Chapter 13
Groundwater and geology

Contents

List of tables

List of figures

13 Groundwater and geology

This chapter summarises the groundwater assessment carried out for the upgrade of the Great Western Highway between Blackheath and Little Hartley (the project). The full groundwater assessment is provided in Appendix I (Technical report – Groundwater).

13.1 Assessment approach

13.1.1 Groundwater assessment

The groundwater assessment approach for the project included:

- identification of a study area comprising a five kilometre radius around the project
- characterisation of the existing environment including climate, topography, geology, groundwater resources including groundwater occurrence, recharge and discharge processes, quality and use, and groundwater dependent ecosystems (GDEs)
- review of previous assessments and previous tunnelling projects with similar geologies in NSW
- geotechnical field investigations including drilling, permeability testing, monitoring bore installation and water level and quality monitoring
- development of a conservative conceptual hydrogeological model and numerical groundwater model
- groundwater modelling to simulate the assumed tunnelling and construction activities for the project and predict groundwater tunnel inflows and drawdown extent
- assessment of potential groundwater-related construction and operational impacts
- development of mitigation measures for ongoing groundwater monitoring and to manage potential impacts and risks including recommendations for monitoring to validate mitigation measures as appropriate.

Geotechnical field investigations to establish baseline groundwater monitoring was carried out simultaneously with the preparation of this assessment and as a result not all monitoring data was available to inform this assessment. As groundwater data becomes available, this would be considered before construction of the project in an updated groundwater numerical model as discussed in Section 13.5. Baseline data used for the groundwater assessment is provided in Section 2.3 of Appendix I (Technical report – Groundwater).

Key assumptions have been made to inform the groundwater assessment including those relating to characterisation of the existing environment and monitoring and these are provided in Section 3 of Appendix I (Technical report – Groundwater).

13.1.2 Settlement (ground movement) assessment

A ground movement assessment has been carried out to identify infrastructure such as buildings (including heritage items), railways and utilities that may be affected by potential ground movement associated with the project. Ground movement refers to a localised lowering of the ground level typically associated with either:

- immediate settlement caused by tunnel excavation (during construction)
- settlement caused by groundwater drawdown (during construction and/or operation).

The settlement assessment methodology included:

- calculation of the zone of influence for settlement and identification of buildings located in areas where maximum settlement levels are exceeded (see Table 13-1)
- calculation of the maximum slope of ground and maximum settlement for the identified buildings. These values were compared against criteria specified in conditions of approval for recent large tunnel projects in NSW
- numerical modelling and structural assessment for those buildings that exceed the settlement criteria or have an assessed damage category that exceeds 'slight' (see Table 13-2).

Table 13-1 Settlement criteria (adopted from recent large tunnel projects in NSW)

Structure/facility	Maximum settlement	Maximum slope of ground
Buildings – one storey or non-sensitive properties such as carparks	30 mm	1:350
Buildings – high or sensitive properties such as heritage items	20 mm	1:500
Roads and parking areas	40 mm	1:250
Parks	50 mm	1:250

Table 13-2 Building damage category and corresponding tensile strain limits (Mair et al, 1996; Rankin, 1988)

Damage category	Description	Maximum building settlement	Maximum building slope
0	Negligible	<10 mm	<1:500
1	Very slight	10 mm	<1:500
2	Slight	50 mm	1:200
3	Moderate	75 mm	1:50
4-5	Severe to very severe	>75 mm	>1:50

13.2 Existing environment

13.2.1 Geology

The project would interact with geological formations from the Mid-Late Permian era (Shoalhaven Group and Illawarra Coal Measures) and Early-Mid Triassic era (Narrabeen Group). Geological formations around the project are described in Table 13-3 and shown in Figure 13-1 to Figure 13-3.

Table 13-3 Geological formations underlying the project

Geological formation	Description
Narrabeen Group – Banks Wall Sandstone	Up to 115 m thick and comprised of quartz-lithic sandstone, claystone and ironstone. Clearly visible as outcroppings and cliffs throughout the Blue Mountains.
Narrabeen Group – Mount York Claystone	Up to 13 m thick and comprised of claystones or claystones split by narrow sandstone layers.
Narrabeen Group – Burra-Moko Head Sandstone	Around 30-112 m thick and comprised of quartz-lithic sandstone with irregular pebbly bands and thin shales.
Narrabeen Group – Caley Formation	Around 27-43 m thick and comprised of siltstone, claystone, shale, and fine-grained sandstone.
Illawarra Coal Measures – Farmers Creek Formation and Gap Sandstone	Around 0.3-12 m thick and comprised of coal, claystone, sandstone, band chert and torbanite.
Illawarra Coal Measures – State Mine Creek Formation, Watts Sandstone, Denman Formation, Glen Davis Formation, Newnes Formation, Irondale Coal, Long Swamp Formation	Around 1.2-27 m thick and comprised of claystone, sandstone, siltstone and torbanite.
Illawarra Coal Measures – Lidsdale Coal, Blackmans Flat Formation, Lithgow Coal, Marrangaroo Formation	Around 0.9-16 m thick and comprised of coal, quartz-lithic sandstone and conglomerate.
Illawarra Coal Measures – Gundangaroo Formation, Coorongooba Creek Sandstone and Mount Marsden Claystone	Around 5-25 m thick and comprised of lithic sandstone, siltstone, shale, coal, torbanite, limestone, dolomite and claystone.
Shoalhaven Group – Berry Formation	Up to around 210 m thick, found in valleys and comprised of sandy, micaceous siltstone.

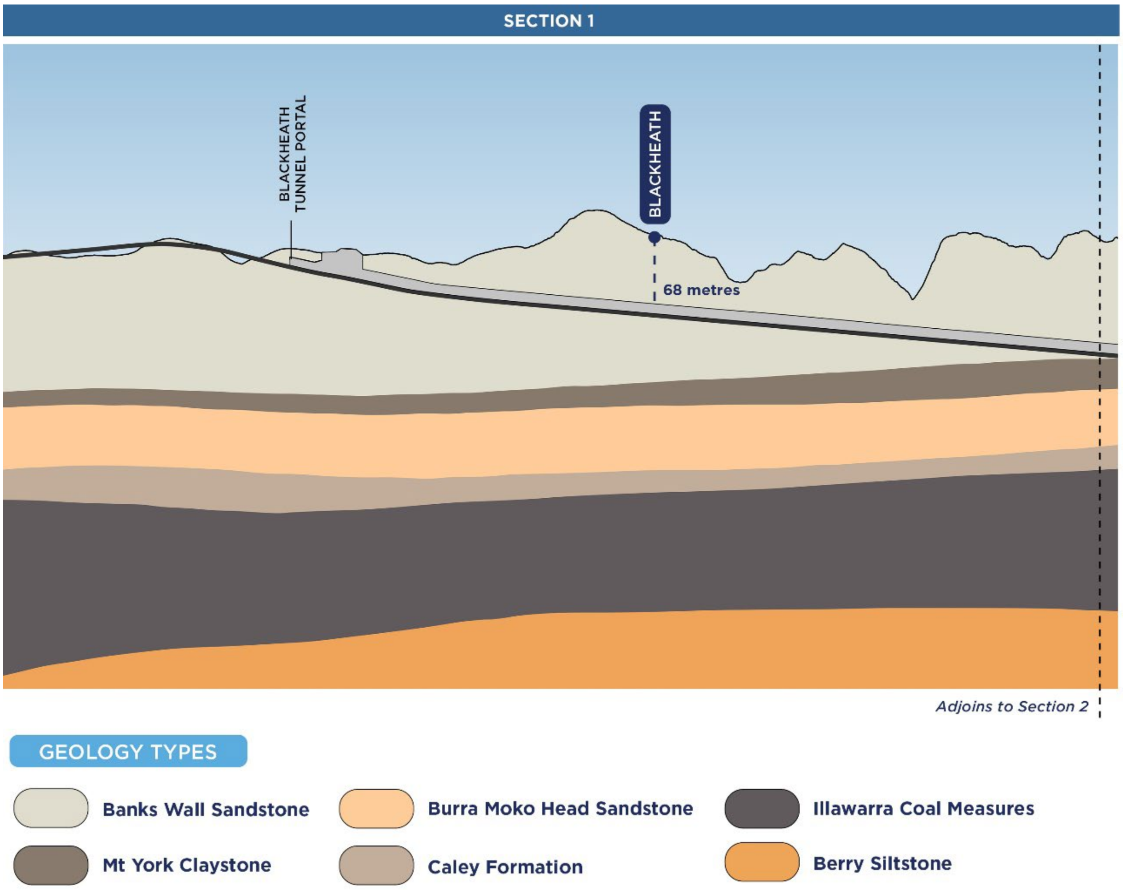

Figure 13-1 Indicative geological formations around the project (section 1 of 3)

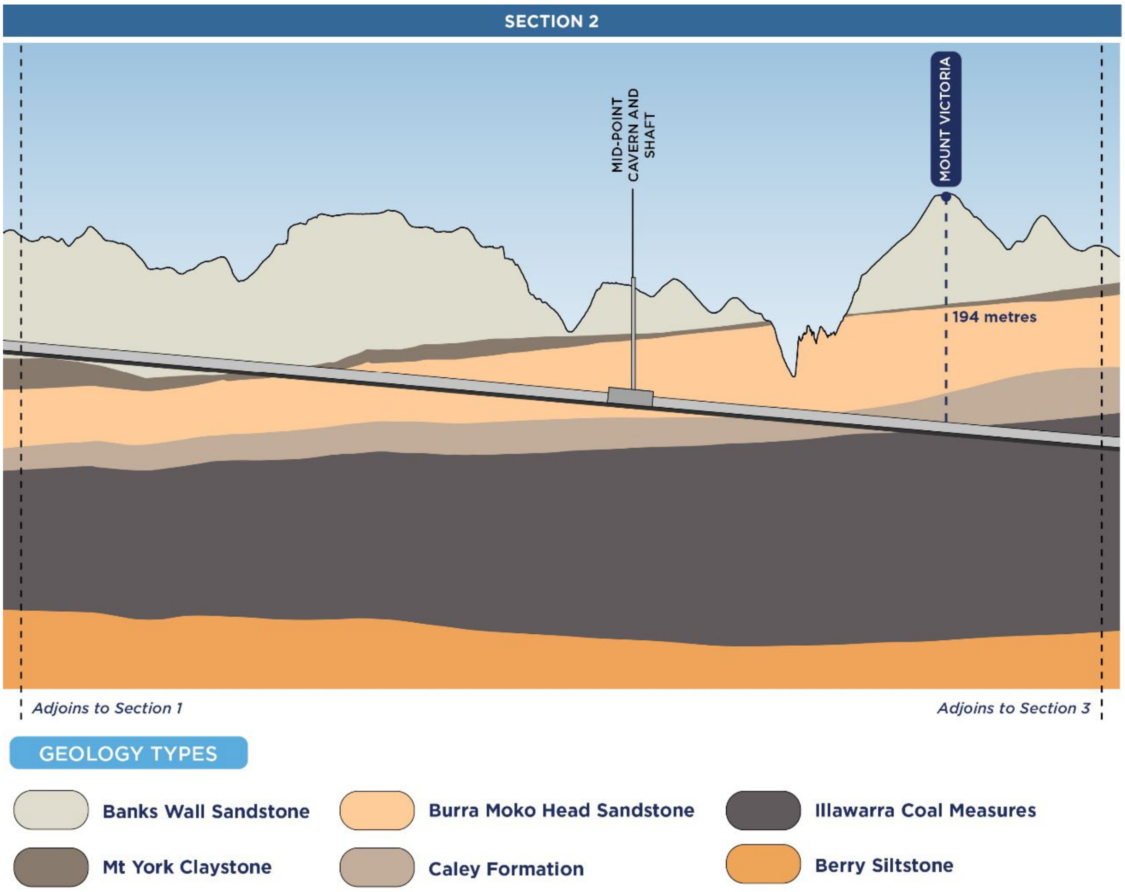

Figure 13-2 Indicative geological formations around the project (section 2 of 3)

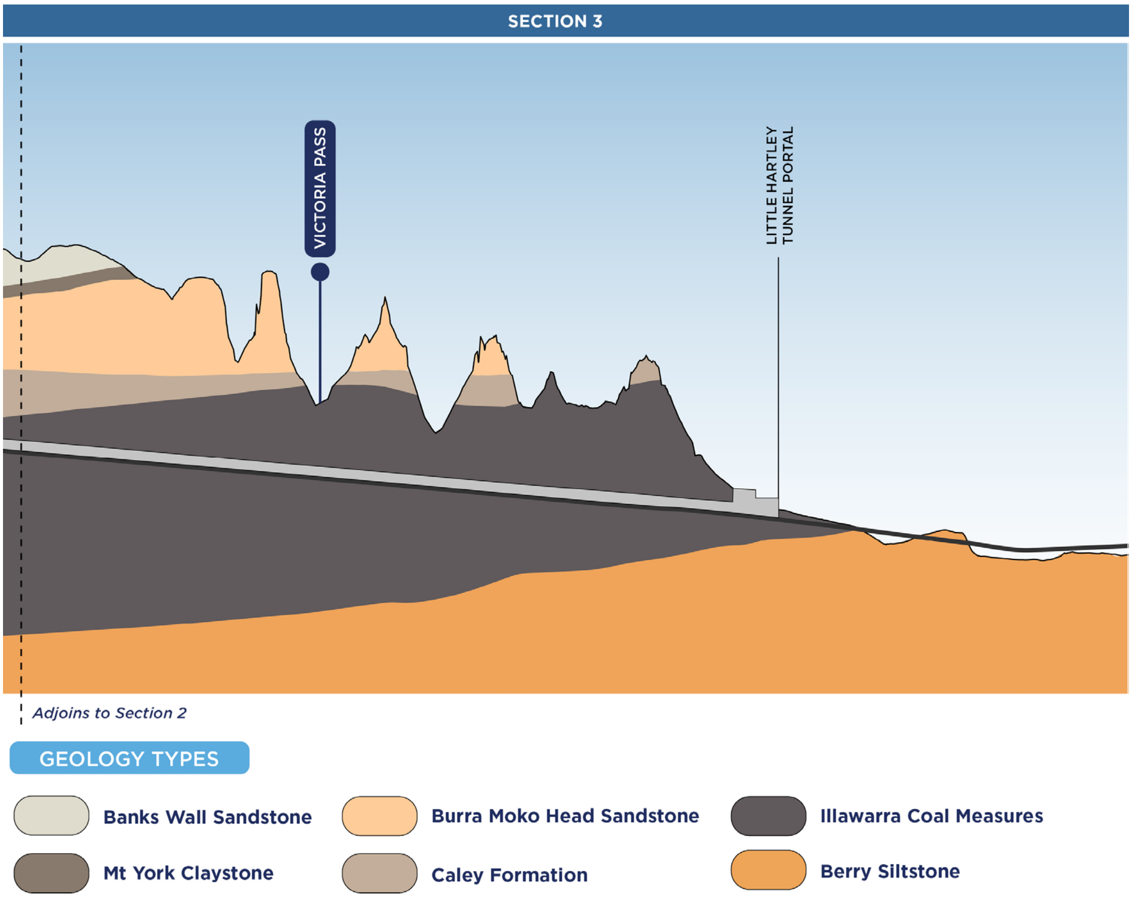

Figure 13-3 Indicative geological formations around the project (section 3 of 3)

Geological structural features

The dominant geological structures around the project include faults (fractures caused by movement of tectonic plates), joints (fractures caused by accumulation of soil and rock on top of existing units that, over time, causes rocks to break apart) and lineaments (linear features in the landscape as a result of an underlying geological structure such as a fault). These features are shown in Figure 13-4 and mainly comprise:

- faults at right angles trending north-northwest to east-northeast
- lineaments trending north to south and north-northeast to south-southwest.

Surface water flow is strongly influenced by these features, with many streams flowing north-northwest and some longer streams following the north-northeast, south-southwest structural features.

Coal seams

Coal seams within the Illawarra Coal Measures geological group may be present around the project. Coal seam gas is a natural gas found in coal deposits. Figure 13-1 to Figure 13-3 show where tunnelling activities for the project would intersect with the Illawarra Coal Measures geological group, which likely contains coal seams.

Acid sulfate rock

Acid sulfate rock (ASR) is unweathered rock (i.e. rock that has not been exposed to water, wind, ice, plants, or changes in temperatures) which contains metal sulfide minerals. When exposed to either oxygen or water, oxidation of the sulfide within the ASR leads to the formation of iron oxides, sulfuric acid, sulfates, and salts.

Potential ASR deposits have been identified around the western half of the project alignment within Illawarra Coal Measures and Shoalhaven geological formations, which are shown in Figure 13-1 to Figure 13-3.

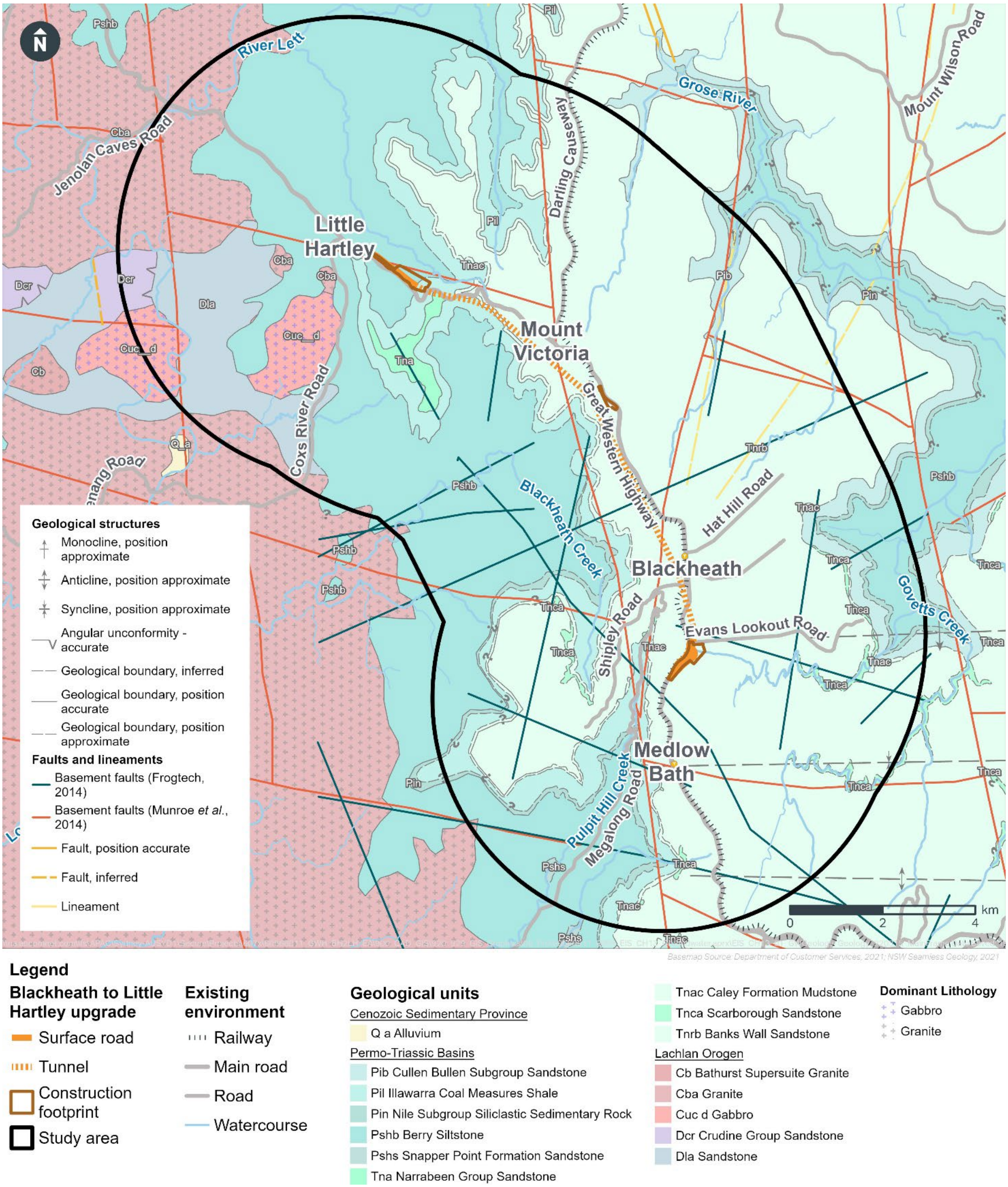

Figure 13-4 Geological structures and units near the project

13.2.2 Groundwater

Groundwater levels and movement

Groundwater near the project is divided into a shallow flow system in Banks Wall Sandstone and a deep flow system between the Mount York Claystone and the Berry Siltstone. In both aquifers, vertical groundwater flow is primarily controlled by structural features such as faults and joints, and horizontal groundwater flow is primarily controlled by topography.

In addition to these aquifers, perched aquifers have been identified near the project (see Figure 12-5 and Figure 12-6 in Chapter 12 (Biodiversity)). Perched aquifers occur when there are small areas of low permeability geological units within a higher permeability unit. The low permeability rock does not allow water to flow down to the natural water table, and groundwater is instead trapped.

The conceptualised groundwater recharge and discharge mechanisms of each aquifer system within the study area are outlined in Table 13-4. The simulated regional groundwater balance is included in Annexure B of Appendix I (Technical report – Groundwater).

The existing groundwater elevation (water table) around the project is shown in Figure 13-5.

Table 13-4 Groundwater recharge and discharge mechanisms

Groundwater system	Geological unit	Recharge mechanisms	Discharge mechanisms
Perched aquifer in unconsolidated sediment	Unconsolidated sediments and fill material	• primarily via seasonal rainfall infiltration • irrigation of land (Little Hartley only) • seepage from surface water drainage features • leakage from stormwater, water distribution and sewerage systems.	• discharge to surface water including swamps • leakage to the underlying shallow groundwater system • evapotranspiration.
Shallow groundwater flow system	Banks Wall Sandstone	• infiltration of rainfall where the unit outcrops • seepage of water from overlying perched groundwater systems • seepage of water from surface water storage dams (e.g. Lake Greaves at Blackheath) • seepage from surface water drainage features • leakage from stormwater, water distribution and sewerage systems.	• discharge to surface water flows and swamps either side of the plateau, with greater discharges expected to the swamps of the eastern escarpment • leakage to or through the underlying discontinuous Mount York Claystone aquitard or where missing leakage to other aquifers within the deep aquifer system • evapotranspiration • groundwater abstraction (licensed and unlicensed bores).

Groundwater system	Geological unit	Recharge mechanisms	Discharge mechanisms
Aquitard (i.e. low permeability geological unit)	Mount York Claystone	• infiltration of rainfall where the unit outcrops • vertical seepage of water from the overlying groundwater systems.	• facilitates horizontal flow (on top of unit) resulting in discharge to surface water flows and swamps either side of the plateau, with greater discharges expected to the swamps of the eastern escarpment • evapotranspiration (hanging swamps of the escarpments) • leakage to aquifers within the deep aquifer system.
Deep groundwater flow system	Burra-Moko Head Sandstone, Caley Formation, Illawarra Coal Measures	• infiltration of rainfall where geological units outcrop (mostly to the north and east of the project) • vertical seepage from the overlying groundwater systems • irrigation of land (Little Hartley only).	• discharge to surface water systems on either side of the plateau, with greater discharges expected to the eastern escarpment • leakage to aquifers within the deeper aquifer system • groundwater abstraction (licensed and unlicensed bores), most likely from the Burra-Moko Head Sandstone.

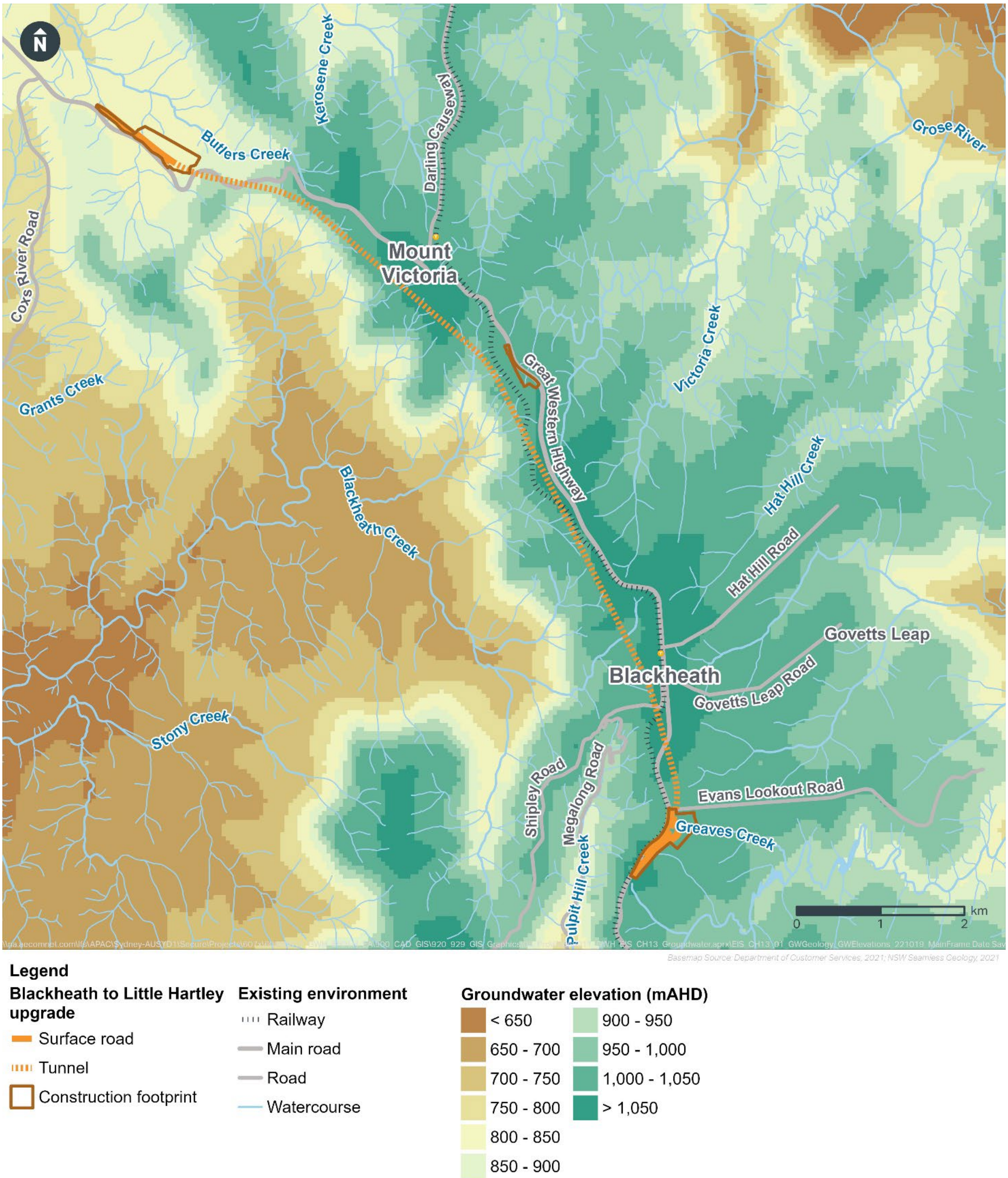

Figure 13-5 Simulated existing groundwater elevations (water table)

Groundwater quality

Groundwater investigations were completed in May and August 2011 for the Great Western Highway Little Hartley to Lithgow Upgrade (Mount Victoria to Lithgow Alliance, 2011). Groundwater quality was tested at 11 locations within the regions of Mount Victoria and Little Hartley with the results summarised in Table 13-5.

Table 13-5 Groundwater quality characteristics

Geological group	Total dissolved solids (mg/L)[1]	Salinity (µS/cm)[2]	pH	Manganese (mg/L)	Iron (mg/L)
Narrabeen Group	46-146	69-185	4.7-5.8	0.032-0.094	<0.05-0.07
Illawarra Coal Measures	80-711	114-1093	5.9-6.9	0.078-1.52	<0.05-6.93
Shoalhaven Group	400-3209	644-4088	5.1-7.4	0.183-1.88	0.34-40.6

Table notes:

1. mg/L = milligrams per litre
2. µS/cm = micro siemens per centimetre (a measure of electrical conductivity used as a proxy for measuring water salinity)

Shallow groundwater in the Narrabeen Group contains low salinity and low dissolved metal concentrations (hence likely recently recharged by rainfall and surface water infiltration) and is slightly acidic. Groundwater within the Illawarra Coal Measures is slightly less acidic but has a relatively high level of total dissolved solids. Groundwater samples taken for the Shoalhaven Group varied widely, however, all samples exceeded the Australian and New Zealand Environment and Conservation Council (ANZECC) guideline levels for salinity. Dissolved manganese concentrations in both Illawarra Coal Measures and Shoalhaven Group exceeded human health levels under the Australian Drinking Water Guidelines.

Areas of potential contamination that may affect groundwater underlying the project, including the potential for dissolved gases, are discussed in Chapter 15 (Soils and contamination).

Groundwater dependent ecosystems (GDEs)

GDEs are communities of plants and animals whose extent and life processes are dependent on groundwater, such as through wetlands or springs. An assessment of the project's potential impacts on GDEs, including groundwater-related biodiversity impacts, is provided in Chapter 12 (Biodiversity).

Groundwater users

Searches of WaterNSW and Bureau of Meteorology databases indicated that there are 112 registered groundwater bores located within the study area (Bureau of Meteorology, 2022; (WaterNSW, 2022). These bores are shown in Figure 13-6 and are generally used for:

- household water supply
- irrigation
- groundwater monitoring
- livestock water supply
- township water supply.

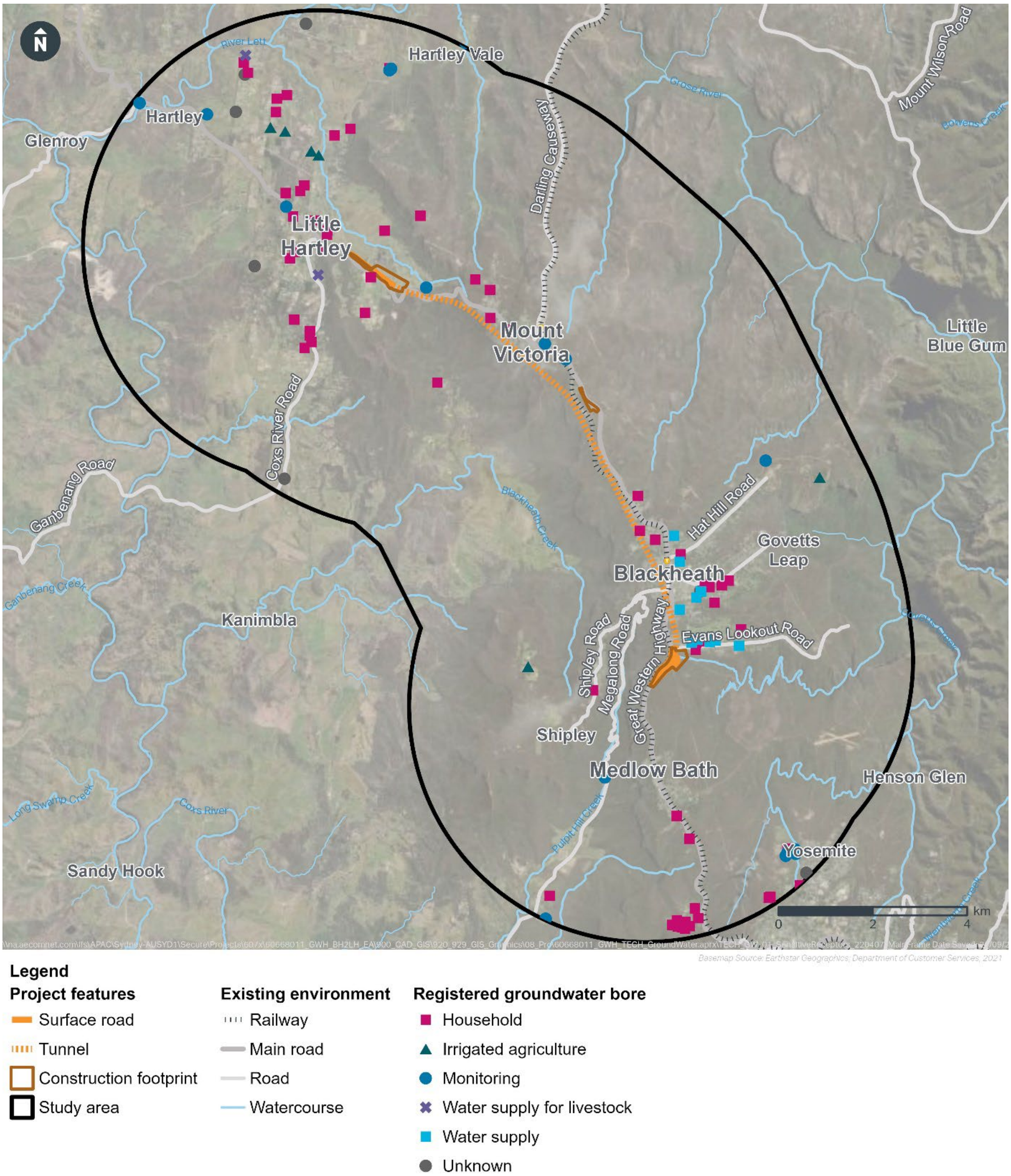

Figure 13-6 Registered groundwater users in the study area

13.3 Potential impacts – construction

During construction ground disturbing activities such as tunnelling are expected to have the largest influence on groundwater. A key design decision for the project is the use of tunnel boring machines (TBMs) rather than roadheaders for the mainline tunnels, which would minimise groundwater impacts through progressive lining of the tunnel (to immediately provide a waterproof barrier).

Temporary groundwater inflow and drawdown is expected to be greatest where the TBM is used in single shield mode (where there is a gap between the cutterheads and the tunnel lining installed, allowing groundwater ingress). A summary of groundwater impacts modelled to occur during construction is provided below. Further information on tunnelling methodologies is provided in Chapter 5 (Construction).

13.3.1 Tunnel groundwater inflow

Groundwater inflow has been estimated using numerical groundwater modelling. Given the data limitations and assumptions made as explained in Section 13.1, groundwater modelling was carried out for a variety of scenarios. To account for the level of uncertainty in the model, results are discussed in terms of a range, considering:

- total inflow according to the 50th percentile of modelling results, which represents the median value of all results (the likely case)
- total inflow according to the 95th percentile of modelling results, which represents a conservative upper end value (the likely worst-case).

Estimated groundwater inflows for the project during construction are provided in Table 13-6, based on modelled average and maximum groundwater inflows. The 50th percentile and 95th percentile values for model runs are presented for the average and maximum groundwater inflows.

Due to the conservative modelling approach, the total estimated construction inflow rate may be substantially lower in practice. The maximum predicted tunnel groundwater inflow volume during construction would peak at around 750 to 1850 cubic metres per day (8.7 to 21.4 litres per second) over the total length of the tunnel. Given the depth and length of the tunnel, as well as its location in hydrological structures within various geological strata, groundwater inflows during construction are likely to be higher than other NSW tunnel projects. Further investigation would be carried out during design development to refine the groundwater model and validate modelling outputs, with the aim of minimising groundwater inflow volumes.

Construction and design assumptions have been made to inform groundwater modelling for the purposes of this assessment, such as where certain TBM modes would be used (refer to Section 4.2 of Appendix I (Technical report – Groundwater). The construction methodology and construction sequencing would be subject to ongoing design development and construction planning and further detailed groundwater modelling would be carried out as part of that process.

As shown in Figure 13-7 maximum predicted tunnel groundwater inflow volumes are predicted to:

- peak during construction of the tunnel (between the mid-tunnel cavern and Blackheath when the TBM switches to earth pressure balance mode), and during construction of the tunnel cross-passages
- decrease around 2029 once construction of these elements is complete, with the cross-passages and twin tunnels being tanked (i.e. structures which prevent groundwater from entering the structure as opposed to a drained structure which captures, diverts and treats groundwater ingress)
- stabilise after construction given most infrastructure would be tanked.

Tunnel groundwater inflow would be pumped to construction water treatment plants at Blackheath, Soldiers Pinch and Little Hartley where it would be treated to levels consistent with water quality requirements before being reused or discharged. Treated water would be discharged to the environment or transported to a suitable disposal facility.

Measures to limit groundwater ingress during construction would be implemented where excessive or greater than predicted inflows are encountered, to reduce the potential impact on the surrounding environment for example pre-grouting of cross-passage if required. Inflow rates during construction may have some impacts on groundwater drawdown, recharge and flow, groundwater users, surface water/groundwater interactions or settlement (discussed in Sections 13.3.2 to 13.3.6).

Table 13-6 Summary of modelled groundwater inflows during construction (mid-2024 to 2030)

Project feature	Tanked or drained structure	Indicative inflow volumes (m^3/day)			
		Average inflow over construction period		Maximum inflow over construction period	
		50th percentile of model runs	95th percentile of model runs	50th percentile of model runs	95th percentile of model runs
Blackheath portal	Drained (unsealed)	21.0	45.4	61.4	144.4
Little Hartley portal	Drained (unsealed)	5.6	16.2	20.6	61.8
Mid-tunnel caverns	Drained (unsealed)	2.5	11.9	18.8	52.9
Mid-tunnel adit	Drained (unsealed)	1.1	12.5	6.8	46.5
Mid-tunnel access shaft	Tanked (sealed) and drained (unsealed)[1]	1.2	8.9	9.9	29.6
Cross-passages	Tanked (sealed)	76.5	222.1	724.6	1,756
Tunnel (between Blackheath and mid-tunnel caverns)[2]	Tanked (sealed)	26.6	82.4	704.3	1,702.3
Tunnel (between mid-tunnel caverns and Little Hartley)[3]	Tanked (sealed)	0.0	0.0	0.0	0.0
Total[4]		**107.8**	**317.2**	**756.2**	**1,847.2**

Table notes:

1. the mid-tunnel access shaft would be tanked (sealed) from the ground surface to the Mount York Claystone and drained (unsealed) from the Mount York Claystone to the shaft depth. See Chapter 5 (Construction) for further description of the mid-tunnel access shaft
2. for the purposed of the groundwater assessment, the TBM would operate in single shield mode between the mid-tunnel caverns and Blackheath, which would possibly allow groundwater ingress as captured by the modelled outputs in the table above
3. the tunnel between Little Hartley and the mid-tunnel caverns would be excavated using TBMs in earth pressure balance mode whereby the tunnel face is stabilised to limit groundwater ingress, resulting in no modelled groundwater ingress
4. total inflow volumes are not the sum of the inflow from each project element, as when each of these inflows occur would depend on construction stage. The total inflow volumes have been estimated based on modelled construction staging (refer to Annexure B of Appendix I (Technical report – Groundwater).

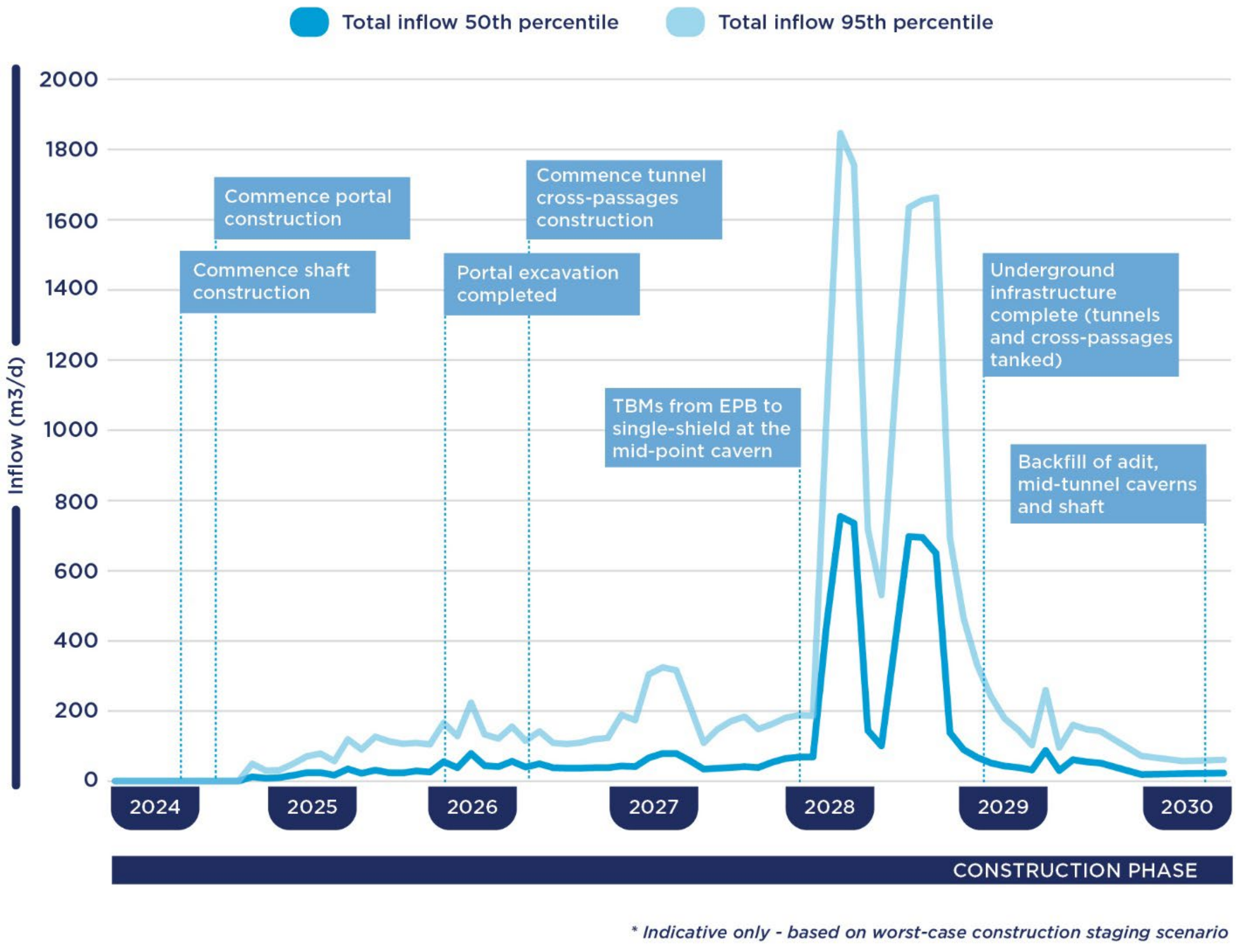

Figure 13-7 Rate of tunnel groundwater inflow during construction

13.3.2 Groundwater drawdown, recharge and flow

The maximum groundwater drawdown during construction of the project has been modelled for the water table and the five geological units above or through which the project would pass (as shown in Figure 13-1 to Figure 13-3):

- Banks Wall Sandstone
- Mount York Claystone
- Burra-Moko Head Sandstone
- Upper Caley Formation
- Marangaroo or Gundangaroo Formation (Illawarra Coal Measures).

The maximum groundwater drawdown (depth of drawdown) during construction modelled for the 50th and 95th percentile is summarised in Table 13-7. The spatial extent of modelled groundwater drawdown during construction is shown in Figure 13-8 (50th percentile within the water table). The spatial extents of drawdown in other geological units are shown in Section 4.4 of Appendix I (Technical report – Groundwater). Drawdown predictions, at different locations, may occur temporarily or may be ongoing during varying stages of construction. These modelled maximum drawdown values are conservative and may not eventuate in practice.

Table 13-7 Modelled groundwater drawdown during construction

Geological unit	Groundwater drawdown
Water table	Maximum drawdown from the 50th percentile of modelling results would be: • between 5.1 and 20 metres at the Blackheath portal • between 5.1 and 20 metres at the Little Hartley portal • between 5.1 and 20 metres at the mid-tunnel caverns • between 2.1 and 5.0 metres at a regional fault east of the Little Hartley portal. Potential drawdown impacts to registered water supply bores and GDEs during construction are further discussed in Section 13.3.4 and Section 12.3 of Chapter 12 (Biodiversity) respectively. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile, but extends to around double the radius.
Banks Wall Sandstone	Maximum drawdown from the 50th percentile of modelling results would be between 5.1 and 20 metres and would occur due to the construction of cross-passages that intercept the Banks Wall Sandstone near the tunnel surface, at geological structures between the mid-tunnel caverns and at the Blackheath portal. The cross-passages would be tanked (sealed) upon construction completion and therefore groundwater drawdown would be temporary and would recover after construction. An additional 0.1 to 0.3 metres maximum drawdown would occur at the regional fault through this geological unit (refer to Figure 13-4). Potential drawdown impacts to registered water supply bores and GDEs are further discussed in Section 13.3.4 and Section 12.3 of Chapter 12 (Biodiversity) respectively. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile, but extends to around double the radius.
Mount York Claystone	Maximum drawdown from the 50th percentile of modelling results would be between 0.3 and 0.5 metres at the tunnel cross-passages and the near-surface twin tunnels south (towards Blackheath) of the mid-tunnel caverns. No registered water supply bores or GDEs are known within the extent of drawdown within these locations. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile, but extends to around four times the radius.
Burra-Moko Head Sandstone	Maximum drawdown from the 50th percentile of modelling results would be between: • 5.1 and 20 metres, at the access shaft • 2.1 and 5.0 metres at the tunnel caverns • 2.1 and 5.0 metres at geological structures north of the mid-tunnel cavern. No registered water supply bores or GDEs are known within the extent of drawdown within these locations. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile, but extends to around four times the radius and presents at a northwest-southeast trending geological structure located south of the mid tunnel caverns.

Geological unit	Groundwater drawdown
Upper Caley Formation	Maximum drawdown from the 50th percentile of modelling results would be between: • 5.1 and 20 metres at the geological structures north of the mid-tunnel caverns • 0.6 and 2.0 metres east of the Little Hartley portals • 0.3 and 0.5 metres south of the mid-tunnel caverns. No registered water supply bores or GDEs are known within the extent of drawdown within these locations. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile, but extends to around double the radius and presents at a northwest-southeast trending geological structure located south of the mid tunnel caverns.
Marangaroo or Gundangaroo Formation	Maximum drawdown from the 50th percentile of modelling results would be between: • 5.1 and 20 metres at Little Hartley portal • 5.1 and 20 metres at the geological structure north of the mid-tunnel caverns • 0.1 and 0.3 metres south of the mid-tunnel caverns. Potential drawdown impacts to GDEs are further discussed in Section 12.3 of Chapter 12 (Biodiversity). No registered water supply bores are known to be screened within this unit within the extent of drawdown. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile, but extends to around four times the radius and presents at a northwest-southeast trending geological structure located south of the mid tunnel caverns.

Groundwater in the study area is recharged primarily through direct rainfall which infiltrates through the soil and rock profile. The project would only result in a minor increase in impervious surfaces compared to the overall extent of the recharge area, and would therefore have a negligible impact on existing recharge rates.

Impacts to groundwater flow, including mounding on the side of the tanked tunnels, during construction may include localised changes to flow rates and drawdown near the Blackheath portal and mid-tunnel access shaft, adit and caverns. Given the low magnitude and localised spatial extent of groundwater drawdown, the project would have a low impact on regional groundwater flow patterns.

The introduction of the tanked tunnels and other tanked infrastructure has the potential to alter groundwater flow during construction. Groundwater flow direction is inferred from east to west, towards the western escarpment. Groundwater flow impacts during construction could result in a reduction of baseflow at hanging swamps, which occur on steep valley sides where there is groundwater seepage. Potential impacts to hanging swamps, including due to reductions in groundwater flow during construction, are discussed in Chapter 12 (Biodiversity).

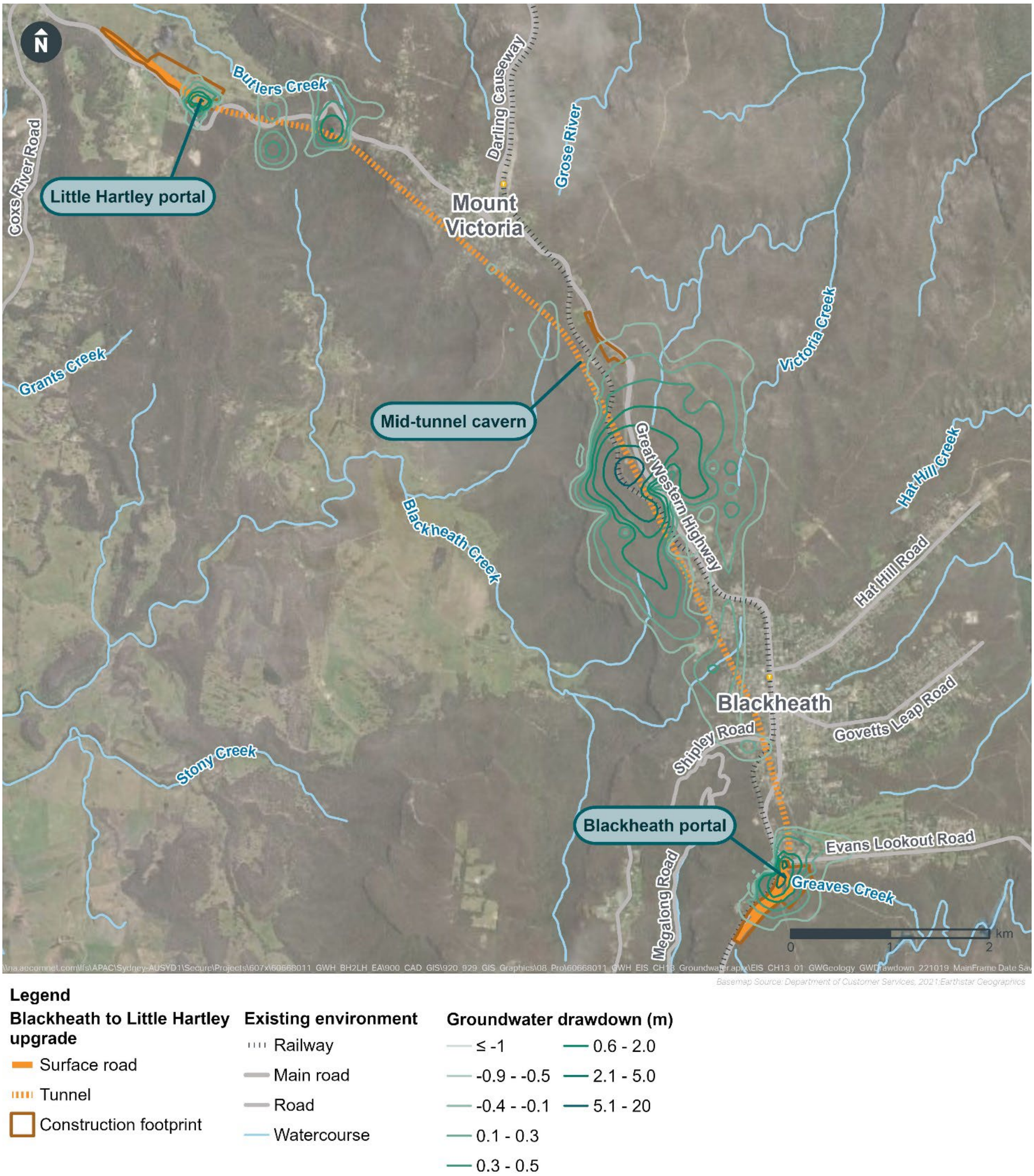

Figure 13-8 Predicted groundwater drawdown in the water table during construction (50th percentile modelling outputs)

13.3.3 Groundwater quality

Potential impacts to groundwater quality during construction could arise from:

- leaks or spills of fuels, oils, or lubricating fluids used for construction machinery
- excavated acid sulfate rock and/or coal seams within the Illawarra Coal Measures seeping into uncontaminated groundwater at the source or once excavated (contamination risks are addressed in Chapter 15 (Soils and contamination))

- construction materials used for construction of underground structures, including:
  - drilling/cutting fluids that may be required for the TBMs and roadheaders
  - particulate matter from tunnelling activities leading to increased total suspended solids
  - cement pollution arising from shotcrete application, grouting or in-situ concrete casting.

Groundwater collected during construction would be treated at construction water treatment plants at Blackheath, Soldiers Pinch and Little Hartley before discharge. With the application of standard construction environmental management and mitigation measures, these activities would be low risk and impacts to groundwater quality during construction of the project would be unlikely.

13.3.4 Groundwater users

Groundwater drawdown during construction of the project would potentially affect 31 registered bores near Blackheath, as shown in Figure 13-9. Predicted groundwater drawdown at Mount Victoria and Little Hartley does not impact existing groundwater users as drawdown is minimal and limited in spatial extent. The potentially impacted bores near Blackheath comprise six monitoring bores, 21 bores used for water supply, two bores used for unknown purposes (assumed to be used for water supply purposes), and two abandoned water supply bores.

No registered water supply bores had a median (50^{th} percentile) maximum predicted drawdown greater than two metres. Two registered water supply bores within Blackheath had a 95^{th} percentile maximum predicted drawdown greater than two metres (GW100157 and GW102214), where there was predicted to be around 3.14 metres and 4.76 metres of drawdown respectively. The frequency that these bores would have drawdown greater than or equal to two metres is relatively low (predicted at around 12.1 per cent at GW100157 and around 22.5 per cent at GW102214).

There is a low frequency (less than four per cent of model realisations) that drawdown would be greater than or equal to two metres at four registered water supply bores (GW058193, GW058236, GW059737, and GW102030). At all other bores, predicted drawdown was less than two metres in all model realisations.

Although there are registered groundwater bores within Mount Victoria and Little Hartley, predicted groundwater drawdown within these areas do not impact these groundwater users as drawdown is minimal and limited in lateral extent.

Detailed groundwater modelling would be carried out as part of further design development and construction planning that would incorporate additional baseline groundwater data, as discussed in Section 7.2 of Appendix I (Technical report – Groundwater). Where this modelling identifies potential for drawdown at registered bores of greater than two metres, a baseline assessment of each at-risk registered bore (including GW100157 and GW102214) would be carried out prior to commencing construction activities. Groundwater monitoring during construction would also validate model predictions.

If drawdown at registered bores is found to exceed two metres, measures would be implemented to 'make good' the impact based on the location of the impacted bores and in consultation with the affected licence holder as discussed in Section 13.5. Results of the initial modelled groundwater levels during construction at each registered groundwater bore location are provided in Appendix I (Technical report – Groundwater).

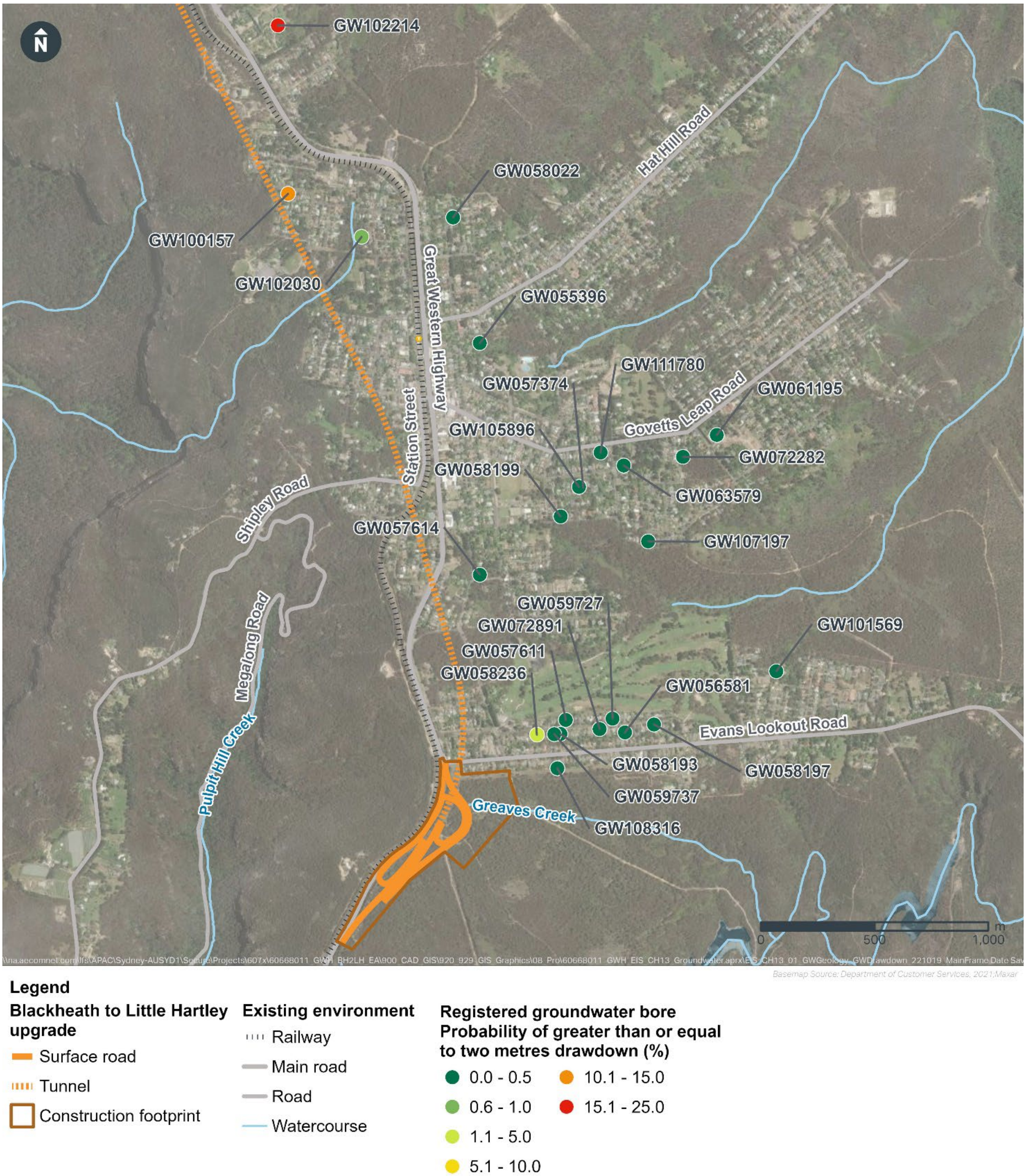

Figure 13-9 Predicted maximum groundwater drawdown (95th percentile) at registered groundwater bores during construction at Blackheath

13.3.5 Surface water/groundwater interaction

Surface water features that are partially or wholly reliant on groundwater to sustain baseflow (regular flow patterns) can be affected by changes to groundwater via:

- groundwater depressurisation or drawdown in the groundwater system connected to a stream
- changes to the gradient of the water table resulting in an increase or decrease in groundwater entering a stream

- installation of segmental tunnel lining as part of TBM excavation which can result in a barrier to groundwater flow between recharge and discharge locations (see Section 13.3.2).

Groundwater modelling and assessment of potential changes to surface water baseflow during construction indicate that dewatering due to construction activities would have the largest impact on baseflow within the Fairy Bower sub-catchment, which is located immediately west of the mid-tunnel caverns, adit and access shaft (refer to Section 4.5.5 of Appendix I (Technical report – Groundwater)). The Fairy Bower sub-catchment has been modelled to experience a predicted maximum baseflow reduction of 5.6 per cent for the 95th percentile modelling outputs.

The impact to this location would be low given the greatest predicted baseflow reduction would be during periods of higher rainfall. During these periods of higher rainfall, the sub-catchment would have higher streamflow contributions from rainfall runoff, which would likely lessen the effects of the baseflow reduction. A full discussion of potential changes to baseflow rates from surface water infiltration during other rainfall periods is provided in Sections 4.5.4 and 4.5.5 of Appendix I (Technical report – Groundwater). Further information about potential impacts to surface water is provided in Chapter 14 (Surface water and flooding).

13.3.6 Settlement (ground movement)

The main cause of settlement relevant to the project would be tunnel excavation. Initial modelling has predicted that settlement due to groundwater drawdown would be low to negligible across the project with the maximum settlement predicted to be around 1.8 millimetres. Given the perched groundwater tables are mainly confined to the rock mass and that overlying fills and clays are typically shallow in depths, long term settlement due to groundwater drawdown would not be a key concern for the project.

Settlement due to tunnel excavation has been evaluated as part of the development of the project design. Settlement calculations indicate that:

- the maximum settlement due to the project is predicted to be up to 30.1 millimetres, and is predicted to occur in areas away from development (including houses and structures)
- a total of 34 buildings and structures are predicted to experience settlement greater than five millimetres, including:
  - all residential and commercial buildings are predicted to experience settlement less than the 30 millimetre criterion for buildings. The most affected building is predicted to experience settlement of 17.8 millimetres
  - all heritage items are predicted to experience settlement less than the 20 millimetre criterion for sensitive buildings, with the most affected heritage item (Tree Tops and garden (Blue Mountains LEP BH065)) predicted to be affected by up to 16.8 millimetres. Further discussion of settlement impacts on heritage items is provided in Chapter 17 (Non-Aboriginal heritage)
  - the Megalong Reservoir and water booster pump is predicted to experience settlement of up to 6.0 millimetres, which is less than the 20 millimetre criterion
- maximum slope and tensile strain criteria is not predicted to be exceeded at any building, structure or infrastructure.

This analysis indicates that the predicted settlement values are within the acceptable criteria and therefore potential settlement impacts would be negligible. Mitigation measures to monitor potential settlement and minimise potential settlement impacts are provided in Section 13.5. Further discussion of potential settlement impacts to properties is provided in Chapter 20 (Business, land use and property).

13.4 Potential impacts – operation

During operation the Little Hartley and Blackheath portals and the mid-tunnel caverns (drained (unsealed) features) are expected to have the largest influence on the groundwater environment.

13.4.1 Tunnel groundwater inflow

Operational groundwater inflow rates are predicted to reach a steady state between the years 2030 and 2100 following completion of the construction phase, with some slight variations due to weather conditions. As shown in Table 13-8, the maximum predicted tunnel groundwater inflow volumes (associated with the Blackheath portal) are predicted to peak at around 21.2 to 42.1 cubic metres per day (0.2 to 0.5 litres per second). Over time, this would steadily decline and would stabilise. Minor leakage may occur in localised areas in the tanked (sealed) sections of the project tunnels, however these are expected to be relatively small and not anticipated to result in measurable impacts to groundwater.

Groundwater inflows captured during operation would be pumped to the operational water treatment plant at Little Hartley and would be treated to levels consistent with water quality requirements before being reused or discharged.

Table 13-8 Summary of modelled groundwater inflows during operation (2030 to 2130)

Project feature	Tanked or drained	Indicative inflow volumes (m^3/day)			
		Average during operation		Maximum during operation	
		50th percentile	95th percentile	50th percentile	95th percentile
Mid-tunnel caverns	Drained (unsealed)	2.0	14.0	2.0	14.9
Little Hartley portal	Drained (unsealed)	4.2	12.8	4.6	13.6
Blackheath portal	Drained (unsealed)	18.2	37.7	21.2	42.1
Estimated peak during operation		**24.4**	**64.5**	**27.7**	**70.4**

13.4.2 Groundwater drawdown, recharge and flow

During operation, groundwater drawdown would occur at permanently drained (unsealed) structures, being the Blackheath and Little Hartley portals and above the mid-tunnel caverns. Maximum groundwater level drawdown for long-term operation (2130) has been modelled for the water table and the five geological units above or through which the project would pass (as shown in Figure 13-1 to Figure 13-3).

The maximum groundwater drawdown during operation modelled for the 50th and 95th percentile is summarised in Table 13-9. The spatial extent of modelled groundwater drawdown during operation is shown in Figure 13-10 (50th percentile within the water table). The spatial extents of drawdown in other geological units are shown in Section 5.3 of Appendix I (Technical report – Groundwater). The modelled maximum drawdown values are conservative and may not eventuate in practice.

Table 13-9 Long-term modelled groundwater drawdown (year 2130)

Geological unit	Groundwater drawdown
Water table	Maximum drawdown from the 50th percentile of modelling results would be: • between 5.1 metres and 20 metres at the Blackheath portal • between 2.1 metres and 5.0 metres at the Little Hartley portal, including areas with mapped GDEs to the north. Minor drawdown would be between 0.3 and 0.5 metres at geological structures that intersect the operational footprint due to reduced recharge to these units. At Blackheath, drawdown would be marginally greater than during the construction phase at this location, given the portals would be permanently drained (unsealed). At Little Hartley, drawdown would be similar to that experienced during construction. Potential drawdown impacts to registered water supply bores and GDEs during operation are further discussed in Section 13.4.4 and Section 12.4 of Chapter 12 (Biodiversity) respectively. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile, but extends to around double the radius.
Banks Wall Sandstone	Maximum drawdown from the 50th percentile of modelling results would be between 0.1 metres and 0.3 metres around the regional fault through this geological unit (refer to Figure 13-4), due to the drained (unsealed) structure of the Blackheath portal. Drawdown is predicted to be less than during the construction phase as the cross-passages and twin tunnels would have been tanked (sealed) prior to operation. The spatial extent of predicted drawdown around the Blackheath portals would be marginally greater than during construction, given the portals would be permanently drained (unsealed), extending to areas of registered water supply bores (see Section 13.4.4).
Mount York Claystone	Maximum drawdown from the 50th percentile of modelling results would be between 0.3 metres and 0.5 metres as a result of the mid-tunnel caverns. Minor drawdown would also potentially occur around regional faults located near the north of the Blackheath portal (around 0.1 to 0.3 metres), as a result of groundwater inflows at this location. Drawdown would not extend to where the unit outcrops and therefore is not predicted to impact GDEs. No registered water supply bores are known within the extent of drawdown in these locations. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile but extends to around double the radius.

Geological unit	Groundwater drawdown
Burra-Moko Head Sandstone	Maximum drawdown from the 50th percentile of modelling results would be between 5.1 metres and 20 metres at the mid-tunnel caverns. The extent of drawdown would be less than during construction as the mid-tunnel access shaft and adit would be infilled at the end of the construction phase and no longer be drained (unsealed)[1]. Minor drawdown would also potentially occur around regional faults located north of the mid-tunnel caverns and Blackheath portals (around 0.1-0.3 metres), as a result of groundwater inflows at these locations. Drawdown would not extend to where the unit outcrops and therefore is not predicted to impact GDEs. No registered water supply bores are known within the extent of drawdown in these locations. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile but extends to around double the radius.
Caley Formation	Maximum drawdown from the 50th percentile of modelling results within this unit would be largely due to drawdown associated with the mid-tunnel caverns due to the project intercepting geological structures. Drawdown would be 0.1 metres to 0.3 metres at the mid-tunnel caverns. Minor drawdown of 0.1 metres to 0.3 metres would also potentially occur around geological structures located north of the Blackheath portals and north of the mid-tunnel caverns as a result of groundwater inflows to these locations. Drawdown would not extend to where the unit outcrops and therefore is not predicted to impact GDEs. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile but extends to around double the radius.
Marangaroo or Gundangaroo Formations	Maximum drawdown from the 50th percentile of modelling results would be around 5.1 metres to 20 metres around the Little Hartley portal. Minor drawdown of 0.1 metres to 0.5 metres would also potentially occur around geological structures located north of the Blackheath portal and east of the Little Hartley portal, as a result of groundwater inflows at these locations. Drawdown would not extend to where the unit outcrops and therefore is not predicted to impact GDEs. No registered water supply bores are known within the extent of drawdown in these locations. The two metre drawdown contour from the (more conservative) 95th percentile model prediction of maximum drawdown occurs around the same features as the 50th percentile but extends to around double the radius.

As the project would result in a minor increase in impervious surfaces for surface road upgrades and operational ancillary facilities, operation of the project would have a negligible impact on regional groundwater recharge.

Groundwater throughflow within geological structures (listed in Table 13-9) near the tunnel post construction is anticipated to revert back to its existing flow from east to west, towards the western escarpment of the Blue Mountains. Impermeable underground infrastructure within the geological units, such as the mostly tanked (sealed) tunnels, have the potential to create mounding on the up-gradient side of the tanked twin tunnels and drawdown on the down-gradient side of the tunnels. Estimated groundwater drawdown and changes to flow during operation within the water table are

[1] The modelling has assumed that the infilled mid-tunnel access shaft and adit would have hydraulic properties not distinctly different to the host rock and therefore groundwater flow would generally return to pre-construction conditions during the operational phase.

shown in Figure 13-10. Given the low magnitude and spatial extent of groundwater mounding and / or drawdown, the project's impact on regional groundwater flow patterns is considered to be low.

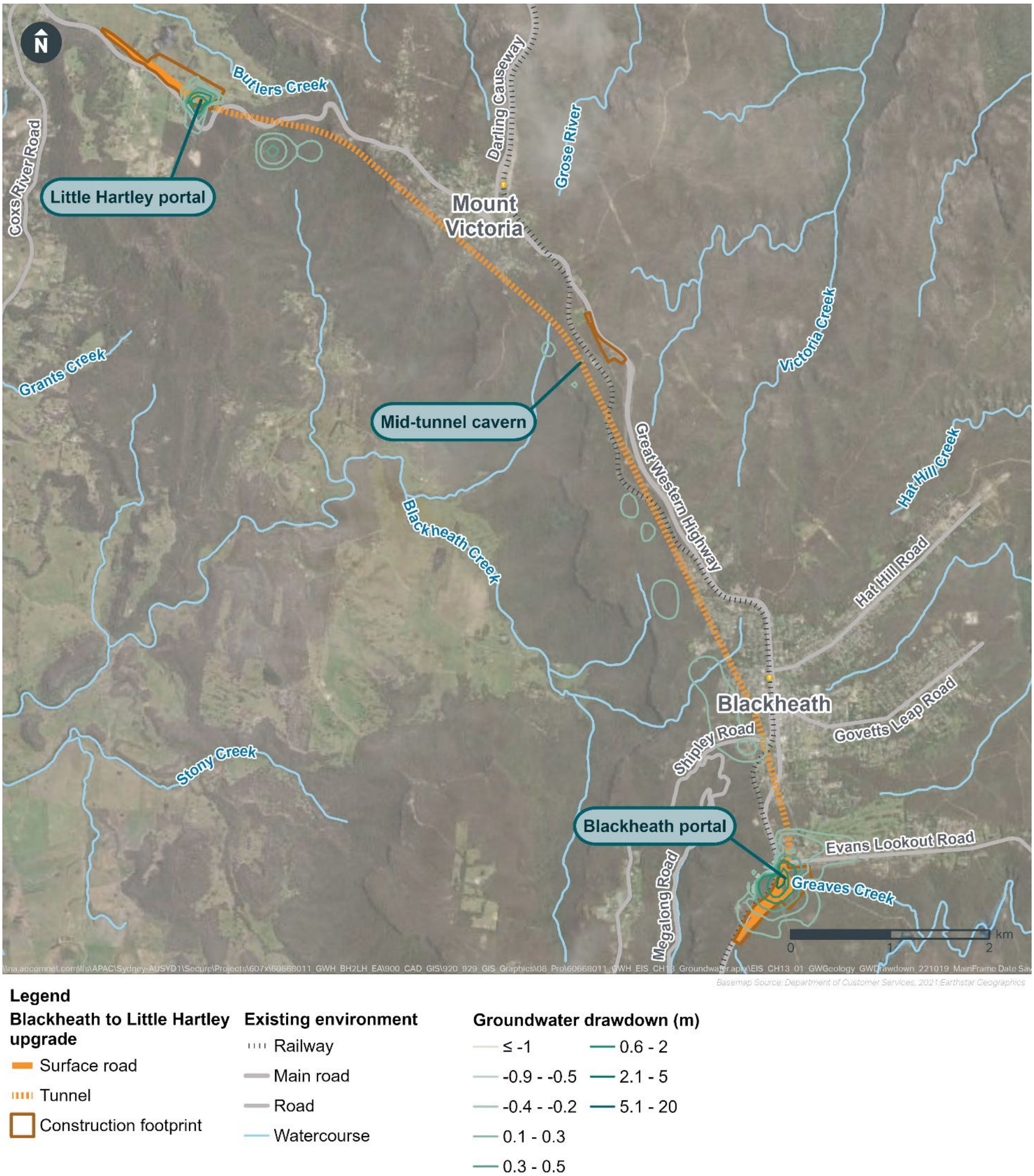

Figure 13-10 Predicted groundwater drawdown in the water table during operation (using 50th percentile modelling outputs)

13.4.3 Groundwater quality

Potential impacts to groundwater quality during operation would arise from:

- leaks or spills of fuels, oils, or lubricating fluids used by vehicles using the tunnels
- groundwater seepage from potential acid sulfate rock (at the Little Hartley portal)

- firefighting system deluge and testing (including vehicle fires if accidents occur within the tunnels).

Groundwater collected during operation would be treated at the water treatment plant at Little Hartley before reuse and/or discharge. With the application of standard mitigation measures, these activities would be low risk and impacts to groundwater quality during operation of the project would be unlikely. Further information on water quality treatment and procedures for spills management, such as spill containment facilities, is provided in Chapter 14 (Surface water and flooding). Consideration of the impact of spills on aquatic receiving environments is addressed in Chapter 12 (Biodiversity). Information about risks from potential acid sulfate rock and firefighting systems is provided in Chapter 15 (Soils and contamination).

13.4.4 Groundwater users

Groundwater drawdown would potentially affect 34 registered bores screened within the Banks Wall Sandstone, Caley Formation or the Shoalhaven Group during operation (2030 to 2130) as shown in Figure 13-10. The higher number of affected registered bores during operation compared with construction relates to groundwater drawdown seepage and spread over time over a larger extent. These bores comprise four monitoring bores, 26 bores used for water supply, two bores used for unknown purposes (assumed to be used for water supply purposes), and two abandoned water supply bores. Long-term (year 2130) impacts are predicted at 23 of these bores, including 20 bores used for water supply, two bores used for unknown purposes (assumed to be used for water supply purposes), and one abandoned water supply bore.

Modelling results indicate that no registered water supply bores would experience a maximum drawdown greater than two metres during operation of the project in the long-term (year 2130). Maximum drawdown during operation would be minimal, around 1.66 metres and is not projected to increase (the long-term maximum predicted groundwater drawdown is around 1.21 metres).

A very low likelihood of drawdown being equal to or greater than two metres was observed in the model at four registered water supply bores in years between 2030 and 2130 (GW058193, GW058236, GW059737, and GW102214) and at one registered supply bore (GW058236) in the year 2031. Results of the modelled groundwater levels during operation at each registered groundwater bore location are provided in Section 5.4.3 of Appendix I (Technical report – Groundwater). Monitoring pre-construction, during construction and during operation will be used to verify model predictions, with model refinements made if required (see Section 13.5).

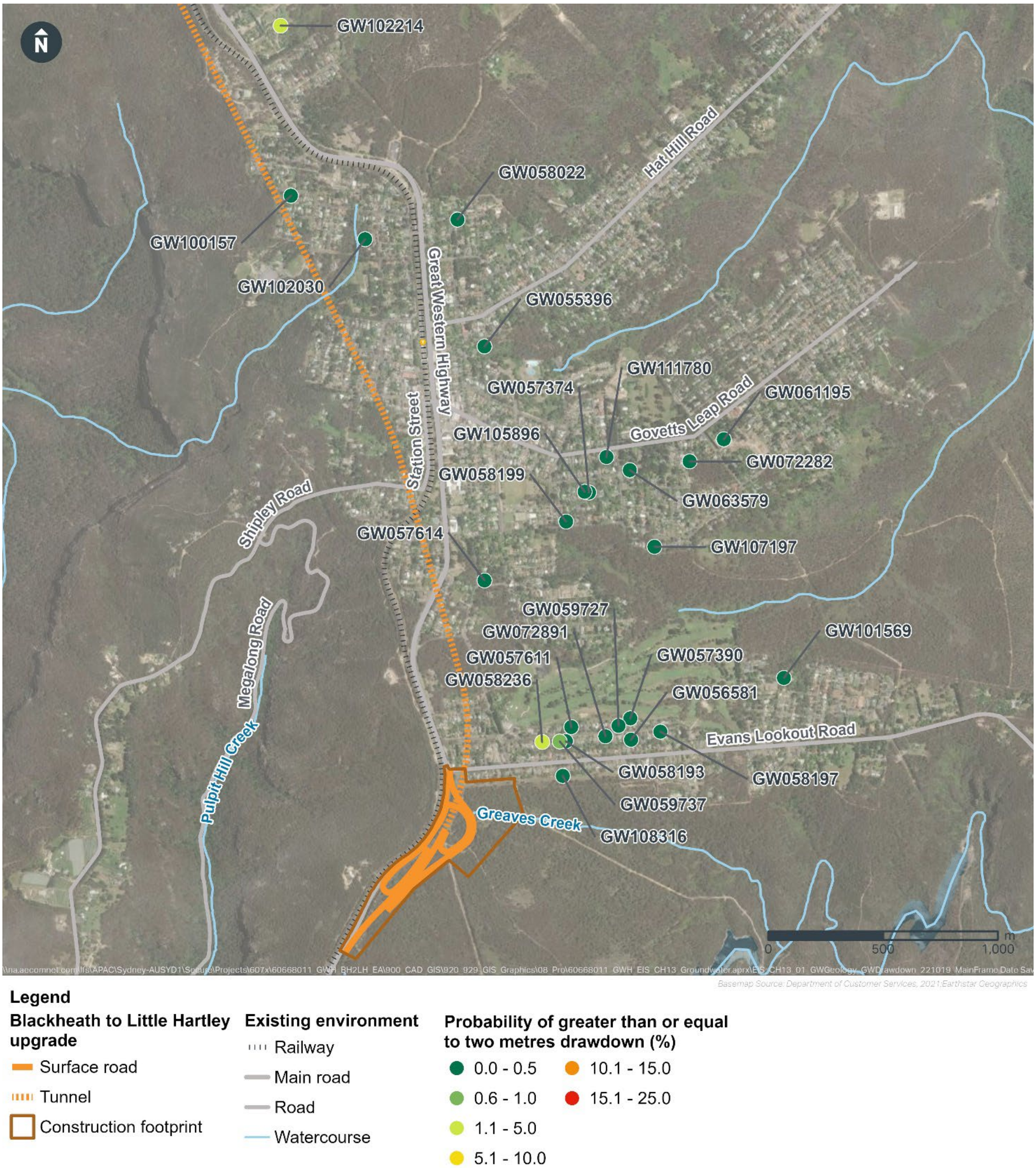

Figure 13-11 Predicted maximum groundwater drawdown (95th percentile) at registered groundwater bores during operation at Blackheath

13.4.5 Surface water/groundwater interaction

Surface water features may be impacted during operation of the project due to continued groundwater inflow to the drained features of the project (portals and mid-tunnel caverns), potentially causing some long-term reduction in stream baseflow at surface water features.

Groundwater modelling and potential changes to surface water baseflow during operation are presented in Section 5.4.5 of Appendix I (Technical report – Groundwater) and indicate that the largest impact on baseflow reduction would be within the Greaves Creek sub-catchment which is located immediately east of the Blackheath portal and flows east towards Greaves Lake.

Lake Medlow and Lake Greaves would be located around 1.3 kilometres and 1.9 kilometres, respectively, from the Blackheath portals and within the Blackheath portion of the Blue Mountains Special Area, listed under Schedule 1 of the Water NSW Regulation 2020. This Special Area forms part of the water supply network for the populations of Medlow Bath, Blackheath and Mount Victoria. Modelling results for these two lakes indicate that a loss (95th percentile model prediction) from the lakes would be 0.06 cubic metres per day (60 litres per day) for Lake Medlow and 0.07 cubic metres per day (70 litres per day) for Lake Greaves. The combined reduction of baseflow for these catchments during dry periods could contribute to reduced water volumes available for water supply purposes, however the loss is predicted to be minimal in the context of surface water flows.

Reduction in baseflows (which would vary across different rainfall seasons) could also affect GDEs, including a threatened ecological community listed under the *Environment Protection and Biodiversity Conservation Act 1999* – Temperate Highland Peat Swamps on Sandstone (THPSS) at Greaves Creek. The loss of baseflow from Greaves Creek and potential impacts on associated GDEs have been assessed as not having a significant impact on the THPSS community. Further information and assessment of potential impacts to surface water bodies and GDEs is provided in Chapter 14 (Surface water and flooding) and Chapter 12 (Biodiversity).

Further investigation into the impacts of baseflow reductions on watercourses and swamps will be undertaken during design development, including field hydrogeological investigations and revised modelling as required.

If revised modelling determines that a reduction in baseflow to the valley floor infill swamps of Greaves Creek is likely and that there is a risk of detrimental impacts to these ecosystems as a result, then further mitigation measures would be investigated. Performance outcomes for the mitigation measures would be developed and agreed upon by subject matter experts, and mitigation actions including design responses such as lining the Blackheath tunnel portal would be assessed for their effectiveness in addressing the risk.

In the instance that residual risk is predicted, monitoring would continue during construction for the hydrogeology, geomorphology and vegetation community likely to be impacted. Observations would be assessed against set triggers, trigger thresholds, and responses developed for observed impacts. Monitoring methods would be developed with reference to supporting justification.

13.4.6 Settlement (ground movement)

Settlement is most likely to occur during construction. It is unlikely that settlement would be an ongoing issue during operation, given the tunnel would be tanked.

Further discussion of potential settlement impacts to properties is provided in Chapter 20 (Business, land use and property).

13.5 Environmental mitigation measures

13.5.1 Performance outcomes

Performance outcomes for the project in relation to groundwater and geology are listed in Table 13-10 and identify measurable performance-based standards for environmental management.

Table 13-10 Groundwater and geology performance outcomes

<table>
<tr><th>SEARs desired performance outcome</th><th>Project performance outcome</th><th>Timing</th></tr>
<tr><td>Long term impacts on surface water and groundwater hydrology (including drawdown, flow rates and volumes) are minimised.</td><td rowspan="2">Design and operate the project to minimise adverse long term impacts on surface water and groundwater, and related environmental values, including:
• minimising the volume and rate of groundwater inflow to the project during operation
• minimising the magnitude and extent of groundwater drawdown around the project during operation
• minimising the reduction in baseflow volumes in watercourses affected by groundwater drawdown around the project during operation
• surface water discharge from the project, including site runoff and water treatment plant discharges, achieves a neutral or beneficial effect on the receiving watercourse and catchment, taking into account relevant Water Quality Objectives.</td><td rowspan="2">Design, construction and operation</td></tr>
<tr><td>The environmental values of nearby, connected and affected water sources, groundwater and dependent ecological systems including estuarine and marine water (if applicable) are maintained (where values are achieved) or improved and maintained (where values are not achieved).</td></tr>
<tr><td>Consideration of tunnel boring methods to minimise groundwater drawdown impacts and dewatering.</td><td>Design and construct the project to minimise groundwater inflow and groundwater drawdown around the project during construction and operation.</td><td>Design, construction and operation</td></tr>
<tr><td>The project is designed, constructed, and operated to protect the NSW Water Quality Objectives where they are currently being achieved, and contribute towards achievement of the Water Quality Objectives over time where they are currently not being achieved, including downstream of the project to the extent of the project impact including estuarine and marine waters (if applicable).</td><td>Manage surface water discharges from the project during construction and operation, including collection and treatment where necessary, to achieve a neutral or beneficial effect on the receiving watercourse and catchment, taking into account relevant Water Quality Objectives.</td><td>Design, construction and operation</td></tr>
</table>

13.5.2 Mitigation measures

Mitigation measures to avoid, minimise or manage potential groundwater and geology impacts as a result of the project are detailed in Table 13-11. A full list of environmental mitigation measures for the project is provided in Appendix R (Compilation of environmental mitigation measures).

Table 13-11 Environmental mitigation measures – groundwater and geology

ID	Mitigation measure	Timing
GW1	The numerical groundwater model for the project will be updated as part of ongoing design development, will consider the construction schedule and methodology, and will take into account relevant additional geotechnical and groundwater monitoring data. Anticipated groundwater impacts will be confirmed and if required inform the development of detailed groundwater mitigation and management measures. The updated numerical groundwater numerical model will be calibrated against groundwater monitoring data collected during the construction phase. If observed groundwater level responses identified through monitoring markedly differ from predictions made by the updated numerical groundwater model, including extent of drawdown and timing, the model will be further refined and calibrated against the observed groundwater conditions.	Design
GW2	Where the updated groundwater model predicts groundwater impacts or related baseflow reductions in surface water resources that markedly differ from predictions presented in the EIS, further environmental mitigation measures and/or design responses will be identified and applied where feasible and reasonable. Design responses could include the review of tanked or drained infrastructure elements, pre-grouting of cross-passages and/or the treatment and discharge of treated groundwater into the affected creeks to address baseflow reductions.	Design
GW3	As part of detailed design, the existing groundwater monitoring network will be reviewed and maintained in consultation with relevant government agencies, and monitoring data will be made available to those agencies upon request, to: • continue to gather representative groundwater monitoring data to inform ongoing project design development, and the updated numerical groundwater model for the project • characterise the hydrogeological environment along and around Greaves Creek and associated groundwater dependent ecosystems in more detail • monitor groundwater prior to, during, and after construction of the project • complement the surface water monitoring network for the project (refer to environmental mitigation measure SW2). A suitably qualified person, such as a hydrogeologist and/or an environmental scientist will undertake periodic reviews of the groundwater monitoring data, and advise on potential groundwater impacts and appropriate mitigation and management measures prior to, during and after construction of the project for up to two years.	Design

ID	Mitigation measure	Timing
GW4	Registered groundwater bores identified as being potentially impacted by two or more metres of drawdown in the updated numerical groundwater model, will be inspected in consultation with the relevant groundwater licence holders. The inspection will aim to confirm the current viability of the bores. If the bores are identified to be viable, they will be monitored and if a material loss of yield occurs as a consequence of the project, make good provisions will be offered to the relevant groundwater licence holders.	Design
GW5	An updated assessment of potential ground settlement as a consequence of tunnel construction activities will be carried out as part of further design development at appropriate locations above the tunnel alignment. Where the assessment or monitoring data identifies an exceedance, or potential for an exceedance, of the acceptance criteria for settlement for buildings/ structures, heritage items and other sensitive buildings, or critical infrastructure, additional mitigation measures will be identified, which may include design and construction measures, and/ or reparatory works to affected buildings, structures or infrastructure.	Construction