11.0 Impact Assessment

11.1 Subsidence

11.1.1 Overview of Approach to the Subsidence Impact Assessment

The proposed mine plan was developed by Tahmoor Coal following a risk assessment process which considered predicted subsidence impacts on built and natural features including the MSA. Tahmoor Coal made a number of revisions to the original Mine Plan, including removal of mining from the eastern domain, shortening of longwalls from the commencing ends so as to not encroach into the MSA, as well as avoiding undermining of sensitive natural features such as incised bedrock creeks and rivers. Refer to **Section 5.3.7** for further information regarding how potential subsidence impacts have been minimised for the proposed Mine Plan.

A Subsidence Impact Assessment for the proposed development has been prepared by Mine Subsidence Engineering Consultants Pty Ltd (MSEC, October 2018) and is provided in **Appendix F**.

11.1.2 Introduction

This section identifies the maximum subsidence predictions for the project and focuses on an assessment of potential impacts on infrastructure and the built environment. While general subsidence predictions and impacts to natural features have been considered in this section, a detailed impact assessment is contained in the relevant section for each environmental aspect, based on the technical predictions made by MSEC (Refer to **Sections 11.2, 11.3**, **11.4**, **11.5**, **11.6**, **11.7**, **11.8** and **11.9**).

The Subsidence Impact Assessment addressed the SEARs relevant to subsidence impacts. These are listed in **Table 11-1**.

Table 11-1 SEARs for the assessment of subsidence impacts

Subsidence SEARs	Section addressed
Subsidence – including a detailed assessment of the potential conventional and non-conventional subsidence effects, subsidence impacts and environmental consequences of the development on the natural and built environments, paying particular attention to features that are considered to have significant ecological, economic, social, cultural and environmental value, taking into consideration:	Subsidence impacts are assessed specifically in **Section 11.1** and **Appendix F**, and throughout **Section 11.0.**
• recorded regional and historic subsidence levels, impacts and environmental consequences;	**Section 11.1.3** and **Appendix F** (Subsidence Impact Assessment, Section 1)
• the potential extent of fracturing of the strata above the longwall panels; and	**Section 11.1.6, 11.2.4, 11.3.4, 11.4.4** and **Appendix F** (Subsidence Impact Assessment, Section 5-11)
• the implementation of a comprehensive subsidence monitoring program which is capable of detecting vertical, horizontal and far-field subsidence movements.	**Section 11.1.7**

11.1.3 Background

Longwall Mining and Subsidence

Longwall mining involves the progressive removal of portions of a coal seam, which creates a void along the width of the longwall panel. The extraction of coal results in the subsequent collapse of overlying strata, resulting in some vertical lowering of the ground surface above the longwall panel, known as subsidence (refer to **Figure 11.1**).

Subsidence occurs because the roof of the void created by mining is unable to support itself following extraction, causing the overlying strata to fracture and cave into the void (goaf). The collapse results in the settling and bending of overlying strata which, in turn, results in the formation of a subsidence trough on the surface. See **Figure 4.5** in **Section 4.0** (Proposed Development) for a schematic illustration of longwall mining.

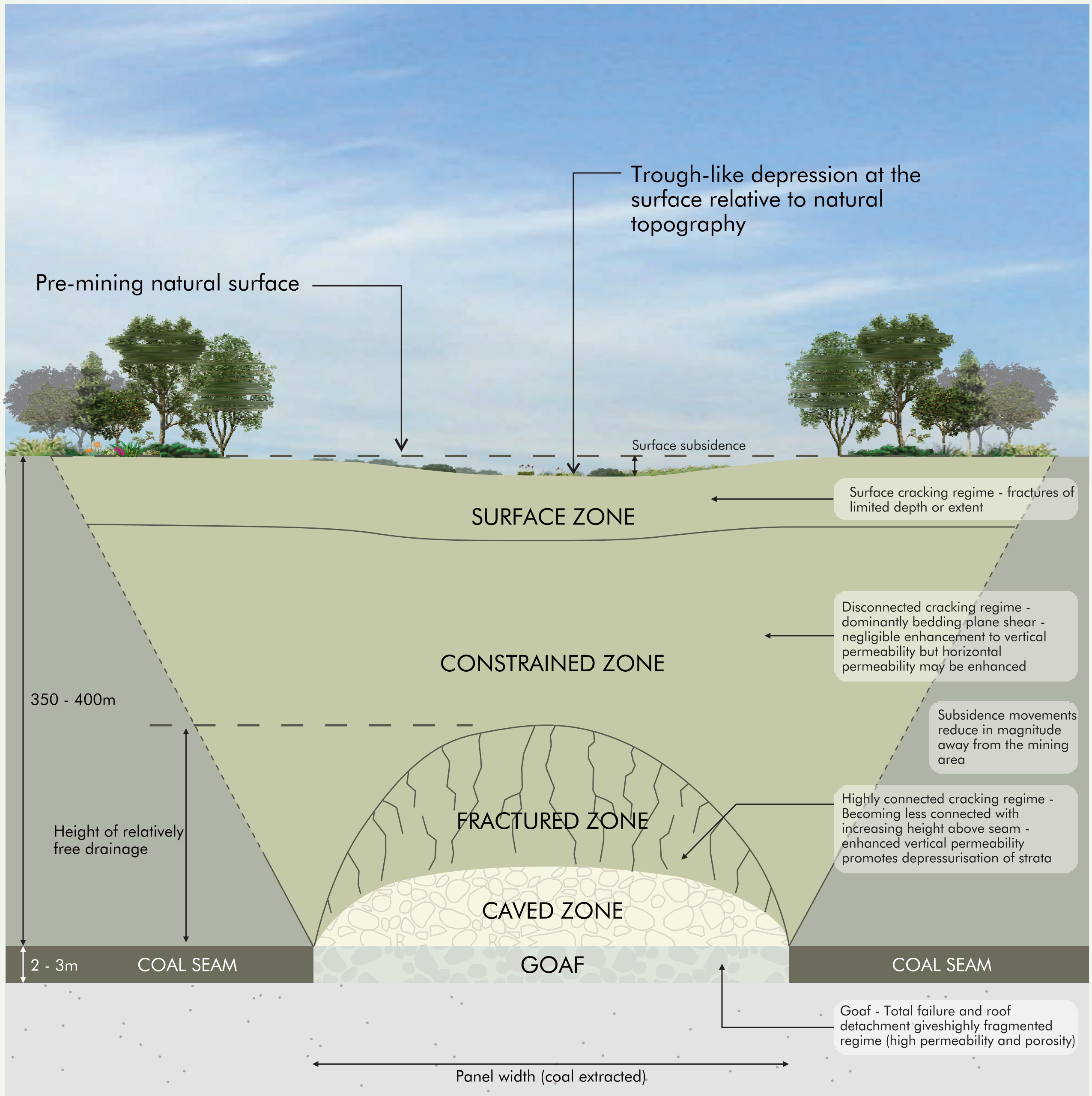
Maximum subsidence of the ground surface typically occurs in the central portion of the depression created at the surface and depends on a number of factors including longwall geometry, depth of cover, extracted seam thickness and overburden geology. There exists a critical width of extraction at which subsidence at the centre of the trough would reach a maximum possible value. The maximum subsidence in the Southern Coalfield, within a single seam and for a single panel of supercritical width of extraction, is generally 65% of the extracted seam thickness. Maximum subsidence at Tahmoor Mine has historically been measured at up to 1,300 mm (Tahmoor Coal, 2017).

In addition to subsidence, longwall mining results in several other surface movements as follows (MSEC, 2018):

- tilt – a change in slope at the surface, calculated as the difference in subsidence between two points on the land surface, divided by the distance between those two points;
- curvature – the bending of the ground as a result of differential subsidence, calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature can be either hogging (convex) or sagging (concave);
- strain – the relative differential horizontal movements of the ground. Normal strain is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Tensile strains occur where the distance between two points increases (often near the tops of valleys) and compressive strains occur when the distance between two points decreases (often within the bases of valleys);
- horizontal shear deformation – occurs across monitoring lines and can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index;
- upsidence – occurs where a valley is undermined and is the relative upward movement or uplift created by horizontal compression and buckling behaviour of rock strata in the vicinity of the valley floor. It is often observed that the valley floor subsides to a lesser extent than surrounding ridges tops (reduced subsidence). The magnitude of upsidence is the difference in subsidence between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain; and
- closure – this is the reduction in the horizontal distance between the valley sides.

Subsidence can result in either conventional (smooth profile) or non-conventional (irregular profile) ground movements (which can result from changes in geological conditions, steep topography or valley related movements). Historical information available for Tahmoor Mine indicates that both types of subsidence impacts occur. Consequently, both have been considered during the impact assessment for the proposed development.

Longwall mining can also create far-field movements. Far-field movements are the measured horizontal movements located beyond the longwall goaf edges and over solid unmined coal areas. These horizontal movements are often much greater than the observed vertical movements at these locations. Far-field horizontal movements are accompanied by very low levels of strain (usually less than the order of survey tolerance being less than 0.3 mm/m), and generally do not result in impacts on natural features or surface infrastructure. Larger structures such as roads and railway bridges may be more sensitive to far-field horizontal movements.



Adapted from Mine Subsidence Engineering Consultants Pty Ltd

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SIMEC MINING

SUBSIDENCE SCHEMATIC

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FIGURE 11.1

Existing Subsidence Monitoring and Management

The existing Tahmoor Mine operates under SMPs which are prepared by Tahmoor Coal prior to the commencement of each longwall and submitted to DRG for approval. SMPs have been prepared for varying infrastructure and public structures (including roads, rail and utilities) to manage public risk and safety. Longwall 32 within Tahmoor North is the last longwall approved under the SMP approval process. This process is informed by subsidence predictions for those structures and a risk assessment to determine the likelihood of impact, and to identify satisfactory management and remedial measures.

Existing subsidence monitoring at Tahmoor Mine includes the monitoring of:

- 806 residential properties;
- 1064 public amenities and commercial buildings;
- 26.2 km of asphalt pavement road directly above extracted longwalls;
- potable water infrastructure, including:
  - 4.8 km of ductile iron concrete lined pipe; and
  - 19 km of cast iron concrete lined pipe;
- 17.9 km gas pipeline;
- 29.4 km of sewer pipeline;
- electricity distribution infrastructure, including:
  - 38.2 km of electrical cables; and
  - 1019 power poles;
- telecommunication infrastructure, including:
  - 43.1 km of buried copper cable;
  - 2.2 km of buried optical fibre cable; and
  - 4.9 km of aerial cable.

Tahmoor Mine has received approval for a SMP for longwalls 24 to 32. Through implementation of the SMP, Tahmoor Coal has measured subsidence impacts and collated years of data collected for the existing operations at Tahmoor North. This data was used to inform the mine planning process for the proposed development.

A constraints analysis, risk assessment and detailed field investigations were undertaken during the mine planning process for the proposed development to identify sensitive natural surface features (such as waterways, cliffs and Aboriginal heritage sites). Monitoring data from the existing operations at Tahmoor North were used to inform the subsidence assessment to gauge the potential impacts to the sensitive natural features.

11.1.4 Methodology

The Subsidence Impact Assessment:

- defined the SSA of the proposed development as the area of influence or reach of subsidence related impacts from the proposed development;
- quantified the predicted subsidence impacts using a prediction model that incorporated the longwall geometry and dimensions, planned extraction depths, underlying seam information, local and regional observed historical data. The model was then used to assess the potential sensitivity of the predictions (as described further below);
- assessed impacts of the proposed development on natural and built features based on the predicted subsidence impacts. The assessment:

- identified the features within the existing environment that could be affected by subsidence, in particular the underlying geology, natural surface features (e.g. waterways and cliffs) and built features (e.g. community and/or public infrastructure and buildings);
- identified maximum predicted subsidence impacts for each of those features; and
- identified measures to avoid, minimise, remediate and/or offset predicted subsidence impacts.

- included a sensitivity analysis using information derived from observed subsidence movements caused by mining at Tahmoor North.

The Subsidence Impact Assessment is based on single seam mining within the Bulli seam (Refer **Figure 11.10** and **Appendix F**).

Extent of Longwalls

The ‘extent of longwalls’ defines the maximum extent of the footprint of the proposed longwall mining and consists of both first (roadways) and second (longwall) workings. The impact assessment for the proposed development assumes that longwall mining would occur only within the extent of longwalls.

The extent of longwalls provides for some flexibility for the modification of mining development work and longwall layout during detailed design, subject to geological conditions. It is proposed that minor changes to the layout would be approved under the Extraction Plan approval process (refer to **Section 11.1.7** for further discussion regarding Extraction Plans and the difference between Extraction Plans and SMPs). The final detailed design of the longwall layouts would be subject to review and approval in consultation with the relevant authorities and to the satisfaction of the Secretary of DPE. Mining operations which are proposed to be undertaken within the extent of longwalls include first workings, comprising main headings, gate roads and cut throughs as well as the development of the longwall panels (second workings).

The Tahmoor South project proposes longwall mining of longwall panels 101 to 109 in the Bulli seam within the Central domain, at depths of cover between approximately 365 m and 410 m below the surface ground level. The longwalls would be orientated in a south-east / north-west direction and parts of some longwalls are located under the Bargo township area. The extent of longwalls for the proposed development is shown in **Figure 4.1**.

Subsidence Study Area

The surface area within which natural surface features and items of infrastructure were identified and assessed for their potential to experience mine subsidence impacts as a result of the proposed extraction of longwalls is defined as the SSA.

The SSA assessed was conservatively derived by combining the areas bounded by the following limits:

- the predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from extraction within the proposed extent of longwalls (determined using the Incremental Profile Method); or
- a minimum of 600 m from the nearest edge of longwalls within the proposed extent of longwalls, as recommended by the independent inquiry report titled *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield – Strategic Review* (NSW Department of Planning, (DoP), 2008).

Therefore to ensure a conservative assessment, the SSA has been defined based on whichever limit outlined above is furthest from the proposed longwalls. The SSA is shown on **Figure 4.1**.

Subsidence Prediction

Incremental Profile Method

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, was determined using the Incremental Profile Method (IPM). The IPM is an empirical model based on a large database of observed monitoring data from previous mining within the Southern, Newcastle, Hunter and Western Coalfields of NSW and the Bowen Basin in Queensland. The IPM was calibrated for local conditions, based on the extensive ground monitoring data from Tahmoor Mine.

The calibrated prediction model was tested using the latest available subsidence data from mining in the Tahmoor North area, in combination with subsidence data from Longwalls 1 to 19. These longwalls are the closest previously mined longwalls to the proposed development and therefore provide the most relevant subsidence data as they are located in a similar geological environment to that of the proposed development. Subsidence observation and prediction profiles for other nearby mines in the Southern Coalfield were also reviewed to test the suitability of the IPM.

The calibration tests demonstrated that observed subsidence at Tahmoor Mine was generally less than the subsidence predicted by the model, with a 93% level of confidence that the maximum observed total subsidence would be less than the maximum predicted total subsidence for the proposed development. Therefore, the IPM is deemed to provide a reasonable and slightly conservative prediction for subsidence impacts associated with the proposed development.

The IPM was used to predict maximum conventional subsidence parameters including tilt and curvature for the proposed development. Further detailed description of the IPM is provided in the Subsidence Impact Assessment in **Appendix F**.

Increased Subsidence Predictions

Surface subsidence levels associated with the current operations at Tahmoor Mine have been measured to be generally in the order of 1,300 mm (Tahmoor Coal, 2017). During mining at Tahmoor Mine, observed subsidence impacts over Longwalls 24A and the southern parts of Longwalls 25 to 27 exceeded the predicted subsidence movements for individual longwalls. The relative increase in incremental subsidence was up to 2.34 times greater than predicted for this area. An investigation into the exceedance was undertaken and it was concluded that the increased magnitude of subsidence was consistent with localised weathering of joint and bedding planes above a depressed water table adjacent to an incised gorge, which in this case relates to the Bargo River (MSEC, 2018).

The location of increased subsidence was determined to be linked to the alignment of the Nepean Fault and proximity to the Bargo River Gorge. While subsidence was greater than anticipated in this location, the surface strains were within expectations. Potential impacts of increased subsidence on the structures and infrastructures within the overlying urban areas of Tahmoor Township were successfully managed by Tahmoor Mine through the implementation of effective subsidence management plans. The investigations undertaken for the proposed development and this EIS have considered the potential presence of similar geological features occurring within the Project Area, and informed the subsidence predictions and management derived for the proposed development.

Increased subsidence has also been observed within areas located above solid intact coal that are left between two extracted areas. Subsidence in these areas has generally been between 50 and 150 mm above what was predicted using the IPM and generally displays low levels of tilt and strain. In addition to IPM modelling of conventional subsidence parameters, the potential for increased subsidence was considered for the proposed development impacts on natural and built features.

Strain Prediction and Analysis

A linear relationship between curvature and strain is generally adopted to predict maximum conventional tensile and compressive strain impacts. Locations that are predicted to experience hogging curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging curvature are expected to be net compressive strain zones. In the Southern Coalfield, a factor of 15 provides a reasonable relationship between the maximum predicted curvatures and the maximum predicted conventional strains and was therefore adopted for the proposed development.

However, as considerable variation can exist between observed and predicted strains, a statistical approach was also adopted using observed strain data from Tahmoor Mine and other Coalfields. Statistical analysis was applied to the observed data to determine confidence levels for strain predictions (refer to **Appendix F** for further detail). Analysis of strains was undertaken for:

- strains measured in survey bays, to account for features that are in discrete locations such as building structures, farm dams and archaeological sites;

- strains along the length of monitoring lines, to account for linear features such as roads, cables and pipelines; and
- shear strains, to account for the relative horizontal movements that occur perpendicular to the direction of measurement (known as horizontal mid-ordinate deviations).

Impact Assessment Methods

Once subsidence predictions and the SSA had been defined, potential impacts were assessed for the natural and built features present within the SSA. This involved:

- reviewing historical data available for subsidence impacts on specific natural and built features in the Southern Coalfields (such as Nepean River), including data from Tahmoor Mine and other nearby mines;
- predicting maximum subsidence and strain impacts at each feature (where previous data was available) and comparing previously observed and predicted impacts on those features from previous mining activity at Tahmoor Mine and in the Southern Coalfields. Consideration of increased predictions was also taken into account where relevant; and
- assessing the impacts on environmental aspects, using subsidence predictions for those aspects and other assessment methods specific to each assessment. These included groundwater, surface water, terrestrial and aquatic ecology, heritage (Aboriginal and non-Aboriginal), land use and other disciplines which are detailed throughout **Section 11.0**.

While general subsidence predictions and impacts to natural and built features have been considered in this section, a detailed impact assessment of each feature is contained in the relevant section for each environmental aspect, as follows:

- Geomorphology – **Section 11.2**
- Groundwater – **Section 11.3**;
- Surface Water – **Section 11.4**;
- Thirlmere Lakes – **Section 11.5**
- Terrestrial Ecology – **Section 11.6**;
- Aquatic Ecology – **Section 11.7**;
- Aboriginal Heritage – **Section 11.8**; and
- Non-Aboriginal Heritage – **Section 11.9**.

Impact Assessment of Housing and Infrastructure

The Subsidence Impact Assessment for the proposed development included:

- prediction of subsidence impacts to built features within the SSA using a prediction model;
    - for linear infrastructure, such as rail, roads and utilities, the most relevant subsidence parameter is the maximum strains measured along monitoring lines (**Appendix F**); and
    - for discrete structures such as buildings, the most relevant subsidence parameter is the maximum strains measured in individual survey bays (**Appendix F**).
- assessment of subsidence impacts on built features as follows:
    - identification of the built features within the existing environment that could be affected by subsidence, in particular community and/or public infrastructure and buildings, transport and associated infrastructure, and utility services. The locations, sizes, and construction details of houses within the SSA were determined from the aerial photographs of the area, kerbside inspections and Google Street View®. In some cases, the houses were inspected at the request or consent of the landowners;
    - identification of the maximum predicted subsidence impacts for each of those features and therefore the potential impacts on those features; and

- consideration of measures to avoid, minimise, remediate and/or offset predicted subsidence impacts.

For impacts to residential dwellings and houses, a classification system for impacts was used. The classification system used for the proposed development is a revised method, which builds on the previous method used at Tahmoor Mine, which is consistent with the classification of damage of the *Australian Standard 2870-1996*. The previous method was revised due to difficulty of using crack width as a main classifying factor for subsidence impacts which involved too great a focus on structural stability and not on other aspects of buildings. The revised method is more closely aligned with all aspects of a building, its finishes and services to reflect the concern of residents for impacts to internal linings, finishes and services in addition to external walls.

The revised method is detailed in **Appendix F** and the resulting classification table is reproduced in **Table 11-2**. This method was also applied to public amenities where they were of a similar size to housing structures.

The classification method was applied to the proposed development using a probability-based approach for each repair category in order to predict impacts to houses within the Subsidence Area (refer to **Appendix F** for further detail).

Table 11-2 Classification based on the extent of repairs (MSEC, 2018)

Repair Category	Extent of Repairs
Nil/ No Claim	No repairs required
R0 Adjustment	One or more of the following, where the damage does not require the removal or replacement of any external or internal claddings or linings: • Door or window jams or swings, or • Movement of cornices, or • Movement at external or internal expansion joints.
R1 Very Minor Repair	One or more of the following, where the damage can be repaired by filling, patching or painting without the removal or replacement of any external or internal brickwork, claddings or linings: • Cracks in brick mortar only, or isolated cracked, broken, or loose bricks in the external façade, or • Cracks or movement < 5 mm in width in any external or internal wall claddings, linings, or finish, or • Isolated cracked, loose, or drummy floor or wall tiles, or • Minor repairs to any services or gutters.
R2 Minor Repair	One or more of the following, where the damage affects a small proportion of external or internal claddings or linings, but does not affect the integrity of external brickwork or structural elements: • Continuous cracking in bricks < 5 mm in width in one or more locations in the total external façade, or • Slippage along the damp proof course of 2 to 5 mm anywhere in the total external façade, or • Cracks or movement > 5 mm in width in any external or internal wall claddings, linings, finish, or • Several cracked, loose or drummy floor or wall tiles, or • Replacement of any services.
R3 Substantial Repair	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or affects the stability of isolated structural elements: • Continuous cracking in bricks of 5 to 15 mm in width in one or more locations in the total external façade, or • Slippage along the damp proof course of 5 to 15 mm anywhere in the total external façade, or • Loss of bearing to isolated walls, piers, columns, or other load-bearing elements, or

Repair Category	Extent of Repairs
	• Loss of stability of isolated structural elements.
R4 Extensive Repair	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or the replacement or repair of several structural elements: • Continuous cracking in bricks > 15 mm in width in one or more locations in the total external façade, or • Slippage along the damp proof course of 15 mm or greater anywhere in the total external façade, or • Re-levelling of building, or • Loss of stability of several structural elements.
R5 Re-build	Extensive damage to house where Tahmoor Coal and the owner have agreed to rebuild as the cost of repair is greater than the cost of replacement.

11.1.5 Existing Environment

Underlying Geology

Tahmoor Mine lies in the southern part of the Permo-Triassic Sydney Basin, within which the main coal bearing sequence is the Illawarra Coal Measures. The Illawarra Coal Measures contain multiple workable coal seams, the uppermost of which is the Bulli seam, which would be mined as part of the proposed development.

Three stratigraphic divisions overlie the Illawarra Coal Measures, being the Narrabeen Group (sandstone and claystone), Hawkesbury Sandstone Group (bedded sandstone) and Wianamatta Group (shales and siltstones). Sandstone units within these stratigraphic divisions dominate the study area and are evident at the surface, often exposed in river gorges and creeks. The Wianamatta Group units evident at the surface are generally limited to along the tops of ridgelines.

Coal exploration for the proposed development has identified a number of geological features within the study area, including two faults being the Nepean fault and the Central fault. The presence of these faults influenced the proposed mine layout as shown on **Figure 4.1**. Further detailed description of the underlying geology is provided in **Section 5.0**.

Groundwater

The proposed development is located within the Sydney Basin sedimentary rock groundwater system. The recognised aquifers/water bearing zones within the Groundwater Study Area are the:

- unconfined Quaternary and Tertiary alluvium/sediment aquifers;
- late Triassic Wianamatta Group minor aquifers and aquitards;
- middle Triassic Hawkesbury Sandstone aquifers;
- lower Triassic Narrabeen Group sandstone aquifers; and
- Permian Illawarra Coal Measures water bearing zones.

Aquifers or known groundwater resources identified within the SSA are detailed in **Section 11.3**.

Natural Surface Features

Natural surface features identified within the SSA are shown in **Figure 11.2** and include:

- catchment areas or declared Special Areas;
- State conservation areas;
- rivers and creeks, including Mermaid Pool;
- cliffs or pagodas;
- steep slopes;
- land prone to flooding or inundation;

- threatened or protected species; and
- natural vegetation.

Detailed descriptions of these natural features are included in the Geomorphology Technical Report (Fluvial Systems, 2013), Surface Water Baseline Study (HEC, 2018), Terrestrial Ecology Assessment (Niche Environment and Heritage Pty Ltd, 2018) and Aquatic Ecology Assessment (Niche Environment and Heritage Pty Ltd, 2018) and are summarised in **Sections 11.2, 11.4, 11.6** and **11.7**, respectively.

Although of anthropogenic significance, archaeological items of Aboriginal significance have been considered a natural surface feature as they are usually linked to landforms such as cliffs and streams (e.g. rock shelters). Archaeological items and sites of Aboriginal significance are described in **Section 11.8** and include a number of open camp sites, grinding groove sites, rock shelter sites, and a scarred tree.

Built Features

Built features identified within the SSA (refer to **Figure 11.3**) include:

- roads and railways, including the M31 Hume Motorway, Remembrance Driveway and Main Southern Railway;
- structures such as culverts, bridges and viaducts, including bridges over rivers (Nepean River, Bargo River) and bridges over the Main Southern Railway;
- dams, reservoirs and associated works (including Nepean Dam and Picton Weir);
- public amenity infrastructure such as schools, Bargo cemetery, shopping centres and ovals;
- farm land and facilities including farm buildings and sheds, irrigation systems, farm dams and fences;
- industrial, commercial and business establishments;
- residential establishments and houses; and
- significant Heritage sites.

Detailed descriptions of these features are included in the non-aboriginal heritage, traffic, social, and land use, agriculture and resources sections of this EIS (refer **Sections 11.9, 11.13**, **11.15, and 11.19** respectively). Key built features (above ground only) are shown in **Figure 11.3**.

Road and Rail

Road and rail infrastructure within the Project Area are shown in **Figure 11.3** and include:

- Main Southern Railway – a key national transport route that carries significant freight and passenger services between Brisbane, Sydney and Melbourne. The Main Southern Railway is maintained by the ARTC. The railway consists of a number of components (other than the track) including major and minor structures such as:
  - a railway viaduct over Bargo River;
  - several bridges, including road overbridges and rail overbridges;
  - Tahmoor overhead rejects conveyor, which crosses the railway;
  - culverts, cuttings, and embankments; and
  - signalling, electrical equipment and telecommunications equipment.
- M31 Hume Motorway – a highway road corridor, linking Sydney with Canberra and Melbourne. The highway is located approximately 520 m from the nearest longwall based on the proposed Mine Plan. The M31 Hume Motorway within the Project Area includes several components (other than the road pavement) that may be subject to subsidence impacts namely bridges, culverts, cuttings and embankments. The M31 Hume Motorway is maintained by RMS.

- Remembrance Driveway – the primary local road within the Project Area, and runs alongside the western side of the Main Southern Railway. Remembrance Driveway is maintained by Wollondilly Shire Council.
- other local roads – local roads are located throughout the Project Area, primarily linking with the Remembrance Driveway and M31 Hume Motorway. There are several local road bridges within the Project Area as part of the local road network including Bargo Road, Kader Street and Pheasants Nest Road bridges.

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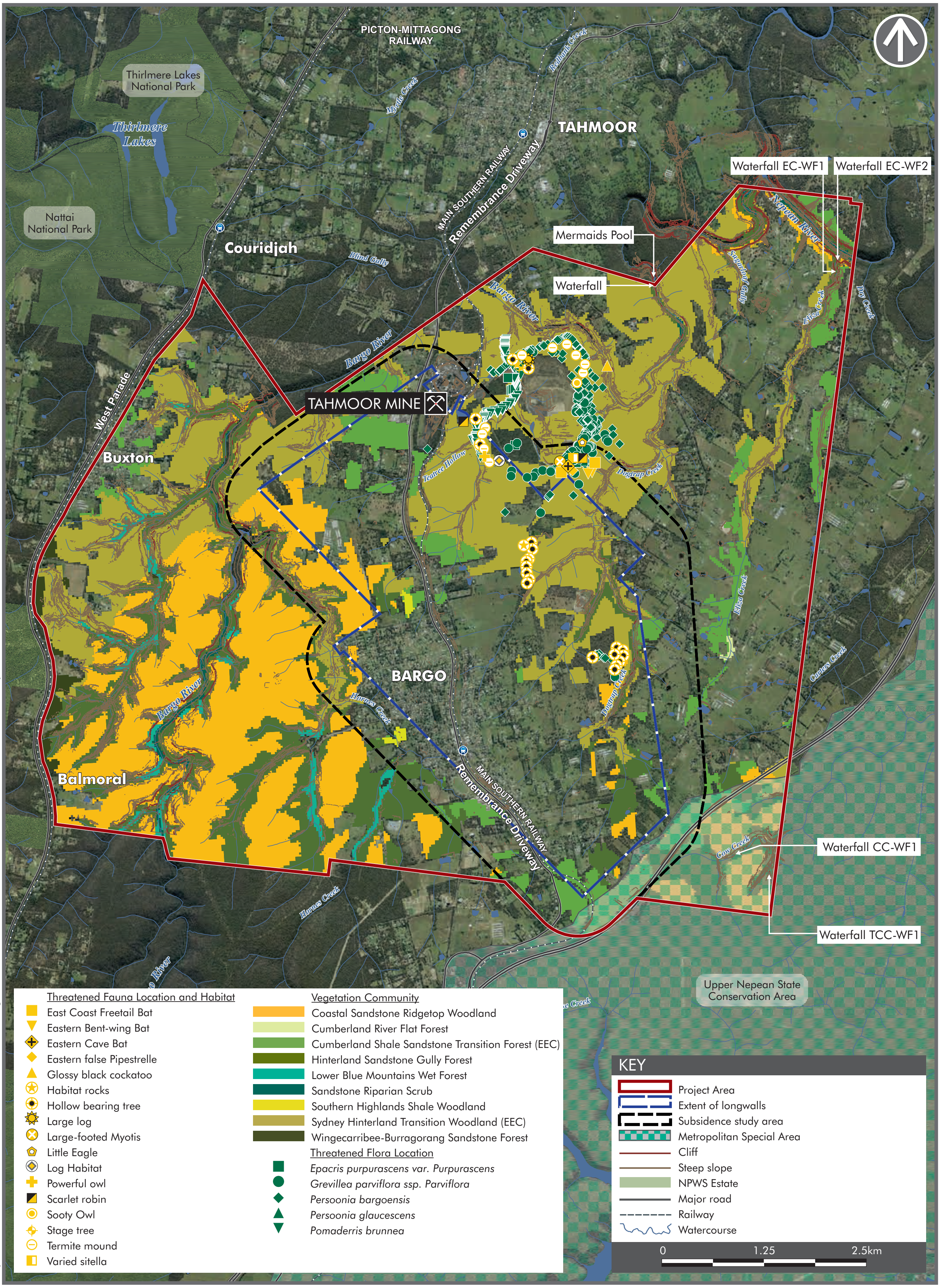

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NATURAL SURFACE FEATURES IDENTIFIED IN THE SUBSIDENCE STUDY AREA

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FIGURE 11.2

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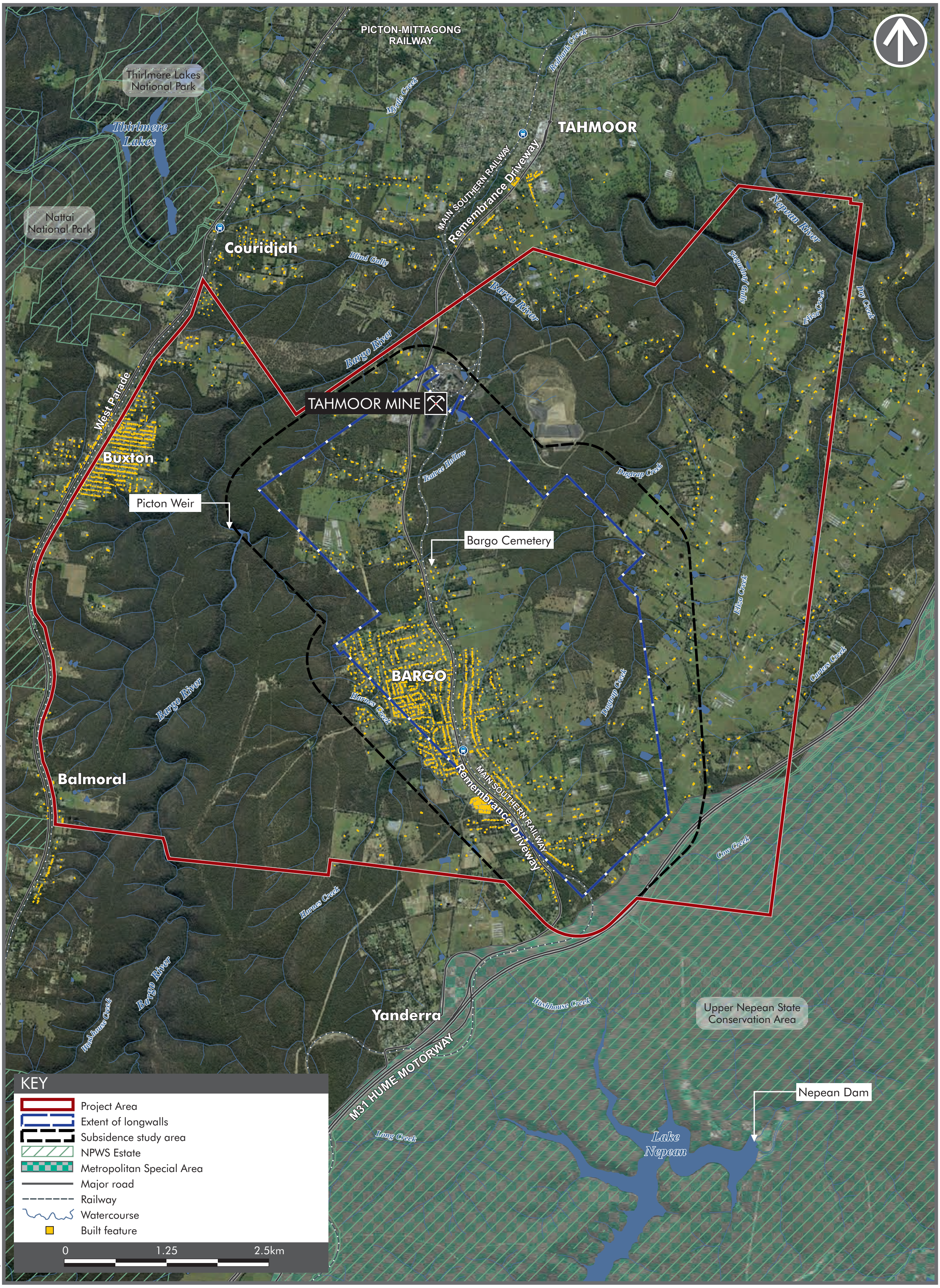

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BUILT FEATURES WITHIN THE SUBSIDENCE STUDY AREA
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FIGURE 11.3

Utility Infrastructure and Services

Utility infrastructure and services within the Project Area are shown in **Figure 11.4** and include:

- potable water infrastructure – includes a rising main, water storage reservoir and distribution network owned and operated by Sydney Water;
- Bargo sewerage scheme - includes a pressure main along Remembrance Driveway and a consumer reticulation network along the local roads. The proposed sewerage system is being designed to accommodate mine subsidence movements and would be approved by the SA NSW prior to construction. The system would consist of polyethylene pipelines with diameters up to approximately 250 mm;
- Bargo Waste Management Centre (BWMC) – is operated by Wollondilly Council and is located on Anthony Road, Bargo. The BWMC would be located directly above the proposed longwall mining area;
- gas infrastructure – includes the Moomba to Sydney Gas Pipeline and the Gorodok Ethane Pipeline (high pressure pipelines) as well as the local gas reticulation network;
- electrical infrastructure – includes 66 kV, 11 kV and low voltage power lines (distribution only); and
- telecommunications infrastructure – includes copper cables, and optical fibre cables owned and operated by Telstra, Optus, AAPT and NextGen. A mobile phone tower is also located within the Project Area.

Public Amenity

Public amenities within the Project Area are located in or near the Bargo Township and include:

- two places of worship (Bargo District Baptist Church and St Paul’s Anglican Church);
- two schools (Wollondilly Anglican College and Bargo Public School);
- a number of small shops in the Bargo township;
- one community centre (Bargo Community Centre);
- two bowling greens (both located at the Bargo Sports Club);
- two sportsgrounds which include ovals and tennis courts (Bargo Sportsground and grounds at Wollondilly Anglican College); and
- other public amenities including a preschool and three childcare centres, the Avon Caravan Village, Bargo Volunteer Bush Fire Brigade and Bargo Cemetery.

Houses

There are 1,458 houses within the SSA. These are shown in **Figure 11.5**. The majority of these houses are within the main township of Bargo and consist of single-storey residences with maximum plan dimensions less than 30 m, and are of brick or brick-veneer construction. Of the 1,458 houses, 751 (52%) are located directly above the proposed longwalls.

Within the SSA, the majority of houses are between 10 m and 30 m long with plan areas between 100 m^2 and 400 m^2. On average houses are around 18 m long with a plan area of 220 m^2. Analysis of historical aerial photographs indicates that the most houses were constructed between 1984 and 1994 and between 2002 and 2013.

The construction style of houses within the SSA is very similar to the distribution of styles within the Tahmoor Township, which have been subject to longwall mining by the Tahmoor Mine. The majority of the houses within the SSA are constructed of brick or brick veneer (75%), which is of a similar percentage (81%) to the construction style of houses affected by the mining of Longwalls 24 to 26 at Tahmoor North. As such, existing experience of subsidence impacts to houses depending on construction style from Tahmoor North would inform the management of subsidence impacts to houses within the Tahmoor South SSA.

Proposed development in mine subsidence districts requires SA NSW approval. SA NSW sets building and construction requirements to protect buildings and other surface improvements from subsidence damage; these requirements cover the nature and class of improvements, including height, type of building materials used and the construction method. Australian standards have been available for use in the design of structures since 1948. It is noted that the great majority of structures at Tahmoor and Thirlmere (approximately 80%) have been constructed after the declaration of the Bargo Mine Subsidence District in November 1975 (MSEC, 2018).

Subsidence Management and Consultation

Tahmoor Mine has been operating for over 30 years and has managed the impacts of mining operations on residences during mining at Tahmoor North using a range of communication and management tools. These tools would continue to be used to engage with the community during operation of the proposed development. These consultation and management tools include:

- **Resident Information Pack** distributed to residents in advance of any potential subsidence occurring at their properties. The resident information pack contains:
  - an overview of subsidence and the mining techniques used by Tahmoor Mine;
  - the rights and responsibilities as a home owner or tenant living in a Mine Subsidence District;
  - details of pre- mining inspections;
  - details of subsidence hazard inspections;
  - how to lodge a damage claim with the SA NSW; and
  - contact details for the relevant personnel at Tahmoor Mine including emergency contact details.
- **Monthly newsletter** containing up to date information on the current position of the longwall with local streets identified on the plan. The monthly newsletter assists residents to identify where they live in relation to current and future longwalls. The monthly newsletter also contains information on:
  - subsidence movements;
  - other major projects within the local area;
  - upcoming community information days; and
  - 24 hour contact numbers for Tahmoor Mine.

  The monthly newsletter is widely distributed in the community as follows:
  - via email to residents;
  - via posted mail to residents;
  - published on the Tahmoor Coal website- www.tahmoorcoal.com.au; and
  - posted to community notice boards in the Tahmoor Town Centre and at Community Links in Harper Close Tahmoor.
- **Community Information Days** held at least twice a year. The community information days are advertised in the Monthly Newsletter, Wollondilly Advertiser and on the Tahmoor Coal website. Representatives from Tahmoor Colliery and the SA NSW are available at each community information day to answer questions raised by community members. The purpose of the community information days is to provide the community with up to date information and the opportunity to talk to a Tahmoor Mine or SA NSW representative regarding a range of issues including:
  - mining updates and details of proposed mining operations at Tahmoor Mine;
  - information about mine subsidence and its impacts;
  - information regarding major projects at Tahmoor Mine;

  - information regarding proposed control procedures, including monitoring programs;
  - expert advice on specific housing and land issues within the area affected by mining;
  - responses to queries about mining and subsidence;
  - access to confidential counselling services; and
  - community guides to mine subsidence and individual properties.
- **Subsidence monitoring** undertaken along the streets regularly to monitor the impacts. Tahmoor Coal has engaged a team of specialists to visually inspect, monitor and survey surface and below surface infrastructure to not only ensure there is no risk to public safety, but also monitor change and discuss any concerns residents may have regarding Tahmoor Coal operations.

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SIMEC MINING

UTILITIES WITHIN THE PROJECT AREA
Tahmoor South Project
Environmental Impact Statement

FIGURE 11.4

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\Projects\605\60588574\4. Tech work area\4.99 GIS\FIGURES\EIS Figures\60588857 F11.5 Houses within the Subsidence Study Area 21 11 2018 TO

SIMEC MINING

HOUSES WITHIN THE SUBSIDENCE STUDY AREA

Tahmoor South Project
Environmental Impact Statement

FIGURE 11.5

11.1.6 Impact Assessment

Longwall mining-induced subsidence can result in both subsurface and surface impacts. Potential subsurface impacts include impacts to groundwater and aquifers. Surface impacts include ground deformations such as surface cracking, heaving, buckling, humping and stepping of land at the surface. The extent and severity of these impacts are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural jointing in the bedrock and the presence of near surface geological structures.

The Tahmoor South Project will involve longwall mining of nine panels (LW101-109). The mining geometry for each of the longwall panels is shown in **Table 11-3**.

Table 11-3 Mining geometry for proposed longwalls (MSEC, 2018)

Location	Longwall Widths (m)	Depths of Cover (m)	Width-to-Depth Ratios	Extraction Heights (m)
LW101 to LW108	285 & 305	370 ~ 415 (390 average)	0.70 ~ 0.82 (0.78 average)	2.05 ~ 2.85 (2.6 average)
LW109	305	380 ~ 410 (400 average)	0.74 ~ 0.80 (0.76 average)	2.1 ~ 2.4 (2.3 average)

Predicted Subsidence

Table 11-4 shows the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed Longwalls 101 to 109 (MSEC, 2018). As shown, the maximum predicted subsidence for the proposed development is 1,900 mm after the completion of the proposed longwalls, which represents around 67% of the extraction height (MSEC, 2018). The maximum predicted total conventional tilt is 13 mm/m (i.e. 1.3 %), which represents a change in grade of 1 in 77 (MSEC, 2018). The maximum predicted total conventional curvatures are 0.19 km^{-1} hogging and 0.33 km^{-1} sagging, which represent minimum radii of curvature of 5 km and 3 km, respectively (MSEC, 2018).

As discussed in **Section 11.1.4**, the outer limits of the SSA was based on the predicted limit of vertical subsidence, taken as the 20 mm subsidence contour or a minimum of 600 m from the nearest edge of the proposed extent of longwalls (whichever was greater). The SSA boundary shown in **Figure 4.1** thereby shows the outer limits of subsidence impacts predicted to result from the proposed development.

Table 11-4 Maximum predicted total conventional subsidence, tilt and curvature resulting from the extraction of each proposed longwall area (MSEC, 2018)

Longwall	Maximum predicted total conventional subsidence (mm)	Maximum predicted total conventional tilt (mm/m)	Maximum predicted total conventional hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LW101 to LW108	1,900	12.0	0.19	0.33
LW109	1,000	8.0	0.09	0.24

Predicted Strain

The maximum predicted conventional strains, based on applying the maximum predicted conventional curvatures of 0.19 km^{1} hogging and 0.33 km^{1} sagging curvature and a factor of 15 to the maximum predicted curvatures, is approximately 3.0 mm/m tensile and 5.0 mm/m compressive for longwalls 101 to 109.

There can be considerable variation between observed and prediction strains. To account for this variability, a statistical approach was adopted for the strain analysis using data obtained from Tahmoor Mine and other collieries, adjusted to account for differences in mine geometry (refer to **Section 11.1.1**). The analysis identified that strains resulting from the extraction of the proposed longwalls would be, on average, around 30% to 50% greater than those previously experienced at Tahmoor Mine, Appin and West Cliff Collieries.

Potential for Increased Subsidence

As described in **Section 11.1.3** and **Appendix F**, Tahmoor Mine has experienced levels of subsidence greater than that which was predicted for previously extracted Longwalls 24A and 25 to 27. The likelihood for increased subsidence was assessed and it was concluded that while increased subsidence similar to that experienced for Longwalls 24A and 25 to 27 may be possible, the following conditions are different for the proposed development and these conditions would influence the potential for increased subsidence:

- the Nepean Fault is less defined in the Project Area for the proposed development compared to the existing Tahmoor North area;
- the proposed longwalls are located further away from major regional streams such as the Bargo River (the magnitude of subsidence generally decreased as distance from the river increased); and
- the groundwater gradients are less than those measured near Longwalls 24A to 26 (refer **Appendix F**).

If greater than predicted subsidence was to occur for the proposed longwalls, it is unlikely that the magnitude of this increased subsidence would be significantly greater than predictions for the following reasons:

- predicted maximum observed incremental subsidence represents 51% of the proposed extraction height. The maximum incremental subsidence for Longwalls 24A to 27 was around 55% of the extraction height;
- predicted maximum total subsidence represents 67% of the proposed extraction height. The maximum observed total subsidence for Longwalls 24A to 27 was around 62% of the extraction height;
- the higher levels of predicted subsidence at Tahmoor South are due to a combination of thicker extraction heights, slightly shallower depths of cover and wider proposed longwall panel widths. They are comparable to or just less than the observed increased subsidence above Longwalls 24A to 27 when expressed as a proportion of extraction height; and
- in the cases of Longwalls 25 and 24A, the observed relative increase in incremental subsidence was greater than predictions by between 2 and 2.34 times, respectively. This was partly because the panels were the first and second in a series of longwalls where reduced subsidence would normally have been expected to develop. Increasing the predicted levels of subsidence by factors of 2 to 2.34 would result in subsidence much greater than the proposed extraction height, which is extremely unlikely to occur.

The potential for increased subsidence resulting from barriers of unmined coal between proposed Longwall 101 and previously extracted Longwall 2 and between proposed Longwalls 101 to 105 and previously extracted Longwalls 14 to 19 has also been assessed. While it is possible that observed subsidence may exceed predictions in these zones, subsidence monitoring at Tahmoor Mine indicates that any increase is accompanied by relatively low systematic tilts, curvature and strains (less than 0.5 mm/m and usually within survey tolerance). Based on previous experience at Tahmoor North, similar observations are considered likely for the proposed development.

Predicted Horizontal Movements

Conventional horizontal movements observed for the Tahmoor Mine are within the normal range in the Southern Coalfield for similar depths of cover. Horizontal movements generally do not result in perceived impacts. However, differential horizontal movements can potentially result in impacts on sensitive features, such as long road and railway bridges. Predictions of absolute and differential far field horizontal movements have been provided for these features.

The far-field horizontal movements for the proposed development are predicted as being very small and accompanied by very low levels of strain, which are generally less than the order of survey tolerance (i.e. less than 0.3 mm/m). However, some far-field horizontal movements can be experienced by road and railway bridges. The potential impacts of far-field horizontal movements on the natural and built features within the vicinity of the proposed longwalls are not expected to be significant.

Impacts on Natural Features

Impacts to natural features have been assessed based on the maximum predictions of subsidence and strains, and observations and experiences gained during the extraction of previous longwalls adjacent to or directly beneath similar natural features. Detailed assessment is provided in the relevant specialist section of this EIS. However, a summary of the impacts is provided in **Table 11-5**.

Table 11-5 Potential impacts to natural features

<table>
<tr><th>Natural feature</th><th>Potential impacts</th><th>Mitigation</th></tr>
<tr><td>Groundwater and aquifers</td><td>Potential impacts may include fracturing of bedrock and drawdown of groundwater. Potential impacts to groundwater as a result of subsidence associated with the proposed development are considered further in Section 11.3, and in Appendix I.</td><td>A number of measures would be implemented to manage potential groundwater impacts, including:
• a Groundwater Management Plan (GWMP) would be developed to define a groundwater monitoring strategy, groundwater level triggers, and a TARP;
• the regional groundwater monitoring network would continue to be developed and maintained; and
• Tahmoor Coal commits to implementing “make good” measures to effectively mitigate impacts to bore users.
Refer to Section 11.3.5 and Appendix I for the full list of measures that would be implemented to manage potential groundwater impacts.</td></tr>
<tr><td>Steep slopes, cliffs and rock formations</td><td>Potential impacts include fracturing and increased rock falls. Potential impacts to slopes, cliffs and rock formations as a result of subsidence associated with the proposed development are in Section 11.2, and in Appendix H.</td><td>Tahmoor Mine has previously developed Management Plans to manage the potential impacts on cliffs during the mining of longwalls. The management plans include consultation with landowners, visual inspections before and after mining and where the public may access the cliffs, erection of warning signs during periods of active mining. Similar management strategies would be developed in consultation with the nearby landowners to manage potential risks to the people who may be visiting or passing by cliffs within the SSA during periods of active mining.

Tahmoor Mine has previously developed subsidence management plans for managing the potential impacts on steep slopes during the mining of Longwalls 22 to 27. These management plans include:
• identification of all structures, dams and roads that lie in close proximity to steep slopes;
• site investigation and landslide risk assessment of structures near slopes by a qualified geotechnical engineer;
• site investigation and structural assessment of structures where recommended by the geotechnical engineer. This may include recommendations to mitigate against potential impacts;
• monitoring, including ground survey and visual inspections; and
• remediation if cracking or slippage occurs.

Tahmoor Mine would continue to develop management plans consistent with existing measures to manage potential impacts on slopes during the mining of the proposed longwalls.</td></tr>
</table>

Natural feature	Potential impacts	Mitigation
Catchment areas, rivers and creeks	Potential impacts include fracturing resulting in loss of flow and surface deformation resulting in ponding. Potential impacts to surface water features are considered further in **Section 11.4**, and in **Appendix J**.	Tahmoor Mine would incorporate a number the measures listed in **Section 11.4.6** into the Extraction Plan for the proposed development. These measures would be consistent with the existing measures that have been implemented to effectively manage potential mining induced impacts to river channels for current operations as part of existing SMPs.
Threatened or protected species and natural vegetation	Potential impacts to vegetation and threatened flora as a result of subsidence are not anticipated to be significant given that impacts from subsidence on vegetation are considered to be localised and minor, and availability of water to vegetation would not be significantly altered. There are no sensitive heath and swamp communities within the SSA. Subsidence impacts to threatened fauna are primarily limited to aquatic species associated with potential impacts on rivers and creeks. Potential impacts to both terrestrial and aquatic flora and fauna are considered in further detail in **Section 11.6** and **11.7**, and in **Appendix K**.	Tahmoor mine would prepare and implement a Corrective Management Action Plan and TARP for potential impacts to pools and other aquatic habitat features identified in the Aquatic Ecology Assessment (**Appendix K**). Stream triggers would be developed using baseline data and anticipated subsidence effects, with specific triggers continuing to be developed as monitoring continues and refined in consultation with key stakeholders. An on-going monitoring program would be undertaken as part of the Biodiversity Management Plan. This program would include monitoring of potential flora and fauna impacts and would be implemented for as long as potential impacts could occur. Monitoring measures would include regular inspection, measures for response if impacts are detected, and monitoring of the success of mitigation. Refer to **Section 11.6.5**, **Section 11.7.5** and **Appendix K** for additional mitigation measures.

Natural feature	Potential impacts	Mitigation
Archaeology and Aboriginal heritage	Potential subsidence impacts to archaeological and Aboriginal heritage include increased rock fall or surface cracking that may damage items and their values and are discussed further in **Section 11.8** and **11.9**, and in **Appendix L**.	The Extraction Plan developed for the longwalls for the proposed development (refer to **Section 11.1.7**) would include the following for Aboriginal heritage: • A schedule for undertaking monitoring at nominated sites; • Appropriately detailed baseline and archival site recordings, including high resolution digital photographs and an impact Trigger and Action Response Plan TARP specific to each of the sites being monitored; - Archival site recordings would include three dimensional scans and digital rendering of rock shelters of high significance which would be provided for use to RAPs; and • Adaptive management techniques. Should monitoring detect the early development of potentially severe differential movements at these archaeological sites during the extraction of Longwalls 101 and 102, consideration would be given to shortening the commencing position of Longwall 103. A site specific Heritage Management Plan would be prepared for each heritage site of local and/ or State significance identified within the Project Area, including Wirrimbirra Sanctuary, Bargo Cemetery, Bargo Railway Bridges (South and North) and Tahmoor Mine. Each Heritage Management Plan would be developed in consultation with property owners/managers and the Wollondilly Shire Council prior to commencement of mining. Refer to **Section 11.8.5**, **Section 11.9.5** and **Appendix L** for additional mitigation measures.

Impacts to Built Features

Impacts to built features have been assessed based on the maximum predictions of subsidence and strains, and observations and experiences gained during the extraction of previous longwalls adjacent to or directly beneath similar built features. Detailed assessment is provided in sections below and a summary of the potential impacts is provided **Table 11-6**.

Table 11-6 Summary of potential impacts to built features

Built feature	Potential impacts	Mitigation
Roads and railways, including the M31 Hume Motorway, Remembrance Driveway and Main Southern Railway	Impacts include subsidence of up to 1,800 mm on the Main Southern Railway and Remembrance Driveway. The M31 Hume Highway would not be undermined and is located outside of the predicted limit of subsidence. Other local roads are located directly above the proposed longwalls and, therefore, could experience the full range of predicted subsidence movements. Potential impacts to roads and railways as a result of subsidence associated with the proposed development are discussed below.	Potential subsidence impacts to built infrastructure are manageable and can be controlled by the preparation and implementation of an Extraction Plan and a series of specific Extraction Plan sub-plans, similar to the SMPs which have already been developed and are being successfully implemented during mining at Tahmoor Mine. These management plans would be developed through consultation with the infrastructure owners and are approved by the relevant government agencies. Refer to **Section 11.1.7** for further detail.
Private properties	Potential impacts to private properties including houses are discussed below.	
Structures such as culverts, bridges and viaducts	For some less ductile structures, there is a possibility that those structures may fail in a brittle manner. Potential impacts to relevant structures as a result of subsidence associated with the proposed development have been considered further below.	
Public utilities such as water, gas or sewerage infrastructure, electricity transmission lines, and telecommunication services	The distribution network is located across the Study Area and, therefore, could experience the full range of predicted subsidence movements. Impacts could include leakage or breaks of water or gas pipes, or pole tilts for electrical (aboveground) infrastructure as discussed below. The main Telstra and Optus Sydney to Melbourne optical fibre cables and National Broadband Network cables follow the alignment of the M31 Hume Motorway and are outside the predicted limit of subsidence. The locations where key infrastructure is co-located would require careful management and would be addressed in the Extraction Plan.	
Varying land uses such as farm land, industrial and commercial establishments	Potential impacts are discussed below.	

Built feature	Potential impacts	Mitigation
Heritage sites	Possible impacts include damage to masonry or timber structures as a result of subsidence. Potential impacts to non-Aboriginal heritage features as a result of subsidence associated with the proposed development are considered further in **Section 11.9**, and in **Appendix L**.	Refer **Section 11.9.5** and **Appendix L.**

Impacts to Road and Rail

Table 11-7 shows the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls in relation to the key road and rail infrastructure discussed in **Section 11.1.3**. The table shows that maximum predicted subsidence is highest for infrastructure that is located directly above longwall panels (such as the Main Southern Railway, Remembrance Driveway and local roads).

Table 11-7 Maximum predicted subsidence impacts for road and rail infrastructure

Infrastructure Item	Maximum predicted total conventional subsidence (mm)	Maximum predicted total conventional tilt (mm/m)	Maximum predicted total conventional hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Main Southern Railway	1,800 *(after LW108)*	8.5 *(after LW102 and 107)*	0.10	0.23
Remembrance Driveway	1,800 *(after LW108)*	8.0 *(after LW107)*	0.12	0.31
Local roads	1,900	12.0	0.19	0.33

Main Southern Railway

Potential impacts to the Main Southern Railway include the potential for:

- changes in track geometry (which could include vertical misalignment, horizontal misalignment, changes in track cant and track twist), changes in grades and changes in rail stress of the rail tracks; and
- cracking, damage or failure of associated structures (bridges and culverts), cuttings and embankments.

The ARTC *National Code of Practice for Track Geometry* provides allowable deviations in track geometry. An assessment of predicted conventional subsidence against this Code showed that that the predicted changes in track geometry are an order of magnitude less than the maximum allowable deviations. However, non-conventional movements could result in exceedances. Previous experience at Tahmoor Mine has demonstrated that potential risk to track safety can be managed through early detection via monitoring and early response through the implementation of triggered response plans. Tahmoor Mine and the Australian Rail Track Corporation (ARTC) previously developed a detailed risk management plan for managing potential mine subsidence impacts on the Main Southern Railway due to the extraction of Longwalls 25 to 32 at Tahmoor Mine and similar measures would be applied to the proposed development, to identify and manage impacts in accordance with ARTC requirements.

Mine subsidence would result in changes to rail stress unless preventive measures are implemented. The maximum predicted change in stress free temperature for the project is sufficient to warrant immediate preventative action on a track with concrete sleepers. If no action is taken, it is likely that the rails would become unstable as a result of the mining of the proposed longwalls. The combination of expansion switches and zero toe load clips has been successfully employed previously at Tahmoor Mine and at Appin Colliery to manage rail stress.

A series of predictions and assessments were also undertaken for each crossing of the Main Southern Railway, including bridges, Bargo viaduct and other crossings (such as Tahmoor Overhead Rejects Conveyor). Potential impacts to these structures include damage from cracking or failure due to their brittle nature. Previous bridge strengthening activities have been undertaken for Tahmoor Mine that would be similarly implemented for the proposed development. As such, potential impacts to these structures are considered to be minor in nature and manageable. Management and mitigation measures for potential subsidence as a result of the project are outlined in **Section 11.1.7** and include the preparation of the Extraction Plan that would be developed through consultation with the infrastructure owners and approved by the relevant government agencies.

M31 Hume Motorway

The M31 Hume Highway would not be undermined and is located outside of the predicted limit of subsidence and as such is not expected to be impacted by subsidence impacts.

M31 Hume Motorway bridges are all located outside the extent of the proposed longwalls. However some far-field horizontal movements may be experienced at the Avon Dam Road overbridge which is located 520m south of the extent of longwalls (noting that far field movements of up to 75mm have been observed up to 400m from previously extracted longwalls). As the remaining bridges are located at least 1.8 km from the proposed longwalls, they are unlikely to experience any measurable conventional subsidence impacts.

The Hume Highway and infrastructure associated with the Hume Highway are not predicted to be significantly impacted. Notwithstanding, management and mitigation measures for potential subsidence as a result of the project are outlined in **Section 11.1.7** and include the preparation of an Extraction Plan that would be developed through consultation with the infrastructure owners and would be approved by the relevant government agencies.

Remembrance Driveway and Local Roads

The Remembrance Driveway follows a similar alignment to the Main Southern Railway and as such is likely to experience similar subsidence movements. The remaining local roads within the SSA are located directly above the proposed longwalls and are likely to experience the full range of predicted subsidence movements. Potential impacts include cracking of the pavement, cracking of concrete culverts and drainage structures, and cracking of road cuttings and embankments. Previous experience of mining beneath roads and culverts indicates that the incidence of impacts is low and generally limited to cracking which can be readily remediated Longwalls 22 to 31 at Tahmoor Mine have mined directly beneath more than 28 km of local roads and a total of 52 impact sites have been observed. There is extensive experience of mining directly beneath local roads in the Southern Coalfield and with the implementation of suitable management strategies, impacts are considered to be manageable.

The most likely impacts of direct undermining of local road bridges could include cracking of the abutments and increased stresses on the decks and the compression heaving of pavements on approach to the bridges. The Tahmoor Mine has previously successfully undermined two local road bridges including undertaking strengthening and monitoring activities. These measures would inform the implementation of similar safeguards for the proposed development. As such, potential impacts to these structures are considered to be minor in nature and manageable. Management and mitigation measures for potential subsidence as a result of the project are outlined in **Section 11.1.7** and include the preparation of an Extraction Plan that would developed through consultation with the infrastructure owners and be approved by the relevant government agencies.

Impacts to Utility Infrastructure and Services

Table 11-8 shows the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls in relation to the key utility infrastructure discussed in **Section 11.1.3**.

Longwall mining in the Southern Coalfield has occurred directly beneath water pipelines in the past and the subsidence impacts of the proposal are anticipated to be consistent with that observed to occur from previous longwall mining. Potential impacts to water infrastructure include localised leaks as a result of strain on pipes. These impacts are more likely to occur at stream crossings due to valley related movements. Previous experience at Tahmoor Mine indicates impacts to water infrastructure are minor in nature and readily remediated.

The Sydney to Moomba Gas Pipeline and the Gorodok Ethane Pipeline are considered to have reasonable flexibility to accommodate conventional subsidence movements. However, the pipeline may be impacted by localised non-conventional subsidence movements near the bases of streams. Previous experience in the Southern Coalfields has indicated that management measures are required to alleviate strain in these situations.

The local gas, sewerage, electrical and telecommunications infrastructure have the potential to experience the full range, or close to the full range, of predicted subsidence movements. The infrastructure is considered flexible and previous experience has demonstrated these assets are able to withstand the full range of subsidence experienced at Tahmoor Mine to date. Management measures are able to readily remediate minor impacts. Management and mitigation measures for potential subsidence as a result of the project are outlined in **Section 11.1.7** and include the preparation of an Extraction Plans that would be developed through consultation with the infrastructure owners and are approved by the relevant government agencies.

The Bargo Waste Management Centre (BWMC) is located on Anthony Road, Bargo directly above the proposed extent of longwalls. The BWMC is expected to experience the full range of predicted subsidence movements. Without the implementation of mitigation measures, mining directly beneath the BWMC may result in impacts on the slopes of the landfill and may result in cracking and potential leakage to groundwater for the surface water treatment ponds at the site. Storage containers at the site used to stored waste liquids such as engine oil are considered likely to be flexible and would tolerate subsidence movements.

Table 11-8 Maximum predicted subsidence impacts for utility infrastructure

Item	Maximum predicted total conventional subsidence (mm)	Maximum predicted total conventional tilt (mm/m)	Maximum predicted total conventional hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
Potable water infrastructure	1,800	7.5	0.12	0.29
Sewer infrastructure	1800	8.0	0.12	0.31
Sydney-Moomba Gas Pipeline and Gorodok Ethane Pipeline	1,850	10.0	0.16	0.33
Local gas network	1,900	12.0	0.19	0.33
Electrical infrastructure	1,900	12.0	0.19	0.33
Telecommunications infrastructure (optical fibre cables)	1,900 (after LW103-108)	10.0	0.15	0.33
Telecommunications infrastructure (optical fibre cables that follow the Sydney-Moomba Gas Pipeline)	1,850	10.0	0.16	0.33
National Broadband Network (NBN) cables and copper cables	1800	10.0	0.15	0.33
Telstra Bargo Exchange	250	2.0	0.02	0.01

Impacts to Public Amenity

The assessment of public amenities considered amenities that:

- are located directly above the longwalls and therefore likely to experience the full range of subsidence predictions (refer **Section 11.1**); and

- are not located directly above the longwalls and therefore have been considered on a case by case basis (i.e. site specific predictions were undertaken, refer **Appendix F**).

Public amenities located directly above the longwalls may experience variable impacts depending on their structure including non-structural cracking of walls, floors or ceilings, tensile surface cracking and localised ground deformations. Some of these impacts may be experienced at public amenities not undermined by the proposed development. However, the nature and scale of impacts would be less than those directly above the longwalls.

Management and mitigation measures for potential subsidence related impacts as a result of the project are outlined in **Section 11.1.7** and include the preparation of an Extraction Plan that would be developed through consultation with the infrastructure owners to ensure all public amenities can be maintained in a safe and serviceable condition.

Impacts to Houses

Of the 1,458 houses identified within the SSA, 751 are located directly above one of the proposed longwalls (approximately 52%). Predicted movements and assessed impacts for each house within the SSA are included in Table D.03 of Appendix D of **Appendix F**.

Over the past thirteen years, Tahmoor Mine has subsided in the order of 1,890 houses above Tahmoor Longwalls 22 to 29, the majority of which experienced little if any damage from mine subsidence impacts. Of the 1,541 houses and buildings, a small percentage (7%) experienced more significant impacts (repair category R3 to R5 requiring substantial repair or rebuilding). These impacts have been rectified or continue to be repaired, replaced or otherwise satisfactorily addressed, by Tahmoor Mine in close working relationship with Subsidence Advisory New South Wales (SA NSW). Tahmoor Mine has been successfully managing subsidence impacts to houses and buildings from longwall mining at Tahmoor North for many years in accordance with an approved SMP and would continue to do so for Tahmoor South with an Extraction Plan for the proposed development.

Recent experience mining Longwalls 22 to 29 at Tahmoor Mine has indicated that residents have not been exposed to immediate or sudden safety hazards as a result of impacts that occur due to mining subsidence movements. Residents living within the active subsidence zone have often provided early feedback about impacts developing at their houses; with contact occurring before impacts develop to a level of severity sufficient to become a safety hazard. The community consultation and notification process is therefore critical to managing subsidence impacts, along with site specific investigations, regular surveys and inspections during mining and triggered response measures.

Potential impacts to houses include:

- changes to height above the flood level as a result of vertical subsidence;
- serviceability impacts (e.g. door swings, guttering and drainage) as a result of tilt; and
- amenity and structural impacts as a result of curvature and strain.

The range of predicted curvatures for the houses within the SSA is considered to be similar to those within the zone of increased subsidence observed above Tahmoor Longwalls 24A to 27. Subsidence impacts to houses within the zone of increased subsidence above Tahmoor Longwalls 24A to 27 involve a higher proportion of R3 to R5 repair category impacts (16%) to 69 out of 432 houses. This is compared to the overall proportion of R3 to R5 repair category impacts across all subsided houses above Tahmoor Longwalls 24A to 27 (7%, reflecting 131 of 1890 houses).

Within the Tahmoor South SSA, approximately 16% of houses directly above longwalls (126 of 751 houses) and 10% of all houses within the SSA (143 of 1,458 houses) are predicted to result in subsidence impacts in the R3 to R5 category. It is noted that the predictions also reflect the conservative nature of assumptions used in the assessment, where all houses were assigned the category of brick veneer on strip footings, noting that this type of construction has been observed to be more susceptible to subsidence impacts. The majority of predicted impacts (52% of houses directly above longwalls and 70% of all houses within the SSA) remain in the No Claim or R0 category (nil impacts or minor adjustment).

A summary of the assessed impacts to houses within the SSA is shown in **Table 11-9**.

Table 11-9 Assessment of likely impacts for the houses within the Study Area (MSEC, 2018)

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All Houses (total 1,458)	**1,019 (70%)**	**296 (20%)**	**115 (8%)**	**28 (2%)**
Above proposed longwalls (total 751)	391 (52%)	234 (31%)	100 (21%)	26 (3%)
Above solid coal (total 707)	628 (89%)	62 (9%)	15 (2%)	2 (<0.5%)

Notes:
Nil/No Claim – No repairs required. No claims
R0 – Adjustment
R1 – Very Minor Repair
R2 – Minor Repair
R3 – Substantial Repair
R4 – Extensive Repair
R5 - Rebuild
Refer to **Table 11-2** for full definitions of repair classifications from MSEC, 2018.

An analysis was completed based on previous longwalls at Tahmoor Mine which suggests potential impacts are more likely to be experienced for:

- houses predicted to experience higher strains and curvatures;
- houses with masonry walls;
- masonry walled houses that are constructed on strip footings;
- larger houses; and
- houses with variable foundations, such as those with extensions.

The primary risk associated with undermining houses is public safety which is managed by the existing Tahmoor Mine operations through SMPs developed in consultation with SA NSW. Tahmoor Mine has extensive experience mining beneath urban areas and has developed and acted in accordance with a risk management plan to manage potential impacts on residential structures. Past mining experience has shown that residents have not been exposed to immediate and sudden safety hazards as a result of impacts from mine subsidence movements in the NSW Coalfields, where the depths of cover were greater than 350 metres, such as the case above the proposed longwalls. This includes the recent experience at Tahmoor Mine, which has affected more than 1,950 houses, and the experiences at Appin, Teralba, West Cliff and West Wallsend Collieries, which have affected around 500 houses (MSEC, 2018).

Management and mitigation measures for potential subsidence as a result of the project are outlined in **Section 11.1.7** and include the preparation of an Extraction Plan that would be developed through consultation with the infrastructure owners and would be approved by the relevant government agencies. In addition, owners of buildings or other surface improvements damaged by mine subsidence can lodge claims for compensation through SA NSW. SA NSW would facilitate compensation from mine operators where damage is the result of an active mining operation.

Impacts to Growth Areas

Wollondilly Shire Council has planned for future urban growth in and around Bargo in the order of an additional 2,000 houses prior to 2036 (as documented in the Council's Growth Management Strategy 2011). The majority of the urban growth is planned to occur to the east of Bargo township and above the longwalls of the proposed development. It should be noted that the additional houses envisaged by the strategy would be subject to development approval. The results of the assessment of potential subsidence impacts to potential future houses in Bargo described below would therefore be subject to change depending on what development is actually approved and constructed.

The Subsidence Impact Assessment in **Appendix F** included a simulation exercise to forecast the potential impacts of the proposed development on the future urban growth area around Bargo. For the purposes of the simulation exercise, 1,930 houses are forecast to be constructed within the SSA, and 1,603 would be located directly above the proposed longwall mining area.

The assessed impacts have been undertaken with all forecast houses assigned as brick veneer on strip footings. As noted before, this is a conservative approach as houses on strip footings have been observed to be more susceptible to impacts than other construction types. A summary of the assessed impacts for the additional 2,000 houses that form part of the future urban growth simulation exercise is provided in **Table 11-10**.

Table 11-10 Assessment of likely impacts for the houses included in the future urban growth simulation exercise

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All future urban growth houses (total 2,000)	**1090 (55%)**	**560 (28%)**	**256 (13%)**	**96 (5%)**
Above proposed longwalls (total 1,603)	736 (46%)	528 (33%)	245 (15%)	94 (6%)
Above solid coal (total 397)	355 (89%)	32 (8%)	9 (2%)	1 (<0.5%)

The exercise indicates that of the 2,000 houses in the growth area, impacts to 55% of the houses would be classified as “no claim” or R0, 28% would be classified as R1 or R2 and 17% would be classified as R3 to R5 (MSEC, 2018).

Table 11-11 shows the overall distribution of assessed impacts where the proposed additional 2,000 houses assumed for the future urban growth simulation exercise are added to the existing houses within the SSA. The overall distribution of predicted impacts within the SSA would increase if the additional houses included in the simulation exercise are constructed in accordance with the current plans by Wollondilly Shire Council for future urban growth in this area. This is primarily due to there being a greater proportion of houses forecast to be located directly above the proposed longwall mining area within the SSA.

Table 11-11 Assessment of likely impacts for existing houses and additional houses assumed in the future urban growth simulation exercise

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All additional houses (total 3,458)	**2,109 (61%)**	**856 (25%)**	**369 (11%)**	**124 (4%)**
Above proposed longwalls (total 2,354)	1,127 (48%)	762 (32%)	345 (15%)	120 (5%)
Above solid coal (total 1,104)	983 (89%)	94 (9%)	24 (2%)	3 (<0.5%)

Notwithstanding, the majority of houses (both existing and predicted to be constructed under Wollondilly Shire Council’s future urban growth plans around Bargo) are predicted to either not require adjustment or only require minor repair (around 61%), with the forecast incidence of substantial or extensive repair or in a worst-case, rebuild, forecast for around 15% of all houses within the SSA.

Management and mitigation measures for potential subsidence as a result of the project are outlined in **Section 11.1.7** and include the preparation of an Extraction Plan that would be developed through consultation with the infrastructure owners and are approved by the relevant government agencies. It is not anticipated that additional management or mitigation measures would be required if the additional houses proposed as part of the Wollondilly Shire Council's future urban growth plans are realised.

It is noted that proposed development (including new houses and other structures) in mine subsidence districts requires SA NSW approval. SA NSW sets building and construction requirements to protect buildings and other surface improvements from subsidence damage. These requirements cover the nature and class of improvements, including height, type of building materials used and the construction method and are consistent with the Australian Building Code. SA NSW has the power to issue stop work notices to prevent illegal construction in mine subsidence districts, and any improvements erected without SA NSW's approval, or contrary to an approval are not eligible for compensation (MSEC, 2018).

11.1.7 Management and Mitigation Measures

Extraction Plan

The Tahmoor Mine currently develops SMPs that incorporate each natural and built feature that would be impacted by subsidence. Existing subsidence monitoring and management at Tahmoor is described in **Section 3.2.9**.

From 1 July 2014 the former Subsidence Management Plan process was replaced by a consolidated Extraction Plan process to ensure that the mining industry meets strict contemporary standards. This provides for the joint regulation of mine subsidence under a single Extraction Plan. The proposed development would therefore manage potential subsidence under a single Extraction Plan, with component management plans developed to manage risks to specific built or natural features as described below.

While specific management measures for each natural feature is contained within the relevant technical section of this EIS, a series of management plans would also be prepared for the proposed development which would form part of the overarching Extraction Plan. These sub plans would be developed to manage the impacts of longwall mining on specific features which could potentially be impacted by subsidence. These features include:

- natural features (such as waterways and cliffs);
- heritage items;
- built features, including:
  - Council owned assets and infrastructure;
  - rail assets and infrastructure;
  - potable water assets and infrastructure;
  - sewer assets and infrastructure;
  - gas assets and infrastructure;
  - power assets and infrastructure;
  - communications assets and infrastructure; and
  - public, commercial and residential structures, which can also include specific sub-plans for large structures, such as bridges, retail complexes and industrial facilities.

The management plans would include details such as:

- proposed mining schedule and mine plan;
- performance measures and criteria for each feature;
- predictions and descriptions of impacts for each feature;

- monitoring requirements for each feature; and
- risk controls and Trigger Action Response Plan (TARP).

The Extraction Plan would consider the potential for increased subsidence impacts above predicted levels. The following actions would be undertaken:

- detailed pre-mining assessment of the potential impacts on surface infrastructure, including an assessment of potential impacts in the unlikely event that actual subsidence is greater than predicted subsidence. Pre-mining assessment would include pre-mining inspections at residential properties. Under SA NSW requirements, Tahmoor Coal is required to: identify properties that have the potential to be impacted by mine subsidence, provide this information (including likely timing of the subsidence) to SA NSW, and complete a pre-mining inspection (PMI) or arrange for a PMI to be completed prior to a property being influenced by mine subsidence. The PMI can be carried out by Tahmoor Coal (in accordance with SA NSW guidelines) or the details of the property can be forwarded to SA NSW to undertake the inspection. PMI's are carried out at no cost to the resident/landowner. The purpose of the inspection is to obtain an accurate record of the condition of the property prior to mining. When conducted, property owners receive a full, written report with photographs on their pre-mining inspection;
- monitoring of subsidence movements above and beyond the proposed mining footprint, including across the projected location of the Nepean Fault on the surface (the monitoring program would be capable of detecting vertical, horizontal and far-field subsidence movements);
- monitoring of the condition of surface infrastructure before, during and after the mining period;
- implementation of planned early response measures to further protect the safety and serviceability of surface infrastructure focussing on pre-determined trigger levels which are based on monitoring data; and
- if increased subsidence were to occur during the mining of a proposed longwall, amendments to the mine plan for future longwalls would be considered to avoid future increased subsidence.

For all infrastructure and housing, a Built Features Management Plan would be prepared which would:

- contain an assessment of the pre-mining condition of the infrastructure (e.g. bridges, road, gas network);
- provide mitigation measures to be implemented prior to mining (if any);
- describe monitoring systems to be installed, which are capable of detecting vertical, horizontal and far-field subsidence movements;
- set up processes for regular review and assess the monitoring data;
- provide timing for the conduct of regular visual inspections; and
- contain procedures for the implementation of planned responses if triggered by monitoring and inspections.

These plans would be developed in consultation with the relevant authority or owner, and SA NSW.

Prior to mining operations commencing for a new longwall, potentially affected residents would receive a Resident Information Pack which includes:

- longwall information;
- an explanation of subsidence and the potential effect of subsidence on houses and other structures;
- anticipated levels of subsidence for the longwall;
- a description of property inspections, surveys and monitoring;
- a description of rights and responsibilities relevant to subsidence; and
- emergency contact details.

Resident Information Packs are issued as part of the existing operations. Resident Information Packs for the proposed development would generally take the same form and structure of Resident Information Packs for existing operations.

Rehabilitation of Subsidence Impacts to Land

Rehabilitation of subsidence impacts to land relates primarily to the rehabilitation of two broad categories subsidence impacts:

- surface cracking; and
- impacts to watercourses and drainage lines.

Rehabilitations of Surface Cracking

Rehabilitation of surface cracks would be undertaken as soon as practical post-subsidence and would include:

- ripping and seeding of areas where required, followed by rehabilitation planting (if clearing was required to allow for ripping and seeding activities);
- seeding and/or planting of appropriate species of vegetation to achieve a land use commensurate to its pre-subsidence condition; and
- subsided areas to be regraded to control surface water flow and minimise erosion and sedimentation.

For areas where ripping is not feasible due to the width of cracks:

- topsoil would be stripped and stockpiled;
- clay, or another suitable, material would be used to fill and seal cracks; and
- topsoil would be respread once cracks have sealed and the area would be seeded with appropriate plant species.

Rehabilitations of Subsidence Impacts to Watercourses

Tahmoor Mine currently implements an approved SMP that considers potential impacts on streams due to mining activities, including monitoring and TARPs. An Extraction Plan would be prepared and implemented for the proposed development and would include specific measures for watercourses in the Project Area.

Rehabilitation of streams that generally have significant sediment accumulation would occur naturally and no further measures are proposed. However, for streams with lower sediment accumulation, it is proposed that fractures and voids would be sealed with grout. Potential impacts to streams and riparian vegetation that may require rehabilitation are discussed in **Section 11.2**.

General rehabilitation of the subsided riparian subsidence areas may involve:

- creating a stable substrate for revegetation of channel banks through topsoil and a weathered rock matrix;
- replacing sand across the channel bed;
- mitigation of erosion of channel banks through placement of timber groynes, woody debris and other measures;
- preventing the uncontrolled flow of runoff through suitable design of local drainage (e.g. diversion bunds);
- topsoiling and revegetation on banks; and
- targeted revegetation in areas where surface water patterns have been affected.

Rehabilitation of Subsidence Impacts to Built Infrastructure

The SSA is located within the Bargo Mine Subsidence District. The *Coal Mine Subsidence Compensation Act 2017* provides for the assessment and management of risks associated with subsidence resulting from coal mine operations and includes provisions for the compensation or repair services required to mitigate the damage caused by mine subsidence following underground coal mining (see **Section 8.1.4** for further details about the *Coal Mine Subsidence Compensation Act 2017* as it applies to the project).

SA NSW is the NSW Government agency responsible for administering the *Coal Mine Subsidence Compensation Act 2017*. SA NSW has two core functions:

1. to provide compensation or manage the provision of compensation where surface developments are damaged by mine subsidence following extraction of coal or shale in NSW; and
2. to regulate surface development within mine subsidence districts to reduce the risk of mine subsidence damage.

The owners of buildings or other surface improvements damaged by mine subsidence can lodge claims for compensation through SA NSW. A SA NSW Case Advisor would be allocated to the claim to support property owners throughout the assessment process and SA NSW would facilitate compensation from mine operators where damage is the result of an active mining operation.

Proposed development in mine subsidence districts requires SA NSW approval. SA NSW sets building and construction requirements to protect buildings and other surface improvements from subsidence damage; these requirements cover the nature and class of improvements, including height, type of building materials used and the construction method.

SA NSW has the power to issue stop work notices to prevent illegal construction in mine subsidence districts, and any improvements erected without SA NSW's approval, or contrary to an approval are not eligible for compensation.

11.1.8 Conclusion

The proposed Mine Plan was developed by Tahmoor Coal following a significant risk assessment process to avoid and minimise impacts to sensitive features including impacts to the Metropolitan Special Area (MSA) and incised bedrock creeks and rivers. Tahmoor Coal made a number of revisions to the original Mine Plan, including shortening Longwall 105 to 108 from the commencing ends so they do not encroach into the MSA and removal of mining in the eastern domain (see **Section 11.1.1**).

The maximum predicted subsidence impacts would impact on natural and built features within the SSA. These impacts are primarily related to surface cracking, localised water loss and ground deformations which can damage or reduce values of these features. Detailed assessment of each feature is provided in the relevant specialist section of this EIS. The assessment of potential subsidence impacts determined that 79% of the houses within the SSA would be unaffected or require minor adjustments only. Far field horizontal movements are predicted to occur. However, impacts experienced at sensitive features are not expected to be significant or measureable (i.e. less than 0.3 mm/m).

The overall findings of the assessments are that the levels of impact and damage to identified natural features and built infrastructure are manageable and can be controlled by the preparation and implementation of an Extraction Plan.

Tahmoor Mine has subsided in the order of 1,541 residential homes and commercial premises, the majority of which experienced little if any damage from mine subsidence impacts. A small percentage experienced more significant impacts which have been rectified or continue to be repaired, replaced or otherwise satisfactorily addressed by Tahmoor Mine in close working relationship with SA NSW. Tahmoor Mine has been successfully managing subsidence impacts to houses and buildings from longwall mining at Tahmoor North in accordance with an approved SMP and would continue to do so for Tahmoor South in accordance with the Extraction Plan for the proposed development. Extraction Plan sub-plans would be developed to manage potential impacts to specific features in consultation with affected stakeholders for approval by relevant government agencies. Specific management measures for natural and built features are described separately throughout **Section 11.0** of the EIS.

11.2 Geomorphology

A Geomorphology Technical Report (Fluvial Systems, 2013) has been undertaken to characterise the geomorphology of waterways and cliffs within the Project Area. The Geomorphology Technical Report is provided in **Appendix H**. A Subsidence Assessment (MSEC, 2018) was undertaken to quantify the potential subsidence impacts of the proposed development on natural features, including waterways and cliffs. The Subsidence Assessment is provided in **Appendix F**. The two assessments were undertaken collaboratively to determine the extent to which subsidence associated with the proposed development would impact on the geomorphology of waterways and cliffs within the SSA.

The Geomorphology Technical Report addressed the SEARs relevant to geomorphology impacts. These are listed in **Table 11-12**. Specific SEARs have not been issued for geomorphology however impacts to geomorphology are relevant for the assessment of potential impacts from subsidence on the natural environment including water resources.

Table 11-12 SEARs for the assessment of geomorphology impacts

Geomorphology SEARs	Section addressed
Subsidence – including a detailed assessment of the potential conventional and non-conventional subsidence effects, subsidence impacts and environmental consequences of the development on the natural and built environments, paying particular attention to features that are considered to have significant ecological, economic, social, cultural and environmental value, taking into consideration:	**Section 11.2.4**. Subsidence impacts are also assessed specifically in **Section 11.1** and **Appendix F**.
An assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, water supply infrastructure and systems and other water users;	**Section 11.2.4**.See also **Section 11.3** and **11.4** for assessment of potential groundwater and surface water impacts.

11.2.1 Background

The proposed development may impact on geomorphological features through the generation of subsidence movements that may alter geomorphological features on the surface. Geomorphic processes and forms are connected to aquatic ecological character and processes through the provision of physical habitat and the influence on water quality. As a result, the potential for the proposed development to create geomorphological changes may have an impact on aquatic ecology and water quality. "*Alteration of habitat following subsidence due to longwall mining*" is a Key Threatening Process listed under Schedule 4 of the *Biodiversity Conservation Act 2016* (BC Act).The Geomorphology Technical Report has focused on characterising the physical aspects of the Project Area that are known to contribute to aquatic and riparian habitat value.

The Geomorphology Technical Report for the Project was completed in 2013 and assesses an alternate mine plan under consideration at the time, which comprised a larger footprint (and associated SSA) to the current Tahmoor South project. The report is considered to present a conservative assessment characterising the geomorphic features within the broader Project Area including and beyond the current mine plan footprint and associated SSA (which has contracted since 2013). The report has been reviewed against the SEARs issued for the Project in 2017 and is considered to meet the requirements of the SEARs. Therefore, the report has not been updated. Mine plan revisions to reduce impacts to sensitive features are detailed in **Section 5.3.7** and **Section 6.2.4**.

The Geomorphology Technical Report characterised the physical environment of the Project Area and identified RMZs for significant or sensitive geomorphological features. The catalogue of geomorphologic features was used to define the existing environment within the Project Area and has been incorporated into other relevant impact assessments undertaken for the proposed development, including terrestrial ecology (**Section 11.6** and **Appendix K**), aquatic ecology (**Section 11.7** and **Appendix K**) and surface water (**Section 11.4** and **Appendix J**).

11.2.2 Methodology

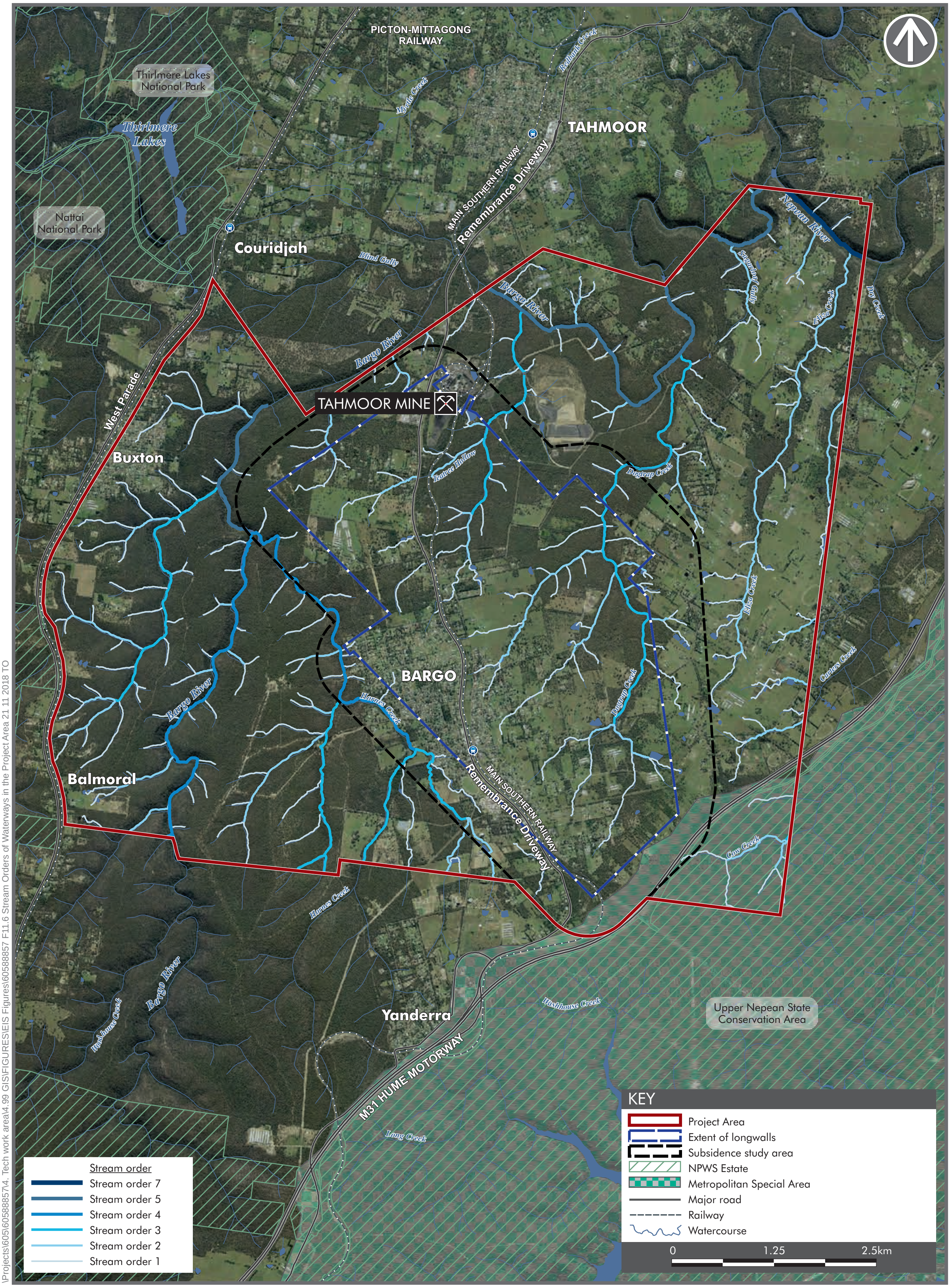
The risks to geomorphological features as a result of the proposed development have been described for the SSA where relevant. However, in order to provide a comprehensive baseline of geomorphological features, the existing geomorphological environment has been described for the entire Project Area.

The methodology for the assessment was undertaken as follows:

- identification of relevant geomorphological variables that would be sensitive to mine subsidence changes including:
  - landscape-scale variables - geology, soils, topography,
  - stream-reach and point-scale variables - stream geomorphic type and condition, riparian and in-channel vegetation including filamentous algae, in-channel bedrock features, in-channel pools, channel slope, channel dimensions, channel bed materials, knickpoints and characteristics of fractures in channel bedrock. Note: knickpoint refers to a local steep fall in channel bed elevation.
- desktop terrain analysis:
  - terrain analysis was performed using two different GIS applications: Global Mapper™ V14.2.2 July 2013 and SAGA (System for Automated Geoscientific Analyses) GIS in order to characterise landform within the Project Area including topography, stream network, slope and valley depth.
- a detailed field survey of the main waterways within the Project Area:
  - a field survey was undertaken over 18 days, during which geomorphic features present within waterway were logged and characterised in the Project Area.
  - due to the level of data captured for the waterways that were surveyed during the field survey, the representative character of the waterways that were not surveyed (for example those on private property) could be inferred through the comparison of landscape scale variables, derived from the desktop study. The field survey particularly focused on pools (a deeper section of a waterway that retains water), knickpoints and bedrock features that were large relative to the channel size to enable the capture of morphological variability of the Project Area at the habitat scale.
- geomorphological characterisation of waterways within the Project Area:
  - waterways in the Project Area were classified according to river type and geomorphic condition using an approach consistent with the River Styles process. The recovery potential of waterways depends on geomorphic condition, with undisturbed waterways close to a natural state more likely to be resilient and recover faster than those that are already degraded.
- impact assessment of geomorphological features:
  - the extent of subsidence predicted by the Subsidence Assessment (refer to **Section 11.1**) for the proposed development was used to determine the likely impacts on the geomorphology of waterways and other landforms.
  - existing and historical operations at Tahmoor Mine included longwall mining beneath Tea Tree Hollow, the Bargo River, Myrtle Creek and Redbank Creek. Records of the observed impacts of subsidence on these waterways were used to inform the prediction of impacts of the proposed development on the geomorphology of waterways within the Project Area.
- identification of RMZs:
  - the Southern Coalfields Inquiry recommends that RMZs be developed for:
    - all waterways classified as 3rd order and above in the Strahler stream order classification;
    - valley infill swamps not on a 3rd order or higher stream; and

- major cliff lines and overhangs not directly associated with watercourses.

- accordingly, RMZ's were identified for the Project Area. The length and mean slope of 2nd order streams and higher within the Project Area were measured using the 2m x 2m Lidar survey and the presence of pools, knickpoints and bedrock features within these waterways were identified in the field survey. The combined data from the terrain analysis and field survey of these waterways in the Project Area indicates that the 3rd order sections of Cow Creek, Dog Trap Creek and Dry Creek, as well as the 4th order section of Hornes Creek had a large number of pools, and also had relatively high number of bedrock features present. As a result of the high density of features such as pools and bedrock features which are sensitive to mining-related subsidence impacts, these waterways are considered to have the highest risk of their geomorphic character being altered by the proposed development.



SIMEC MINING

STREAM ORDERS OF WATERWAYS IN THE PROJECT AREA

Tahmoor South Project
Environmental Impact Statement

FIGURE 11.6

11.2.3 Existing Environment

The existing operations at Tahmoor North have undermined Myrtle Creek and Redbank Creek. As part of the SMPs for each longwall, each creek is monitored for impacts associated with subsidence movements. Impacts observed at the creeks are summarised below.

Myrtle Creek - between 2004 and 2014, longwalls 22 to 28 were mined beneath a three km section of the creek. Impacts observed along this creek included localised bed cracking in exposed sandstone areas, surface flow diversions in four locations over Longwalls 22, 23B and 25 as well as cracking in soil within the upper banks and flanks over Longwall 23B (MSEC, 2018). At times of low flow, pools were also observed to drain (MSEC, 2018).

Redbank Creek - since 2008 a two km section of Redbank Creek has been undermined by longwalls 25 to 31. Impacts observed along the creek included: cracks along most pools located directly above longwalls 25 to 31, draining of pools at times of low flow, subsurface flow diversion observed to re-emerge downstream of Longwall 30, and some adverse changes in water quality at times of low flow (MSEC, 2018, SIMEC, 2017).

Landscape-scale Geomorphological Characteristics of the Project Area

The Project Area is located in a region characterised by weakly developed soils on sandstone and shale which are highly susceptible to erosion by concentrated water flow. Waterways within the Project Area comprise:

- small headwater waterways on relatively low gradient plateaus; and
- waterways eroded into rocky gorges rimmed by relatively stable cliffs, with densely vegetated talus slopes below the cliffs.

Within the Project Area, land elevation ranges from between 95m to 448m AHD and the slope of the land ranges up to a maximum of 85.6°.The south-western section of the Project Area is heavily dissected with high elevation and high sloping land is present. Within the central portion of the Project Area, the landform is dissected and of mid elevation comprising undulating plateau land. Downstream of the Bargo Fault, there is a small section of land in the Project Area exhibiting a landform that is dissected and of low elevation.

Bargo and Nepean River

The Nepean and Bargo Rivers would not be directly undermined by the project. Early mine plan investigations ruled out longwall mining under the Bargo River taking into consideration sensitive environmental features including the Bargo River Gorge and Mermaid Pools (neither feature being within the SSA of the current mine plan).

Only a 165 metres long length of the Bargo River that is immediately upstream from the Picton Weir is located inside the SSA. This length of the river that is within the SSA is a 4th order perennial stream as defined by the Strahler Stream Order Method (MSEC, 2018). No part of the Nepean River is within the SSA.

Cliffs and Steep Slopes

Three hundred and sixteen (316) major cliff features were identified within the Project Area in the terrain analysis. Of these, a total of 24 cliffs are located within the SSA generally located within the valleys of the Bargo River, Dog Trap Creek and the lower reaches of Hornes Creek (MSEC, 2018).

In the terrain analysis, steep slopes were mostly identified along the Bargo and Nepean Rivers, which are deeply dissected drainage lines (Refer to Figure 15 of **Appendix H**). At the landscape-scale, cliffs within the Project Area appear to be relatively stable, with historical photographs of the Project Area not displaying any evidence of recent rock falls. It is likely that natural rock falls may be present at the local scale.

There has been extensive experience of mining beneath steep slopes in the Southern Coalfield including along the Cataract, Nepean, Bargo and Georges Rivers and streams such as Myrtle Creek and Redbank Creek above Tahmoor Mine Longwalls 22 to 31, and slopes on Redback Range above Tahmoor Mine Longwalls 26 and 27 (MSEC, 2018). No large-scale slope failures have been observed along these slopes even in the case of direct undermining of the slopes. Whilst, surface cracking and minor rock falls along clifflines or rock outcrops have been observed (e.g. mining of Appin Longwalls 301 and 302 adjacent to the Cataract River), no large-scale slope failures have been observed (MSEC, 2018).

An approximately 20 metres high waterfall on Eliza Creek (EC-WF2) was identified as being a significant topographical feature within the Project Area, however as Eliza Creek is not located within the SSA, impacts to this feature are not expected.

Other Waterways within the Project Area

Of the waterways identified within the Project Area, the following are located within the SSA for the proposed development (in addition to the section of Bargo River described earlier):

- Hornes Creek – 4th order creek, which would not be directly undermined.
- Dog Trap Creek - 3rd order creek. Approximately 3.1 km of this waterway would be undermined by the proposal.
- Tea Tree Hollow – 3rd order creek. Approximately 1.9 km of this waterway would be undermined by the proposal.
- Tributary to Tea Tree Hollow – 3rd order creek. Approximately 2.4 km of this waterway would be undermined by the proposal.
- Tributary 1 to Dog Trap Creek – 2nd order creek. Approximately 2.6 km of this waterway would be undermined by the proposal.
- Tributary 2 to Dog Trap Creek – 2nd order creek. Approximately 2.4 km of this waterway would be undermined by the proposal.

As a result of mine plan investigations including the ruling out of mining in the eastern domain and the shortening of commencement ends of longwalls, impacts have been minimised or avoided to other waterways identified within the Project Area (including Eliza Creek, Dry Creek, Sugar Loaf Gully, Carters Creek and Cow Creek), which would remain outside of the SSA.

Stream Reach and Point-scale Characteristics of the Project Area

Waterway Geomorphic Type

Within the extent of the Project Area, the Bargo and Nepean Rivers were identified as the Gorge-strong geomorphic type. Tributary streams and lower order streams from the Bargo and Nepean Rivers largely comprise headwater streams (weak, moderate and strong), as well as a smaller number of weak to moderate gorges.

Channel dimensions were measured during the field survey at 249 sites within the Project Area. The data from these measurements indicates that gorge type streams are larger than headwater type streams and strong type streams were larger than moderate and weak type streams.

The distribution of geomorphic types within the Project Area (refer to Figure 36 of **Appendix H**) corresponds to the spatial distributions of elevation, valley depth, landform class, steep slopes, dominant bed material and grass cover on the low flow channel.

Waterway Geomorphic Condition

Waterways within the Project Area are bedrock controlled and naturally resilient to geomorphic change with the majority of waterways in a stable, close to natural geomorphic condition. Several characteristics/factors present in waterways within the Project Area were identified as having potential relevance for the ecological condition within creeks, but do not strongly influence geomorphic condition. These factors include clearance of riparian trees, licensed discharges, incision, mobile knickpoints, and filamentous algae. Some waterways were affected by loss of water to the subsurface over short reaches, and others were impacted by ferruginous seeps and suspended colloids.

With the exception of Tea Tree Hollow and Eliza Creek, the majority of the surveyed sites along creeks within the Project Area were considered to be in good condition for the majority of their length. Of the 696 surveyed sites in the Project Area, 85% were considered to be in good condition. Fifteen percent (15%) of individual sites, including a length of Tea Tree Hollow to the east of the pit top and the middle reach of Eliza Creek were considered to be in moderate condition. Sites of moderate condition east of the existing pit top related to the impact of licensed discharges from existing mine operations into Tea Tree Hollow. Sites of moderate condition along the middle reaches of Eliza Creek related to fill tipped into the channel and evidence of a failed dam. The isolated survey sites of moderate condition were associated with the occurrence of minor culverts or track crossings and/or low riparian vegetation cover.

Channel Bed Profiles and Material Composition

Waterways of the Southern Coalfield, such as those within the Project Area that flow through sandstone and/or shale regularly have a significant proportion of their beds formed in exposed bedrock. Bedrock is typically visible as flat to gently sloping slabs of rock exposed along a bedding plane and elevated rock bars crossing a channel. Exposed rock is often associated with pools by forming a low permeability bed surface or by acting as a hydraulic control. Long profiles of major waterways flowing into and out of the Project Area (refer to Figure 34 of **Appendix H**) were plotted using Digital Elevation Model and topographic map data, revealing three types of stream profiles present:

- river mainstream with major profile variation, namely the Bargo and Nepean Rivers;
- tributary streams lacking a major fixed knickpoint near their junction with the river mainstream, including Hornes Creek, Tea Tree Hollow and Dog Trap Creek; and
- tributary streams with a major fixed knickpoint near their junction with the river mainstream, including Carters Creek, Cow Creek, Dry Creek, Eliza Creek, Sugarloaf Gully and several unnamed creeks (XA2, XB2, XC2, XD3, XE2, XI2, XJ2, and XM2) (Note: these waterways are outside of the SSA).

In tributary streams where there is no major knickpoint, the slopes of the stream profiles are slightly greater than that of the Bargo River into which they flow. The tributary streams that have a major fixed knickpoint close to their junction with the Bargo or Nepean River have fairly steep slopes.

A wide range of channel bed materials were observed throughout the Project Area during the field survey. Across the Project Area, channel bed material was identified as being spatially variable. Mud was the prevalent material in the headwaters of waterways, and along small waterways on the plateau. The other commonly dominant bed materials within the Project Area included boulders and bedrock material.

Lower Eliza Creek and Creeks XA and XB exhibited particularly frequent bedrock features. Dog Trap Creek, Cow Creek and Dry Creek all contained higher frequencies of bedrock features and in-channel pools. Carters Creek, Hornes Creek and Tea Tree Hollow displayed the least abundance of bedrock features (refer to **Figure 11.7**). Tea Tree Hollow also displayed a lower frequency of pools compared to other creeks in the Project Area. Bedrock fractures were present at 32% of the sites where exposed bedrock was located.

Bedrock Fractures

Bedrock fractures observed were considered to be natural characteristics of the rock, varying in density from 0.11 to 0.15 fractures per 10m and an average bedrock density of 2.3 fractures per 10m (refer to Figure 23 of **Appendix H**). Within the Project Area, Hawkesbury Sandstone is present as massive beds with widely spaced and roughly vertical joint sets. As a result, it is anticipated that natural fractures would be present in the bedrock within the Project Area which are very old in geological terms, and are a result of historical episodes of deformation and relief of stress.

Mining-induced fractures in waterway beds have a different appearance to historic, natural bedrock fractures. Based on circumstantial evidence (namely observations of creeks previously undermined as part of the current Tahmoor North operations), bedrock fractures observed at two locations (XA2-1 and XB2-1) were tentatively suggested as being a result of mining-related subsidence due to their distinctively different appearance to other fractures in the Project Area. Fractures have open, sharp, unweathered edges as well as evidence of some overriding of bedding slabs, consistent with the findings of *The Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield: Strategic Review* (NSW Department of Planning, 2008).

In-channel Pools

The dimensions of observed in-channel pools within the Project Area are variable. The largest pool observed was Mermaids Pool, along the Bargo River, with a reported depth of 12m (National Parks Association, Macarthur, 2006), which is not within the SSA or limits of subsidence (20mm subsidence contour) predicted. The hydraulic controls of pools within the Project Area include boulders (47%), rock bars (33%), high points of cohesive material (12%), gravel, cobble or sand bars (8%) and artificial material (1%). The spatial distribution of hydraulic controls within the Project Area was considered to be variable.

Knickpoints

Within the Project Area, 149 hard knickpoints and 44 soft knickpoints were observed. Soft knickpoints were mostly observed along small plateau waterways through cleared and uncleared land, ranging in height from 0.22m to 1.4m with an average height of 0.62m. Hard knickpoints were located largely along steeper waterways, with the highest observed knickpoint being 35m in height, located at the confluence of Eliza Creek and the Nepean River Gorge. Other high, steep hard knickpoints were also observed near Mermaids Pool and along Cow Creek, which are all outside of the SSA.

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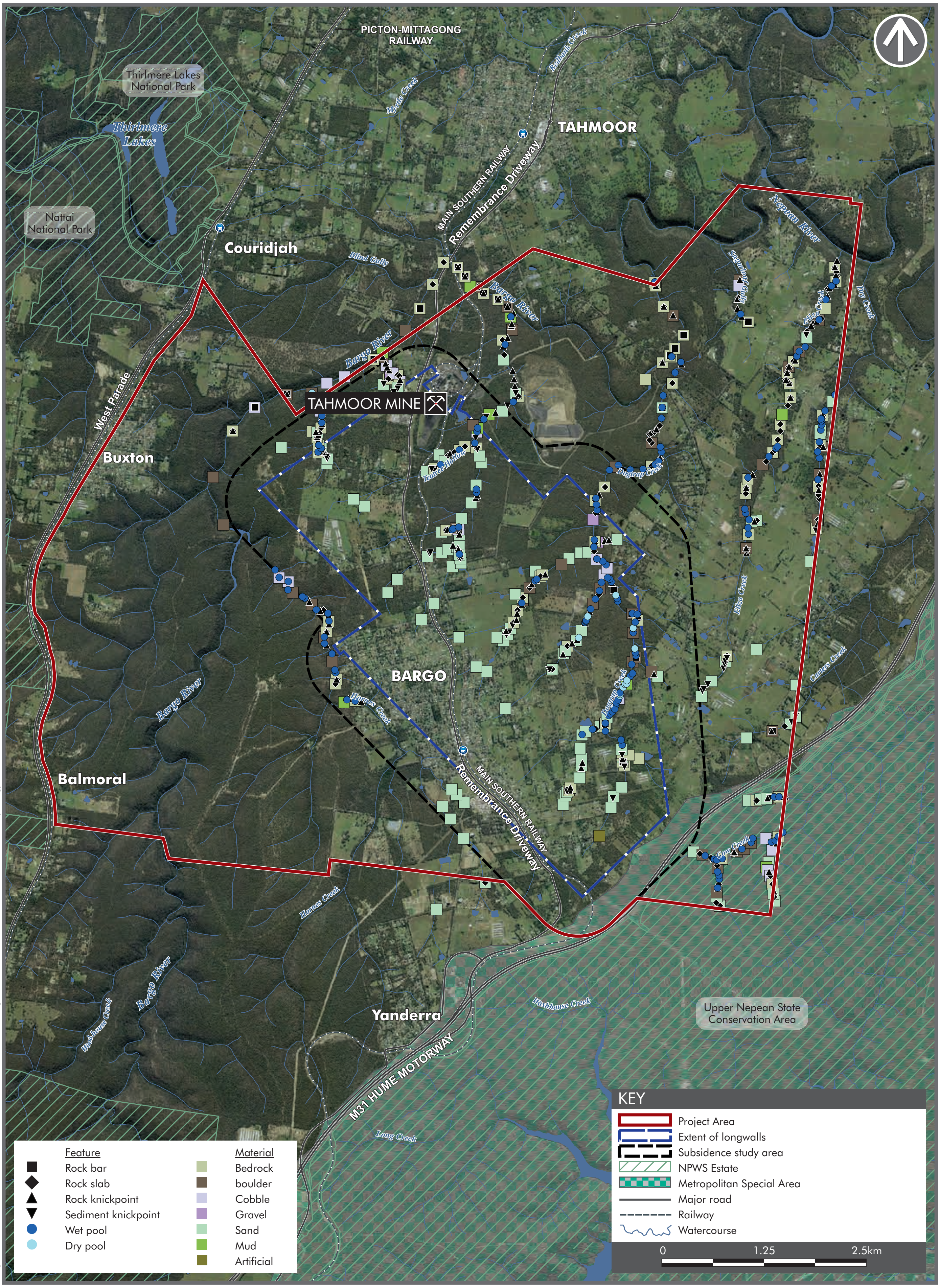

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GENERAL STREAM GEOMORPHOLOGY

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FIGURE 11.7

Riparian Vegetation

Geomorphic condition is strongly linked to the degree of naturalness and extent of cover of riparian vegetation (Outhet and Cook, 2004; Outhet and Young, 2004). The following was observed within the Project Area during the field survey:

- the width of riparian vegetation was greater than 50 m at more than 90% of surveyed sites on both banks of waterways;
- the continuity of vegetation within the Project Area was greater than 75% at more than 90% of the sites on both banks of waterways;
- riparian tree cover was considered to be generally high, with the greatest degree of tree cover tending to be located within dissected valleys and gorges, namely the Nepean and Bargo Rivers. A moderate level of riparian tree cover was within the natural range of undisturbed sites; and
- the Project Area generally exhibited a moderate to high riparian vegetation cover index, with 62% of sites having an index greater than 0.6. The lowest riparian vegetation cover index scores (8% of sites, with an index of 0.2-0.4) were associated with small plateau waterways that flow through cleared land.

It was considered that the presence of small areas of poor quality riparian width and vegetation continuity does not present a significant threat to the geomorphic stability of waterways in the Project Area.

Extensive grass cover on the bed of a low flow channel is indicative of a low energy headwater environment where the bed shear stress of high flows is inadequate to overcome the resistance of vegetation roots, and the baseflow is not deep or persistent enough to discourage grass growth. Grass cover was found on all of the small headwater waterways in the Project Area (refer to Figure 31 of **Appendix H**). With the exception of Dry Creek, grass cover was uncommon in 2^{nd} order streams and higher (refer to Figure 31 of **Appendix H**).

Large woody debris is considered to contribute to the structural stability of streams. Large wood was present in 57% of waterways in the Project Area. Surveyed sites with low riparian tree cover (Figure 29 of **Appendix H**) tended to have a low frequency of large wood. The density of large wood was so variable within streams of the Project Area that is was not considered to be a reliable indicator of stream condition when considered in isolation.

11.2.4 Impact Assessment

Waterways confined within bedrock valleys, such as those within the Project Area, maintain a relatively stable position over time. However, the channel can widen, narrow, deepen (scour) or shallow (aggrade). These changes can occur in natural systems. However, mining-related subsidence has the potential to impact the rate and/or extent of such changes.

Impacts to geomorphology in the SSA as a result of the proposed development have been assessed qualitatively, and are described in **Table 11-13** and in further detail in the relevant technical specialist studies as referenced below. For the purposes of the qualitative impact assessment, the risks to the geomorphology within the SSA as a result of the proposed development have been separated into events where the risk is constant over the entire SSA and events where the risk is variable.

The mine has been designed in the first instance to avoid undermining major watercourses where feasible. Major water courses were identified as part of the development of RMZs which informed the development of the mine plant for the proposed development. Revisions undertaken to mine plans to avoid sensitive features including the Bargo River and the MSA are detailed in **Section 5.3.7** and **Section 6.2.4**.

A range of practical strategies to mitigate and remediate mining induced impacts to river channels are provided in **Section 11.2.5** and **Section 11.1.7**.

Table 11-13 Potential impacts to natural features

Natural feature	Potential impacts
Impacts to Headwater and Gorge Types	The Project Area comprises Headwater and Gorge types. These types are considered have a low fragility, meaning that the potential for change in type over management time scales (i.e. less than 100 years) is minimal. Changes in these types over such a time scale generally only comprise minor changes to bedform and the type never changes to another, regardless of the level of damaging impact. It is therefore considered unlikely that waterways within the Project Area would be exposed to a change in geomorphic type as a result of subsidence associated with the Project. If such an event was to occur, changes to type would be localised and more likely to occur in headwaters rather than gorges, with headwaters potentially being altered to Cut and Fill (Cook and Schneider, 2006). Such a change would be reversible with the application of appropriate and proactive management measures. Waterways within the Project Area are largely located within valleys, with beds and banks controlled by bedrock or hard regolith. This restricts the potential for the alignment of channels to be altered across the entire Project Area. It is unlikely that the proposed development would result in a change in channel alignment within the Project Area due to the highly incised nature of the waterway channels within the valleys.
Impacts to In-Channel Pools	In-channel pools are often a focus of habitat assessments due to their ability to act as a refuge when waterways stop flowing (Bond et al, 2008). In the Project Area, where in-channel pools are bedrock controlled, pools are likely to be found in association with rock bars, which are potentially at risk of fracturing due to mining-related subsidence. There is a high probability that at least part of the bed of most in-channel pools within the Project Area have been formed in bedrock. A reduction in the volume of existing in-channel pools as a result of the proposed development is dependent on the extent of fracturing that occurs on rock bars and rock slabs that form the bed of such pools. Pools within the SSA that have rock bars acting as the main hydraulic control (33%) would potentially hold water for shorter periods of the year if they are fractured as a result of the Project, assuming that the hydrology at this location remains unaltered. Differential subsidence across the SSA could potentially result in the formation of new in-channel pools, or could increase the depth of existing in-channel pools. The likelihood of this occurring depends on the spatial distribution and depth of subsidence within the SSA. Impacts to in-channel pools in waterways within the SSA have been assessed in **Section 11.4.4**.
Impacts to knickpoints	Under disturbance from mining-induced subsidence, or a significant increase in stream flow, hard knickpoints are assumed to be resilient to change, while existing soft knickpoints were assumed to be fragile, and thereby susceptible to the formation of new soft knickpoints. Soft knickpoints within the SSA occur in locations that have been disturbed through urbanisation and agricultural development, as well as in undisturbed and well vegetated waterways. Should knickpoints be located in small headwater waterways on the plateau area where differential subsidence could potentially occur, there is the potential for the natural rate of knickpoint migration to be accelerated, or new knickpoints could potentially be created. These locations are discussed further in **Appendix H** and provided on Figure 27 of **Appendix H**.

Natural feature	Potential impacts
Impacts to sedimentation processes in channels	Within the Project Area, accumulation of sediment appeared to be low. The headwater strong types in the Project Area are free of loose sediment, or contain boulders with less cobble gravel, sand and mud present in the channel-bed, suggesting that rock falls are rare and talus slopes are stable. This is evidenced by the field observations that the talus slopes observed were covered in dense vegetation. Mining-related subsidence could potentially increase the angle of talus slopes in the SSA, causing them to destabilise, resulting in an increase of sediment supply into channels within the Project Area as well as further downstream. Impacts to the geomorphology of the Project Area from a potential increase in sedimentation within waterways resulting from the destabilisation of talus slopes due to mining-induced subsidence are considered to be minor. Potential talus slopes within the Project Area are only located within the Bargo and Nepean systems, which are high energy and high flow waterways. The supply of additional sediment to these waterways would not impact on the sedimentation processes as the high energy environment would mean that sediment would be rapidly transported through the system. Potential downstream impacts associated with the settlement of additional sediment on existing aquatic ecology habitat are discussed in **Section 11.7**. Changes to bed slope due to mining-related subsidence has the potential to reduce stream power to below the sediment transport threshold. The field survey undertaken as part of the Geomorphology Technical Report found that waterways within the Project Area would likely exhibit high energy under high flow conditions. This is consistent with the results of a study undertaken by Nanson and Young (1983) which concluded that waterways within sandstone landscapes contain very little sediment storage. Therefore, the potential for mining related subsidence to reduce stream power to below the sediment transport threshold is low as bedslopes of waterways within the Project Area are already steep with little sediment accumulation occurring within the channels. Within the Project Area, sediment transport is considered to be efficient under existing conditions, and the majority of stream beds are not sensitive to sediment scouring as they are bedrock controlled with limited opportunity for scouring to occur. The steepening of the slope of a channel within the Project Area due to mining-related subsidence has the potential to increase stream power, and increase the rate of sediment scouring. The likelihood that sediment scouring in the Project Area is increased as a result of the proposed development is considered to be low due to the low sensitivity of bedrock controlled waterways to scouring. Further, the predicted changes in stream bed grade as a result of subsidence from the proposed development are typically less than one percent (1%) from current grade. The predicted maximum increase in stream bed grade of 1.2% is relatively small compared to natural gradients and is not anticipated to significantly increase the potential for scouring.
Impacts to Channel-bed Vegetation	The potential impacts to channel bed vegetation would occur as a result of increased scour and surface fracturing within channel beds. However, the predicted maximum increase in stream bed grade is relatively small compared to natural gradients and is not anticipated to significantly increase the potential for scouring. Further changes to waterway velocities and flooding also have the potential to impact channel bed vegetation. Potential impacts to channel bed vegetation as a result of mining-induced subsidence are discussed further in **Section 11.7**.

Natural feature	Potential impacts
Impacts to rock fall frequency	The majority of cliffs within the Project Area including those along the Nepean River, Bargo Rivers and Hornes Creek would not be directly undermined as part of the proposed development. It is possible that isolated rock falls could occur, particularly at those cliffs located closest to the proposed long walls. Impacts are expected to represent less than 0.5% of the total face area of cliffs within the Project Area. The Subsidence Impact Assessment notes that while cliffs within the SSA would potentially experience very low levels of vertical subsidence, it is unlikely that cliffs beyond the extent of this would experience large instabilities (refer to **Appendix F**). The likelihood of a significant increase in the rate of rock falls from cliffs and talus slopes in the Project Area as a result of mining-related subsidence is considered low.

Impact Summary

Based on the above assessment, the impacts of the proposed development on geomorphological features within the Project Area are summarised below.

- **Headwater and Gorge Types** – it is considered unlikely that subsidence from the proposed development would change the geomorphic type of waterways within the Project Area or alter channel alignment due to the highly incised nature of the waterway channels within the valleys.
- **Channel Pools** – subsidence related fracturing could reduce the volume of in-channel pools or potentially result in pools holding water for shorter periods. Differential subsidence across the SSA could potentially result in the formation of new in-channel pools, or could increase the depth of existing in-channel pools.
- **Knickpoints** - subsidence impacts on small headwater waterways (in plateau areas where differential subsidence could occur) have the potential to accelerate the natural rate of knickpoint migration, or create new knickpoints.
- **Sedimentation processes in channels** - changes to stream bed grades as a result of subsidence are predicted to be relatively small (typically less than one percent compared to the current grade) and therefore are not anticipated to significantly increase the potential for in-channel scouring. Furthermore, given the low sensitivity of bedrock controlled waterways to scouring, the potential for increased channel scouring in the Project Area is considered to be reduced.
- **Channel-bed vegetation** – vegetation along waterways has the potential to be impacted by subsidence related changes to in-channel process including changes to pool holding capacity, flooding velocities and inundation. Risks to vegetation from significant increases to scour and sedimentation have been assessed as low.
- **Rock fall frequency** - The majority of cliffs within the Project Area would not be directly undermined and the likelihood of a significant increase in the rate of rock falls from cliffs and talus slopes in the Project Area as a result of mining-related subsidence is considered to be low. Tahmoor Coal would incorporate mitigation measures to manage potential subsidence impacts to natural features described above into the Extraction Plan for the proposed development. This would include trigger action response plans, detailed pre-mining assessments, monitoring of subsidence, monitoring of the condition of geomorphological features during and after the mining period; and the consideration of amendments to the mine plan for future longwalls if higher than expected subsidence were to occur during the mining of a proposed longwall.

Refer to **Section 11.2.5** for further discussion on the measures that would be implemented to mitigate impacts on geomorphology.

11.2.5 Management and Mitigation Measures

Risk Management Zones

As part of the Geomorphology Technical Report, relevant high value features were identified as being all waterways classified as 3rd order and above in the Project Area (refer to **Figure 11.6**) in accordance with the recommendation of the Southern Coalfields Inquiry, and major cliffs within the Project Area. RMZs were identified as 400 m wide buffers around these features. When these risk areas were compared with the mine plan for the Project, it was identified that detailed monitoring and management during mining is required in the following locations:

- upper Tea Tree Hollow; and
- upper Dog Trap Creek.

The RMZs for the Project and the location of the abovementioned relevant features are shown on **Figure 11.8**.

Remediation Measures

There are a range of practical strategies to mitigate and remediate mining induced impacts to river channels as outlined within *Damage Criteria and Practical Solutions for Protecting River Channels* (SCT Operations Pty Ltd, 2009), a research project undertaken by the Australian Coal Association Research Program (ACARP Project C12016). The three primary strategies suggested for managing impacts on river systems, without unnecessarily sterilising valuable coal resources, include:

- avoid mining within proximity of river channels through mine design, to limit the potential subsidence impacts on specific river systems to levels that can be estimated with reasonable confidence;
- provide open space within the rock mass at the base of a river channel to absorb valley closure movements or implement an artificial barrier that forces the hydraulic gradient to the surface. A thin, flexible, impermeable barrier installed across a rock bar has the potential to act as an effective barrier to subsurface flow; and
- actively fill fractures in the subsurface fracture network with introduced material to accelerate the natural remediation process, whereby the mining induced fracture network is filled with sand, silt and clay materials, gradually increasing hydraulic resistance. This strategy involves filling of the subsurface fracture network with fill material such as cementitious grouting, sand or polyurethane resin.

Management Measures

Tahmoor would incorporate the measures listed below into the Extraction Plan for the proposed development. These measures would be consistent with the existing measures that have implemented to effectively manage potential mining induced impacts to river channels for current operations as part of existing SMPs.

- develop and implement an Extraction Plan prior to mining to manage the potential impacts of the proposed development on the geomorphological features of waterways within the SSA as a result of longwall mining. The Extraction Plans would require:
  - triggered action response plans to provide adaptive management strategies that provide specific mitigation measures for natural features that have been identified as potentially affected by the proposed development;
  - detailed pre-mining assessment of the potential impacts on geomorphological features, including an assessment in the unlikely event that increased subsidence occurs;
  - monitoring of subsidence movements above and beyond the proposed mining footprint, including across specific geological features such as faults;
  - monitoring of the condition of geomorphological features during and after the mining period; and

  - if increased subsidence were to occur during the mining of a proposed longwall, amendments to the mine plan for future longwalls would be considered to avoid future increased subsidence.
- undertake pre, during and post mining photographic surveys and visual inspections of geomorphological features for each longwall. Annual photographic surveys of sensitive geomorphic features would be undertaken at 10 headwater photographic sampling locations to monitor mining-induced subsidence impacts of the proposed development over time; and
- prepare an annual report on the results of the photographic survey. The assessment and report would:
  - provide data for baseline geomorphic conditions of waterways in the Project Area; and
  - be repeated annually within areas that have been undermined to identify potential impacts to geomorphology as a result of subsidence.
- undertake a pre and post mining catchment-wide survey, assessment and report for waterway geomorphological conditions. The survey would include a sample of randomly distributed headwater sites on headwater waterways. Headwater sampling would be undertaken to confirm the assessment that the risk to geomorphological character within the Project Area as a result of mining-related subsidence is insignificant;
- for each longwall monitor risk of knickpoint formation and implement appropriate controls to prevent knickpoint formation. This would include:
  - regular monitoring to detect if there is potential for knickpoint formation;
  - an assessment of the potential consequences of any identified knickpoint formation locations; and
  - the implementation of appropriate controls to prevent knickpoint formation such as rock grade control structures and/ or large wood structures. The most appropriate form of control for each location would be determined on a case-by-case basis.

11.2.6 Conclusion

The Geomorphology Technical Report characterised the geomorphology of the Project Area and identified RMZs for significant streams and major cliffs. Waterways within the Project Area consist of two main types; headwater or gorge, and range in stream order from 2^{nd} order to 7^{th} order streams. The waterways are bedrock controlled, and as a result are resilient to geomorphological change. The majority of streams were considered to be in a stable and close to natural geomorphic condition.

The qualitative assessment of geomorphology found that the overall risk of geomorphic change as a result of mining-induced subsidence was minor. Waterway types within the Project Area were assessed to be resilient and generally in good condition. Should the proposed development result in subsidence related changes to creek geomorphology, it is considered that subject to appropriate monitoring and management the geomorphology of waterways would be able to recover.

Providing that the mitigation and management measure are implemented, the proposed development is not anticipated to present a significant risk of change in the geomorphic character of waterways in the Project Area.

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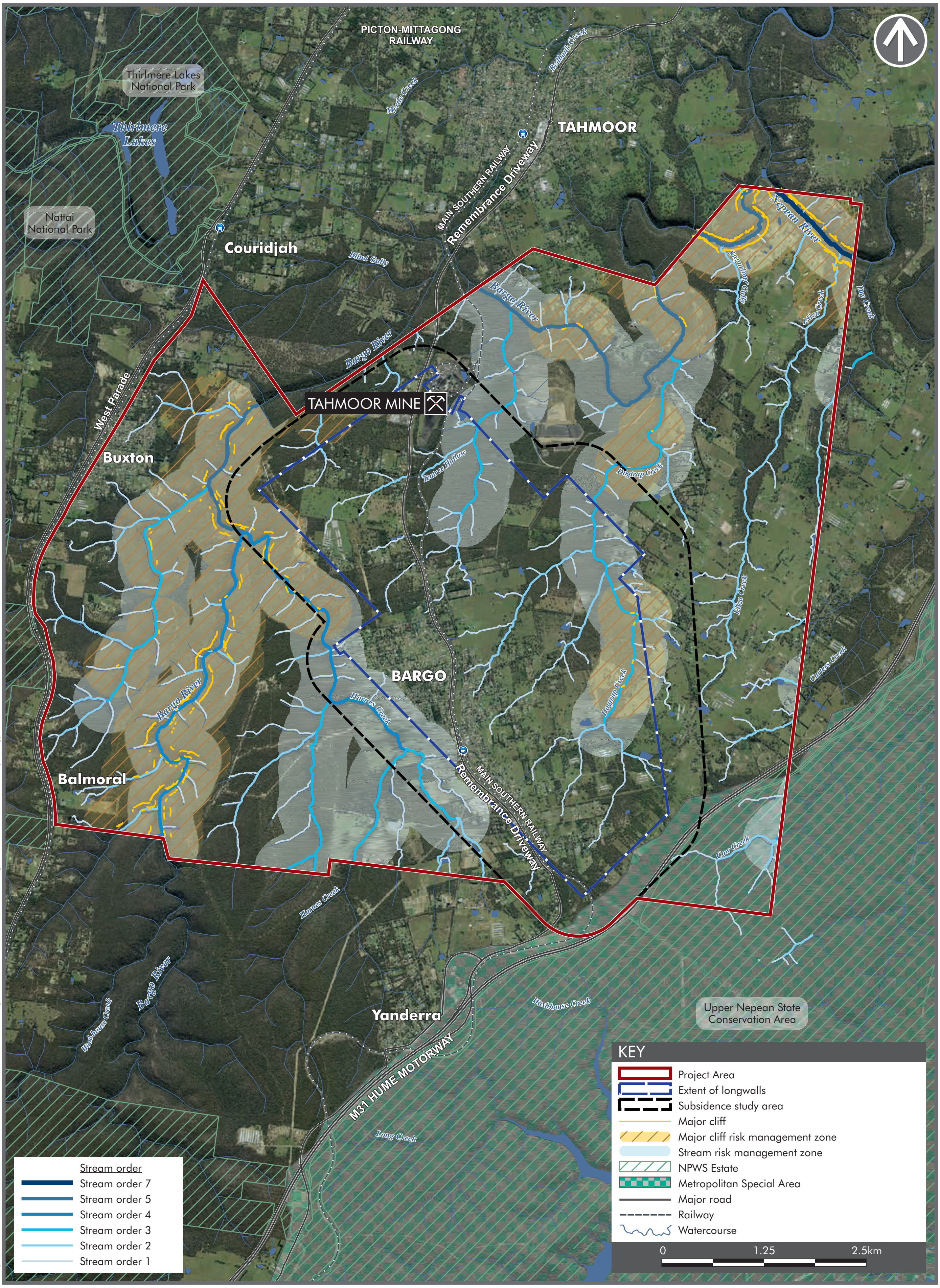

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RISK MANAGEMENT ZONES FOR GEOMORPHOLOGY
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FIGURE 11.8

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11.3 Groundwater

A Groundwater Assessment for the proposed development was undertaken by HydroSimulations (2018). The Groundwater Assessment included the development of a conceptual model and numerical groundwater model to represent the historical behaviour of groundwater at Tahmoor Mine, and to predict impacts to groundwater behaviour as a result of the proposed development.

The Groundwater Assessment was peer reviewed by Prathapar & Associates (November, 2018). The peer review considered the Groundwater Assessment to be robust, technically appropriate and consistent with:

- *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012);
- the requirements of the *NSW Aquifer Interference Policy* (NSW Government, 2012); and
- the *Information guidelines for Independent Expert Scientific Committee advice of coal seam gas and large mining development proposals* (IESC, October 2015).

Both the Groundwater Assessment for the proposed development and the peer review report are provided in **Appendix I**.

The Groundwater Assessment addressed the SEARs and Supplementary SEARs relevant to groundwater impacts. These are listed in **Table 11-14**. Impacts relating to surface water, flooding and aquatic ecology are addressed in **Sections 11.4** and **11.7** of this EIS. Where relevant, pertinent information from the Surface Water Impact Assessment (HEC, 2018) prepared for this EIS has been referenced in this section.

Table 11-14 SEARs for the assessment of water resource impacts

Water Resource SEARs	Section addressed
Water Resources – including:	
• 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. DI Water's) and WaterNSW's requirements and recommendations;	• Surface Water - **Section 11.4.4**, **Section 11.5.4** and **Appendix J** (Surface Water Impact Assessment – Sections 5, 7,8, 9, 10,12) • Groundwater - **Section 11.3.4**, **Section 11.5.4** and **Appendix I** (Sections 4-6)
• an assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, water supply infrastructure and systems and other water users;	• Surface Water - **Section 11.4.4**, **Section 11.5.4** and **Appendix J** (Surface Water Baseline Study, Surface Water Impact Assessment – Sections 5, 7,8, 9, 10,12) • Groundwater - **Section 11.3.4**, **Section 11.5.4** and **Appendix I** (Sections 3-6) • Surface water features are also described and assessed in **Sections 11.2** and **Appendix H** (Geomorphology) and **Section 11.7** and **Appendix K (**Aquatic Ecology).
• 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*;	• Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Impact Assessment – Section 13)

Water Resource SEARs	Section addressed
• 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;	• **Section 11.4.5** and **Appendix J** (Water Balance Report)
• a detailed description of the proposed water management system (including sewerage), beneficial water re-use program and all other proposed measures to mitigate surface water and groundwater impacts;	• **Section 11.4.5** and **Appendix J** (Water Balance Report, **Section 11.4.6** (Surface water mitigation measures) and **Section 11.3.5** (Groundwater mitigation measures)
• 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; and	• **Appendix J** (Surface Water Baseline Study), **Appendix I** (Section 3.8), **Section 11.4.6** (Surface water mitigation measures) and **Section 11.3.5** (Groundwater mitigation measures)
• an assessment of the potential flooding impacts of the development.	• **Section 11.4.4** and **Appendix J** (Flood Study)
Water Resource Supplementary SEARs	
Water resource, in relation to coal seam gas development and large coal mining development	
• The EIS should provide a description of the location, extent and ecological characteristics and values of the identified water resource potentially affected by the project.	• Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Baseline Study, Surface Water Impact Assessment – Section 3) • Groundwater - **Section 11.3.4** and **Appendix I** (Sections 3) • Surface water features are also described and assessed in **Sections 11.2** and **Appendix H** (Geomorphology) and **Section 11.7** and **Appendix K (**Aquatic Ecology).
• The assessment of impacts should include information on:	
- Any substantial and measurable changes to the hydrological regime of the water resource, for example a substantial change to the volume, timing, duration or frequency of ground and surface water flows;	- Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Impact Assessment – Sections 5, 7,8, 9, 10,12) - Groundwater - **Section 11.3.4** and **Appendix I** (Sections 4-6)
- The habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the water resource being seriously affected; and	- **Sections 11.6** (Terrestrial Ecology) and **11.7** (Aquatic Ecology) and **Appendix K**

Water Resource SEARs	Section addressed
- Substantial and measurable change in the water quality and quantity of the water resource – for example a substantial change in the level of salinity, pollutants or nutrients in the wetland or water temperature that may adversely impact on biodiversity, ecological integrity, social amenity or human health.	- Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Impact Assessment – Sections 10) - Groundwater - **Section 11.3.4** and **Appendix I** (Sections 4-6) - Aquatic Ecology – **Section 11.7.4** and **Appendix K**
• The EIS must provide adequate information to allow the project to be reviewed by the Independent Expert Scientific Committee of Coal Seam Gas and Large Mining Development, as outlined in the *Information Guideline for Independent Expert Scientific Committee advice of coal seam gas and large mining development proposals* (IESC, October 2015).	• **Sections 1-4, 11.1**, **11.2**, **11.3**, **11.4**, **11.5**, **11.6** and **11.7** • **Appendix F**, I, **H**, **J**, **K** • The requirements of the IESC guideline have also been specifically assessed in **Appendix I.**
• The proponent should ensure that a comprehensive and scientifically rigorous water monitoring program and adaptive management program is put in place to ensure Thirlmere Lakes are not being impacted by the proposed action. The listed studies should be considered by the Proponent when assessing the impacts of the proposed action on ground water and surface water.	• **Appendix J** (Surface Water Impact Assessment – Sections 8, 11), **Appendix I** (Section 6-7), **Section 11.4.6** (Surface water mitigation measures) and **Section 11.3.5** (Groundwater mitigation measures) and **Section 11.5** (Thirlmere Lakes). • The studies considered by the assessments are listed in the reference sections of each specialist report.

11.3.1 Background

Longwall mining removes large rectangular panels of coal from a coal seam which results in the overburden caving into the void, creating stresses that propagate upwards, and outward, through the overlying strata. It is generally understood, based on experience of monitoring and modelling groundwater impacts in the Southern Coalfields, that fracturing and deformation of the overlying strata results in some changes, from very large to no change, in the permeability and water storage properties of this caved and deformed overburden (HydroSimulations, 2018).

In NSW, impacts to groundwater resources are regulated consistent with water sharing plans (WSPs) enacted under the *Water Management Act 2000* (WM Act) and the *NSW Aquifer Interference Policy* (NSW Government, 2012).

Water Sharing Plans

The relevant groundwater WSP for the proposed development is the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (GMRGS Plan). The GMRGS Plan comprises several groundwater sources or ‘Groundwater Management Areas’ which are used to manage the average long-term annual volume of water extracted. The Groundwater Management Area relevant to the proposed development is ‘Sydney Basin - Nepean Sandstone’. The Sydney Basin – Nepean Sandstone Groundwater Management Area is further subdivided into Management Zones. The proposed development lies within Zone 2 of the Sydney Basin – Nepean Sandstone Groundwater Management Area.

The relevant WSP for the proposed development, in terms of surface water, is the Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011. Particularly relevant to the proposed development is the Upper Nepean River source, which is segmented into management zones. The proposed development is covered by the Pheasants Nest Weir to Nepean Dam management zone, the Stonequarry Creek management zone and the Maldon Weir management zone.

NSW Aquifer Interference Policy

The *NSW Aquifer Interference Policy* (NSW Government, 2012) requires estimation of the volume of water that is likely to be taken from any water source as a result of an activity. The *NSW Aquifer Interference Policy* also requires that an assessment be undertaken to predict the impacts generated by the activity. The 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 available baseline data that has been collected at an appropriate frequency and scale and over a sufficient period of time.

Development proposals for mining and coal seam gas projects on Biophysical Strategic Agricultural Land (BSAL) are subject to assessment by a Gateway Panel prior to lodgement with DPE. The NSW Government has mapped strategic agricultural land across NSW at a desktop level and the Project Area is not located within an area mapped as BSAL. As discussed in **Section 8.1.3**, Tahmoor Coal has applied for and received a Site Verification Certificate from DPE on 23 October 2018 confirming that the Project Area is not located on BSAL land. Therefore, the proposed development is not subject to the Gateway process, and a “complex modelling platform” is required to inform the groundwater impact assessment for the proposed development.

The *NSW Aquifer Interference Policy* provides the framework for the assessment of impacts of a proposed development on aquifers in NSW. The policy categorises groundwater sources as either “highly productive” or “less productive” depending on salinity and aquifer yield.

Zone 2 of the Sydney Basin – Nepean Sandstone Groundwater Management Area (where the Project Area is located) is defined by the *NSW Aquifer Interference Policy* as being ‘highly productive’. As a result, the groundwater resource is subject to the minimal impact considerations for highly productive groundwater as stipulated by the policy. These considerations relate to thresholds for water table and groundwater pressure drawdown, and changes in groundwater and surface water quality. The minimal impact considerations for highly productive groundwater are listed in **Table 11-19**.

The ‘highly productive’ categorisation within the *NSW Aquifer Interference Policy* does not distinguish vertically between the higher-yielding Hawkesbury Sandstone groundwater system and the low-yielding Narrabeen Group groundwater system, or the Permian (and deeper) groundwater systems lying at depth. However, most groundwater exploited for human or environmental purposes in this area comes from the Hawkesbury Sandstone, and only a small fraction from the Narrabeen Group or underlying Coal Measures. Hence the focus of the Groundwater Assessment has been on the potential impact that can propagate to the shallower stratigraphic units, most importantly the more utilised Hawkesbury Sandstone.

The groundwater impact assessment for the proposed development has been undertaken in line with the requirements outlined by the *NSW Aquifer Interference Policy*.

Licences

Dewatering operations at Tahmoor Mine are governed by groundwater licence 10WAl18745 with an annual total of less than or equal to 1,642 ML. Water entering the mine is collected into sumps, pumped to the Surface Facilities Area and either treated at the recycled water treatment plant or discharged via LDP1 to Tea Tree Hollow in accordance with EPL 1389.

The proposed development would operate under the existing groundwater licence and EPL as discussed in **Section 4.0**. The existing groundwater entitlement volume currently held by Tahmoor Coal is 1,642 ML/a. An additional groundwater licence would be required to be secured to account for increased groundwater inflows for the proposed development, as discussed further in **Section 11.3.4**.

Independent Expert Scientific Committee

The Independent Expert Scientific Committee (IESC) on coal seam gas and large coal mining development is a statutory body established under the EPBC Act. The Commonwealth Minister for the Environment is required to seek the advice of the IESC on coal seam gas or large coal mining developments that have the potential to significantly impact water resources.

In 2012, the Commonwealth Government entered into the National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development with the NSW, Victorian, Queensland, South Australian and Northern Territory Governments. Under the Agreement, the Commonwealth Government and signatory states agreed to seek advice from the IESC at appropriate stages in the assessment and approvals process for coal seam gas and large coal mining development proposals that are likely to have a significant impact on water resources.

The proposed development was declared a controlled action under the provisions of the EPBC Act by the DoEE in January 2018, due to the potential for significant impacts on matters of national environmental significance, including water resources. Accordingly, the groundwater assessment has been carried out considering the Information Guidelines formulated by the IESC (2015). The requirements of the IESC guideline have also been specifically assessed in **Appendix I**. As previously noted in **Section 1.6.4**, the DoEE referral and Controlled Action determination of the proposed development was based on an earlier mine plan layout, which included mining in both the Central and Eastern domains. As discussed in **Section 6.2.4**, subsequent mine planning has led to a revised mine plan involving mining in the Central Domain only (current proposed development), and is anticipated to result in reduced overall impacts to water resources.

11.3.2 Methodology

In order to determine the extent of impact of the proposed development on groundwater resources, the Groundwater Assessment included:

- an analysis of data inputs including baseline monitoring data from Tahmoor Coal's groundwater monitoring program;
- establishing a groundwater assessment study area;
- the development of a hydrogeological conceptual model; and
- numerical modelling to assess impacts of mine development.

Baseline Monitoring

The groundwater monitoring network at Tahmoor Mine is used for operational monitoring of the Tahmoor North Mine, as well as providing baseline data for the Tahmoor South Project. Various bores have been operational since 2008 for multiple years as shown in Figure 3-7 of HydroSimulations, 2018. Baseline monitoring of surface and groundwater resources has been undertaken in the vicinity of the proposed development to inform the conceptual model and to establish trigger response values for the ongoing monitoring and management of these resources during mining. Surface water monitoring sites are presented and discussed in **Section 11.4**. Groundwater monitoring data used to inform the assessment were obtained from the following sources, also shown on **Figure 11.9**:

- five bore installations within the Existing Tahmoor Approved Mining Area, each with between six and eight vibrating wire piezometers installed at different locations within the stratigraphic sequence;
- multiple piezometers installed in bore TBF040c, located above longwall 10A of the existing operations;
- nine shallow bores within the Hawkesbury Sandstone above the existing operations, labelled as piezometers P1 to P9 on **Figure 11.9**. Of these P5 and P6 are no longer active;
- four DI Water monitoring bores at Thirlmere Lakes that monitor the shallow Hawkesbury Sandstone and/or alluvium;
- thirty monitoring bores installed across the Project Area, 17 with dual piezometer installations and 13 with multi piezometer installations;

- a bore census (survey) of standing water levels and geochemistry from 23 private, DI Water registered bores located across the Project Area and six Tahmoor Coal monitoring bores (GeoTerra, 2013a);
- a deep horizon water sampling bore (TBC035) for EC, oxygen, deuterium and tritium isotope sampling; and
- two piezometers monitoring groundwater at the REA: TGW5 (up-gradient) and TGW4 (down-gradient).

Monitoring bores provide information regarding groundwater levels and also provide information regarding groundwater pressure where piezometers are installed within the monitoring bores.

Groundwater quality data for the Study Area was sourced from publicly available data from the NSW government Groundwater Works/Pinneena database, Dendrobium Mine, and from the bore census conducted by GeoTerra (2013a). Water quality sampling has been carried out at 29 local bores since early 2013, 6 of which are Tahmoor Coal monitoring bores and the remainder being private landowner bores (see GeoTerra, 2013a). Additionally, there is monitoring of water quality within deeper horizons of the stratigraphic sequence. This is done via sampling of TBC035 (see GeoTerra, 2013a) and also monthly sampling, since January 2012, of the water pumped out of the mine, which is primarily groundwater.

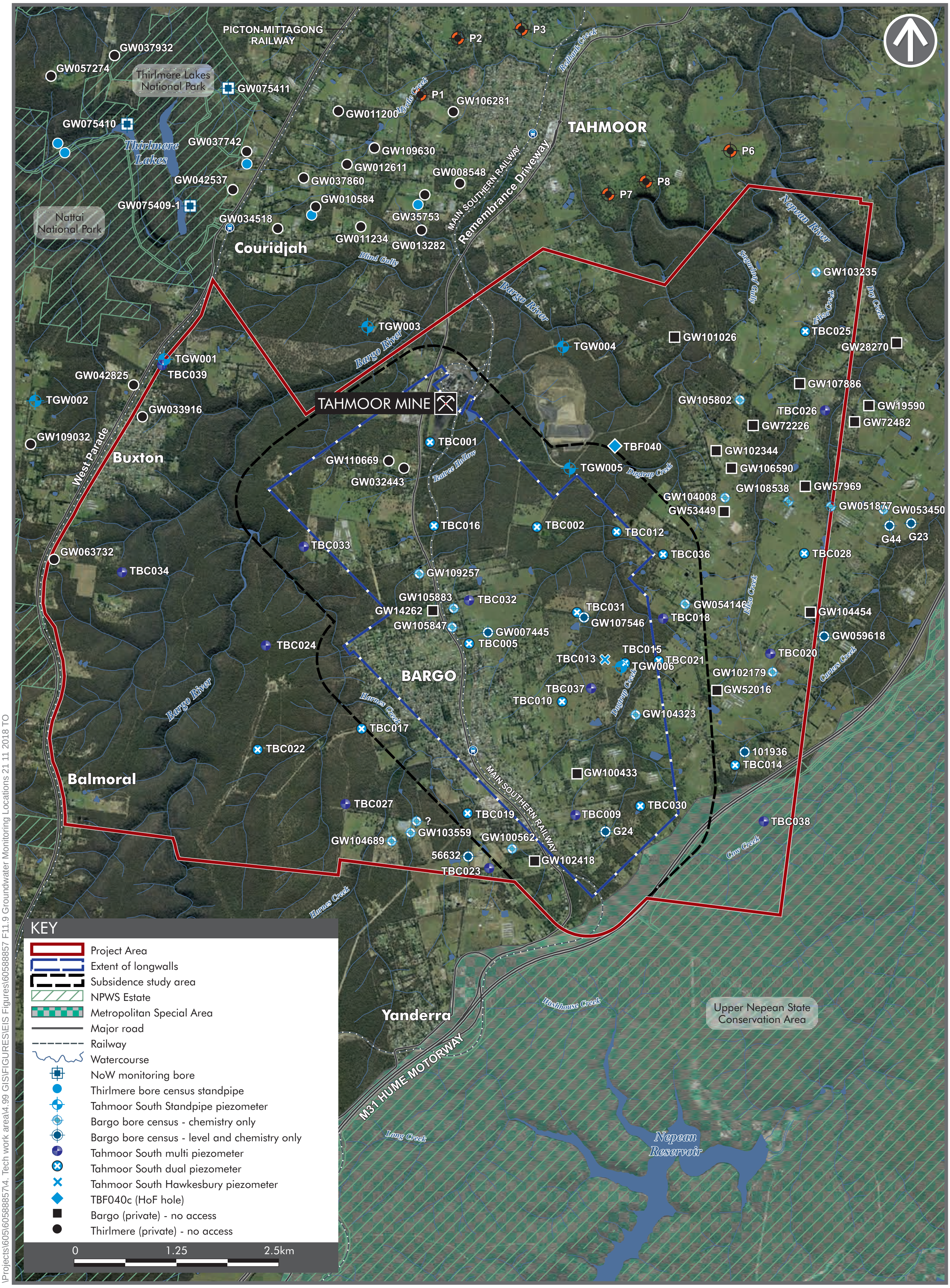
Groundwater Assessment Study Area

A groundwater assessment study area was established to encompass the geological and hydrological features that might be important to the proposed development and to the numerical model built for the purpose of impact assessment. The groundwater assessment study area is centred on the Tahmoor Mine, extending beyond Lake Burragorang to the west, past Wollongong to the south east, beyond the Illawarra Escarpment in the east, and into the suburbs of Sydney in the north and north east (refer to Figure 1-1 of HydroSimulations, 2018).

Conceptual Model

A review of literature and data was carried out as a basis for the development of the conceptual model. This included review of available information on geology, rock mass hydraulic properties, neighbouring mine workings and strata geometry for the area interpreted stratigraphy bore logs from the Tahmoor Lease area (MBGS, 2013), and modelling techniques for considering potential effects of longwall mining on the overlying strata. In particular, previous investigations commissioned by Tahmoor Coal at Tahmoor Mine were reviewed, comprising predicted changes to permeability in the goaf and overburden via geotechnical modelling (SCT, 2013) and down-hole investigations into fracturing above a longwall (SCT, 2014). 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.

Cross-sections of the stratigraphy within the Tahmoor Lease Area (based on the regional conceptual model) are shown in **Figure 11.10**.



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GROUNDWATER MONITORING LOCATIONS WITHIN THE PROJECT AREA

Tahmoor South Project
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FIGURE 11.9

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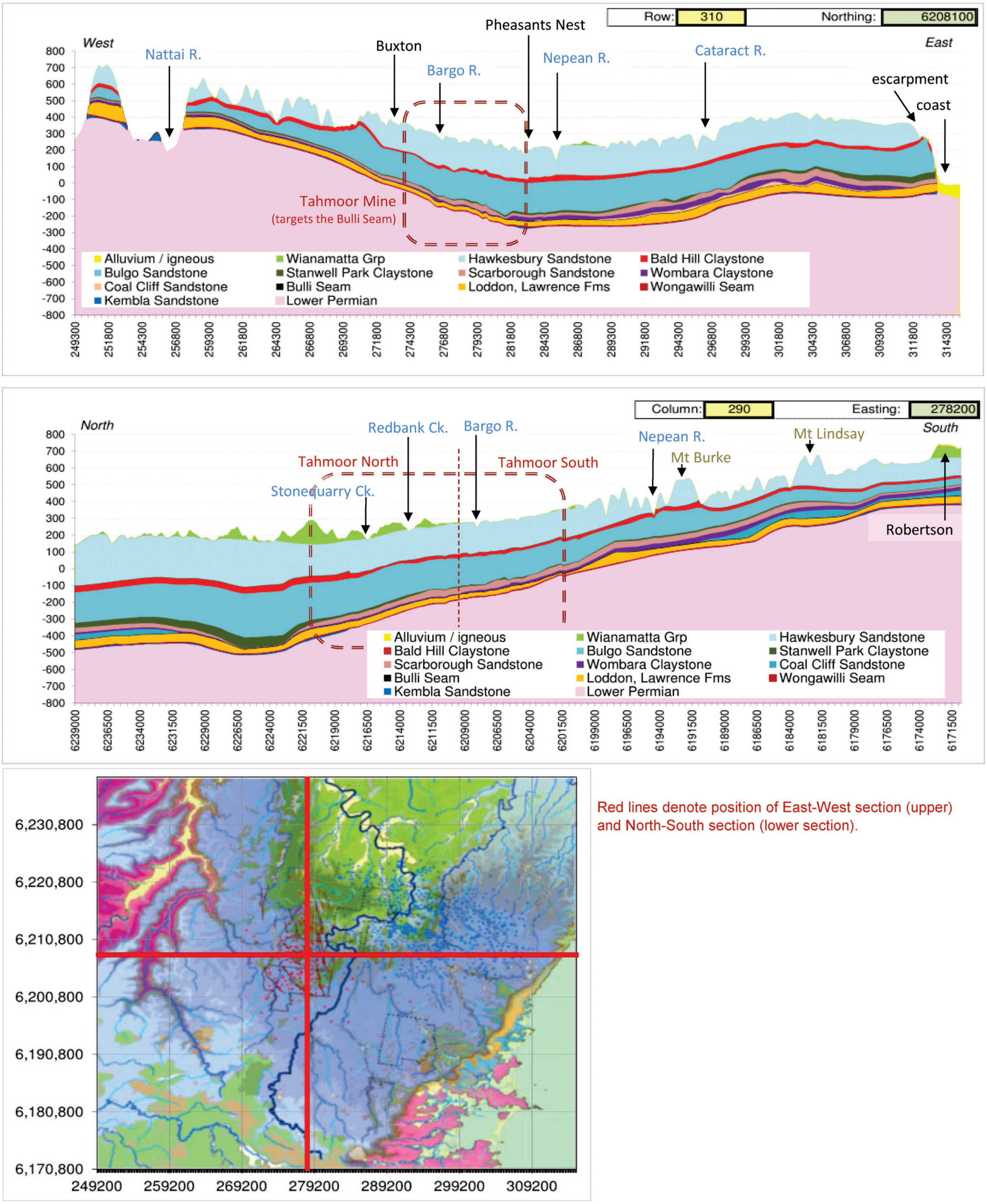

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CROSS-SECTIONS OF THE STRATIGRAPHIC UNITS IN THE PROJECT AREA

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Source: Hydrosimulations (2018)

FIGURE 11.10

Numerical Model

The numerical model was developed in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012), which build on the Murray-Darling Basin Commission Groundwater Flow Modelling Guideline (MDBC, 2001). The model was developed to assess the proposed development meets a 'Class 2' confidence level under the Barnett et al (2012) guide, which is equivalent to a 'medium' model complexity classification under MDBC (2001). This level of model complexity is deemed by the guidelines to be suitable for predicting the impacts of the proposed development.

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. USG allows finer grid scale to focus on sensitive areas (such as the Thirlmere lakes) and allows the inclusion of localised layers.

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 following modelling approach was adopted:

- development of a steady state calibration model representing hypothetical, un-impacted or natural (pre-mining) condition using average climate and no mine stresses;
- development of a transient calibration model that simulated mining stresses from Tahmoor Mine and neighbouring mines for the period 1980 until October 2017;
- development of a transient predictive model extending through the end of the Tahmoor North operations (~2022), then through the operation of Tahmoor South (2023-2035), and the simulation of post-mining recovery through to 2500 (i.e. >450 years of recovery); and
- implementation of a sensitivity analysis to test the impacts of various hydrogeological features and behaviours including:
    - testing the possibility that the barrier faults are 'weaker' (more permeable) than simulated in the baseline model;
    - testing the possibility that faults in the project area act as hydraulically conductive features;
    - testing the potential impact of increasing the height of fracturing above the coal seam; and
    - testing the inclusion of enhanced groundwater storage parameters in the groundwater model.

The potential impacts of the development were assessed by making comparisons between the predictive scenarios summarised in **Table 11-15**.

Table 11-15 Summary of modelled scenarios

Scenario	Description	Mining – proposed development	Mining – other
Scenario A	Scenario A is the 'null' run as described in the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) and otherwise known as a hypothetical 'natural' or non-impacted scenario whereby all aquifer interference activities were removed from simulation. In Scenario A the hydrological environment was created without any of the existing mines, longwall/ subsidence impacts on strata and no groundwater extraction from bores.	Not included	Not included

Scenario	Description	Mining – proposed development	Mining – other
Scenario B	Scenario B represents the existing environment with all mining activities simulated, except for the proposed development. The existing longwall mining operations (Tahmoor mine and other mines) modelled in this scenario are detailed in Figure 2-3 of HydroSimulations, 2018.	Not included	Included (existing operations at Tahmoor North and others)
Scenario C	Scenario C represents the proposed scenario with all mining activities occurring. This is the same as Scenario 'B' but with the proposed development also operating.	Included	Included (existing operations at Tahmoor North and others)

Modelling these scenarios allowed the net impact of the proposed 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 proposed development. When Scenarios A and C are compared, the difference between the two represents the cumulative impact of all the mining activities in the area.

Groundwater extraction bores were not simulated in Scenarios B or C given the uncertainty around actual extraction versus entitlement, as well as due to the possible presence of unregistered bores.

A schematic of the 'post-mining' groundwater conceptual model is provided in **Figure 11.11**.

Thirlmere Lakes

A discussion of the assessment of groundwater impacts to the Thirlmere Lakes is provided in **Section 11.5**.

11.3.3 Existing Environment

The existing environment of the groundwater assessment study area is described below and forms the conceptual model for the Groundwater Assessment.

Physical Environment

Topography and Surface Drainage

The elevation of the groundwater assessment study area ranges from 100 m to 370 m Australian Height Datum (m AHD) due to the highly incised nature of the watercourses. The topography is dominated by the Illawarra Escarpment which is both the regional high point and also the high rainfall area. The escarpment acts as a divide with most rivers and creeks flowing west into the Nepean catchment. The Nepean River is perennial and flows from the south through Lake Nepean, to the east of the Tahmoor South Project, and up to the north through Camden toward Penrith.

The Avon and Cordeaux Rivers are the largest tributaries to the Nepean River, with the confluence of these lying to the east of the Project Area. Bargo River flows through the middle of the Tahmoor leases, before flowing into the Nepean River. Other notable topographic features include the Nattai River valley and Lake Burragorang to the west of the Project Area.

Natural surface features identified within the groundwater assessment study area, and related to the Groundwater Assessment, include:

- the Thirlmere Lakes, to the west along the upper reaches of Blue Gum Creek. In order from upstream to downstream, the lakes comprise: Lake Gandagarra, Lake Werri Berri, Lake Couridjah, Lake Baraba and Lake Nerrigorang;
- catchment areas or declared Special Areas which include five major water storage reservoirs operated by WaterNSW (**Table 11-16**); and
- waterways and high value features including Mermaid Pool (as detailed in **Section 11.4**).

Table 11-16 Major water storage reservoirs (Hydrosimulations, 2018)

Reservoir[1]	Surface area (approx.) (km^2)	Full storage level (approx.) (m AHD)
Lake Burragorang (Warragamba Dam)	72	117
Lake Nepean	3	317
Lake Avon	9.5	320
Lake Cordeaux	7.5	304
Lake Cataract	8.5	290

[1] The locations of the lakes are shown in **Figure 1.1**

Streamflow monitoring indicates that the Bargo River, the Nepean River (Maldon Weir) and Hornes Creek are baseflow-fed streams. The monitoring data and flow duration curves suggest that waterways in the east of the Project Area, Eliza, Dry and Carters Creeks, have the lowest flows. Carters Creek and Dry Creek also have the steepest flow duration curves suggesting baseflow discharge is a less significant process at low flows in these catchments. While some creeks appear to have only a minor contribution from baseflow, there is no evidence for complete disconnection between streams and groundwater.

No significant springs or soaks have been identified within the Project Area, either by published data or the Shallow Groundwater Assessment commissioned by Tahmoor Coal as part of the feasibility investigations for the proposed development (GeoTerra, 2013). However, there are likely to be some localised springs and soaks due to the presence of saturated and perched aquifers within the Permo-Triassic strata, especially the Hawkesbury Sandstone, resulting in some groundwater discharge at surface before flowing into local creeks and rivers.

Climate

Topography in the region influences rainfall distribution so that rainfall decreases with distance from the Illawarra Escarpment (over 1,600 mm per annum) to the Lake Burragorang in the west (750-800 mm per annum). The long-term trend in rainfall in the Nepean catchment comprises a long period of lower than average rainfall between 1890-1950, with multiple year droughts occurring in around 1900 ('Federation Drought') and 1936-45 ('WWII Drought') (Verdon-Kidd and Kiem, 2009). This period of lower than average rainfall was followed by a sustained period of above average rainfall that continued until the early 1990s, and was followed by the 'Millennium Drought' (1997-2011).

The annual average 'Area Actual Evapotranspiration' (Bureau of Meteorology) is approximately 680 mm per year at Tahmoor. The Bureau of Meteorology 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.

Designated Areas

National Parks, State Forests and WaterNSW Special Areas (drinking water catchments) are present within the groundwater assessment study area. These include:

- Thirlmere Lakes National Park and the Warragamba 'Special Area with Restricted Entry' zone (managed by WaterNSW) to the west of the proposed development;
- Upper Nepean;
- Bargo; and
- the MSA immediately to the south-east of the extent of proposed longwalls.

Groundwater Dependent Ecosystems

Groundwater dependent ecosystems in the region that are listed on the GMRGS Plan as high priority are:

- Thirlmere Lakes, located approximately 3.5 km from the proposed development at its nearest proposed longwalls;
- O'Hares Creek located more than 23 km to the east of the proposed development; and
- Macquarie Rivulet Estuary located more than 29 km south east of the proposed development.

Potential impacts to Thirlmere Lakes are assessed and discussed in **Section 11.5**. O'Hares Creek and Macquarie Rivulet are beyond the boundaries of the impact assessment model. The proposed development is unlikely to impact these features due to their distance from the proposed development. Other GDEs are limited to North Pole Swamp which is located 21 km south of the proposed development.

The High Priority Endangered Ecological Vegetation Communities, as listed on the GMRGS Plan that exist within the groundwater assessment study area are:

- Temperate Highland Swamps on Sandstone, approximately 20-25 km to the south of the proposed development; and
- Cumberland Plain Woodland (Cumberland Plain Shale Woodlands and Shale- Gravel Transition Forest) mapped to the north of the proposed development.

No upland swamp communities or Cumberland Plain Woodland is identified in the Terrestrial Ecology assessment (Niche, 2018), as occurring within the proposed development area. Further discussion of these communities is provided in **Section 11.6**.

Underlying Geology

The proposed development is located in the southern part of the Permo-Triassic Sydney Basin, within which the main coal bearing sequence is the Illawarra Coal Measures. The Illawarra Coal Measures contain multiple workable seams, the uppermost of which is the Bulli Seam, and this seam is targeted for extraction by the proposed development.

Three stratigraphic divisions overlie the Illawarra Coal Measures, being the Narrabeen Group (sandstone and claystone), Hawkesbury Sandstone Group (bedded sandstone) and Wianamatta Group (shales and siltstones). Sandstone units within these stratigraphic divisions dominate the study area and are evident at the surface, often exposed in river gorges and creeks. The Wianamatta Group units evident at the surface are generally limited to along the tops of ridgelines.

Exploration has identified a number of geological features within the study area, including two major faults being the Nepean fault and the Central fault. These faults are included in the conceptual groundwater model. Further detailed description of the underlying geology is provided in **Section 5.0**.

Groundwater Flow Systems

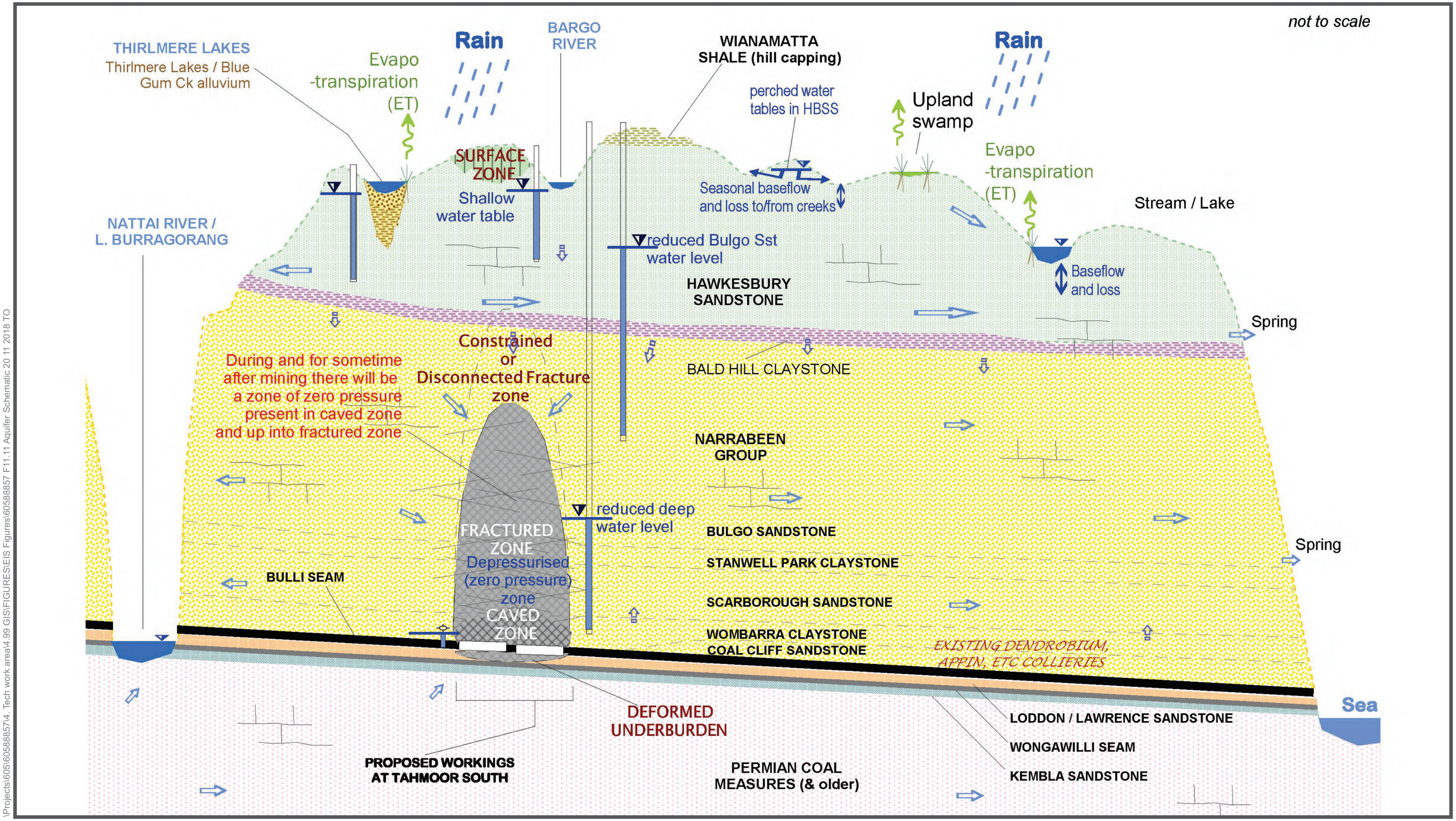
The major hydrostratigraphic units within the groundwater assessment study area are the Sydney Basin Permian and Triassic rock units, which form a porous and fractured rock aquifer (**Figure 11.11**). The Sydney Basin Permian and Triassic rock units are classified within the Nepean Groundwater Management Area as 'Highly Productive'. The primary aquifer within this grouping is the Hawkesbury Sandstone, although smaller quantities of water can be extracted from parts of the Narrabeen Group (such as the Bulgo Sandstone) and from the Illawarra Coal Measures. The geological sequence comprises interlayered sandstone, claystone (including Bald Hill Claystone), siltstone and, within the Permian strata, coal seams, to depths of 400-500 m.

Minor hydrostratigraphic units within the groundwater assessment study area include:

- Thirlmere Lakes alluvium: an alluvial aquifer, attributed as being Cretaceous in age, associated with Blue Gum Creek. It primarily comprises clayey sands and sandy clays, reaching a maximum thickness of 40-60 m or more, although restricted to a thin valley (only a hundred or a few hundred m wide); and

- 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.

Inter-aquifer flow rates between the hydrostratigraphic units are likely limited by the contrasting permeability differences between these units. Consequently, 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, would probably occur at significantly slower rates than in the alluvium, even considering the clay-rich nature of the Thirlmere Lakes alluvium.



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SUBSIDENCE SCHEMATIC

Tahmoor South Project

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FIGURE 11.11

Hydraulic Properties

Across all formations, with the exception of the Bulli Seam, the hydraulic conductivity measurements from the Project Area indicate that permeability has a general trend of decreasing with depth. The trend indicates two broad groups with regards to permeability:

- decreasing permeability from the Hawkesbury Sandstone down to the Wombarra Claystone, an apparent increase in permeability between the Wombarra Claystone and the Bulli Seam; and
- a further decreasing trend in strata underlying the Bulli Seam.

Most of the faults in the area are thought to act as barriers to flow (hydraulic barriers), noting that this does not mean they are impermeable, just less permeable than most of the surrounding rock mass. In contrast, water inflows to the longwalls at Tahmoor North were observed to be higher than normal at a point where the mine workings intersected the Nepean fault zone. For this reason the Nepean Fault is believed to be a conductive fault that is more permeable than the surrounding geology. However, calibration of the hydraulic zones as part of the conceptual model involved consideration of the Nepean Fault as conductive and as a barrier to understand the overall influence of the fault for both scenarios (refer to **Appendix I** for further information).

Groundwater Recharge and Discharge

The regional recharge is stated by DI Water (2010) to be 6% of the long term average rainfall. However, the analysis in the Groundwater Assessment suggests that recharge to the consolidated Hawkesbury Sandstone and Wianamatta Formation is likely to be approximately 2-3% of long term average rainfall in the area around Tahmoor and Bargo.

The higher average rate stated in DI Water (2010) might apply across the Nepean Groundwater Source as a whole, as it encompasses areas of higher rainfall to the south (Southern Highlands) and east (Illawarra escarpment) of Tahmoor. The Groundwater Assessment conceptual model has adopted the lower rate of 10-20 mm per year or 2-3% of long term average rainfall for recharge to the Hawkesbury Sandstone. Recharge to this aquifer is predominantly from rainfall recharge with some recharge from stream leakage. This is consistent with the close calibration of the model with water levels in the local piezometer network.

Recharge, including rainfall recharge as well as stream leakage, to alluvium in the region is likely to be occurring at higher rate, in the order of 10-20% of long term average rainfall.

Groundwater discharge is primarily to streams with some evapotranspiration occurring from shallow groundwater in lower lying areas via outcrops of fractured rock. A small portion of groundwater is extracted for anthropogenic use by production bores. Discharge from alluvium is primarily via baseflow to the lakes and watercourses, as well as evapotranspiration from shallow water table areas.

Groundwater Quality

Publicly available data from the NSW government Groundwater Works/Pinneena database, and from the bore census conducted by GeoTerra (2013a) indicates the following with regard to groundwater quality for hydrogeological units within the Study Area:

- 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: Groundwater 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.
- Narrabeen Group or Illawarra Coal Measures: There is little available data for these units. Older units such as the Shoalhaven Group exhibit a range of salinities from fresh to saline.

Publicly available water quality data from surrounding mines were also reviewed, including from the Dendrobium Mine 12 km to the south east. A summary of groundwater quality at Dendrobium Mine indicated:

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

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

The Reject Emplacement Area (REA) located within the surface infrastructure area has been operated by Tahmoor for most of the period of historical mining. It is located on outcropping Hawkesbury Sandstone, just south of the Bargo River. A review of water quality monitoring around the REA suggests there is no adverse effect from the rejects within the REA on local groundwater quality.

Groundwater Extraction

Private Bores

Database searches identified 982 registered groundwater bores within the groundwater Study Area on the NSW government PINNEENA database. Based on a search of the NSW Water Access Licence register, 791 of the 982 bores returned matches to Water Access Licences amounting to a licensed groundwater entitlement of 3,272 ML of water per year for private or small scale government use within the groundwater assessment study area. There is some additional 981,000 ML of water per year associated with unregulated river licences held by government agencies, although these licences are also associated with licensed groundwater works. In addition, there is approximately 1,000 ML of water per year of unlicensed groundwater use for stock and domestic purposes (assuming that use for these purposes is 1 - 2 ML of water per year).

Most of the groundwater usage in the region is from the Hawkesbury Sandstone or from surficial alluvium and basalt aquifers (about 89% of the total), with about 10% from the Bulgo Sandstone. The disparity between use from the Hawkesbury Sandstone and the Bulgo Sandstone is suspected to be due to generally lower yields, poorer water quality, and increased drilling costs for accessing the deeper Bulgo Sandstone (HydroSimulations, 2018).

Mine Inflows

Inflows into the mine workings following mining create a vertical gradient in the surrounding aquifers and add to the discharge of groundwater from the system. Mine inflows at the existing operations of Tahmoor Mine come from the deeper aquifers in the Narrabeen and Permian strata. Mine inflows range between 1 and 4.5 ML of water per day. In the last 4-5 years, the total water make has been fairly steady at around 3-4 ML of water per day (HydroSimulations, 2018).

Existing Mining Operations

The Southern Coalfield includes a number of currently operational coal mines as shown on **Figure 2.1**. The nearest mines to the proposed development form part of the existing groundwater environment due to the cumulative impact that coal mining has had on groundwater pressure in the region. The nearest mining operations to the proposed development are identified in **Table 2.1** and are shown in **Figure 2.1**.

The majority of the existing mines in the Southern Coalfield mine the Bulli Seam. However, some also mine other seams within the Illawarra Coal Measures including the Wongawilli Seam. The numerical model assessed the cumulative impacts of the proposed development in the context of the nearest mining operations identified in **Figure 2.1**.

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 285 and 305 m wide (most 305 m), and the mined thickness would be up to 2.85 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.

The conceptual model of the impacts of mining on the permeability of caved and deformed overburden has been based on experience of monitoring and groundwater modelling gained at Tahmoor and in other locations, combined with the recent research available for subsidence impacts on aquifer materials.

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. The analysis identified that mining-induced fractures occur from around 75-80 m above the mined seam in the area. The analysis also showed that at shallow depths fracturing was not connected in a vertical sense, nor permeable enough in a horizontal sense to result in significant changes to the groundwater pressures within the local geology (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. Further information is provided in **Appendix I**.

11.3.4 Impact Assessment

Impacts of longwall mining on the groundwater regime 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. The caving of the overburden and the subsequent extraction of groundwater, impacts the hydrogeological system during and after mining operations. The extent to which the proposed development is likely to result in the following impacts is presented below:

- **Aquifer Interference** - inflow of water to the underground mine and the management of that mine water;
- **Baseflow** - impacts of baseflow capture on surface waterways during and after mining;
- **Drawdown** - impacts on groundwater levels during and after mining; and
- **Groundwater quality** - impacts on groundwater quality via mining-induced mixing of groundwater from different strata.

Impacts of the proposed development on groundwater have also been assessed against the criteria for minimal impact considerations specified by the *NSW Aquifer Interference Policy* (NSW Office of Water, 2012) which relates to:

- **Aquifer Interference** - licensable takes of water (and their partitioning);
- **Drawdown** - water table and pressure head drawdown; and
- **Groundwater quality**.

Aquifer Interference

The mine inflow rates for the proposed development are predicted to average approximately 4.7ML of groundwater per day for the life of the proposed development; with peaks in 2029-30 and 2032 of around 7.5-8 ML per day (HydroSimulations, 2018).

In annual terms, the inflows equate to an average of 1,700 ML of water per annum over the period of mining for the proposed development. The peak annual flows are predicted to be approximately 2,850ML in 2029 and 2,600 ML of water in 2032.

The existing groundwater entitlement volume currently held by Tahmoor Coal is 1,642 ML/a, meaning a short fall of a maximum of 1,208 ML/a (based on the maximum predicted inflow of 2,850 ML in 2029). Additional groundwater licence(s) would need to be secured to account for the increased groundwater inflows for the proposed development. The Nepean Sandstone Groundwater Source has an annualised limit on entitlement of 99,568 ML (HydroSimulations, 2018) with a current entitlement of 28,841 ML (based on the WaterNSW Water Register). Whilst current Unassigned Water volumes are not published on the Water Register, the most recent Report Card for the Sydney Basin Nepean Groundwater Source (NOW, 2011a), identified that there was 37,303 ML/a of Unassigned Water (equivalent to 102.2 ML/d) available. Therefore it is considered that there would be available water to increase the entitlement held by Tahmoor Coal. Tahmoor Coal would purchase additional groundwater allocations as required in consultation with DI Water.

Sensitivity testing of the numerical model suggests that mine inflows could be higher than predicted by the 'base case' model. That is, average inflows of 4.7-5.5 ML per day (1,700 to 2,000 ML/a) and peak inflows during 2029 and 2032 of up to 2,850 and 3,700 ML/a in a 12 month period for the proposed development.

However, the Groundwater Assessment demonstrated a high degree of correlation between the modelled inflows, for the calibrated historical model, with the observed inflows. Therefore, the high inflows from the sensitivity test are considered overly conservative for licensing annual rates of groundwater extraction (HydroSimulations, 2018). Periodically, the model predictions would be compared with measured data and if there are any inconsistencies the model (and where required licence allocations) would be updated accordingly.

As noted in **Section 11.3.1,** the Tahmoor South Project is subject to the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (GMRGS Plan), which is divided into a number of groundwater sources. The proposed development is located within the *Sydney Basin – Nepean Sandstone* groundwater source (Management Zone 2). The proposed development is located some 10-11 km from the nearest part of the *Sydney Basin – Nepean Sandstone* Management Zone 1 and still further from other groundwater sources under the GMRGS Plan such as the *Sydney Basin - Central* (10km) and *Sydney Basin – South* (15-20km).

The groundwater modelling for the proposed development included consideration of groundwater 'take' (inter-zone fluxes) from other groundwater sources. The modelling indicated that on average, only interzone fluxes for *Sydney Basin – Nepean Sandstone* Management Zone 1 and *Sydney Basin– Central* would be affected by Tahmoor South, and only in the post-closure phase as it takes time for the drawdown to propagate. The modelling predicted that the proposed development would result in increased groundwater influxes as follows:

- *Sydney Basin – Nepean Sandstone* Management Zone 1: Average of <1 ML/a; Max of 2 ML/a; and
- *Sydney Basin – Central*: Average of <1 ML/a; Max of 1 ML/a.

It is considered that the predicted influxes do not represent a significant component of these groundwater resources.

Baseflow Impacts

Waterways

'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. Baseflow impacts determined by the conceptual model have informed the surface water impact assessment which is described in **Section 11.4**.

Baseflow impacts predicted to result from the proposed development and the cumulative case are summarised in **Table 11-17** below.

Table 11-17 Predicted baseflow reductions to watercourses

Watercourses	Proposed Development (Estimated max ML/d)	Cumulative Case (Estimated max ML/d)	Impacts as % of mean flow (project-only and cumulative)
Eliza Creek (SW-18)	0.0	0.003	0.0% - 0.5%
Carters Creek (SW-23)	0.0	0.004	0.0% – 0.4%
Dog Trap Creek (SW-15)	0.26	0.28	5.3% – 5.7%
Tea Tree Hollow (SW-22)	0.11	0.13	3.7% – 4.5%
Cow Creek (SW-24)	0.005	0.022	0.2% – 0.9%
Stonequarry Creek (212053)	0.06	0.29	0.4% - 1.9%
Bargo River (SW-1)	0.0013	0.17	0.3% - 3.6%
Bargo River (SW-13)	0.01	0.30	0.4% - 1.3%
Bargo River (SW-14)	0.54	0.83	1.7% - 2.6%
Hornes Creek (SW-9)	0.01	0.1	0.4% - 3.8%
Nepean River (SW-21 – Maldon Weir)	0.59	1.3	1.2% - 2.7%

The modelling indicates that baseflow impacts from the proposed development would likely be greatest at Dog Trap Creek (peak reductions up to 5.3% – 5.7% of mean flow), Tea Tree Hollow (peak reductions up to 3.7% – 4.5% of mean flow) and Bargo River (peak reductions up to around 2% of mean flow). These impacts are anticipated to occur at different times (e.g. 2024 at Bargo River, SW1 and 2035 at Dog Trap Creek), including in some cases after the operational life of the proposed development (e.g. 2041 at Bargo River, SW13 and 2043 at Hornes Creek and Cow Creek).

For the cumulative scenario, the modelling indicates typically greater impacts, which in most cases is the result of the impacted watercourses such as Stonequarry Creek and Blue Gum Creek, being located in closer proximity to existing approved mining operations (i.e. Tahmoor North longwalls).

The Surface Water Baseline Study undertaken by HEC (2018) indicates that baseflows make up a relatively small contribution of mean flows at watercourses in proximity to the proposed development (i.e. baseflow index of 0.1) (HEC, 2018).

Given this, the impacts of baseflow reduction on total stream flow are expected to be relatively small. This is demonstrated in the groundwater assessment results summarised in **Table 11-17** which indicates that the percentage of mean flow reduction (as a result of baseflow changes) for all waterways would be less than 3.8% under the proposed development and less than 4.9% under the cumulative scenarios.

The reductions in baseflow would likely be most noticeable during periods of low flow which would normally be dominated by baseflow (HEC, 2018). Furthermore, reductions in baseflow at Tea Tree Hollow would likely be offset by on-going licensed discharge from LDP1 (HEC, 2018). Baseflow impacts and other subsidence induced impacts to watercourses are further discussed in **Section 11.4.4**.

Surface Water Sharing Plans

As discussed in **Section 11.3.1**, the proposed development is also subject to the following (surface) water sharing plan: *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011*. Within the WSP, the proposed development is located within the Upper Nepean River source. The proposed development (including other mining as part of the cumulative impact assessment) would result in a reduction in baseflow in three management zones (MZs) in the Nepean River Water source:

- Pheasants Nest Weir Nepean Dam MZ, which is predicted to experience baseflow depletion of around 0.04 ML/d (Tahmoor South), 0.5 ML/d (cumulative mining effect);
- Stonequarry Creek MZ, which is predicted to experience baseflow depletion of around 0.06 ML/d (Tahmoor South), 0.29 ML/d (cumulative mining effect); and
- Maldon Weir MZ, which is predicted to experience baseflow depletion of around 0.6 ML/d (Tahmoor South), 1.3 ML/d (cumulative mining effect).

The highest baseflow losses are predicted at the Nepean River, Maldon Weir MZ (up to 1.3 ML/d – cumulative effect). However, as identified in **Table 11-17,** this is equivalent to an overall reduction in mean flow rates within the Nepean River of up to 1.2% (under the proposed development) and up to 2.7% (under the cumulative scenario), which is not considered to be significant.

Water Storage Reservoirs

There are five WaterNSW water storage reservoirs partly or wholly within the groundwater model domain. The predicted leakage rates for the closest reservoirs associated with the proposed development are up to around 0.007 ML per day for Lake Nepean and 0.006 ML/d from Lake Avon. The predicted leakage rates associated with the Tahmoor South Project are considered to be small given the total capacity of the reservoirs (around 70 ML for Lake Nepean and 214,360 ML for Lake Avon).

The NSW Dam Safety Committee specifies tolerable limits for induced leakage from these reservoirs. For Lake Nepean and Lake Avon this is 1 ML/d. The predicted leakage rates for the Tahmoor South Project (0.007 ML per day for Lake Nepean and 0.006 ML/d from Lake Avon) are much less than this level.

Special Areas

The change in water balance for the MSA and Warragamba Special Area was calculated from groundwater model results.

The proposed Mine Plan was developed by Tahmoor Coal following consultation risk assessment process and included consideration of predicted subsidence impacts on the MSA and associated built and natural features. Tahmoor Coal made a number of revisions to the original Mine Plan, including shortening Longwall 105 to 108 from the commencing ends so they do not encroach into the MSA and no longer proposing mining within the eastern domain. The proposed development is predicted to result in less than 0.05 ML per day (less than 18 ML per year) decline in baseflow in the MSA and this impact would peak around the year 2100. A large proportion of the MSA catchment flows out through Maldon Weir. Average daily flow at the weir is approximately 180 ML/d, so the predicted flow depletion is about 0.1% of mean daily flow.

Cumulative impacts on the MSA would primarily include the reduction of baseflow and evapotranspiration from shallow groundwater. Baseflow is predicted to decline by a maximum of 0.16 ML per day (60 ML per year) in around 2070-2100. The impact to baseflow would decrease over the period following the year 2100, although it would never fully recover. This is due to the cumulative impact of the proposed development adjacent the MSA and historical, current and proposed workings at Russell Vale, Cordeaux, and Dendrobium mines. Licensed and registered bores may also account for further cumulative effects on baseflow and reduced evapotranspiration.

For the Warragamba Special Area, impacts to baseflow are predicted to be less than 0.005 ML per day (less than 2 ML per year) and less than <0.001% of the mean flow for the area. Cumulative impacts, including from the existing Tahmoor Mine, on the Warragamba Special area are predicted to include a reduction in baseflow of 0.005 ML per day (2 ML per year), which peaked at 0.1 ML per day (35 ML per year) in the 1980-90s. The (un-modelled) effects of bore pumping are likely to be greater in this area than in the MSA, given the bore use to the northwest of Tahmoor Mine.

Given that predicted flow depletion is expected to be around 0.1% and <0.001% of mean daily flow for the MSA and the Warragamba Special Area respectively, impacts are considered to be very minor.

Drawdown

Over the life of the proposed development, mine inflows would total around 21 GL. In annual terms, the groundwater take averages around 1,700 ML per year over the period of longwall mining. Mine inflows would result in a consequent decline in groundwater levels or ‘drawdown’.

Drawdown is predicted to be strongest in the mined coal seam (with a peak of 350 m drawdown) and becoming less pronounced in the overlying stratigraphy. Moving upward through the sequence, drawdown is predicted as follows: Bulgo Sandstone - more than 250 m drawdown, Hawkesbury Sandstone - approximately 25 m drawdown and upper Hawkesbury - within one m of natural levels.

The model suggests that in the proposed mining footprint most of the recovery would be complete about 150 years after the cessation of the proposed development. Within the Central Domain longwall areas, recovery of water levels in the deeper layers (e.g. Bulli Seam, Scarborough Sandstone) is predicted to be incomplete, with a drawdown of 10-20 m in the lower Bulgo Sandstone and 20-30 m in the Bulli Seam predicted in 2500. Residual drawdown in 2500 is predicted to be much less in the upper layers.

To the east and southwest of the proposed development, recovery is predicted to be quicker than to the north (100 years rather than 150 years) as these areas are up-gradient of Tahmoor South, rather than downgradient.

At some locations and in some units there is predicted to be final recovery to beyond the natural level. Final recovery beyond natural levels is predicted to occur in these layers due to subsidence and fracturing causing greater vertical and horizontal connectivity through the strata around and above the underground mine and connecting areas with naturally higher levels to those with lower levels, resulting in recovery to an ‘average’ level.

Groundwater Dependent Ecosystems

The numerical groundwater model was used to generate estimates of drawdown in shallow groundwater beneath high priority GDEs for the proposed development. Estimates of drawdown impacts on GDEs were then used to inform the predicted impacts on surface 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) as well as any head separation between the water body and the underlying aquifer.

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

The numerical model was used to assess the impacts from the proposed development on the water table elevation at or beneath various high priority GDEs. Cumulative impacts to GDEs were also assessed. A discussion of impacts to the Thirlmere Lakes (listed as a high priority GDE) is provided in **Section 11.5**.

Other potential impacts to GDEs are limited to North Pole Swamp which is the closest of the upland swamps, located 21 km south of the proposed development. Modelling identified that the North Pole Swamp would not experience drawdown or baseflow impacts as a result of the proposed development.

Bore Users

The *NSW Aquifer Interference Policy* sets the threshold for acceptable impacts of proposed developments on bore users at less than 2 m of drawdown. Bore users within the study area were identified from the 2013 bore survey commissioned by Tahmoor Coal (GeoTerra, 2013) and by reviewing NSW Government Groundwater Works/Pinneena database and Water Register. The numerical model was used to assess the impacts of the proposed development on the 791 bore users identified within the groundwater assessment Study Area.

The Groundwater Assessment predicts that a total of 30 registered bores and three unregistered bores would experience drawdown of greater than 2 m as a result of the proposed development (refer to **Table 11-18**). Of the 30 bores affected beyond 2 m, 14 are predicted to experience greater than 5 m maximum drawdown, and 4 to experience greater than 10 m.

Accounting for cumulative impacts of the existing operations at Tahmoor North and other mines within the groundwater model, the number of impacted bores with >2m drawdown would increase to 94 registered bores and eight unregistered bores.

Table 11-18 Registered bores where predicted impacts exceed the 2 m drawdown threshold

Degree of impact	Number of bores exceeding threshold		
(m)	Base case model		Sensitivity analysis (maximum drawdown)
	Proposed development	Cumulative	Additional bores affected
>2 m	30	94	+28
Total bores in model area	791		

Tahmoor Coal would manage potential bore impacts through the existing process to ‘make good’ on impacted users’ water sources. Groundwater would be monitored during mining using manual and data logger based standing water level monitoring. Tahmoor Coal has been operating this process during the life of Tahmoor North. In addition, the process allows for bore owners to apply to Tahmoor Coal if they believe the level or water quality has declined in their groundwater bore. 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. Tahmoor Coal has committed to continue this ‘make good’ process through the operation of the proposed development (refer to **Section 11.3.5** for further information).

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SIMEC MINING

PRIVATELY OWNED BORES POTENTIALLY AFFECTED BY GROUNDWATER DRAWDOWN

Tahmoor South Project
Environmental Impact Statement

FIGURE 11.12

Groundwater Quality

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

Electrical conductivity data for the groundwater in the Southern Coalfield indicates a general trend of increasing salinity with depth (with the Wianamatta Formation being one exception to this generalisation). As such, it is considered that mining-induced mixing of groundwater would result in changes to the salinity of the Hawkesbury Sandstone and Bulgo Sandstone, the two most commonly utilised aquifers. Changes are expected to be more likely in the Bulgo Sandstone, which is not as heavily utilised by bore users due to existing natural hydraulic gradients from the Illawarra Coal Measures into the lower Bulgo Sandstone. Any changes in salinity or specific nutrients (e.g. iron, manganese) are unlikely to alter or impact on the beneficial uses of groundwater in the Permo-Triassic rock aquifers in or around the mine lease. The risk of these impacts decreases with distance from the active mining area and enhanced rock mass deformation and fracturing. There are no anticipated risks of reduced beneficial uses of the Nepean Ground Water Management Area (GMA) porous rock aquifer as a result of the Tahmoor South mine.

As described above, Tahmoor Coal would ‘make good’ any impacts to the groundwater quality of groundwater bore users (refer to **Section 11.3.5** for further information).

Summary of Aquifer Interference Policy Assessment

The implications of the predicted impacts of the proposed development on groundwater are summarised in **Table 11-19** against the minimal impact considerations under the *NSW Aquifer Interference Policy*. Given the simulated potential cumulative impact on the water table at Thirlmere Lakes (refer to **Section 11.5**), as well as on existing groundwater users’ bores within the Permian and Triassic strata, the proposed development is classified as Level 2 within the minimal impact considerations of the *NSW Aquifer Interference Policy*. A detailed discussion on the potential impacts to Thirlmere Lakes is provided in **Section 11.5**.

Mining Near/under Alluvial Water Sources

The proposed development would not take place beneath designated alluvial Water Source and would be three to four km away from the nearest mapped body of alluvium lying along the Thirlmere Lakes and Blue Gum Creek. No alluvial floodplains were identified in the Project Area as identified in **Appendix H**. Consequently, the *NSW Aquifer Interference Policy* requirements for mining activity beneath or near to alluvial water sources do not apply to the proposed development.

Table 11-19 Summary of Aquifer Interference Policy Assessment – Permo-Triassic Porous Rock (HydroSimulations, 2018)

Aquifer	**Sydney Basin Porous Rock (Nepean Groundwater Source, Management Zone 2)**
Category	**Highly productive**
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.	There are three high-priority GDE in the groundwater assessment study area. Thirlmere Lakes: There is a risk of groundwater drawdown in the alluvium underlying the lakes of < 0.03m from the proposed development and a peak of 0.05m as a result of cumulative impacts. The cumulative impact groundwater drawdown is close to or above the 10% threshold criterion (refer **Section 11.5** for assessment of impacts on Thirlmere Lakes). Other listed GDEs: O'Hares Creek and Macquarie Rivulet are beyond the boundaries of the impact assessment model. There were no Culturally Significant Sites in the study area listed in the WSP. Hence there are no known risks of mine development to such sites. Probable 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 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 40m from the activity.	Mining-induced changes to the hydraulic properties and depressurisation of the strata in the mined area would result in mixing of potentially chemically different groundwater between overlying and underlying units. However, it is considered unlikely that this would 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.**

11.3.5 Management and Mitigation Measures

The proposed development is classified as Level 2 within the minimal impact considerations of the *NSW Aquifer Interference Policy*. Consequently, the proposed development would require risk mitigation, prevention or avoidance strategies to be implemented so that groundwater impacts are managed and minimised. Tahmoor Coal would implement the following strategies in order to manage groundwater impacts:

- the existing Tahmoor Mine Groundwater Management Plan (GWMP) would be updated for the proposed development to define a groundwater monitoring strategy, groundwater level triggers, and include a TARP;

- the regional groundwater monitoring network would continue to be developed and maintained, including specific monitoring of Thirlmere Lakes (refer to **Section 11.5**) and to existing users' water supply. Monitoring sites would be reviewed and sites requiring repair, replacement or augmentation to improve confidence would be addressed in the next revision of the GWMP. This would include consideration of additional bores to sample groundwater quality from the mid/lower Hawkesbury Sandstone and Bulgo Sandstone within the project area and ongoing groundwater monitoring at the REA;
- additional reviews of groundwater monitoring data would be conducted on an annual basis in order to compare actual groundwater drawdown levels to those predicted by the numerical model;
- monitoring in longwall centre-lines of pre- and post-mining conditions would be conducted to assist in defining a profile of fracturing and depressurisation above longwalls;
- the volumetric take (total mine inflow) metering method, including improved monitoring of inflows to the drift and different areas within the underground mine, would continue to be employed. The data from this monitoring would be periodically used, 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 would include revision of the modelling and identified risks as required; and
- Tahmoor Coal commits to the implementation of appropriate "make good" measures to mitigate and/or remediate impacts to bore users. This could involve deepening and/or replacing bores and wells, and/or providing an alternative water source to affected users. Prior to commencement of mining all water works identified as being potentially adversely affected in the Groundwater Assessment (HydroSimulations, 2018) and the Subsidence Impact Assessment (MSEC, 2018) would be surveyed for their existence, location, use, and construction details. Subsequent to this, remedial action can be planned and undertaken as required.

11.3.6 Conclusion

A numerical groundwater model was developed using information from a review of the data, literature and conceptual hydrogeology associated with current operations at Tahmoor, as well as other mines in the area, and other hydrogeological studies. The model was peer reviewed and was determined to be technically appropriate and consistent with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012).

The results of the numerical groundwater model indicate that the impacts of the proposed development on groundwater resources include inflows into the mine, drawdown, water quality and changes to stream baseflow.

Additional groundwater licence volumes would need to be secured to account for increased groundwater inflows as a result of the proposed development. Based on the most recent Report Card for the Sydney Basin Nepean Groundwater Source (NOW, 2011a), there was 37,303 ML per annum of Unassigned Water (equivalent to 102.2 ML/d). Therefore it is considered that there is available water to increase the entitlement held by Tahmoor Coal, and Tahmoor Coal would purchase additional groundwater allocations as required.

The groundwater modelling indicated that proposed development and cumulative modelling would result in reductions to baseflow within surrounding waterways, however that these reductions would comprise only a small proportion of total mean flow rates.

Potential impacts to Thirlmere Lakes are described in **Section 11.5**. Other GDEs in the region, such as O'Hares Creek and Macquarie Rivulet, are beyond the boundaries of the impact assessment model. The proposed development is unlikely to impact these features due to their distance from the proposed development.

The assessment determined that changes in groundwater salinity are unlikely to alter or impact on the beneficial uses of groundwater in the Permo-Triassic rock aquifers in or around the mine lease. There are no anticipated risks of reduced beneficial uses of the Nepean GMA porous rock aquifer as a result of the Tahmoor South mine. Tahmoor Coal would 'make good' any impacts to the groundwater quality of groundwater bore users.

It is predicted that a total of 30 registered bores and three unregistered bores would experience drawdown of greater than 2 m as a result of the proposed development. Tahmoor Coal would mitigate and manage potential impacts on these bore users through the implementation of appropriate ‘make good’ measures, as it currently does for operations at Tahmoor North.

Tahmoor Coal would continue to develop and maintain its established regional groundwater monitoring network to monitor potential drawdown risks to existing users’ bores and groundwater resources.

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11.4 Surface Water

Hydro Engineering & Consulting Pty Ltd (2018) has undertaken an assessment of surface water impacts for the proposed development. The surface water assessment comprises four components (provided in **Appendix J**):

- Surface Water Baseline Study;
- Water Management System and Site Water Balance Report;
- Flood Study; and
- Surface Water Impact Assessment.

The surface water assessment addressed the SEARs relevant to surface water impacts. These are listed in **Table 11-20**.

Table 11-20 SEARs for the assessment of water resource impacts

Water Resource SEARs	Section addressed
Water Resources – including:	
• an assessment of the likely impacts of the development on the quantity and quality of surface and groundwater resources, having regard to EPA's, DI Water's and WaterNSW's requirements and recommendation;	• Surface Water - **Section 11.4.4**, **Section 11.5.4** and **Appendix J** (Surface Water Impact Assessment – Sections 5, 7,8, 9, 10,12) • Groundwater - **Section 11.3.4**, **Section 11.5.4** and **Appendix I** (Sections 4-6)
• an assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, water supply infrastructure and systems and other water users;	• Surface Water - **Section 11.4.4**, **Section 11.5.4** and **Appendix J** (Surface Water Baseline Study, Surface Water Impact Assessment – Sections 5, 7,8, 9, 10,12) • Groundwater - **Section 11.3.4**, **Section 11.5.4** and **Appendix I** (Sections 3-6) • Surface water features are also described and assessed in **Sections 11.2** and **Appendix H** (Geomorphology) and **Section 11.7** and **Appendix K (**Aquatic Ecology).
• 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*;	• Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Impact Assessment – Section 13)
• 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;	• **Section 11.4.5** and **Appendix J** (Water Balance Report)
• a detailed description of the proposed water management system (including, sewerage), beneficial water re-use program and all other proposed, measures to mitigate surface water and groundwater impacts;	• **Section 11.4.5** and **Appendix J** (Water Balance Report, **Section 11.4.6** (Surface water mitigation measures) and **Section 11.3.5** (Groundwater mitigation measures)

Water Resource SEARs	Section addressed
• 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; and	• **Appendix J** (Surface Water Baseline Study), **Appendix I** (Section 3.8), **Section 11.4.6** (Surface water mitigation measures) and **Section 11.3.5** (Groundwater mitigation measures)
• an assessment of the potential flooding impacts of the development.	• **Section 11.4.4** and **Appendix J** (Flood Study)
Water Resource Supplementary SEARs	
Water resource, in relation to coal seam gas development and large coal mining development	
• The EIS should provide a description of the location, extent and ecological characteristics and values of the identified water resource potentially affected by the project.	• Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Baseline Study, Surface Water Impact Assessment – Section 3) • Groundwater - **Section 11.3.4** and **Appendix I** (Sections 3) • Surface water features are also described and assessed in **Sections 11.2** and **Appendix H** (Geomorphology) and **Section 11.7** and **Appendix K (**Aquatic Ecology).
• The assessment of impacts should include information on:	
- Any substantial and measurable changes to the hydrological regime of the water resource, for example a substantial change to the volume, timing, duration or frequency of ground and surface water flows;	• Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Impact Assessment – Sections 5, 7,8, 9, 10,12) • Groundwater - **Section 11.3.4** and **Appendix I** (Sections 4-6)
- The habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the water resource being seriously affected; and	• **Sections 11.6** (Terrestrial Ecology) and **11.7** (Aquatic Ecology) and **Appendix K**
- Substantial and measurable change in the water quality and quantity of the water resource – for example a substantial change in the level of salinity, pollutants or nutrients in the wetland or water temperature that may adversely impact on biodiversity, ecological integrity, social amenity or human health.	• Surface Water - **Section 11.4.4** and **Appendix J** (Surface Water Impact Assessment – Sections 10) • Groundwater - **Section 11.3.4** and **Appendix I** (Sections 4-6) • Aquatic Ecology – **Section 11.7.4** and **Appendix K**
• The EIS must provide adequate information to allow the project to be reviewed by the Independent Expert Scientific Committee of Coal Seam Gas and Large Mining Development, as outlined in the Information Guideline for Independent Expert Scientific Committee advice of coal seam gas and large mining development proposals (IESC, October 2015).	• **Sections 1-4, 11.1**, **11.2**, **11.3**, **11.4**, **11.6** and **11.7** • **Appendix F**, I, **H**, **J**, **K** • The requirements of the IESC guideline have also been specifically assessed in **Appendix A.**

Water Resource SEARs	Section addressed
• The proponent should ensure that a comprehensive and scientifically rigorous water monitoring program and adaptive management program is put in place to ensure Thirlmere Lakes are not being impacted by the proposed action. The listed studies should be considered by the Proponent when assessing the impacts of the proposed action on ground water and surface water.	• **Appendix J** (Surface Water Impact Assessment – Sections 8, 11), **Appendix I** (Section 6-7), **Section 11.4.6** (Surface water mitigation measures), **Section 11.3.5** (Groundwater mitigation measures) and **Section 11.5** (Thirlmere Lakes). • The studies considered by the assessments are listed in the reference sections of each specialist report.

11.4.1 Background

The 2012 Southern Coalfields Inquiry placed particular focus on the potential for longwall mining to impact surface water systems. Key recommendations of the Southern Coalfields Inquiry relevant to the surface water assessment for the proposed development include:

- waterways classified under the Strahler stream classification as being 3rd order or higher are to be managed within an RMZ;
- a minimum of two years of baseline data, collected at appropriate frequency and scale should be provided for significant natural features; and
- an understanding and predicting impacts on valleys and their rivers and significant streams. Coal mining companies should focus on the prediction of valley closure in addition to local upsidence.

To satisfy these recommendations, the surface water assessment has relied upon data from:

- the Tahmoor South Surface Water Monitoring Program, which was undertaken between February 2012 and June 2015. The monitoring program was set up with the aim of providing at least two years of baseline data for all surface water sources within and adjacent to the proposed development;
- the Subsidence Impact Assessment undertaken for the proposed development (MSEC, 2018) (**Appendix F**) – the assessment predicted subsidence impacts to watercourses within the Project Area and has been used as a basis for the Surface Water Impact Assessment. The Subsidence Impact Assessment considered previous predictions and monitoring data in its assessment, as well as comparisons with impacts recorded at other collieries within the Southern Coalfields; and
- the Groundwater Assessment undertaken for the proposed development (HydroSimulations, 2018) (**Appendix I**). The assessment predicted impacts to groundwater resources as a result of the proposed development and has been used to assess potential impacts to surface water flows as a result of changes to groundwater baseflow.

11.4.2 Methodology

The methodology for the surface water assessment of the proposed development included four separate assessments as follows:

Surface Water Baseline Study

The Surface Water Baseline Study for watercourses in the Project Area included:

- review and assessment of rainfall data from mine site climate stations, local climate stations operated by the Bureau of Meteorology (BoM) and long term synthetic rainfall and evaporation records obtained from the SILO Data Drill[1] system for the Project Area;
- identifying and characterising watercourses within the Project Area identifying both baseline and impact sites;

[1] The SILO Data Drill is a system which provides synthetic data sets for a specified point by interpolation between surrounding point records held by the BoM. Refer https://www.longpaddock.qld.gov.au/silo/datadrill/

- monitoring of surface water at gauging stations shown in **Figure 11.13** (covering impact and baseline sites), including monitoring of:
    - flow of selected watercourses; and
    - water quality for comparison against the ANZECC guidelines.
- catchment modelling of surface water using the *Australian Water Balance Model* (Broughton, 2004) to simulate surface runoff and baseflow processes. The model was run for Bargo River (upstream), Dog Trap Creek (downstream) and Eliza Creek catchments. Streamflow characteristics for Cow Creek and Carter Creek catchments were estimated based on the modelling for Eliza Creek and Dog Trap Creek catchments, respectively, which were found to have closely similar hydrology. **Table 11-21** below summarises the location of these waterways in terms of impact or baseline sites.

The surface water monitoring program was designed to provide an adequate dataset to inform the baseline hydrological and water quality characteristics of watercourses in and around the Project Area. In order to provide an adequate dataset, the design of the monitoring program took into account the proposed extent of longwall mining when identifying suitable monitoring locations to ensure that:

- monitoring locations are located upstream and downstream of areas likely to be impacted by subsidence;
- the locations selected include watercourses that would be undermined and some that would not be undermined so that potentially impacted sites and control sites could be established; and
- sensitive watercourses have been included in the monitoring program.

The Tahmoor South Surface Water Monitoring Program was undertaken between February 2012 and June 2015. The monitoring period has provided a robust dataset that accommodates seasonality and variations in precipitation. Surface water monitoring is also undertaken as part of existing operations at Tahmoor North.

The surface water monitoring locations are summarised in **Table 11-21** below and shown in **Figure 11.13**.

Table 11-21 Summary of surface water monitoring locations

Site ID on Figure 11.13	Site ID in Baseline Study (HEC, 2018)	Site Description	Category
1	SW-1 / 300061 Bargo River	Long pool with flat hydraulic control	Control site
9	SW-9 / 300062 Hornes Creek	Rock bar and pool	Control site
13	SW-13 / 300010A Bargo River Upstream Bargo	Rock bar and pool	Baseline/impact site
14	SW-14 / 300011A Bargo River Downstream Rockford Road Bridge	Rock bar and pool	Baseline/impact site
15	SW-15 / 300063 Dog Trap Creek Downstream	Long rock bar and pool	Baseline/impact site
16	SW-16 / 300064 Dog Trap Creek Upstream	Rock/mud bar and large pool	Baseline/impact site
18	SW-18 / 300073 Eliza Creek	Rock bar and pool	Baseline
20A	SW-20A / 300074 Dry Creek	Rock bar and large deep pool	Baseline
21	SW-21 / 300065 Nepean River at Maldon Weir	Pool behind weir	Baseline/impact site
22	SW-22 / 300056 Tea Tree Hollow	Rock bar	Baseline/impact site
23	SW-23 / 300076 Carters Creek	Rock bar	Baseline
24	SW-24 / 300075 Cow Creek	Rock bar	Baseline site

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SIMEC MINING

SURFACE WATER BASELINE MONITORING LOCATIONS

Tahmoor South Project
Environmental Impact Statement

FIGURE 11.13

Water Management System and Site Water Balance Report

A water management and site water balance report was prepared for the Project which describes:

- the existing water management system;
- the proposed changes to the site water management system for the Project;
- the results of a water balance model simulation of the proposed water management system over the life of the Project including;
  - water supply efficiency and site water reuse;
  - controlled releases and storage overflows; and
  - stored water volume in underground water storage.
- the adequacy of the current discharge licence to Tea Tree Hollow to manage the release of water as per the EPL; and
- the risk of overflows under a wide range of climatic conditions.

Flooding Assessment

A flood study was conducted to assess the likelihood and scale of flooding as a result of the proposed development. This assessment involved:

- hydrological modelling using the RORB modelling software to simulate flood hydrographs for the Project Area;
- hydraulic modelling using the 2D hydrodynamic model Tuflow4TM to estimate affected areas;
- hydrologic and hydraulic modelling to predict flood levels for flood events up to the Probable Maximum Flood (PMF) level in areas affected by mine subsidence before and after mining. The effects of subsidence on flooding within the Project Area has been assessed during 50%, 10%, 1% (1:100), 0.5% (1:200), 0.2% (1:500) Annual Exceedance Probability (AEP) flood events and a Probable Maximum Flood (PMF) event; and
- identifying where flooding risks would change as a result of subsidence, and an assessment of the likely effects of subsidence on surface stormwater management infrastructure in the urban areas of the Bargo township.

Surface Water Impact Assessment

The surface water baseline monitoring data, subsidence predictions undertaken by MSEC (**Appendix F**) and the groundwater assessment undertaken by HydroSimulations (**Appendix I**), were used to assess the extent to which the proposed development could impact on surface water catchments and watercourses within the Project Area. The assessment investigated potential impacts to flow rate, changes to the hydraulic characteristics and associated impacts to the physical stability of the watercourses, and impacts to the water quality characteristics of watercourses.

Thirlmere Lakes

A discussion of the assessment of potential surface water impacts to the Thirlmere Lakes is provided separately in **Section 11.5**.

11.4.3 Existing Environment

Regional Catchments and Watercourses

The existing Tahmoor Mine and the Project Area are located within the Bargo River catchment. From its headwaters near the townships of Hill Top and Yerrinbool, the Bargo River flows in a generally north-easterly direction through incised valleys and gorges to its confluence with the Nepean River, near the Pheasants Nest Weir. The lower 4 km of the river pass through the Bargo River Gorge, which is characterised by steep rock faces up to 110 m high. The river consists of a sequence of pools, glides and rock bars across sandstone bedrock, with occasional boulder fields and cobblestone riffles. The Bargo River drains a total catchment of some 130 square kilometres (km^2) at its confluence with the Nepean River, which has a catchment area of approximately 710 km^2 at this point.

The Bargo River has intermittent flow in its upstream reaches. In its upper reaches flows are, to some degree, regulated by the Picton Weir which is located approximately 14 km upstream of the Nepean River confluence. Downstream of the Tahmoor Mine pit top (i.e. downstream of the Tea Tree Hollow confluence) flow is perennial due to persistent licensed discharges from Tahmoor Mine. The Bargo River flows into the Nepean River 9 km downstream of the Tea Tree Hollow confluence.

The Nepean River rises in the Great Dividing Range to the west of the Project Area. Its headwaters also lie in the coastal ranges to the east of the Project Area. Flows in the upper reaches of the Nepean River are highly regulated by the Upper Nepean Water Supply Scheme, operated by WaterNSW, which incorporates four major water supply dams on the Cataract, Cordeaux, Avon and Nepean Rivers. The Nepean Dam is situated some 18 km upstream of the Bargo River confluence, while the Pheasant's Nest Weir is located approximately 7 km upstream of the confluence. Flows in the Nepean River near and downstream of the Project Area (downstream of the Peasant's Nest Weir) are not part of a WaterNSW Drinking Water Catchment Area.

The Nepean River flows into the Warragamba River near Wallacia, downstream of which it is referred to as the Hawkesbury-Nepean River. The Hawkesbury- Nepean catchment is one of the largest coastal catchments in NSW with an area of some 21,400 km^2 at its mouth in Broken Bay on the northern side of the Sydney Metropolitan area.

The Project Area is also within and adjacent to the Sydney Drinking Water Catchment, with major drinking water catchments in the areas to the east, surrounding Lake Nepean, Lake Avon, Lake Cordeaux and Lake Cataract located within the MSA. Notably, the Project Area is downstream of these areas, mostly within the Bargo catchment and contributing to the Nepean Catchments downstream of the MSA. Importantly, no longwall panels, nor surface infrastructure, are proposed in the MSA. The proposed development has been specifically designed to avoid extending longwall panels into the MSA as described in **Section 5.3.7** and **Section 6.2.4**.

Water Sharing Plan

DIP – Water implements water regulation according to the *Water Management Act 2000*. A primary objective is the sustainable management and use of water resources, balancing environmental, social and economic considerations. Water Sharing Plans (WSPs) have been developed for much of the State and these establish rules for sharing and trading water between the environment town water supplies, basic landholder rights and commercial uses. The Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011 (the WSP) is the relevant plan for surface waters for the proposed development.

The proposed development would involve continued use of water for coal processing within the existing facilities at Tahmoor, and for the control of dust emissions from the REA. The water used in these operations is sourced from the underground operations and from water captured within the existing site water management system – principally at the coal handling and REA areas. Some water is also supplied under agreement with Sydney Water. None of these activities involve extraction of water or water sharing from sources covered by the WSP.

Project Area Catchments and Watercourses

The watercourses and catchment within and adjacent to the Project Area are described by HEC 2018, as follows:

- the Project Area is predominantly drained by Tea Tree Hollow and Dog Trap Creek which flow generally north and eastward toward the Bargo River;
- a small area on the south western side of the proposed longwall panels is drained by headwater tributaries of Hornes Creek which flows into the Bargo River at Picton Weir;
- the eastern portion of the Project Area is predominantly drained by Eliza Creek which flows generally northward to the Nepean River;
- a small part of the eastern portion of the Project Area is also drained by Carters Creek which flows north-eastward to the Nepean River; and
- Cow Creek, which is within the MSA, lies to the east of the Project Area and is a tributary of the Nepean River upstream of Pheasant's Nest Weir.

A summary of watercourses within the Project Area is provided in **Table 11-22** and are shown in **Figure 11.6**. As part of the baseline monitoring program for the proposed development, surface water monitoring locations were established at a number of stream locations both upstream of the proposed development (control sites) and at locations that would be directly undermined by the proposed development as shown on **Figure 11.13** and described in **Table 11-21**.

Table 11-22 Watercourses within the project Area

Watercourse	Strahler Stream Order	Description in relation to proposed longwalls
Nepean River	7th order	River is not located within the SSA.
Bargo River	5th order	River would not be directly mined beneath and is located 975m from the nearest longwall (LW102). Only a 165 metres long length of the Bargo River that is immediately upstream from the Picton Weir is located inside the SSA. This length of the river that is within the SSA is a 4th order perennial stream.
Hornes Creek	4th Order	Not directly mined beneath and located 360 metres south-west of proposed LW108.
Carters Creek	3rd order	Creek is not located within the SSA.
Cow Creek	3rd order	Creek is not located within the SSA.
Dry Creek	3rd order	Creek is not located within the SSA.
Dog Trap Creek	3rd Order	Located directly above proposed LW101 to LW109, with a total length of 3.1 kilometres directly mined beneath.
Tea Tree Hollow	3rd order	Located directly above proposed LW101 to LW105, with a total length of 1.9 kilometres directly mined beneath.
Tributary to Tea Tree Hollow	3rd Order	Located directly above the proposed LW101 to LW106, with a total length of 2.4 kilometres directly mined beneath
Eliza Creek	2nd order	Creek is not located within the SSA.
Sugarloaf Gully	2nd order	Creek is not located within the SSA.
Tributary 1 to Dog Trap Creek	2nd order	Located directly above the proposed LW101 to LW107, with a total length of 2.6 kilometres directly mined beneath
Tributary 2 to Dog Trap Creek	2nd order	Located directly above the proposed LW101 to LW107, with a total length of 2.4 kilometres directly mined beneath

Catchment modelling of surface water based on baseline data was undertaken to simulate surface runoff and baseflow processes which are discussed below. A description of the fluvial geomorphology for each stream is contained within **Appendix H**, and was relied upon for the modelling and assessment.

Analysis of rainfall data found that on average, annual rainfall is highest (940 mm/annum) in the south eastern part of the Project Area and reduces further north and west to about 850 mm/annum near the existing surface facilities and 790 mm in Thirlmere. The average annual rainfall yield (percent of average annual catchment rainfall) was consistent for most streams (between 11 and 18%) in the Project Area. However, flow volumes and velocities were variable based on stream geomorphology. The results of surface water catchment modelling are summarised below.

Within the SSA

- Bargo River (upstream) is a consistently high flow stream (23.9 ML per day);
- Dog Trap Creek is a stream with moderate flow (4.95 ML per day), and flow is highly variable. Flow velocity is high due to the relatively steep bed gradient (max velocity 3.3m/s). However, lower velocities occur in the upper reaches of the creek where the channel is flatter; and
- Tea Tree Hollow is a stream with consistently moderate flow (6.3 ML per day) due to the release of water in accordance with EPL 1389 from Tahmoor Mine. In the absence of mine discharge via LDP1, Tea Tree Hollow would consist of an ephemeral creek environment, flowing only after rainfall. Flow velocity is high due to the relatively steep bed gradient (maximum velocity of 3.5m/s). However, lower velocities occur in the upper reaches of the creek where the channel is flatter.

Outside of the SSA

- Carters Creek is a stream with very low flow (0.44 ML per day), and flow is highly variable. Flow velocities are generally low in the upper reaches and increase downstream with steeper bed gradient (maximum velocity of 2.1m/s);
- Cow Creek is a stream with consistently low flow (1.19 ML per day). Flow velocity is generally high due to the steep confined channel geometry (max velocity 4 m/s); and
- Eliza Creek is a stream with consistently low flow (0.95 ML per day). Flow velocities are generally low in the upper reaches (less than 0.5m/s) and increase downstream (max velocity 2.5m/s).

Increased shear bed stress is usually associated with higher relative velocities and therefore for most watercourses occurs in the upper reaches of streams.

Water quality parameters were monitored at each of the monitoring locations identified in **Table 11-21**. The monitoring locations are broadly representative of three categories:

- sites undermined/affected by existing Tahmoor Mine operations and likely to be impacted by Tahmoor South:
  - SW-13 – Bargo River upstream of Tea Tree Hollow,
  - SW-14 – Bargo River Rockford Bridge downstream of Tea Tree Hollow,
  - SW-15 – Dog Trap Creek downstream, and
  - SW-22 – Tea Tree Hollow.
- sites not undermined/affected by existing Tahmoor Mine operations and likely to be affected by Tahmoor South Project:
  - SW-16 – Dog Trap Creek upstream
  - SW-21 – Nepean River Maldon Weir,
- sites unlikely to be impacted (control or baseline sites):
  - SW-1 – Bargo River upper reaches,
  - SW-9 – Hornes Creek,
  - SW-18 – Eliza Creek,
  - SW-20A – Dry Creek,
  - SW-23 – Carters Creek, and
  - SW-24 – Cow Creek.

Exceedances of ANZECC (2000) guideline values for aquatic ecosystems and recreational users were recorded at the various monitoring sites as summarised in **Table 11-23**.

The results of the water quality monitoring indicate that:

- all monitored watercourses recorded samples with elevated levels of aluminium, zinc, cadmium and iron and of pH outside of the water quality range. Observations of water quality data over the monitoring period indicated variability of water quality in watercourses that span the majority of the Project Area (HEC, 2018);
- the two sites downstream of the Tahmoor Mine licensed discharge point LDP 1 (SW-22 Tea Tree Hollow and SW-14 Bargo River Rockford Bridge) displayed similar water quality profiles including elevated levels of bicarbonate, sodium and barium which was not identified at other locations; and
- with the exception of the two locations directly downstream of licensed discharge point LDP 1, the water quality at creeks affected by subsidence from Tahmoor Mine (SW-13, SW-15) remained broadly similar to the water quality of un-impacted creeks including baseline/ reference sites upstream, both in terms of the range and incidence of exceedances of water quality parameters. This indicates that in terms of mining processes, discharge water from LDP1 is a key controlling factor of water quality for the affected streams.

Table 11-23 Number of recorded exceedances of ANZECC 2000 guidelines at water quality monitoring locations

Monitoring Location	pH		Aluminium (milligrams per litre (mg/L))		Zinc (mg/L)		Copper (mg/L)		Cadmium (mg/L)		Iron (mg/L)		Selenium (mg/L)		Lead (mg/L)		Arsenic (mg/L)	
	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2	ANZECC 1	ANZECC 2
Sites undermined/affected by existing Tahmoor Mine operations and likely to be impacted by Tahmoor South																		
SW-13 Bargo River (upstream of SW-22)[a]	11		23	14	35	-	5	-	6	6	-	15	-	-	1	-	1	1
SW-14 Bargo River Rockford Bridge (down-stream of SW-22)[b]	31	-	32	13	35	-	14	-	6	6	-	8	21	21	4	-	20	13
SW-15 Dog Trap Creek downstream[c]	2	-	25	23	22	-	6	-	1	1	-	7	-	-	-	-	-	-
SW-22 Tea Tree Hollow[b,c]	28	-	23	6	26	-	20	-	7	7	-	1	26	26	8	-	26	23
Sites not undermined/affected by existing Tahmoor Mine operations but likely to be affected by Tahmoor South Project operations																		
SW-16 Dog Trap Creek upstream[c]	5	-	34	32	31	-	9	-	3	3	-	9	-	-	-	-	-	-
SW21 Nepean River Maldon Weir[c]	10	-	23	11	30	-	8	-	6	5	-	4	1	1	4	-	1	-
Sites unlikely to be impacted (control or reference sites)																		
SW-1 Bargo River upper reaches	13	-	15	5	14	-	-	-	7	6	-	27	1	1	-	-	-	-
SW-9 Hornes Creek[c]	16		30	17	37	-	8	-	5	4	-	16	4	4	-	-	-	-
SW-18 Eliza Creek[c]	14	-	13	12	34	-	17	-	7	7	-	29	10	10	4	-	-	-
SW-20A Dry Creek[c]	9	-	27	18	27	-	9	-	2	2	-	4	-	-	2	-	-	-
SW-23 Carters Creek[c]	5	-	29	19	29	-	9	-	1	1	-	3	-	-	-	-	-	-
SW-24 Cow Creek	10	-	29	19	20	-	3	-	2	2	-	3	-	-	-	-	-	-

ANZECC[1] – ANZECC Aquatic Ecosystems Guideline Value
ANZECC[2] – ANZECC Recreational User Guideline Value
[a] SW-13 also recorded single exceedances of ANZECC[2] values for barium (mg/L) and mercury (mg/L)
[b] SW-22 and SW-14 also recorded exceedances of ANZECC[2] values for bicarbonate alkalinity ($CaCO_3$ mg/L), sodium (mg/L) and barium (mg/L). SW-22 further recorded exceedances of ANZECC[1] values for electrical conductivity (micro siemens per centimetre (µS/cm))
[c] These monitoring locations also recorded exceedances of ANZECC[1] and/ or ANZECC[2] values for Turbidity (NTU)

Existing Tahmoor Mine

A summary of the existing water management system at Tahmoor Mine, including an overview of the existing surface water demand, water discharge, surface water infrastructure and water storage structures, is provided in **Section 3.3.6**. Existing approvals held by Tahmoor Coal under the *Water Management Act 2000* are discussed in **Section 8.0** and the existing discharges and water management for the Tahmoor Mine are outlined in the water balance presented in **Section 11.4.5**.

Surface water discharge from the Tahmoor Mine is licenced under Environmental Protection Licence (EPL) 1389, which limits discharge volumes at LDP1 to 15.5 ML per day and places the following 100th Percentile concentration limits for discharge water quality:

- pH: 6.5-9.0
- Electrical conductivity (EC) (µS/cm): 2600
- Arsenic (microgram per litre (µg/L)): 200
- Nickel (µg/L): 200
- Zinc (µg/L): 300
- Turbidity (NTU): 150
- Total Suspended Solids (mg/L): 30
- Oil and grease (mg/L): 10

A series of PRPs aimed at managing water quality have been implemented at Tahmoor Mine since 2005. **Table 11-24** below provides a summary of current and completed PRPs relevant to managing water quality at the existing Tahmoor Mine.

Surface water discharge from licensed discharge point (LDP1) is monitored monthly for the water quality criteria listed under EPL 1398. Tahmoor has demonstrated a significant reduction in historical non-compliances with EPL water conditions, with the performance improvement attributed to the implementation of the water management PRPs outlined in **Table 11-24**. Surface water monitoring in 2017 indicated that existing surface water discharges at Tahmoor Mine are compliant with the volumetric discharge limit and discharge water quality criteria for LDP1 under EPL 1389.

Table 11-24 PRPs relevant to managing water quality at the existing Tahmoor Mine

PRP No.	Year completed	Description
5 7	2005	These two PRPs investigated: • Improving the quality of mine water discharged into the Bargo River catchment; • Increasing the re-use of mine water and minimising the use of potable water in mine operations; and • Reducing pollutant loads discharged from the site.
10	2006	Implementation of a pilot scale water treatment plant to test the effectiveness in meeting the water quality goals for discharges from LPD1.
11	2006	To implement improvements to surface water management resulting from investigations made in PRP 7, and subsequent additional investigations into improving discharge water quality at LOPs 3, 4 and 5.
15	2011	Construction of the Stormwater Improvement Project.
20	2012	Construction of the Water Recycling Plant.
21	2013	Consolidation of Mine discharges into LDP1.

PRP No.	Year completed	Description
22	Ongoing	Development and commissioning of a water treatment plant to reduce the concentrations of arsenic, nickel and zinc in mine water released from LDP1. The WWTP was constructed in June 2015 to treat up to 6 ML/d of mine water to achieve the following metal concentration limits: • Arsenic: 0.013 mg/L • Nickel: 0.011 mg/L • Zinc: 0.008 mg/L The WWTP was constructed at Tahmoor Underground Mine in June 2015 as part of PRP22 to improve the quality of water discharged from LDP1. Following modifications, detailed commissioning of the WWTP occurred during September to November 2018. PRP22 on EPL 1389 for the WWTP has been extended until November 2018.
23	2016	Research and investigation program in Tea Tree Hollow and the Bargo River to define site specific trigger values for electrical conductivity at LDP1. This investigation was completed and did not recommend any changes to existing discharge licence limits to EC/ salinity and is further discussed in **Section 11.7.4** (Aquatic Ecology).
26	Ongoing	An aquatic health assessment in Tea Tree Hollow and the Bargo River within nine months following WWTP recommissioning to determine any changes to aquatic health (refer **Section 11.7.5**).

11.4.4 Impact Assessment

Subsidence Predictions

Subsidence predictions for watercourses within the SSA were determined by MSEC (2018) and are provided in **Table 11-25**.

Table 11-25 Maximum Predicted Total Subsidence, Upsidence and Closure for Watercourses within the Subsidence Study Area

Watercourse	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Bargo River	<20	<20	<20
Dog Trap Creek	1850*	550*	425*
Hornes Creek	50	30	50
Tea Tree Hollow	1400*	400*	275*
Tributary 1 to Dog Trap Creek	1850	750	725
Tributary 2 to Dog Trap Creek	1800	525	450
Tributary to Tea Tree Hollow	1700	475	400

* Note: downstream sections of Dog Trap Creek and Tea Tree Hollow have been previously mined beneath by LW12 and LW13 and by LW1 and LW2, respectively, at Tahmoor Mine. The maximum predicted parameters provided in the above table include those resulting from the extraction of these earlier longwalls.

Watercourses that lie directly over the longwalls (Dog Trap Creek and Tea Tree Hollow) are predicted to experience a greater range of subsidence impacts. Impacts to stream bed grade are likely to occur as a result of tilt and curvature. MSEC (2018) predicted that changes in stream bed grade would be typically less than one percent of the existing grade. The predicted maximum increase in stream bed grade is 1.2 %, which is considered relatively small compared to the natural gradients.

Based on the previous experience at Tahmoor Mine, it is likely that fracturing and surface flow diversions would occur in the sandstone bedrock along the streams, particularly for streams that are located directly above the proposed longwalls (MSEC, 2018). Potential impacts to watercourses are further discussed below.

Impacts to Watercourses

Overview

Potential impacts to surface waters are likely to occur as a result of mining induced subsidence from the proposed development and surface water discharges from the expansion and operation of the REA and the Surface Facilities Area. These include:

- impacts to flow rate or the quantity of flow, which can occur as a result of flow diversion or loss;
- changes to the hydraulic characteristics and associated impacts to the physical stability of the watercourses, which can occur as a result of shear stress and changes to the stream bed; and
- impacts to the water quality characteristics of watercourses, which can occur as a result of changes to or increasing in scour, mine discharge and/or gas release.

The impacts are discussed further below. These potential impacts may also have indirect implications for hydrological and other values such as landscape, heritage or ecological values (such as riparian land). These matters have been addressed in other sections of this EIS (Refer **Sections 11.6** to **Section 11.9**). Measures to manage potential impacts to watercourses caused by subsidence are outlined in **Section 11.1.7**.

Impacts to Flow

Impacts to flow in watercourses have the potential to occur due to:

- reduced flows due to reduction in catchment size;
- loss of flow to subsidence induced fracturing;
- loss of flow to baseflow reduction;
- reduced flows due to trapping runoff in subsidence depressions; and
- increased flows due to controlled discharges and overflows from the water management system.

The potential for each of these to occur as a result of the proposed development are discussed below.

Reduced flow is likely to occur in areas immediately impacted by the expansion of the REA. This is as a result of reduction of the catchment in this location, in particular sections of the Tea Tree Hollow and Bargo River catchments. In contrast, increased flow is likely to be experienced for Tea Tree Hollow and Bargo River immediately downstream of the REA, as a result of increases in controlled discharge via LDP1 (although within the current discharge limits of the licence). This would offset the reductions to catchment area associated with the REA expansion from the proposed development.

Localised reduced flow is likely to be experienced by watercourses due to subsidence induced fracturing. Cracking is likely to occur along stream beds and there is potential for some diversion of surface water and drainage of pools at some locations. Considering the predicted subsidence and upsidence for watercourses, it is considered that Tea Tree Hollow and Dog Trap Creek are at greatest risk of impacts resulting in losses of surface water to groundwater and localised diversion of surface water, including reduced water holding capacity of pools, decreased frequency of overflow and loss of interconnection between pools. Based on MSEC (2018) observations relating to valley closure impacts on rock-bar controlled pools in watercourses, the surface water impact assessment identified a number of pools that would be at risk of flow holding capacity impacts, as follows:

- two of the approximately 14 mapped pools in Tea Tree Hollow were identified to be at moderate risk; and
- 14 of the over 70 mapped pools in Dog Trap Creek were identified to be at moderate to high risk.

Baseflow reduction 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 reducing the rate at which baseflow occurs.

HydroSimulations (2018) have made predictions of baseflow reductions for local and regional streams including Bargo River, Tea Tree Hollow and Dog Trap Creek. The maximum predicted reduction in flow at each watercourse is relatively small in terms of mean daily flow (0.4-5.3%) but represents a significant percentage of the average estimated baseflow at Dog Trap Creek (52.5%) and a small to moderate percentage at the Bargo River (4.2%) and Tea Tree Hollow (3.1%). The reduction in flow in Tea Tree Hollow (downstream) would be offset by on-going licensed discharge from LDP1. It is expected that reduction in baseflow would be most noticeable during periods of low flow which would normally be dominated by baseflow. The surface water impact assessment identified the following potential effects to low flows as a result of baseflow reductions:

- Bargo River – the probability that flow would be greater than 0.1 ML/day would reduce from 99% to 97% of days, which is considered imperceptible compared to natural variability and therefore negligible;
- Dog Trap Creek – the probability that flow would be greater than 0.1 ML/day would reduce from 87% to 45% of days, which is considered to be distinguishable from natural variability and therefore significant; and
- Tea Tree Hollow – downstream impacts would be offset by discharge from LDP1 and therefore negligible. However, upstream impacts are likely to be similar to Dog Trap Creek given the similarity of catchments and therefore detectable and significant during periods of low flow.

Therefore, perceptible impacts to flow are only predicted to occur in Dog Trap Creek and upstream of LDP1 in Tea Tree Hollow. It is unlikely that there would be any net loss of water from the catchment overall since any redirected flow is unlikely to intercept any flow path that would allow the water to be diverted into deeper strata.

Pool water and low flow levels at Tea Tree Hollow and Dog Trap Creek would be monitored prior to and during mining to confirm any mining related impacts and formulate appropriate remediation where required (refer **Section 11.4.6**). Measures to remediate subsidence impacted watercourses are outlined **Section 11.1.7**.

Impacts to Watercourse Hydraulics and Stability

Modelled scenarios for impacts to flow velocity and shear bed stress are presented in **Appendix J**. The findings identified that for all watercourses peak flow velocities decrease in some areas and increase in others. Generally watercourses demonstrated no significant changes to pattern or distribution in shear bed stresses. However, localised increases in bed shear stress were identified in isolated sections of Dog Trap Creek and Tea Tree Hollow. Changes to flow velocity and bed shear stress have the potential to cause localised increased erosion, depending on the specific nature of the bed materials. Suggested management and mitigation measures are provided in **Section 11.4.6**.

The potential for increased scouring in streams as a result of the proposed development would not be significant, as the maximum increase in bed grade would be 1.2% (MSEC, 2018) which is relatively small compared to natural gradients. Localised changes in ponding are anticipated to be minor, also due to the minimal changes to stream bed grade predicted (up to a maximum of 1.2%).

Stream stability can be indirectly impacted by loss of vegetation resulting from subsidence induced fracturing and changes to groundwater drainage. However, previous experience at Tahmoor Mine and the Southern Coalfields has not reported such impacts to date with no significant changes to riparian vegetation observed along waterways within areas subjected to subsidence. It is considered that riparian vegetation associated with streams overlying the Project Area is unlikely to be sensitive to minor changes in drainage patterns. Refer **Sections 11.6 and 11.7** for further assessment of riparian and aquatic ecology impacts.

Impacts to Water Quality

Potential impacts to water quality can occur as a result of:

- discharge or spill of contaminants from mine infrastructure, including the pit top, to watercourses;
- liberation of contaminants from subsidence induced fracturing in watercourses;
- changes to chemical composition of surface flows due to increased or decreased groundwater baseflow contribution to watercourses; and
- drainage and expression of strata gas through surface water.

The results of predictive modelling of the proposed water management system over the remaining mine life indicate that total discharges from the pit top of the combined existing Tahmoor operation and the Project are unlikely to increase above current LDP1 volume limits. It is therefore expected that the Project would not result in additional water quality impacts due to releases and overflows from the site water management system compared to the existing situation. The upgraded WWTP would control heavy metal concentrations from LDP1 for the proposed development and would continue to meet licensed water quality limits.

Accidental spills could also occur which could result in transient impacts to water quality. The risk of accidental spills is not likely to increase as a result of the Project and would be managed as part of the site EMS, as it is now.

Subsidence fracturing of bed rock is predicted to occur and upsidence related buckling of stream beds is predicted along some sections of creeks. Based on past experience in the Southern Coalfields, including experience at the existing Tahmoor operation, it is expected that upsidence induced fracturing may lead to releases of aluminium, iron, manganese and zinc (HEC, 2018). It is likely that there may be transient, localised spikes in metal concentrations at Tea Tree Hollow, Dog Trap Creek and downstream watercourses, while subsidence is active. The extent of these impacts is expected to be similar to impacts observed in similar streams in the Southern Coalfields (refer to **Appendix J** for further information).

Measures to manage potential subsidence fracturing are outlined in **Section 11.4.6** and **Section 11.1.7** including measures to actively fill fractures in the subsurface fracture network with introduced material to accelerate the natural remediation process.

While there have been some occurrences of gas release within the Southern Coalfields, studies have shown that gas flows do not impact water quality due to the low solubility of methane and the short residence time in the water column. However, there have been rare instances reported of vegetation die back which could impact stream stability. This is unlikely to occur for the proposed development and is further assessed in **Section 11.6**.

Neutral or Beneficial Effects (NorBE)

Under the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011* all development in the Sydney drinking water catchment is required to demonstrate a NorBE on water quality. The Project would involve mining adjacent to but not beneath the MSA. Longwall panels for the Project have been specifically reduced in length so that they do not extend into the MSA. Cow Creek is located within the MSA and was included in the impact assessment; however this watercourse would not be impacted by the Project and is located outside of the project SSA. Therefore the Project would not trigger NorBE requirements.

Cow Creek, which is located within the MSA is located approximately one km from the nearest Project longwall. At this distance, the maximum predicted subsidence upsidence and closure are less than 20 mm and the potential for localised impacts on Cow Creek, such as fracturing and surface water flow diversion, are at extremely low levels.

It is therefore highly unlikely that there would be any identifiable water quality impacts to flow in Cow Creek as longwall mining is sufficiently remote from the creek, meaning that the potential for fracturing is extremely low. In the unlikely event that fracturing was to occur, it would not result in a detectable change to water quality in Cow Creek. This is consistent with the definition of a neutral effect on water quality (“no identifiable potential impact”) in accordance with guidelines published by NSW Water (2015) for assessing compliance with NorBE criteria of a development on water quality.

Cumulative Impacts

There has been significant past development in both the immediate and downstream catchment areas of the Project Area, including widespread agricultural and urban development. Cumulative effects of this previous development are inherently incorporated into the baseline monitoring results of surface water resources for the Tahmoor South Project.

HydroSimulations (2018) has assessed cumulative impacts to baseflow capture due to the combined effects of the proposed development and the effects of other existing mining operations, primarily Tahmoor North.

In general, the predicted maximum cumulative baseflow capture rates are similar to the maximum baseflow capture rates due to the Project alone. The largest predicted increases in baseflow capture rates are at Dog Trap Creek and the Bargo River.

At Dog Trap Creek, the probability of flows being greater than 0.01 ML/day would reduce from 87% to 45% of days as a result of baseflow reductions from the project alone and down to 43% of days as a result of cumulative baseflow reductions. The negligible additional impact under the cumulative scenario indicates that the Tahmoor South Project (proposed to directly undermine up to 3.1 km of Dog Trap Creek) would have the most influence on this watercourse in contrast to the existing operations (Tahmoor North) where the longwalls extend to the north and west further away from this creek.

At Bargo River, the probability of flows being greater than 0.01 ML/day would reduce from 99% to 97% of days as a result of base flow reductions from the project alone and down to 90% of days as a result of cumulative base flow reductions. The lesser influence of the Tahmoor South Project in comparison to the cumulative scenario is reflective of the Tahmoor South workings progressing away from the Bargo River. The existing operations impose a stronger influence (although still relatively small) on the Bargo River due to its closer proximity. It is noted that this level of change would not be detectable during normal periods of low flow and would likely be indistinguishable from natural variability in catchment conditions.

Flooding

Flooding of Catchments

The flood study (**Appendix J**) identified that the upper reaches of catchments are more likely to be susceptible to flood inundation due to the flatter terrain and low capacity drainage channels in these areas. The effect of culverts and other constructed constrictions in the more urbanised upland areas also have the potential to increase the extent of flooding in these areas. Flooding in the lower reaches is confined by steep, incised channel geometry (HEC, 2018).

The flood study modelled peak flood inundation under pre-subsidence and post-subsidence conditions to determine if the proposed development is likely to increase flooding. The results are shown in **Appendix J** and summarised in **Table 11-26** below. Localised increases of inundation during flood events are predicted for Tea Tree Hollow (upstream) at Remembrance Driveway near Caloola Road which is near an urbanised area in the Bargo township. Drainage enhancement works, including provision of additional drainage culverts or pipes are proposed under Remembrance Drive, to reduce the impacts associated with the predicted increased flood inundation at this location.

Negligible changes to flooding are predicted at other locations. Notably, changes to peak flood inundation were considered to be minor or negligible for these catchments.

Table 11- 26 Predicted Effects of Subsidence on increasing flood inundation

Watercourse		1% AEP Flood Event	50% AEP Flood Event
Dog Trap Creek	Upstream (Southern)	Increases to inundation confined to small areas on the edges of the floodplains overlying longwalls 106 and 107. Flood inundation increases are close to the resolution of the model i.e. +/- 3m.	Impacts would be less than the larger 1% AEP event and inundation increases confined to the same areas as the 1% AEP event.
	Downstream (Northern)	No detectable increase in inundation and no new areas inundated. Flooding contained within the main channel.	No detectable increase in inundation and no new areas inundated. Flooding contained within the main channel.
Tea Tree Hollow	Upstream (Southern)	The effects of subsidence would increase areas subject to flood inundation on the western side of Remembrance Driveway, with the largest increase in the area overlying longwall 103. Drainage enhancement works, including provision of additional drainage culverts or pipes under Remembrance Driveway, are proposed to reduce the impacts associated with the predicted increased flood inundation at this location.	The predicted effects of subsidence on increasing flood inundation are minor and at the limit of the model resolution.
	Downstream (Northern)	No detectable increase in inundation. Flooding contained within the main channel.	No detectable increase in inundation. Flooding contained within the main channel.

Localised Flooding in Bargo

Consideration of the potential for subsidence to increase local flooding in Bargo focused on the location of overland flow paths in the township. This was based on identifying where overland flow paths intersect the gate roads between longwall panels, which would form relatively elevated areas in the post subsidence topography (for example areas over remaining pillars which would not subside relative to areas directly over the goaf) and potentially increase local flooding. Overland flow path locations identified in the flood study are presented in **Appendix J** and the outcomes of the flood assessment are summarised in **Table 11-27**.

The results show that flooding is unlikely to be increased in the Bargo Township as a result of the proposed development, with the exception of minor localised flooding at Dymond Road and Wattle Street. This flooding extent would not impact surrounding residential developments. Given the minor nature of predicted flood impacts the project would have no impact on existing flood emergency management procedures (such as evacuation and emergency services procedures and notifications).

Table 11-27 Potentially affected overland flow paths in Bargo Township

Location	Predicted flood risk
Overland Flow Path 1 – Wellers Road	The average slope of overland flow path in the area is predicted to reduce from about 2.8% to 2.2% due to predicted subsidence. This slope change would result in about a 10% increase in normal flow depth, equivalent to the effect of natural vegetation changes (such as the length of grass) on flow depth. Predicted change in slope represents minor change in gradient and flow depth and is unlikely to pose a significant risk of increased flooding outside the immediate timbered area.
Overland Flow Path 2 – Hambridge Road	The average slope of overland flow path in the area is predicted to reduce from about 5.6 to 5.4% due to predicted subsidence. This slope change would result in about a 2% increase in normal flow depth, which is considered to be negligible. Due to the small upslope catchment size the risk of significant overland flow and flooding is minor. Predicted change in slope would result in negligible changes to flow depth.
Overland Flow Path 3 – Remembrance Driveway	The average slope of overland flow path in the area is predicted to reduce from about 8.9 to 8.8% due to predicted subsidence. This slope change would result in about a 2.3% increase in normal flow depth, which is considered to be negligible. Due to the small upslope catchment size, the risk of significant overland flow and flooding is low. Predicted change in slope would result in negligible changes to flow depth.
Overland Flow Path 4 – Hawthorne Road	The average slope of overland flow path in the area is predicted to reduce from about 3.3% to 3.1% due to predicted subsidence. This slope change would result in about a 3.6% increase in normal flow depth, which is minor and less than the effect of natural vegetation changes on flow depth. Predicted change in slope represents a relatively small change in gradient and flow depth and is unlikely to pose a significant risk of increased flooding outside the immediate open area.
Overland Flow Path 5 - Bargo Road	The average slope of overland flow path in the area is predicted to reduce from about 3.2 to 3% due to predicted subsidence. This slope change would result in about a 4% increase in normal flow depth, which is minor and less than the effect of natural vegetation changes on flow depth. Due to the small upslope catchment size, the risk of significant overland flow and flooding is low. Predicted change in slope represents a relatively small change in gradient and flow depth and is unlikely to pose a significant risk of increased flooding outside the immediate open area.
Overland Flow Path 6 – Wellers Road and Hogans Drive	The average slope of overland flow path in the area is predicted to reduce from about 2.6 to 2.2% due to predicted subsidence. This slope change would result in about a 7.4% increase in normal flow depth, which is small and less than the effect of natural vegetation changes on flow depth. Predicted change in slope represents a relatively minor change in gradient and flow depth and is unlikely to pose a significant risk of increased flooding outside the immediate treed area.
Overland Flow Path 7 - Hogans Drive	The average slope of overland flow path in the area is predicted to reduce from about 4.8 to 4.3% due to predicted subsidence. This slope change would result in about a 5% increase in normal flow depth, which is small. Predicted change in slope represents a relatively minor change in gradient and flow depth and given the extensive open area and relatively elevated level of the surrounding area, the changes are considered unlikely to pose a significant risk of increased flooding outside the immediate open area.

Location	Predicted flood risk
Overland Flow Path 8 - Great Southern Road	The average slope of overland flow path in the area is predicted to reduce from about 4.4 to 3.9% due to predicted subsidence. This slope change would result in about a 5.5% increase in normal flow depth, which is small. The predicted change in slope is minor and is unlikely to pose a significant risk of increased flooding outside the immediate area.
Overland Flow Path 9 – Hawthorne Road	The average slope of overland flow path in the area is predicted to reduce from about 3 to 2.5% due to predicted subsidence. This slope change would result in about an 8% increase in normal flow depth, which is comparable to the effect of natural vegetation changes on flow depth. Predicted change in slope represents a relatively small change in gradient and flow depth and is unlikely to pose a significant risk of increased flooding outside the immediate open area.
Overland Flow Path 10 – Dymond Road and Wattle Street	The average slope of overland flow path in the area is predicted to reduce from about 1.6 to 1% due to predicted subsidence. Predicted change in slope would result in an approximate 19% increase in normal flow depth. As a result minor localised flooding may occur in the immediate open area. However, it is unlikely to increase flooding within the surrounding developed areas.
Overland Flow Path 11 – Dymond Road	The average slope of overland flow path in the area is predicted to reduce from about 2.5 to 2.1% due to predicted subsidence. This slope change would result in about a 7.8% increase in normal flow depth, which is small. Predicted change in slope represents a relatively minor change in gradient and flow depth and is unlikely to pose a significant risk of increased flooding outside the immediate area.

11.4.5 Water Balance

Existing Water Management System

The existing water management system for Tahmoor Mine involves management of the following site components:

- Surface Facilities Area;
- ventilation shaft sites;
- REA; and
- underground mine workings.

The existing management water system is shown in **Figure 3.4**, **Figure 3.5** and **Figure 3.6.**

Discharge Points

There is one licensed discharge point for controlled releases (LDP1). The REA has three sedimentation ponds which overflow at three licensed overflow discharge points (LOP 3, 4 and 5) from the existing Tahmoor Mine as shown on **Figure 3.4**, **Figure 3.5** and **Figure 3.6**. All discharge points release water into Tea Tree Hollow.

Proposed Water Management System

Tahmoor Coal has an existing water management system which effectively manages water in accordance with the EPL. This system would continue to be used with minor modifications as described below to allow for the proposed development:

- development and expansion of the stormwater drainage management and runoff control for the planned staged expansion of the REA, including:
  - the construction and commissioning of Dam S11 and S12 at the start of the Project. Water from dams S11 and S12 would be pumped (via open drains) to dam S9. Any overflow from dam S11 would flow into the Bargo River and any overflow from Dam S12 would flow into Tea Tree Hollow; and

  - the decommissioning of Dam S7, S7a, S7b, S8 and S10 which would either be covered with rejects within the expanded REA or left to overflow passively to Tea Tree Hollow.

- upgrading of existing water supply and water reticulation infrastructure to handle increased coal throughput and coal handling facilities;
- changes to underground mine water supply and mine dewatering reticulation needed to service the Tahmoor South operations;
- development of an underground storage within goafed areas of the Tahmoor North underground, in order to store water pumped from sediment dam M3 at times when inflow to dam M3 is in excess of the WWTP capacity. At times of lower inflow, water could be recovered from the underground storage, treated within the WWTP and released via LDP1. The underground storage would be formed within the void space of the mined longwall panels up to and including LW30. A storage capacity of 4,751 ML has been estimated within this area. Water would be pumped into and out of the storage via the existing drift and no new surface infrastructure is envisaged outside the pit top area; and
- upgrade of the sewage treatment plant at the pit top to treat sewage on site for additional proposed bathhouses.

A schematic of the proposed water management system is provided in **Figure 11.14**.

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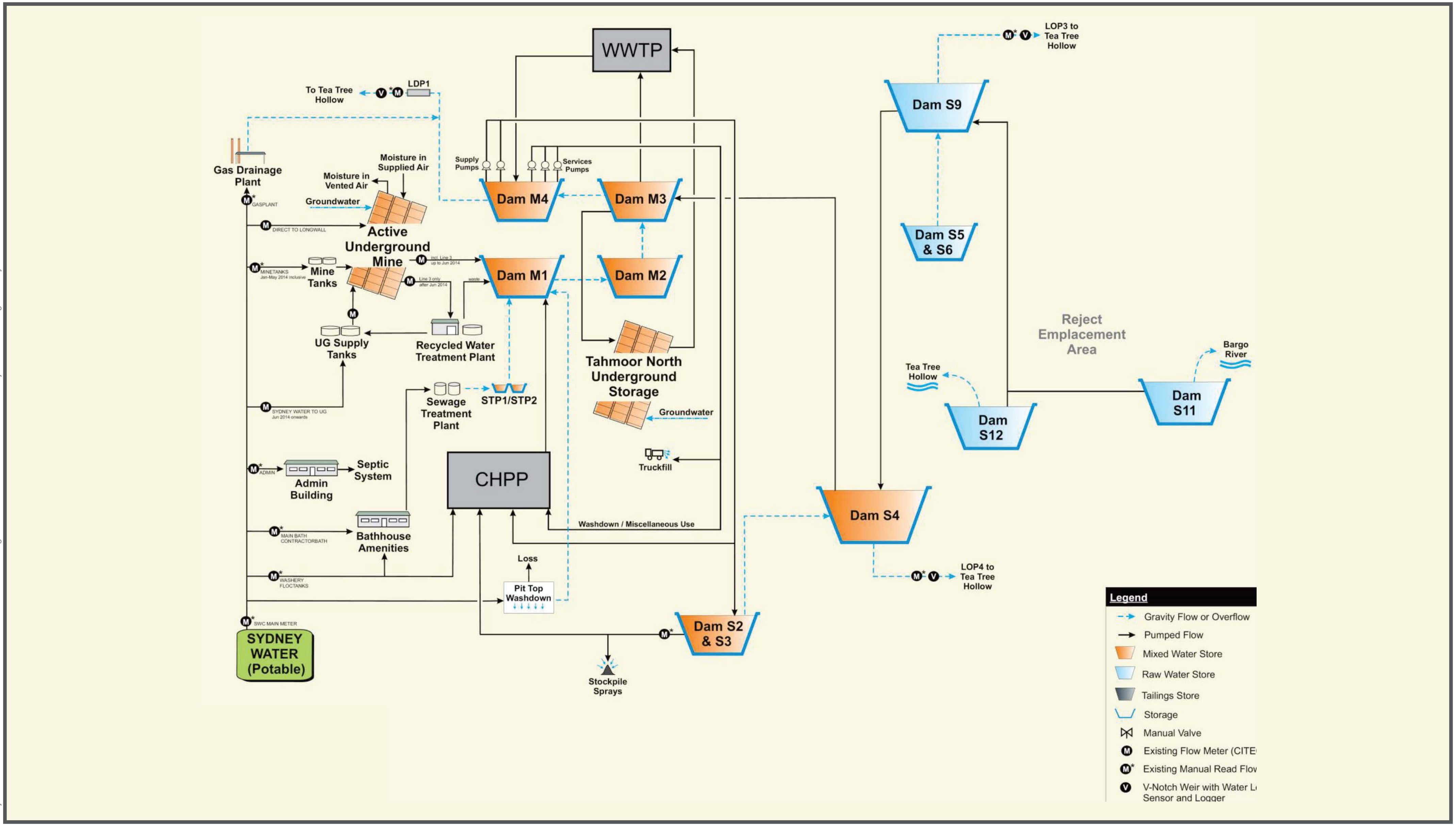

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SIMEC MINING

SCHEMATIC OF PROJECT WATER MANAGEMENT SYSTEM

Tahmoor South Project

Environmental Impact Statement

Source: Hydro Engineering & Consulting (2018)

FIGURE 11.14

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Site Water Balance

Inputs and Outputs

The major inputs and outputs of water into the site water cycle are detailed in **Table 11-28**.

Table 11-28 Simulated average water balance (over project life) (HEC, 2018)

Source	ML per annum	% of Total flow
Inflows		
Runoff	373	14
Sydney Water Supply (for use in CHPP flocculation, CHPP make-up water, pit top washdown, surface amenities, gas drainage plan, underground mine use)	485	18
Groundwater inflow to underground mine	1,693	63
Ventilation moisture (in)	136	5
Total inflows	2,687	100
Outflows		
Evaporation	56	2
Discharge via LDP1	2,135	82
Discharge via LOPs	58	2
CHPP make-up water supply	76	3
Haul road dust suppression	11	<1
Stockpile sprays (dust suppression)	26	1
Pit top washdown water	14	1
Ventilation moisture (out)	224	9
Totals outflows	2,600	100

Performance

In assessing performance of water management on site, consideration was given to the following:

- the average water balance which provides an overall (i.e. high level) understanding of the magnitude of different components of the water balance;
- water supply efficiency - the capacity of the water management system to satisfy the various water demands from recycling and reuse of water on site; and
- capacity to contain water on site and capacity to manage off-site releases within conditions of the EPL.

The objective of water supply management at Tahmoor Mine is to minimise the reliance on Sydney Water for supply and enable greater re-use.

Existing operations incorporate water efficiency measures to minimise water import requirements from Sydney Water and these measures would continue to be applied to the proposed development. The CHPP is a major water user at the mine; however a significant proportion of the water used is internally recycled via the use of a tailings belt filter press. Make-up water requirements for the CHPP are met by recycled water from dam M4 (in the first instance) with a small additional raw water demand for pump glands, flocculation and reagent dosing supplied by Sydney Water.

Water from dam M4 is also used for dust suppression on the haul road to the REA and on the REA itself. Water for dust suppression on the product coal stockpile area is drawn from dams S2/S3.

The underground mining operation currently uses water for non-potable uses (dust suppression on the coal face, drilling, wash down and other miscellaneous) and potable use (in the longwall machine), which is supplied by Sydney Water. A Recycled Water Treatment Plant was constructed in 2012 to treat a proportion of the water recovered from the underground mine and to recycle it back underground for non-potable uses.

The water balance model concluded that a high level of water supply efficiency would be maintained for the proposed development by on site recycling with 55% of water demand for underground operations met by water recycled from the mine. A portion of water recovered from underground mining operations would continue to be treated in the Recycled Water Treatment Plant at the surface to be reused for non-potable underground mining purposes. The remainder of recovered mine water would be pumped to dam M1 as per existing practices. However, ongoing supply from Sydney Water would still be required to meet water supply requirements, which would account for approximately 18% of system inflows over the life of the proposed development.

While efforts are made to contain water on site, the water balance identified the on-going need for controlled releases of treated water to Tea Tree Hollow via LDP1 of around 2,200 ML per annum over the life of the Project. Simulated releases were all compliant with EPL daily volumetric release limits. Other offsite releases included overflows from sediment dams predicted by the model, including:

- overflow releases to Tea Tree Hollow (LPD1) via the LOPs are predicted to occur during higher rainfall climatic conditions. The maximum annual simulated overflow from all Tea Tree Hollow overflow points was 325 ML; and
- small overflows from dam S11 to the Bargo River during higher rainfall climatic conditions. The maximum simulated annual overflow was 116ML per annum.

The 6 ML/day capacity WWTP (refer to **Section 3.3.6**), in combination with the proposed 4,751 ML capacity underground water storage, would be adequate to ensure continued treatment of water discharged via LDP1 at least until 2031. Thereafter a WWTP capacity upgrade of between 1.5 to 3 ML/day is likely be required, depending on actual conditions experienced. The WWTP can be scaled to process up to 9 ML/day if required.

11.4.6 Management and Mitigation Measures

The following mitigations and management measures would be implemented for the various stages of the proposed development.

Risk Management Zones

Refer to **Section 11.2.5** for discussion regarding RMZs.

Baseline Monitoring

The existing network of streamflow monitoring (gauging stations) and water quality monitoring sites would be maintained. In addition:

- an additional gauging station would be installed on Tea Tree Hollow at a suitable location downstream of the predicted subsidence impact zone and upstream of the LDP 1. The station would be established at least 2 years prior to commencement of longwall mining in the central domain; and
- the gauging station at Dog Trap Creek (downstream) (SW-15) would be incorporated with enhanced low flow control weirs in order to reliably record low flows. In addition a new gauging station (which would also include a low flow weir) would be established upstream of LDP1 at Tea Tree Hollow.

A continuous pool water level monitoring network would be established. The network would be established prior to commencement of longwall mining at Tahmoor South and include the following sites:

- Dog Trap Creek; and
- Tea Tree Hollow.

Flood Remediation Measures

The flood assessment concluded that an upgrade of the capacity of the Remembrance Driveway culvert crossing of Tea Tree Hollow near Caloola Road would be required. Details of this would be included in the Extraction Plan for the proposed development. Tahmoor Mine has previously successfully upgraded culvert and flood drainage infrastructure around road and rail infrastructure.

Operational Monitoring

Prior to the commencement of longwall mining in each domain, an adaptive monitoring and management plan would be developed as part of the Extraction Plan and in consultation with the relevant authorities and infrastructure owners. The following surface water elements would be incorporated into the plan:

- action response triggers for water quality exceedances based on recommended approaches in ANZECC (2000) and in particular schemes which incorporate both baseline and control monitoring data;
- action response trigger for unexpected flow loss based on analysis of baseline (i.e. pre-subsidence) streamflow data, post-subsidence streamflow data and contemporaneous data from control sites. Catchment flow modelling would also be used in the analysis;
- action response trigger for unexpected loss of pool water holding capacity based on analysis of baseline (i.e. pre-subsidence) pool water level data, post-subsidence pool water level data and contemporaneous data from control pool sites. Pool water balance modelling would also be used in the analysis particularly during unusual climatic/hydrological conditions;
- periodic inspections, photographic reconnaissance and field based water quality monitoring in watercourse(s) when longwall mining is within 200 m of any watercourse, at sites upstream and downstream of the potentially affected area. Water quality samples would be collected and analysed monthly and if weekly field monitoring results indicate a change from background (e.g. exceedance of 80th percentile value). Results of monitoring would be analysed in relation to action response triggers on a monthly basis when longwall mining is within 200 m of a watercourse; and
- a monitoring program to monitor the erosional stability and nature of bed and banks in the areas identified by HEC, 2018 as likely to experience significant increase in bed shear. In the event of scour /instability which exceeds that observed at control sites, develop and implement a restoration plan specific to the location and the bed and bank material.

Site Water Management

The Water Management System and Site Water Balance Report indicated that the proposed water management system would have capacity to contain water on site and capacity to manage off-site releases within conditions of the EPL 1389 until at least 2031.

The performance of the water management system would be assessed by comparing the monitored water balance with water balance model predictions. Revision to the water management plan would be undertaken if the performance review indicates the water management system has, or is likely to be, unable to meet its regulatory performance requirements. The water management plan revision would document the measures to be implemented and their effectiveness in meeting regulatory requirements.

In order to maintain treatment of water to be discharged via LDP1, it is anticipated that the capacity of the WWTP would need to be upgraded at some stage after 2031. The WWTP would be upgraded as required to meet mine water treatment demand post 2031 to ensure that licence discharge limits at LDP1 are met.

PRP 22 - Mine Water Treatment Plant – upgrade of the waste water treatment plant to reduce the concentrations of arsenic, nickel and zinc in mine water released from LDP1. PRP 22 is scheduled to be completed during November 2018.

Post Mining Monitoring

Monitoring of streamflow, pool water levels and water quality would continue in accordance with the Extraction Plan following cessation of longwall subsidence related movement in a watercourse or following completion of any stream/pool remediation. Monitoring data would be reviewed at annual intervals over this period. Reviews would involve assessment against long term performance objectives which would be based on the pre-mine baseline conditions or an approved departure from these.

Contingency Measures

Potential contingency measures in the event of unforeseen impacts or impacts in excess of those predicted would include:

- the conduct of additional monitoring (e.g. increase in monitoring frequency or additional sampling) to inform the proposed contingency measures;
- the implementation of stream remediation measures to reduce the extent and effect of subsidence fracturing;
- the implementation of revegetation measures to remediate impacts of vegetation loss due to subsidence;
- the provision of a suitable offset(s) to compensate for the reduction in the quantity of water resources/flow; and/or
- the implementation of adaptive management measures – e.g. reducing the thickness of the coal seam extracted, narrowing of the longwall panels and/or increasing the setback of the longwalls from the affected area.

11.4.7 Conclusion

The surface water assessment considered baseline monitoring data to inform the identification and assessment of potential impacts.

Subsidence predictions identified that watercourses that lie directly over the longwalls are exposed to a greater range of subsidence impacts than those that do not directly overly the longwalls. The maximum predicted reduction in baseflow due to subsidence for watercourses represents a significant percentage (52.5%) of the average estimated baseflow at Dog Trap Creek and a small to moderate percentage at the Bargo River (4.2%) and Tea Tree Hollow (3.1%). It is expected that reduction in baseflow would be most noticeable during periods of low flow which would normally be dominated by baseflow.

Management measures would include further monitoring during mining, remediation measures and post-mining monitoring programs. TARPs would be prepared for the proposed development, focusing on water quality exceedances, unexpected flow loss, and unexpected loss of pool water holding capacity. Over the past 13 years, PRPs have been effectively implemented by Tahmoor Coal to manage potential water quality impacts (refer to **Table 11-24**).

The assessment of flooding identified that minor localised increases of flooding are predicted at Tea Tree Hollow (upstream). Flood inundation upstream of the Remembrance Driveway culvert crossing of Tea Tree Hollow near Caloola Road could impact an urbanised area of Bargo Township, however the flood study has identified that subsidence related inundation increases would be minor at this location (compared to existing) and can be mitigated through improvements to culvert capacity. Flooding is unlikely to be increased in the Bargo Township as a result of changes to overland flow paths from the proposed development (refer **Appendix J**).

The water balance for the Project identified that a high level of water supply efficiency is provided by on site recycling. However, ongoing supply from Sydney Water is still required to meet water supply requirements. Controlled releases of treated water to Tea Tree Hollow via LDP1 would continue to be required for the proposed development.

11.5 Thirlmere Lakes

11.5.1 Background

The Thirlmere Lakes are located to the west of the existing Tahmoor Mine, in the upper reaches of Blue Gum Creek, which ultimately flows to Lake Burragorang (Warragamba Dam) – Sydney's main water supply storage. The Thirlmere Lakes lie within the Thirlmere Lakes National Park which is part of the Greater Blue Mountains World Heritage Area.

The Lakes are a series of five interconnected lakes including (in order of upstream to downstream):

- Lake Gandangarra;
- Lake Werri Berri;
- Lake Couridjah;
- Lake Baraba; and
- Lake Nerrigorang.

The Thirlmere Lakes are approximately 3.5 km from the proposed development at its nearest proposed longwalls. Given previous community concern about potential impacts to the Thirlmere Lakes as a result of nearby mining operations (see **Section 5.3**), a separate impact assessment of Thirlmere Lakes is provided in this chapter for the proposed development.

Thirlmere Lakes Inquiry

As described in **Section 5.3**, the Thirlmere Lakes Inquiry was undertaken in 2011 in response to community concern about water level decline in the Thirlmere Lakes.

The inquiry found that variations in climate such as droughts and floods were the primary influence on water level changes in Thirlmere Lakes; however identified that other factors may be involved in the present low levels. The Inquiry found evidence of groundwater leakages from the Lakes towards the east and north-east within the Hawkesbury Sandstone Aquifers and towards the west and down Blue Gum Creek. The Inquiry did not find any direct evidence of longwall mining impacting on lake water levels or breaching geologic containment structures underneath the lakes.

Consideration of Thirlmere Lakes During the Design of the Proposed Development

As described in **Section 5.3.7**, groundwater beneath Thirlmere Lakes was identified as a significant natural feature within the Project Area. Consideration of significant natural features informed the development of RMZ for the development of the proposed mine plan for the Project. The proposed development would involve longwall mining to the south east of the Bargo River and therefore away from the Thirlmere Lakes (located to the west of the Bargo River and 3-4 km away). The Thirlmere Lakes would not be undermined by the proposed development and are located outside of the development area, and well outside the area anticipated to experience mine subsidence as a result of the proposed development (the 20mm subsidence contour which remains to the east of the Bargo River).

Modifications undertaken to the mine plan to avoid or minimise impacts to other significant or sensitive items and natural features is outlined in **Section 6.2.4**.

11.5.2 Methodology

Potential impacts to the Thirlmere Lakes have been assessed throughout the technical assessments prepared for the proposed development including the:

- Groundwater Assessment prepared by HydroSimulations (2018) (**Appendix I**);
- Surface Water Baseline Study and Surface Water Impact Assessment prepared Hydro Engineering & Consulting Pty Ltd (2018) (**Appendix J**);
- Terrestrial Ecology Assessment prepared by Niche Environment and Heritage Pty Ltd (2018) (**Appendix K**); and
- Aquatic Ecology Assessment prepared by Niche Environment and Heritage Pty Ltd (2018) (**Appendix K**).

The methodology for the assessment of potential impacts to the Thirlmere Lakes is described below.

Groundwater and Surface Water

A groundwater assessment study area was established to encompass the geological and hydrological features that might be important to the proposed development and to the groundwater model built for the purpose of impact assessment. The assessment area included the Thirlmere Lakes.

Baseline monitoring of groundwater resources was undertaken in the vicinity of the proposed development to inform the groundwater model and to establish trigger response values for the ongoing monitoring and management of these resources during mining. Baseline monitoring included four DI Water monitoring bores at Thirlmere Lakes that monitor the shallow Hawkesbury Sandstone and/or alluvium.

Groundwater modelling was undertaken using MODFLOW-USG which allows finer grid scale to focus on sensitive areas such as the Thirlmere lakes. Refer to **Section 11.3.2** for further information regarding the groundwater model and methodology for the groundwater assessment.

A water balance model of the Thirlmere Lakes was developed in order to simulate the potential impacts of the Project on the behaviour of the Thirlmere Lakes as part of the Surface Water Impact Assessment (**Appendix J**). Surface water baseline monitoring data, subsidence predictions (**Appendix F**) and the outcomes of the Groundwater Assessment (**Appendix I**) were used in the Surface Water Impact Assessment to assess the extent to which the proposed development may impact on surface water catchments and watercourses, including the Thirlmere Lakes. The assessment included an investigation into whether impacts to lake water levels could occur as a result of the project.

Terrestrial and Aquatic Ecology

The Terrestrial Ecology Assessment and Aquatic Ecology Assessment considered the findings of the Groundwater Assessment and Surface Water Impact Assessment to predict the potential for impacts to terrestrial and aquatic ecology at the Thirlmere Lakes. The Thirlmere Lakes are located outside of the Project Area and would not be subject to surface disturbance and therefore detailed assessment of potential impacts to terrestrial ecology at the Thirlmere Lakes was not required.

11.5.3 Existing Environment

As described in **Section 11.5.1**, the Thirlmere Lakes are a series of five interconnected lakes located to the west of the existing Tahmoor Mine, in the upper reaches of Blue Gum Creek. The Thirlmere Lakes lie within the Thirlmere Lakes National Park which is part of the Greater Blue Mountains World Heritage Area.

The catchment of the Thirlmere Lakes is estimated at approximately five km^2 with the largest portion of the catchment comprised of Lake Gandangarra (39%). The total catchment area of the lakes is relatively small and therefore the volume of water in the lakes varies significantly with climate.

The surface geology within the catchment of Thirlmere Lakes is dominated by areas of Hawkesbury Sandstone which outcrop on the valley sides and ridges. There is significant topographic relief within the catchment of the Thirlmere Lakes. Surface elevations vary from approximately 350 m Australian Height Datum (AHD) to approximately 300 m AHD.

Catchment ground cover primarily comprises undisturbed eucalypt woodlands with some cleared land located along the eastern and north-western boundaries. The lakes generally comprise dense fringing vegetation around their perimeter around water level with sedges and grasses within the inundation area.

A significant depth (around up to 50 m) of alluvium has accumulated below the Thirlmere Lakes. Groundwater within this alluvium forms a perched system above the deeper water table within the bedrock. Alluvial groundwater is connected to the ponded water within the Lakes. Surface water – groundwater interactions within the Lakes and alluvial systems are an important component of the water balance of the Thirlmere Lakes. Perched groundwater within the alluvium recharges the deeper bedrock water table and the Thirlmere Lakes are therefore considered a naturally ‘losing’ system (whereby water outputs from evaporation/evapotranspiration and leakage to groundwater are greater than inputs from rainfall).

The water balance model determined that the most significant outflow component from the Thirlmere Lakes is evaporation/evapotranspiration, comprising approximately two-thirds of outflows. Groundwater recharge by contrast comprises approximately a quarter of outflows. The Project would only affect the groundwater recharge component.

The Thirlmere Lakes are listed as a High Priority GDE in the Water Sharing Plan (WSP) for the Metropolitan Groundwater Sources 2011, and specifically for the Sydney Basin – Nepean Groundwater Source. The dependence of the Thirlmere Lakes on groundwater has been investigated as part of the Thirlmere Lakes Inquiry and the Groundwater Assessment for the proposed development.

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.

As described above and in the Groundwater Assessment, leakage from streams to shallow aquifers is considered to be a significant groundwater recharge mechanism for the Thirlmere Lakes, which acts as a naturally 'losing' system. It is therefore considered that there is limited dependence on groundwater for the water levels and associated ecosystems of the Thirlmere Lakes.

11.5.4 Impact Assessment

Groundwater and Surface Water

The numerical groundwater model was used to generate estimates of drawdown in shallow groundwater beneath the Thirlmere Lakes for the proposed development. Estimates of drawdown impacts were then used to inform the predicted impacts on surface water features.

The groundwater drawdown estimates, as opposed to reductions in surface water level, expected to occur as a result of the proposed development are presented in **Table 11-29** for the Thirlmere Lakes.

Table 11-29 Proposed development groundwater drawdown at high priority GDEs

GDE		Predicted Maximum Drawdown (m)	Predicted time to water level recovery
Thirlmere Lakes	Gandangarra	0.02	150 years post-mining
	Werri Berri	0.01	
	Couridjah	0.03	
	Baraba	0.02	
	Nerrigorang	0.02	n/a

The estimates for groundwater drawdown expected to occur as a result of the proposed development and other mines (cumulative scenario) are presented in **Table 11-30** for the Thirlmere Lakes.

Table 11-30 Cumulative impacts - groundwater drawdown at high priority GDEs (HydroSimulations, 2018)

GDE		Predicted Maximum Drawdown (m)	Predicted time to water level recovery
Thirlmere Lakes	Gandangarra	0.05	150 years post-mining
	Werri Berri	0.03	
	Couridjah	0.05	
	Baraba	0.05	
	Nerrigorang	0.05	

Based on the baseflow reductions outlined above, potential impacts to Thirlmere Lakes were analysed in the Surface Impact Assessment Study prepared by HEC (2018).

The HEC (2018) assessment indicated a modelled 330 ML (or 2.6 ML/year average) increase in groundwater recharge as a result of the Project and a 107 ML (or 0.8 ML/year average) decrease in discharge to Blue Gum Creek (from Lake Nerrigorang). This level of change would be very small compared to natural variability in downstream catchment conditions, and in the context of the potential impacts on inflow to downstream Lake Burragorang (Warragamba Dam), it would be imperceptible. The predicted impacts are close to the limit of accuracy of the model.

Over the modelled 129 years, it is anticipated that water levels in the Thirlmere Lakes would decrease by between 0.01 m and 0.06 m on average. The predicted average number of weeks per decade that the Lakes would be without any discernible ponded water increases by between 3 and 5.2 weeks. These levels of change would be imperceptible and very small compared to natural variability and are therefore considered negligible.

As the groundwater assessment (HydroSimulations, 2018) indicates eventual recovery of water levels over time, it is anticipated that consequent impacts to surface water at Thirlmere Lakes would also decrease over time with the completion of mining.

Terrestrial and Aquatic Ecology

Based on the relatively imperceptible impacts to the Thirlmere Lakes identified in the Groundwater Assessment and Surface Water Impact Assessment it was determined that:

- it is highly unlikely that the terrestrial biodiversity values of the Thirlmere Lakes system would be impacted in a manner that would result in loss of vegetation and habitat, or die back of vegetation. Compared to natural variability, any change would be minor to negligible; and
- it is unlikely that the minor impacts to surface water and groundwater relative to natural variability would affect aquatic flora or fauna.

Summary of Aquifer Interference Policy Assessment

The implications of the predicted impacts of the proposed development on groundwater (including the Thirlmere Lakes) are summarised in **Table 11-19** of **Section 11.3** against the minimal impact considerations under the *NSW Aquifer Interference Policy*. 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 proposed development is classified as Level 2 within the minimal impact considerations of the *NSW Aquifer Interference Policy*. Impacts to groundwater are assessed in detail in **Section 11.3**.

11.5.5 Management and Mitigation Measures

The groundwater mitigation and monitoring measures outlined in **Section 11.3.5** would be implemented to manage and monitor the impacts of the proposed development including in relation to Thirlmere Lakes.

11.5.6 Conclusion

Based on available information, including the investigations undertaken as part of the Thirlmere Lakes Inquiry, the Thirlmere Lakes appear to act as a naturally ‘losing’ system under both dry and wet conditions. Therefore, there is limited dependence on groundwater for the water levels and associated ecosystems of the Thirlmere Lakes.

The water balance model determined that the most significant outflow component from the Thirlmere Lakes is evaporation/evapotranspiration, comprising approximately two-thirds of outflows. Groundwater recharge by contrast comprises approximately a quarter of outflows. The Project would only affect the groundwater recharge component, albeit to a minor extent.

It has been determined that the proposed development would have negligible groundwater and surface water impacts on the Thirlmere Lakes that would be comparable to levels of natural variability (i.e. changes to lake levels of 0.01 m and 0.06 m on average) and would be imperceptible in many circumstances. Potential impacts to terrestrial and aquatic ecology within the Thirlmere Lakes were also determined to be minor to negligible.

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