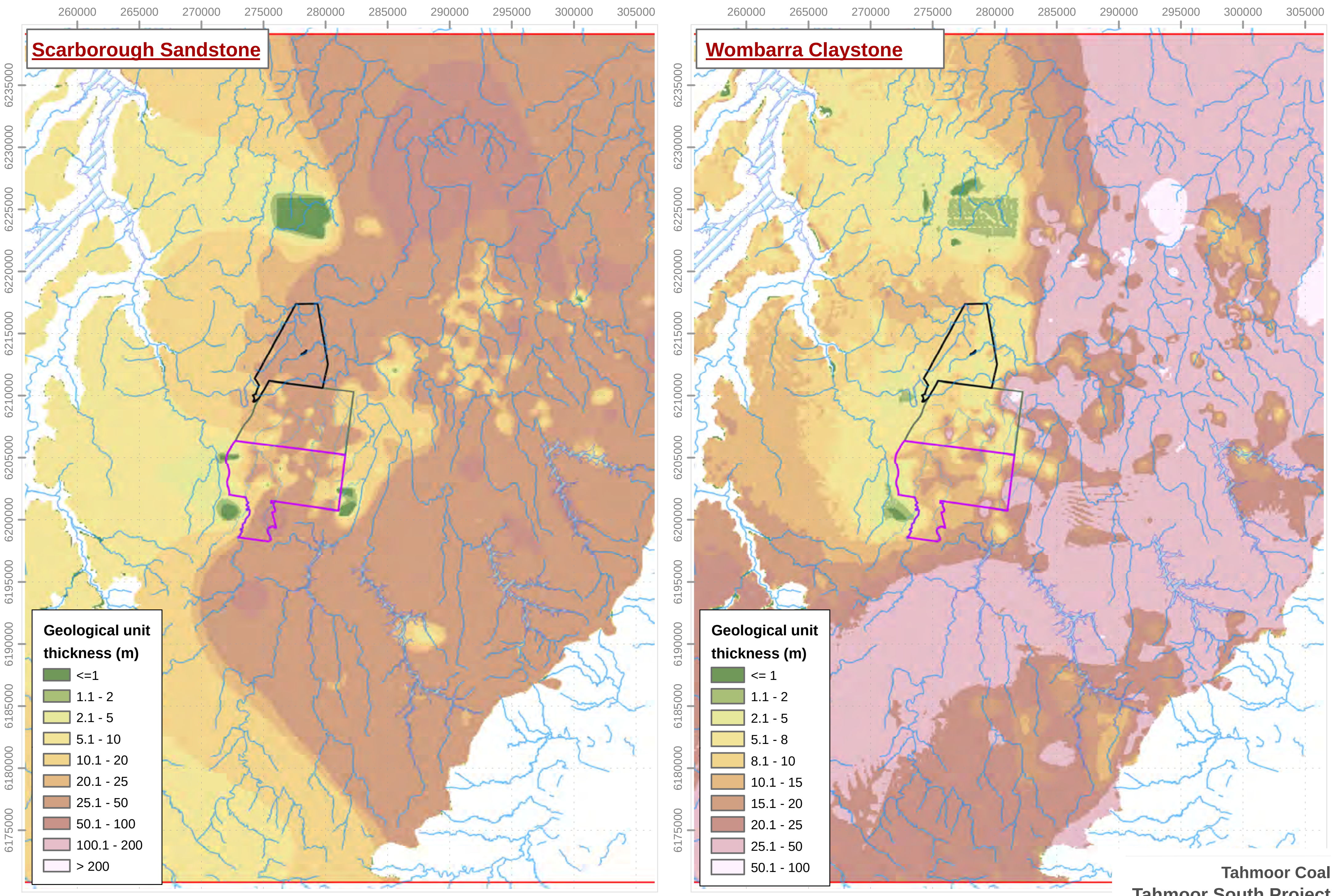
Rev: A - 1/11/2018 | by: BWhite

Tahmoor Coal
Tahmoor South Project

Geological Model: Bulgo Sandstone and Stanwell Park Claystone isopachs

Figure F-3



Tahmoor Coal
Tahmoor South Project

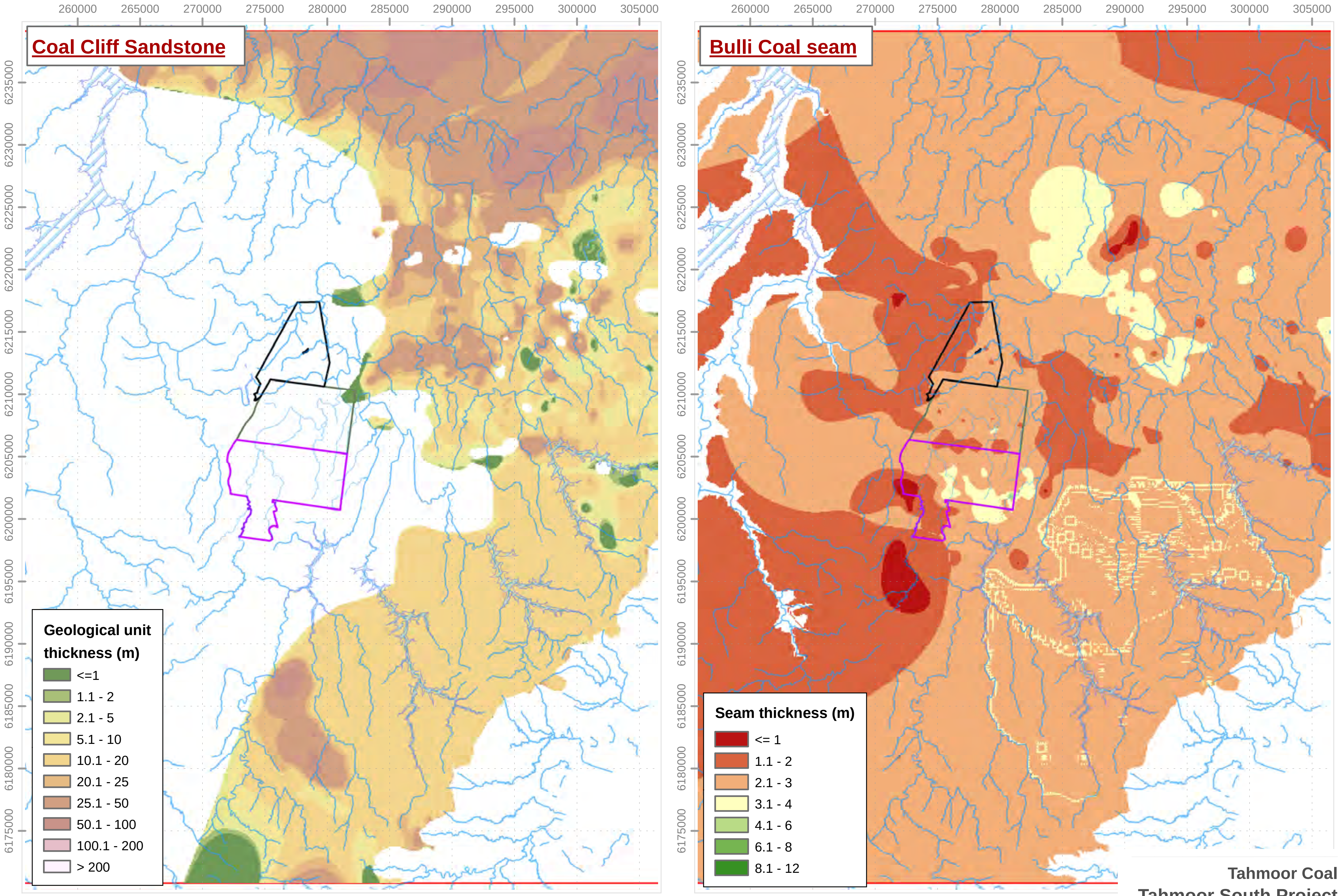
Scale: 375,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

Geological Model: Scarborough Sandstone and Wombarra Claystone isopachs

Figure F-4

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX4_SBSS&WBCSisopachs_A4L.mxd Rev: A - 1/11/2018| by: BWhite



Scale: 375,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

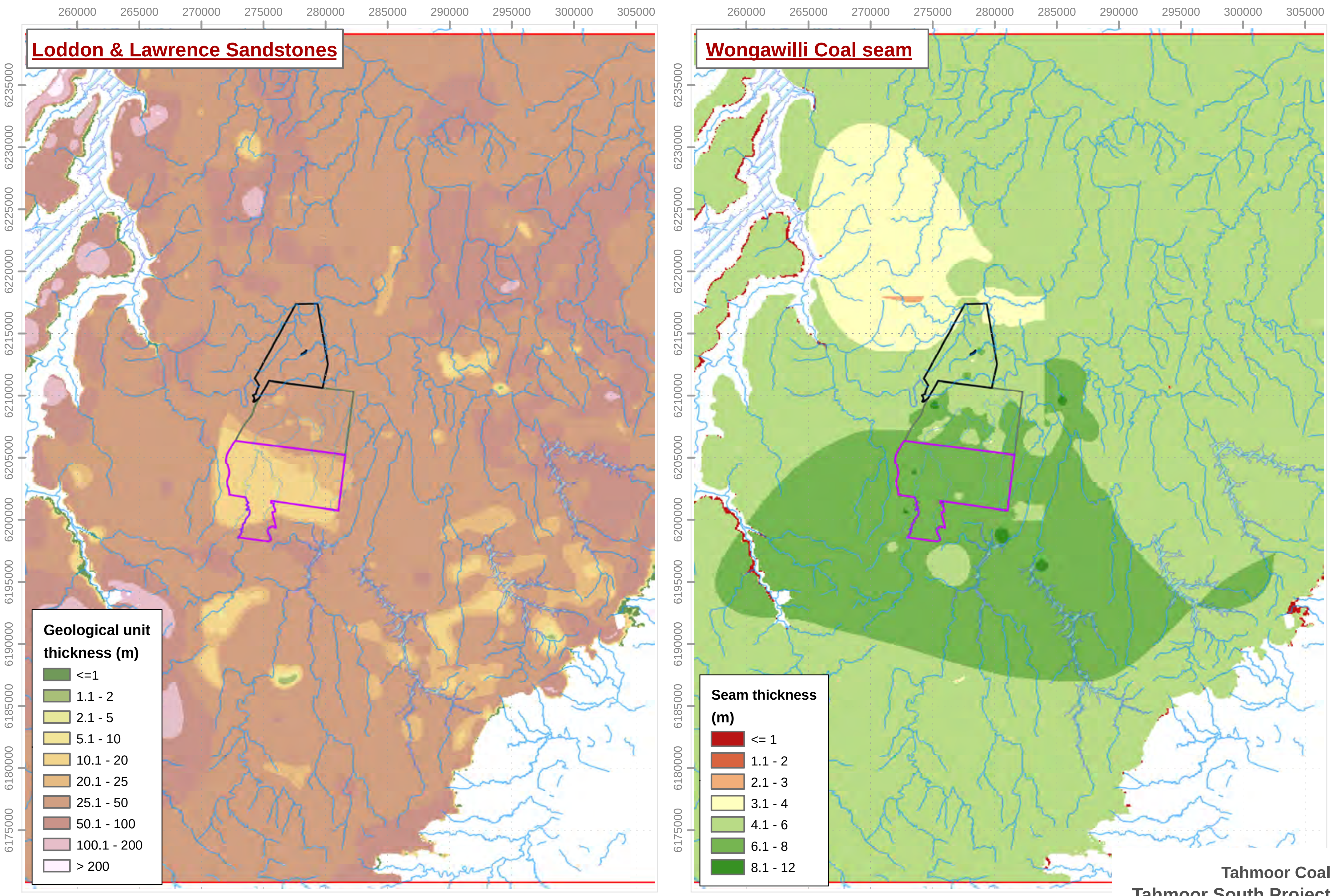
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX5_CCSS&BUSMisopachs_A4L.mxd

Rev: A - 1/11/2018 | by: BWhite

Tahmoor Coal
Tahmoor South Project

Geological Model: Coal Cliff Sandstone and Bulli Coal seam isopachs

Figure F-5



Scale: 375,000
GDA 1994 MGA Zone 56

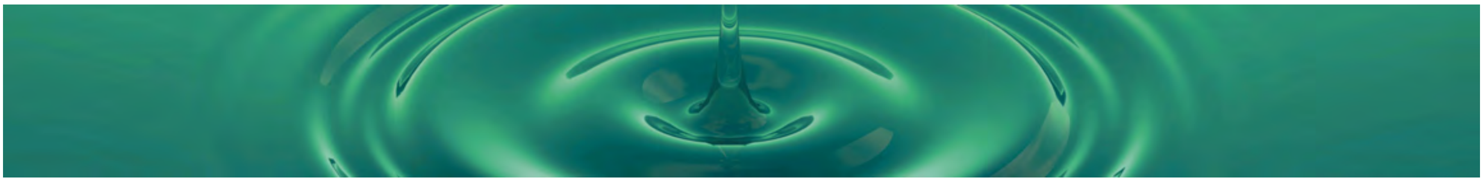
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH_AppendixX6_LRSS&WWSMisopachs_A4L.mxd

Rev: A - 1/11/2018 | by: BWhite

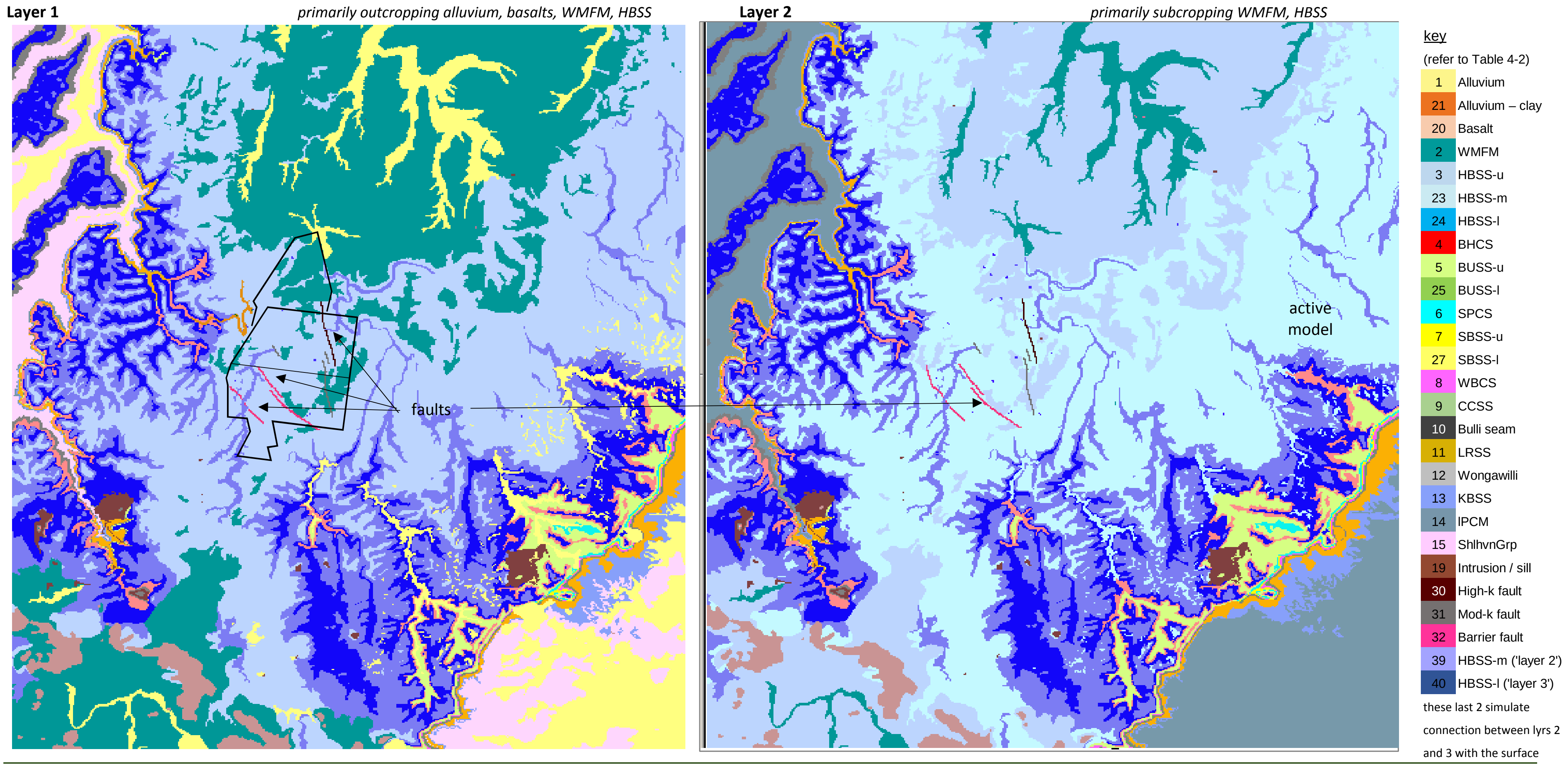
Geological Model: Loddon & Lawrence Sandstones and Wongawilli Coal seam isopachs

Tahmoor Coal
Tahmoor South Project

Figure F-6



APPENDIX G Groundwater model hydraulic conductivity zones



key

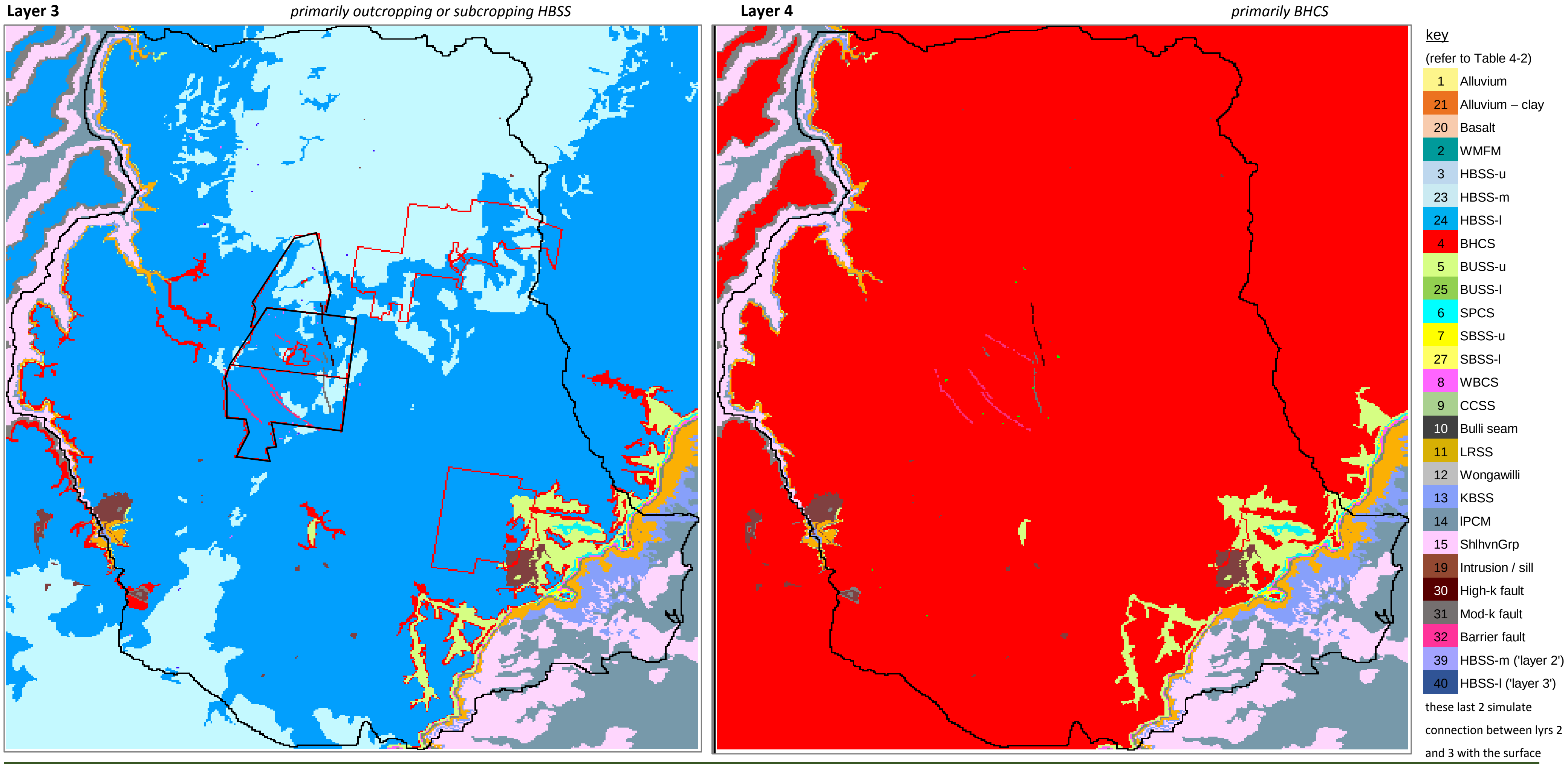
(refer to Table 4-2)

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
39	HBSS-m ('layer 2')
40	HBSS-l ('layer 3')

these last 2 simulate
connection between lyrs 2
and 3 with the surface

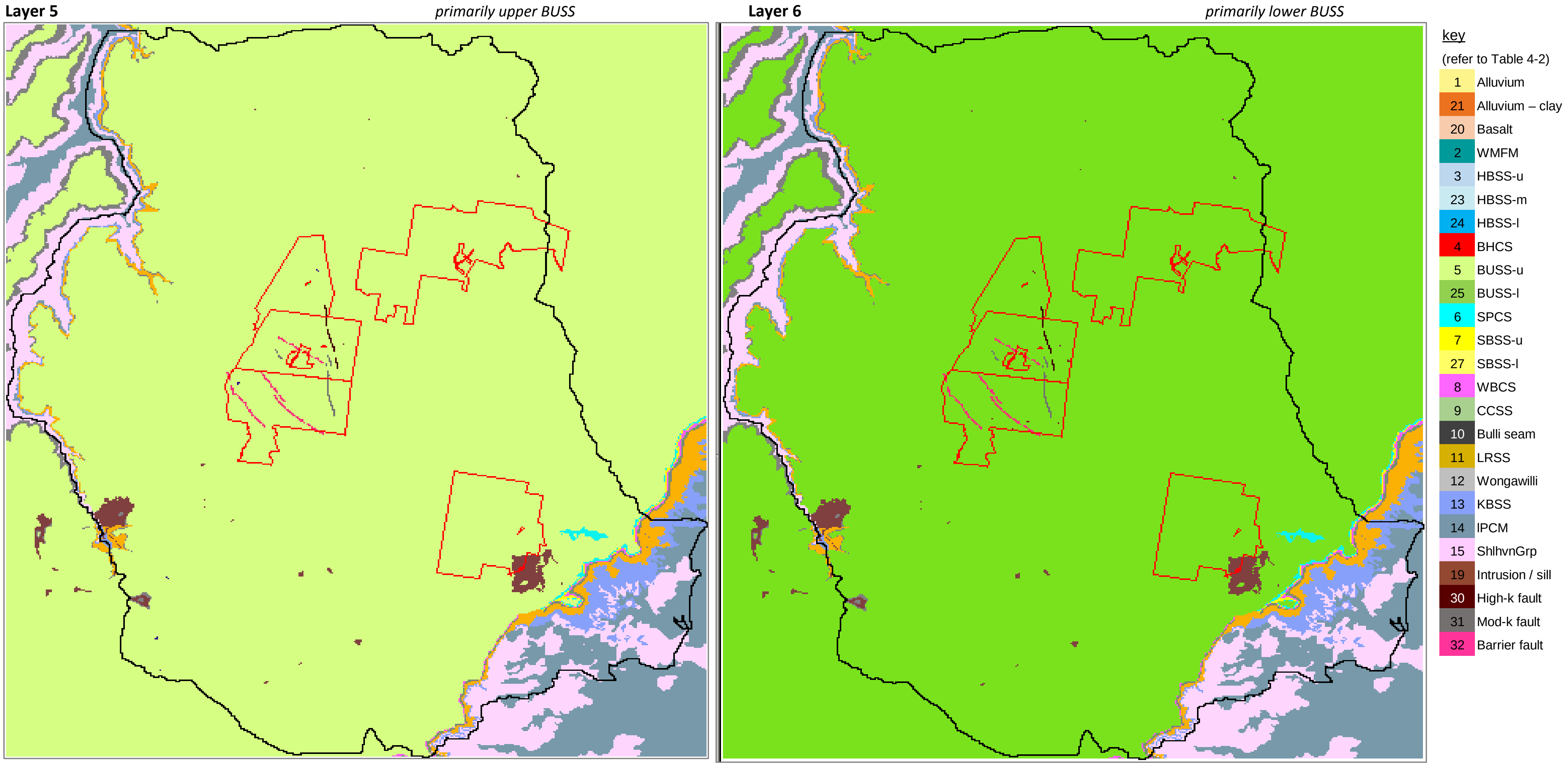
**Groundwater model hydraulic property zones:
Layer 1 and Layer 2**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx



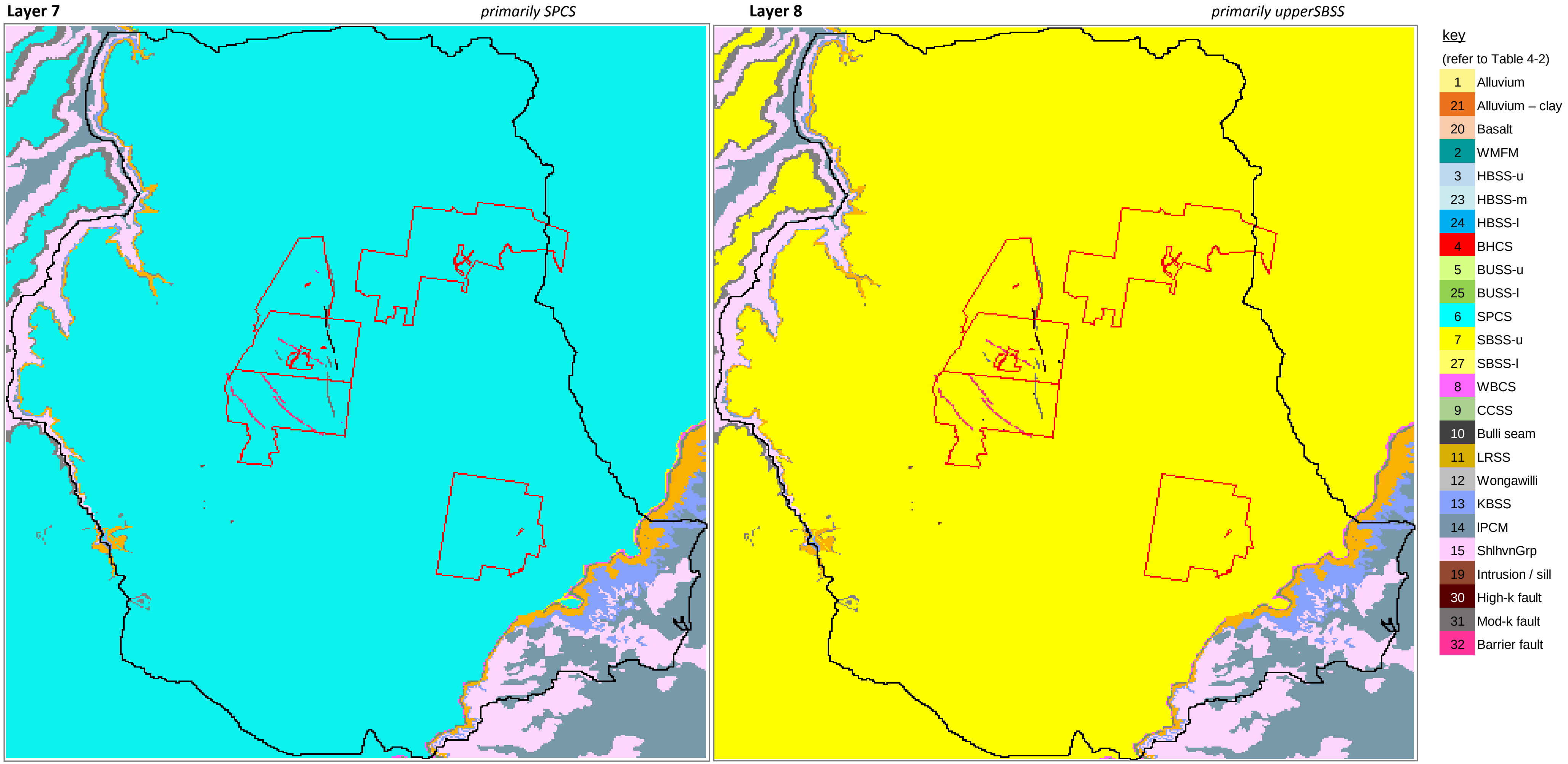
**Groundwater model hydraulic property zones:
Layer 3 and Layer 4**

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx



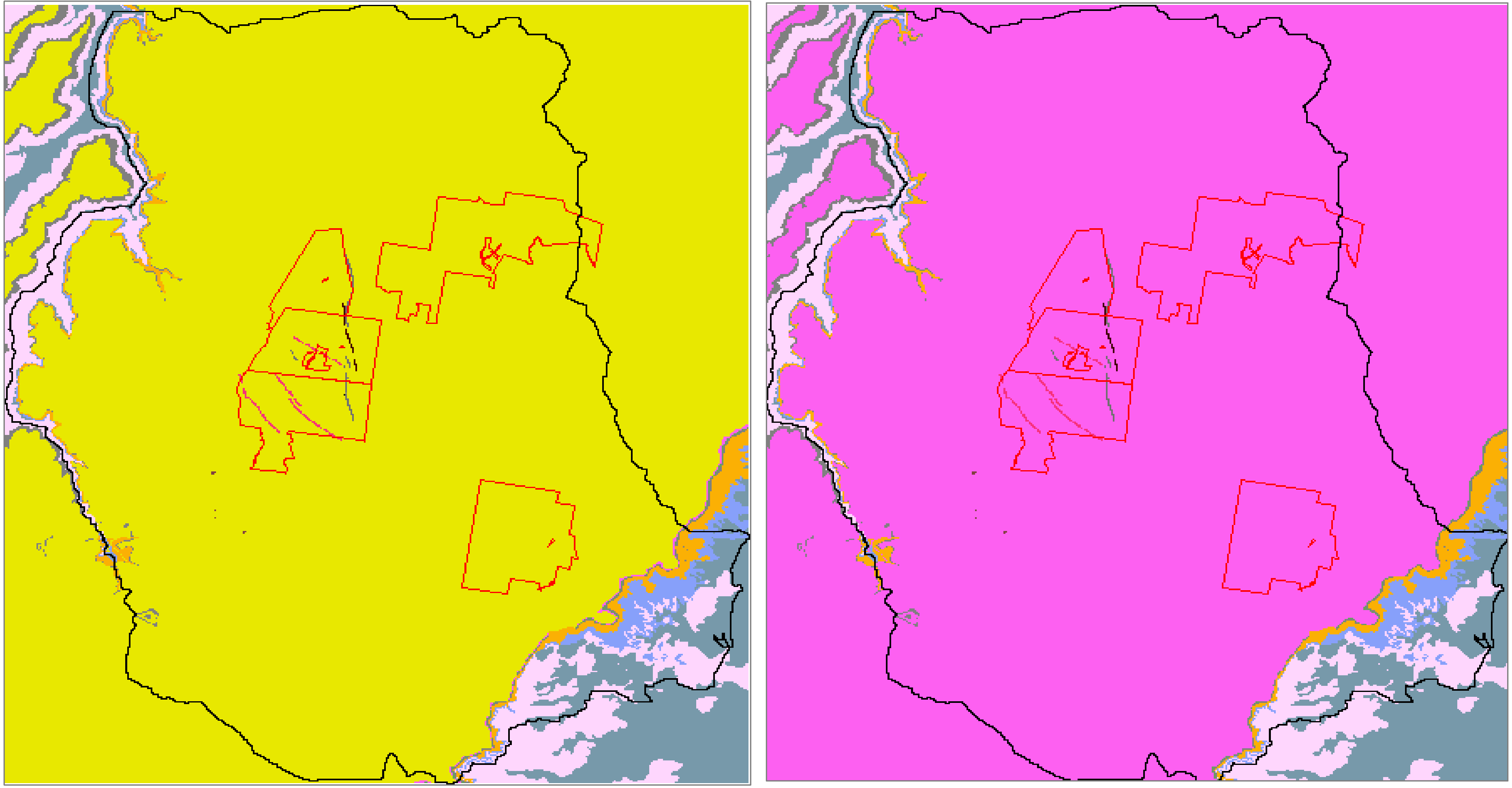
**Groundwater model hydraulic property zones:
Layer 5 and Layer 6**

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



Layer 9 *primarily lower SBSS*

Layer 10 *primarily WBCS*

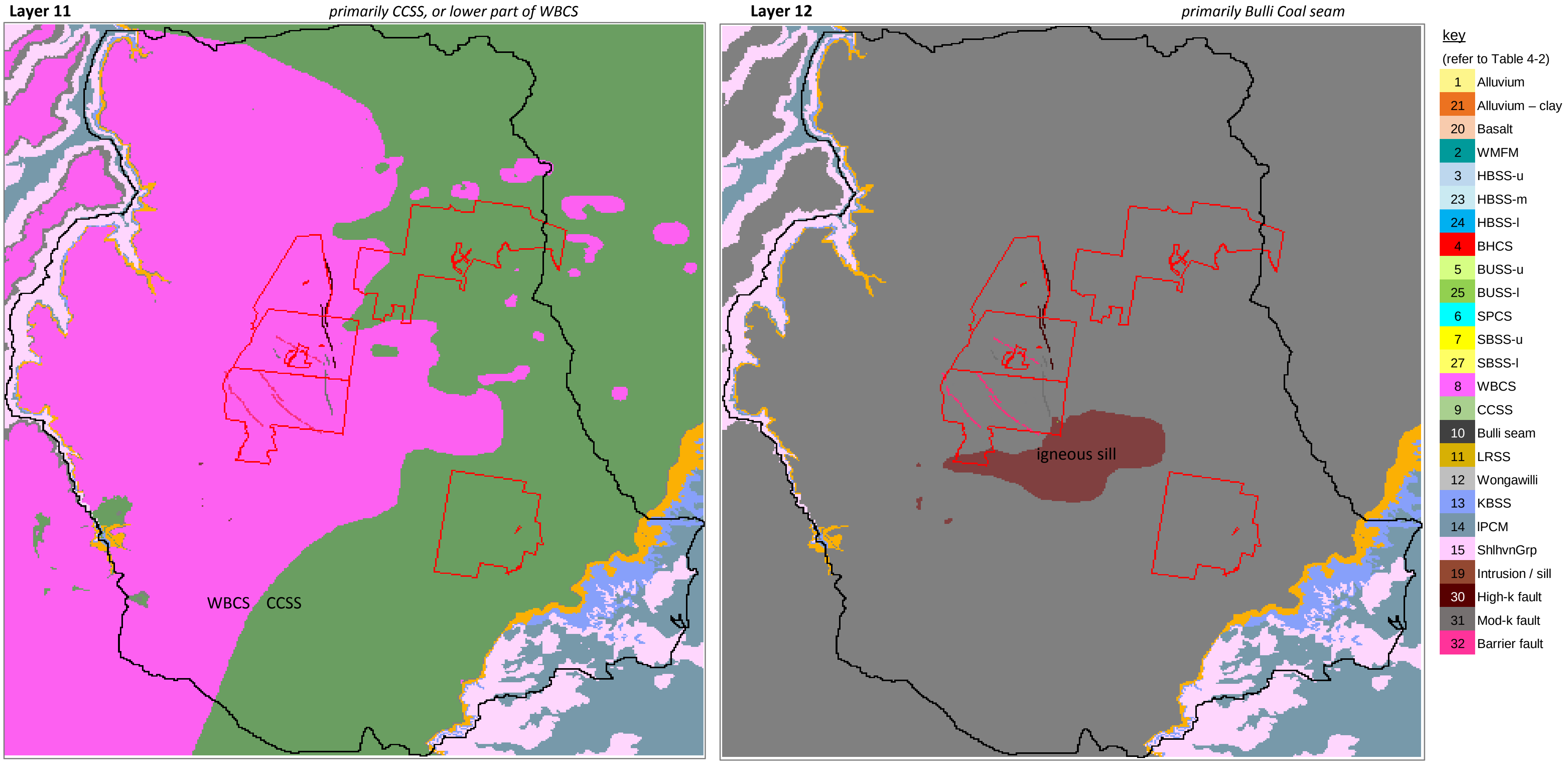
key

(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

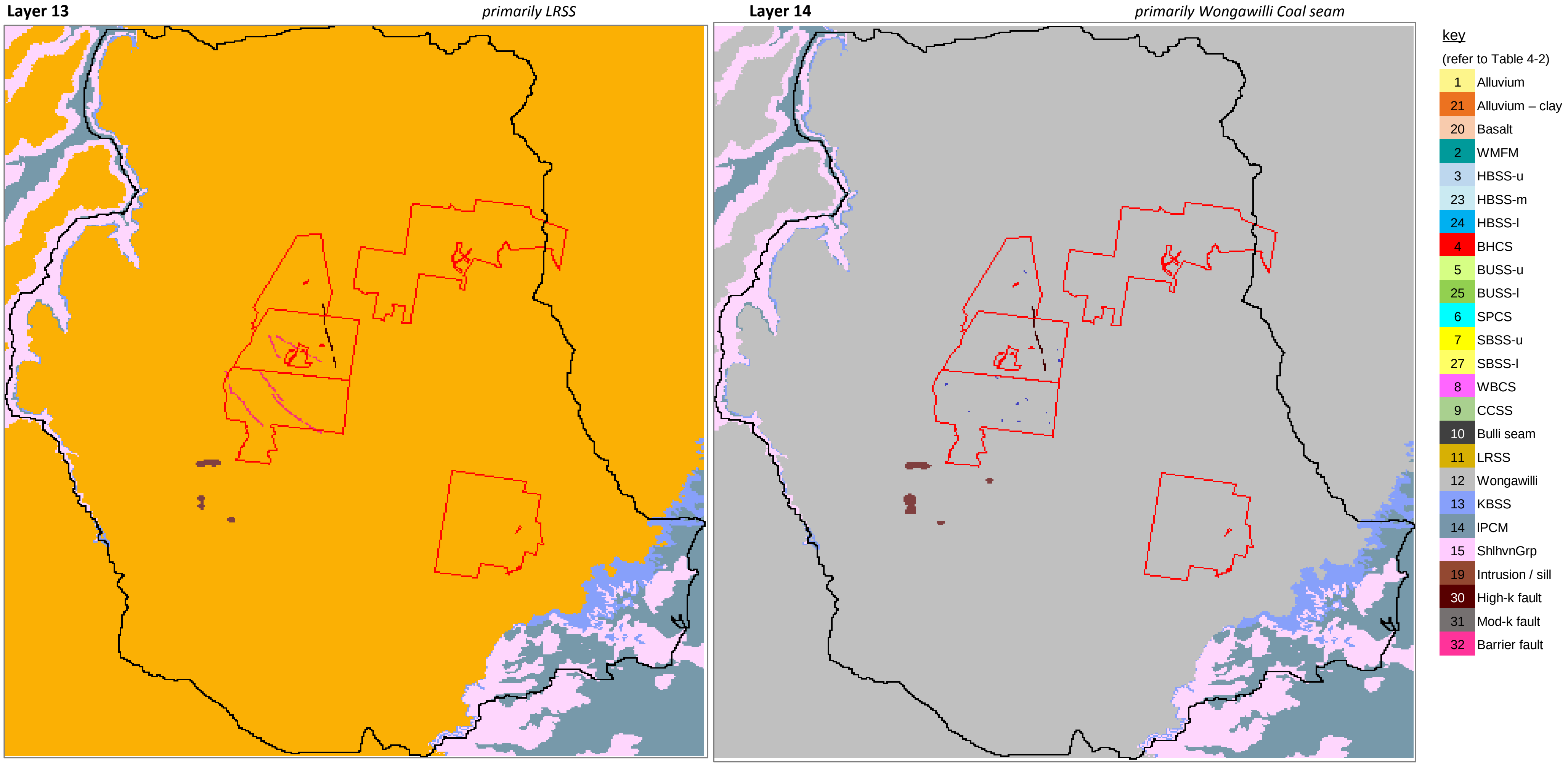
Groundwater model hydraulic property zones: Layer 9 and Layer 10

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx



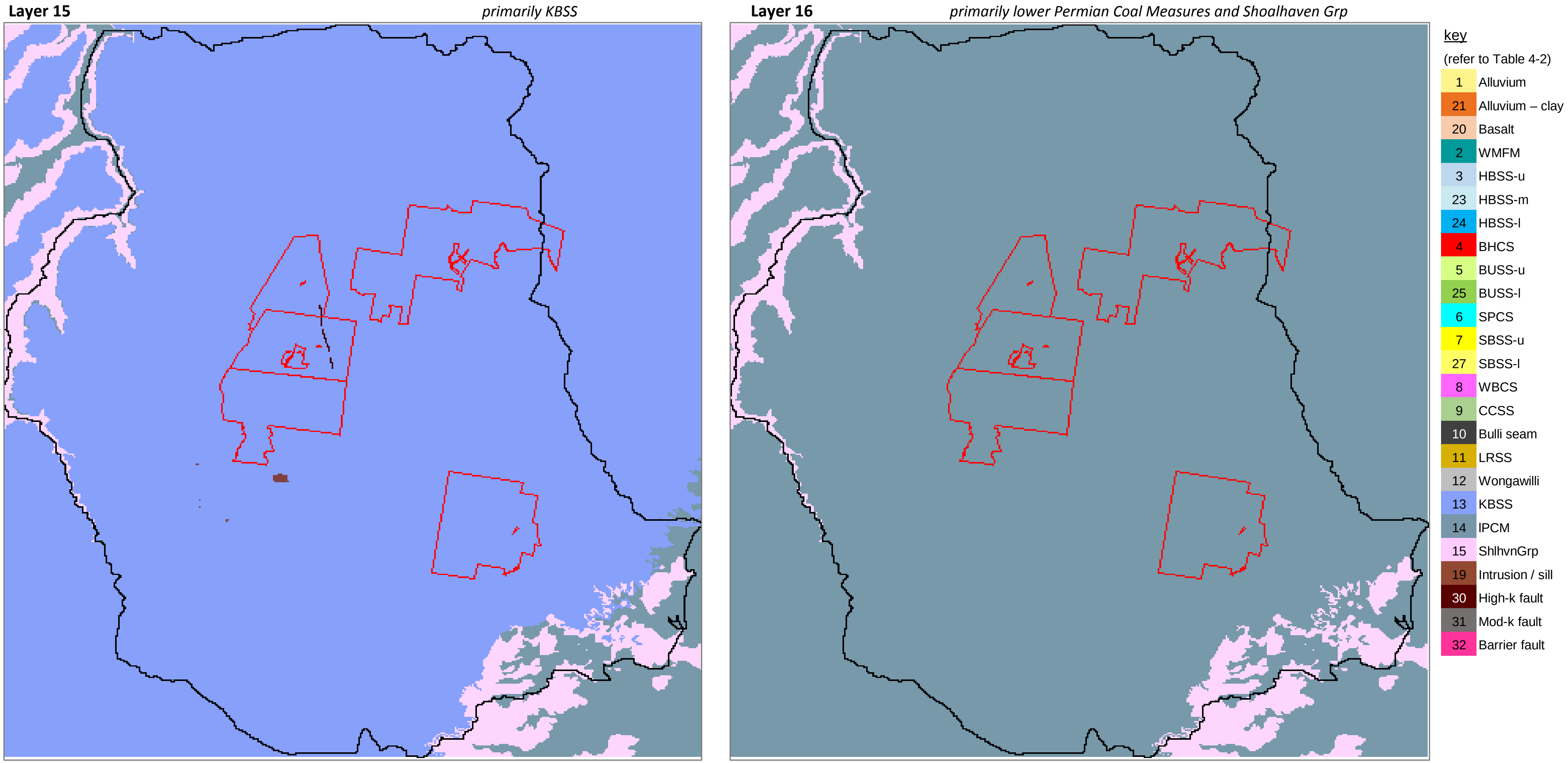
Groundwater model hydraulic property zones:
Layer 11 and Layer 12

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx



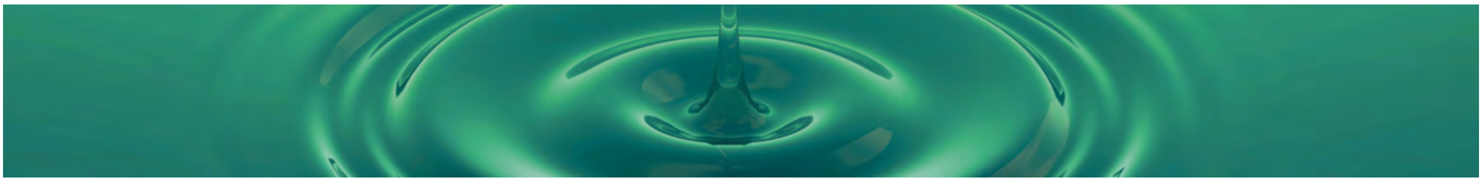
Groundwater model hydraulic property zones:
Layer 13 and Layer 14

C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx

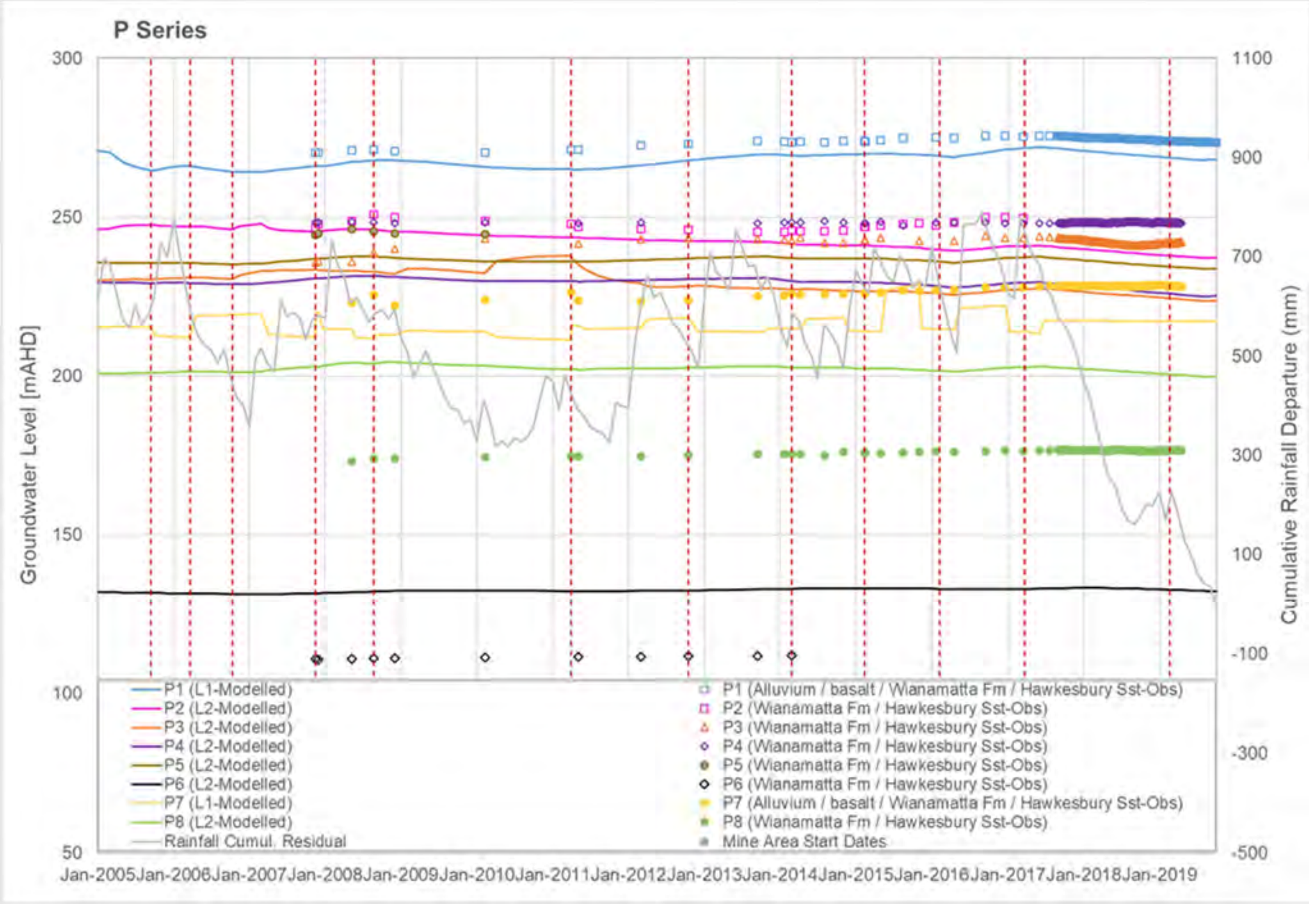


Groundwater model hydraulic property zones:
Layer 15 and Layer 16

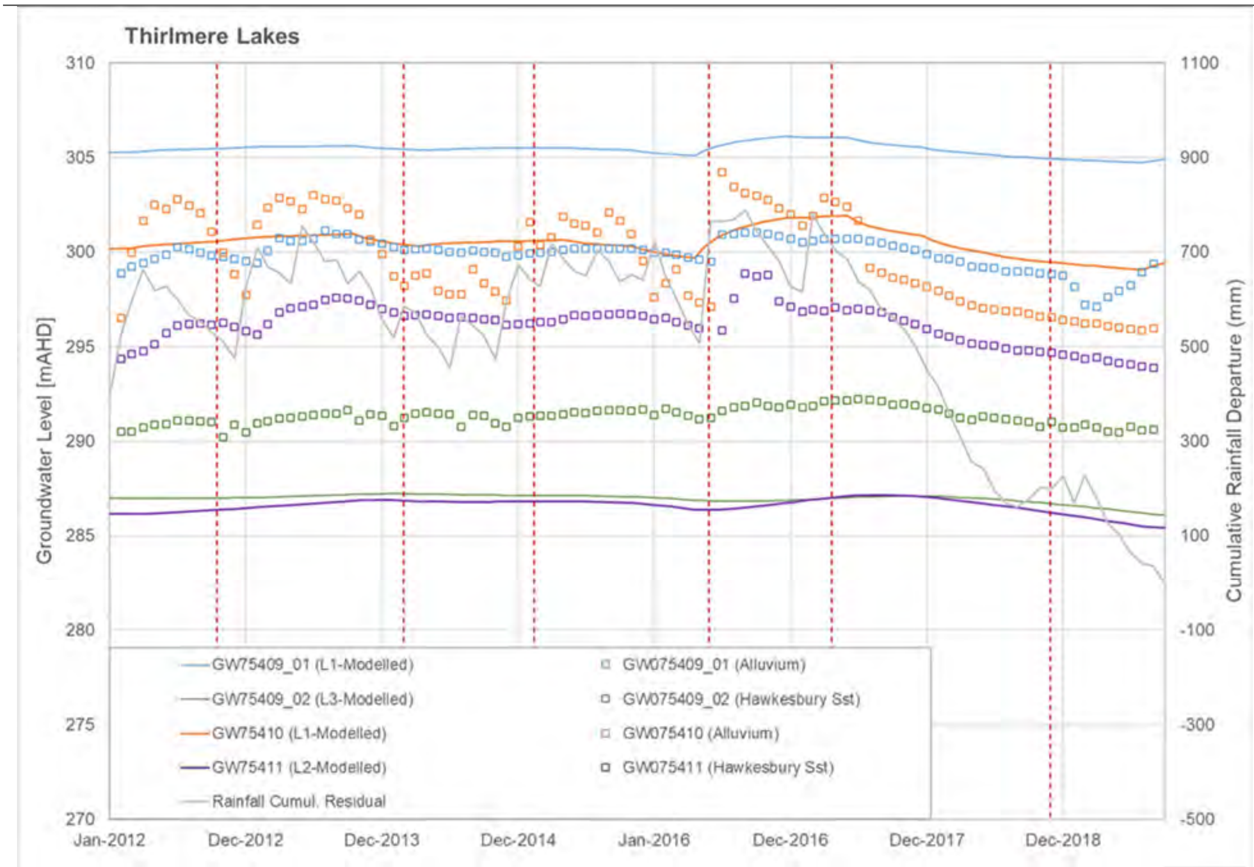
C:\HydroSim\TAH001\WP\HC2013-023_supportingdocs\Appendix_ModelkZones\Model_k_zones_v1TR026k.xlsx

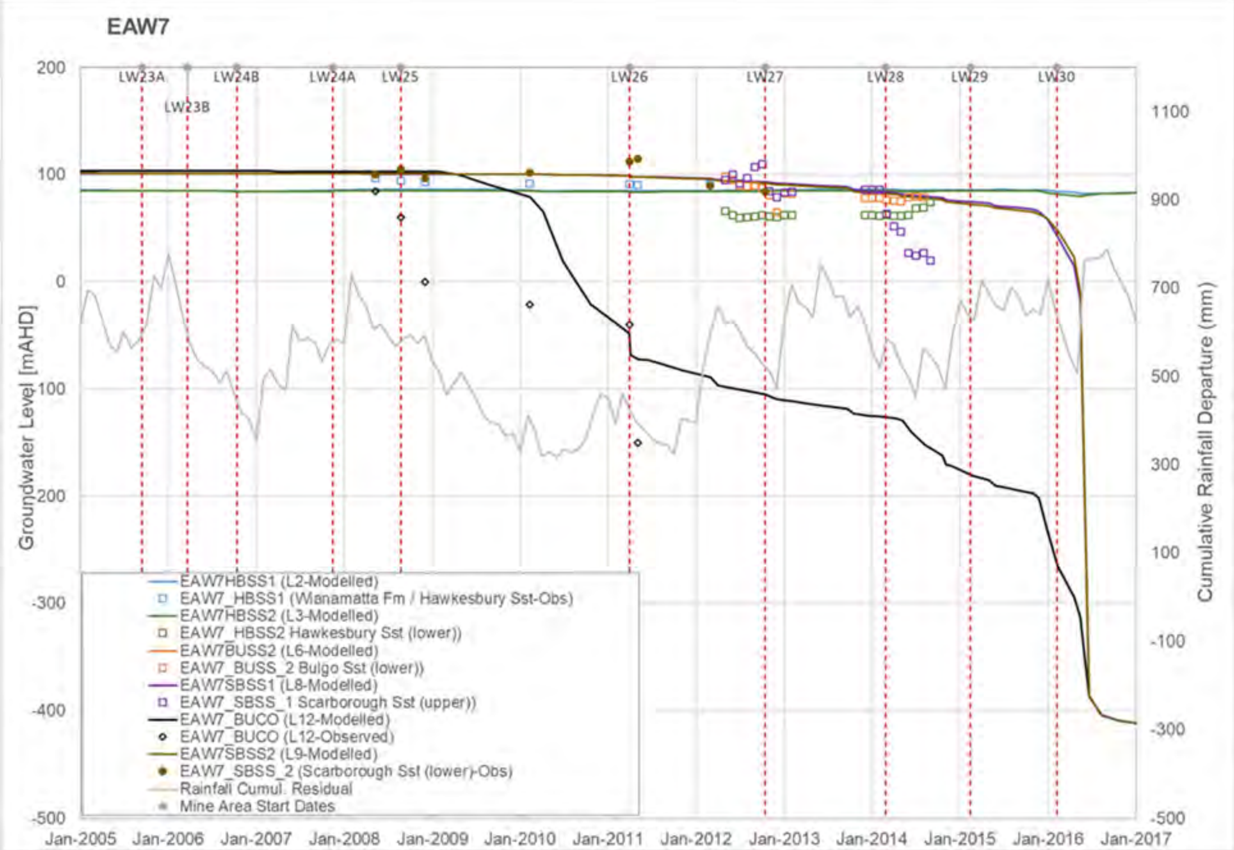


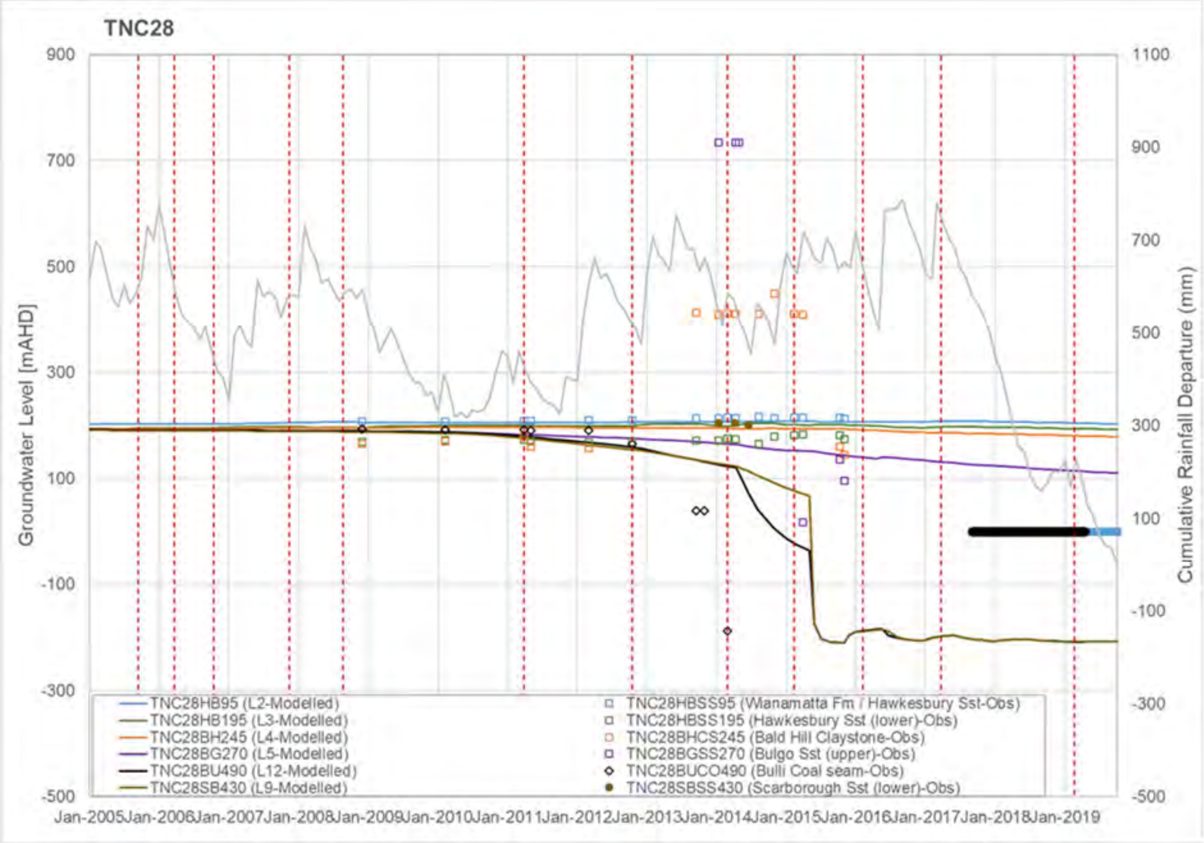
APPENDIX H Modelled groundwater level hydrographs

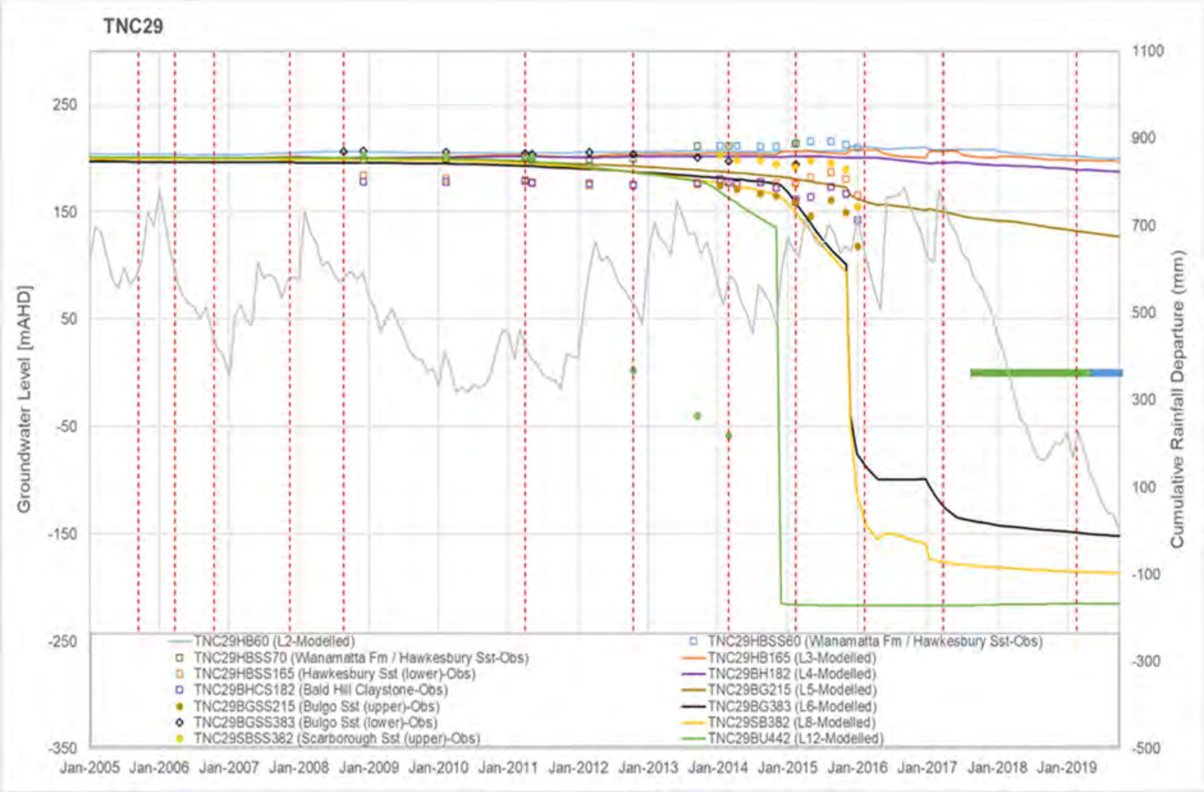

P Series
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
300
250
200
150
100
50
1100
900
700
500
300
100
-100
-300
-500
P1 (L1-Modelled)
P2 (L2-Modelled)
P3 (L2-Modelled)
P4 (L2-Modelled)
P5 (L2-Modelled)
P6 (L2-Modelled)
P7 (L1-Modelled)
P8 (L2-Modelled)
Rainfall Cumul. Residual
P1 (Alluvium / 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
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
Jan-2018
Jan-2019

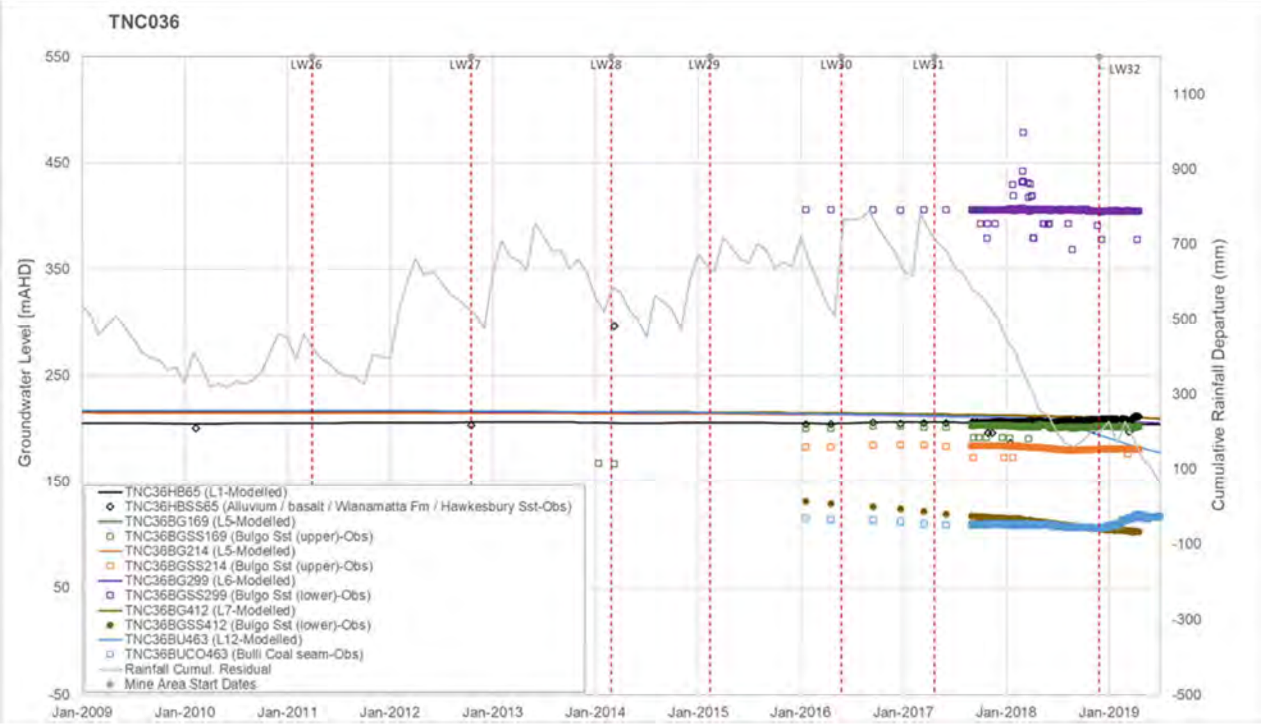

P9
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
205
200
195
190
185
180
1100
900
700
500
300
100
-100
-300
-500
LW23A
LW23B
LW24B
LW24A
LW25
LW26
LW27
LW28
LW29
LW30
LW31
LW32
P9_V1 (L1-Modelled)
P9_V1 (Hawkesbury Sst-Obs)
P9_V2 (L1-Modelled)
P9_V2 (Hawkesbury Sst-Obs)
P9_V3 (L2-Modelled)
P9_V3 (Hawkesbury Sst-Obs)
P9A24 (L1-Modelled)
P9A24 (Hawkesbury Sst-Obs)
Rainfall Cumul. Residual
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
Jan-2018
Jan-2019

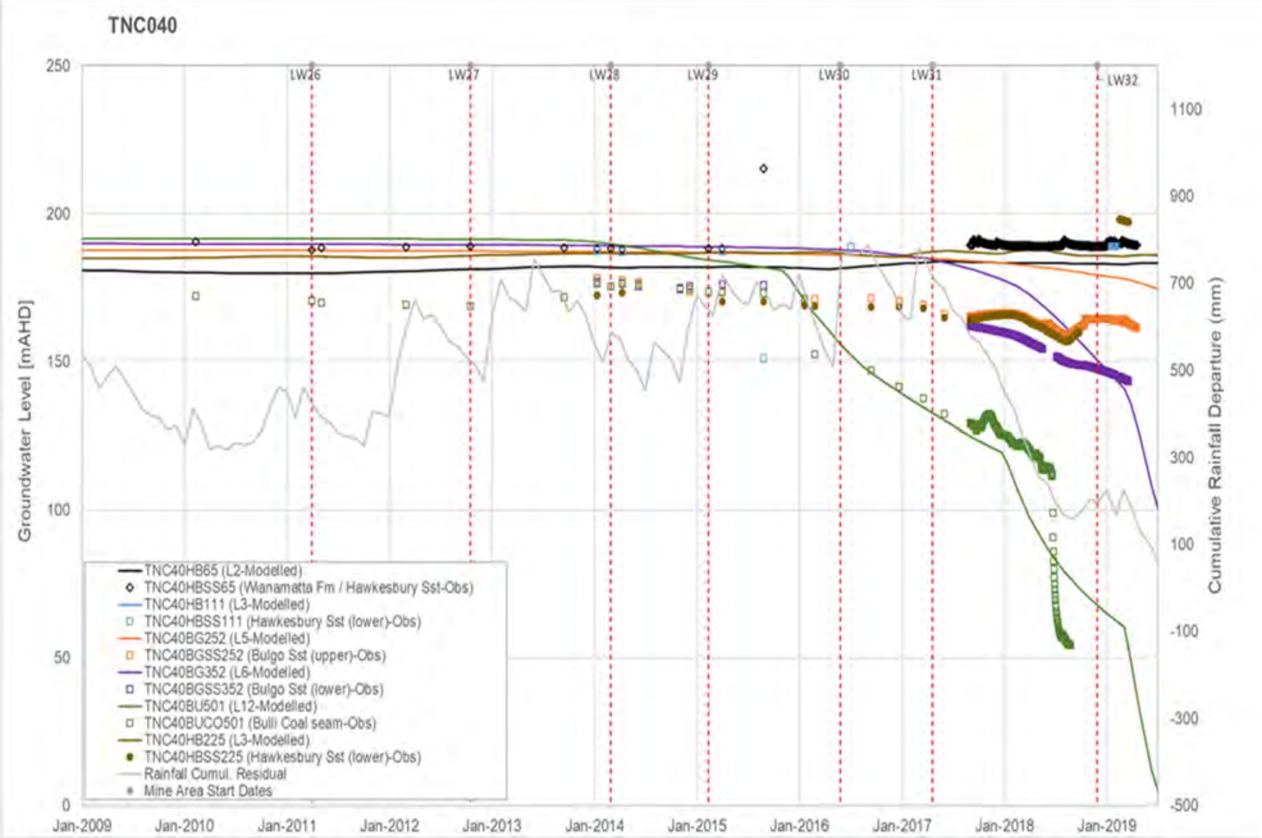

Thirlmere Lakes
Groundwater Level [mAHD]
310
305
300
295
290
285
280
275
270
Cumulative Rainfall Departure (mm)
1100
900
700
500
300
100
-100
-300
-500
Jan-2012
Dec-2012
Dec-2013
Dec-2014
Jan-2016
Dec-2016
Dec-2017
Dec-2018
GW75409_01 (L1-Modelled)
GW75409_02 (L3-Modelled)
GW75410 (L1-Modelled)
GW75411 (L2-Modelled)
Rainfall Cumul. Residual
GW075409_01 (Alluvium)
GW075409_02 (Hawkesbury Sst)
GW075410 (Alluvium)
GW075411 (Hawkesbury Sst)

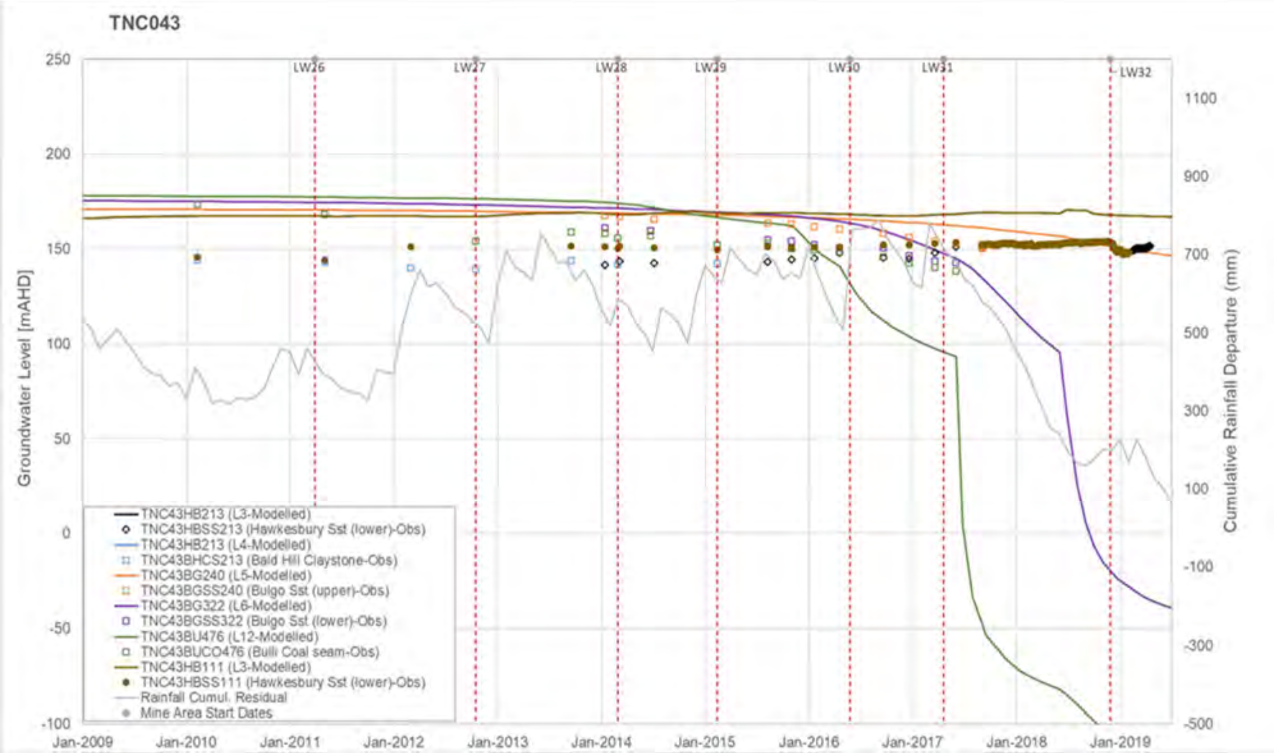

EAW7
Groundwater Level [mAHD]
200
100
0
-100
-200
-300
-400
-500
Cumulative Rainfall Departure (mm)
1100
900
700
500
300
100
-100
-300
-500
LW23A
LW23B
LW24B
LW24A
LW25
LW26
LW27
LW28
LW29
LW30
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
EAW7HBSS1 (L2-Modelled)
EAW7_HBSS1 (Wianamatta Fm / Hawkesbury Sst-Obs)
EAW7HBSS2 (L3-Modelled)
EAW7_HBSS2 Hawkesbury Sst (lower))
EAW7BUSS2 (L6-Modelled)
EAW7_BUSS_2 Bulgo Sst (lower))
EAW7SBSS1 (L8-Modelled)
EAW7_SBSS_1 Scarborough Sst (upper))
EAW7_BUCO (L12-Modelled)
EAW7_BUCO (L12-Observed)
EAW7SBSS2 (L9-Modelled)
EAW7_SBSS_2 (Scarborough Sst (lower)-Obs)
Rainfall Cumul. Residual
Mine Area Start Dates

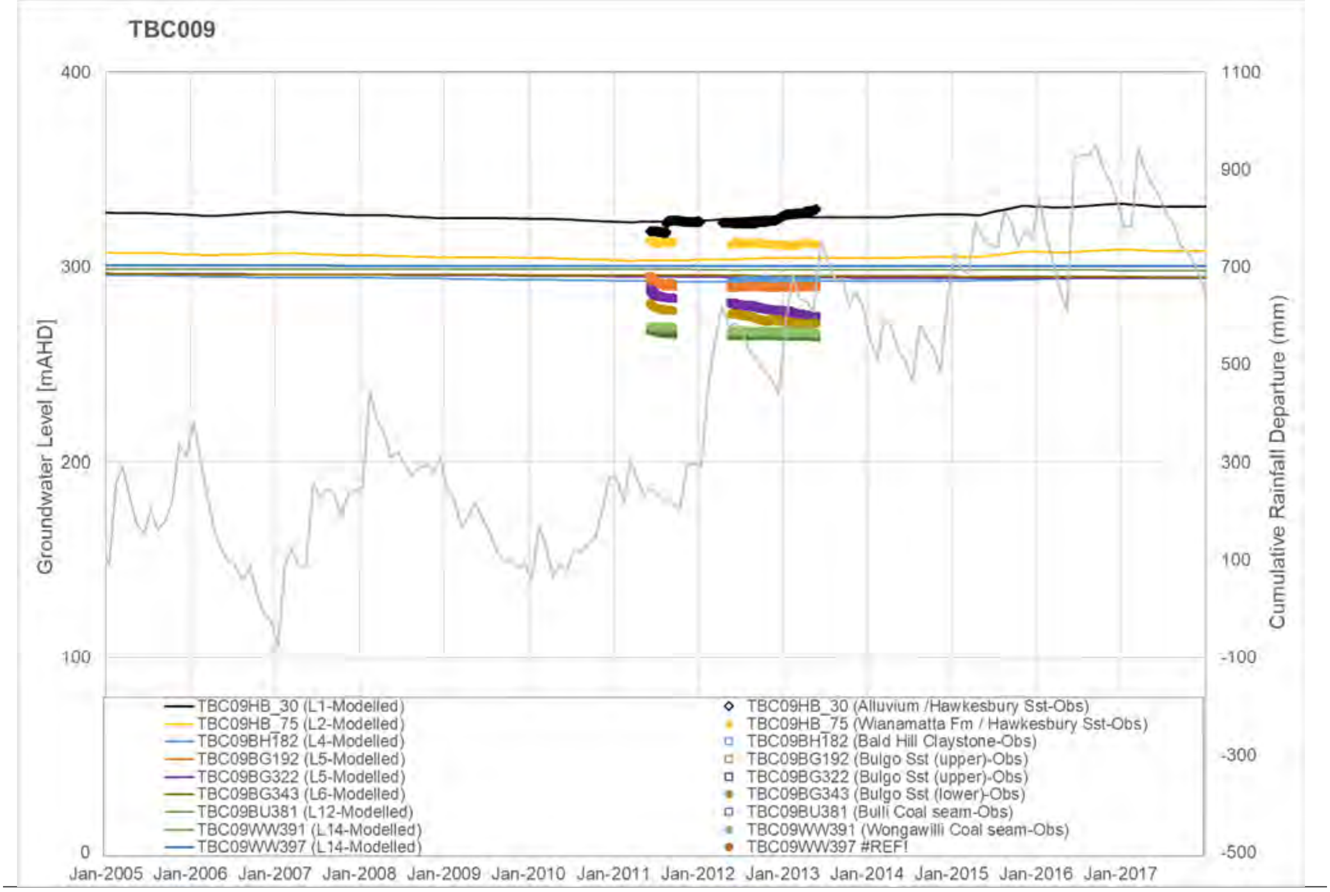

TNC28
Groundwater Level [mAHD]
900
700
500
300
100
-100
-300
-500
Cumulative Rainfall Departure (mm)
1100
900
700
500
300
100
-100
-300
-500
TNC28HB95 (L2-Modelled)
TNC28HB195 (L3-Modelled)
TNC28BH245 (L4-Modelled)
TNC28BG270 (L5-Modelled)
TNC28BU490 (L12-Modelled)
TNC28SB430 (L9-Modelled)
TNC28HBSS95 (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)
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
Jan-2018
Jan-2019

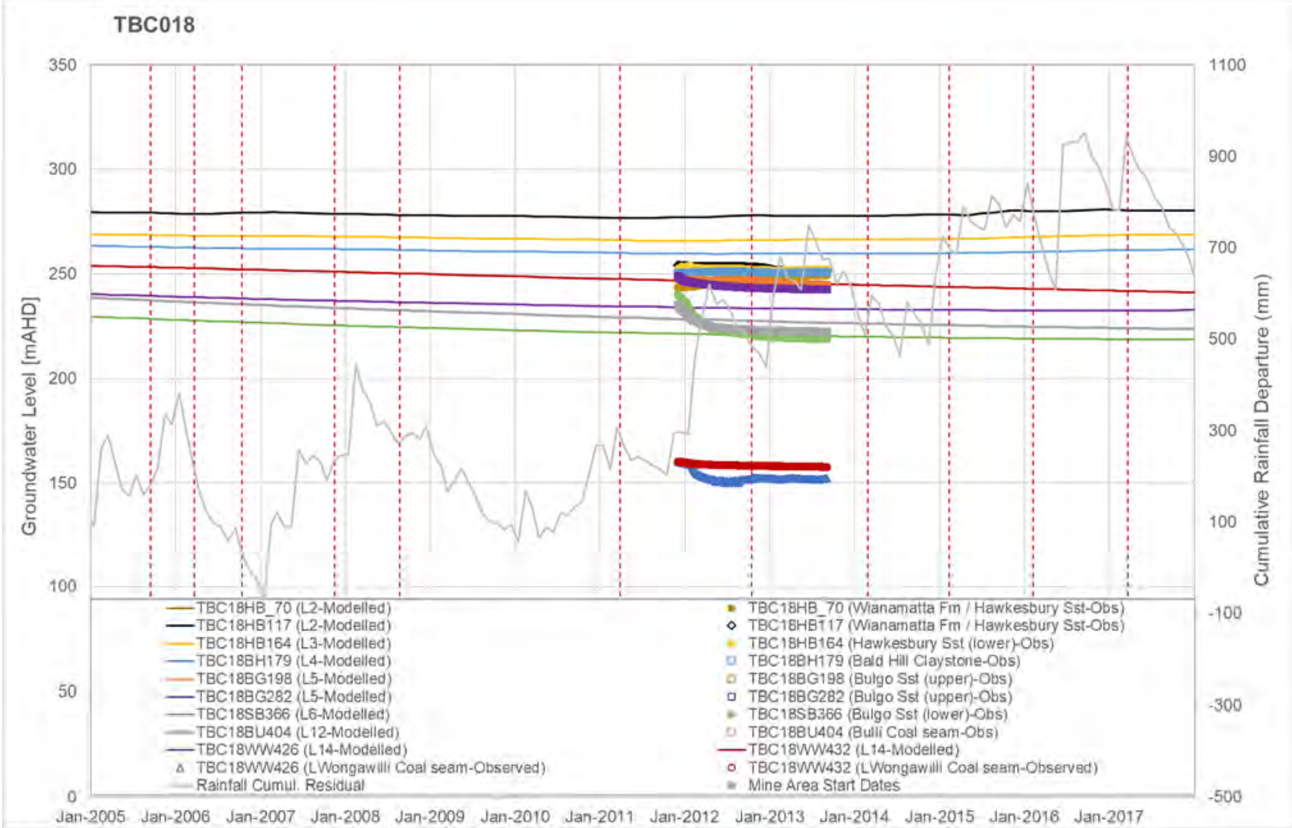

TNC29
Groundwater Level [mAHD]
250
150
50
-50
-150
-250
-350
Cumulative Rainfall Departure (mm)
1100
900
700
500
300
100
-100
-300
-500
TNC29HB60 (L2-Modelled)
TNC29HBSS70 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC29HBSS165 (Hawkesbury Sst (lower)-Obs)
TNC29BHCS182 (Bald Hill Claystone-Obs)
TNC29BGSS215 (Bulgo Sst (upper)-Obs)
TNC29BGSS383 (Bulgo Sst (lower)-Obs)
TNC29SBSS382 (Scarborough Sst (upper)-Obs)
TNC29HBSS60 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC29HB165 (L3-Modelled)
TNC29BH182 (L4-Modelled)
TNC29BG215 (L5-Modelled)
TNC29BG383 (L6-Modelled)
TNC29SB382 (L8-Modelled)
TNC29BU442 (L12-Modelled)
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
Jan-2018
Jan-2019

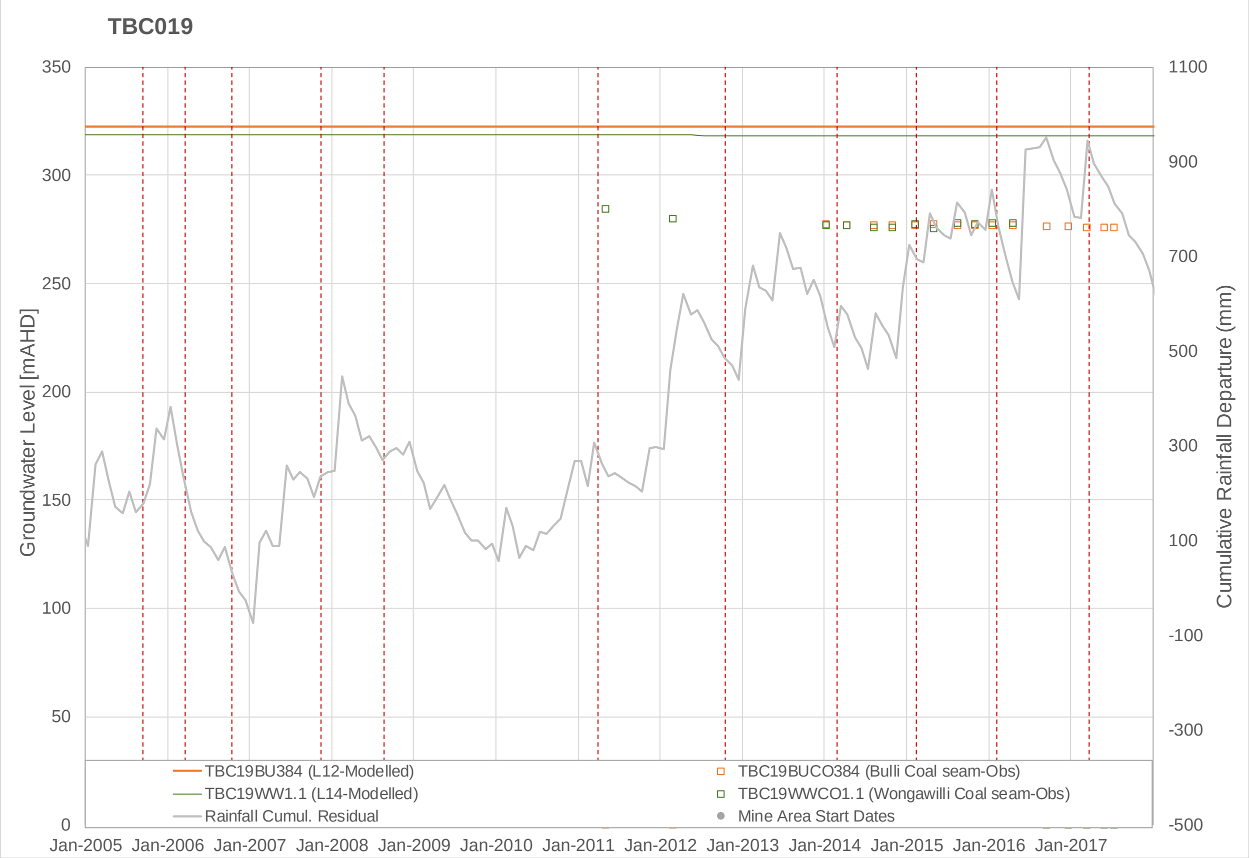

TNC036
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
550
450
350
250
150
50
-50
1100
900
700
500
300
100
-100
-300
-500
LW26
LW27
LW28
LW29
LW30
LW31
LW32
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
TNC36HB65 (L1-Modelled)
TNC36HBSS65 (Alluvium / basalt / Wianamatta Fm / Hawkesbury Sst-Obs)
TNC36BG169 (L5-Modelled)
TNC36BGSS169 (Bulgo Sst (upper)-Obs)
TNC36BG214 (L5-Modelled)
TNC36BGSS214 (Bulgo Sst (upper)-Obs)
TNC36BG299 (L6-Modelled)
TNC36BGSS299 (Bulgo Sst (lower)-Obs)
TNC36BG412 (L7-Modelled)
TNC36BGSS412 (Bulgo Sst (lower)-Obs)
TNC36BU463 (L12-Modelled)
TNC36BUCO463 (Bulli Coal seam-Obs)
Rainfall Cumul. Residual
Mine Area Start Dates


TNC040
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
250
200
150
100
50
0
1100
900
700
500
300
100
-100
-300
-500
LW26
LW27
LW28
LW29
LW30
LW31
LW32
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
TNC40HB65 (L2-Modelled)
TNC40HBSS65 (Wianamatta Fm / Hawkesbury Sst-Obs)
TNC40HB111 (L3-Modelled)
TNC40HBSS111 (Hawkesbury Sst (lower)-Obs)
TNC40BG252 (L5-Modelled)
TNC40BGSS252 (Bulgo Sst (upper)-Obs)
TNC40BG352 (L6-Modelled)
TNC40BGSS352 (Bulgo Sst (lower)-Obs)
TNC40BU501 (L12-Modelled)
TNC40BUCO501 (Bulli Coal seam-Obs)
TNC40HB225 (L3-Modelled)
TNC40HBSS225 (Hawkesbury Sst (lower)-Obs)
Rainfall Cumul. Residual
Mine Area Start Dates


TNC043
Groundwater Level [mAHD]
Cumulative Rainfall Departure (mm)
250
200
150
100
50
0
-50
-100
1100
900
700
500
300
100
-100
-300
-500
LW26
LW27
LW28
LW29
LW30
LW31
LW32
Jan-2009
Jan-2010
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
Jan-2017
Jan-2018
Jan-2019
TNC43HB213 (L3-Modelled)
TNC43HBSS213 (Hawkesbury Sst (lower)-Obs)
TNC43HB213 (L4-Modelled)
TNC43BHCS213 (Bald Hill Claystone-Obs)
TNC43BG240 (L5-Modelled)
TNC43BGSS240 (Bulgo Sst (upper)-Obs)
TNC43BG322 (L6-Modelled)
TNC43BGSS322 (Bulgo Sst (lower)-Obs)
TNC43BU476 (L12-Modelled)
TNC43BUCO476 (Bulli Coal seam-Obs)
TNC43HB111 (L3-Modelled)
TNC43HBSS111 (Hawkesbury Sst (lower)-Obs)
Rainfall Cumul. Residual
Mine Area Start Dates


TBC009
Groundwater Level [mAHD]
400
300
200
100
0
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
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!


TBC018
Groundwater Level [mAHD]
350
300
250
200
150
100
50
0
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
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



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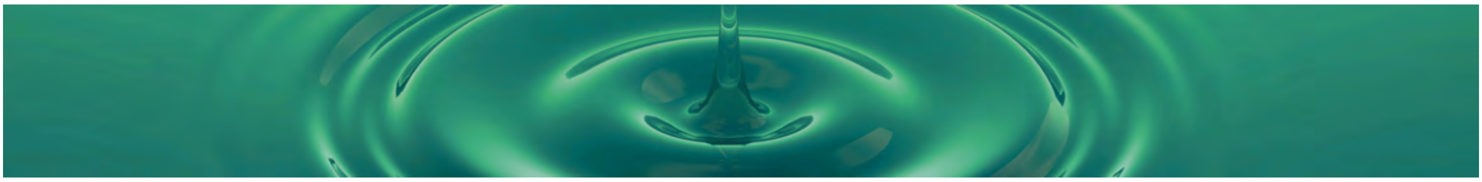


APPENDIX I Predicted drawdown effects at registered bores

Bore impact assessment - Bores/works registered with NSW government

Tahmoor South Project

E:\HYDROSIM\TAHMOOR\Model\Processing\MaxDDN\DDNcalc\[BoreDrawdown Assessment_v6TR069-XXX_&_sensitivity_V4.xlsx]Report_Appendix_RegisteredBores

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW005316	295345	6219715	Water supply	HBSS	2	0.0	0.1	3.9	3.4
GW007445	277454	6204323	Irrigation	HBSS	3	>50	>50	>50	>50
GW008537	277989	6211214	Irrigation	HBSS	2	0.4	1.4	9.3	46.6
GW008548	277099	6209867	Irrigation	HBSS	1	0.1	1.0	2.8	4.5
GW010062	270809	6217885	Domestic	HBSS	1	0.0	0.7	0.1	0.7
GW010301	271591	6216301	Domestic	HBSS	1	0.0	0.6	0.2	0.7
GW010459	274240	6213745	Irrigation	HBSS	2	0.1	0.4	2.6	4.2
GW010460	274760	6214497	Irrigation	HBSS	1	0.0	0.7	0.2	0.7
GW010496	276413	6211793	Irrigation	HBSS	1	0.0	0.9	7.5	9.2
GW010584	275340	6209548	Unknown	HBSS	1	0.1	1.0	15.5	17.4
GW010604	276637	6214234	Livestock	HBSS	2	0.1	0.4	5.7	8.0
GW010654	274949	6211974	Irrigation	HBSS	1	0.0	0.8	3.3	4.4
GW010968	276062	6214682	Domestic	HBSS	1	0.0	0.9	0.3	1.0
GW011042	289617	6208862	Livestock	HBSS	1	0.0	0.6	10.1	11.3
GW011200	275607	6210735	Irrigation	HBSS	2	0.5	1.9	9.8	16.7
GW011234	275883	6209314	Domestic	HBSS	1	0.1	1.0	10.3	11.9
GW011299	275273	6209450	Irrigation	HBSS	1	0.2	1.0	16.0	17.8
GW011634	275622	6232090	Livestock	HBSS	1	0.0	0.7	0.0	0.7
GW011930	268753	6192215	Water supply	HBSS	2	0.0	0.5	0.0	0.5
GW012577	269836	6187709	Domestic	HBSS	2	0.0	0.6	0.0	0.6
GW012611	275711	6210081	Water supply	HBSS	1	0.1	1.0	13.8	15.8
GW012612	275398	6210320	Water supply	HBSS	1	0.1	1.0	14.6	16.5
GW012613	282909	6231058	Water supply	HBSS	3	0.0	0.1	0.3	0.5
GW013282	276627	6209270	Irrigation	HBSS	1	0.1	0.9	0.8	2.2
GW013326	269820	6189374	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW013336	268274	6190939	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW013634	274304	6216428	Domestic	HBSS	1	0.0	0.8	0.1	0.8
GW013826	274330	6216429	Irrigation	HBSS	1	0.0	0.8	0.1	0.8
GW013855	278126	6218431	Water supply	HBSS	2	0.0	0.4	0.4	0.6
GW014253	275724	6232154	Water supply	HBSS	1	0.0	0.7	0.0	0.7
GW014262	276764	6204587	Livestock	HBSS	1	15.3	31.8	16.0	33.2
GW014273	275713	6217510	Water supply	WMFM / HBSS	1	0.0	0.5	0.0	0.5
GW015069	276226	6200351	Water supply	HBSS	1	0.0	1.2	0.0	1.2
GW015549	274027	6193978	Water supply	HBSS	1	0.0	1.1	0.0	1.1
GW015789	273581	6194430	Water supply	HBSS	2	0.0	0.7	0.0	0.7
GW015816	272063	6217977	Irrigation	HBSS	1	0.0	0.7	0.1	0.7
GW016553	274592	6195996	Water supply	HBSS	3	0.0	0.4	0.0	0.4
GW017315	286642	6220354	Water supply	WMFM / HBSS	1	0.0	0.7	1.3	1.2
GW017627	269765	6223902	Water supply	HBSS	2	0.0	0.6	0.0	0.6
GW017628	270156	6221538	Irrigation	HBSS	2	0.0	0.4	0.0	0.4
GW018080	268562	6187554	Irrigation	HBSS	3	0.0	0.4	0.0	0.4
GW018568	274881	6210554	Irrigation	HBSS	2	0.5	1.7	8.3	14.5
GW018800	271658	6214576	Water supply	HBSS	2	0.0	0.5	1.0	1.6
GW019590	282131	6207118	Water supply	HBSS	2	1.9	4.8	2.8	5.9
GW022245	273516	6207685	Water supply	HBSS	1	0.5	1.3	3.1	5.9
GW023161	268579	6228343	Irrigation	HBSS	3	0.0	0.3	0.0	0.3
GW023189	272087	6228645	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW023213	281313	6234628	Unknown	HBSS	2	0.0	0.5	0.0	0.6
GW023343	270096	6220858	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW023412	285720	6232725	Irrigation	HBSS	3	0.0	0.1	0.3	0.6
GW023483	271717	6226940	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW023588	284629	6227676	Irrigation	HBSS	2	0.0	0.3	0.1	0.4
GW023685	275677	6226542	Water supply	HBSS	2	0.0	0.6	0.1	0.6
GW024351	291921	6223863	Unknown	WMFM / HBSS	1	0.0	0.7	0.2	0.7
GW024353	291479	6224161	Unknown	HBSS	2	0.0	0.3	0.0	0.3
GW024354	291866	6224047	Unknown	WMFM / HBSS	1	0.0	0.6	0.1	0.6
GW024417	276063	6200748	Water supply	HBSS	1	0.0	0.7	0.0	0.7
GW024565	275680	6215660	Livestock	HBSS	1	0.0	0.5	0.1	0.6
GW024623	271717	6206901	Livestock	HBSS	1	0.2	0.4	0.8	0.9
GW024644	286479	6209500	Irrigation	HBSS	2	0.0	0.4	7.3	7.2

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW024750	277098	6216403	Irrigation	WMFM / HBSS	1	0.0	0.3	1.8	2.4
GW025594	270318	6225396	Water supply	HBSS	2	0.0	0.6	0.0	0.6
GW025598	274369	6196730	Domestic	HBSS	3	0.1	0.3	0.1	0.3
GW025600	270454	6220898	Domestic	HBSS	2	0.0	0.6	0.1	0.6
GW026239	289192	6226669	Irrigation	HBSS	2	0.0	0.3	0.0	0.3
GW026400	275566	6226909	Irrigation	HBSS	2	0.0	0.7	0.1	0.7
GW026469	292182	6222513	Irrigation	HBSS	2	0.0	0.3	1.3	2.8
GW026470	292880	6222220	Irrigation	Alluvium	1	0.0	0.0	0.0	0.0
GW026471	292243	6222082	Irrigation	Alluvium	1	0.0	0.0	0.0	0.0
GW026472	291403	6226410	Irrigation	Alluvium	1	0.0	0.3	0.0	0.3
GW026473	291651	6222193	Irrigation	Alluvium	1	0.0	0.3	0.0	0.4
GW026474	291428	6226472	Irrigation	Alluvium	1	0.0	0.3	0.0	0.3
GW026516	289037	6220994	Irrigation	HBSS	2	0.0	0.2	1.5	2.7
GW026529	286629	6223190	Irrigation	WMFM / HBSS	1	0.0	0.7	0.0	0.7
GW026533	289089	6226667	Irrigation	HBSS	2	0.0	0.3	0.0	0.3
GW026545	291137	6222243	Irrigation	Alluvium	1	0.0	0.3	0.8	0.6
GW026551	291127	6223845	Irrigation	Alluvium	1	0.0	0.4	0.0	0.4
GW026557	291625	6222192	Irrigation	Alluvium	1	0.0	0.3	0.0	0.4
GW026934	268546	6226524	Irrigation	HBSS	3	0.0	0.3	0.0	0.3
GW027792	285386	6230498	Domestic	HBSS	3	0.0	0.1	0.4	0.7
GW028270	282471	6207897	Livestock	HBSS	1	0.1	0.8	0.3	1.0
GW028859	274601	6211534	Domestic	HBSS	1	0.1	0.8	3.7	4.8
GW028935	270372	6226353	Irrigation	HBSS	3	0.0	0.3	0.0	0.3
GW029020	283614	6231660	Irrigation	HBSS	2	0.0	0.8	0.0	0.8
GW029143	274796	6210860	Water supply	HBSS	2	0.4	1.4	7.4	12.9
GW029382	271648	6218183	Irrigation	HBSS	2	0.0	0.4	0.2	0.5
GW031294	279732	6205706	Irrigation	HBSS	2	6.2	27.4	9.3	32.8
GW031353	273003	6225738	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW031438	289830	6229088	Irrigation	WMFM / HBSS	1	0.0	0.6	0.1	0.6
GW032179	268826	6227671	Irrigation	HBSS	3	0.0	0.3	0.0	0.3
GW032426	272857	6225426	Water supply	HBSS	2	0.0	0.5	0.0	0.5
GW032443	276415	6206336	Irrigation	HBSS	2	9.0	24.7	13.7	30.0
GW032724	289510	6229666	Water supply	HBSS	2	0.0	0.3	0.1	0.4
GW033846	270058	6221351	Water supply	HBSS	1	0.0	1.0	0.0	1.0
GW033872	269326	6226111	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW033916	273200	6206968	Water supply	HBSS	2	0.4	0.8	1.7	3.2
GW033932	272422	6217955	Domestic	HBSS	1	0.0	0.9	0.0	0.9
GW034351	291132	6228223	Irrigation	HBSS	3	0.0	0.1	1.0	1.7
GW034425	289184	6215603	Water supply	HBSS	2	0.0	0.3	4.9	5.9
GW034450	291372	6228968	Unknown	HBSS	3	0.0	0.1	0.8	1.4
GW034518	274860	6209289	Irrigation	HBSS	1	0.2	1.0	17.0	18.5
GW034615	272328	6225013	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW034636	278188	6234339	Livestock	HBSS	2	0.0	0.6	0.0	0.6
GW034687	278221	6209000	Unknown	HBSS	2	1.2	5.4	6.8	12.2
GW034702	271327	6186297	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW034941	275859	6226454	Domestic	HBSS	2	0.0	0.6	0.1	0.6
GW035033	288045	6214961	Livestock	HBSS	3	0.0	0.1	7.1	12.6
GW035431	274319	6226510	Domestic	BUSS	1	0.0	0.6	0.0	0.6
GW035753	276668	6209703	Irrigation	HBSS	2	0.9	3.5	9.2	14.2
GW035844	277150	6215294	Irrigation	HBSS	1	0.0	0.9	0.2	1.0
GW037285	268464	6190481	Irrigation	HBSS	1	0.0	1.0	0.0	1.0
GW037289	275015	6209232	Irrigation	HBSS	1	0.2	1.0	17.0	18.8
GW037294	272114	6213755	Commerc./Indust.	HBSS	3	0.1	0.4	1.9	3.1
GW037302	274014	6224252	Irrigation	HBSS	2	0.0	0.4	0.0	0.4
GW037425	273673	6225631	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW037426	273747	6225725	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW037428	273321	6227472	Irrigation	HBSS	3	0.0	0.2	0.1	0.2
GW037496	273263	6227717	Irrigation	HBSS	3	0.0	0.2	0.1	0.2
GW037742	274479	6210236	Irrigation	HBSS	2	0.5	1.7	7.4	12.5
GW037743	282609	6229602	Irrigation	HBSS	3	0.0	0.1	0.4	0.7
GW037744	282374	6228703	Irrigation	HBSS	3	0.0	0.1	0.5	0.8
GW037745	271753	6226509	Irrigation	HBSS	3	0.0	0.3	0.1	0.3

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW037746	271926	6229966	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW037747	276246	6199519	Irrigation	HBSS	2	0.4	0.5	0.4	1.2
GW037860	275178	6209914	Irrigation	HBSS	3	1.6	6.4	14.3	26.0
GW037932	272853	6211419	Irrigation	HBSS	1	0.0	0.8	0.4	1.0
GW037952	273251	6226083	Irrigation	HBSS	3	0.0	0.2	0.1	0.3
GW038040	273444	6228739	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW038060	274680	6210364	Irrigation	HBSS	1	0.1	0.8	8.4	9.5
GW038074	278216	6209215	Irrigation	HBSS	2	1.1	4.5	7.1	12.7
GW038191	271382	6219626	Irrigation	HBSS	2	0.0	0.3	0.1	0.3
GW038451	274667	6196059	Water supply	HBSS	3	0.0	0.4	0.1	0.4
GW038551	272484	6226003	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW040954	293340	6216720	Unknown	HBSS	1	0.0	0.5	3.8	4.2
GW040954	293340	6216720	Unknown	HBSS	1	0.0	0.5	3.8	4.2
GW042537	274310	6209770	Irrigation	HBSS	1	0.1	0.8	8.1	7.5
GW042644	265560	6189113	Irrigation	SBSS	7	0.0	0.4	0.0	0.4
GW042647	277115	6230830	Irrigation	HBSS	3	0.0	0.2	0.1	0.2
GW042695	271883	6230705	Irrigation	HBSS	1	0.0	0.7	0.0	0.7
GW042788	280420	6210244	Irrigation	HBSS	3	0.7	1.3	6.9	9.6
GW042825	273088	6207366	Irrigation	HBSS	2	0.4	0.8	1.9	3.4
GW042941	272266	6216996	Irrigation	HBSS	3	0.0	0.3	0.9	1.6
GW042944	276631	6229617	Irrigation	HBSS	2	0.0	0.5	0.0	0.6
GW043154	275295	6211427	Domestic	HBSS	1	0.1	0.8	6.8	8.2
GW043276	272491	6223202	Domestic	HBSS	1	0.0	0.8	0.0	0.8
GW043277	273802	6223445	Irrigation	HBSS	3	0.0	0.1	0.3	0.5
GW043278	273865	6222953	Domestic	HBSS	3	0.0	0.1	0.3	0.6
GW043690	290290	6210819	Domestic	HBSS	3	0.0	0.0	9.4	7.4
GW043728	273581	6194430	Domestic	HBSS	2	0.0	0.7	0.0	0.7
GW043863	292422	6211668	Domestic	HBSS	3	0.0	0.0	10.2	8.5
GW043876	272471	6189655	Water supply	HBSS	2	0.0	0.7	0.0	0.7
GW044208	282266	6234495	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW045404	282217	6206689	Water supply	HBSS	1	2.2	5.6	3.1	6.8
GW047037	272445	6213856	Irrigation	HBSS	2	0.0	0.4	1.2	2.0
GW047054	271710	6199841	Irrigation	HBSS	2	0.0	0.3	0.0	0.3
GW047128	282267	6229995	Irrigation	HBSS	3	0.0	0.1	0.3	0.6
GW047129	271904	6229843	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW047144	271250	6217680	Water supply	HBSS	2	0.0	0.4	0.3	0.5
GW047148	272508	6216539	Domestic	HBSS	2	0.0	0.4	0.6	1.0
GW047217	271932	6203361	Irrigation	HBSS	3	0.1	0.3	0.2	1.5
GW047330	273076	6221640	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW047416	274634	6211226	Domestic	HBSS	1	0.1	0.8	4.2	5.3
GW047444	282445	6227841	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW047446	272822	6223699	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW047576	274720	6223652	Irrigation	HBSS	2	0.0	1.1	0.1	1.1
GW047596	274332	6223828	Irrigation	HBSS	3	0.0	0.1	0.3	0.6
GW047600	272200	6223961	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW047684	274575	6225437	Irrigation	HBSS	3	0.0	0.2	0.2	0.5
GW047710	270967	6228248	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW047817	274029	6215096	Irrigation	HBSS	1	0.0	0.8	0.2	0.9
GW047903	275698	6213496	Domestic	HBSS	2	0.2	0.4	5.4	8.0
GW047933	269634	6224022	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW047998	275028	6231181	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW048301	281997	6230574	Livestock	Alluvium	1	0.0	0.3	0.0	0.3
GW049292	276242	6200752	Water supply	HBSS	1	0.1	1.2	0.1	1.2
GW049516	276335	6200076	Domestic	HBSS	1	0.0	1.1	0.0	1.1
GW049796	275127	6210961	Domestic	HBSS	1	0.1	0.9	10.7	12.2
GW050397	270482	6186369	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW050408	276435	6200140	Water supply	HBSS	1	0.1	1.1	0.1	1.2
GW050754	282127	6228265	Livestock	HBSS	3	0.0	0.1	0.6	0.9
GW051118	270145	6217777	Irrigation	HBSS	1	0.0	0.9	0.2	14.5
GW051668	270268	6217995	Domestic	HBSS	2	0.0	0.4	0.2	0.4
GW051877	281673	6205875	Livestock	HBSS	2	3.2	8.2	4.2	9.7
GW052016	280259	6203604	Livestock	HBSS	3	17.0	33.4	19.0	35.9

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW052125	281891	6227397	Water supply	HBSS	2	0.0	0.3	0.1	0.3
GW052126	285424	6223193	Water supply	HBSS	3	0.0	0.1	4.0	3.8
GW052159	284124	6228435	Domestic	HBSS	1	0.0	0.6	0.1	0.6
GW052540	276719	6200055	Domestic	HBSS	1	0.1	1.1	0.1	1.1
GW052628	276308	6200137	Domestic	HBSS	1	0.0	1.2	0.0	1.2
GW052657	281585	6228407	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW053002	281755	6228842	Irrigation	HBSS	2	0.0	0.3	0.0	0.3
GW053070	270256	6194503	Irrigation	HBSS	1	0.0	1.2	0.0	1.2
GW053288	289756	6207231	Irrigation	HBSS	2	0.0	0.5	2.7	3.0
GW053294	277445	6200719	Irrigation	HBSS	1	0.2	1.2	0.2	1.2
GW053306	276492	6199926	Irrigation	HBSS	1	0.0	1.1	0.0	1.1
GW053449	280369	6205813	Irrigation	HBSS	2	4.9	12.2	6.8	14.7
GW053450	282303	6205837	Irrigation	HBSS	2	2.6	6.4	3.4	7.5
GW053808	266539	6189785	Irrigation	HBSS	1	0.0	0.6	0.0	0.6
GW053980	282104	6217075	Irrigation	HBSS	3	0.0	0.2	7.1	6.2
GW054008	271254	6217526	Domestic	HBSS	1	0.0	0.6	0.1	0.6
GW054010	274687	6223990	Domestic	Alluvium	1	0.0	0.2	0.0	0.2
GW054146	279886	6204676	Domestic	HBSS	3	18.5	48.7	22.0	>50
GW054182	271523	6186641	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW054316	272712	6224005	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW055146	276094	6200502	Domestic	HBSS	1	0.0	1.1	0.0	1.1
GW055147	276191	6200720	Domestic	HBSS	1	0.0	1.1	0.0	1.1
GW055149	276168	6200627	Domestic	HBSS	1	0.0	1.1	0.0	1.1
GW055154	276653	6199621	Domestic	HBSS	1	0.1	1.0	0.1	1.0
GW055510	279377	6233966	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW055918	277154	6200065	Domestic	HBSS	2	0.7	1.0	0.7	2.2
GW056632	277202	6201580	Water supply	HBSS	1	0.0	1.1	0.0	1.1
GW056708	278469	6231109	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW056750	283210	6206928	Livestock	HBSS	2	1.3	3.3	1.9	4.2
GW057274	272074	6211164	Livestock	HBSS	1	0.0	1.5	1.9	3.2
GW057797	284062	6211047	Irrigation	HBSS	3	0.1	0.2	7.1	6.3
GW057806	270478	6219912	Irrigation	HBSS	2	0.0	0.3	0.1	0.3
GW057829	290335	6206504	Irrigation	HBSS	1	0.0	1.0	0.1	1.0
GW057837	282733	6227570	Livestock	HBSS	3	0.0	0.1	0.8	1.1
GW057886	277468	6228000	Irrigation	HBSS	2	0.0	0.4	0.1	0.4
GW057907	269564	6222664	Irrigation	HBSS	2	0.0	0.4	0.0	0.4
GW057969	281350	6206116	Irrigation	HBSS	3	5.9	13.3	8.0	16.1
GW058431	271428	6226162	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW058634	279479	6203419	Domestic	HBSS	2	20.2	>50	21.5	>50
GW058644	274910	6196589	Domestic	HBSS	2	0.0	0.6	0.0	0.6
GW058832	289897	6206618	Livestock	BUSS	5	0.1	0.2	16.7	16.6
GW059075	269838	6229330	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW059090	281573	6226711	Irrigation	HBSS	2	0.0	0.4	0.1	0.4
GW059106	282268	6207800	Irrigation	HBSS	2	1.4	3.6	2.2	4.6
GW059152	271506	6219783	Domestic	HBSS	1	0.0	0.7	0.1	0.7
GW059311	273294	6212643	Irrigation	HBSS	1	0.0	1.2	0.2	1.4
GW059325	281663	6229457	Livestock	HBSS	2	0.0	0.3	0.0	0.3
GW059326	281864	6228568	Commerc./Indust.	HBSS	2	0.0	0.3	0.0	0.3
GW059401	281488	6228158	Irrigation	HBSS	2	0.0	0.3	0.0	0.3
GW059446	294627	6212672	Commerc./Indust.	HBSS	2	0.0	0.0	9.1	5.9
GW059481	275024	6222765	Irrigation	HBSS	2	0.0	0.5	0.2	0.5
GW059618	281587	6204277	Domestic	HBSS	2	5.1	10.8	6.0	12.0
GW059626	281382	6229420	Irrigation	HBSS	3	0.0	0.1	0.3	0.6
GW059692	279572	6227836	Domestic	HBSS	1	0.0	0.5	0.1	0.5
GW059695	274794	6230220	Unknown	HBSS	2	0.0	0.5	0.0	0.5
GW059773	286102	6227216	Irrigation	HBSS	3	0.0	0.1	1.2	1.5
GW060205	275109	6212779	Irrigation	HBSS	1	0.0	0.8	1.2	1.9
GW060238	274508	6211159	Domestic	HBSS	1	0.1	0.8	3.7	4.7
GW060286	272476	6200970	Irrigation	HBSS	1	0.0	0.9	0.0	0.9
GW060375	271666	6224812	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW060778	280050	6224950	Livestock	HBSS	2	0.0	0.3	0.0	0.3
GW061588	266395	6189412	Domestic	HBSS	1	0.0	0.8	0.0	0.8

GW work no.	Easting	Northing	Purpose	Assumed		Modelled Maximum Drawdown (at any time); [m]			
				Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW061592	271912	6190566	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW062068	276581	6209579	Domestic	HBSS	3	2.0	8.6	17.3	27.8
GW062661	282609	6207469	Domestic	HBSS	3	2.3	5.5	3.8	7.4
GW062945	287960	6221031	Domestic	HBSS	2	0.0	0.4	10.0	9.4
GW063525	276568	6214326	Irrigation	HBSS	1	0.0	0.9	0.7	1.1
GW063557	277107	6225000	Domestic	HBSS	2	0.0	0.4	0.1	0.4
GW063732	272117	6205215	Domestic	HBSS	3	0.3	0.4	0.9	3.1
GW064073	279303	6233841	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW064080	277508	6201276	Domestic	HBSS	1	0.1	1.3	0.1	1.3
GW064081	277795	6201036	Domestic	HBSS	1	0.2	1.4	0.2	1.4
GW064083	276977	6201016	Domestic	HBSS	1	0.1	1.3	0.1	1.3
GW064084	276850	6200983	Domestic	HBSS	1	0.1	1.3	0.1	1.3
GW064284	281519	6234601	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW064330	282333	6234898	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW064420	267017	6192141	Domestic	HBSS	1	0.0	0.7	0.0	0.7
GW064469	277346	6215669	Domestic	HBSS	1	0.0	0.9	0.2	0.9
GW064813	276015	6231760	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW064814	294354	6222807	Domestic	WMFM / HBSS	1	0.0	0.5	1.3	1.6
GW064815	294355	6222776	Domestic	HBSS	2	0.0	0.4	1.3	1.6
GW064932	290387	6207615	Domestic	HBSS	1	0.0	1.4	0.7	1.5
GW064952	281750	6234576	Domestic	HBSS	3	0.0	0.1	0.1	0.3
GW065022	271310	6188023	Domestic	HBSS	1	0.0	0.0	0.0	0.0
GW065042	282074	6229436	Irrigation	HBSS	3	0.0	0.1	0.4	0.6
GW065084	271317	6227578	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW065516	271720	6217322	Irrigation	WMFM / HBSS	1	0.0	0.6	0.2	0.6
GW065725	263157	6201231	Domestic	HBSS	1	0.0	0.7	0.0	0.7
GW066043	271210	6199983	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW066786	270381	6198760	Domestic	HBSS	1	0.0	1.0	0.0	1.0
GW067380	270536	6220677	Irrigation	HBSS	2	0.0	0.4	0.1	0.4
GW067391	269494	6191369	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW067392	269494	6191368	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW067393	266139	6190514	Domestic	HBSS	1	0.0	0.6	0.0	0.6
GW067412	272300	6188657	Domestic	HBSS	2	0.0	0.7	0.0	0.7
GW067570	277070	6213716	Domestic	HBSS	2	0.2	0.4	8.7	11.3
GW067606	282421	6212095	Irrigation	HBSS	3	0.1	0.3	4.3	8.2
GW067682	276859	6216739	Commerc./Indust.	HBSS	2	0.0	0.4	1.4	1.9
GW068323	275003	6219829	Domestic	HBSS	1	0.0	0.5	0.3	0.5
GW068452	278299	6232551	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW069174	267175	6189437	Domestic	HBSS	2	0.0	0.6	0.0	0.6
GW070245	280090	6205714	Domestic	HBSS	2	5.2	13.2	7.3	15.9
GW070979	275315	6211674	Unknown	HBSS	1	0.1	0.8	5.9	7.2
GW072168	276751	6199455	Domestic	HBSS	2	0.4	0.6	0.4	1.3
GW072196	288911	6218867	Domestic	Alluvium	1	0.0	0.3	3.0	5.7
GW072197	285108	6224185	Domestic	HBSS	3	0.0	0.1	3.0	3.0
GW072226	280704	6206868	Domestic	HBSS	1	0.8	1.6	1.3	2.2
GW072229	282175	6230510	Domestic	HBSS	3	0.0	0.1	0.3	0.5
GW072249	288091	6215538	Domestic	HBSS	2	0.0	0.4	5.8	3.8
GW072296	273297	6227738	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW072309	285170	6227902	Irrigation	WMFM / HBSS	1	0.0	0.6	0.0	0.6
GW072343	276313	6228521	Domestic	HBSS	3	0.0	0.2	0.2	0.4
GW072344	285164	6223323	Domestic	HBSS	3	0.0	0.1	3.7	3.6
GW072377	277252	6228131	Domestic	HBSS	2	0.0	0.4	0.1	0.5
GW072388	269494	6191368	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW072391	272497	6202284	Domestic	HBSS	3	0.0	1.1	0.0	1.2
GW072402	277685	6216905	Domestic	HBSS	2	0.0	0.4	2.2	2.5
GW072432	273364	6212851	Domestic	HBSS	2	0.1	0.4	2.1	3.5
GW072444	274606	6229969	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW072458	269917	6189739	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW072465	278298	6232551	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW072469	278299	6232550	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW072473	273553	6223607	Domestic	HBSS	2	0.0	0.4	0.1	0.4
GW072474	279644	6233727	Domestic	HBSS	2	0.0	0.5	0.0	0.5

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW072482	281952	6206909	Domestic	HBSS	1	0.1	0.8	0.4	1.0
GW072619	272657	6216612	Domestic	HBSS	1	0.0	0.9	0.1	0.9
GW072623	276593	6199905	Domestic	HBSS	1	0.1	1.1	0.1	1.1
GW072630	274371	6225855	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW072874	288601	6217630	Domestic	HBSS	3	0.0	0.2	9.7	7.5
GW072887	276590	6200387	Domestic	HBSS	1	0.1	1.2	0.1	1.2
GW072928	282257	6229911	Domestic	HBSS	3	0.0	0.1	0.3	0.6
GW072962	272913	6192088	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW073018	279979	6206567	Domestic	HBSS	1	0.8	2.3	3.9	15.2
GW073364	282891	6228574	Irrigation	HBSS	3	0.0	0.1	0.6	0.9
GW073406	275273	6209444	Domestic	HBSS	1	0.2	1.0	16.0	17.8
GW075051	293649.2	6230672.9	Unknown	HBSS	2	0.0	#N/A	0.0	0.0
GW075056	294314.8	6229797.6	Unknown	WMFM / HBSS	1	0.0	#N/A	0.1	0.1
GW075057	292007	6230929	Unknown	WMFM / HBSS	1	0.0	#N/A	0.0	0.0
GW075409	273772	6209569	Unknown	HBSS	2	0.0	0.8	0.5	1.2
GW100047	274375	6216677	Irrigation	HBSS	2	0.0	0.4	0.8	1.4
GW100056	285251	6226420	Domestic	HBSS	3	0.0	0.1	1.5	1.8
GW100088	287015	6223396	Domestic	HBSS	3	0.0	0.1	4.3	4.5
GW100089	274885	6196683	Irrigation	BUSS	5	0.2	0.3	0.3	0.7
GW100116	269068	6197063	Domestic	HBSS	1	0.0	1.1	0.0	1.1
GW100117	277320	6232706	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW100130	270330	6186235	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW100148	267949	6190622	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW100173	265546	6201818	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW100283	279768	6218698	Irrigation	HBSS	3	0.0	0.2	3.9	3.9
GW100289	288686	6218937	Domestic	HBSS	2	0.0	0.3	6.7	6.6
GW100329	289288	6227553	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW100390	272165	6216867	Irrigation	WMFM / HBSS	1	0.0	0.6	0.2	0.6
GW100428	274087	6223959	Domestic	HBSS	3	0.0	0.1	0.3	0.5
GW100433	278540	6202588	Domestic	HBSS	3	>50	>50	>50	>50
GW100455	281877	6207020	Livestock	HBSS	2	2.0	5.1	3.0	6.3
GW100480	287377	6209419	Domestic	HBSS	3	0.0	0.1	7.5	6.8
GW100519	275345	6215766	Domestic	HBSS	1	0.0	0.6	0.1	0.7
GW100562	277747	6201653	Irrigation	HBSS	1	0.0	0.4	0.0	8.6
GW100605	287015	6223397	Domestic	HBSS	3	0.0	0.1	4.3	4.5
GW100611	272190	6217022	Domestic	HBSS	3	0.0	0.3	0.9	1.6
GW100673	286235	6216160	Livestock	HBSS	3	0.0	0.5	9.9	13.6
GW100687	282621	6229816	Irrigation	HBSS	3	0.0	0.1	0.4	0.6
GW100710	272072	6218208	Domestic	HBSS	2	0.0	0.4	0.3	0.5
GW100721	276240	6200043	Domestic	HBSS	1	0.0	1.2	0.0	1.2
GW100733	284956	6223259	Domestic	HBSS	3	0.0	0.1	3.7	3.6
GW100753	279647	6227755	Commerc./Indus	HBSS	3	0.0	0.1	0.5	0.7
GW100802	276182	6200277	Domestic	HBSS	1	0.0	1.2	0.0	1.2
GW100806	279525	6234363	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW100816	281482	6217311	Recreation/cult.	HBSS	3	0.0	0.2	6.2	5.5
GW100817	271412	6228042	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW100959	278299	6232550	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW101010	281704	6234930	Unknown	HBSS	2	0.0	0.5	0.0	0.5
GW101026	279751	6207946	Domestic	HBSS	1	0.0	0.3	0.8	16.7
GW101031	287016	6223397	Domestic	WMFM / HBSS	1	0.0	0.0	0.0	0.0
GW101066	285162	6226122	Domestic	HBSS	3	0.0	0.1	1.7	1.9
GW101133	289443	6214100	Domestic	HBSS	2	0.0	0.0	0.4	20.1
GW101174	274478	6215569	Unknown	HBSS	3	0.1	0.3	2.5	4.4
GW101175	271429	6226132	Unknown	HBSS	3	0.0	0.3	0.0	0.3
GW101247	272151	6210333	Domestic	HBSS	3	0.1	0.4	1.3	2.4
GW101314	286912	6223222	Domestic	HBSS	3	0.0	0.1	4.4	4.5
GW101414	273136	6221819	Domestic	HBSS	3	0.0	0.1	0.3	0.6
GW101430	270857	6187735	Irrigation	HBSS	2	0.0	0.4	0.0	0.4
GW101437	291642	6216361	Irrigation	HBSS	3	0.0	0.0	4.0	21.2
GW101517	278839	6232844	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW101520	273196	6193791	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW101530	282549	6228892	Domestic	HBSS	2	0.0	0.3	0.0	0.3

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW101554	277200	6200244	Unknown	HBSS	1	0.2	1.1	0.2	1.1
GW101575	270949	6188236	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW101654	274473	6219794	Irrigation	HBSS	3	0.0	0.2	0.9	1.4
GW101656	272030	6200897	Domestic	HBSS	3	0.0	0.3	0.1	0.4
GW101727	285754	6226898	Domestic	HBSS	3	0.0	0.1	1.4	1.7
GW101867	271129	6186374	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW101881	267723	6190740	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW101936	280604	6202851	Domestic	HBSS	3	18.3	32.8	19.9	34.9
GW101939	269153	6189903	Domestic	HBSS	2	0.0	0.6	0.0	0.6
GW101986	288223	6217328	Domestic	HBSS	3	0.0	0.2	9.8	7.5
GW102043	289777	6214659	Domestic	HBSS	3	0.0	0.0	2.4	9.2
GW102045	281266	6203733	Domestic	HBSS	3	11.1	23.3	12.8	25.5
GW102048	268832	6196950	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW102084	273727	6195361	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW102144	285921	6220466	Domestic	HBSS	3	0.0	0.1	7.6	6.4
GW102152	266955	6189518	Domestic	HBSS	2	0.0	0.6	0.0	0.6
GW102153	271774	6218248	Domestic	HBSS	2	0.0	0.4	0.2	0.5
GW102167	271522	6217733	Irrigation	WMFM / HBSS	1	0.0	0.6	0.1	0.6
GW102177	281535	6228375	Irrigation	HBSS	3	0.0	0.1	0.5	0.8
GW102179	280953	6203826	Irrigation	HBSS	3	13.7	27.5	15.5	29.8
GW102231	272116	6217744	Domestic	WMFM / HBSS	1	0.0	0.7	0.1	0.7
GW102258	272616	6192094	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW102292	274895	6231290	Livestock	HBSS	3	0.0	0.2	0.1	0.2
GW102295	275512	6217351	Domestic	WMFM / HBSS	1	0.0	0.6	0.7	1.2
GW102337	272135	6216068	Domestic	HBSS	3	0.0	0.3	1.1	1.9
GW102338	271504	6216731	Unknown	HBSS	1	0.0	0.6	0.2	0.6
GW102344	280248	6206553	Irrigation	HBSS	1	1.3	3.1	2.7	8.0
GW102355	274565	6196026	Unknown	HBSS	3	0.0	0.4	0.0	0.4
GW102369	271745	6217369	Irrigation	HBSS	3	0.0	0.3	0.7	1.3
GW102390	274006	6212845	Domestic	HBSS	2	0.1	0.4	3.2	5.2
GW102405	280631	6225302	Domestic	HBSS	3	0.0	0.1	1.2	1.4
GW102412	280833	6225461	Domestic	HBSS	3	0.0	0.1	1.2	1.4
GW102418	278015	6201504	Domestic	HBSS	1	0.0	0.9	0.0	0.9
GW102439	274477	6210080	Domestic	HBSS	2	0.5	1.9	7.8	13.1
GW102440	277778	6220149	Domestic	HBSS	3	0.0	0.1	1.9	2.2
GW102452	277234	6200992	Livestock	HBSS	3	2.4	3.2	2.5	8.1
GW102465	278687	6228370	Domestic	HBSS	2	0.0	0.4	0.1	0.4
GW102468	274822	6198098	Commerc./Indust.	HBSS	3	0.2	0.3	0.2	0.7
GW102478	276810	6200083	Domestic	HBSS	2	0.6	0.9	0.7	2.0
GW102498	271545	6217132	Domestic	WMFM / HBSS	1	0.0	0.6	0.2	0.6
GW102507	284396	6221961	Commerc./Indust.	HBSS	3	0.0	0.1	4.8	4.4
GW102528	289222	6204784	Domestic	HBSS	3	0.0	0.2	1.9	2.2
GW102549	281301	6222975	Irrigation	HBSS	3	0.0	0.1	2.5	2.6
GW102581	280514	6223727	Irrigation	HBSS	2	0.0	0.3	0.2	0.3
GW102584	289626	6216445	Domestic	HBSS	3	0.0	0.3	8.0	7.0
GW102585	271283	6218421	Domestic	HBSS	2	0.0	0.3	0.2	0.4
GW102609	270478	6221144	Irrigation	HBSS	3	0.0	0.2	0.1	0.3
GW102619	287887	6220525	Irrigation	HBSS	3	0.0	0.1	8.2	8.4
GW102630	273332	6211914	Domestic	HBSS	1	0.0	0.8	0.6	1.3
GW102696	271589	6216363	Domestic	HBSS	1	0.0	0.6	0.2	0.7
GW102704	277409	6200619	Irrigation	HBSS	1	0.2	1.1	0.3	1.1
GW102706	271245	6213073	Commerc./Indust.	HBSS	3	0.1	0.4	1.2	1.9
GW102721	271242	6187682	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW102722	271438	6188026	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW102738	270618	6187050	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW102765	271550	6216948	Irrigation	HBSS	1	0.0	0.6	0.2	0.6
GW102770	276132	6231177	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW102794	276601	6200303	Domestic	HBSS	1	0.1	1.2	0.1	1.2
GW102796	276633	6200167	Domestic	HBSS	1	0.1	1.1	0.1	1.1
GW102798	289990	6214783	Irrigation	HBSS	2	0.0	0.1	0.8	23.4
GW102891	282081	6228890	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW102910	269341	6228796	Domestic	HBSS	3	0.0	0.3	0.0	0.3

GW work no.	Easting	Northing	Purpose	Assumed		Modelled Maximum Drawdown (at any time); [m]			
				Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW102912	271019	6219771	Irrigation	HBSS	3	0.0	0.2	0.2	0.5
GW102927	271838	6226906	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW102928	271566	6200461	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW102951	275244	6224562	Domestic	HBSS	3	0.0	0.2	0.4	0.6
GW103010	276077	6216106	Irrigation	HBSS	3	0.1	0.3	2.9	4.7
GW103011	267052	6189173	Domestic	HBSS	3	0.0	0.5	0.0	0.5
GW103023	277261	6200993	Livestock	HBSS	3	2.4	3.2	2.5	8.1
GW103036	276840	6200964	Domestic	HBSS	3	2.0	2.6	2.2	7.0
GW103037	271495	6227690	Irrigation	HBSS	3	0.0	0.3	0.0	0.3
GW103095	279684	6220398	Irrigation	HBSS	3	0.0	0.1	3.0	3.1
GW103125	271607	6189629	Irrigation	HBSS	3	0.0	0.4	0.0	0.4
GW103140	283731	6224662	Domestic	HBSS	3	0.0	0.1	2.2	2.4
GW103202	266246	6190132	Domestic	HBSS	3	0.0	0.7	0.0	0.7
GW103235	281482	6208754	Domestic	HBSS	3	1.6	3.6	4.0	8.6
GW103320	283769	6210457	Domestic	HBSS	3	0.1	0.2	6.5	6.4
GW103341	272667	6227246	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW103457	276438	6200258	Domestic	HBSS	1	0.1	1.2	0.1	1.2
GW103479	272278	6200069	Domestic	BUSS	5	0.5	0.5	0.8	3.1
GW103532	275198	6219185	Domestic	HBSS	3	0.0	0.2	1.1	1.7
GW103535	272520	6201995	Domestic	HBSS	3	0.1	0.3	0.1	0.9
GW103536	284144	6220887	Domestic	HBSS	3	0.0	0.1	6.1	5.3
GW103559	276499	6201858	Irrigation	HBSS	1	0.0	1.3	0.0	1.3
GW103611	273880	6216628	Irrigation	HBSS	3	0.0	0.2	1.5	2.6
GW103614	271252	6228244	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW103615	279720	6204034	Domestic	HBSS	3	28.4	>50	31.3	>50
GW103625	272697	6216892	Domestic	HBSS	2	0.0	0.4	0.5	0.9
GW103704	271634	6200721	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW103783	272300	6188657	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW103989	271345	6200643	Domestic	HBSS	2	0.0	0.2	0.0	0.2
GW104008	280368	6205982	Domestic	HBSS	2	4.7	11.6	6.4	13.8
GW104024	271665	6215201	Domestic	HBSS	2	0.0	0.4	0.7	1.2
GW104025	286999	6222389	Commerc./Indust.	HBSS	3	0.0	0.1	5.5	5.5
GW104068	289519	6214530	Domestic	HBSS	3	0.0	0.1	2.6	8.5
GW104077	275333	6211928	Domestic	HBSS	1	0.0	0.8	4.1	5.2
GW104090	278208	6215913	Recreation/cult.	HBSS	3	0.2	0.6	6.0	7.6
GW104092	280223	6225062	Domestic	HBSS	3	0.0	0.1	1.2	1.4
GW104121	276840	6233538	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW104146	271549	6218470	Domestic	HBSS	2	0.0	0.4	0.2	0.4
GW104154	291233	6216088	Domestic	HBSS	3	0.0	0.0	3.9	21.5
GW104155	269218	6228436	Irrigation	HBSS	3	0.0	0.3	0.0	0.3
GW104159	285845	6222764	Domestic	HBSS	3	0.0	0.1	4.6	4.3
GW104183	274448	6198075	Commerc./Indust.	HBSS	3	0.1	0.2	0.2	0.6
GW104194	281646	6226802	Domestic	HBSS	2	0.0	0.4	0.1	0.4
GW104202	271720	6201698	Domestic	HBSS	3	0.0	0.3	0.1	0.5
GW104211	273505	6231339	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW104223	284889	6223027	Domestic	HBSS	3	0.0	0.1	3.9	3.7
GW104224	283963	6222859	Domestic	HBSS	3	0.0	0.1	3.7	3.5
GW104323	279259	6203318	Domestic	HBSS	3	45.4	>50	47.7	>50
GW104326	276542	6200749	Domestic	HBSS	1	0.1	1.3	0.1	1.3
GW104347	284012	6217884	Domestic	HBSS	3	0.0	0.1	9.4	7.5
GW104370	285503	6226299	Domestic	HBSS	3	0.0	0.1	1.7	1.9
GW104383	283414	6223610	Domestic	HBSS	3	0.0	0.1	2.8	2.8
GW104385	286784	6233581	Domestic	HBSS	2	0.0	0.6	0.0	0.6
GW104402	273579	6228066	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW104412	271648	6200536	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW104446	273751	6229005	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW104454	281410	6204568	Domestic	HBSS	2	4.9	10.8	5.9	12.2
GW104461	270011	6218143	Domestic	HBSS	3	0.0	0.3	0.3	0.5
GW104466	277332	6217528	Domestic	HBSS	3	0.1	0.2	2.6	3.4
GW104499	289920	6206816	Domestic	HBSS	2	0.0	0.5	2.2	2.4
GW104513	272694	6231110	Domestic	HBSS	3	0.0	0.2	0.0	0.2
GW104515	275487	6222733	Domestic	HBSS	3	0.0	0.1	0.6	0.9

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW104531	277188	6200159	Domestic	HBSS	2	0.7	1.1	0.8	2.3
GW104546	283573	6212241	Domestic	HBSS	3	0.1	0.2	4.9	6.0
GW104547	274936	6221982	Domestic	HBSS	3	0.0	0.2	0.6	0.9
GW104558	282447	6211841	Domestic	HBSS	3	0.1	0.3	4.4	9.5
GW104560	281795	6227548	Domestic	HBSS	3	0.0	0.1	0.7	1.0
GW104565	271943	6203049	Domestic	HBSS	3	0.1	0.3	0.2	1.3
GW104577	275482	6215322	Domestic	HBSS	2	0.1	0.4	2.0	3.2
GW104590	274714	6215475	Irrigation	HBSS	1	0.0	0.9	0.2	0.9
GW104593	277373	6219823	Domestic	WMFM / HBSS	1	0.0	0.6	0.3	0.6
GW104602	289054	6216338	Livestock	HBSS	3	0.0	1.5	8.6	6.5
GW104603	271842	6190262	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW104612	274193	6224293	Domestic	HBSS	3	0.0	0.1	0.3	0.5
GW104616	272327	6201844	Domestic	HBSS	3	0.1	0.3	0.1	0.8
GW104620	284099	6227949	Domestic	HBSS	3	0.0	0.1	0.8	1.1
GW104628	271746	6200210	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW104630	269351	6190968	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW104633	295351	6215109	Domestic	HBSS	1	0.0	0.5	7.0	16.4
GW104649	265663	6190029	Domestic	SBSS	7	0.0	0.3	0.0	0.3
GW104659	276617	6207391	Irrigation	HBSS	3	19.8	>50	49.7	>50
GW104661	289118	6216661	Domestic	HBSS	3	0.0	0.8	8.8	6.6
GW104689	276279	6201756	Domestic	HBSS	2	0.7	0.9	0.8	2.9
GW104690	275761	6214988	Irrigation	HBSS	2	0.1	0.4	2.8	4.3
GW104700	272262	6218000	Domestic	HBSS	2	0.0	0.4	0.3	0.5
GW104720	274451	6211918	Domestic	HBSS	2	0.2	0.7	4.8	7.9
GW104722	282777	6234686	Domestic	HBSS	3	0.0	0.1	0.1	0.3
GW104756	269737	6222831	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW104760	274627	6230551	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW104763	276430	6229649	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW104766	287663	6220995	Domestic	HBSS	3	0.0	0.1	8.0	9.2
GW104793	268021	6191728	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW104860	282745	6206178	Commerc./Indust.	HBSS	3	3.4	8.2	4.8	10.0
GW104959	281388	6222659	Domestic	HBSS	3	0.0	0.1	2.6	2.7
GW104965	281462	6222697	Domestic	HBSS	3	0.0	0.1	2.7	2.7
GW104967	280717	6222856	Domestic	HBSS	3	0.0	0.1	2.3	2.4
GW104978	271198	6190788	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW104986	272662	6227723	Irrigation	HBSS	3	0.0	0.2	0.1	0.2
GW105042	277491	6218561	Domestic	HBSS	2	0.0	0.4	0.4	0.6
GW105043	280730	6234965	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW105053	272897	6218371	Irrigation	HBSS	3	0.0	0.2	0.8	1.5
GW105145	275872	6210499	Domestic	HBSS	2	0.6	2.1	10.1	15.7
GW105148	278006	6209733	Domestic	HBSS	3	1.6	5.2	13.9	38.5
GW105196	271703	6215976	Domestic	HBSS	2	0.0	0.4	0.5	0.9
GW105197	271857	6217075	Domestic	HBSS	2	0.0	0.4	0.4	0.6
GW105203	277180	6230661	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW105205	283689	6230724	Domestic	HBSS	3	0.0	0.1	0.3	0.6
GW105207	285148	6223080	Domestic	HBSS	3	0.0	0.1	4.0	3.8
GW105228	278451	6216837	Domestic	HBSS	2	0.0	0.4	2.7	3.1
GW105236	275487	6211099	Domestic	HBSS	1	0.1	0.9	11.5	13.4
GW105243	280629	6225123	Domestic	HBSS	3	0.0	0.1	1.2	1.5
GW105244	280805	6224206	Domestic	HBSS	3	0.0	0.1	1.6	1.8
GW105246	274934	6211237	Domestic	HBSS	3	0.8	2.5	11.1	20.4
GW105251	284660	6229667	Domestic	HBSS	3	0.0	0.1	0.5	0.8
GW105254	278246	6211856	Domestic	HBSS	3	0.7	2.5	12.4	36.6
GW105260	272932	6223837	Domestic	HBSS	3	0.0	0.2	0.2	0.4
GW105262	278609	6200731	Domestic	HBSS	3	3.5	6.0	3.7	10.0
GW105271	279104	6233701	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW105296	270731	6221290	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW105301	270172	6201071	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW105306	272139	6220699	Domestic	HBSS	1	0.0	0.7	0.0	0.7
GW105309	269368	6229896	Irrigation	BUSS	5	0.0	0.1	0.0	0.1
GW105325	287685	6221474	Recreation/cult.	HBSS	3	0.0	0.1	7.8	9.1
GW105336	279817	6216879	Recreation/cult.	HBSS	3	0.1	0.2	4.7	4.7

GW work no.	Easting	Northing	Purpose	Assumed		Modelled Maximum Drawdown (at any time); [m]			
				Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW105339	291919	6218356	Domestic	HBSS	3	0.0	1.7	8.0	19.9
GW105356	277217	6200741	Domestic	HBSS	2	0.9	1.4	1.0	3.1
GW105376	289443	6218380	Domestic	HBSS	3	0.0	0.2	9.6	7.6
GW105388	289888	6217892	Domestic	HBSS	3	0.0	0.2	9.3	7.2
GW105395	278543	6203037	Domestic	HBSS	2	31.9	>50	33.1	>50
GW105467	277279	6215251	Domestic	HBSS	2	0.1	0.4	4.0	5.5
GW105483	284916	6231684	Domestic	HBSS	3	0.0	0.1	0.3	0.6
GW105484	272509	6191356	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW105506	275834	6221753	Domestic	HBSS	3	0.0	0.2	0.8	1.1
GW105531	287664	6218430	Domestic	HBSS	3	0.0	0.2	9.9	7.8
GW105534	288655	6217297	Domestic	HBSS	3	0.0	0.2	9.5	7.3
GW105536	277011	6216893	Domestic	HBSS	2	0.0	0.4	1.7	2.1
GW105546	276997	6215723	Irrigation	HBSS	3	0.2	0.4	5.1	8.2
GW105562	272154	6217892	Domestic	HBSS	3	0.0	0.3	0.7	1.3
GW105563	272836	6215463	Domestic	HBSS	2	0.0	0.4	0.9	1.5
GW105574	289656	6218908	Domestic	HBSS	3	0.0	0.2	9.7	7.9
GW105577	280728	6207041	Irrigation	HBSS	3	5.3	10.1	11.3	23.3
GW105679	274382	6215472	Domestic	HBSS	2	0.0	0.4	1.4	2.2
GW105704	272682	6191424	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW105705	271172	6191283	Unknown	HBSS	1	0.0	1.0	0.0	1.0
GW105710	278010	6225931	Livestock	HBSS	2	0.0	0.3	0.1	0.4
GW105735	276814	6199660	Domestic	HBSS	3	1.3	1.8	1.4	4.0
GW105737	283351	6227384	Domestic	HBSS	3	0.0	0.1	0.9	1.2
GW105751	281818	6227257	Domestic	HBSS	2	0.0	0.3	0.1	0.3
GW105785	283181	6227139	Domestic	HBSS	3	0.0	0.1	1.0	1.3
GW105787	282092	6209593	Domestic	HBSS	3	0.3	0.9	2.8	4.4
GW105789	285485	6231633	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW105802	280547	6207174	Domestic	HBSS	1	0.7	1.4	1.3	2.3
GW105803	282278	6204644	Domestic	HBSS	3	5.2	12.4	6.5	14.1
GW105813	279408	6213106	Domestic	HBSS	3	0.4	2.8	5.4	9.7
GW105821	275351	6213650	Domestic	HBSS	3	0.3	0.7	7.7	12.7
GW105827	276889	6200247	Irrigation	HBSS	1	0.1	1.1	0.1	1.1
GW105847	277020	6204404	Unknown	HBSS	1	14.8	>50	15.2	>50
GW105860	282520	6208359	Unknown	HBSS	1	0.1	0.9	0.2	1.0
GW105863	274208	6214937	Unknown	HBSS	1	0.0	0.9	0.2	0.9
GW105869	269245	6189636	Unknown	WMFM / HBSS	1	0.0	0.5	0.0	0.5
GW105876	271871	6214700	Unknown	HBSS	1	0.0	0.8	0.4	0.9
GW105883	277040	6204629	Unknown	HBSS	1	12.9	38.9	13.3	40.2
GW105884	281588	6210112	Unknown	HBSS	1	0.0	1.3	0.7	1.6
GW105927	272574	6224638	Unknown	HBSS	1	0.0	0.7	0.0	0.7
GW105933	277845	6225998	Unknown	WMFM / HBSS	1	0.0	0.4	0.0	4.0
GW105944	282182	6209287	Unknown	HBSS	1	0.0	0.3	0.4	0.4
GW105958	269552	6189600	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW106008	272038	6188416	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW106147	271672	6229163	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW106157	274034	6221680	Domestic	HBSS	3	0.0	0.2	0.5	0.8
GW106174	286816	6233726	Domestic	HBSS	3	0.0	0.1	0.3	0.6
GW106205	282759	6230599	Domestic	HBSS	3	0.0	0.1	0.3	0.5
GW106250	286336	6209811	Domestic	HBSS	3	0.0	0.1	8.8	7.7
GW106290	271617	6222779	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW106292	276654	6200100	Domestic	HBSS	1	0.1	1.1	0.1	1.1
GW106334	271054	6224453	Domestic	HBSS	3	0.0	0.3	0.1	0.3
GW106406	275580	6216195	Domestic	HBSS	3	0.1	0.3	2.6	4.2
GW106412	280922	6217038	Domestic	HBSS	2	0.0	0.9	0.9	1.1
GW106446	288570	6228846	Domestic	HBSS	3	0.0	0.1	0.8	1.2
GW106490	281131	6225637	Irrigation	HBSS	3	0.0	0.1	1.1	1.4
GW106546	282785	6206765	Domestic	HBSS	3	2.8	6.8	4.2	8.7
GW106566	276213	6200551	Domestic	HBSS	2	0.6	0.8	0.6	2.0
GW106574	290123	6218350	Domestic	HBSS	3	0.0	0.3	9.5	7.5
GW106590	280442	6206344	Domestic	HBSS	3	8.6	17.8	12.9	30.1
GW106593	276442	6234253	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW106606	276860	6226795	Domestic	HBSS	2	0.0	0.5	0.1	0.5

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW106612	273834	6215981	Irrigation	HBSS	2	0.0	0.5	0.9	1.5
GW106613	276660	6201037	Irrigation	HBSS	3	1.9	2.4	2.1	6.8
GW106620	282046	6229023	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW106648	274728	6228099	Domestic	HBSS	1	0.0	0.7	0.0	0.7
GW106663	270369	6200065	Domestic	BUSS	5	0.2	0.2	0.4	1.2
GW106669	278629	6227609	Domestic	HBSS	3	0.0	0.2	0.4	0.6
GW106673	275940	6216040	Domestic	HBSS	3	0.1	0.3	2.9	4.8
GW106675	288797	6218642	Domestic	HBSS	3	0.0	0.3	9.7	7.7
GW106690	270342	6218375	Domestic	HBSS	2	0.0	0.3	0.2	0.4
GW106702	278569	6227335	Domestic	HBSS	3	0.0	0.2	0.4	0.7
GW106901	276780	6231030	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW106979	276811	6230433	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW106997	271508	6200375	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW107011	277410	6200688	Domestic	HBSS	1	0.2	1.1	0.3	1.1
GW107116	294895	6211394	Unknown	WMFM / HBSS	1	0.0	0.0	9.5	7.8
GW107117	295107	6211331	Unknown	WMFM / HBSS	1	0.0	0.0	17.5	19.8
GW107140	283491	6224497	Domestic	HBSS	3	0.0	0.1	2.3	2.4
GW107200	272934	6190150	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW107363	267786	6190585	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW107421	286003	6222692	Domestic	HBSS	3	0.0	0.1	4.8	4.4
GW107457	272895	6224377	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW107470	282069	6208057	Domestic	HBSS	3	2.1	4.9	4.0	7.3
GW107517	274004	6223869	Domestic	HBSS	3	0.0	0.1	0.3	0.5
GW107525	274856	6211080	Domestic	HBSS	3	0.9	2.7	11.0	20.7
GW107570	272219	6231143	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW107608	282854	6226596	Domestic	HBSS	3	0.0	0.1	1.1	1.4
GW107616	273360	6226061	Domestic	HBSS	2	0.0	0.5	0.0	0.6
GW107687	272584	6215864	Domestic	HBSS	2	0.0	0.5	0.8	1.3
GW107692	283455	6208096	Unknown	HBSS	1	0.1	0.8	0.2	0.9
GW107696	281158	6234413	Domestic	HBSS	3	0.0	0.1	0.1	0.3
GW107718	284938	6223729	Domestic	HBSS	3	0.0	0.1	3.3	3.2
GW107721	286368	6222728	Domestic	HBSS	3	0.0	0.1	4.8	4.4
GW107781	267492	6188859	Commerc./Indust.	BUSS	5	0.0	0.2	0.0	0.2
GW107786	271920	6215301	Domestic	HBSS	2	0.0	0.4	0.7	1.2
GW107791	289415	6220392	Domestic	HBSS	3	0.0	0.1	8.8	10.6
GW107811	272794	6190923	Irrigation	HBSS	2	0.0	0.5	0.0	0.5
GW107818	287244	6225291	Recreation/cult.	HBSS	3	0.0	0.1	2.5	2.9
GW107853	277467	6233084	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW107886	281276	6207377	Domestic	HBSS	1	0.1	0.7	0.4	1.0
GW107915	269530	6194354	Domestic	HBSS	3	0.0	0.2	0.0	0.2
GW107918	279629	6211559	Domestic	HBSS	1	0.1	0.9	0.5	1.8
GW107925	276613	6199968	Domestic	HBSS	1	0.1	1.1	0.1	1.1
GW107988	276795	6229253	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW107995	274017	6220167	Irrigation	HBSS	3	0.0	0.2	0.7	1.1
GW108022	278460	6228280	Domestic	HBSS	3	0.0	0.2	0.3	0.5
GW108055	284640	6225734	Irrigation	HBSS	3	0.0	0.1	1.8	2.0
GW108155	279212	6217250	Domestic	HBSS	3	0.1	0.2	4.2	4.2
GW108186	274296	6197951	Commerc./Indust.	BUSS	5	0.5	0.5	0.6	1.5
GW108192	272015	6200536	Domestic	BUSS	5	0.5	0.5	0.9	3.6
GW108208	286175	6227656	Domestic	HBSS	3	0.0	0.1	1.1	1.4
GW108242	263166	6201260	Domestic	BUSS	5	0.0	0.2	0.0	0.2
GW108276	271905	6224809	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW108312	291534	6217750	Commerc./Indust.	HBSS	3	0.0	0.6	7.5	16.6
GW108318	272930	6190480	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW108389	268657	6187413	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW108414	267201	6189096	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW108451	271400	6185153	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW108524	273663	6193472	Domestic	HBSS	3	0.0	0.4	0.0	0.4
GW108538	281155	6205941	Domestic	HBSS	1	3.7	9.2	5.0	10.8
GW108542	267804	6187586	Domestic	BUSS	5	0.0	0.1	0.0	0.1
GW108606	275988	6217019	Domestic	HBSS	2	0.0	0.4	0.8	1.5
GW108615	273015	6222473	Domestic	HBSS	3	0.0	0.1	0.3	0.5

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW108621	265957	6191841	Domestic	HBSS	3	0.0	0.6	0.0	0.6
GW108624	288024	6226703	Domestic	HBSS	3	0.0	0.1	1.6	2.1
GW108629	274456	6215006	Domestic	HBSS	2	0.1	0.4	1.7	2.7
GW108667	276603	6229529	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW108765	267838	6190765	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW108786	269560	6225662	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW108826	271577	6187194	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW108842	282500	6204716	Irrigation	HBSS	3	4.4	10.7	5.6	12.4
GW108863	293738	6222478	Commerc./Indust.	HBSS	2	0.0	0.4	1.3	1.6
GW108907	288602	6218547	Domestic	HBSS	3	0.0	0.3	9.7	7.7
GW108908	275336	6233491	Domestic	HBSS	3	0.0	0.2	0.0	0.2
GW108930	272663	6191760	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW108981	276641	6210801	Recreation/cult.	HBSS	3	1.1	4.4	17.0	36.3
GW108990	290347	6219588	Domestic	HBSS	3	0.0	0.4	9.8	13.3
GW109010	278173	6211781	Domestic	HBSS	3	0.8	2.7	13.0	46.7
GW109012	270596	6218276	Domestic	HBSS	2	0.0	0.4	0.2	0.4
GW109032	271824	6206636	Domestic	HBSS	1	0.2	0.7	0.8	1.0
GW109153	272074	6207558	Domestic	HBSS	2	0.3	0.5	1.1	1.7
GW109159	280600	6211398	Domestic	HBSS	3	0.4	0.8	4.8	7.7
GW109163	273877	6224731	Irrigation	HBSS	3	0.0	0.1	0.2	0.4
GW109203	274797	6212250	Domestic	HBSS	2	0.2	0.7	5.1	8.2
GW109224	279140	6211222	Domestic	HBSS	3	0.9	2.1	10.4	28.7
GW109257	276603	6205052	Domestic	HBSS	2	13.2	34.3	13.6	35.8
GW109560	280724	6224373	Domestic	HBSS	3	0.0	0.1	1.5	1.8
GW109630	276049	6210284	Irrigation	HBSS	2	0.6	2.5	10.1	15.8
GW109950	276471	6200106	Domestic	HBSS	1	0.1	1.1	0.1	1.2
GW110185	274345	6221032	Domestic	HBSS	3	0.0	0.2	0.6	1.0
GW110215	276066	6200472	Domestic	HBSS	1	0.0	1.2	0.0	1.2
GW110300	274632	6223345	Domestic	HBSS	3	0.0	0.1	0.4	0.7
GW110413	291837	6224389	Commerc./Indust.	HBSS	3	0.0	0.1	5.3	7.6
GW110491	288745	6229609	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW110523	274807	6212696	Domestic	HBSS	2	0.2	0.5	4.8	7.6
GW110550	283788	6218949	Domestic	HBSS	3	0.0	0.1	8.4	6.8
GW110562	274626	6226744	Domestic	HBSS	3	0.0	0.2	0.2	0.4
GW110586	288755	6226962	Irrigation	HBSS	2	0.0	0.3	0.0	0.3
GW110587	288219	6227523	Irrigation	HBSS	2	0.0	0.3	0.0	0.3
GW110613	281442	6215610	Domestic	HBSS	3	0.1	0.2	6.5	6.1
GW110669	274565	6207896	Domestic	HBSS	3	2.5	11.4	11.1	28.0
GW110671	288717	6216340	Domestic	HBSS	3	0.0	1.9	8.8	6.7
GW110708	284529	6227139	Domestic	HBSS	3	0.0	0.1	1.1	1.4
GW110892	282016	6228533	Unknown	HBSS	3	0.0	0.1	0.5	0.8
GW111047	280015	6206037	Domestic	HBSS	2	4.7	12.1	7.1	16.5
GW111145	271680	6216094	Domestic	HBSS	2	0.0	0.4	0.5	0.8
GW111147	277239	6227365	Domestic	HBSS	2	0.0	0.4	0.1	0.4
GW111148	277301	6227675	Domestic	HBSS	2	0.0	0.4	0.1	0.4
GW111177	278366	6231309	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW111192	276453	6234069	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW111298	271807	6227226	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW111306	276543	6199634	Domestic	HBSS	2	0.4	0.6	0.5	1.4
GW111357	277051	6200982	Recreation/cult.	HBSS	3	2.2	2.8	2.4	7.6
GW111367	280753	6222174	Domestic	HBSS	3	0.0	0.1	2.7	2.7
GW111415	273997	6196517	Irrigation	BGSS	5	0.1	0.2	0.2	0.5
GW111416	274773	6196497	Irrigation	BGSS	6	0.3	0.3	0.5	1.0
GW111431	276323	6233547	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW111494	274833	6196626	Domestic	HBSS	3	0.1	0.3	0.1	0.3
GW111501	269262	6192667	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW111518	276882	6200987	Domestic	HBSS	3	2.0	2.6	2.2	7.0
GW111519	276454	6200571	Domestic	HBSS	1	0.1	1.2	0.1	1.3
GW111520	276383	6200356	Domestic	HBSS	1	0.0	1.2	0.1	1.2
GW111521	276485	6200525	Domestic	HBSS	1	0.1	1.2	0.1	1.3
GW111550	282778	6234380	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW111645	269103	6223466	Unknown	HBSS	3	0.0	0.2	0.0	0.2

				Assumed		Modelled Maximum Drawdown (at any time); [m]			
GW work no.	Easting	Northing	Purpose	Aquifer unit	Model layer	Tahmoor South drawdown estimate	Max effect, uncertainty Tahmoor South	Cumulative mining effect	Max effect, uncertainty Cumulative mining
GW111645	269103	6223466	Unknown	HBSS	3	0.0	0.2	0.0	0.2
GW111669	276232	6206450	Domestic	HBSS	3	14.3	>50	25.1	>50
GW111723	273205	6226635	Domestic	HBSS	3	0.0	0.2	0.1	0.3
GW111725	282794	6230419	Domestic	HBSS	3	0.0	0.1	0.3	0.6
GW111727	287506	6221188	Domestic	HBSS	3	0.0	0.1	7.7	9.0
GW111771	279177	6217642	Recreation/cult.	HBSS	3	0.1	0.2	3.9	4.0
GW111781	285334	6217542	Domestic	HBSS	3	0.0	0.1	10.6	8.2
GW111810	277034	6204407	Domestic	HBSS	3	>50	>50	>50	>50
GW111828	282391	6205638	Irrigation	HBSS	3	4.5	10.6	5.9	12.6
GW111841	275884	6214479	Irrigation	HBSS	2	0.1	0.4	3.7	5.5
GW111842	282654	6205664	Irrigation	BGSS	5	10.8	10.7	16.7	24.8
GW111889	275849	6231736	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW111909	277561	6233413	Domestic	HBSS	3	0.0	0.2	0.1	0.2
GW111912	267630	6191279	Domestic	HBSS	2	0.0	0.4	0.0	0.4
GW111985	270814	6199030	Domestic	HBSS	3	0.0	0.3	0.0	0.3
GW112341	277176	6228917	Domestic	HBSS	3	0.0	0.2	0.2	0.4
GW112347	278415	6232853	Domestic	HBSS	2	0.0	0.5	0.0	0.5
GW112381	288743	6218191	Domestic	HBSS	3	0.0	0.2	9.7	7.6
GW112394	281817	6227813	Domestic	HBSS	3	0.0	0.1	0.7	0.9
GW112415	277479	6200865	Domestic	HBSS	3	2.5	3.6	2.7	8.3
GW112426	277975	6227963	Domestic	HBSS	1	0.0	0.4	0.0	0.4
GW112436	279570	6219333	Domestic	HBSS	3	0.0	0.1	3.4	3.5
GW112437	288659	6215538	Domestic	HBSS	3	0.0	0.1	7.8	9.9
GW112441	289940	6217284	Domestic	BGSS	5	0.0	0.5	>50	>50
GW112473	276577	6202010	Irrigation	HBSS	3	2.4	2.7	2.7	9.7
GW112476	291161	6225992	Commerc./Indust.	lwr Permian	13	0.0	0.0	27.7	27.5
GW112477	291760	6225067	Commerc./Indust.	lwr Permian	15	0.0	0.0	42.7	42.5
GW112481	288663	6219694	Commerc./Indust.	lwr Permian	13	0.0	0.8	>50	>50
GW112482	291805	6228129	Commerc./Indust.	lwr Permian	15	0.0	0.0	8.6	8.5
GW112486	273306	6223231	Livestock	HBSS	3	0.0	0.1	0.2	0.5
GW113437	279128	6219303	Domestic	HBSS	3	0.0	0.1	3.1	3.2
GW114441	271649	6213061	Domestic	HBSS	3	0.1	0.4	1.6	2.5
GW114443	268628	6198074	Domestic	HBSS	2	0.0	0.3	0.0	0.3
GW114590	272469	6189832	Domestic	HBSS	3	0.0	0.3	0.0	0.3

Risk of impaired bore yield indicated as:

metres drawdown: 2 to 5
5 to 10
>10

FIGURES TO ACCOMPANY REPORT

TAHMOOR SOUTH AMENDED PROJECT (APR): GROUNDWATER ASSESSMENT

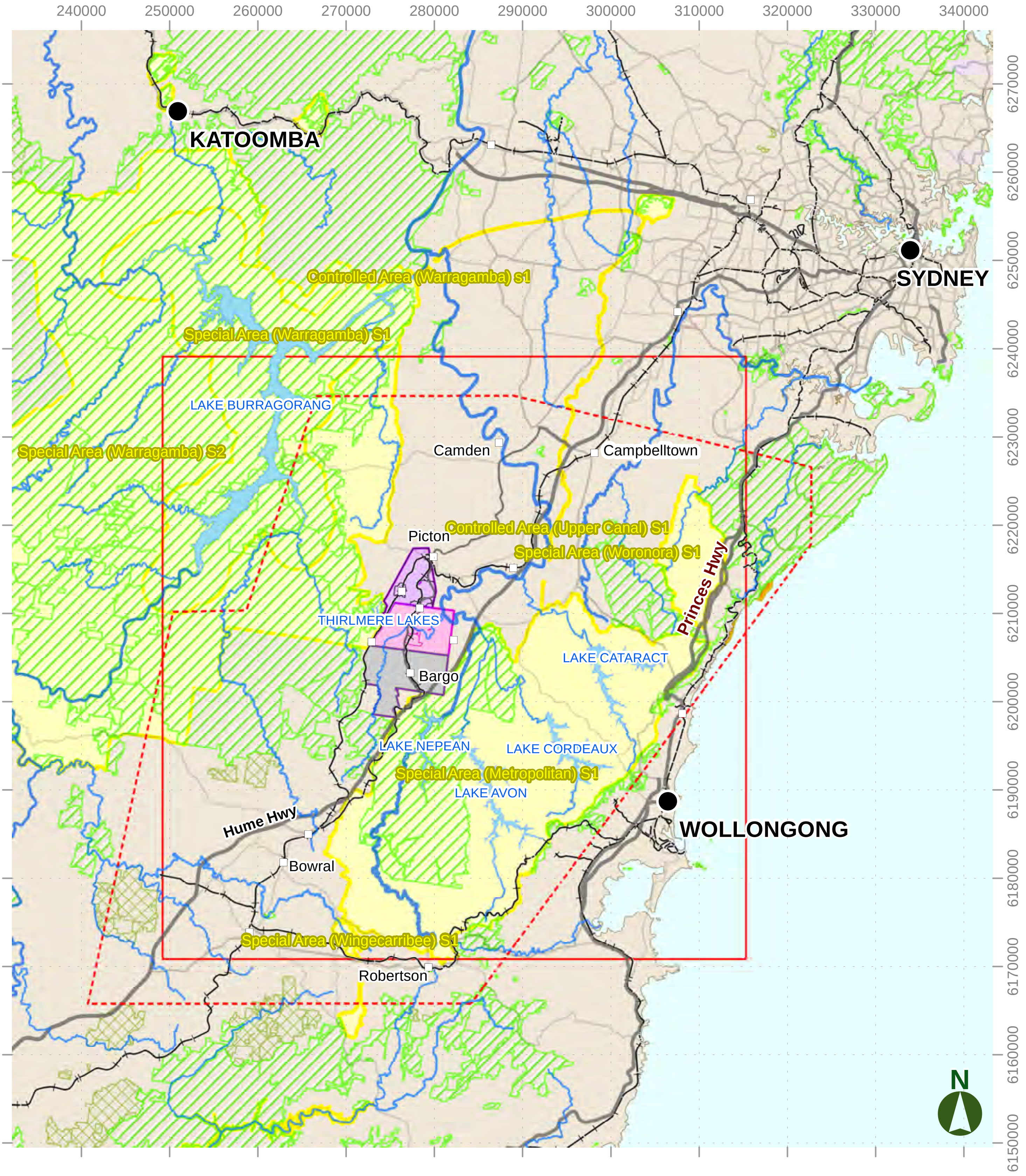
FOR

TAHMOOR COAL PTY LTD

Report: HS2019-042

Date: February 2020

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

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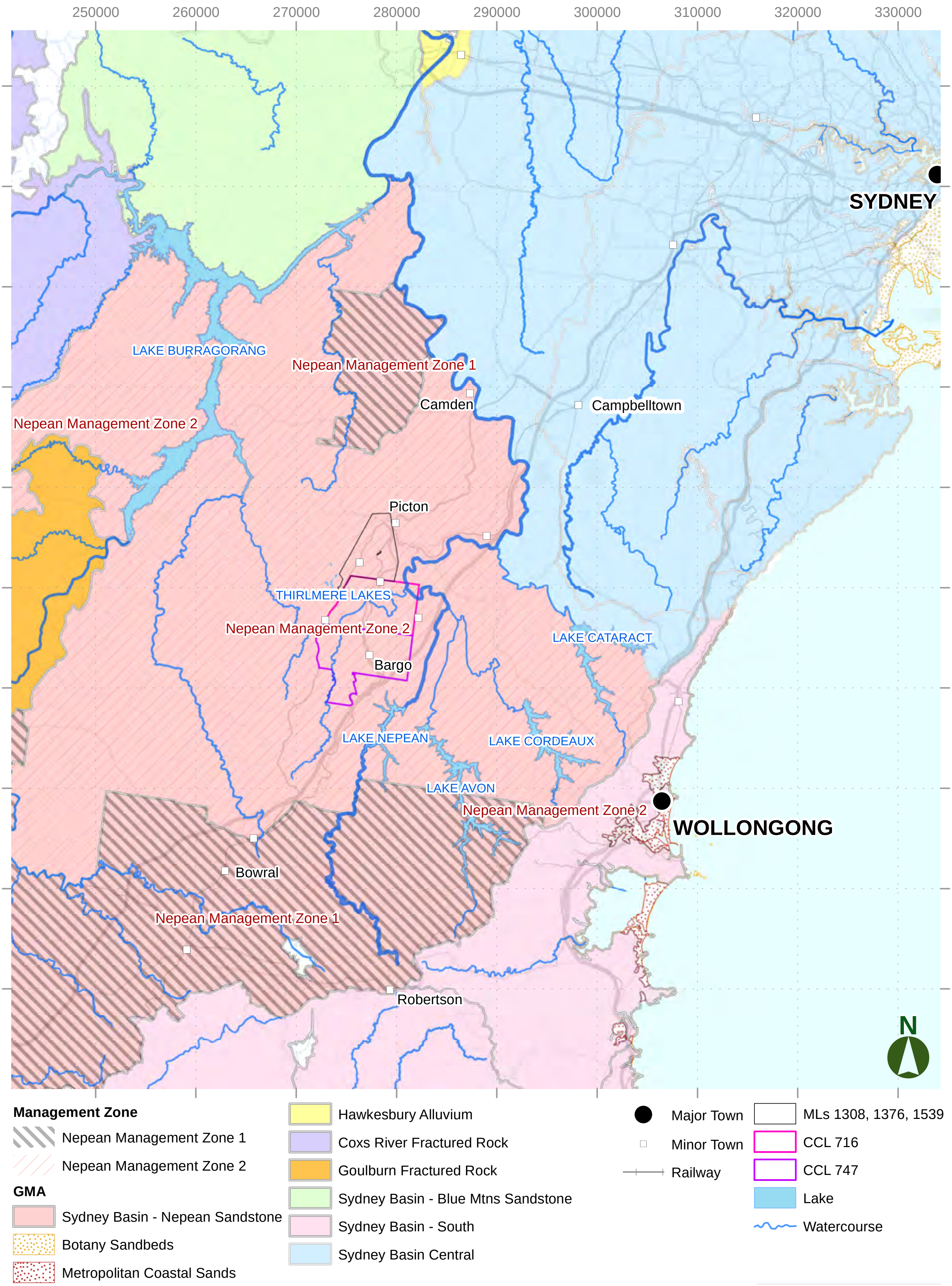
DrawingNo: TAH-004 | Rev: A | Created by: B.White | Date: 25/09/2018

Tahmoor Coal
Tahmoor South Project

Figure 1-1

Project Location



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GDA 1994 MGA Zone 56

0 2 4 8 12 16 20 kilometres

Tahmoor Coal
Tahmoor South Project

Figure 1-2

Water Management and Regulatory boundaries

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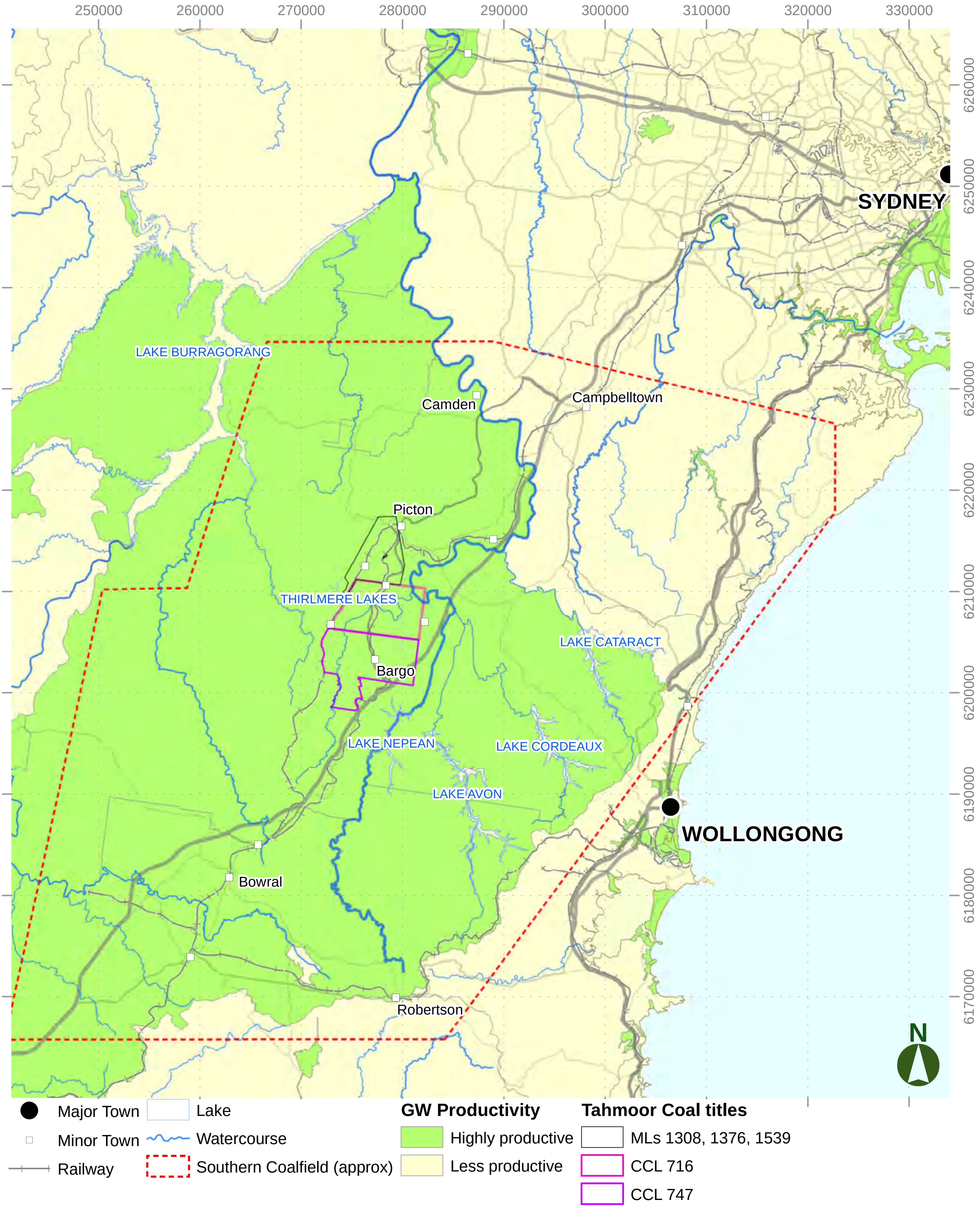
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018



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GDA 1994 MGA Zone 56

0 2 4 8 12 16 20
kilometres

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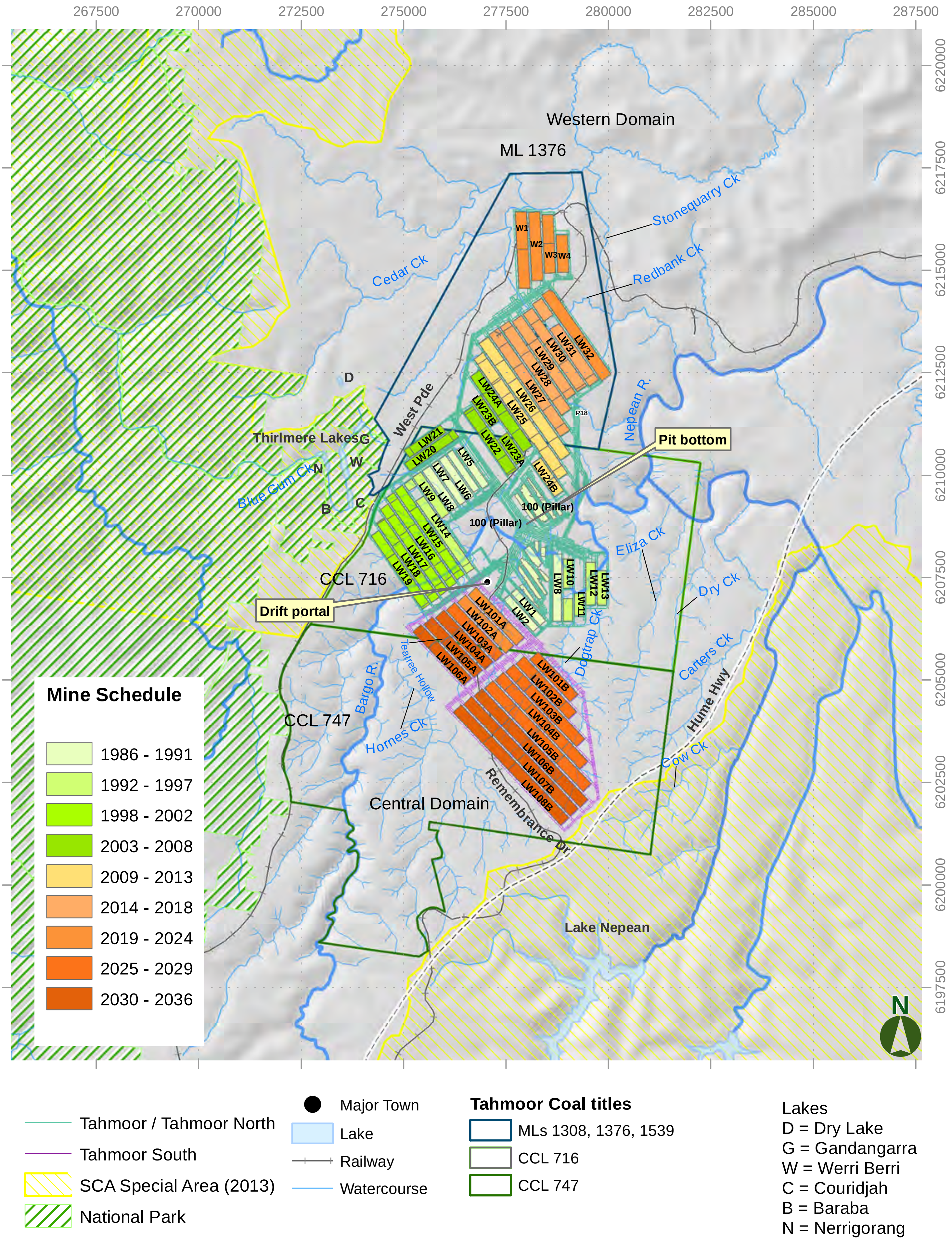
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HYDROSIMULATIONS

Tahmoor Coal
Tahmoor South Project

Figure 1-3

Groundwater Productivity



Scale: 120,000
GDA 1994 MGA Zone 56

0 0.5 1 2 3 4 kilometres

Tahmoor Coal
Tahmoor South Project

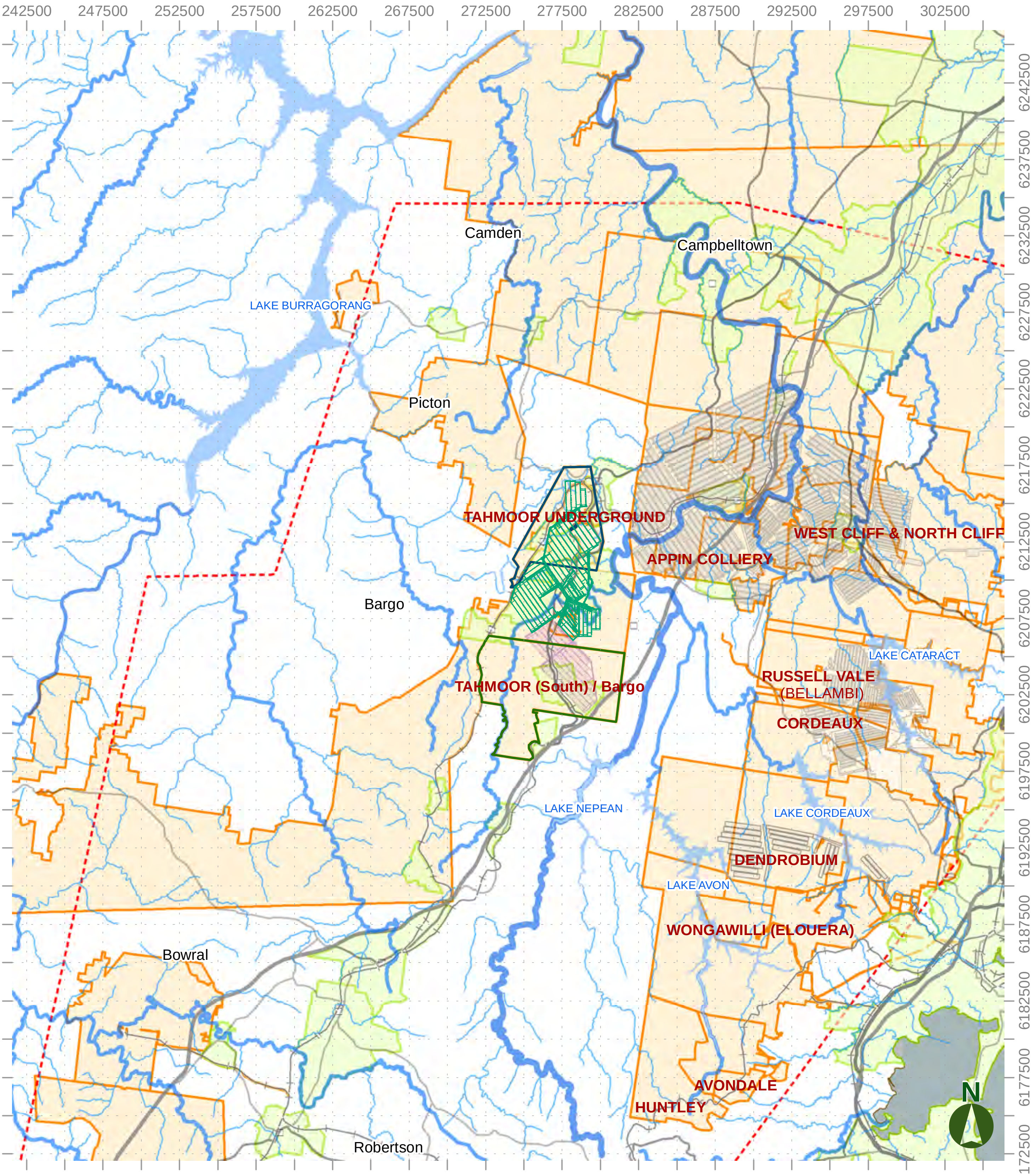
Figure 2-1

Mine plan and schedule for Tahmoor South APR

Project: TAH-006 | Rev: A | Created by: B.White | Date:01/10/2019

HYDRO SIMULATIONS

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_MinePlan_APRv2.mxd



—	Tahmoor South	☐	NSW coal titles
—	Tahmoor North		**Tahmoor Coal titles**
□	Minor Town	☐	MLs 1308, 1376, 1539
┼	Railway	☐	CCL 716
🟩	Urban area	☐	CCL 747
🟦	Lake		
⬚	Southern Coalfield (approx)		

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

Tahmoor Coal
Tahmoor South Project

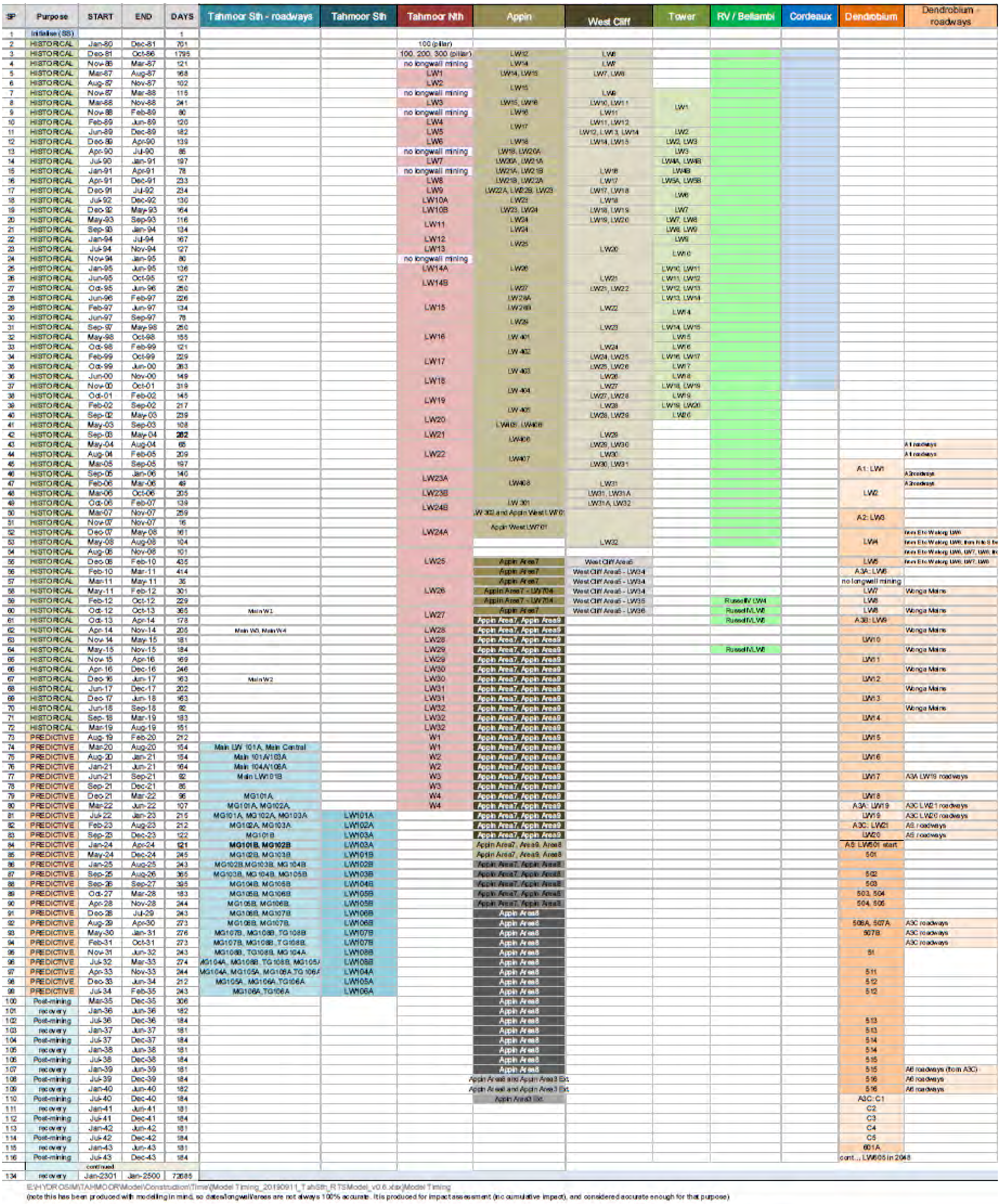
Figure 2-2

Coal mining activity in the Southern Coalfield

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 14/11/2019

HYDROSIMULATIONS

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_SurroundingMines.mxd

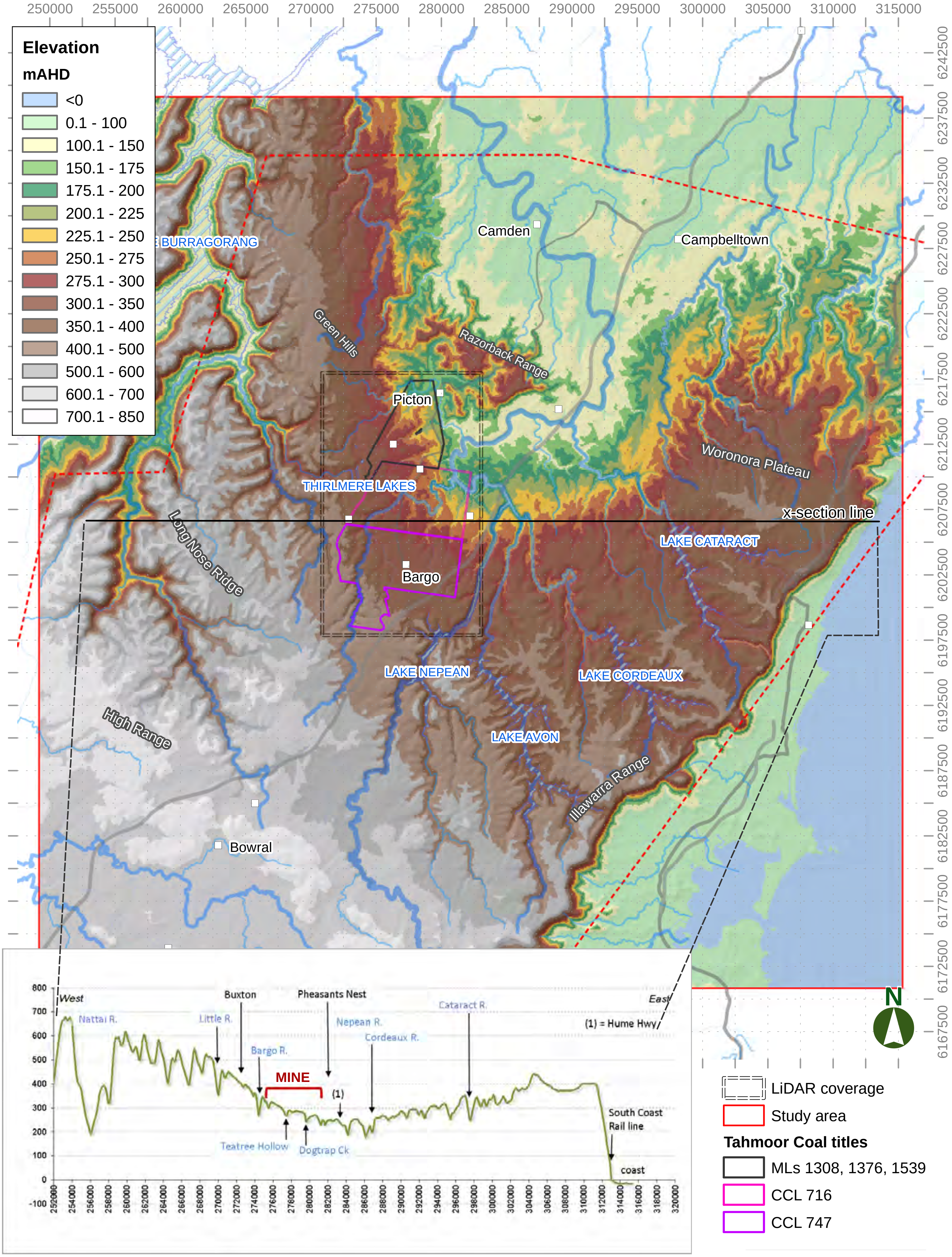


SP	Purpose	START	END	DAYS	Tahmoor Sth - roadways	Tahmoor Sth	Tahmoor Nth	Appin	West Cliff	Tower	RV / Bellambi	Cordeaux	Dendrobium	Dendrobium - roadways
1	Initialise (SS)			1										
2	HISTORICAL	Jan-80	Dec-81	701			100 (pillar)							
3	HISTORICAL	Dec-81	Oct-86	1795			100, 200, 300 (pillar)	LW12	LW6					
4	HISTORICAL	Nov-86	Mar-87	121			no longwall mining	LW14	LW7					
5	HISTORICAL	Mar-87	Aug-87	168			LW1	LW14, LW15	LW7, LW8					
6	HISTORICAL	Aug-87	Nov-87	102			LW2	LW15						
7	HISTORICAL	Nov-87	Mar-88	115			no longwall mining		LW8	LW1				
8	HISTORICAL	Mar-88	Nov-88	241			LW3	LW15, LW16	LW10, LW11					
9	HISTORICAL	Nov-88	Feb-89	80			no longwall mining	LW16	LW11					
10	HISTORICAL	Feb-89	Jun-89	120			LW4	LW17	LW11, LW12					
11	HISTORICAL	Jun-89	Dec-89	182			LW5		LW12, LW13, LW14	LW2				
12	HISTORICAL	Dec-89	Apr-90	139			LW6	LW18	LW14, LW15	LW2, LW3				
13	HISTORICAL	Apr-90	Jul-90	86			no longwall mining	LW18, LW20A		LW3				
14	HISTORICAL	Jul-90	Jan-91	197			LW7	LW20A, LW21A		LW4A, LW4B				
15	HISTORICAL	Jan-91	Apr-91	78			no longwall mining	LW21A, LW21B	LW16	LW4B				
16	HISTORICAL	Apr-91	Dec-91	233			LW8	LW21B, LW22A	LW17	LW5A, LW5B				
17	HISTORICAL	Dec-91	Jul-92	234			LW9	LW22A, LW22B, LW23	LW17, LW18	LW6				
18	HISTORICAL	Jul-92	Dec-92	130			LW10A	LW23	LW18					
19	HISTORICAL	Dec-92	May-93	164			LW10B	LW23, LW24	LW18, LW19	LW7				
20	HISTORICAL	May-93	Sep-93	116			LW11	LW24	LW19, LW20	LW7, LW8				
21	HISTORICAL	Sep-93	Jan-94	134				LW24	LW20	LW8, LW9				
22	HISTORICAL	Jan-94	Jul-94	167			LW12	LW25		LW9				
23	HISTORICAL	Jul-94	Nov-94	127			LW13			LW10				
24	HISTORICAL	Nov-94	Jan-95	80			no longwall mining	LW26						
25	HISTORICAL	Jan-95	Jun-95	136			LW14A		LW21	LW10, LW11				
26	HISTORICAL	Jun-95	Oct-95	127			LW14B			LW11, LW12				
27	HISTORICAL	Oct-95	Jun-96	250				LW27	LW21, LW22	LW12, LW13				
28	HISTORICAL	Jun-96	Feb-97	226			LW15	LW28A	LW22	LW13, LW14				
29	HISTORICAL	Feb-97	Jun-97	134				LW28B		LW14				
30	HISTORICAL	Jun-97	Sep-97	78				LW29	LW23					
31	HISTORICAL	Sep-97	May-98	250			LW16			LW14, LW15				
32	HISTORICAL	May-98	Oct-98	155				LW 401	LW24	LW15				
33	HISTORICAL	Oct-98	Feb-99	121				LW 402		LW16				
34	HISTORICAL	Feb-99	Oct-99	229			LW17		LW24, LW25	LW16, LW17				
35	HISTORICAL	Oct-99	Jun-00	263				LW 403	LW25, LW26	LW17				
36	HISTORICAL	Jun-00	Nov-00	149			LW18		LW26	LW18				
37	HISTORICAL	Nov-00	Oct-01	319				LW 404	LW27	LW18, LW19				
38	HISTORICAL	Oct-01	Feb-02	145			LW19		LW27, LW28	LW19				
39	HISTORICAL	Feb-02	Sep-02	217				LW 405	LW28	LW19, LW20				
40	HISTORICAL	Sep-02	May-03	239			LW20		LW28, LW29	LW20				
41	HISTORICAL	May-03	Sep-03	108				LW405, LW406	LW29					
42	HISTORICAL	Sep-03	May-04	**282**			LW21	LW406						
43	HISTORICAL	May-04	Aug-04	85			LW22		LW29, LW30					A1 roadways
44	HISTORICAL	Aug-04	Feb-05	209				LW407	LW30					A1 roadways
45	HISTORICAL	Mar-05	Sep-05	197					LW30, LW31				A1: LW1	
46	HISTORICAL	Sep-05	Jan-06	140			LW23A	LW408	LW31					A2 roadways
47	HISTORICAL	Feb-06	Mar-06	49									LW2	A2 roadways
48	HISTORICAL	Mar-06	Oct-06	205			LW23B		LW31, LW31A					
49	HISTORICAL	Oct-06	Feb-07	139			LW24B	LW 301	LW31A, LW32					
50	HISTORICAL	Mar-07	Nov-07	259				LW 302 and Appin West LW701	LW32				A2: LW3	
51	HISTORICAL	Nov-07	Nov-07	16			LW24A	Appin West LW701						
52	HISTORICAL	Dec-07	May-08	161									LW4	from E to W along LW4
53	HISTORICAL	May-08	Aug-08	104										from E to W along LW6, from N to S be
54	HISTORICAL	Aug-08	Nov-08	101			LW25							from E to W along LW6, LW7, LW8, fro
55	HISTORICAL	Dec-08	Feb-10	435				Appin Area7	West Cliff Area5				LW5	from E to W along LW6, LW7, LW8
56	HISTORICAL	Feb-10	Mar-11	414				Appin Area7	West Cliff Area5 - LW34				A3A: LW6	
57	HISTORICAL	Mar-11	May-11	35			LW26	Appin Area7	West Cliff Area5 - LW34				no longwall mining	
58	HISTORICAL	May-11	Feb-12	301				Appin Area7 - LW704	West Cliff Area5 - LW34				LW7	Wonga Mains
59	HISTORICAL	Feb-12	Oct-12	229				Appin Area7 - LW704	West Cliff Area5 - LW35		RussellV LW4		LW8	
60	HISTORICAL	Oct-12	Oct-13	365	Main W1		LW27	Appin Area7	West Cliff Area5 - LW36		RussellVLW5		LW8	Wonga Mains
61	HISTORICAL	Oct-13	Apr-14	178				Appin Area7, Appin Area9			RussellVLW5		A3B: LW9	
62	HISTORICAL	Apr-14	Nov-14	205	Main W3, Main W4		LW28	Appin Area7, Appin Area9						Wonga Mains
63	HISTORICAL	Nov-14	May-15	181			LW28	Appin Area7, Appin Area9					LW10	
64	HISTORICAL	May-15	Nov-15	184			LW29	Appin Area7, Appin Area9			RussellVLW5			Wonga Mains
65	HISTORICAL	Nov-15	Apr-16	169			LW29	Appin Area7, Appin Area9					LW11	
66	HISTORICAL	Apr-16	Dec-16	246			LW30	Appin Area7, Appin Area9						Wonga Mains
67	HISTORICAL	Dec-16	Jun-17	163	Main W2		LW30	Appin Area7, Appin Area9					LW12	
68	HISTORICAL	Jun-17	Dec-17	202			LW31	Appin Area7, Appin Area9						Wonga Mains
69	HISTORICAL	Dec-17	Jun-18	163			LW31	Appin Area7, Appin Area9					LW13	
70	HISTORICAL	Jun-18	Sep-18	92			LW32	Appin Area7, Appin Area9						Wonga Mains
71	HISTORICAL	Sep-18	Mar-19	183			LW32	Appin Area7, Appin Area9					LW14	
72	HISTORICAL	Mar-19	Aug-19	151			LW32	Appin Area7, Appin Area9						
73	PREDICTIVE	Aug-19	Feb-20	212			W1	Appin Area7, Appin Area9					LW15	
74	PREDICTIVE	Mar-20	Aug-20	154	Main LW 101A, Main Central		W1	Appin Area7, Appin Area9						
75	PREDICTIVE	Aug-20	Jan-21	154	Main 101A/103A		W2	Appin Area7, Appin Area9					LW16	
76	PREDICTIVE	Jan-21	Jun-21	164	Main 104A/106A		W2	Appin Area7, Appin Area9						
77	PREDICTIVE	Jun-21	Sep-21	92	Main LW101B		W3	Appin Area7, Appin Area9					LW17	A3A LW19 roadways
78	PREDICTIVE	Sep-21	Dec-21	85			W3	Appin Area7, Appin Area9						
79	PREDICTIVE	Dec-21	Mar-22	96	MG101A		W4	Appin Area7, Appin Area9					LW18	
80	PREDICTIVE	Mar-22	Jun-22	107	MG101A, MG102A,		W4	Appin Area7, Appin Area9					A3A: LW19	A3C LW21 roadways
81	PREDICTIVE	Jul-22	Jan-23	215	MG101A, MG102A, MG103A	LW101A		Appin Area7, Appin Area9					LW19	A3C LW20 roadways
82	PREDICTIVE	Feb-23	Aug-23	212	MG102A, MG103A	LW102A		Appin Area7, Appin Area9					A3C: LW21	A5 roadways
83	PREDICTIVE	Sep-23	Dec-23	122	MG101B	LW103A		Appin Area7, Appin Area9					LW20	A5 roadways
84	PREDICTIVE	Jan-24	Apr-24	**121**	**MG101B, MG102B**	LW103A		Appin Area7 , Area9, Area8					A5: LW501 start	
85	PREDICTIVE	May-24	Dec-24	245	MG102B, MG103B	LW101B		Appin Area7 , Area9, Area8					501	
86	PREDICTIVE	Jan-25	Aug-25	243	MG102B,MG103B, MG104B	LW102B		Appin Area7, Appin Area8						
87	PREDICTIVE	Sep-25	Aug-26	365	MG103B, MG104B, MG105B	LW103B		Appin Area7, Appin Area8					502	
88	PREDICTIVE	Sep-26	Sep-27	395	MG104B, MG105B	LW104B		Appin Area7, Appin Area8					503	
89	PREDICTIVE	Oct-27	Mar-28	183	MG105B, MG106B	LW105B		Appin Area7, Appin Area8					503, 504	
90	PREDICTIVE	Apr-28	Nov-28	244	MG105B, MG106B,	LW105B		Appin Area7, Appin Area8					504, 505	
91	PREDICTIVE	Dec-28	Jul-29	243	MG106B, MG107B	LW106B		Appin Area8						
92	PREDICTIVE	Aug-29	Apr-30	273	MG106B, MG107B,	LW106B		Appin Area8					506A, 507A	A3C roadways
93	PREDICTIVE	May-30	Jan-31	276	MG107B , MG108B, TG108B	LW107B		Appin Area8					507B	A3C roadways
94	PREDICTIVE	Feb-31	Oct-31	273	MG107B, MG108B , TG108B,	LW107B		Appin Area8						A3C roadways
95	PREDICTIVE	Nov-31	Jun-32	243	MG108B , TG108B, MG104A	LW108B		Appin Area8					51	
96	PREDICTIVE	Jul-32	Mar-33	274	MG104A , MG108B, TG108B, MG105	LW108B		Appin Area8						
97	PREDICTIVE	Apr-33	Nov-33	244	MG104A, MG105A, MG106A,TG106	LW104A		Appin Area8					511	
98	PREDICTIVE	Dec-33	Jun-34	212	MG105A , MG106A ,TG106A	LW105A		Appin Area8					512	
99	PREDICTIVE	Jul-34	Feb-35	243	MG106A ,TG106A	LW106A		Appin Area8					512	
100	Post-mining	Mar-35	Dec-35	306				Appin Area8						
101	recovery	Jan-36	Jun-36	182				Appin Area8						
102	Post-mining	Jul-36	Dec-36	184				Appin Area8					513	
103	recovery	Jan-37	Jun-37	181				Appin Area8					513	
104	Post-mining	Jul-37	Dec-37	184				Appin Area8					514	
105	recovery	Jan-38	Jun-38	181				Appin Area8					514	
106	Post-mining	Jul-38	Dec-38	184				Appin Area8					515	
107	recovery	Jan-39	Jun-39	181				Appin Area8					515	A6 roadways (from A3C)
108	Post-mining	Jul-39	Dec-39	184				Appin Area8 and Appin Area3 Ext					516	A6 roadways
109	recovery	Jan-40	Jun-40	182				Appin Area8 and Appin Area3 Ext					516	A6 roadways
110	Post-mining	Jul-40	Dec-40	184				Appin Area3 Ext					A3C: C1	
111	recovery	Jan-41	Jun-41	181									C2	
112	Post-mining	Jul-41	Dec-41	184									C3	
113	recovery	Jan-42	Jun-42	181									C4	
114	Post-mining	Jul-42	Dec-42	184									C5	
115	recovery	Jan-43	Jun-43	181									601A	
116	Post-mining	Jul-43	Dec-43	184									cont... LW605 in 2048	
		continued												
134	recovery	Jan-2301	Jan-2500	72686										

E:\HYDROSIM\TAHMOOR\Model\Construction\Time\[Model Timing_20190911_TahSth_RTSModel_v0.6.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)

Figure 2-3 Comparative Mine Schedule



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

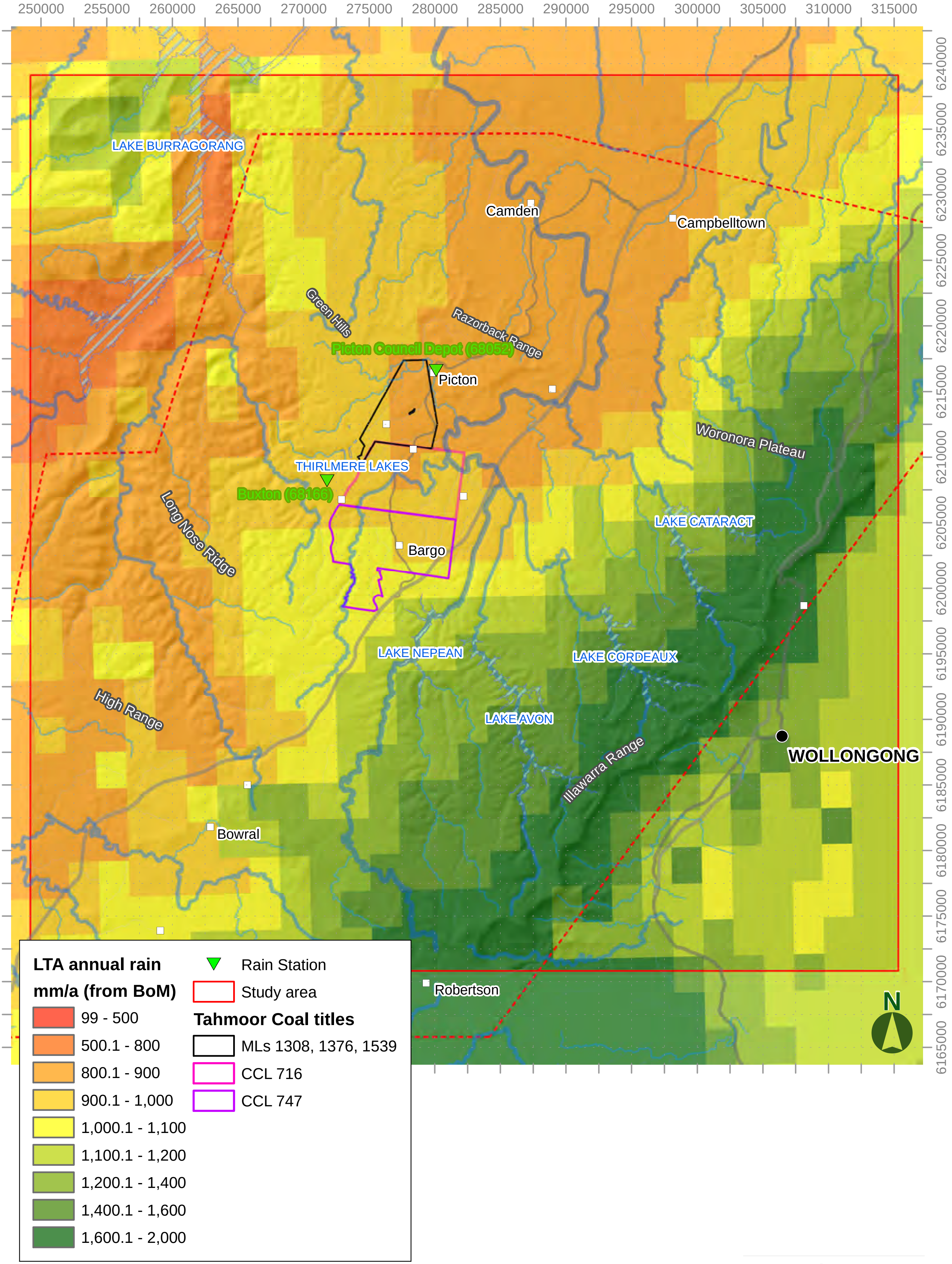
DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

HydroSimulations

Tahmoor Coal
Tahmoor South Project

Figure 3-1

Topography of the Tahmoor area



Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres

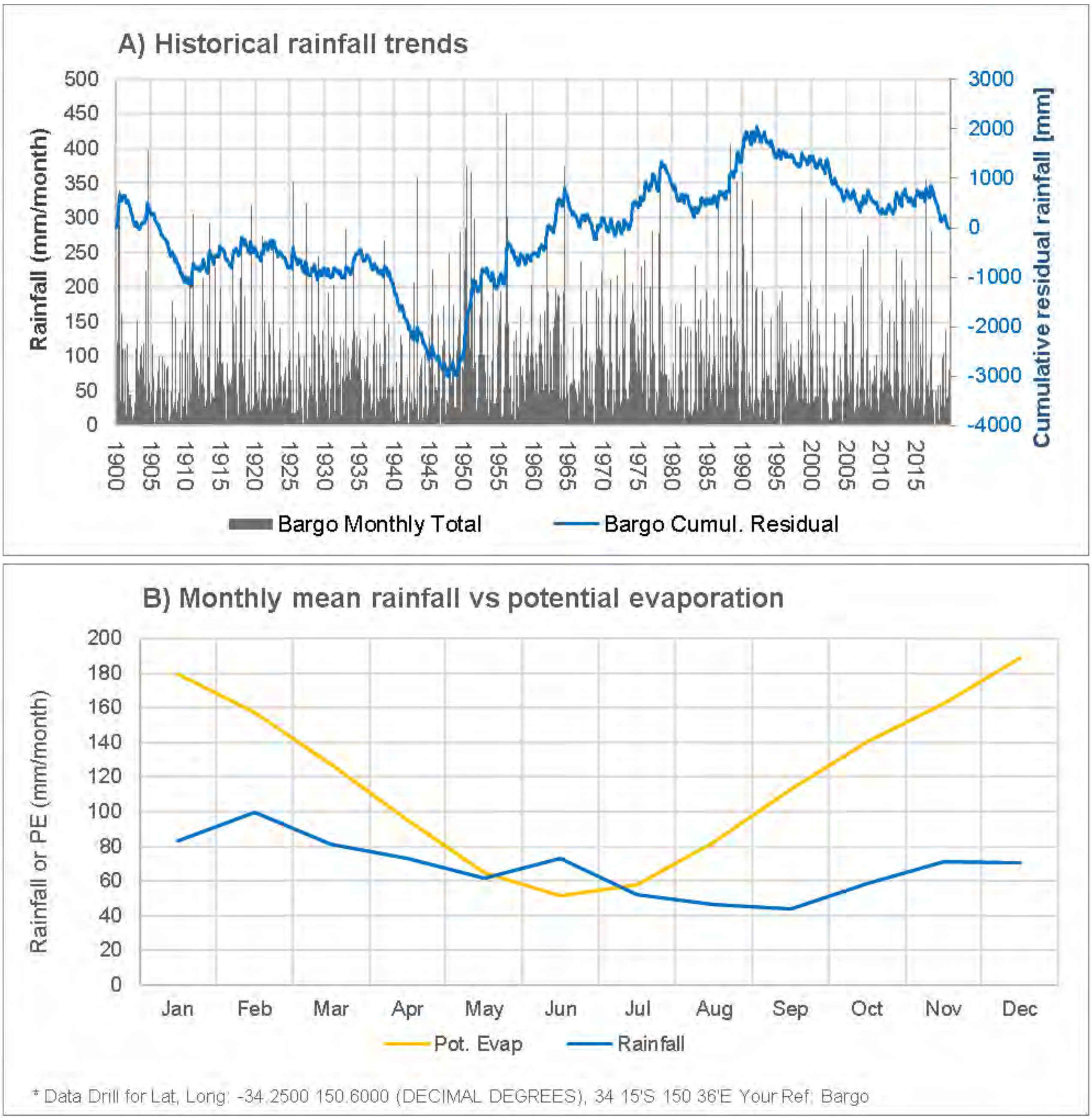
T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH008a_Rainfall_A4P.mxd

DrawingNo: TAH-004 | Rev: A | Created by: B. White | Date: 07/09/2018

Tahmoor Coal
Tahmoor South Project

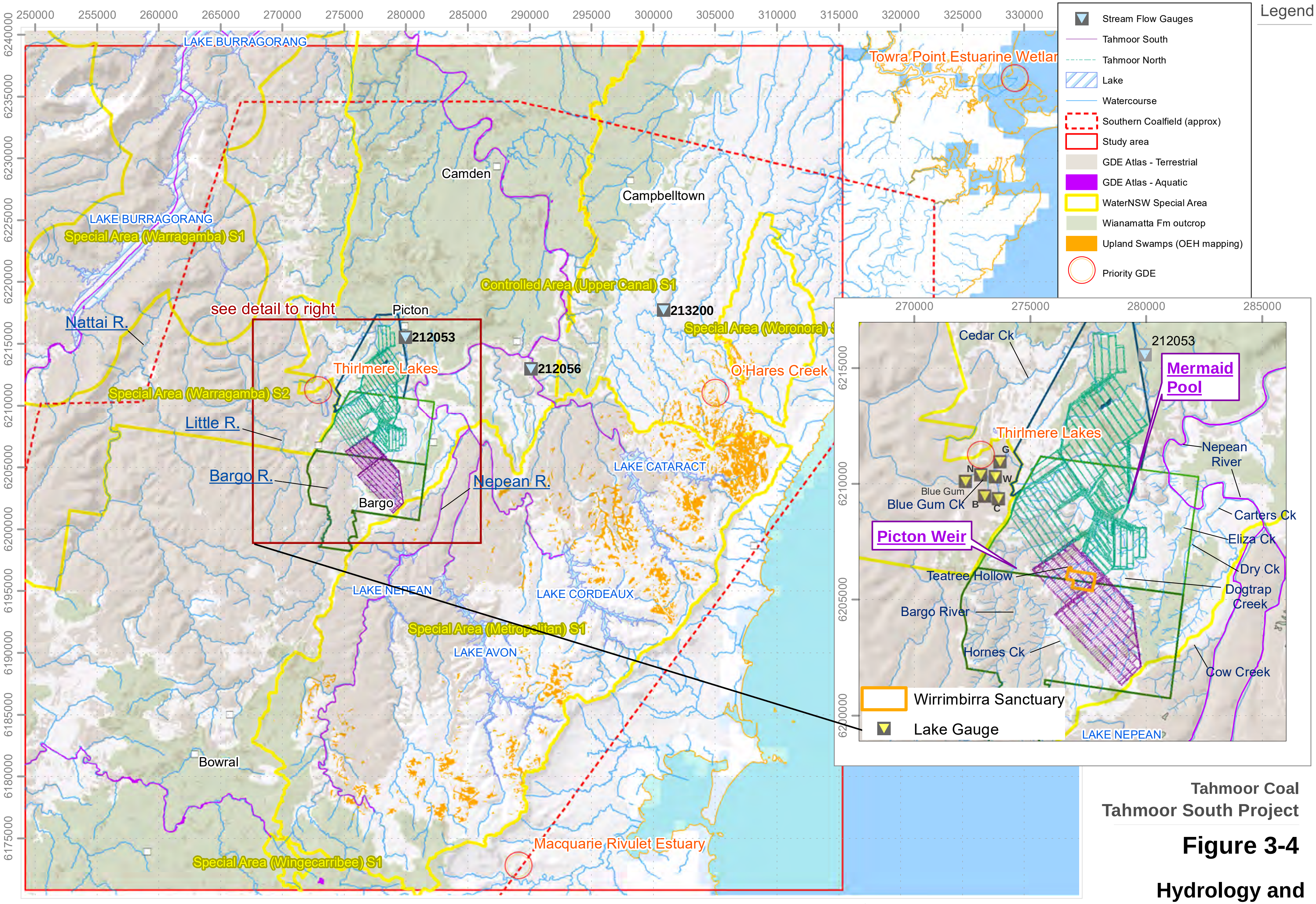
Figure 3-2

Mean annual rainfall



E:\HYDROSIM\TAHMOOR\Tech\Climate&Recharge\[BoM_SILO_TahmoorMine_Comparison.xlsx]Bargo

Figure 3-3 Historical rainfall and potential evaporation



Scale: 375,000
GDA 1994 MGA Zone 56

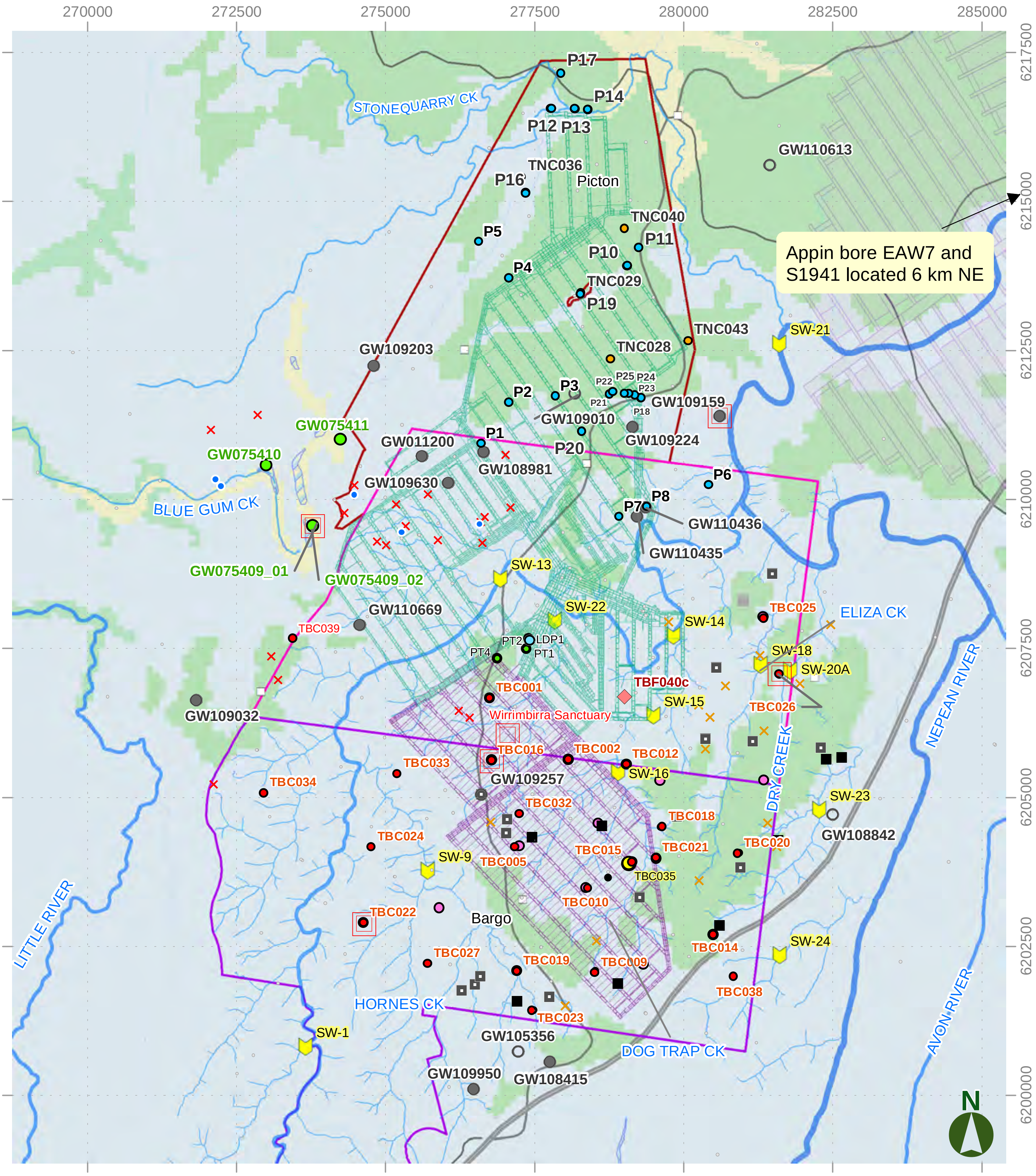
Tahmoor Coal
Tahmoor South Project

Figure 3-4

Hydrology and environmental sites around Tahmoor

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 01/10/2019

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_Hydrology_AmendedProject.mxd



● 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
☐ Predictive Hydrographs locations (refer to Section 5.6 of the text)
— Tahmoor South workings
— Tahmoor North workings
☐ MLs 1308, 1376, 1539
☐ CCL 716
☐ CCL 747

Scale: 90,000 at A4
GDA 1994 MGA Zone 56

0 0.45 0.9 1.8 2.7 3.6 4.5 kilometres

Tahmoor Coal
Tahmoor South Project

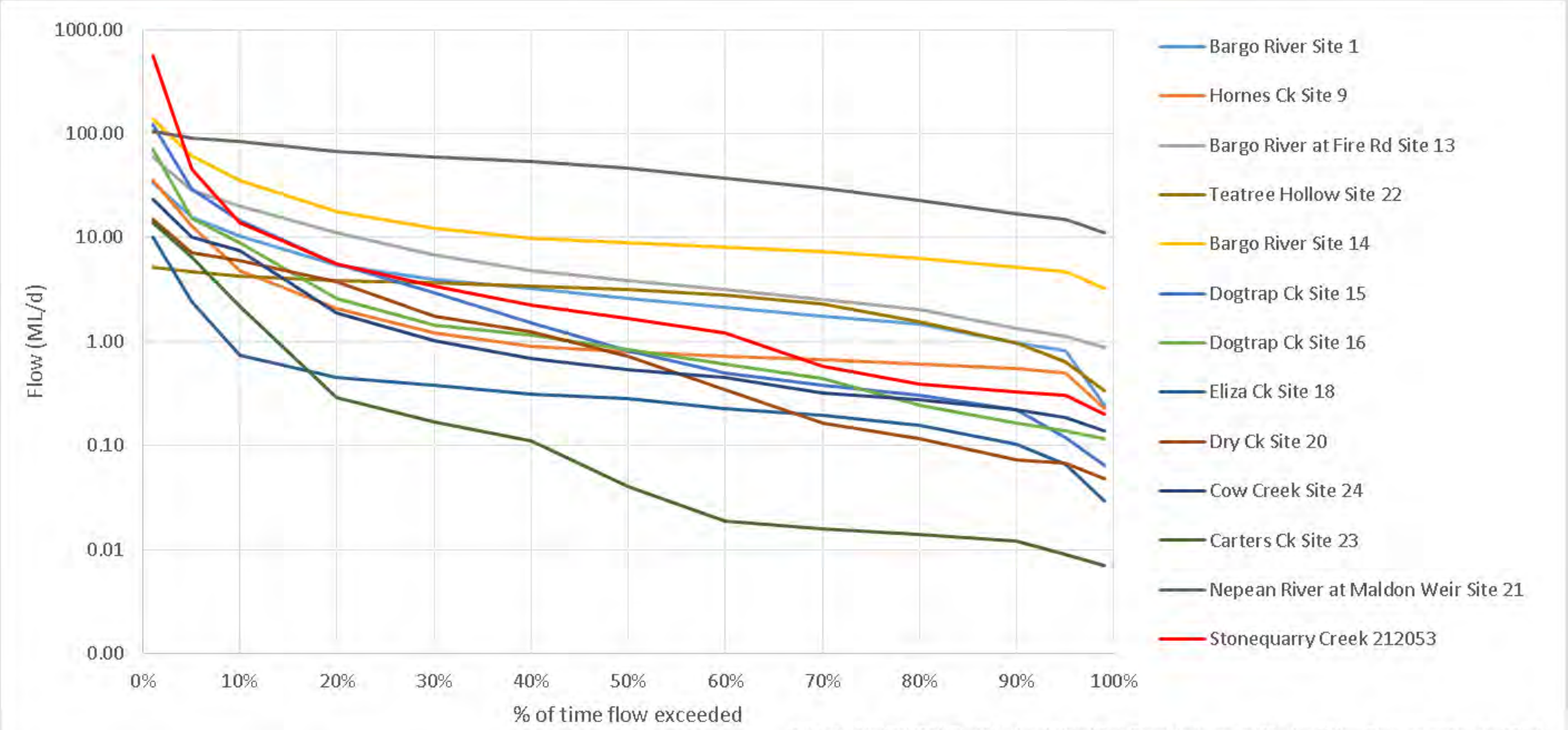
Figure 3-5

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 26/09/2019

HYDRO SIMULATIONS

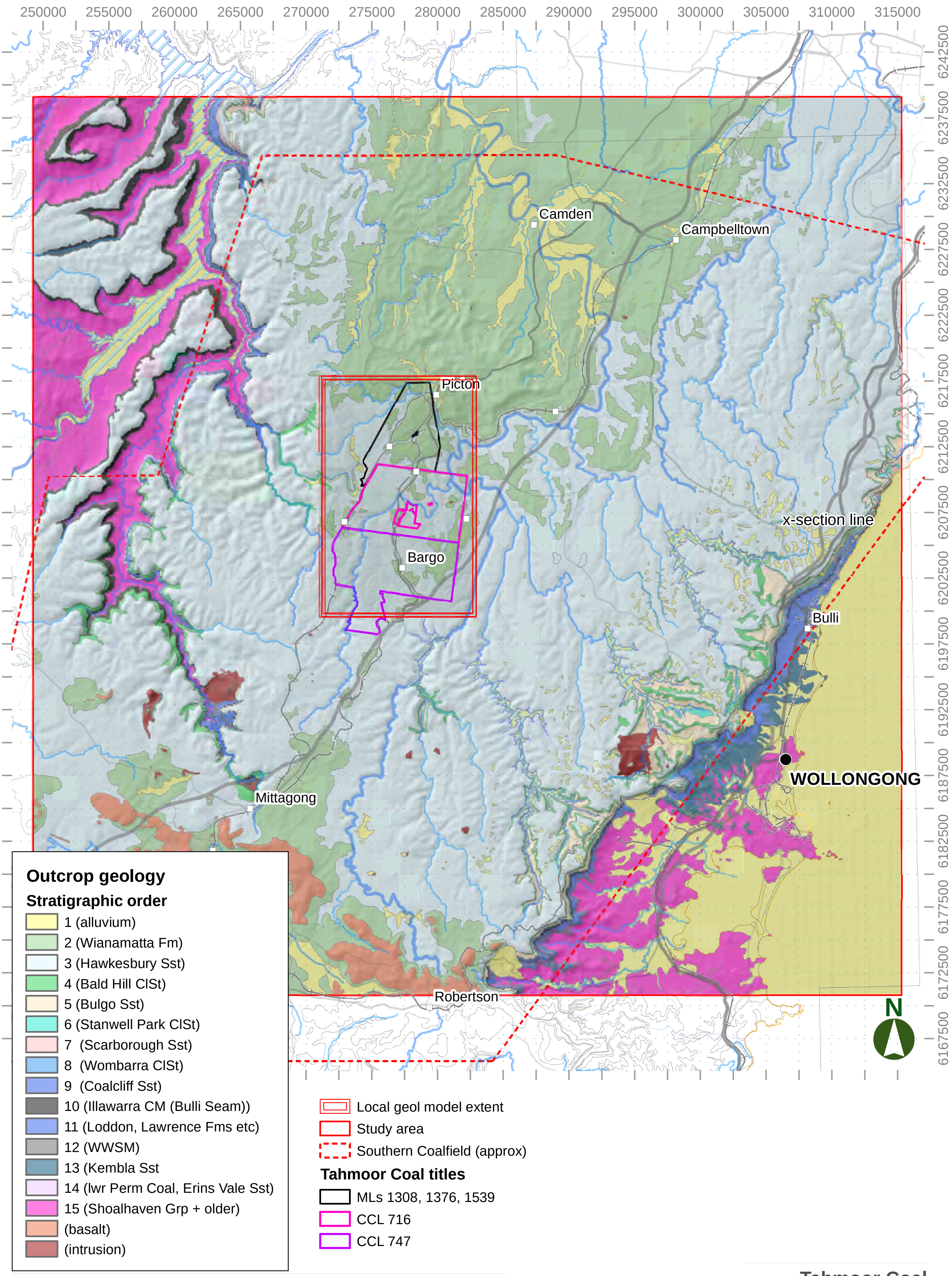
Monitoring locations

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_MonitoringLocations_A4P_PPR.mxd



C:\HydroSim\TAH001\Tech\SurfaceWater\DataFromHydrometric\[SurfaceWaterData_compiled.xlsx]SiteL

Figure 3-6 Flow duration curves for local watercourses



Scale: 375,000
GDA 1994 MGA Zone 56

Tahmoor Coal
Tahmoor South Project

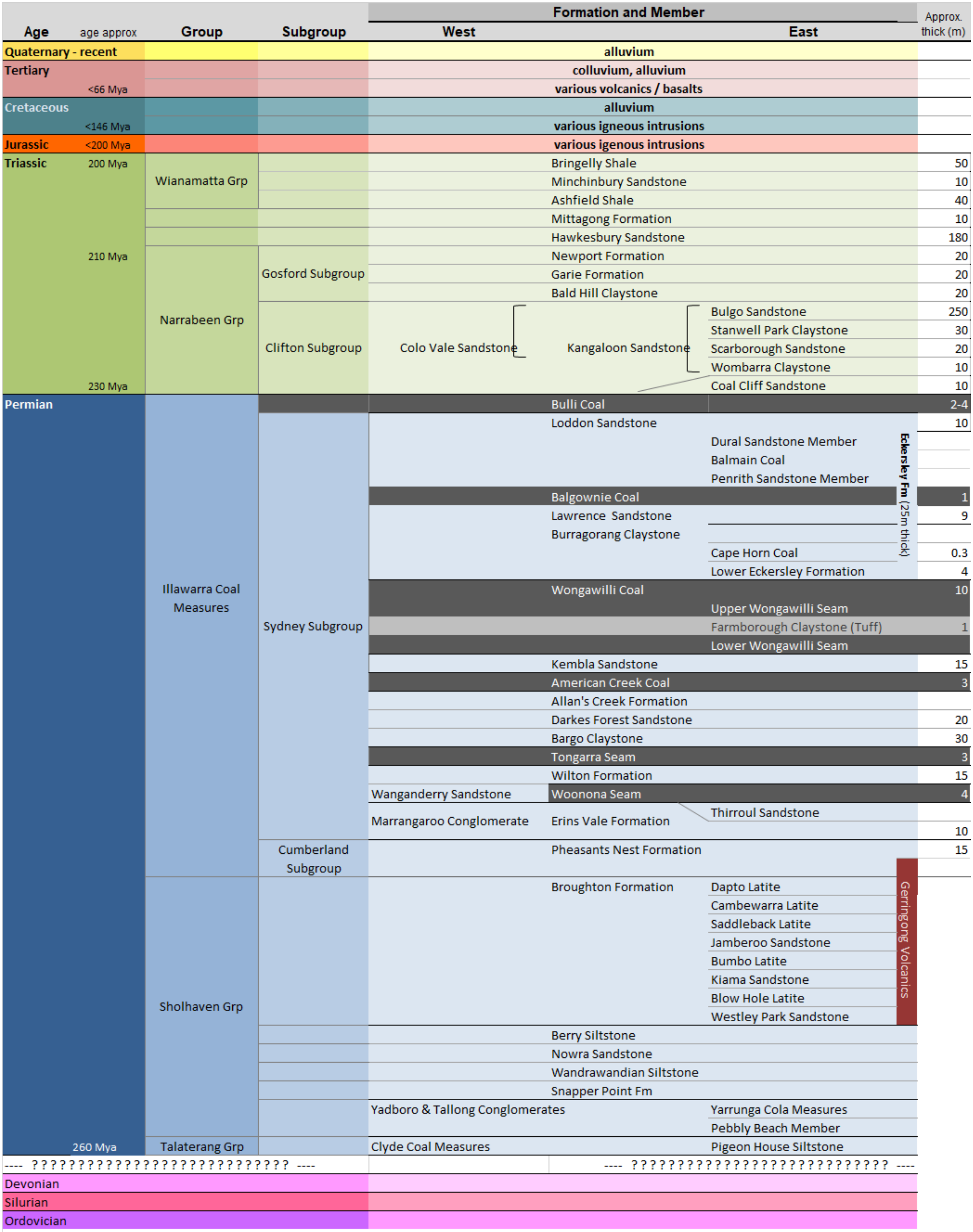
Figure 3-7

Outcrop geology (Southern Coalfield 100k)

C:\HydroSim\TAH001\GIS\Maps\Deliverable\TAH010a_Geology_A4P.mxd

DrawingNo: TAH-010 | Rev: A | Created by: WMinchin | Date: 08/10/2013

HYDRO SIMULATIONS



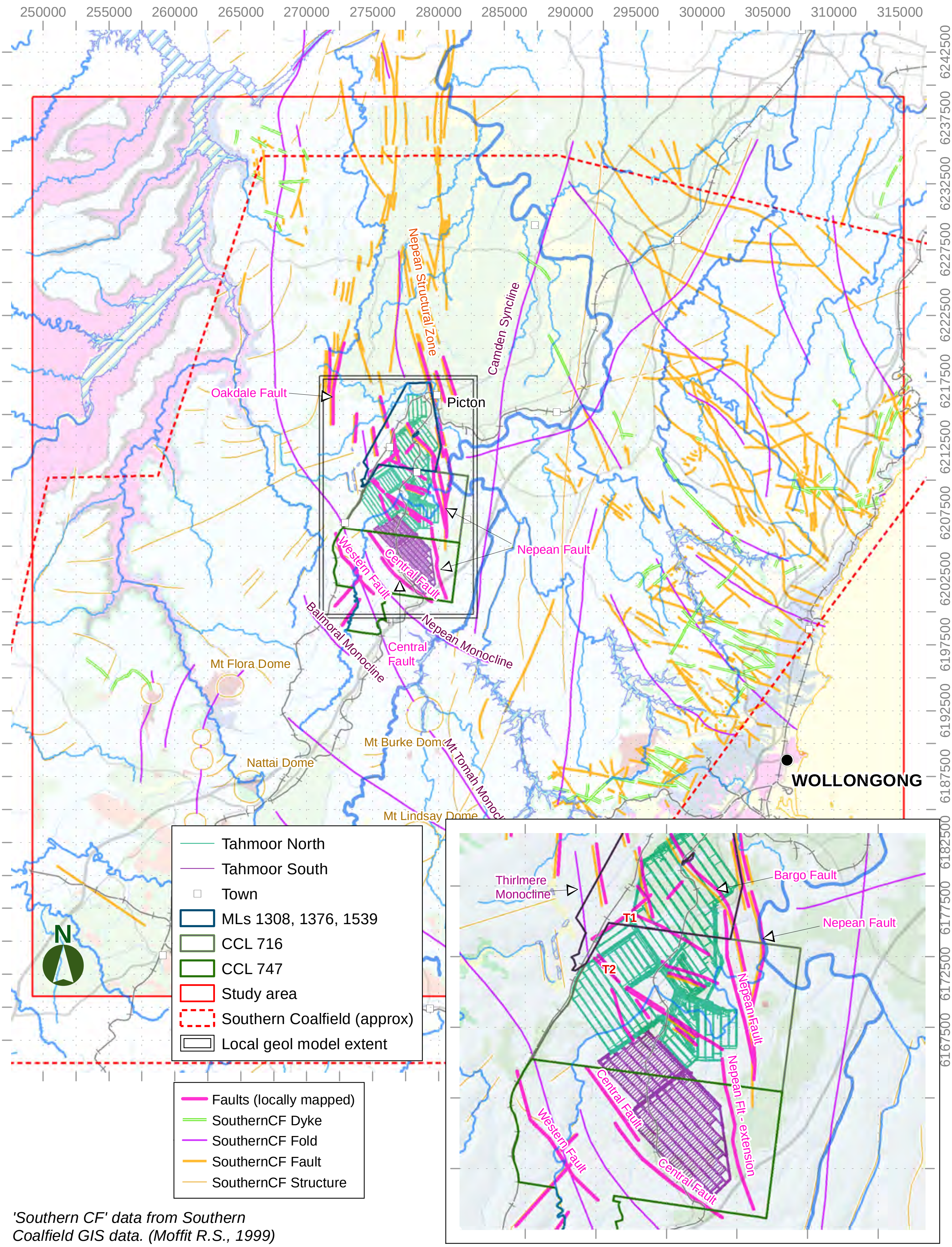
Age	age approx	Group	Subgroup	Formation and Member: West		Formation and Member: East		Approx. thick (m)
Quaternary - recent					alluvium			
Tertiary					colluvium, alluvium			
	<66 Mya				various volcanics / basalts			
Cretaceous					alluvium			
	<146 Mya				various igneous intrusions			
Jurassic	<200 Mya				various igenous intrusions			
Triassic	200 Mya	Wianamatta Grp			Bringelly Shale			50
					Minchinbury Sandstone			10
					Ashfield Shale			40
					Mittagong Formation			10
					Hawkesbury Sandstone			180
	210 Mya	Narrabeen Grp	Gosford Subgroup		Newport Formation			20
					Garie Formation			20
					Bald Hill Claystone			20
			Clifton Subgroup	Colo Vale Sandstone	Kangaloon Sandstone	Bulgo Sandstone		250
						Stanwell Park Claystone		30
						Scarborough Sandstone		20
						Wombarra Claystone		10
	230 Mya					Coal Cliff Sandstone		10
Permian		Illawarra Coal Measures			Bulli Coal			2-4
			Sydney Subgroup		Loddon Sandstone			10
						Dural Sandstone Member	Eckersley Fm (25m thick)	
						Balmain Coal		
						Penrith Sandstone Member		
					Balgownie Coal			1
					Lawrence Sandstone			9
					Burragorang Claystone			
						Cape Horn Coal		0.3
						Lower Eckersley Formation		4
					Wongawilli Coal			10
						Upper Wongawilli Seam		
						Farmborough Claystone (Tuff)		1
						Lower Wongawilli Seam		
					Kembla Sandstone			15
					American Creek Coal			3
					Allan's Creek Formation			
					Darkes Forest Sandstone			20
					Bargo Claystone			30
					Tongarra Seam			3
					Wilton Formation			15
				Wanganderry Sandstone	Woonona Seam			4
				Marrangaroo Conglomerate	Erins Vale Formation	Thirroul Sandstone		
								10
			Cumberland Subgroup		Pheasants Nest Formation			15
		Sholhaven Grp			Broughton Formation	Dapto Latite	Gerringong Volcanics	
						Cambewarra Latite		
						Saddleback Latite		
						Jamberoo Sandstone		
						Bumbo Latite		
						Kiama Sandstone		
						Blow Hole Latite		
						Westley Park Sandstone		
					Berry Siltstone			
					Nowra Sandstone			
					Wandrawandian Siltstone			
					Snapper Point Fm			
				Yadboro & Tallong Conglomerates		Yarrunga Cola Measures		
						Pebbly Beach Member		
	260 Mya	Talaterang Grp		Clyde Coal Measures		Pigeon House Siltstone		
---- ??????????????????????????? ----						---- ??????????????????????????? ----		
Devonian								
Silurian								
Ordovician								

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



'Southern CF' data from Southern Coalfield GIS data. (Moffit R.S., 1999)

Outcrop geology legend on Figure 3.7

Scale: 375,000 at A4
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres

Tahmoor Coal
Tahmoor South Project

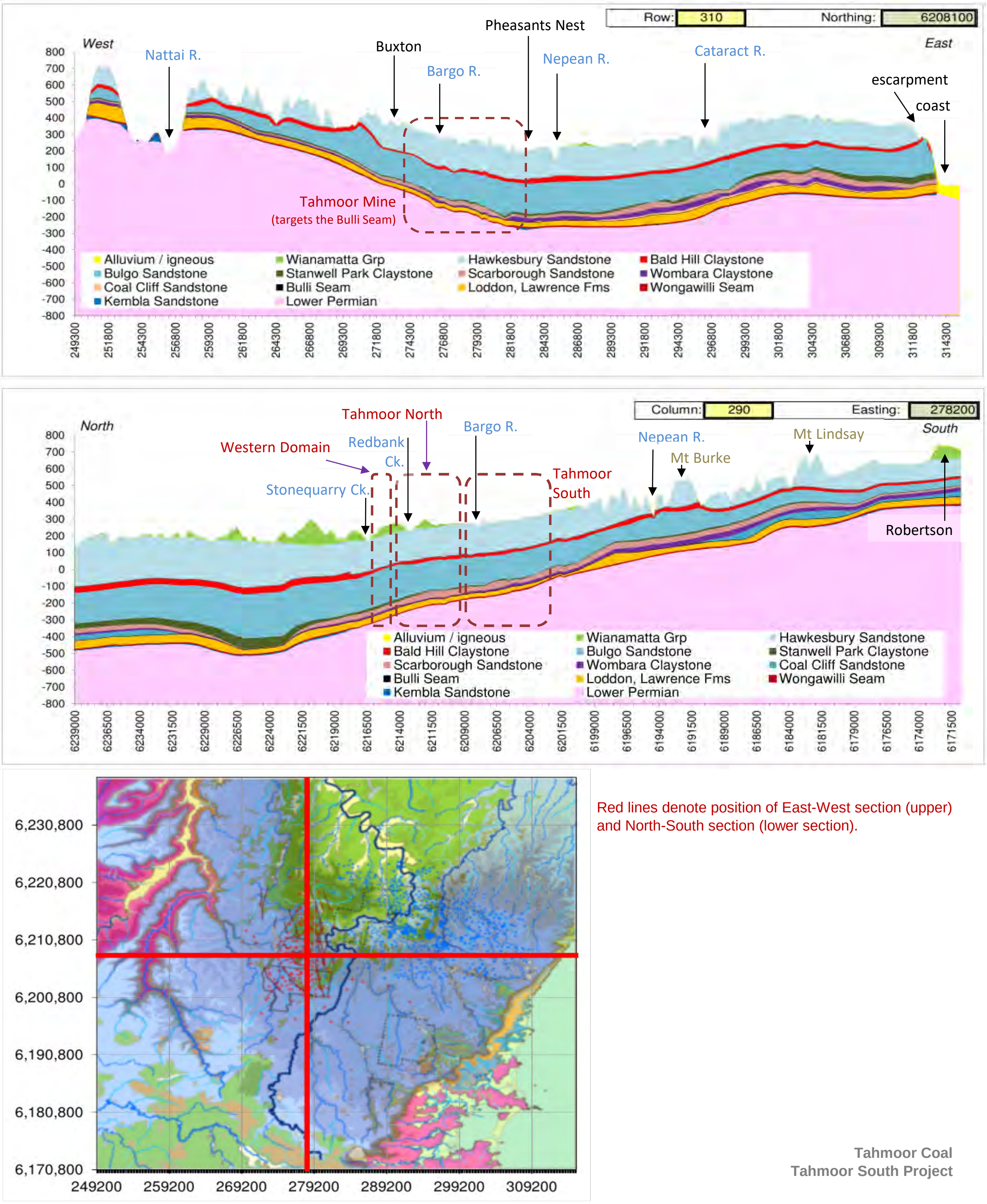
Figure 3-9

HYDROSIMULATIONS

Geological structure

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 01/10/2019

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_GeologicalStructure_PPR.mxd



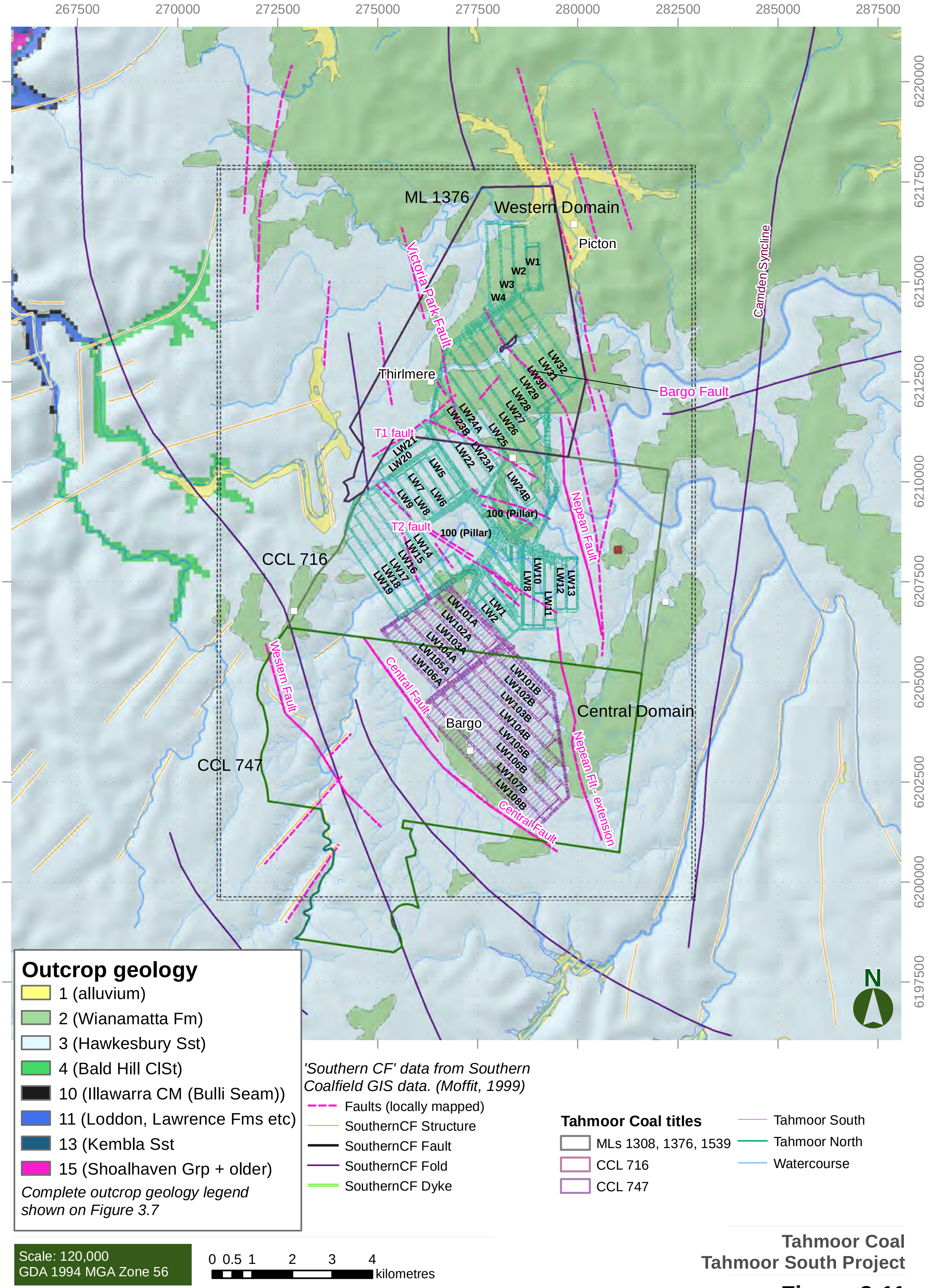
Red lines denote position of East-West section (upper) and North-South section (lower section).

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**



Tahmoor Coal
Tahmoor South Project

Figure 3-11

Site geology

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 01/10/2019

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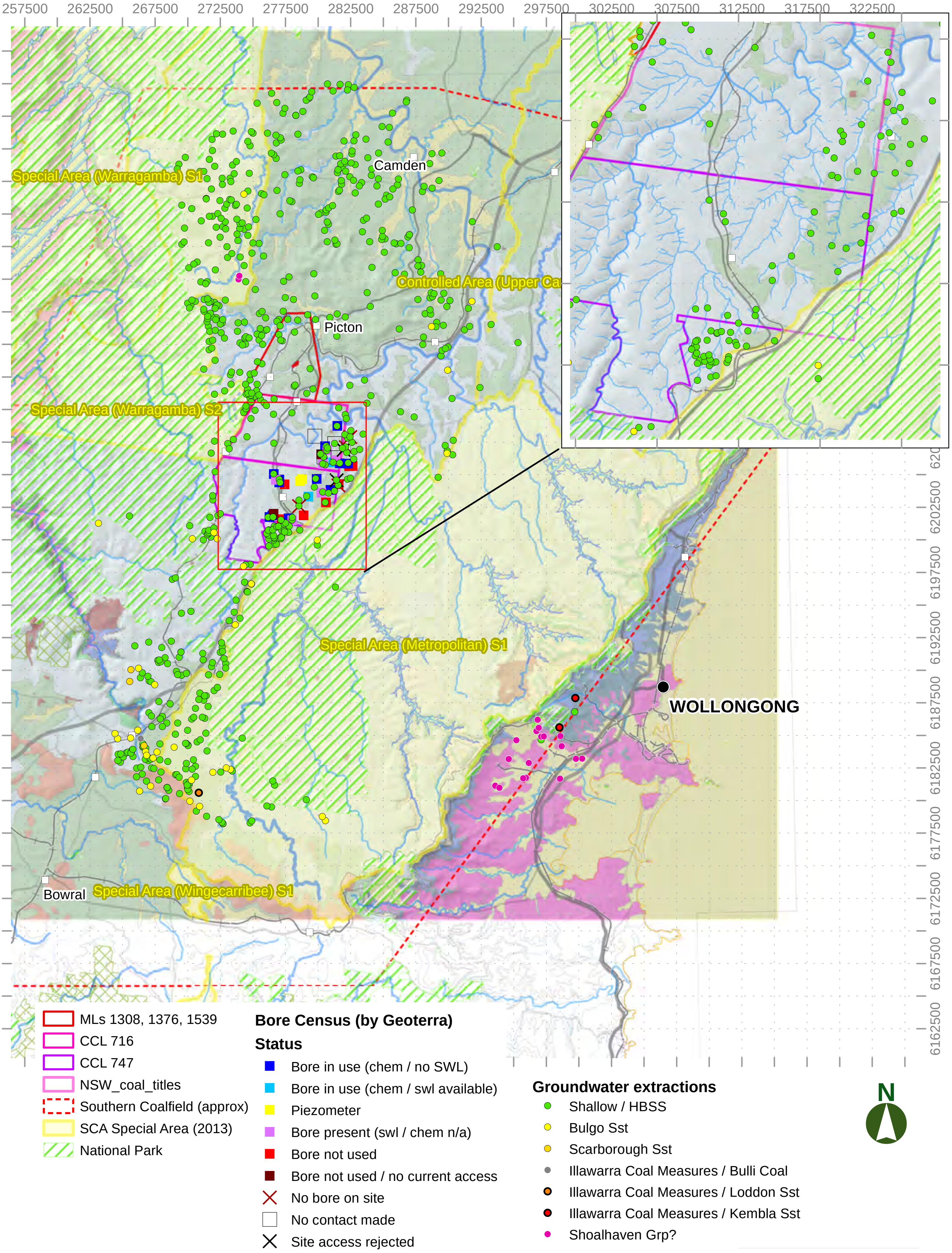


Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15
kilometres

T:\TAHMOOR\GIS\Maps\Deliverable\TAH004\TAH016a_GroundwaterUsers_A4P.mxd

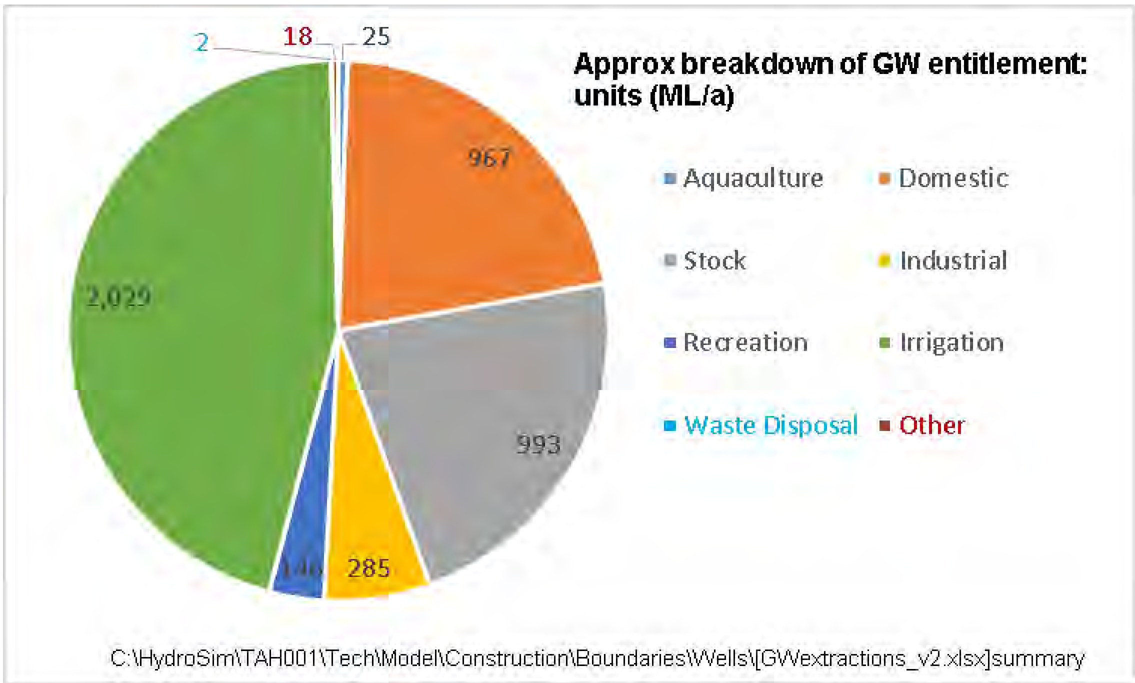
DrawingNo: TAH-004 | Rev: A | Created by: B. Whtite | Date: 07/09/2018

HYDROSIMULATIONS

Tahmoor Coal
Tahmoor South Project

Figure 3-12

Groundwater extraction bores and Tahmoor bore census results



C:\HydroSim\TAH001\Tech\Model\Construction\Boundaries\Wells\[GWextractions_v2.xlsx]summary

Figure 3-13 Breakdown of groundwater entitlement and use

(data from 2014)

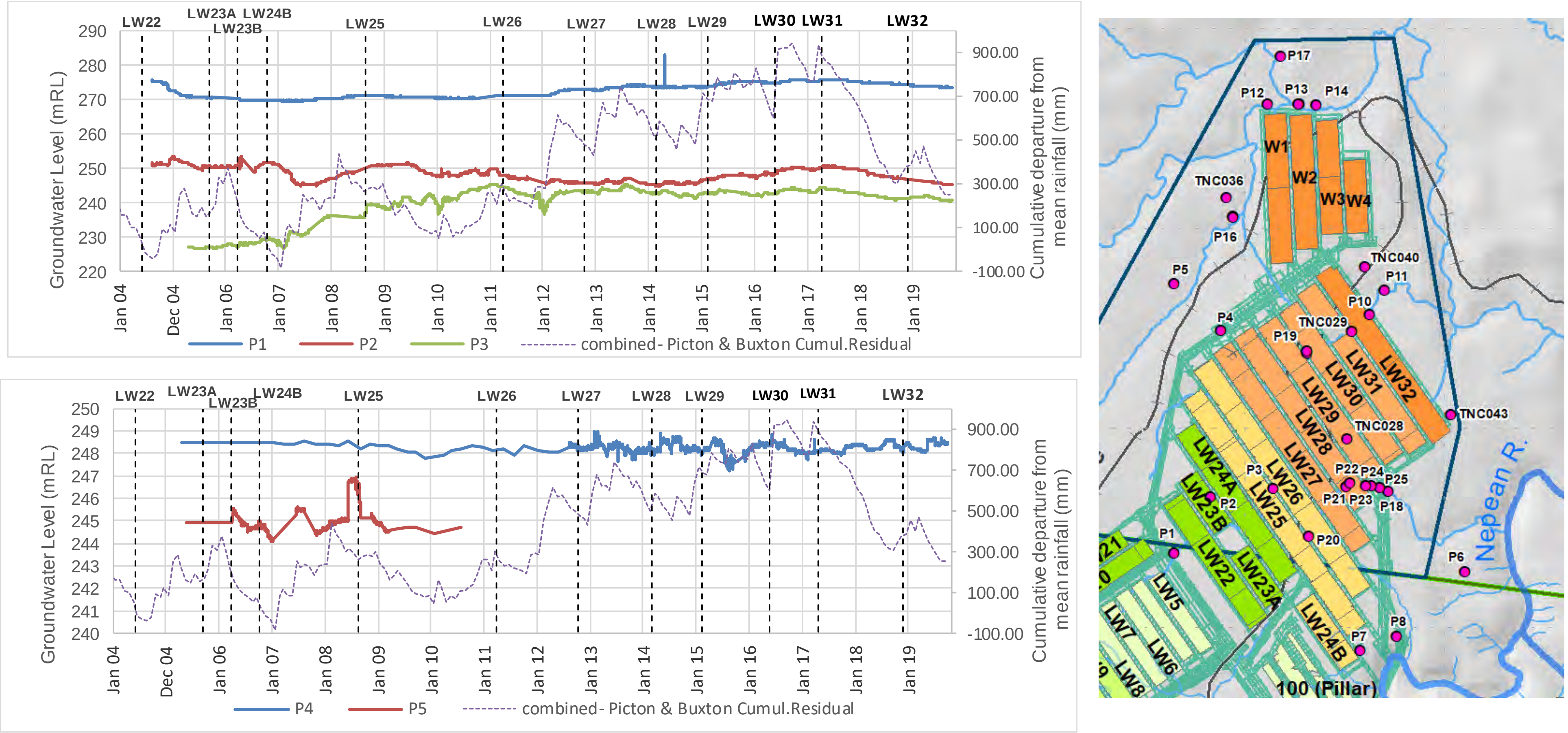
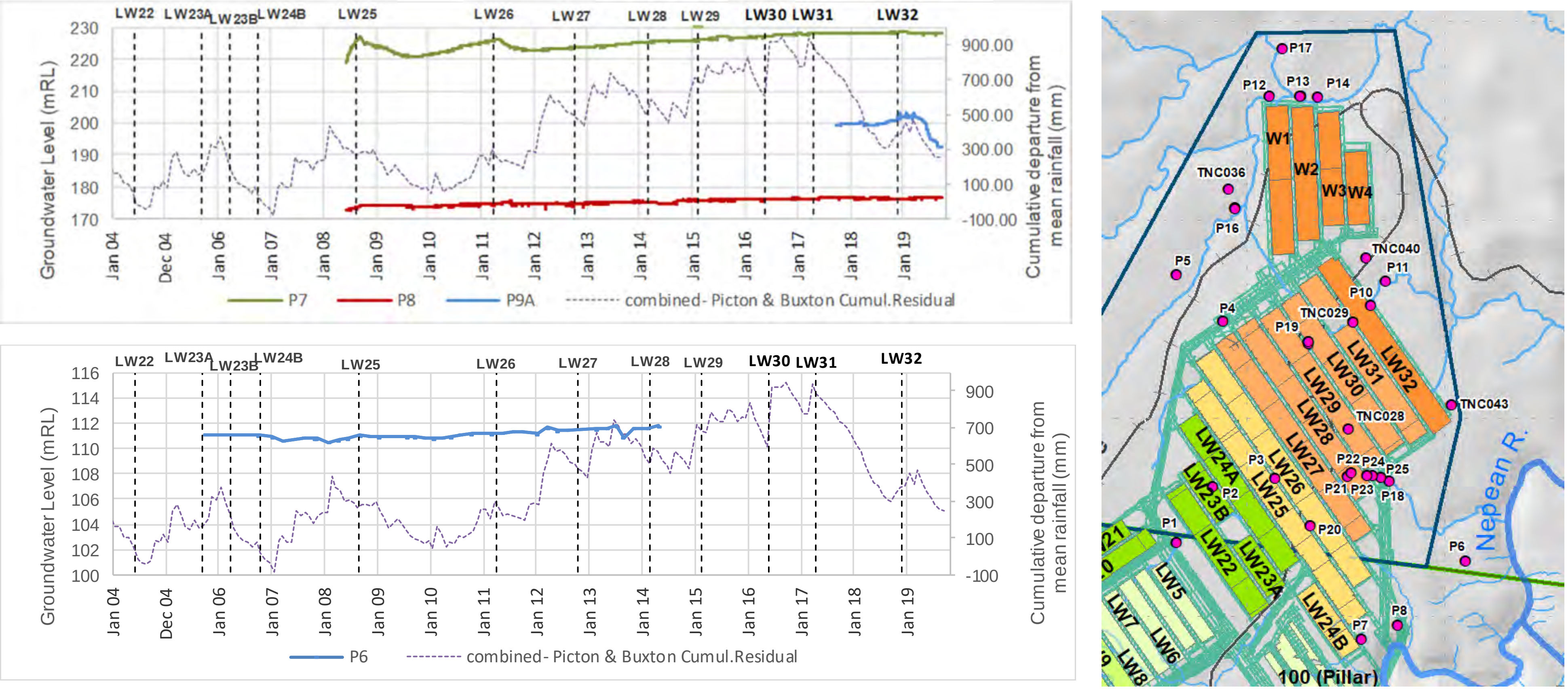
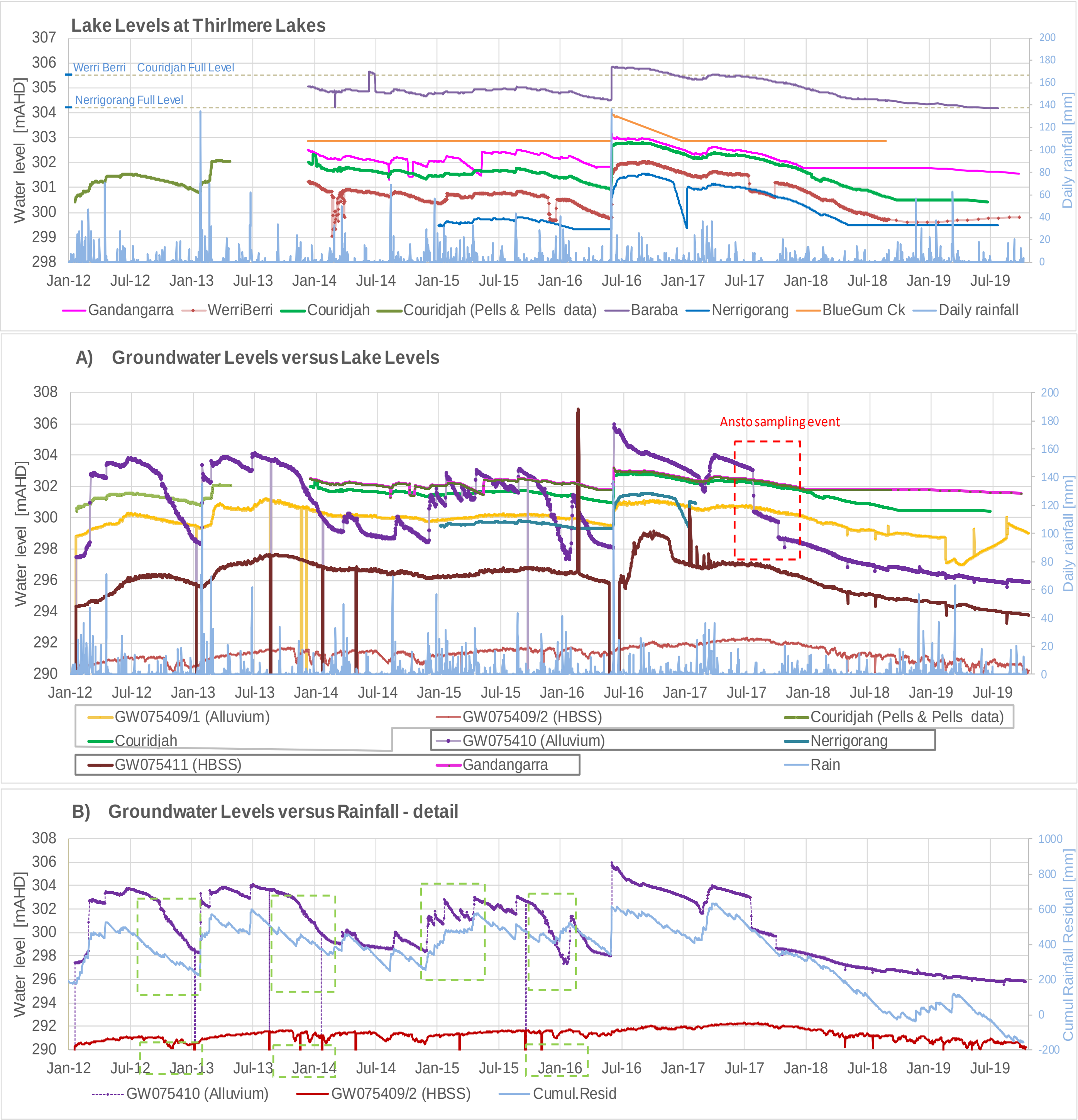


Figure 3-14 Water level trends – shallow aquifer (P1-P5)



H:\Projects-SLR\660-Srv WOL\660-WOL\665.10010 Tahmoor GW RTS\05 Client Data\03 Groundwater\[Tahmoor shallow bores (P1-P9)_201910.xlsx]graphs

Figure 3-15 Water level trends – shallow aquifer (P6-P9)

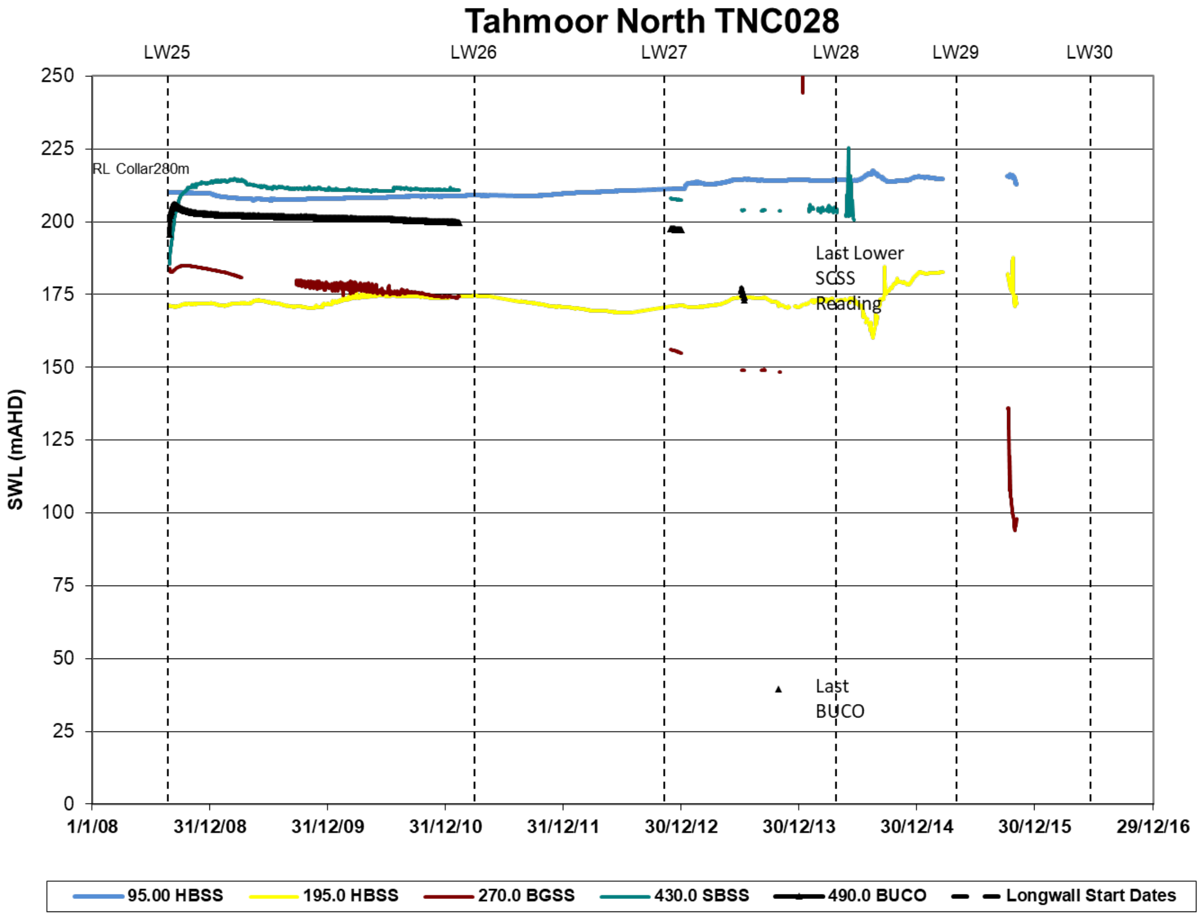

Lake Levels at Thirlmere Lakes

A) Groundwater Levels versus Lake Levels

B) Groundwater Levels versus Rainfall - detail

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\02 Site Notes & Measurements\02 Surface Water\01 Lakes\ThirlmereLakes_WaterLevels_Compiled_201910.xlsx

Figure 3-16 Thirlmere Lakes: lake and groundwater levels



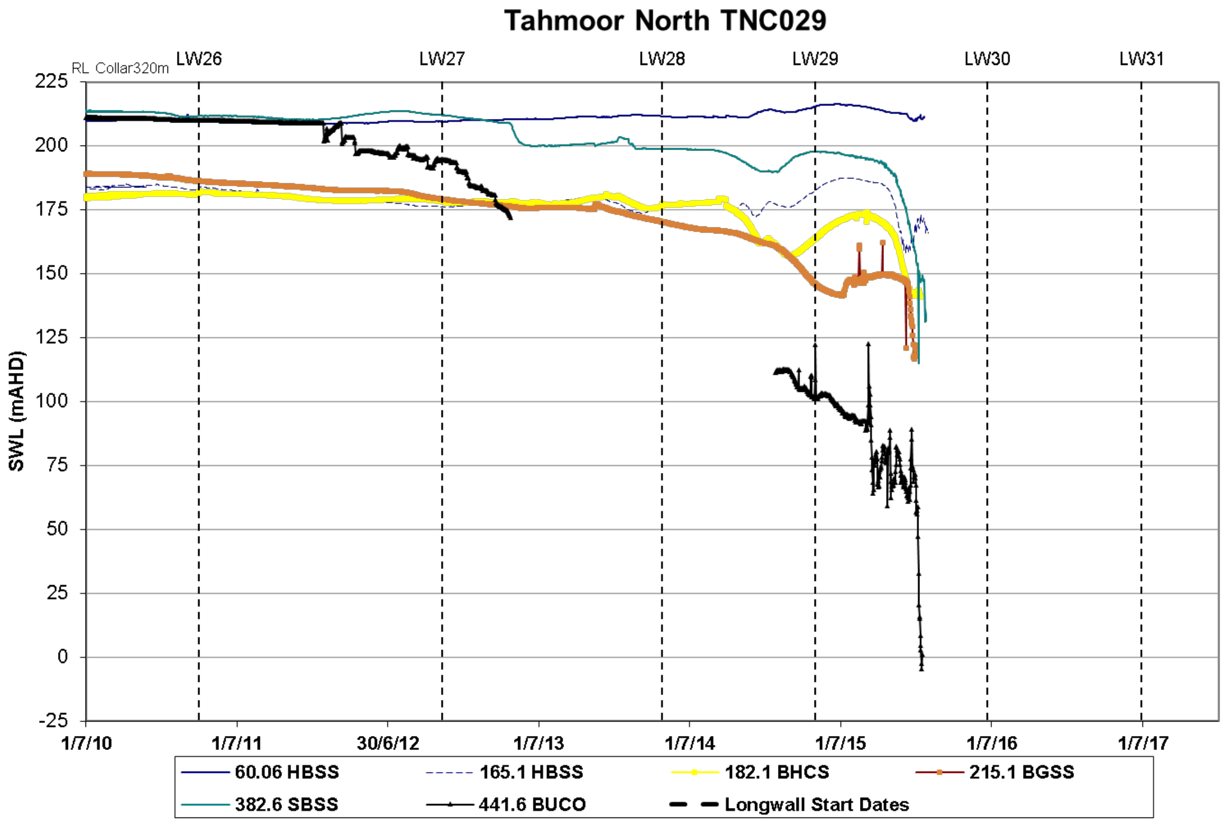
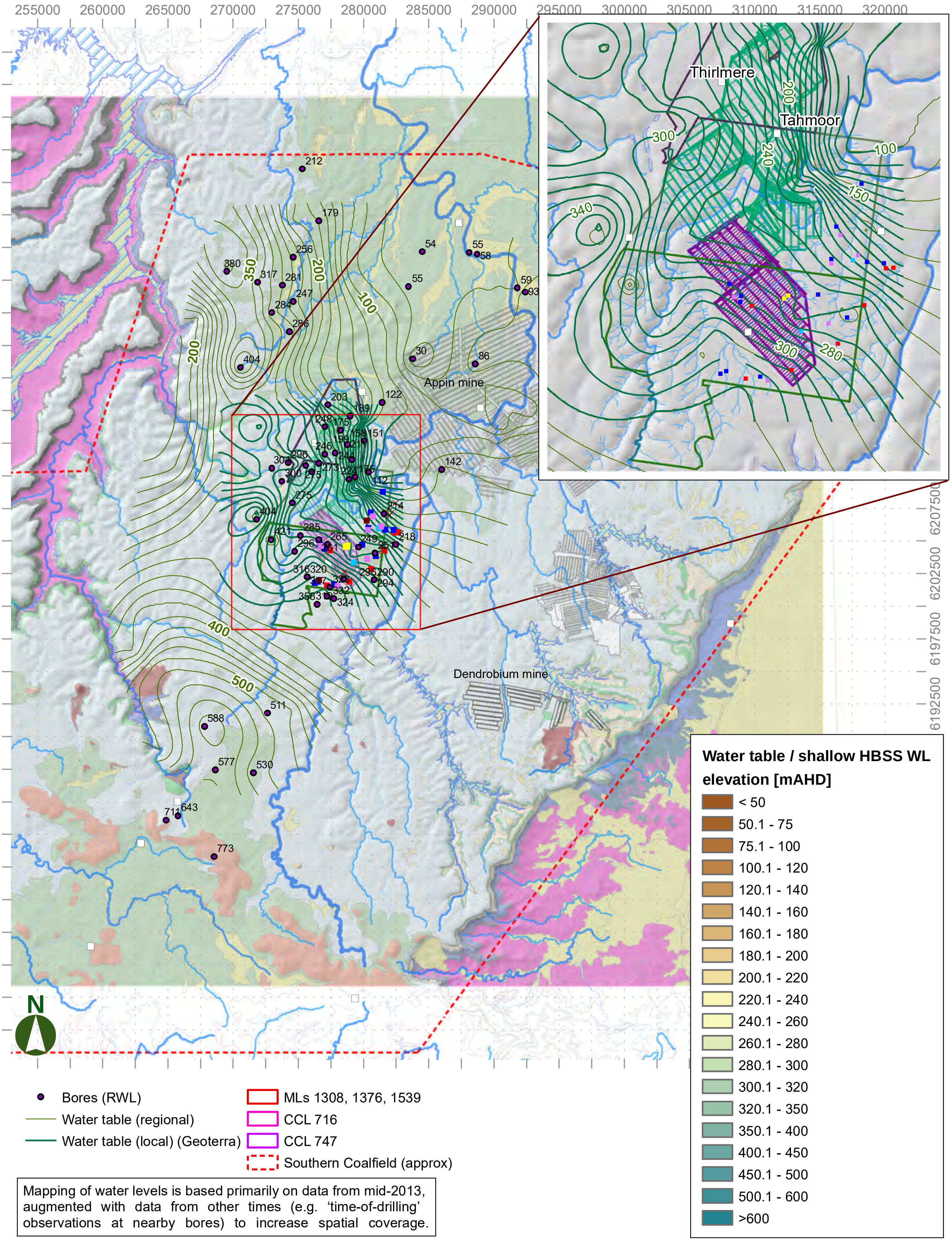


Figure 3-17 Water level trends – deeper units



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

Tahmoor Coal
Tahmoor South Project

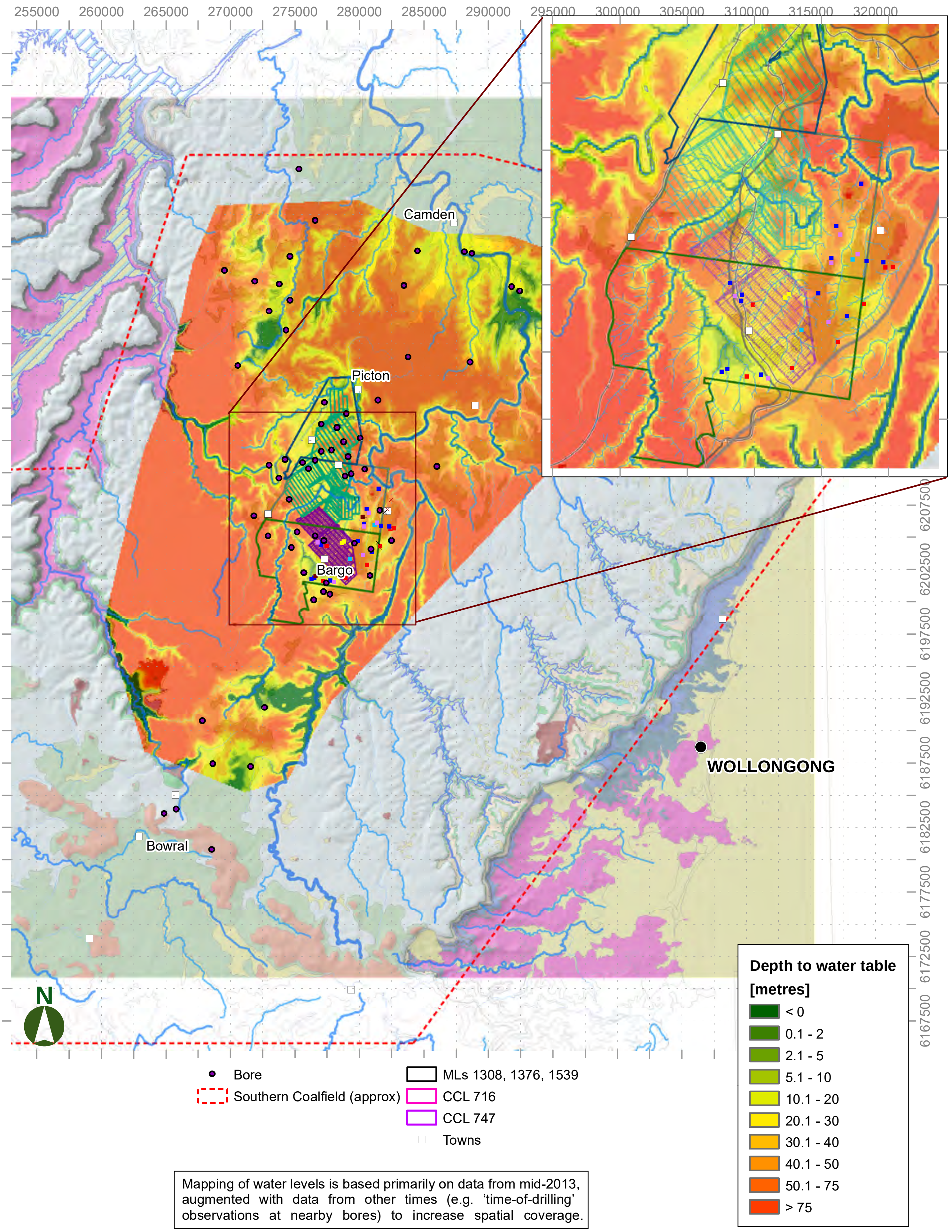
Figure 3-18

Interpreted water table / Hawkesbury Sandstone water levels

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 30/09/2019

HYDROSIMULATIONS

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_WaterTableHBSS_AmendedProject.mxd



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

Tahmoor Coal
Tahmoor South Project

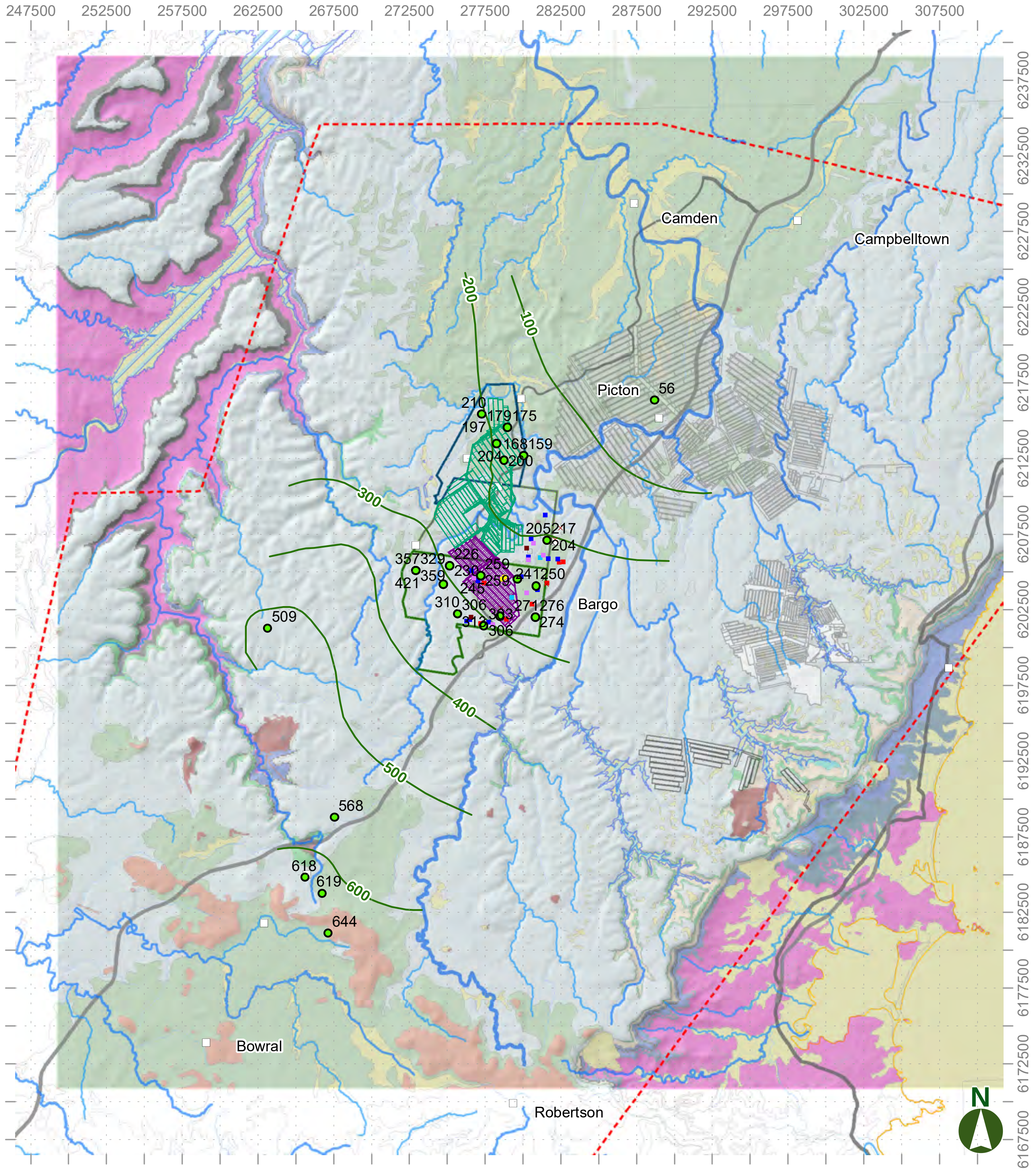
Figure 3-19

Interpreted depth to water table (Hawkesbury Sandstone water levels)

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 30/09/2019

HydroSimulations

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_UnsaturatedDepth_AmendedProject.mxd



- ● 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

Tahmoor Coal
Tahmoor South Project

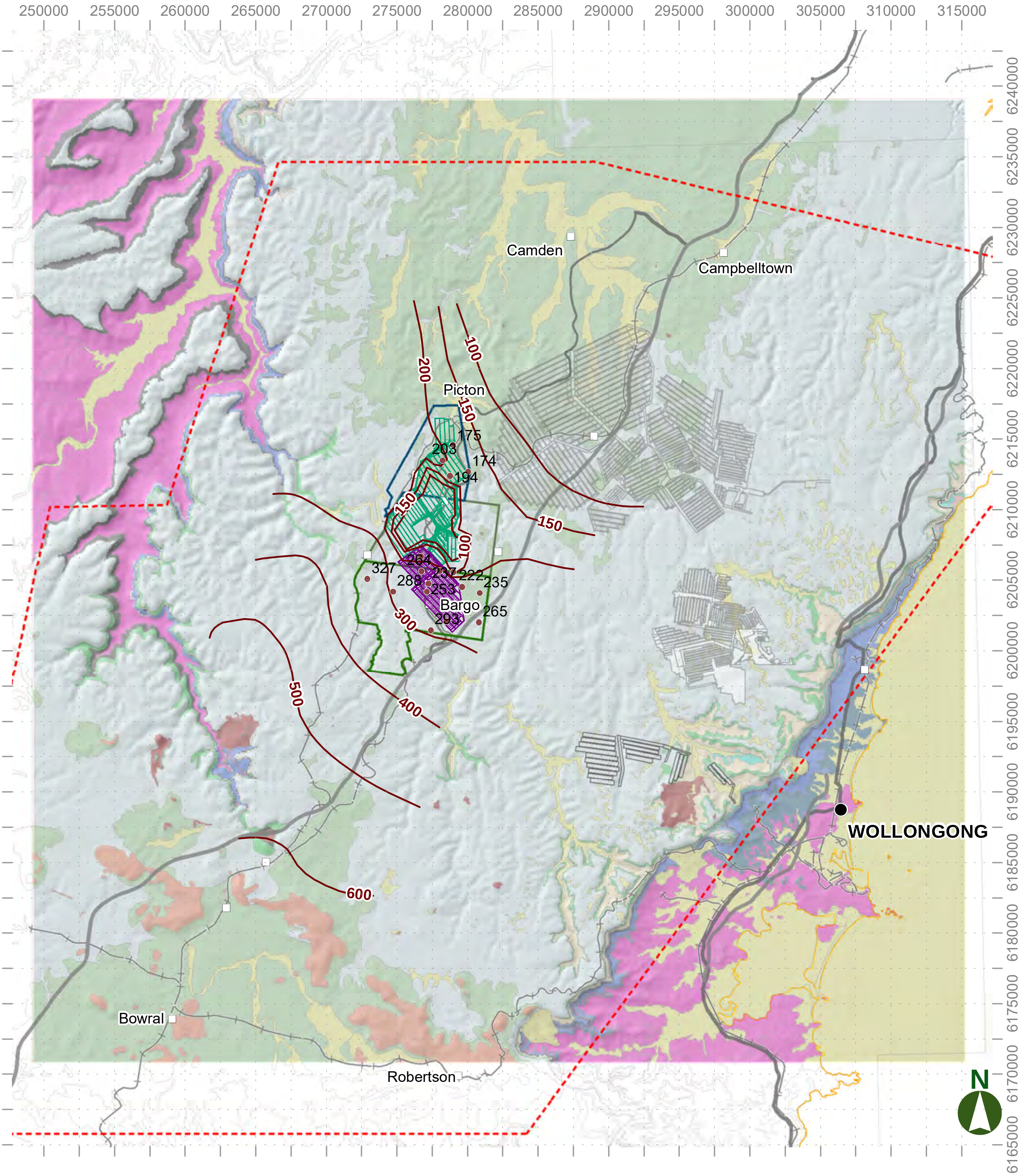
Figure 3-20

Water levels in the Bulgo Sandstone

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 30/09/2019

HYDROSIMULATIONS

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_BulgoSstWLs_Amendedproject.mxd



● 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

Tahmoor Coal
Tahmoor South Project

Figure 3-21

Water levels in the Bulli Coal Seam

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 30/09/2019

HYDROSIMULATIONS

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_BulliSeamWLs_A4P_AmendedProject.mxd

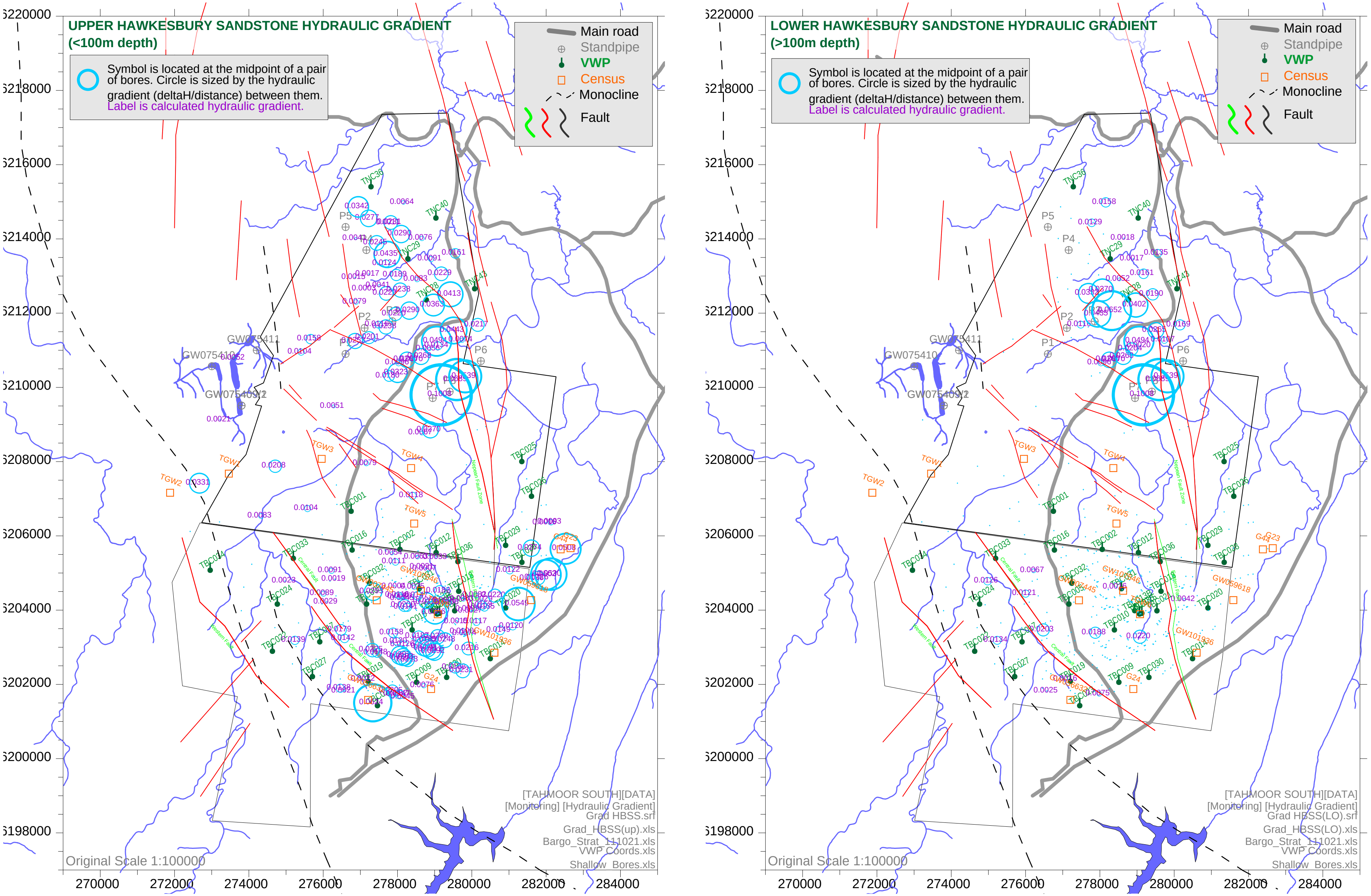


Figure 3-22 Hydraulic gradient analysis: Hawkesbury Sandstone upper and lower

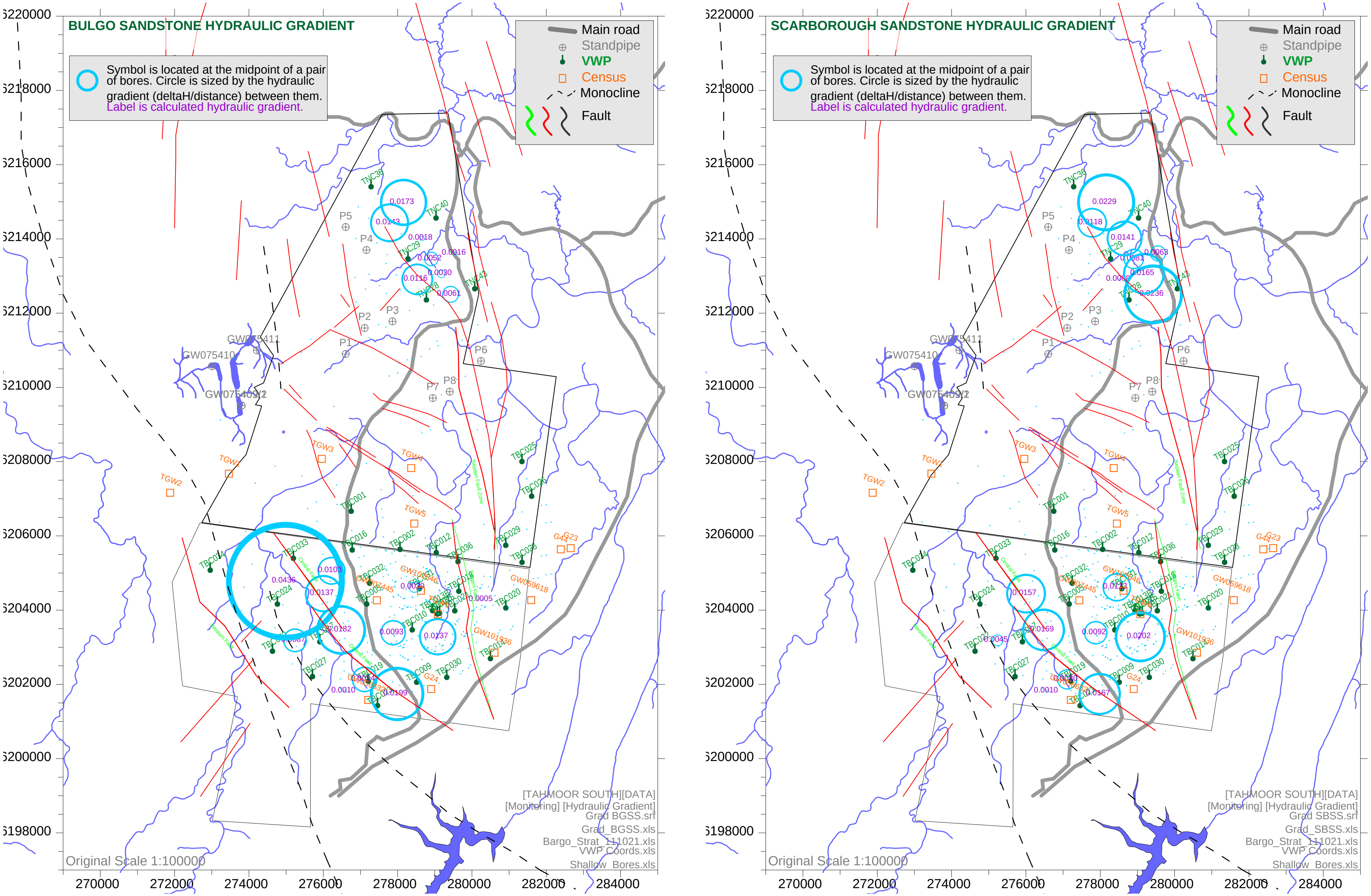


Figure 3-23 Hydraulic gradient analysis: Bulgo and Scarborough Sandstones

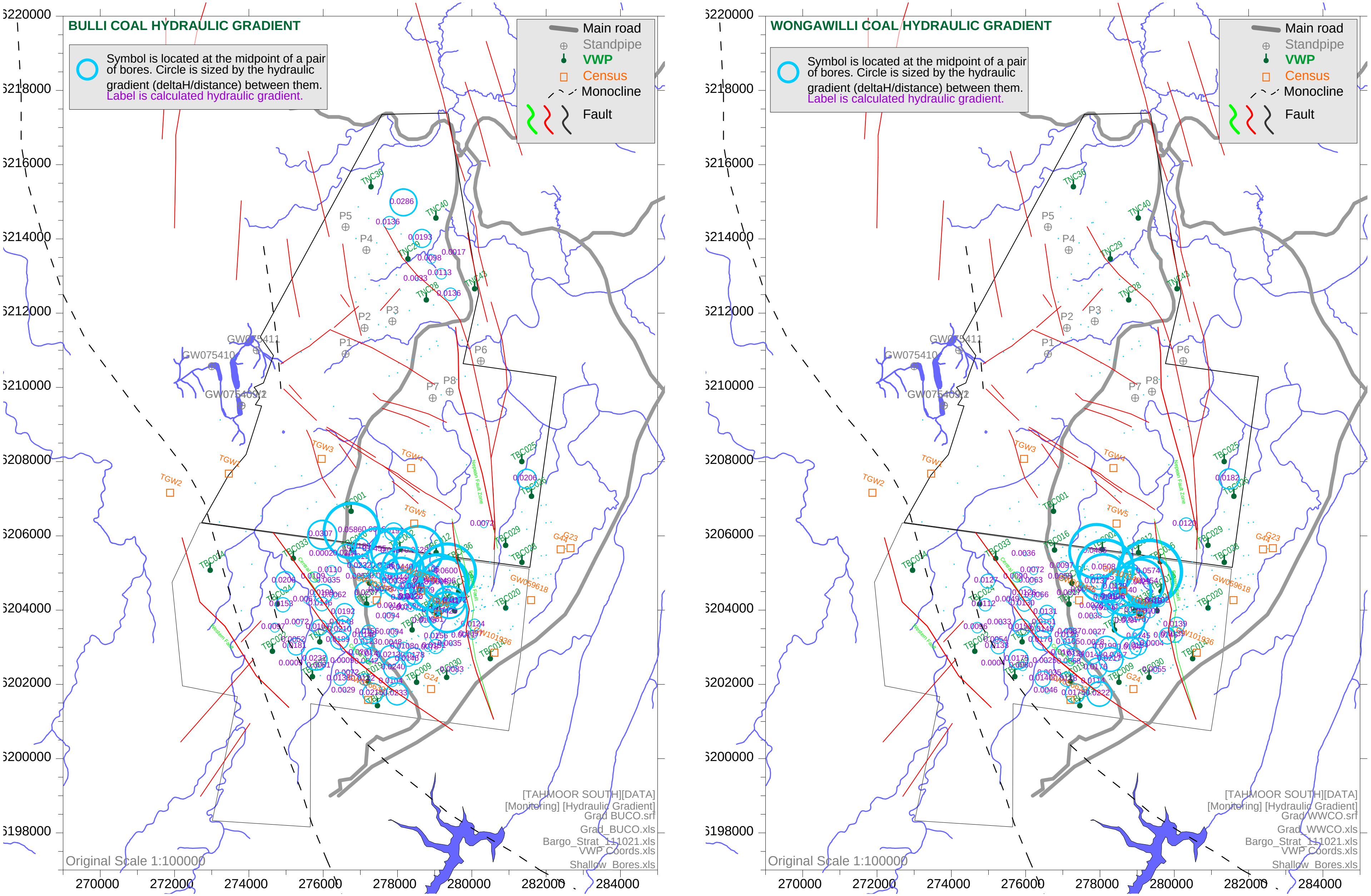
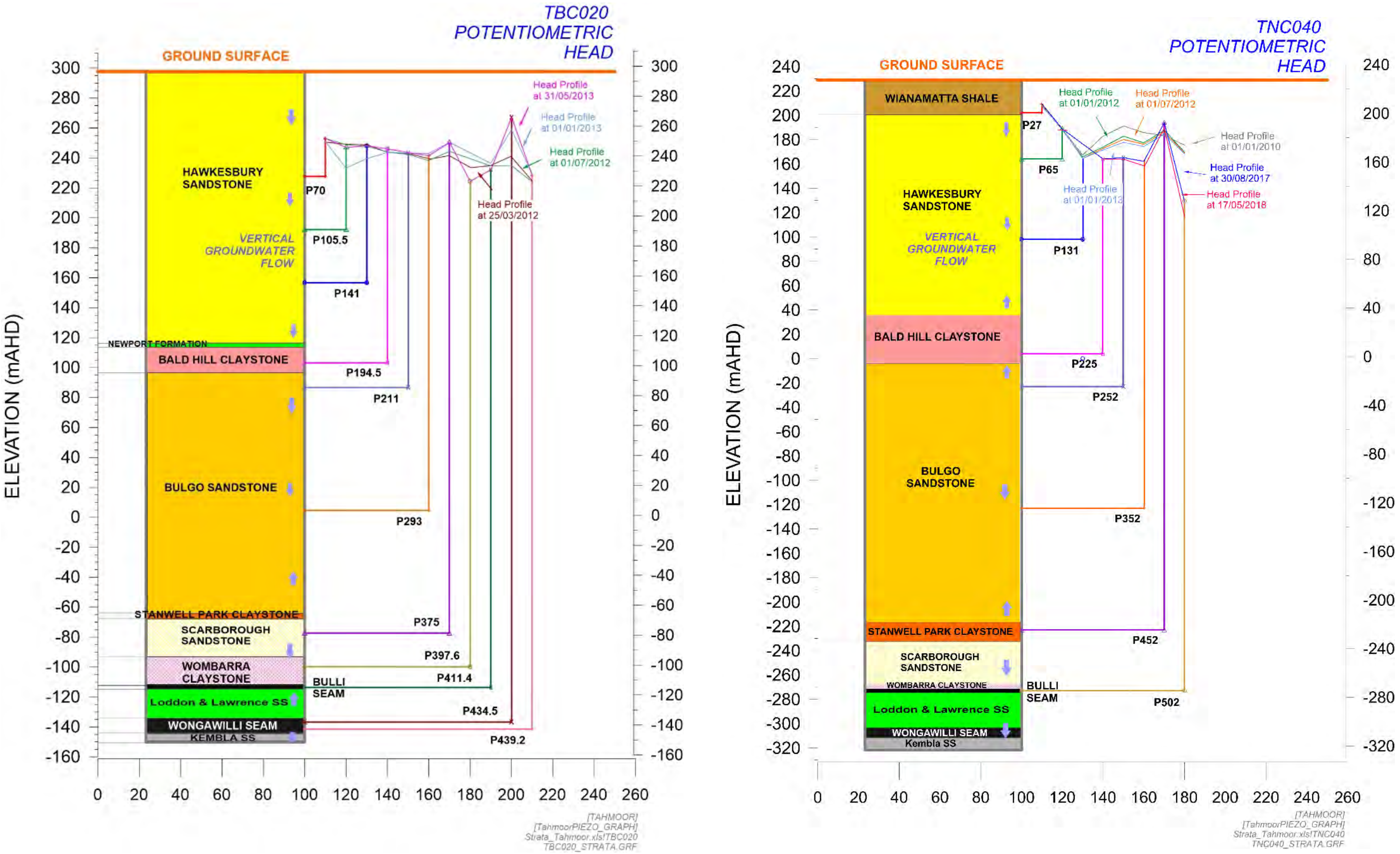


Figure 3-24 Hydraulic gradient analysis: Bulli and Wongawilli coal seams



[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TBC020
TBC020_STRATA.GRF

[TAHMOOR]
[TahmoorPIEZO_GRAPH]
Strata_Tahmoor.xls!TNC040
TNC040_STRATA.GRF

Figure 3-25 Vertical head profiles: TBC020 and TNC040

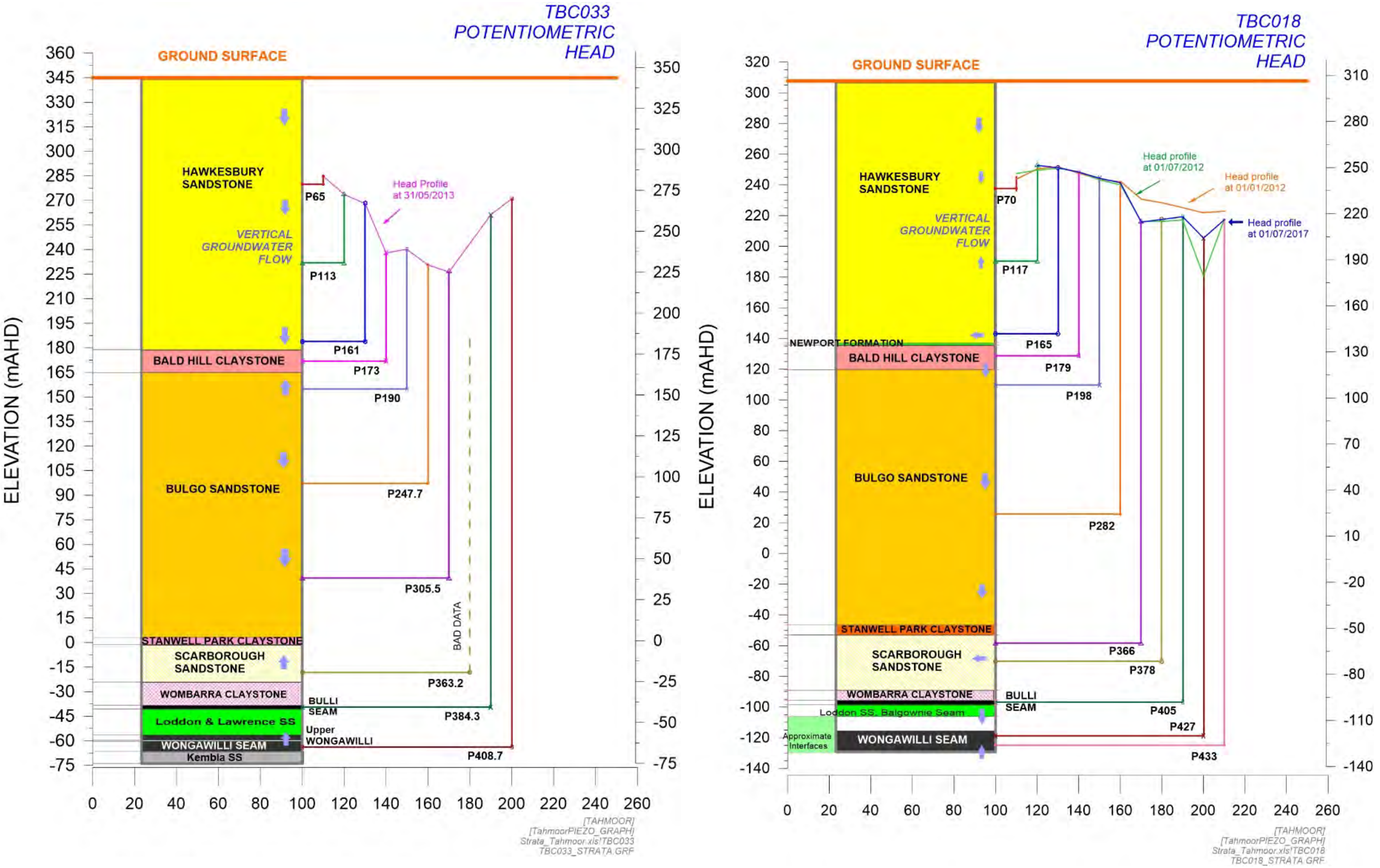
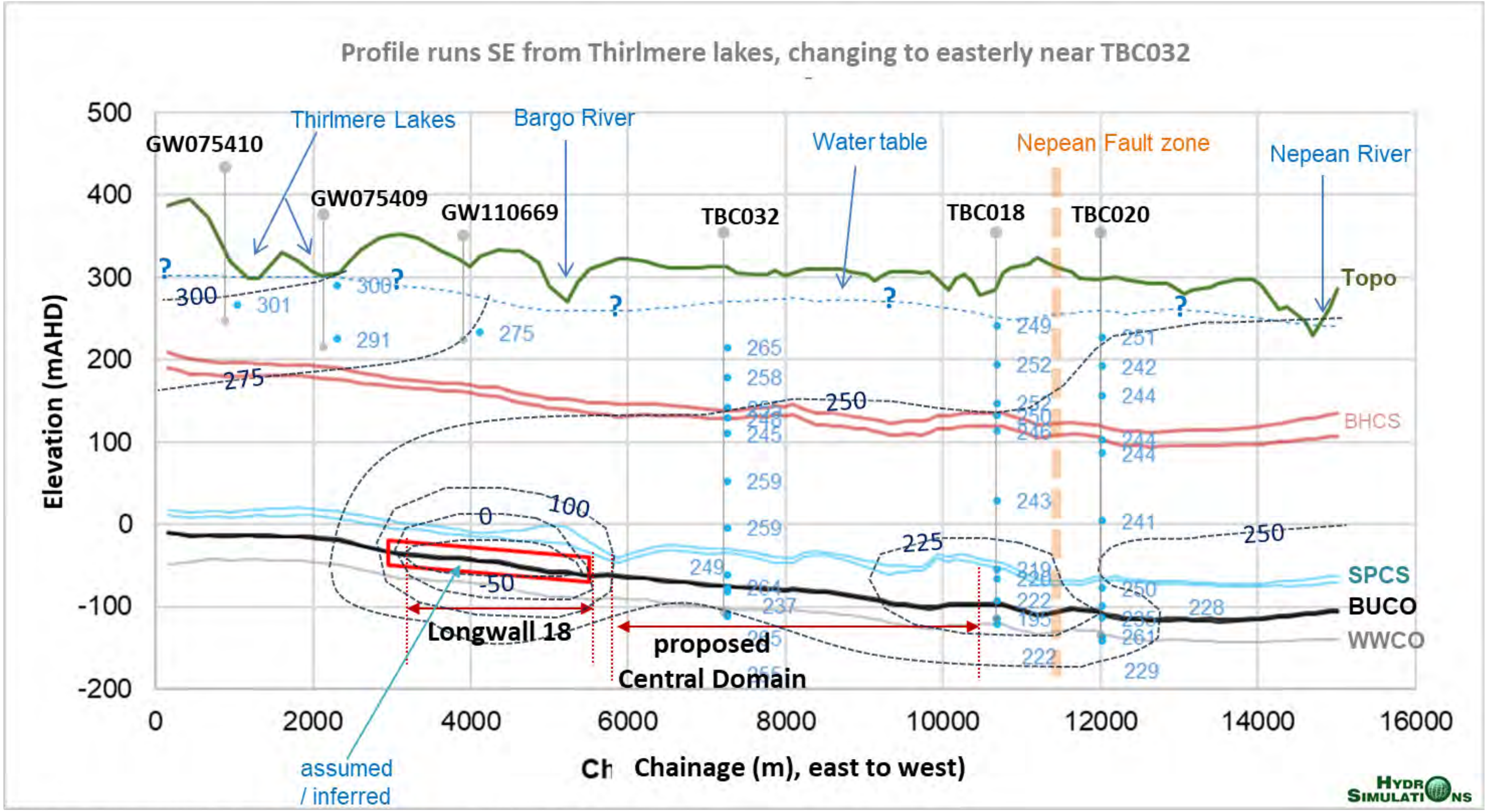
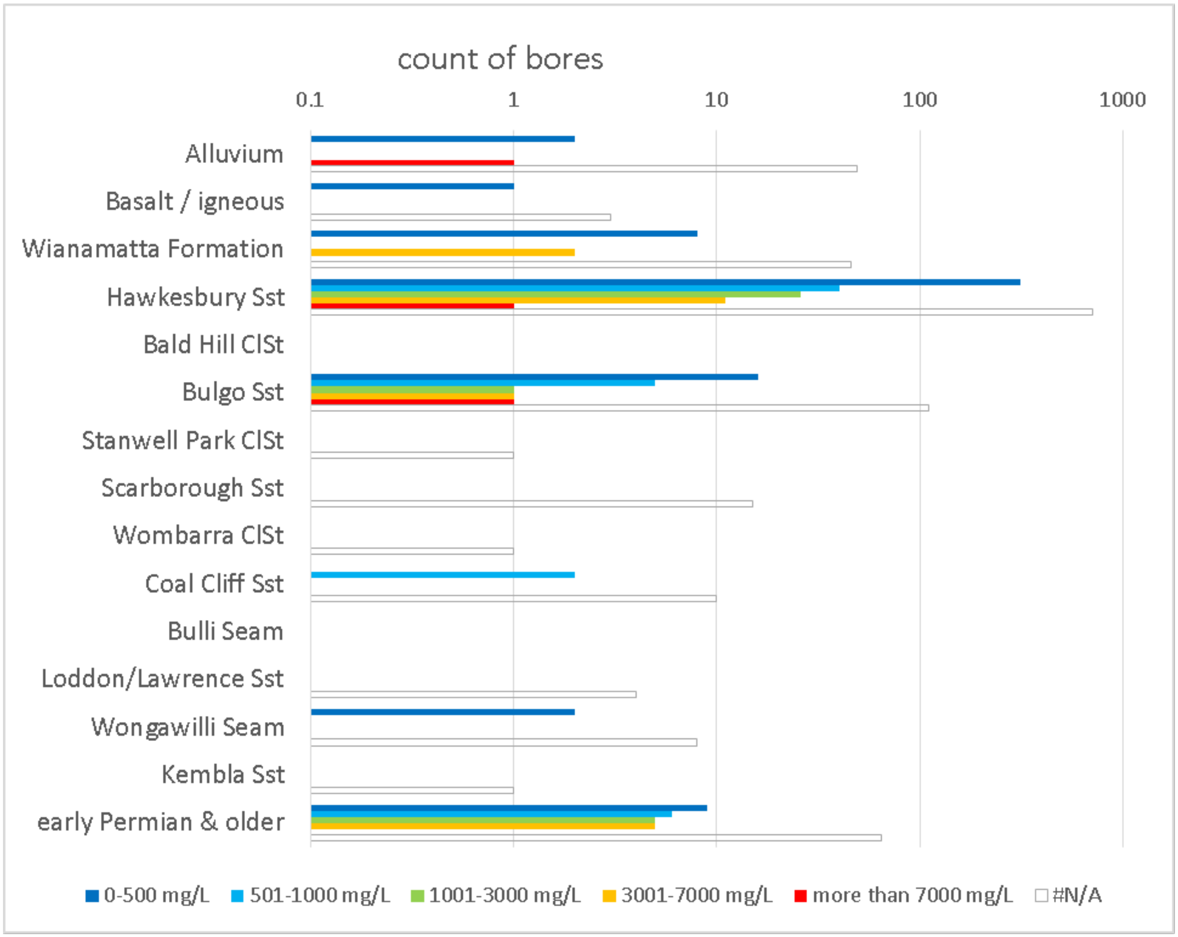


Figure 3-26 Vertical head profiles: TBC033 and TBC018



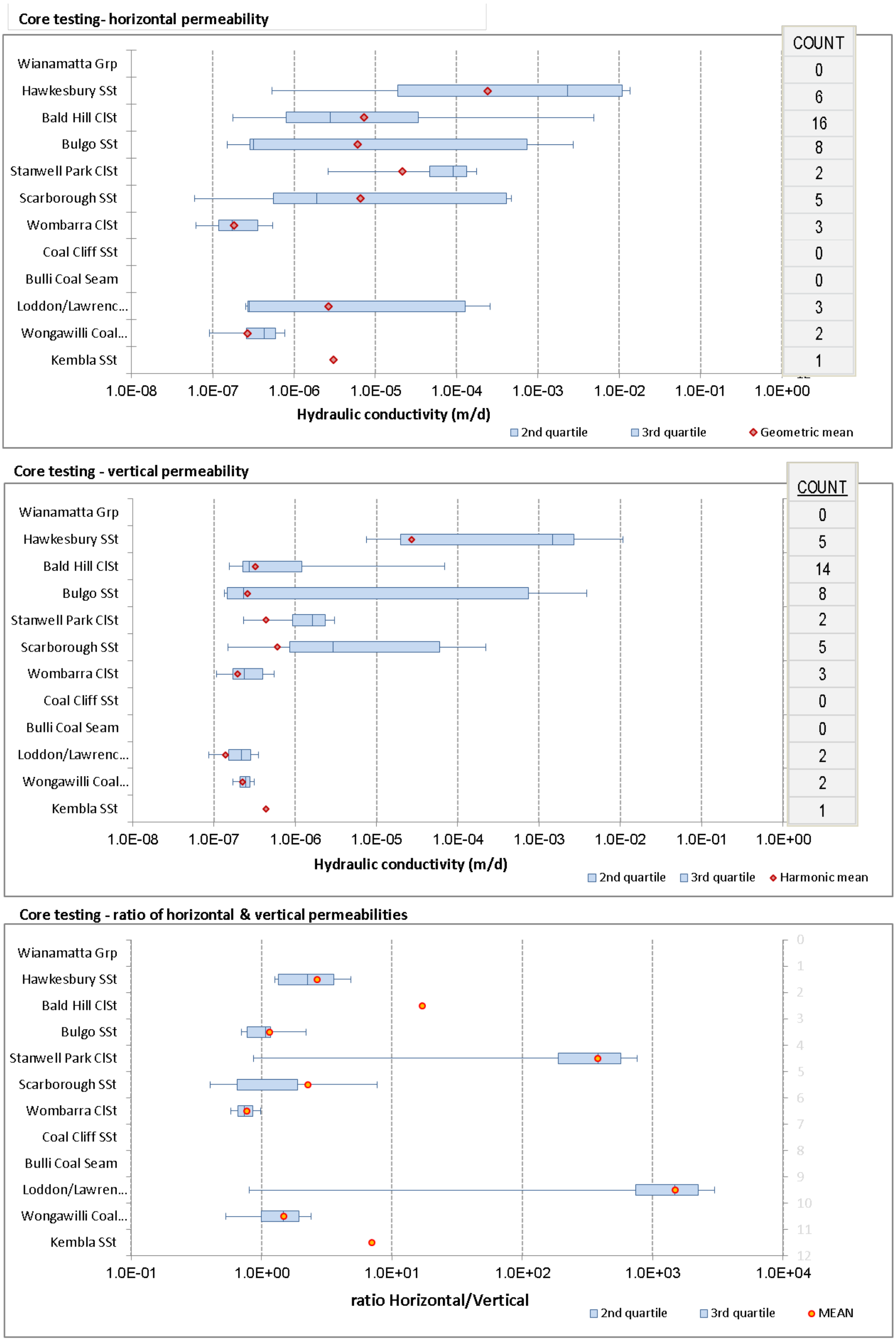
C:\HydroSim\TAH001\Tech\WaterLevels\WaterLevel_Xsection\WaterLevel_X-section.pptx
and WaterLevel_Xsection_TahmoorSouthCentral.xlsx

Figure 3-27 Hydraulic head profile through Tahmoor South



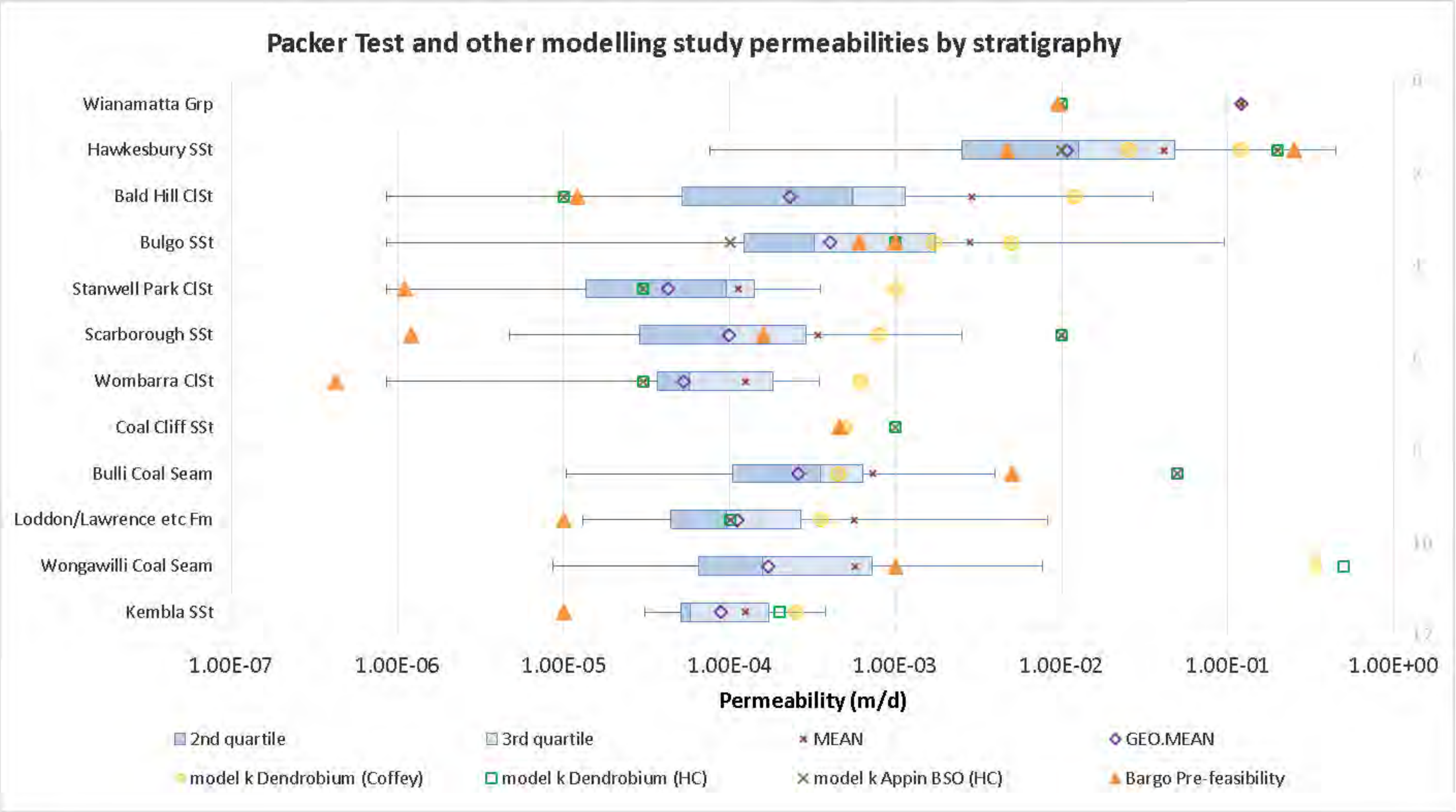
C:\HydroSim\TAH001\Tech\GroundwaterUse\NSW_GroundwaterWorks_Bores.xlsx

Figure 3-28 Summary of groundwater salinity data



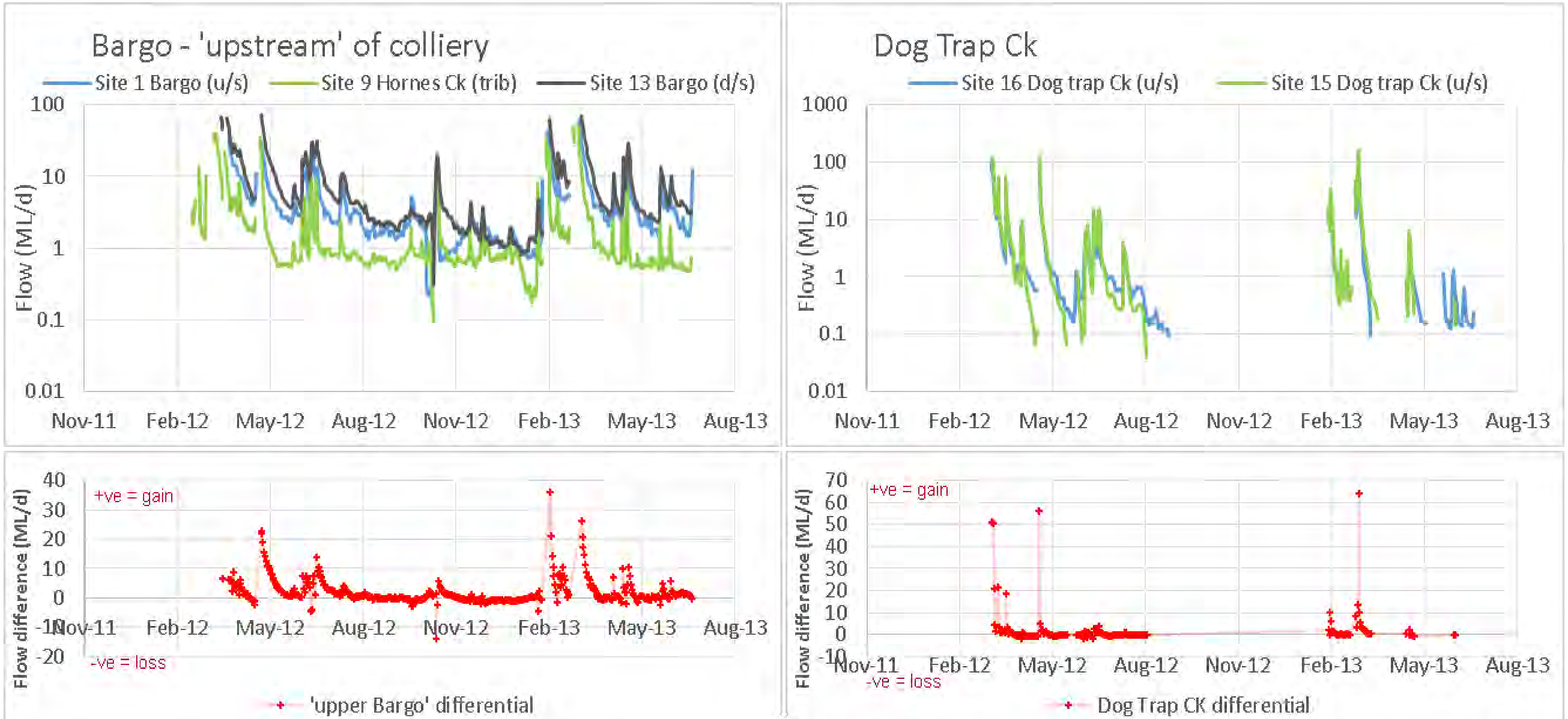
C:\HydroSim\TAH001\Tech\Permeability\[Tahmoor Packer&CorePermeability_v3xls]Report

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



C:\HydroSim\TAH001\Tech\SurfaceWater\DataFromHydrometric\[SurfaceWaterData_compiled.xlsx]FlowDifferentials

Figure 3-31 Flow differentials along the Bargo River and Dog Trap Creek

(refer to site locations on Figure 3-5)

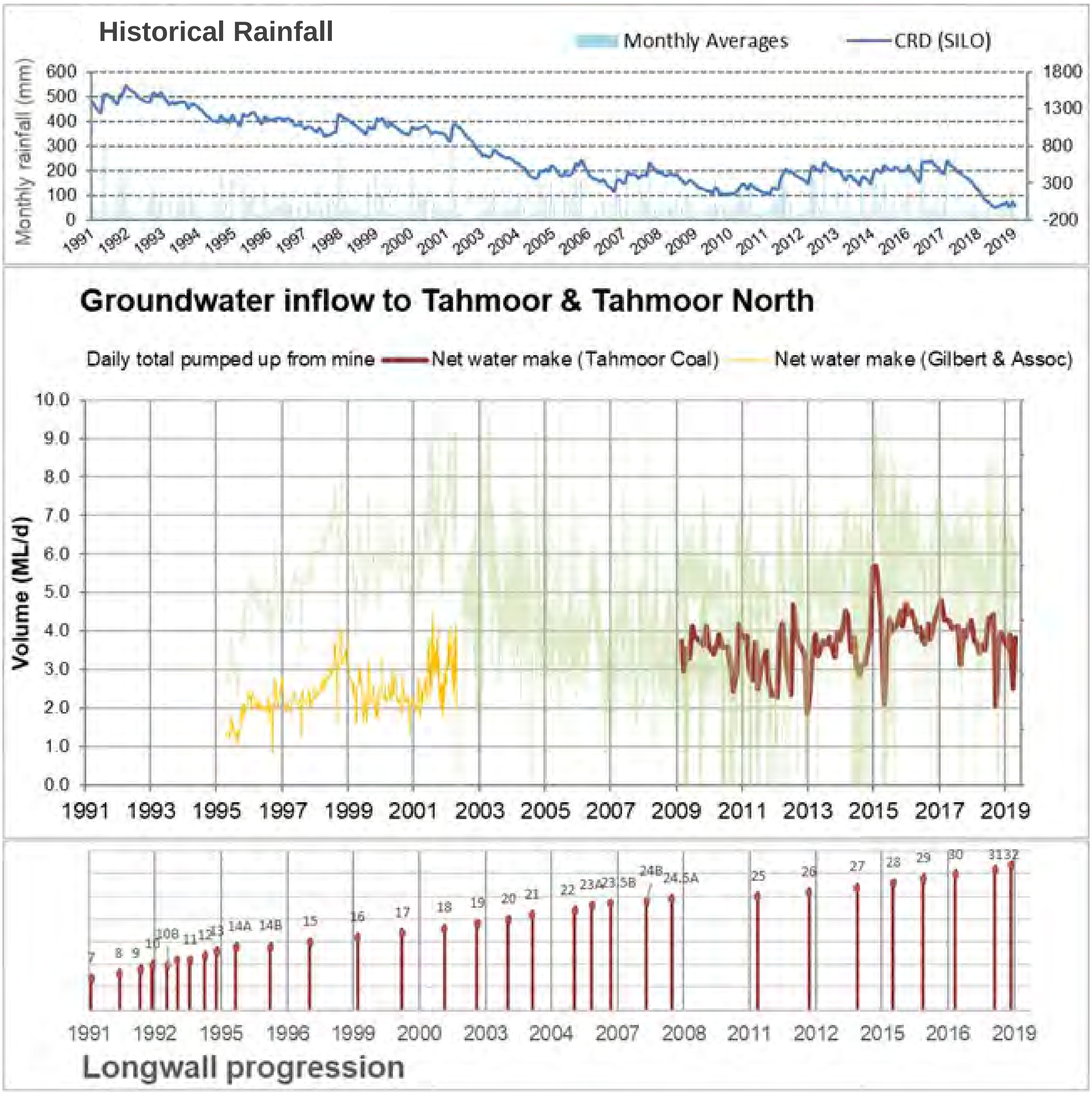
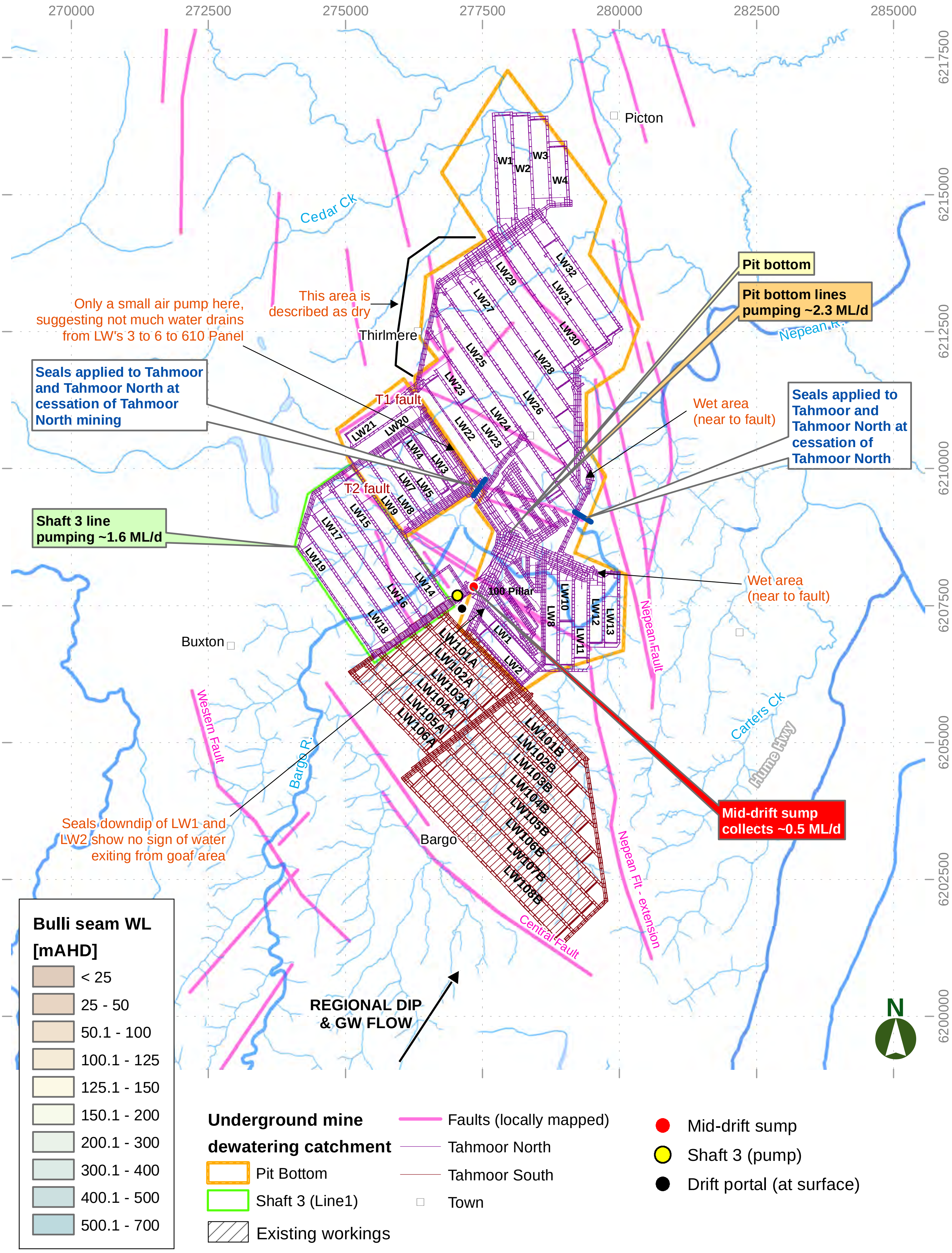


Figure 3-32 Historical record of inflows at Tahmoor North



Scale: 90,000 at A4
GDA 1994 MGA Zone 56

0 0.5 1 2 3 4 kilometres

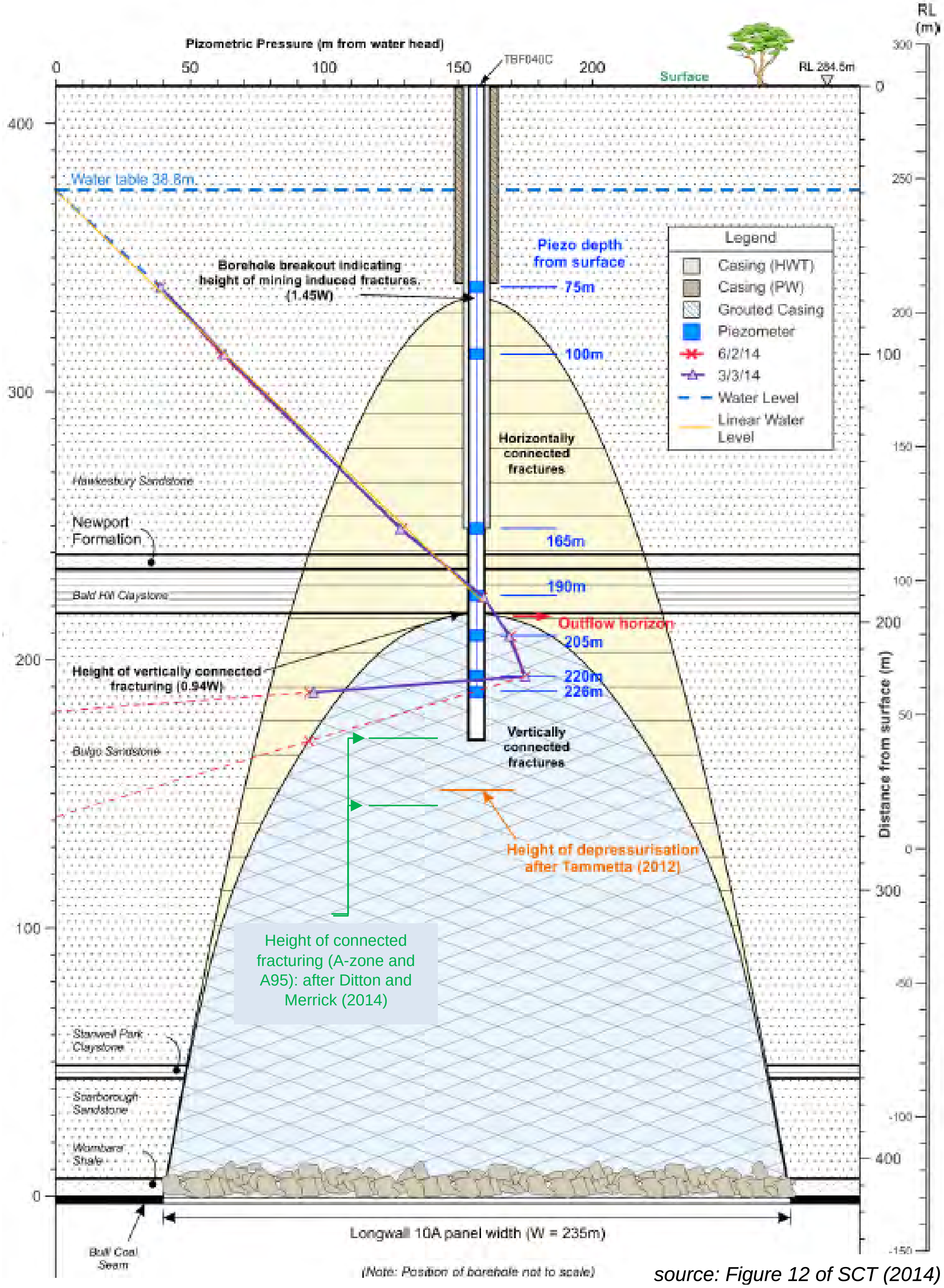
Tahmoor Coal
Tahmoor South Project

Figure 3-33

Record of observations of inflow and drainage plan

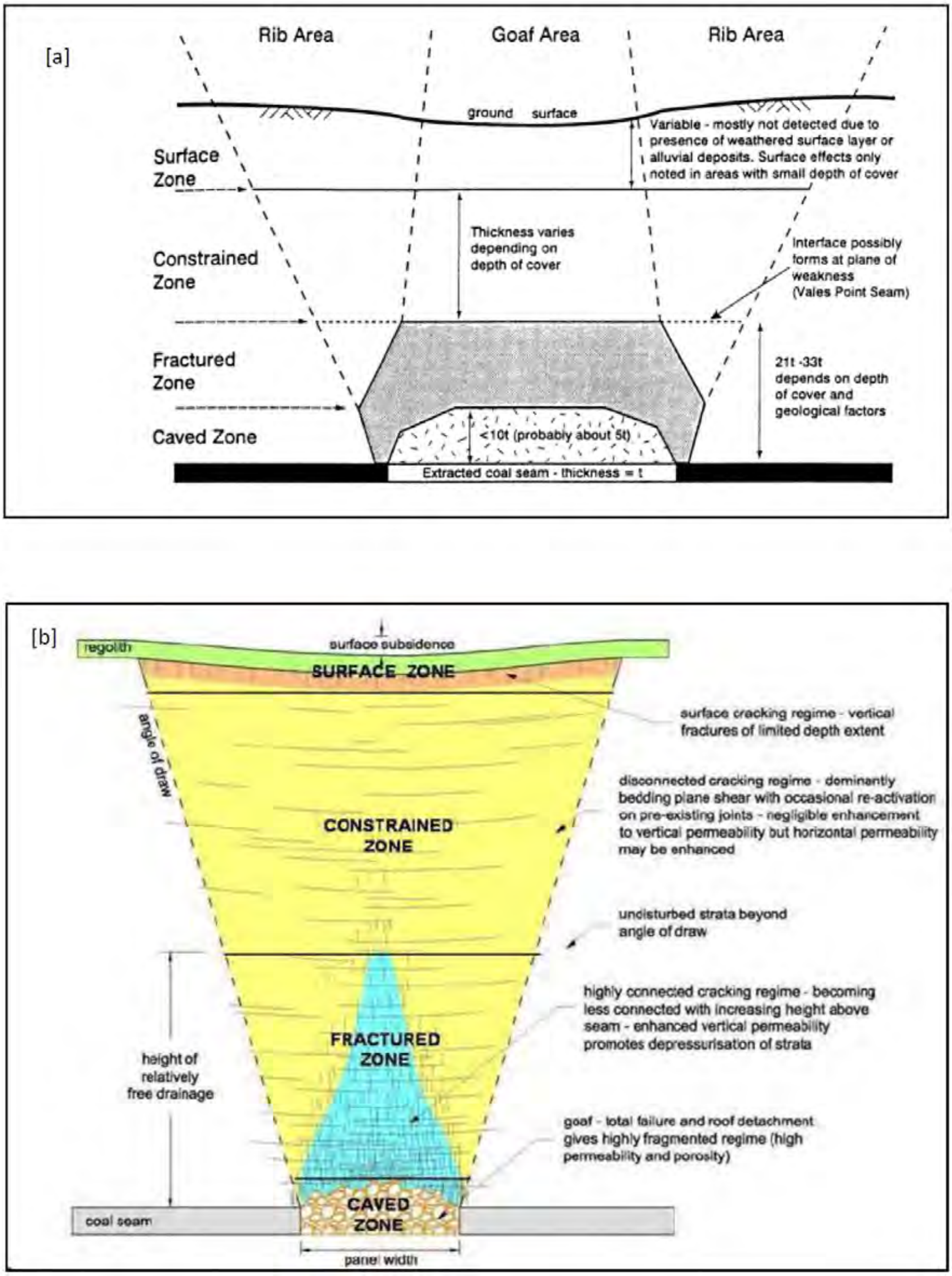
DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 30/09/2019

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_MineInflows&Drainage_AmendedProject.mxd



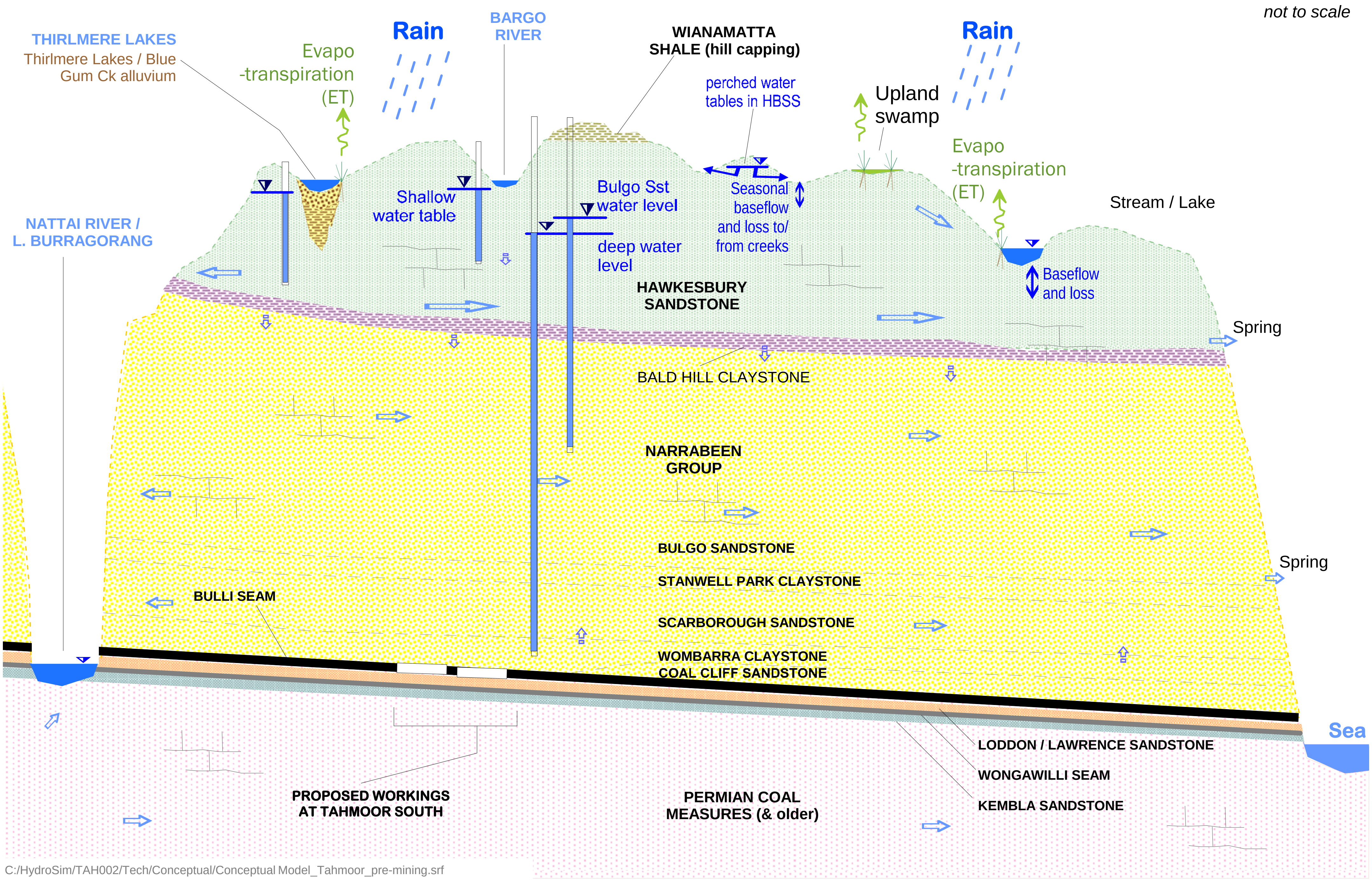
source: Figure 12 of SCT (2014)

Figure 3-34 Profile with piezometric and geotechnical observations from TBF040

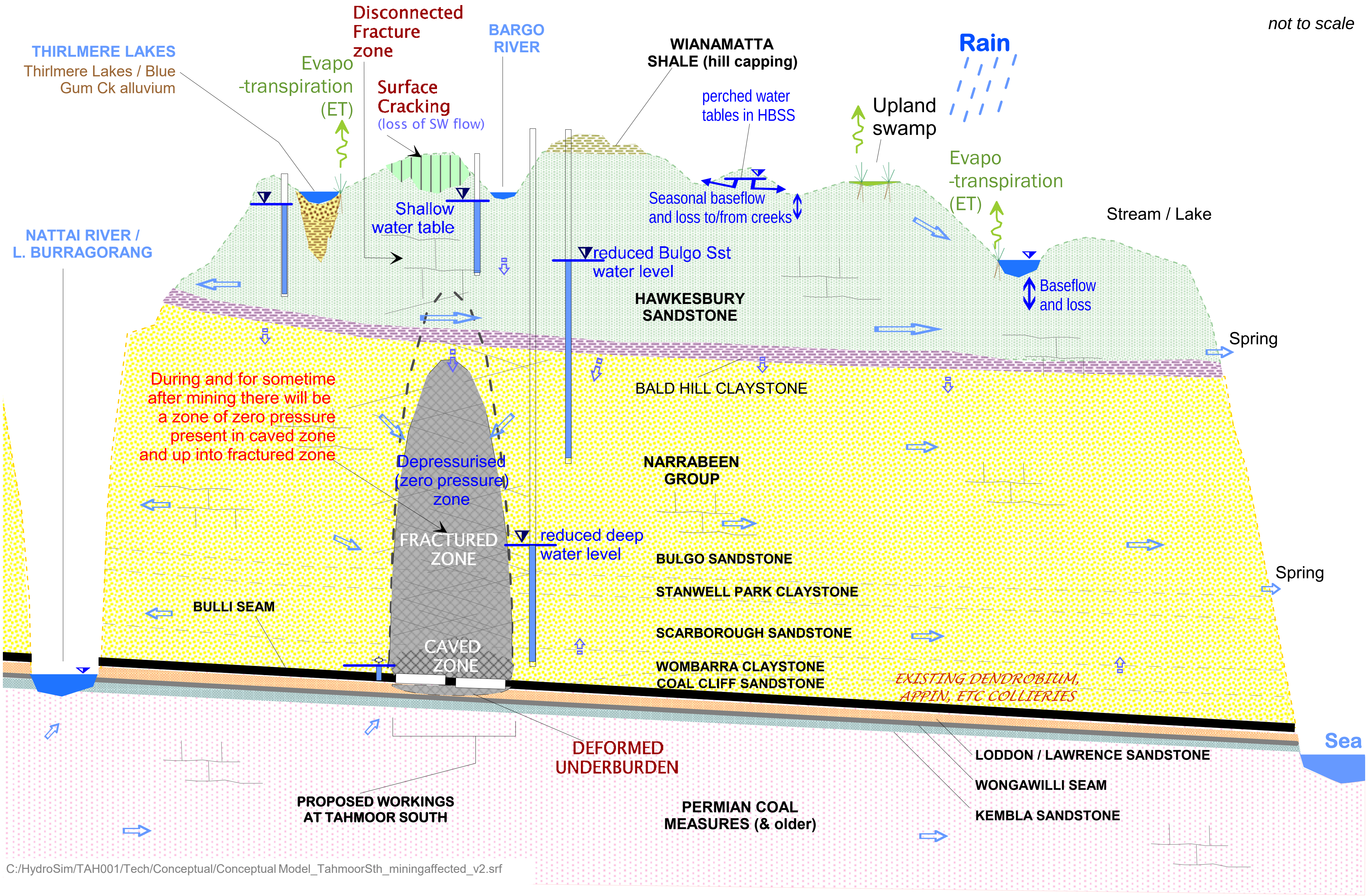


(source Forster & Enever, 1992 and Department of Planning, 2008)

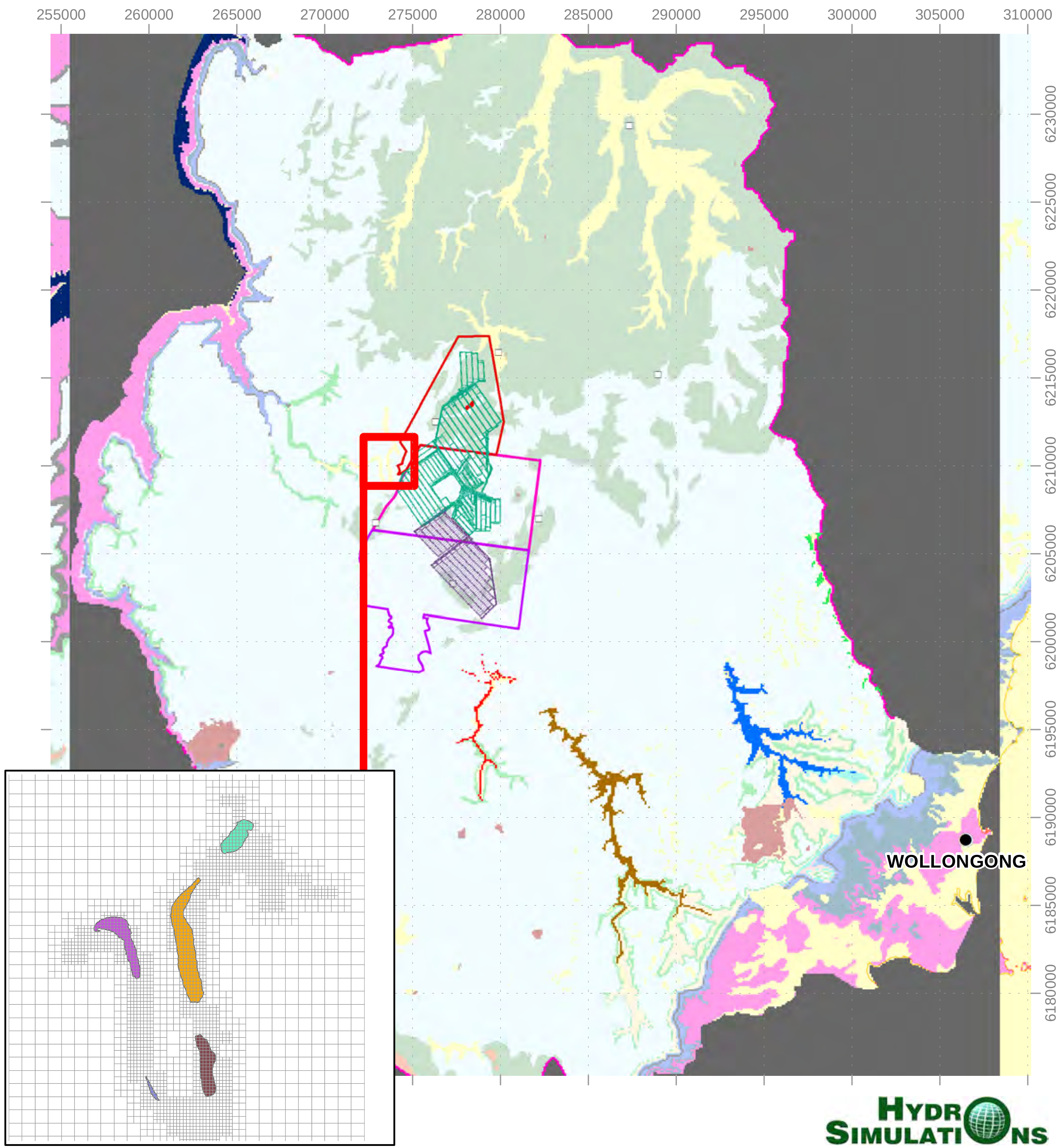
Figure 3-35 Conceptual Model of Longwall Mining-Induced Rock Deformation



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

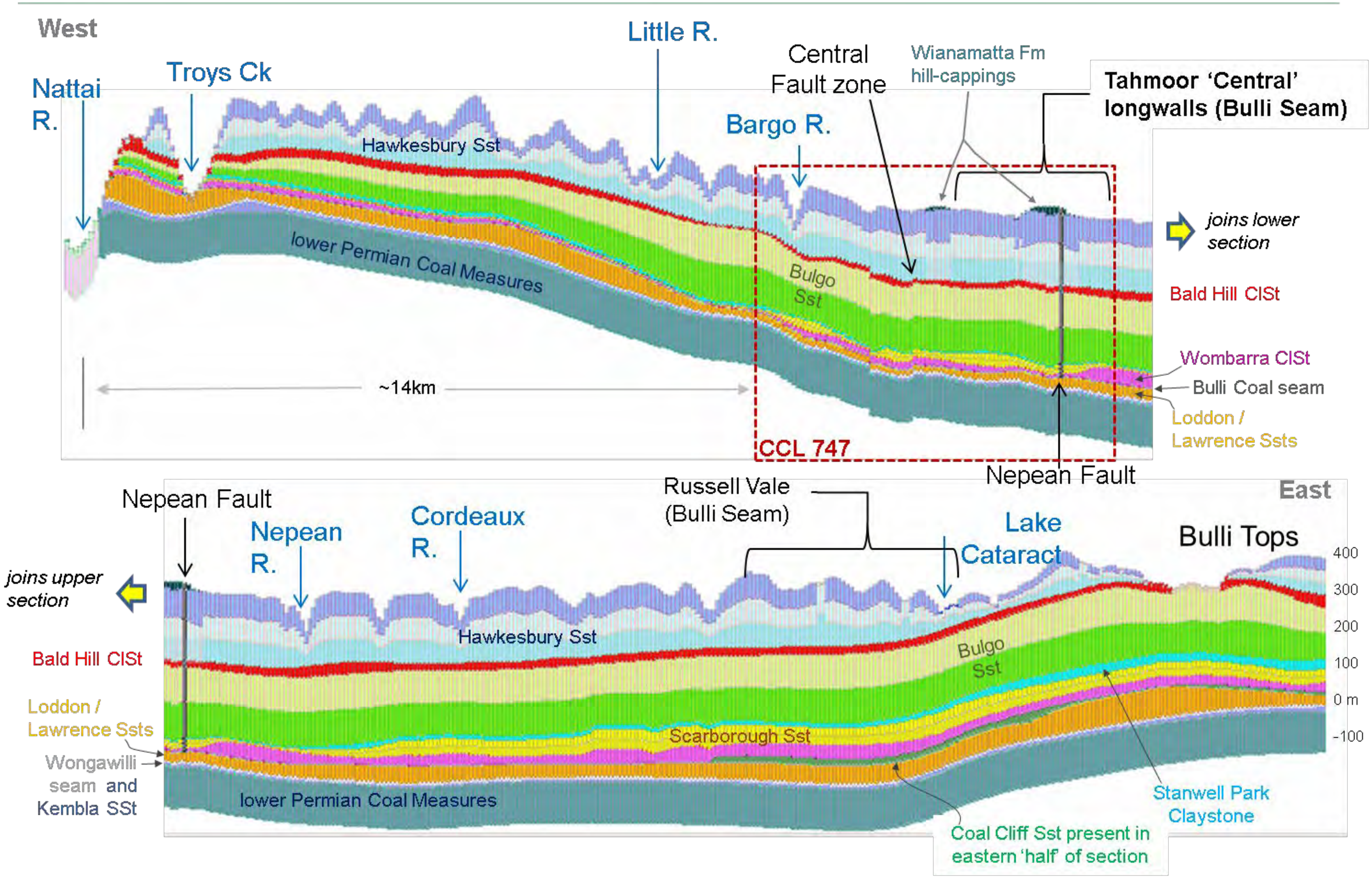
Tahmoor Coal
Tahmoor South Project

Figure 4-1

Groundwater flow model domain and boundary conditions

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH06_ModelDomain_AmendedProject.mxd

DrawingNo: TAH-006 | Rev: A | Created by: B. White | Date: 22/10/2019



Note: the Bulli coal seam is too thin to be visible at this scale.
Model section from Groundwater Vistas 6 (TahmoorSouth_v6TR069.gwv – model row 320 (Northing: 6203050) coloured by hydraulic conductivity zone).

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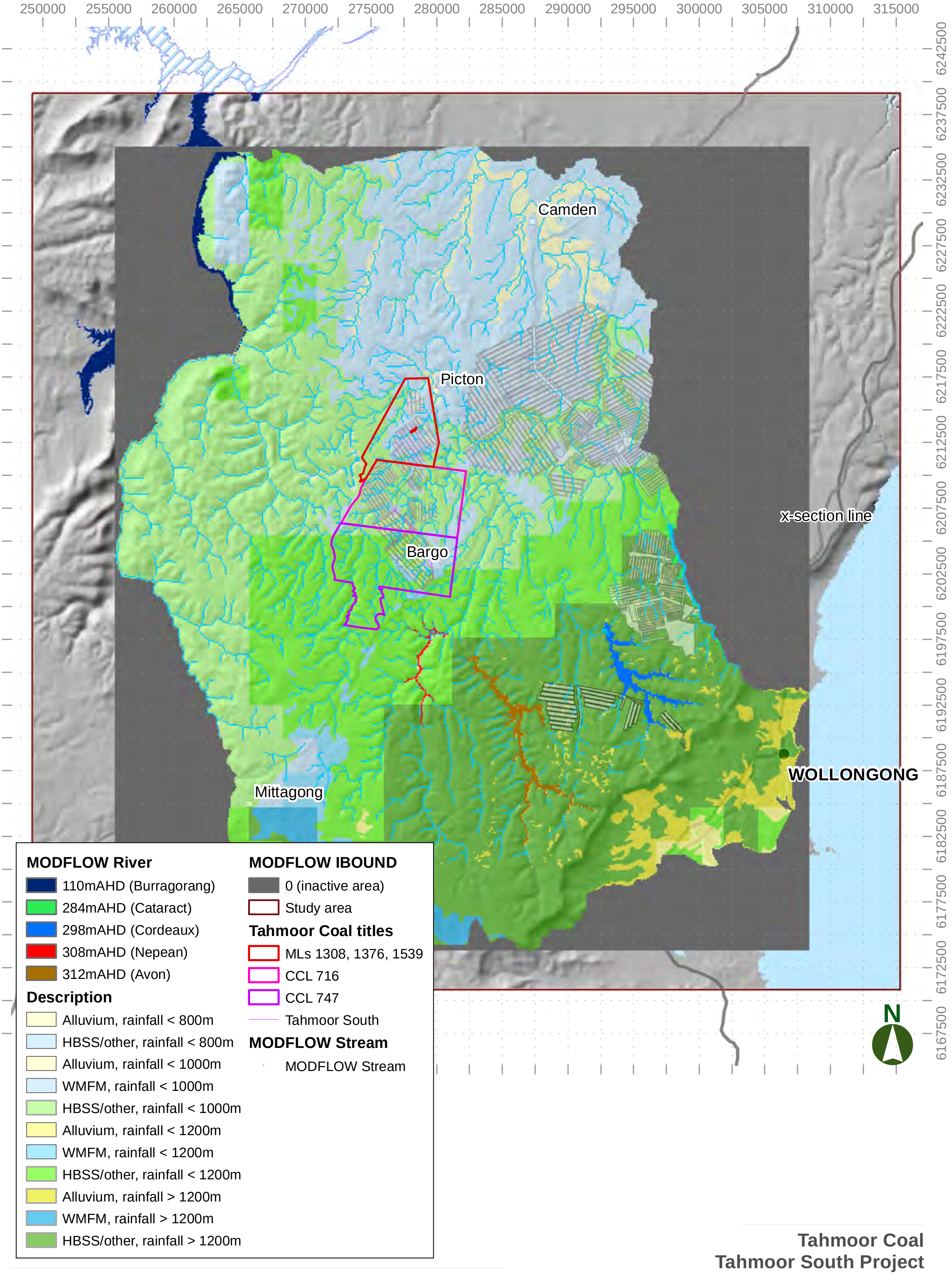
Figure 4-2 Representative Model Cross-section



Scale: 375,000
GDA 1994 MGA Zone 56

0 1.5 3 6 9 12 15 kilometres

HYDRO SIMULATIONS

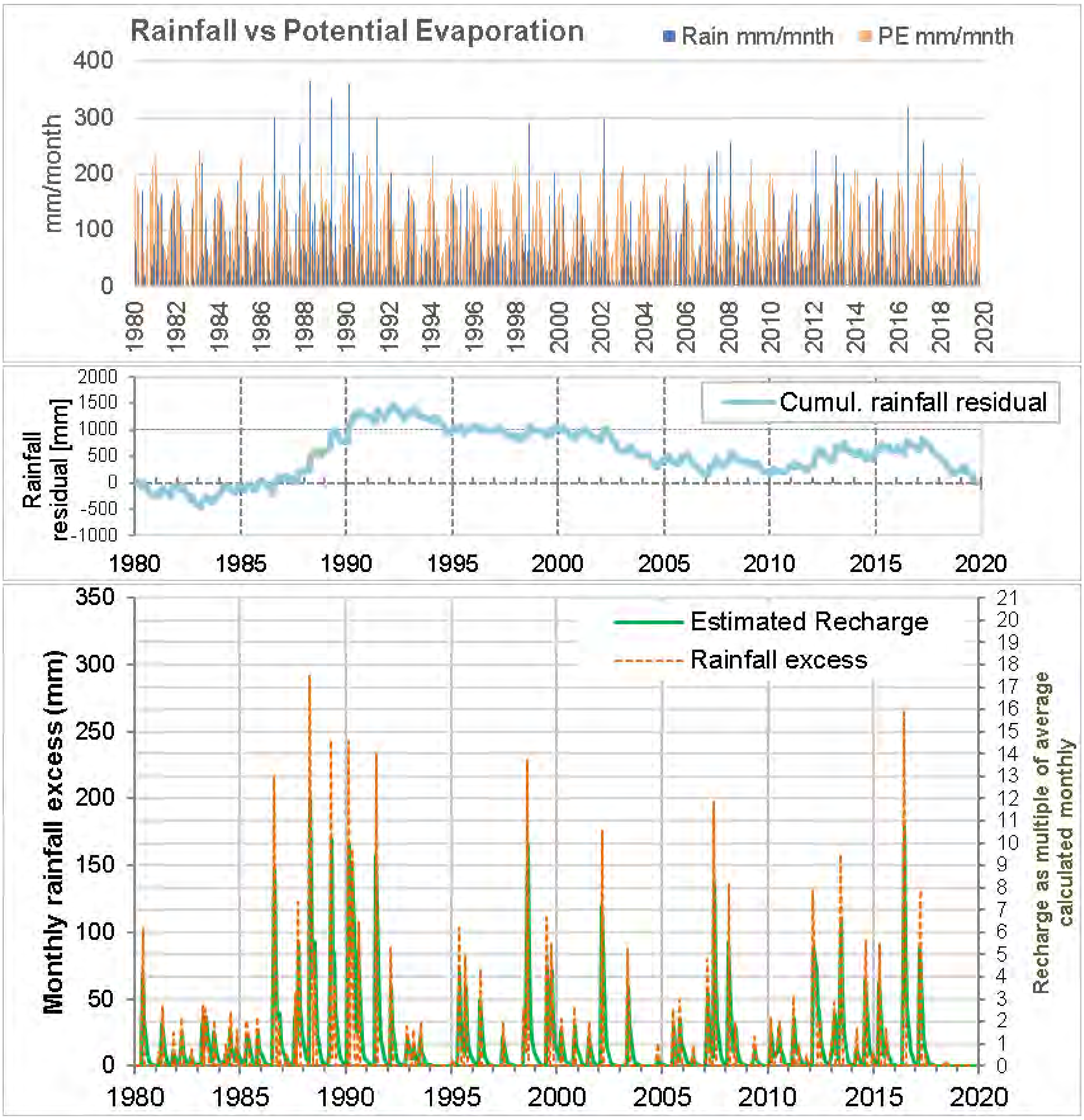
Tahmoor Coal
Tahmoor South Project

Figure 4-3

Recharge zonation
in the groundater model

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH006_ModelRechargeZones_APR.mxd

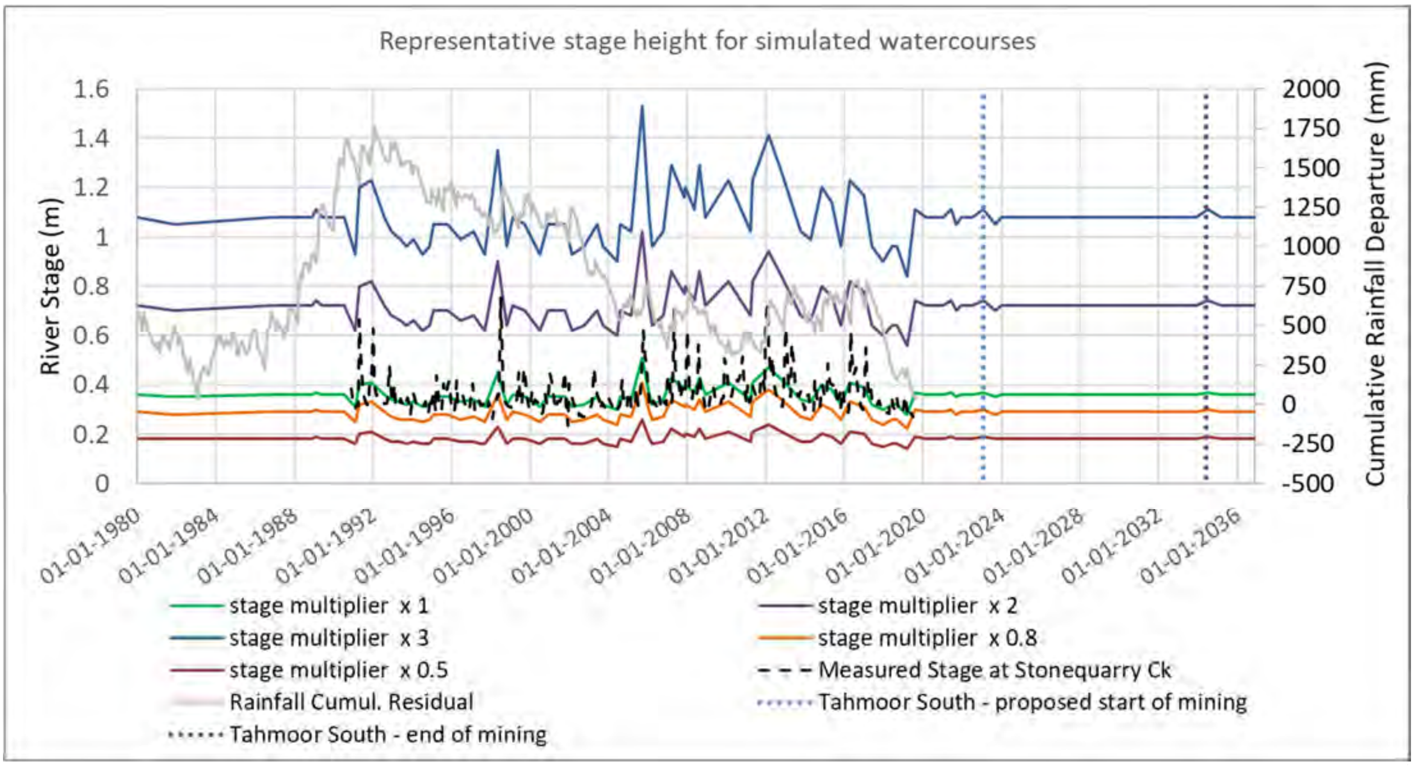
DrawingNo: TAH-006 | Rev: A | Created by: WMinchin | Date: 23/10/2019



E:\HYDROSIM\TAHMOOR\Tech\Climate&Recharge\[Rainfall&Recharge_20191031.xlsx]REPORT

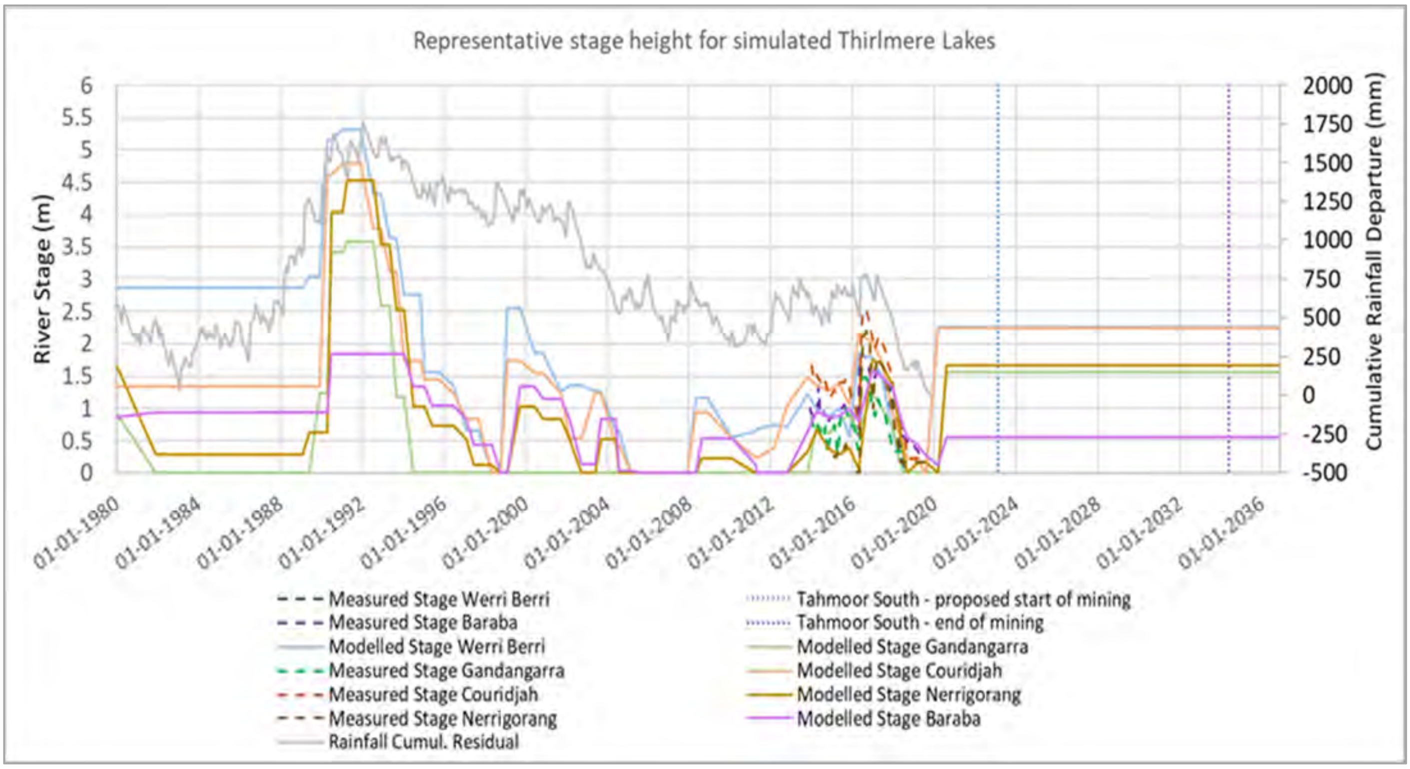
Figure 4-4 Modelled recharge sequence (monthly)

A) Modelled stage heights for watercourses



\\au.slr.local\Corporate\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\05 Modelling\Construction\Boundaries\Rivers\TAH_Transient_RiversWorking_v1.0.xlsx

B) Modelled stage heights for Thirlmere Lakes



H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\05 Modelling\Construction\Boundaries\Rivers\ThirlmereLakes_TransientLevels_v0.8.xlsx

Figure 4-5 Modelled river stages applied to watercourses and Thirlmere Lakes

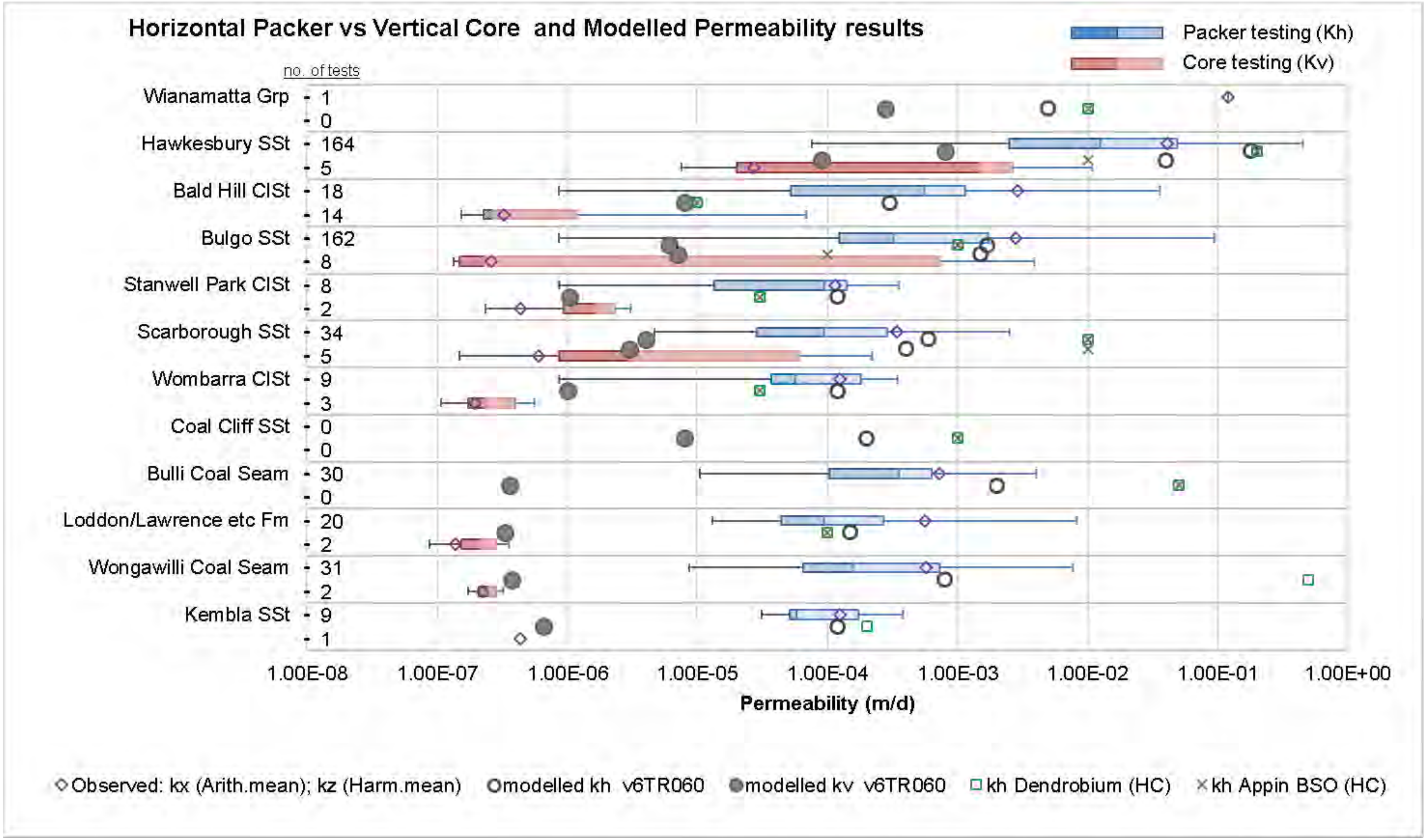


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Figure 4-6 Comparison of modelled hydraulic conductivity and measured data

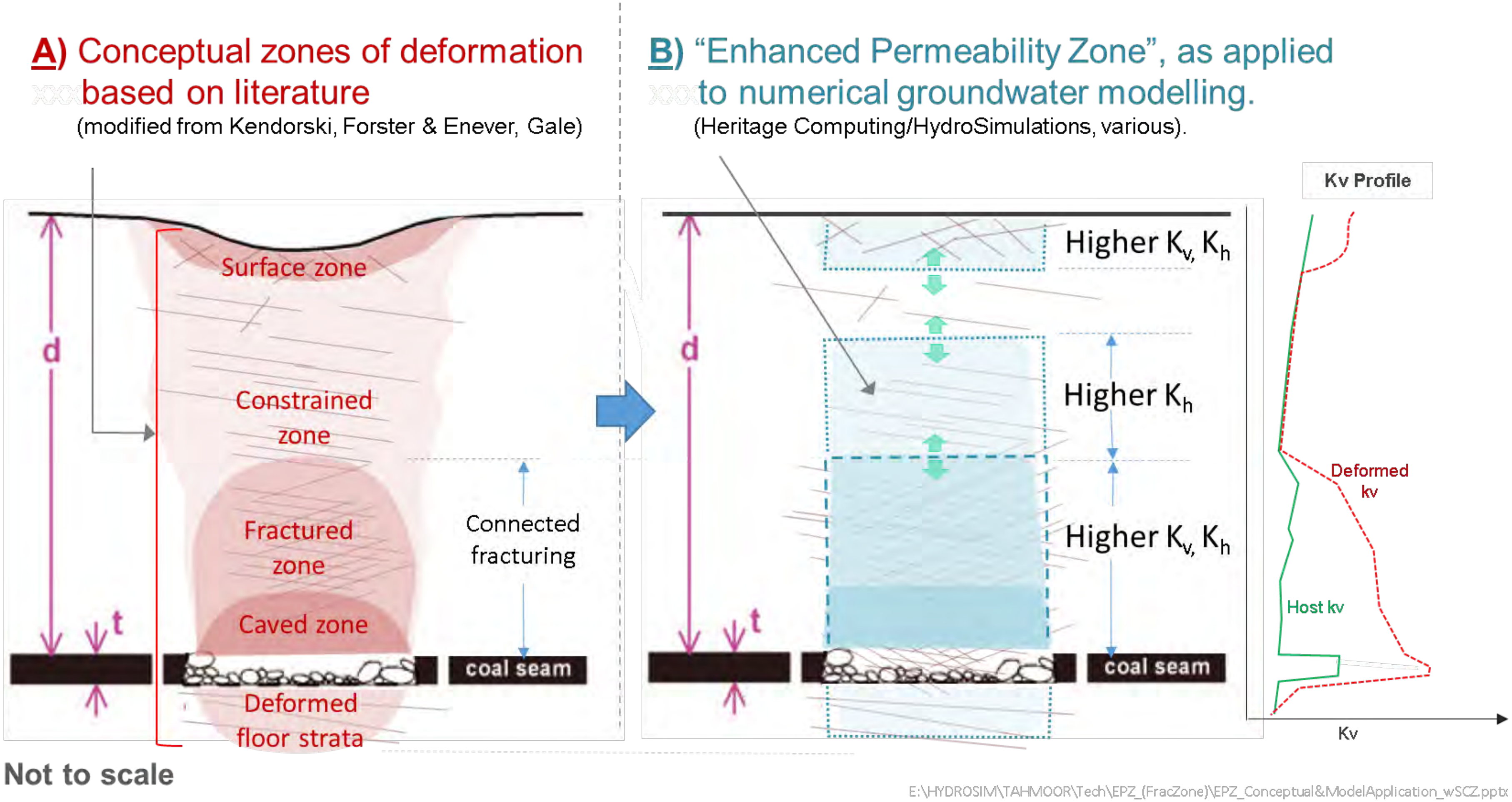


Figure 4-7 Application of enhanced permeability within the groundwater model

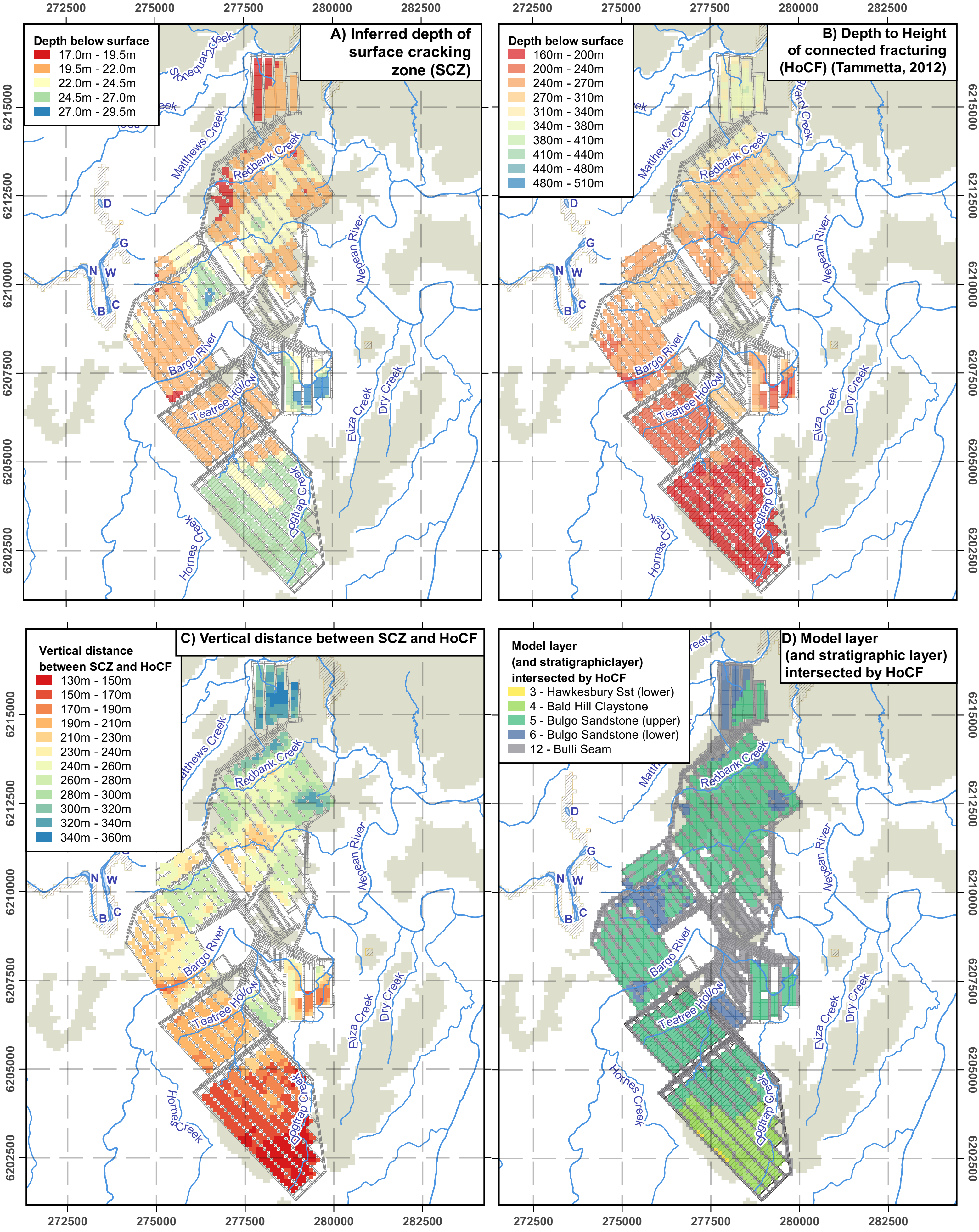


Figure 4-8 - Spatial variation in inferred surface cracking zone and height of connected fracturing

Tahmoor Coal
Tahmoor South - Amended Project Revision

HYDRO SIMULATIONS

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\QGIS\Workspaces\TAH006_cartography.qgs.qgz

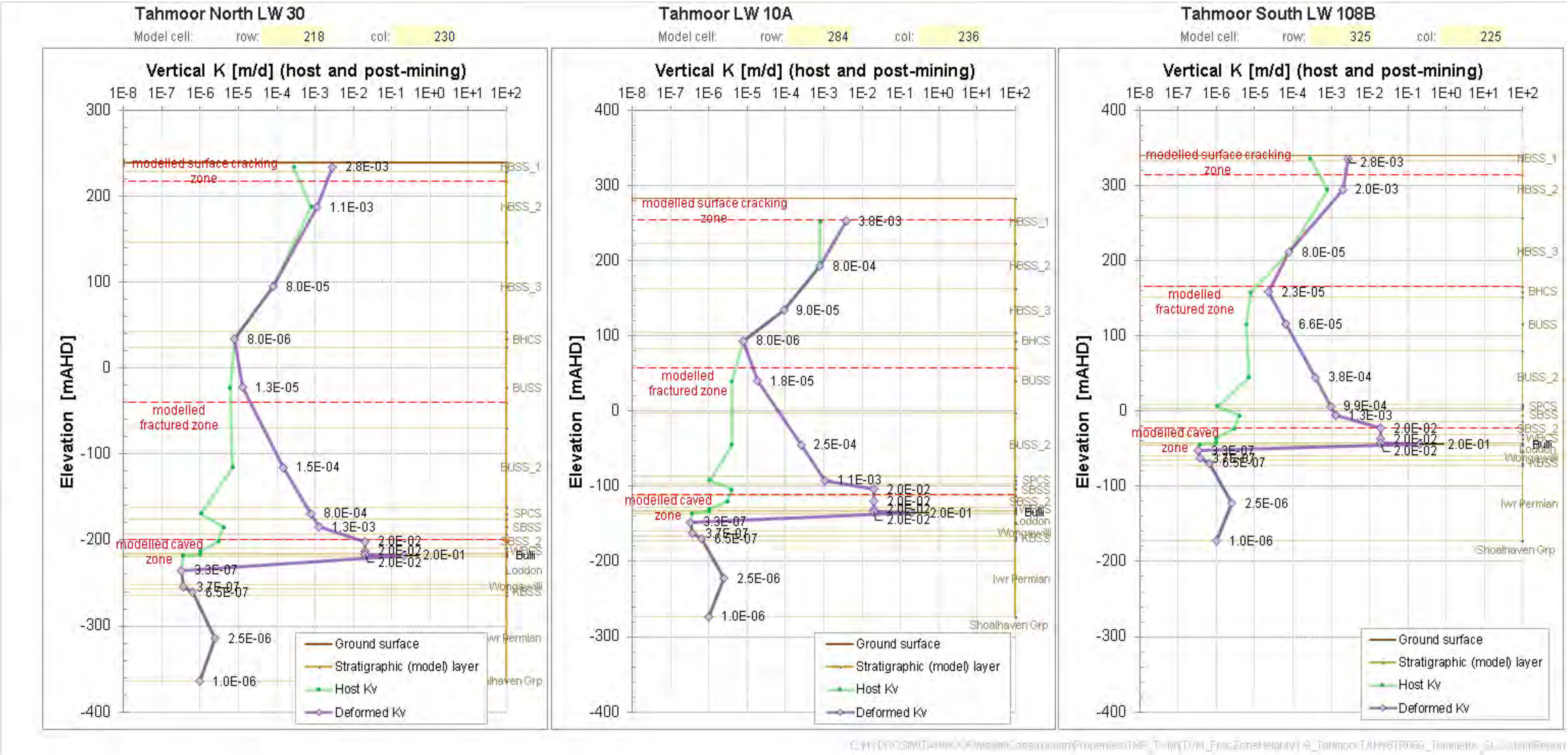
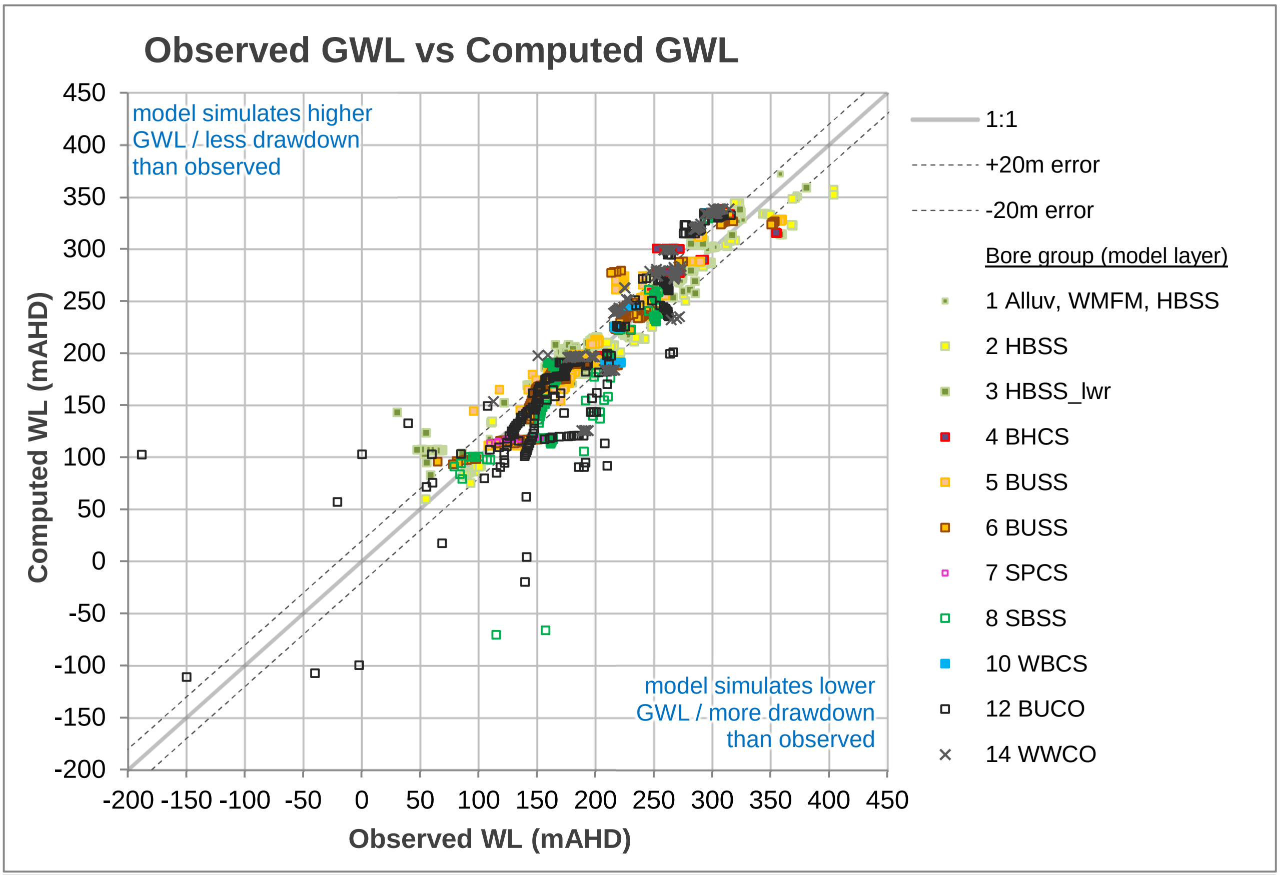
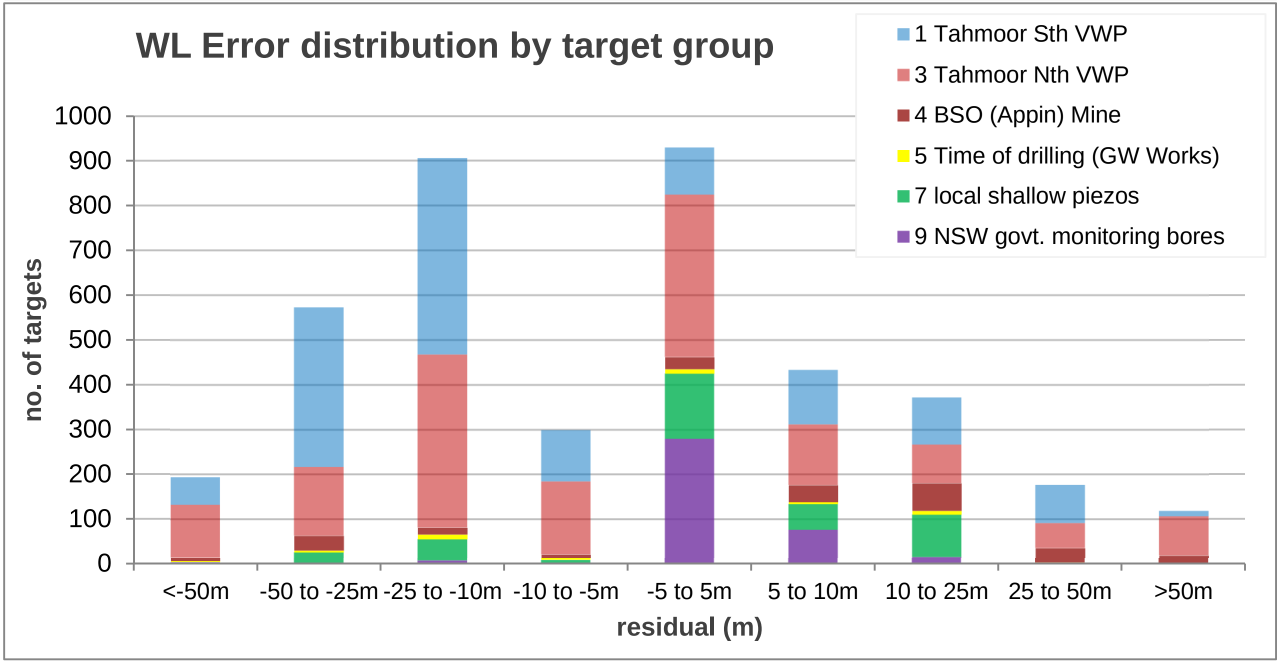


Figure 4-9 Vertical profiles illustrating modelled permeability in the Fractured Zone



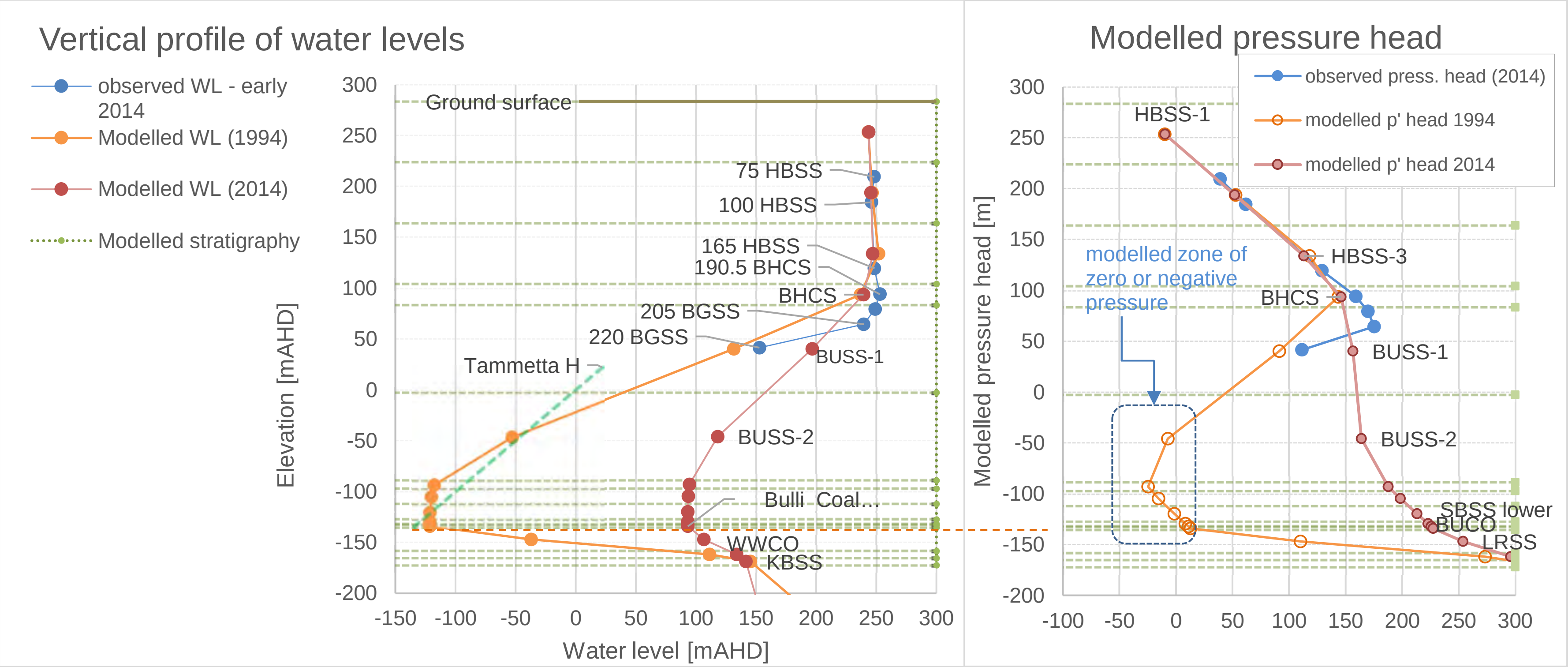


E:\HYDROSIM\TAHMOOR\Model\Processing\Calibration\[TahmSthv06Run069_CAL_calibration_v6_Report.xlsx]CalibCalcs&Plot

Results from model run: v6TR069_C

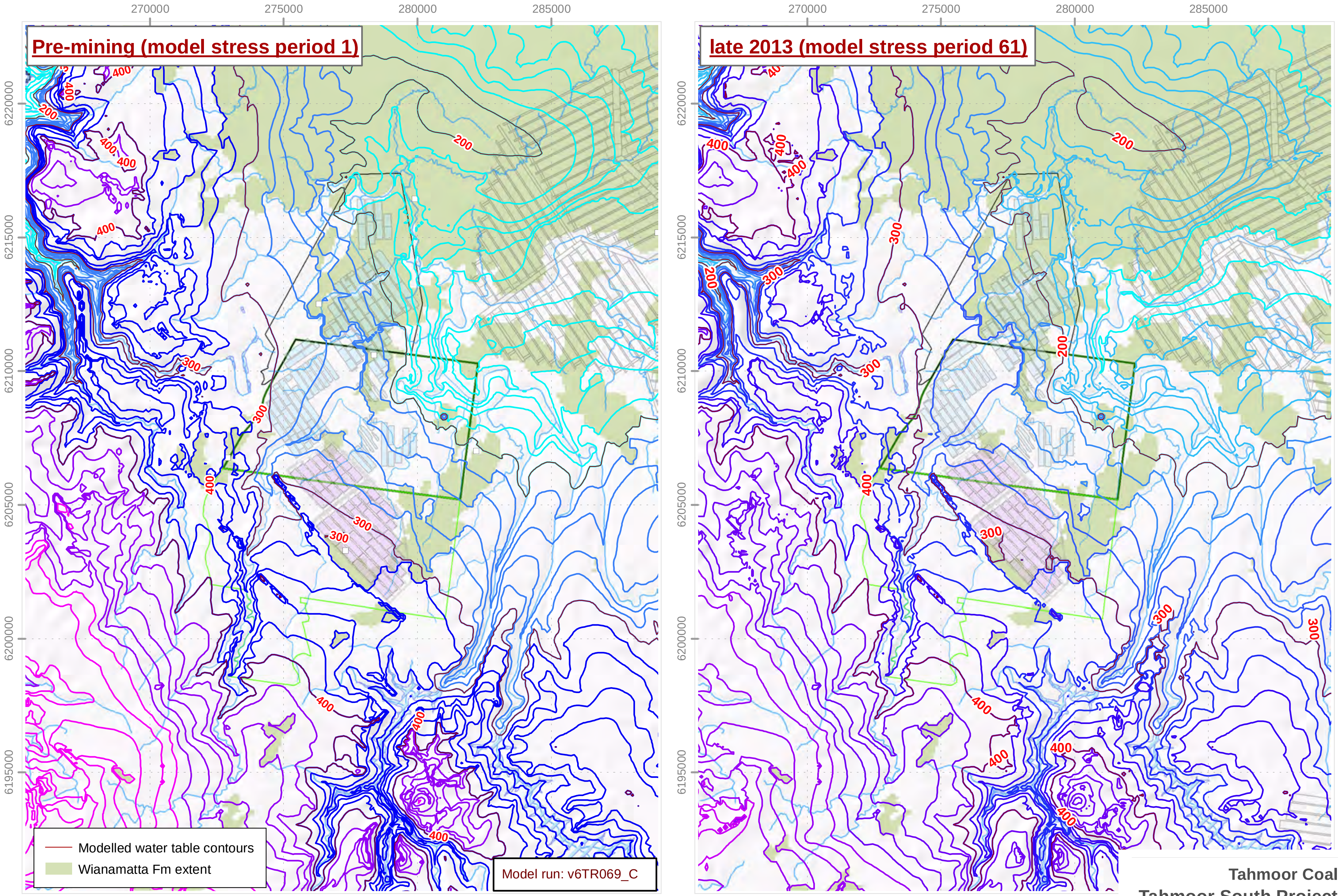
HYDROSIMULATIONS

Summary of model calibration **Figure 4-10**



E:\HYDROSIM\TAHMOOR\Model\Processing\Calibration\[TahmSthv06Run069_CAL_calibration_v6_Report.xlsx]Profile_TNC040_hof

Simulation of water levels in TBF040c (‘HoF’) borehole **Figure 4-11**



Scale: 175,000
GDA 1994 MGA Zone 56

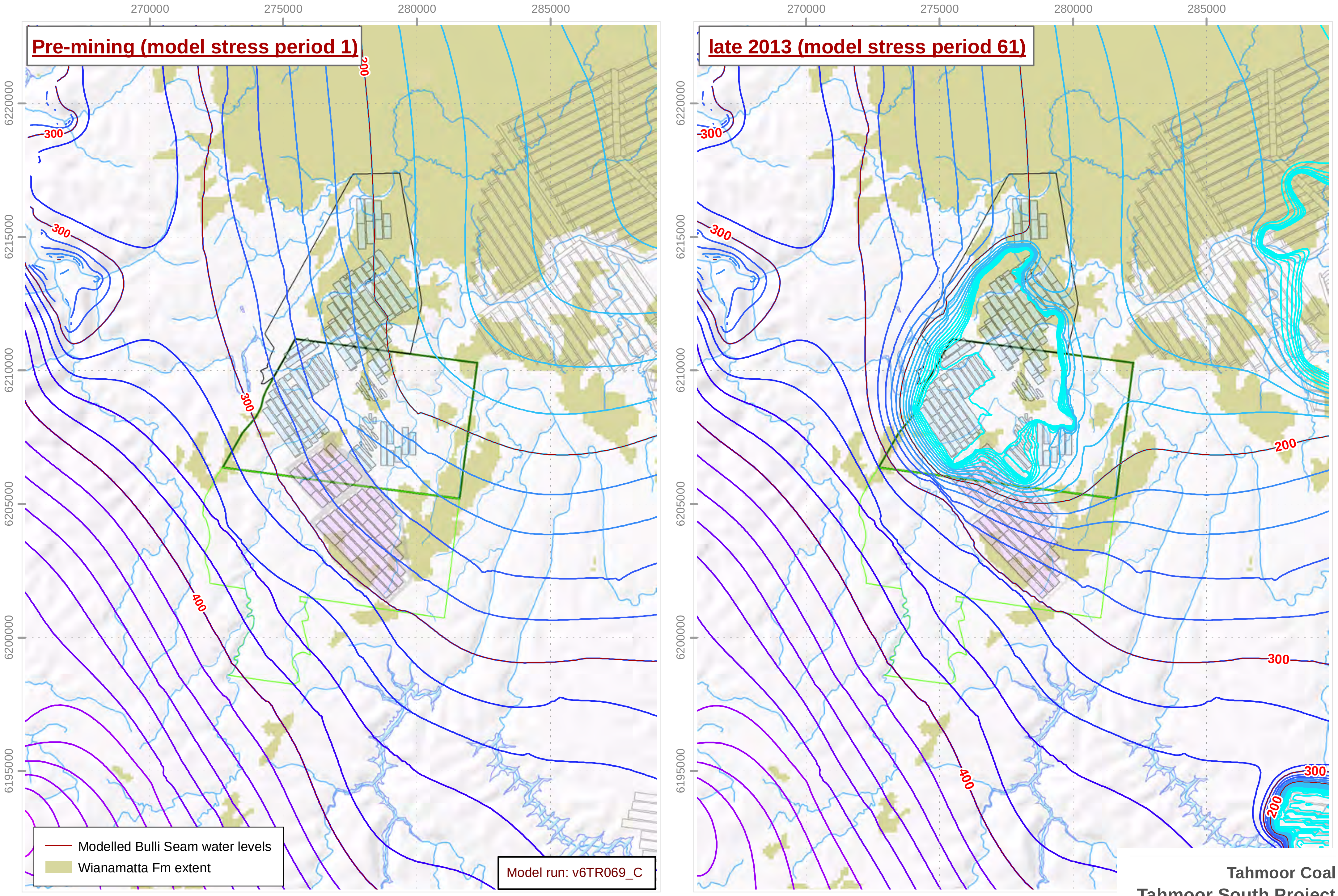
Rev: A - 13/11/2019 | by: B.White

Tahmoor Coal
Tahmoor South Project

Modelled water table: pre-mining (i.e. ~1980) and late 2013 levels

Figure 4-12

H:\Projects-SLR\660-SrvWOL\660-WOL\665.10010 Tahmoor GW RTS\06 SLR Data\01 CADGIS\ArcGIS\Workspaces\TAH06_ModelledWatertable_APR.mxd



Scale: 175,000
GDA 1994 MGA Zone 56

HYDROSIMULATIONS

Tahmoor Coal
Tahmoor South Project

Modelled water levels in the Bulli Seam: pre-mining (i.e. ~1980) and late 2013 levels

Figure 4-13

Rev: A - 13/11/2019 | by: B.White

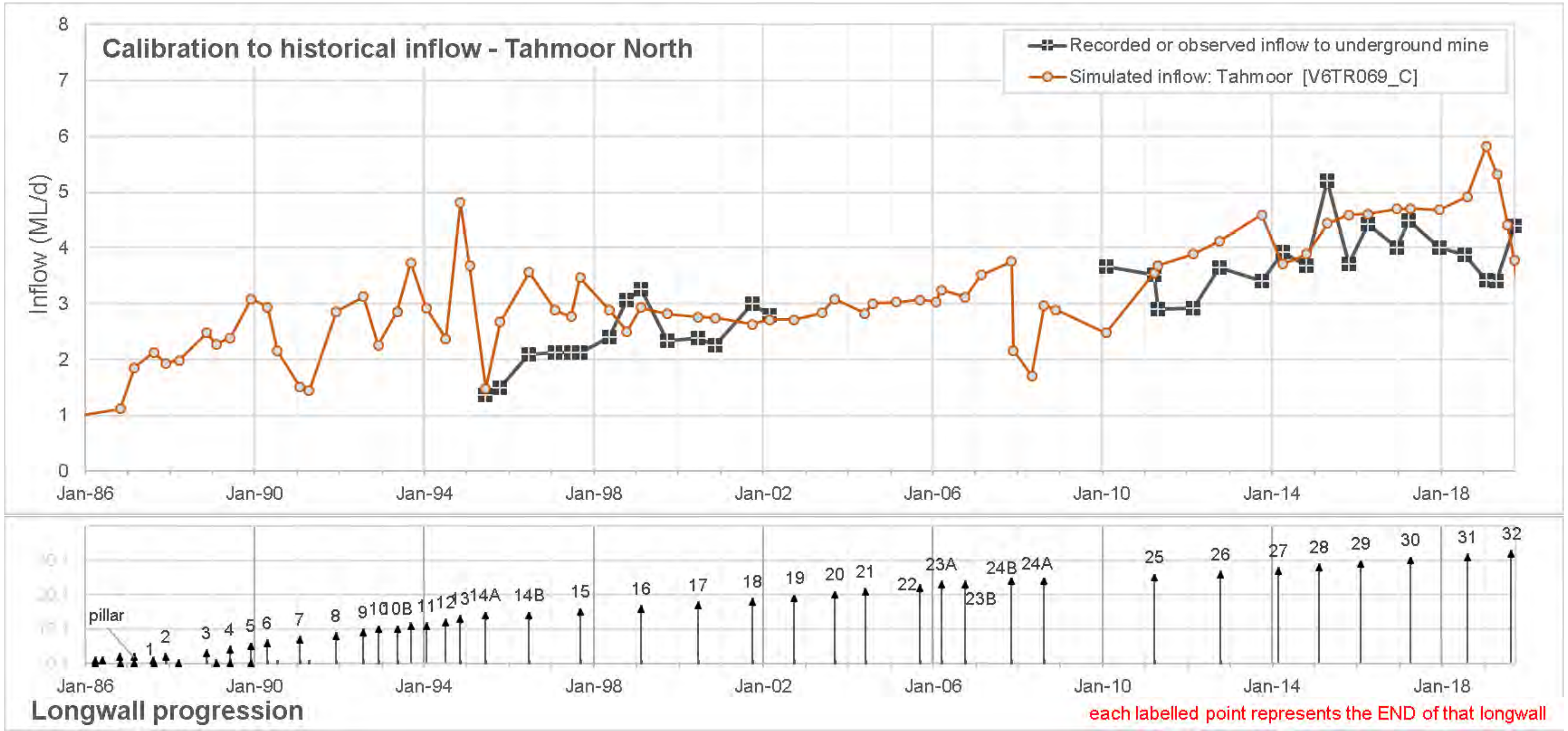


Figure 4-14 Comparison of observed and modelled inflow at Tahmoor

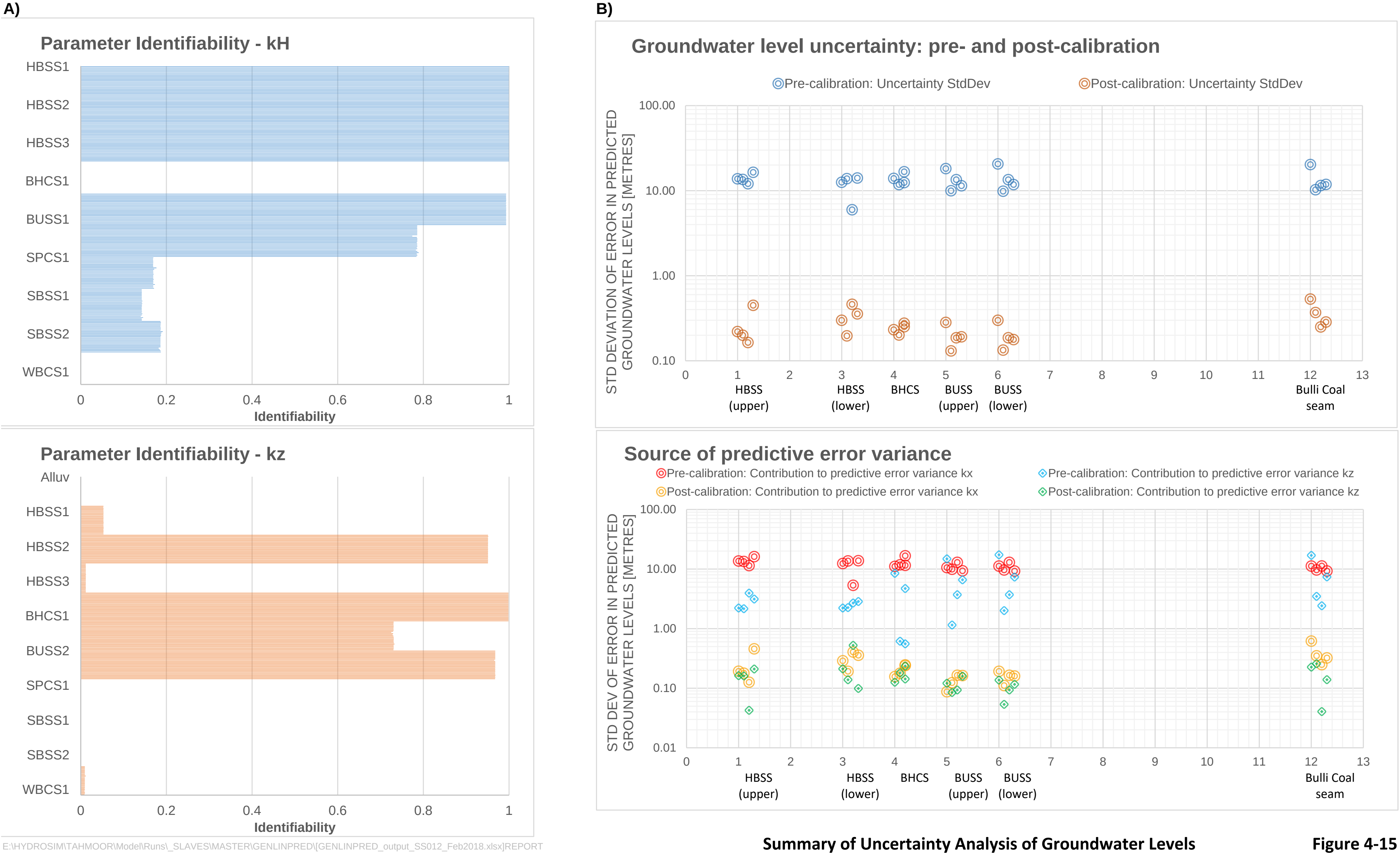


Figure 4-15 Summary of Uncertainty Analysis of Modelled Groundwater Levels

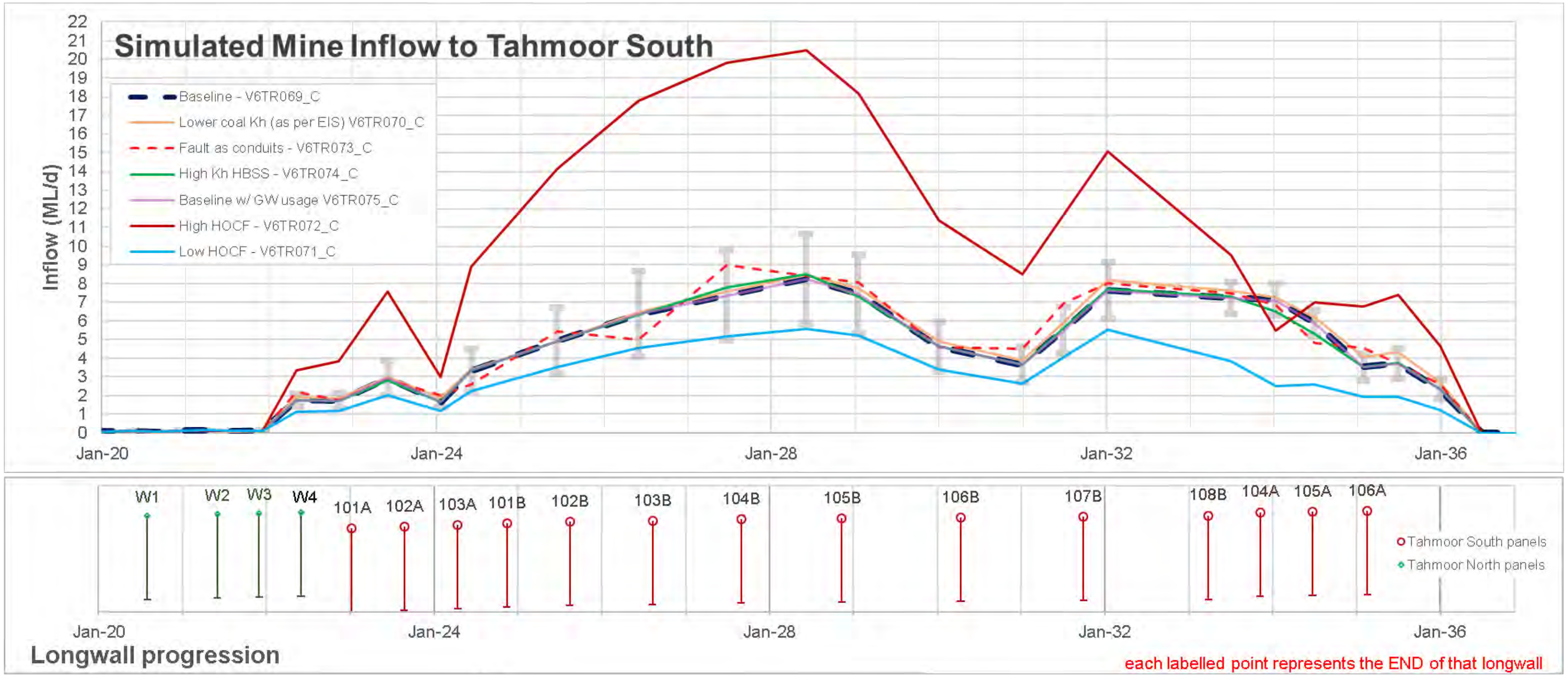


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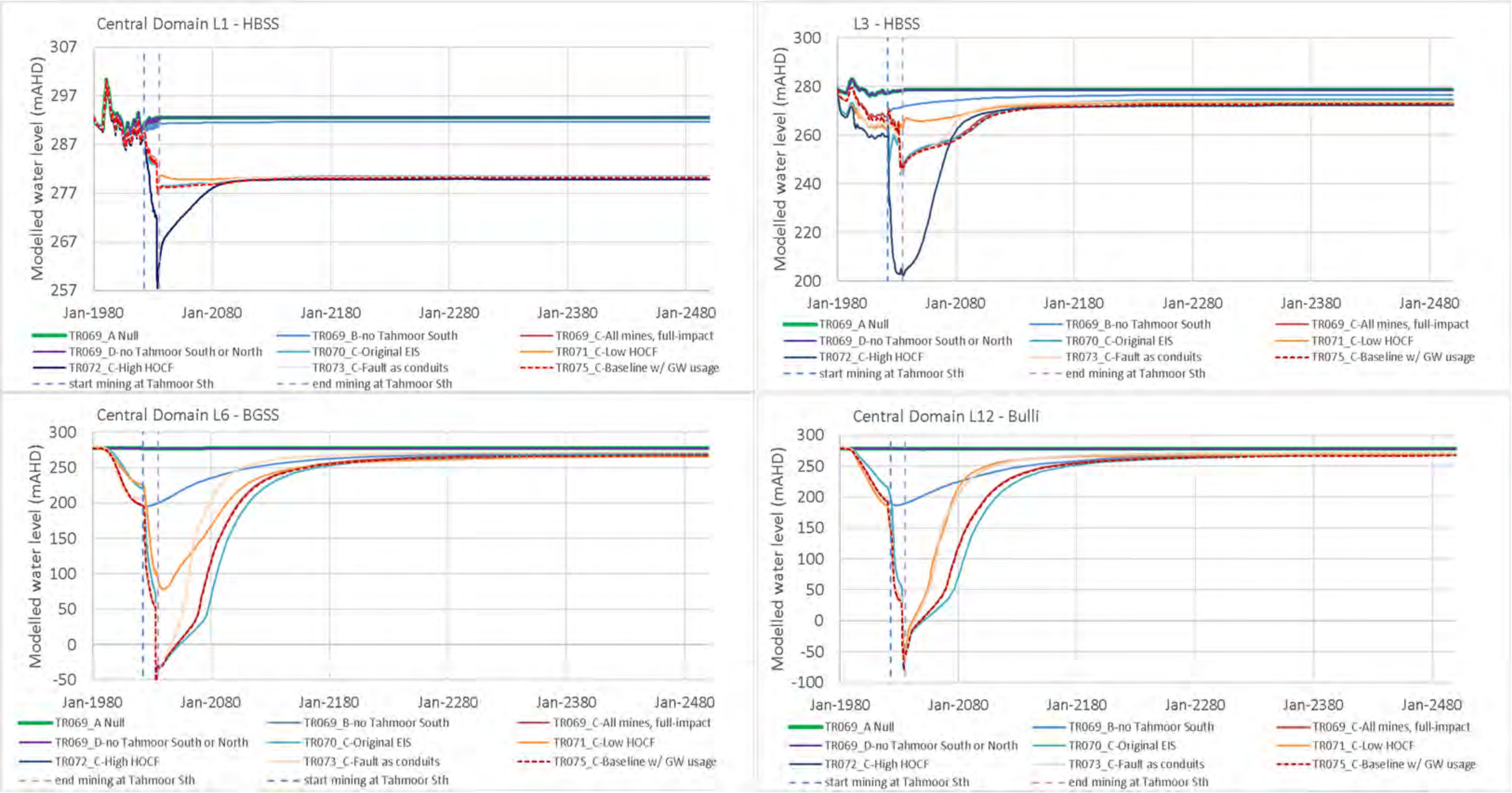
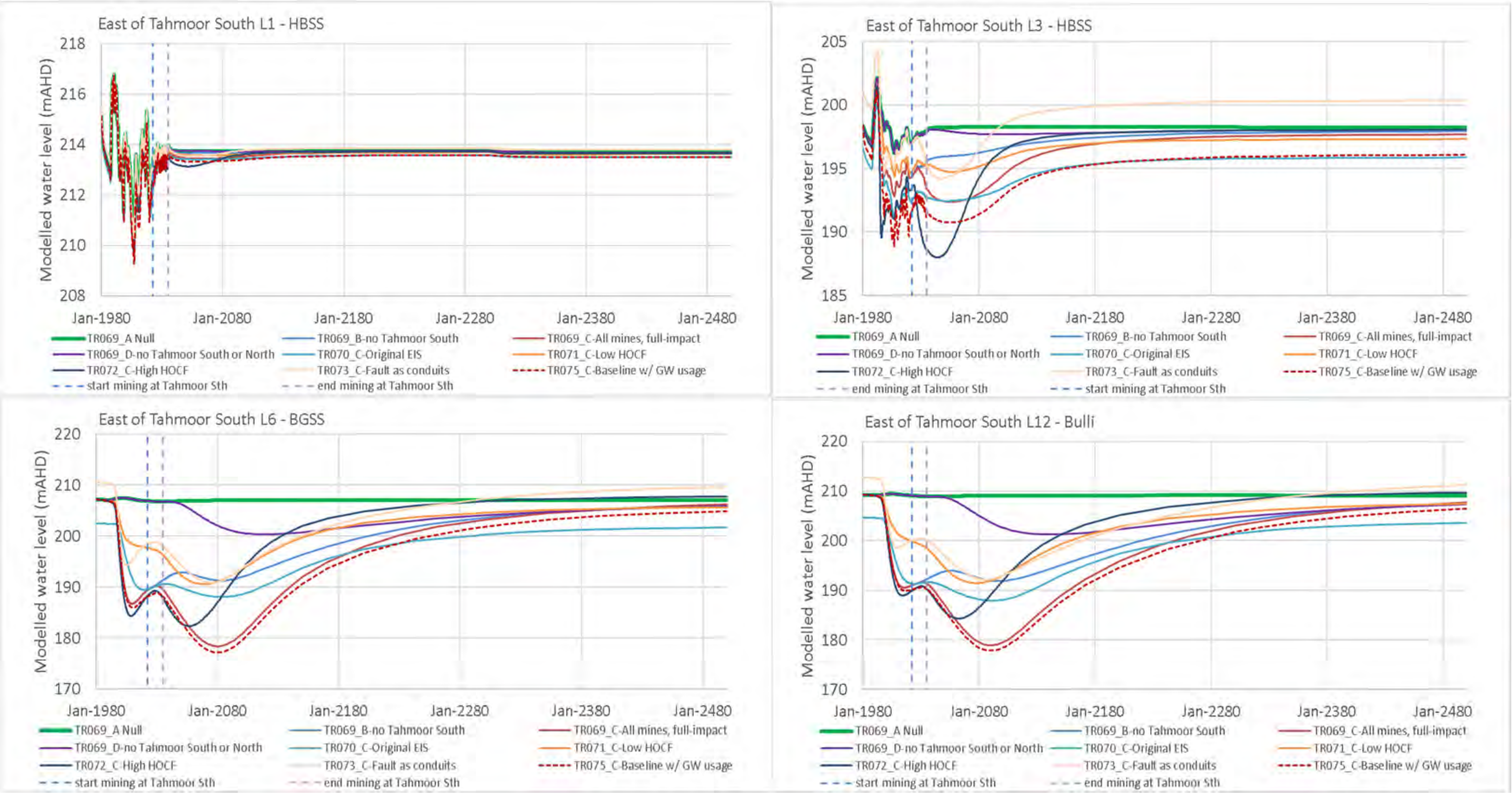
Figure 5-1 Modelled Tahmoor South Mine Groundwater Inflows and Uncertainty



This location is at TBC016. Refer to Figure 3-5 for locations

Figure 5-2 Modelled groundwater levels: Tahmoor South - Central Domain



East of Tahmoor South L1 - HBSS

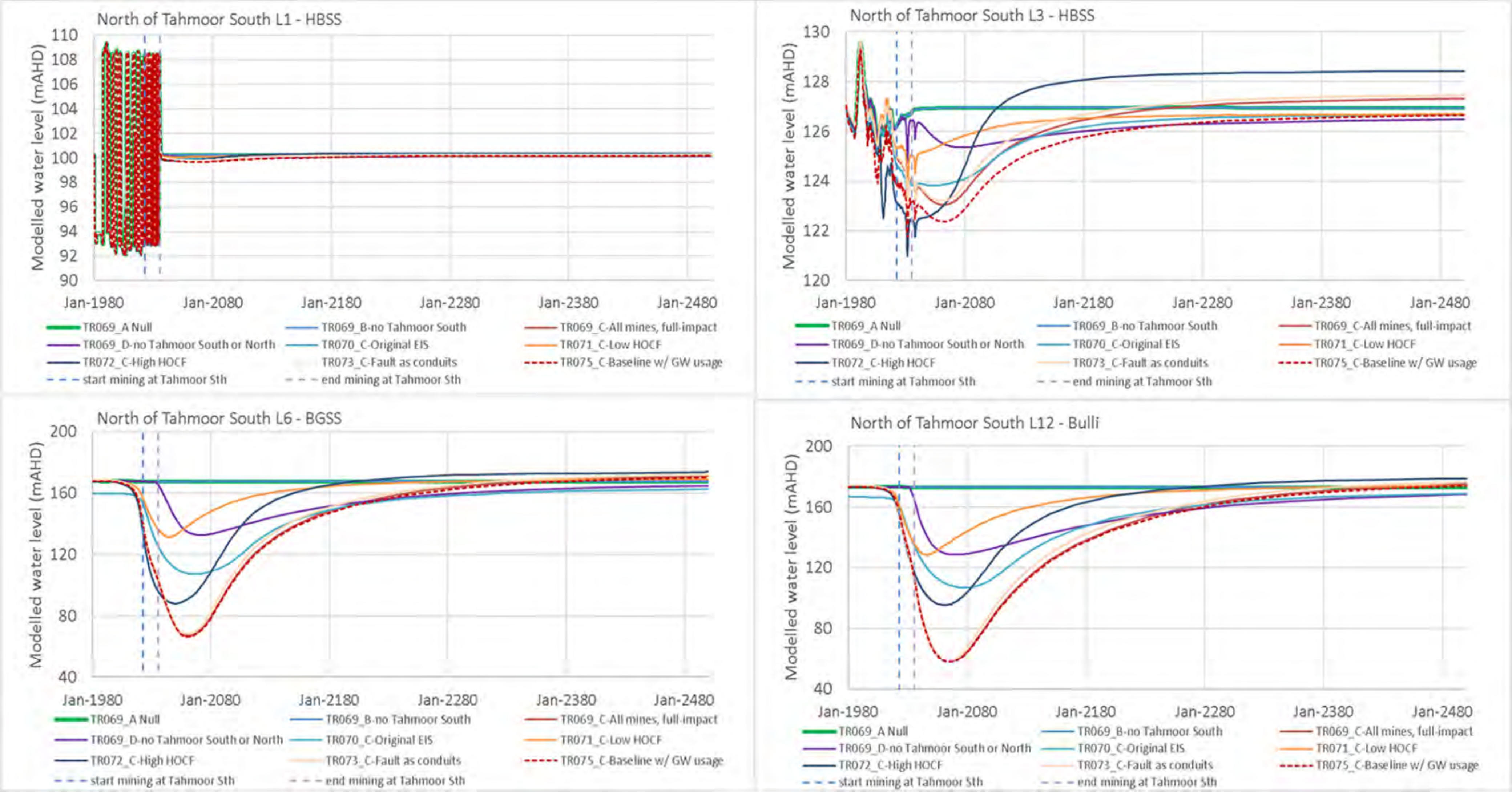
East of Tahmoor South L3 - HBSS

East of Tahmoor South L6 - BGSS

East of Tahmoor South L12 - Bulli

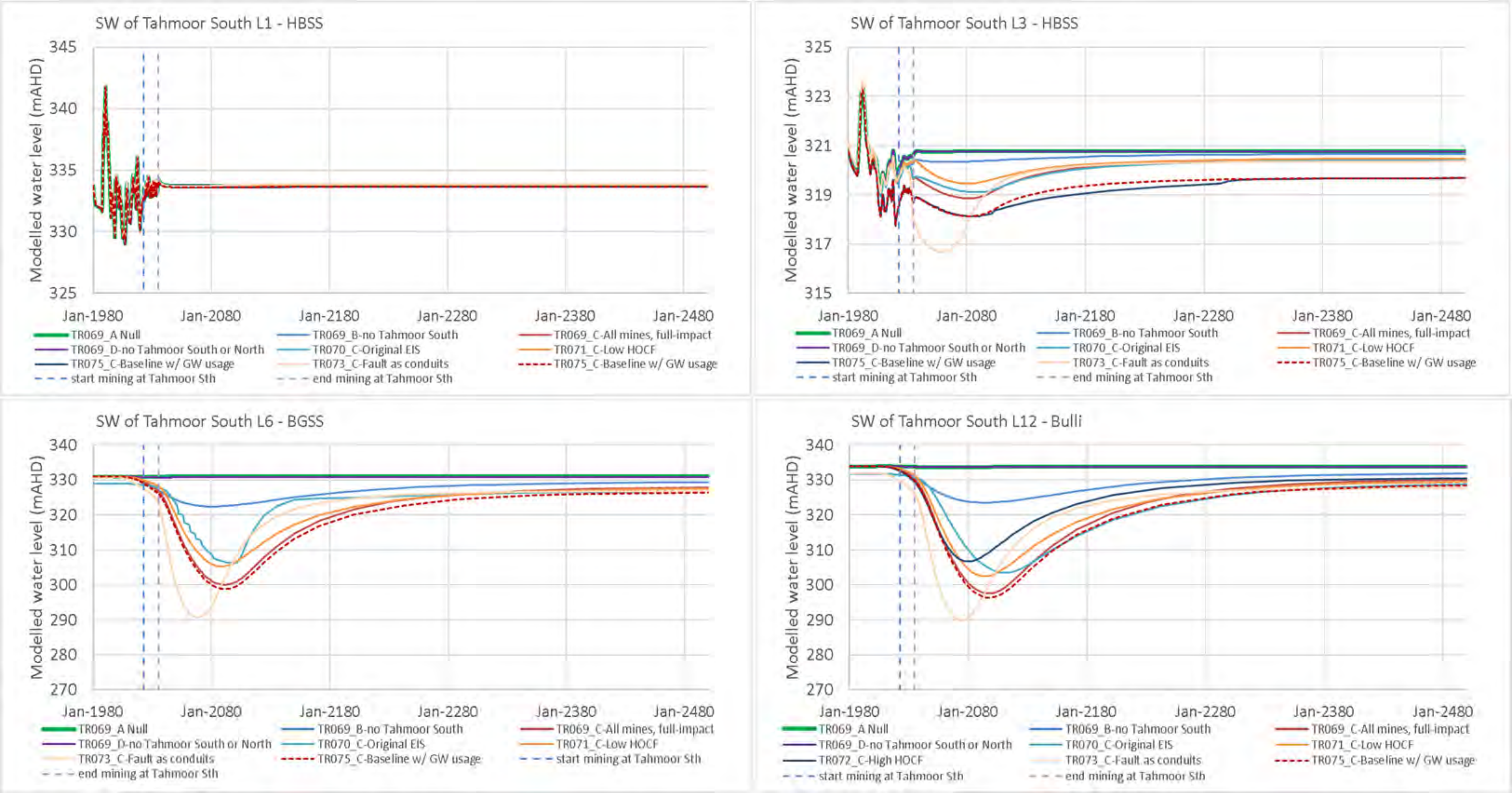
This location is at TBC026. Refer to Figure 3-5 for locations

Figure 5-3 Modelled groundwater levels: east of Tahmoor South



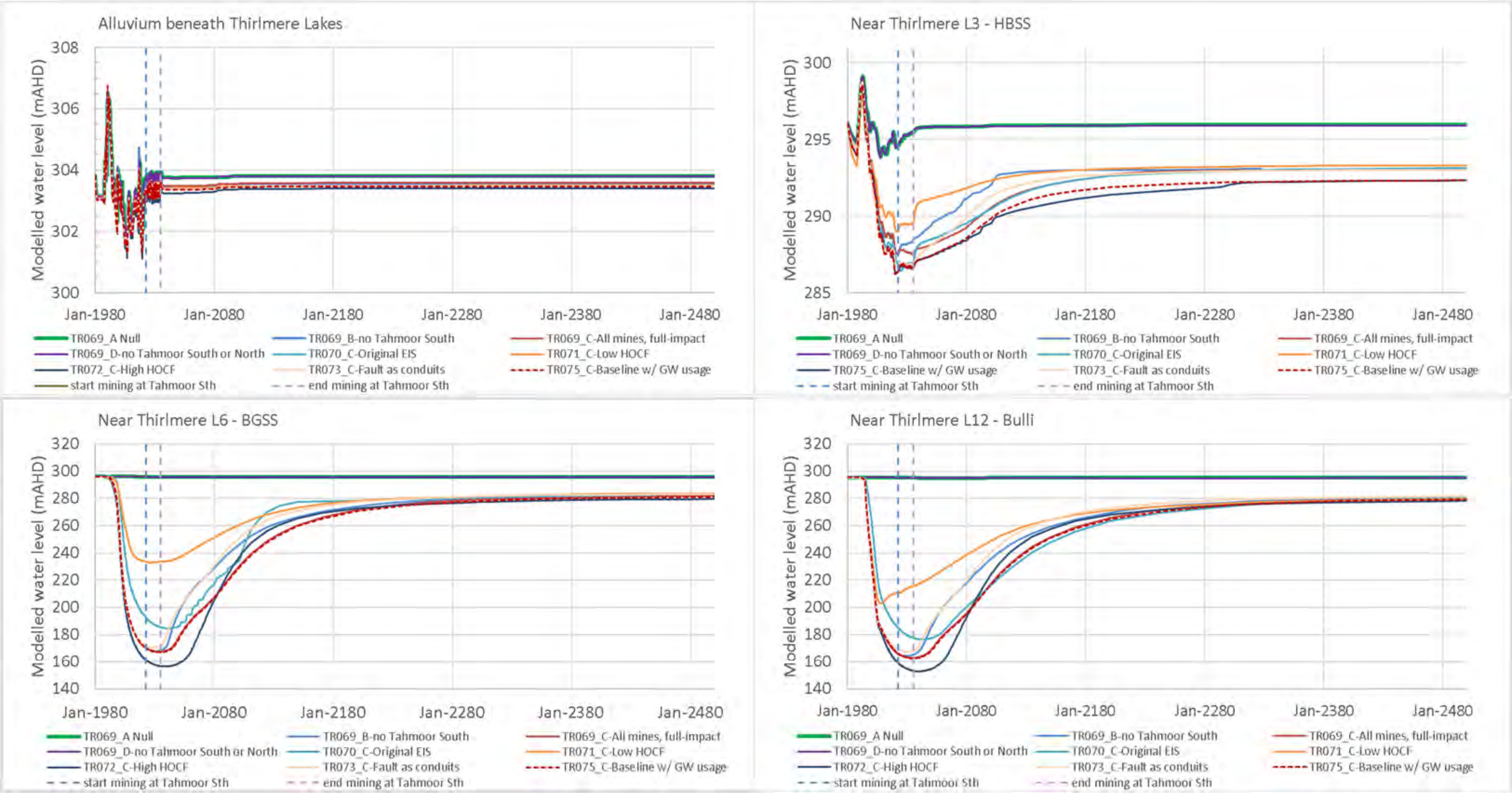
This location is at GW109159. Refer to Figure 3-5 for locations

Figure 5-4 Modelled groundwater levels: GW109159 (north of Project)



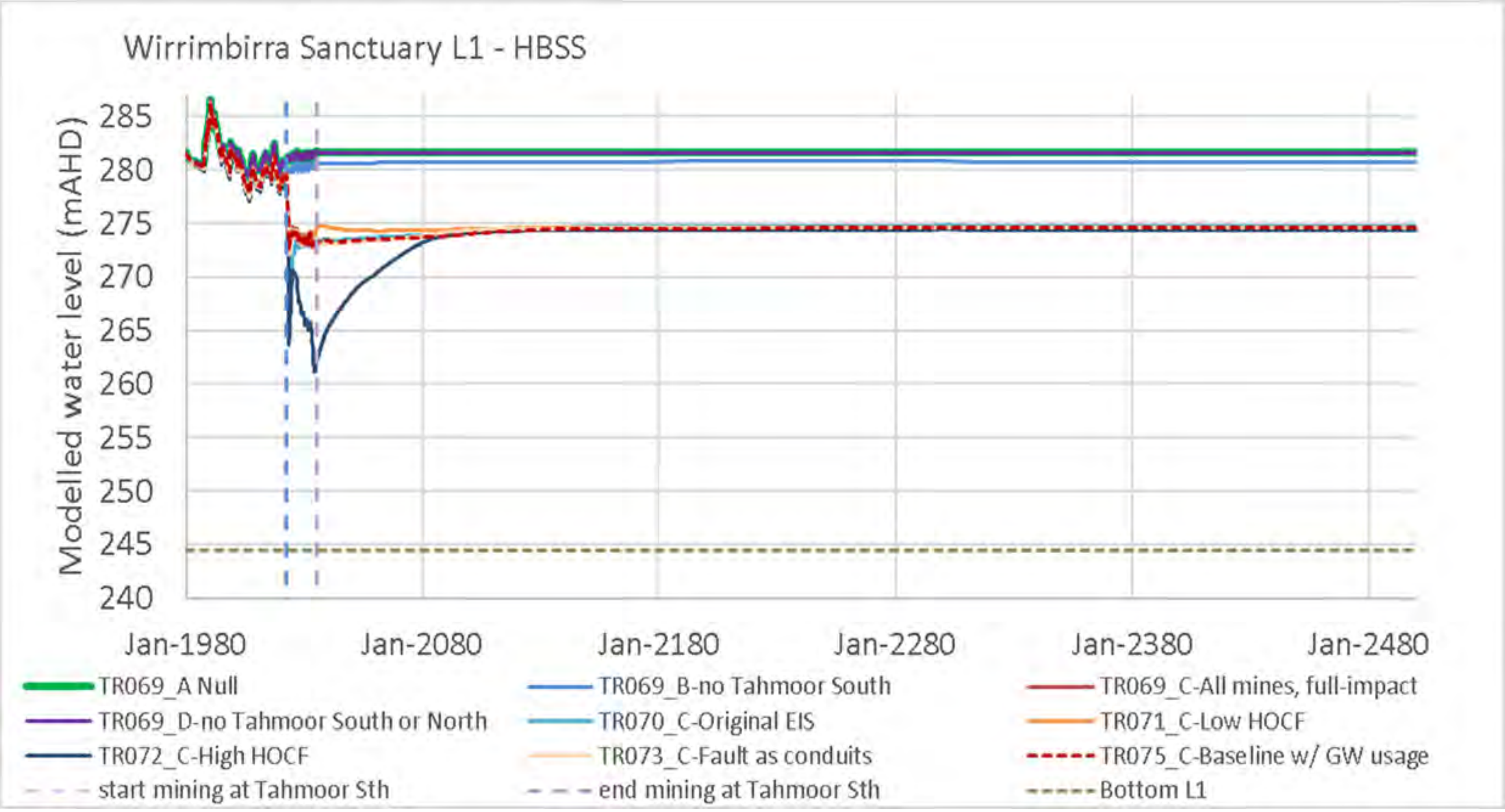
This location is at TBC022. Refer to Figure 3-5 for locations

Figure 5-5 Modelled groundwater levels: TBC026 (southwest of Project)



This location is at GW075409. Refer to Figure 3-5 for locations

Figure 5-6 Modelled groundwater levels near Thirlmere Lakes (L. Couridjah)



Refer to Figure 3-5 for location.

Figure 5-7 Modelled groundwater levels at Wirrimbirra Sanctuary

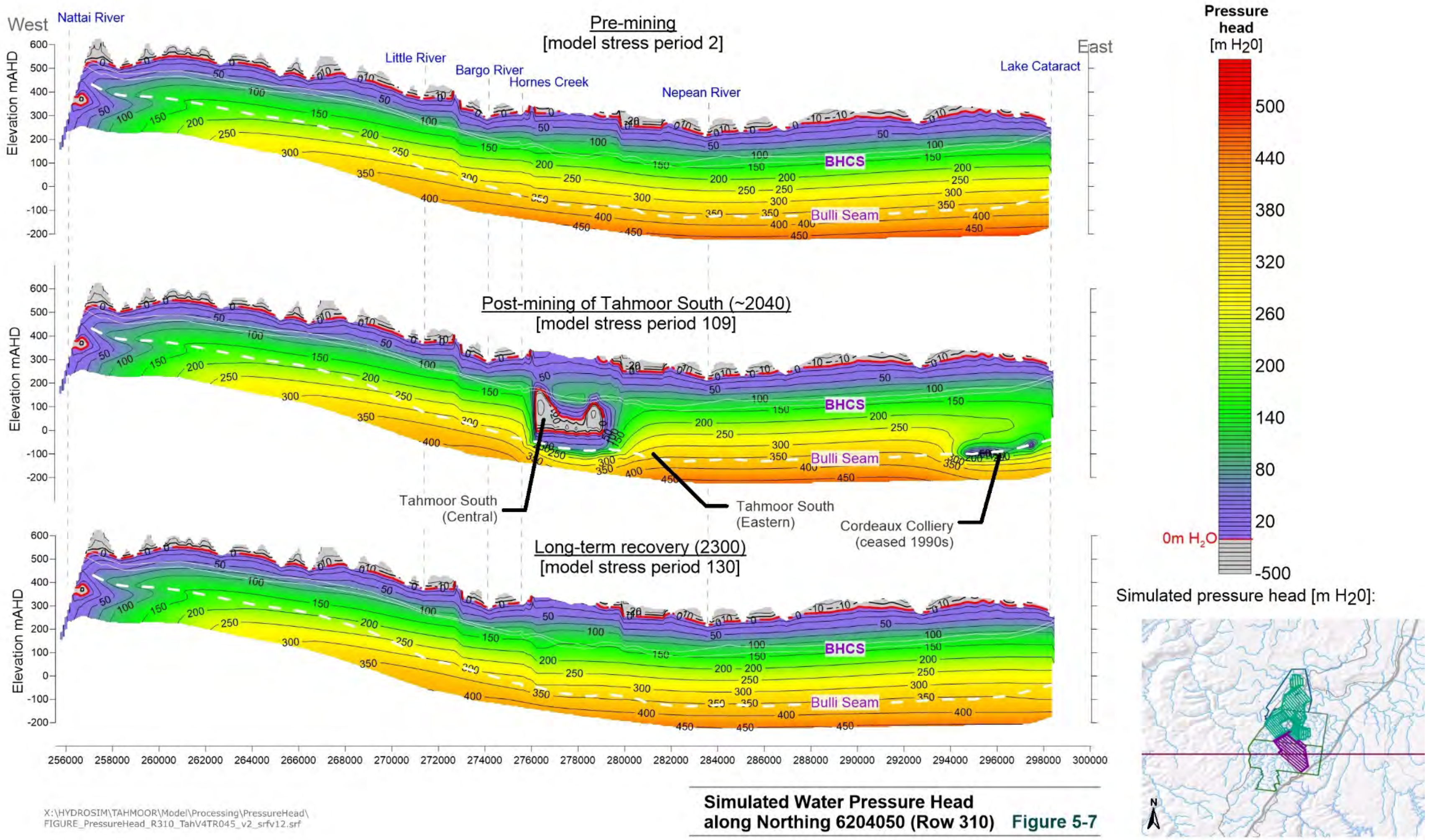
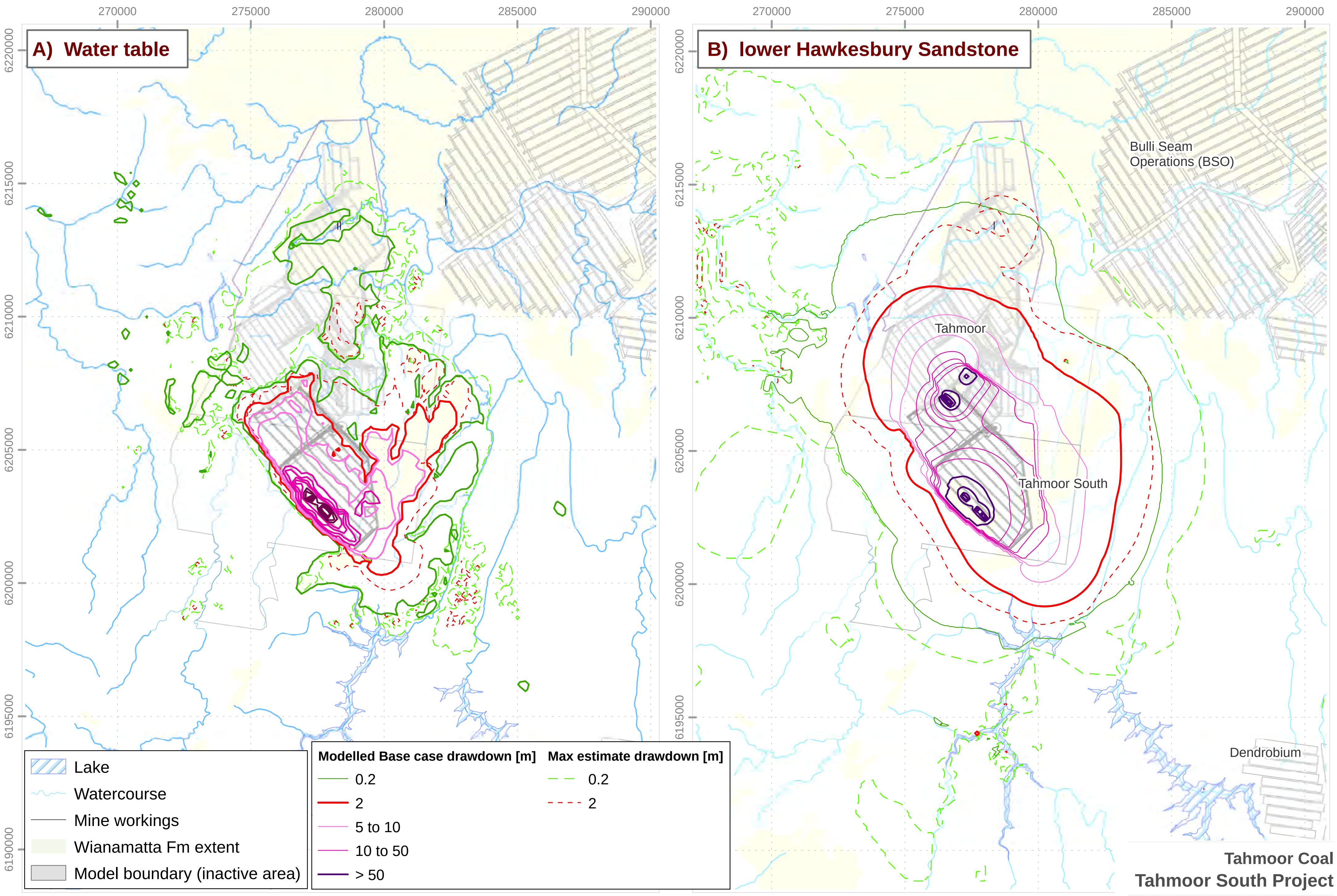


Figure 5-8 Modelled pressure head cross-section



Tahmoor Coal
Tahmoor South Project

Scale: 175,000
GDA 1994 MGA Zone 56

0 0.5 1 2 3 4 5 kilometres

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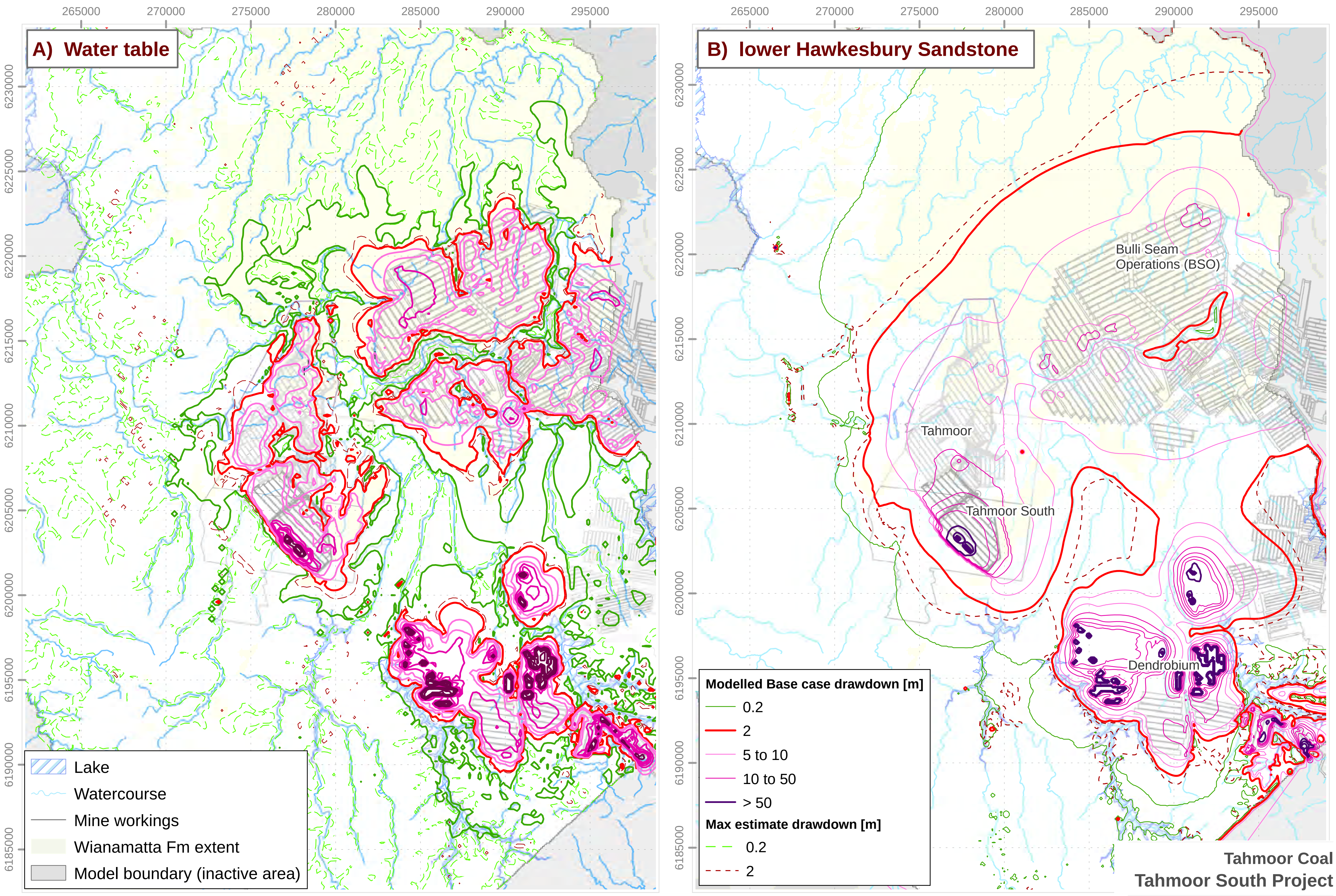
Predicted maximum drawdown due to the Tahmoor South Project

Figure 5-9



Tahmoor Coal
Tahmoor South Project

Scale: 275,000
GDA 1994 MGA Zone 56

0 1 2 4 6 8
kilometres

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Predicted maximum drawdown due to cumulative mining

Figure 5-10

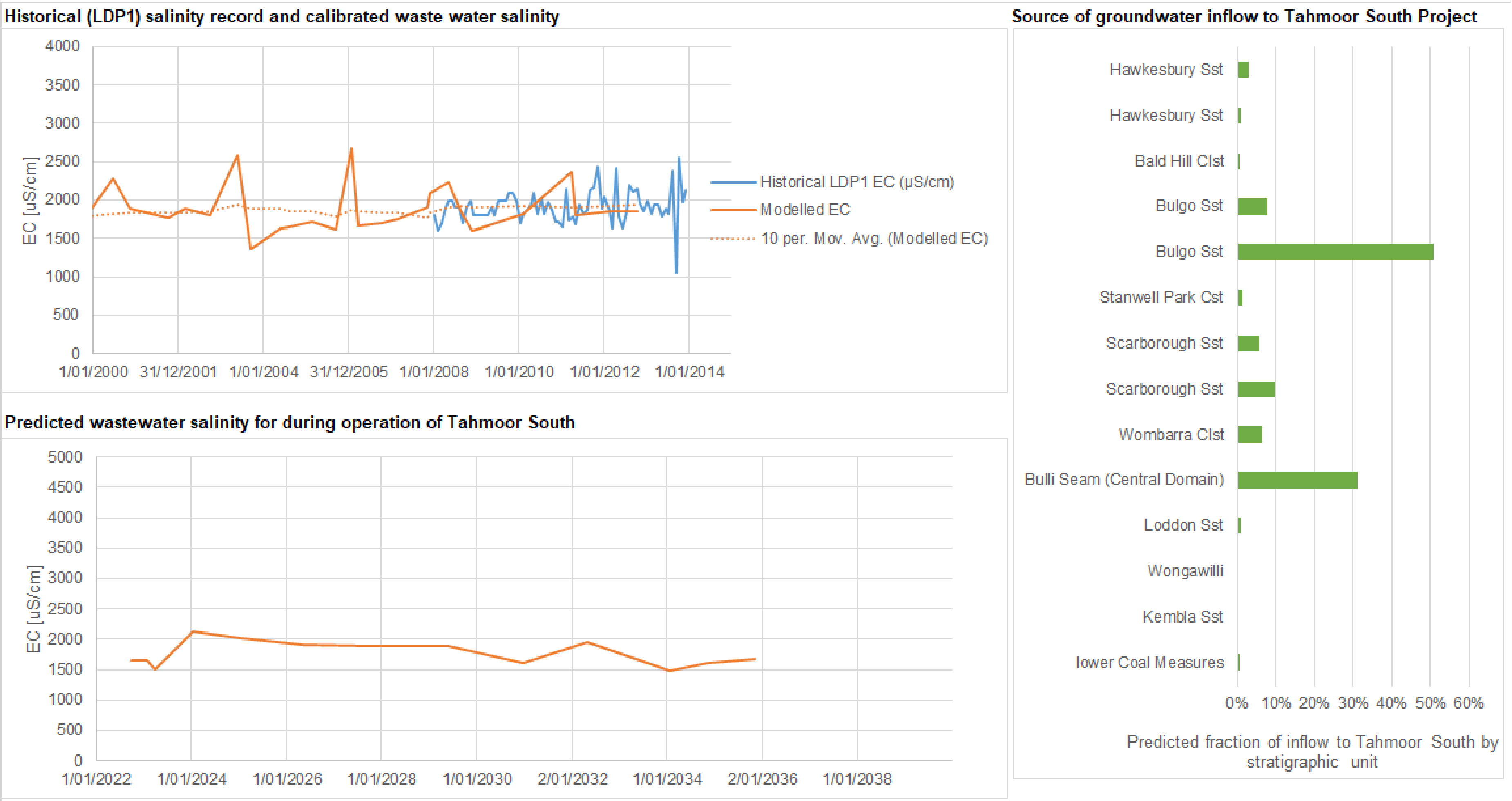

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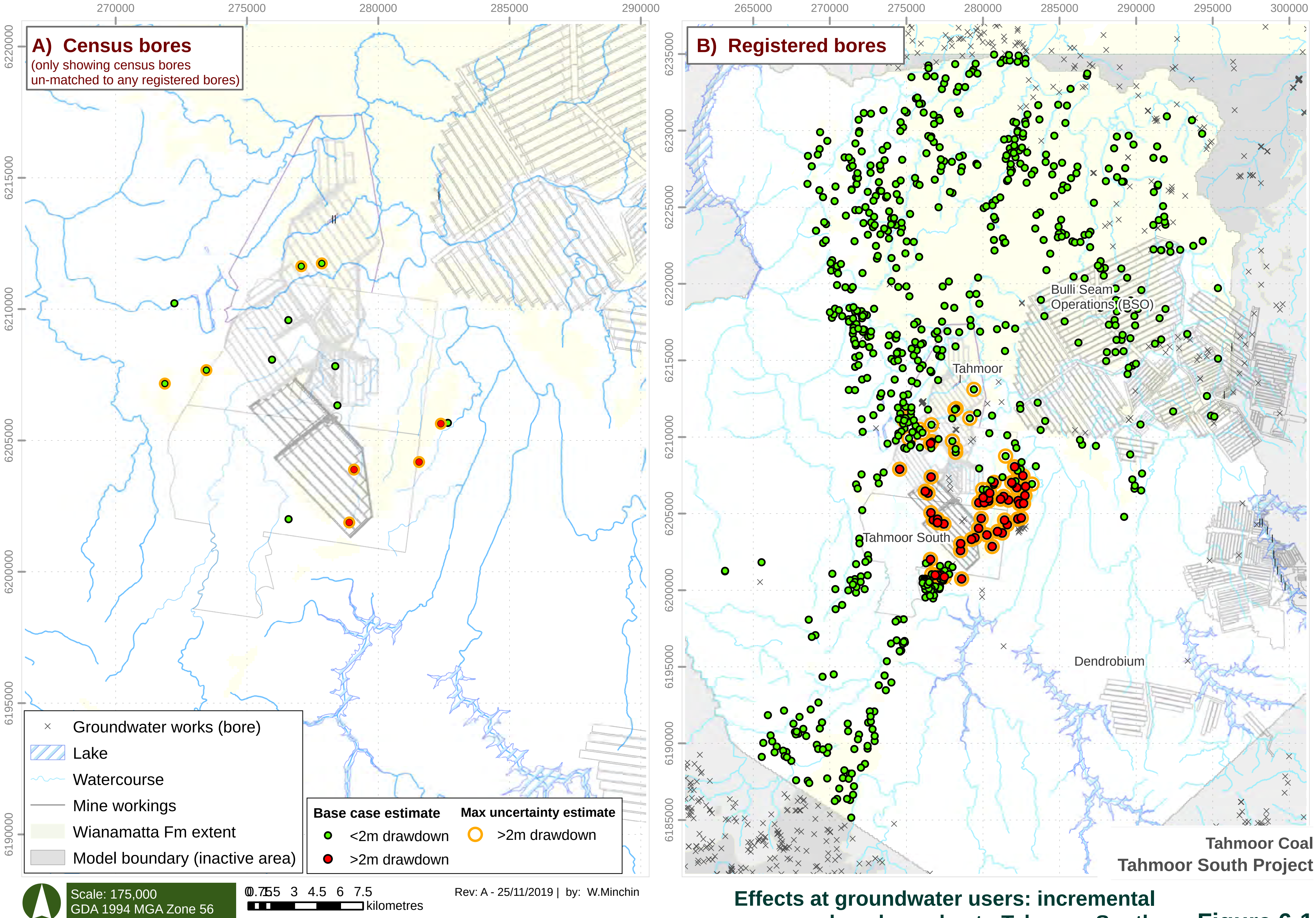
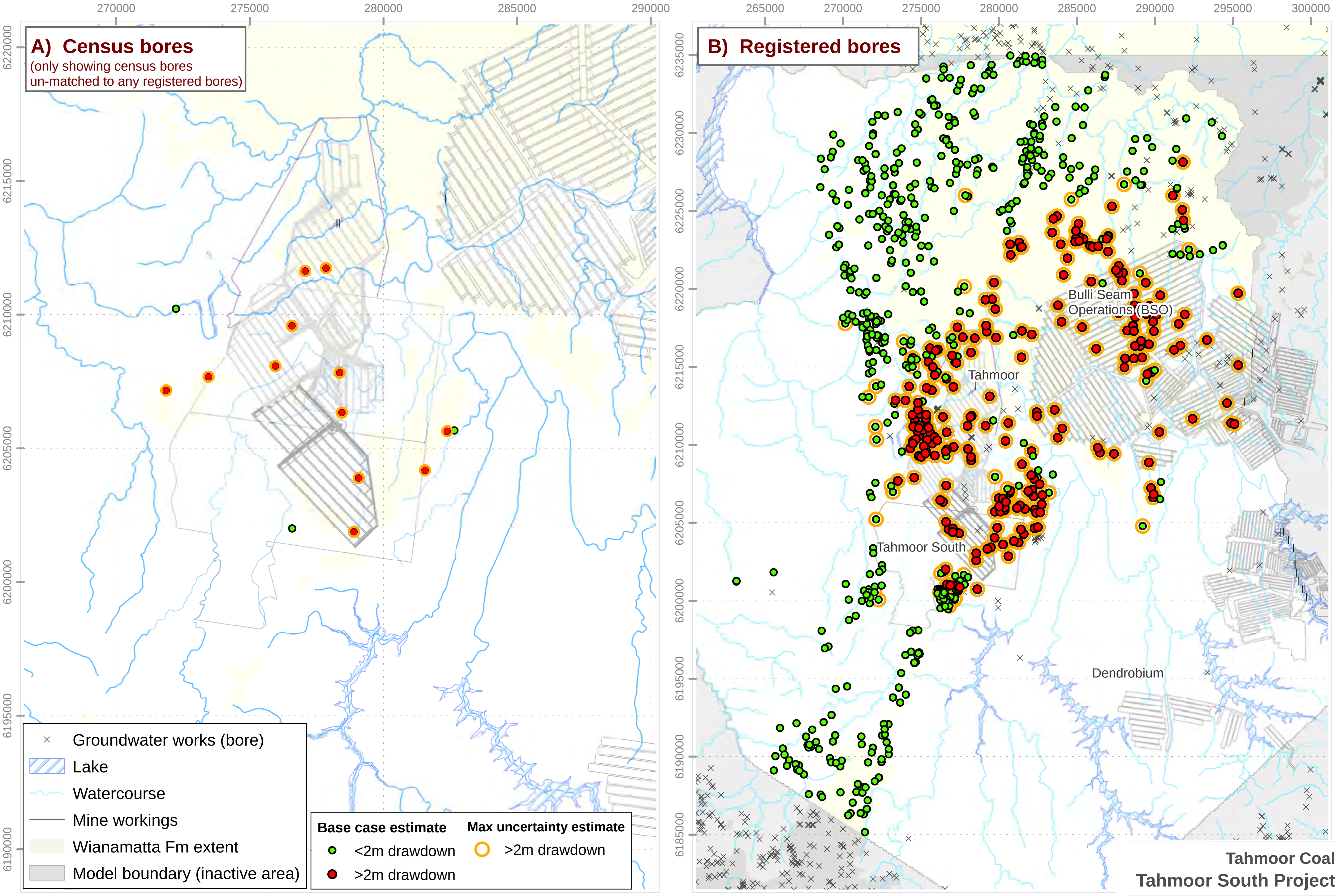
Figure 5-11 Historical and Predicted Salinity of Mine Inflow



Effects at groundwater users: incremental drawdown due to Tahmoor South

Figure 6-1



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Tahmoor Coal
Tahmoor South Project

Effects at groundwater users: drawdown due to cumulative mining effects

Figure 6-2