Transport for NSW

# Beaches Link and Gore Hill Freeway Connection

## Appendix D – Expanded groundwater modelling uncertainty analysis

November 2021

Jacobs

# Memorandum

Level 7, 177 Pacific Highway
North Sydney NSW 2060 Australia
PO Box 632 North Sydney
NSW 2059 Australia
T +61 2 9928 2100
F +61 2 9928 2444
www.jacobs.com

| | | | |
|---|---|---|---|
| **Subject** | Groundwater Assessment - Results of expanded uncertainty analysis | **Project Name** | Beaches Link and Gore Hill Freeway Connection |
| **Date** | September 2021 | **Project No.** | IA146500 |

## 1. Introduction

This memorandum provides additional information relevant to the assessment of groundwater impacts for the Beaches Link and Gore Hill Freeway Connection project ('the project') following exhibition of the environmental impact statement in December 2020.

Appendix N (Technical working paper: Groundwater) provides an assessment of the potential groundwater impacts of the project. The groundwater model used in the environmental impact assessment was developed following feedback from regulators on previous tunnelling projects. Based on this feedback and the geotechnical information available at the time, a number of conservative assumptions were incorporated into the model. Details of the model development and assessment of groundwater impacts are presented in the groundwater modelling report provided in Annexure F of Appendix N (Technical working paper: Groundwater).

Groundwater modelling was used to estimate potential changes in groundwater levels due to the project and associated impacts on various environmental and anthropogenic features. However, given that the available data used to develop the model was limited by the early stage of design, there is an element of uncertainty in the groundwater modelling results and therefore the potential impacts.

To address this uncertainty, Annexure F of Appendix N (Technical working paper: Groundwater) contains an uncertainty analysis prepared in accordance with the Australian groundwater modelling guidelines (Barnett et al, 2012). The purpose of the uncertainty analysis modelling was to investigate the sensitivity of model predictions to parameter values assigned to the groundwater model. The uncertainty analysis involved targeted sensitivity analyses to assess potential groundwater-related impacts, identifying key factors of high and low range hydraulic parameter values. This analysis estimated the potential changes in groundwater table drawdown under extreme parameter value modelling conditions.

The 'cumulative scenario' was considered in the uncertainty analysis documented in Annexure F of Appendix N (Technical working paper: Groundwater). The cumulative scenario is defined in Section 6.1.2 of Appendix N (Technical working paper: Groundwater) and considers the potential cumulative impacts due to the project, together with the Sydney Metro City and Southwest project, and the Western Harbour Tunnel and Warringah Freeway Upgrade project. Annexure F of Appendix N (Technical working paper: Groundwater) includes these results as well as a summary of the range of associated environmental impacts.

Following receipt of submissions from public agencies, public organisations and the community in which the potential for significant groundwater baseflow reductions in Flat Rock Creek, Quarry Creek and Burnt Bridge Creek was indicated to be of concern, further analysis of the potential impacts on environmental features has been carried out. This further analysis includes both new investigations and assessment as well as further discussion and analysis in relation to existing information developed for the environmental impact statement.

With regard new investigations and analysis, Transport for NSW has conducted further investigations and assessment of predicted groundwater baseflow reductions and the potential environmental impacts. The additional investigations and analysis completed, including the freshwater ecology and groundwater dependent ecosystem impacts at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, are provided in Appendix E of this submissions report and not discussed further in this memorandum.

This memorandum presents further details of the uncertainty analysis of predicted impacts documented in Annexure F of Appendix N, including the range of environmental impacts that could occur to the following:

- Groundwater supply bores
- Areas of environmental interest for contamination
- Groundwater dependent ecosystems and sensitive environments
- Surface water systems.

This expanded uncertainty analysis is based on the groundwater model used in the environmental impact statement.

For details of the groundwater model development, calibration and approach to the uncertainty analysis, please refer to the relevant sections of Annexure F of Appendix N (Technical working paper: Groundwater).

The results of the uncertainty analysis relating to potential water table drawdown are presented in Annexure F of Appendix N (Technical working paper: Groundwater) and included in this memorandum for context only. All other information presented in this memorandum is supplementary to that presented in the environmental impact statement.

## 2. Uncertainty analysis modelling

Uncertainty analysis modelling compared the groundwater related impacts for the “Base case” modelling scenario to the “Scenario A” and “Scenario B” modelling scenarios (described below). The “Base case” modelling scenario refers to the prediction model with the same parameter values as the calibrated transient model, as reported in Annexure F of Appendix N (Technical working paper: Groundwater).

The “Scenario A” modelling scenario provides the most conservative groundwater impacts based on combinations of model input parameter values at the high and low end of the plausible range of the model parameters, with parameters adjusted to yield greater groundwater inflows to the project tunnels and greater associated groundwater level drawdown.

The “Scenario B” model scenario provides modelled groundwater-related impacts based on the selected high and low parameter ranges, with parameters adjusted to yield lesser groundwater inflows to the project tunnels and lesser associated groundwater level drawdown.

Table 2-1 provides summary information on the parameter values assigned to the “Scenario A” and “Scenario B” modelling scenarios. The maximum specific storage value assigned to any hydrogeological unit for the “Scenario B” scenario was $1.3\times10^{-5}$ $m^{-1}$.

**Table 2-1 Parameter values assigned to uncertainty analysis model scenarios**

| Parameter | Scenario A | Scenario B |
|---|---|---|
| Horizontal hydraulic conductivity | One order of magnitude higher than values applied to Base case | One order of magnitude lower than values applied to Base case |
| Vertical hydraulic conductivity | One order of magnitude higher than values applied to Base case | One order of magnitude lower than values applied to Base case |

| Parameter | Scenario A | Scenario B |
|---|---|---|
| Recharge | 50 per cent of the recharge rates assigned to the Base case | 200 per cent of the recharge rates assigned to the Base case |
| Specific storage | 50 per cent of the recharge rates assigned to the Base case | The lesser of:<br>• 200 per cent of the recharge rates assigned to the Base case and<br>• $1.3 \times 10^{-5}$ $m^{-1}$ |
| Specific yield | 50 per cent of the value assigned to the Base case | 200 per cent of the value assigned to the Base case |

## 3. 100 years after the commencement of operation

### 3.1 Water table drawdown

Figure 3-1 and Figure 3-2 show the predicted water table drawdown after 100 years of operation for the Base case.

The predicted drawdown in the Base case is up to 39 metres in the Northbridge area, and up to 16 metres at Seaforth and Balgowlah. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 1.7 kilometres northwards in the Willoughby/Chatswood area, extending westwards up to around 0.5 kilometres in the Lane Cove area and extending southwards up to around 1.7 kilometres in the North Sydney/Waverton area. The drawdown is predicted to reach both sides of Middle Harbour as well as Berrys Bay and Balls Head Bay.

Figure 3-3 and Figure 3-4 show the predicted water table drawdown after 100 years of operation for Scenario A.

For Scenario A, the maximum predicted drawdown is significantly greater than the Base case to the south of Middle Harbour, at around 45 metres immediately overlying the tunnel centreline in the Northbridge area. In general, however, drawdown is less than for the Base case across the entire alignment. For Scenario A, the predicted drawdown propagates away from the tunnels to the north and west significantly more than for the Base case (around 3.1 kilometres northwards into the Chatswood area, around two kilometres westwards into Lane Cove North). North of Middle Harbour, the predicted drawdown is greater in magnitude than for the Base case, with maximum predicted drawdown of 53 metres between Seaforth and Balgowlah. The extent of predicted drawdown for Scenario A is similar to the Base case.

Figure 3-5 and Figure 3-6 show the predicted water table drawdown after 100 years of operation for Scenario B.

For Scenario B, the maximum predicted drawdown is less than for the Base case to the south of Middle Harbour. However, the drawdown distribution to the south of Middle Harbour is different for Scenario B compared to the Base case, due to the localised interactions between the assumed model parameter values. The extent of predicted drawdown to the south of Middle Harbour is generally less for Scenario B compared to the Base case. North of Middle Harbour, the predicted drawdown is significantly lesser in magnitude for Scenario than the Base case, with maximum predicted drawdown of 11 metres between Seaforth and Balgowlah. The extent of predicted drawdown north of Middle Harbour is also significantly less for Scenario B than for the Base case.

As noted earlier, the method of choosing the model parameter values for the uncertainty analysis and the fact that the model is not then calibrated can lead to some local anomalies in terms of drawdown. In addition, some model parameters, and the magnitude of variation, have a greater influence over other parameters when assessing drawdown effects in certain areas of the model (e.g., for Scenario A, high hydraulic conductivity can override the drawdown effects of low storage, resulting in laterally broader but shallower drawdown in certain parts of the model. However, the likely impacts and the appropriateness of the recommended environmental management measures can be considered based on the general observations from the uncertainty scenarios.

It should be noted that the modelled groundwater inflows to the tunnels were controlled by bulk rock and fracture permeability, which for certain sections of the proposed tunnel causes inflows to the tunnels to be greater than 1 L/s/km. However, a design criterion for the project is that the tunnel inflows do not exceed 1 L/s/km for any given kilometre of tunnel and measures would be taken to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling for the Base case and Scenario A.

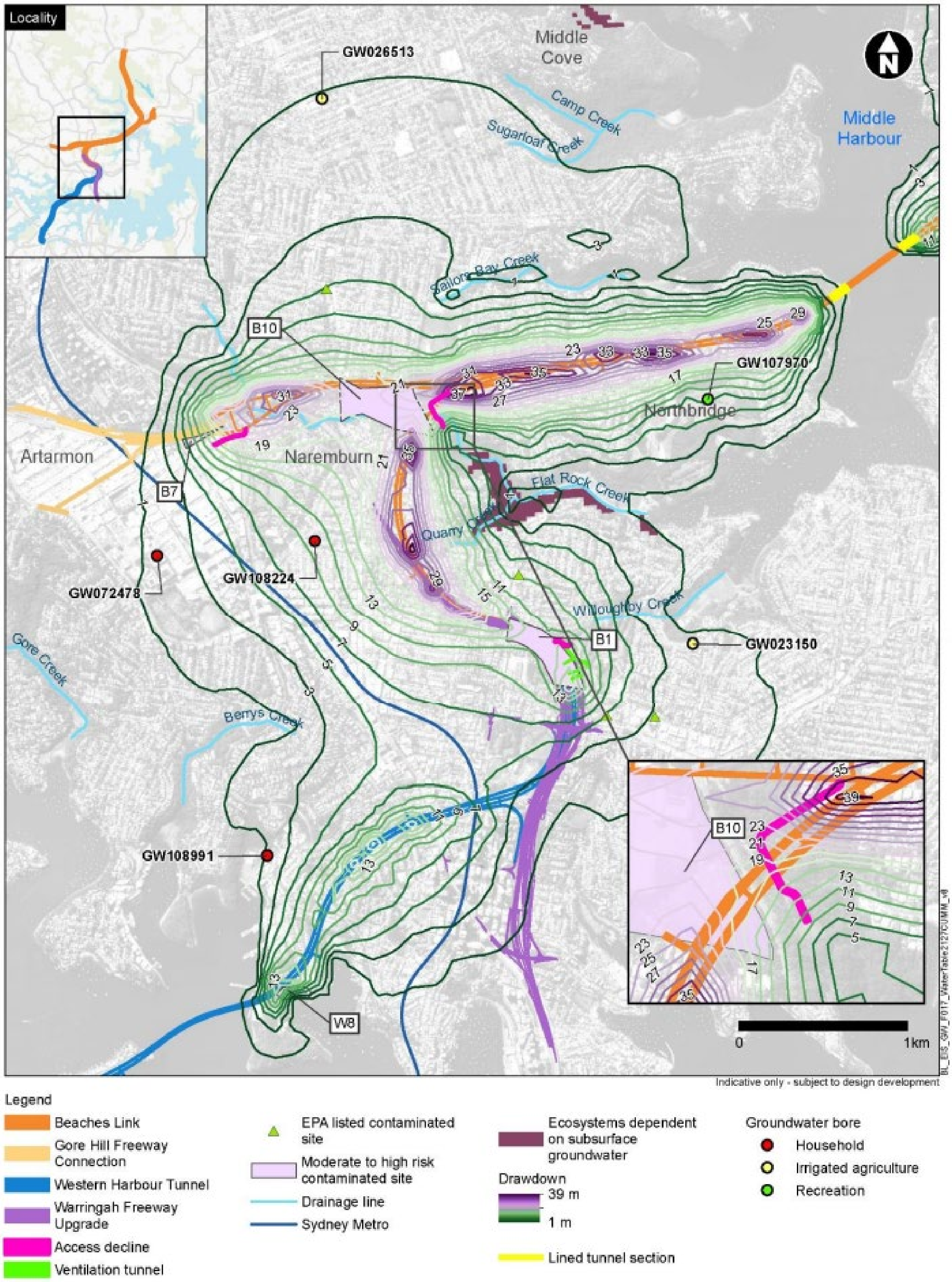


**Figure 3-1**: **Predicted cumulative (all projects) drawdown in the water table after 100 years of operation (south), 2128, for the Base case (source: Figure 6-7 of Appendix N (Technical working paper: Groundwater))**

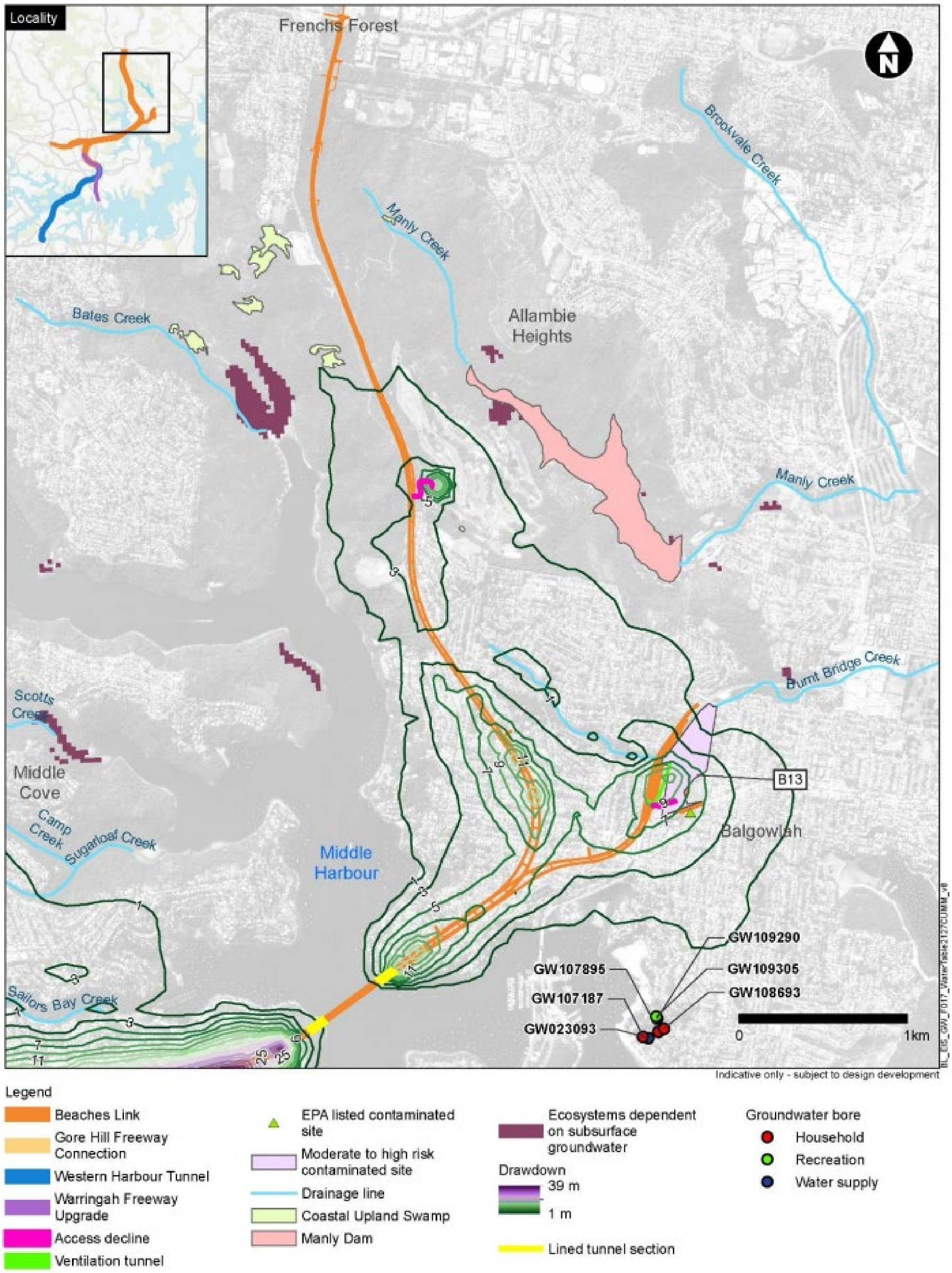


**Figure 3-2**: **Predicted cumulative (all projects) drawdown in the water table after 100 years of operation (north), 2128, for the Base case (source: Figure 6-8 of Appendix N (Technical working paper: Groundwater))**

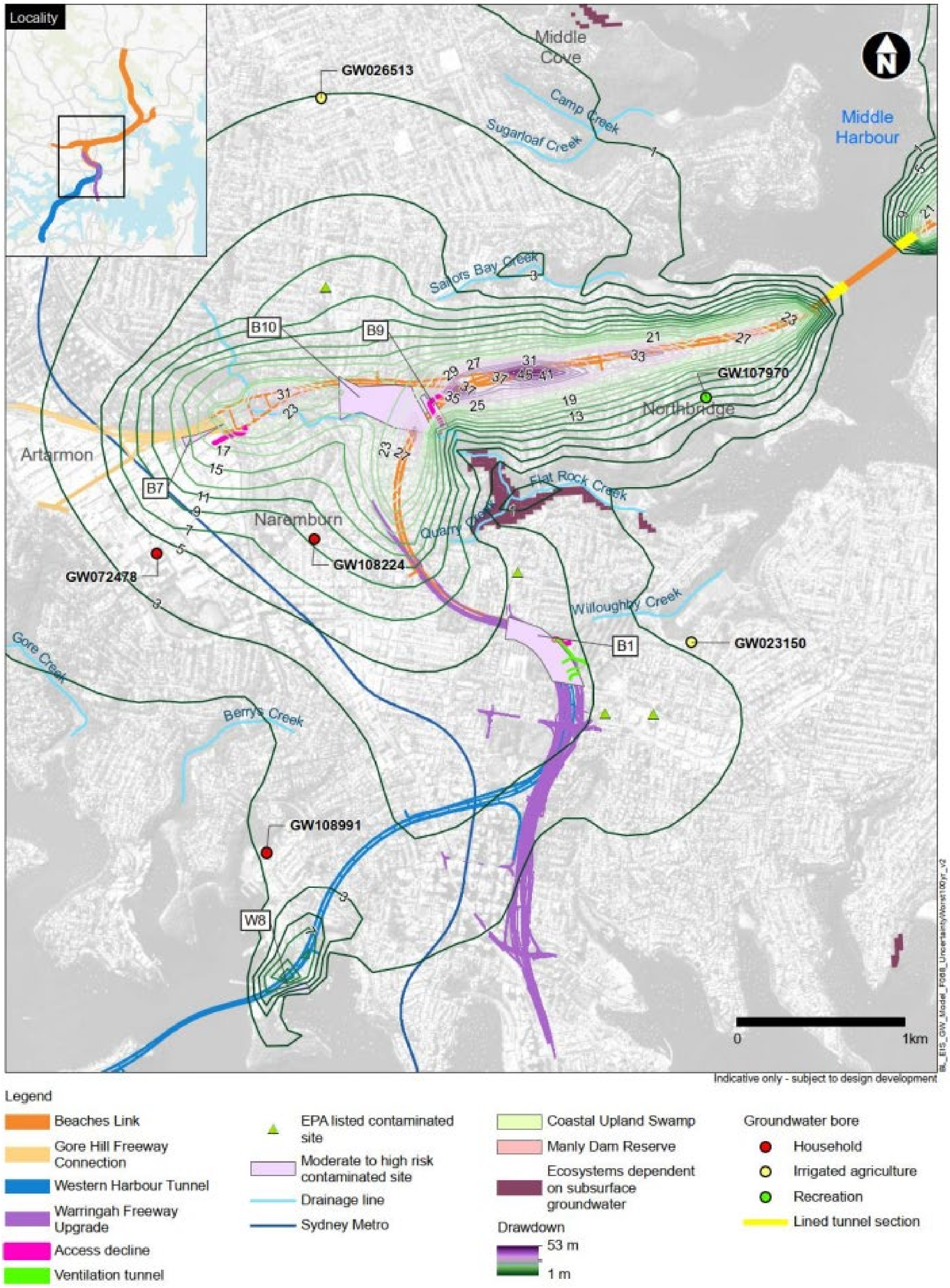


**Figure 3-3**: **Predicted cumulative (all projects) drawdown in the water table after 100 years of operation (south), 2128, for Scenario A**

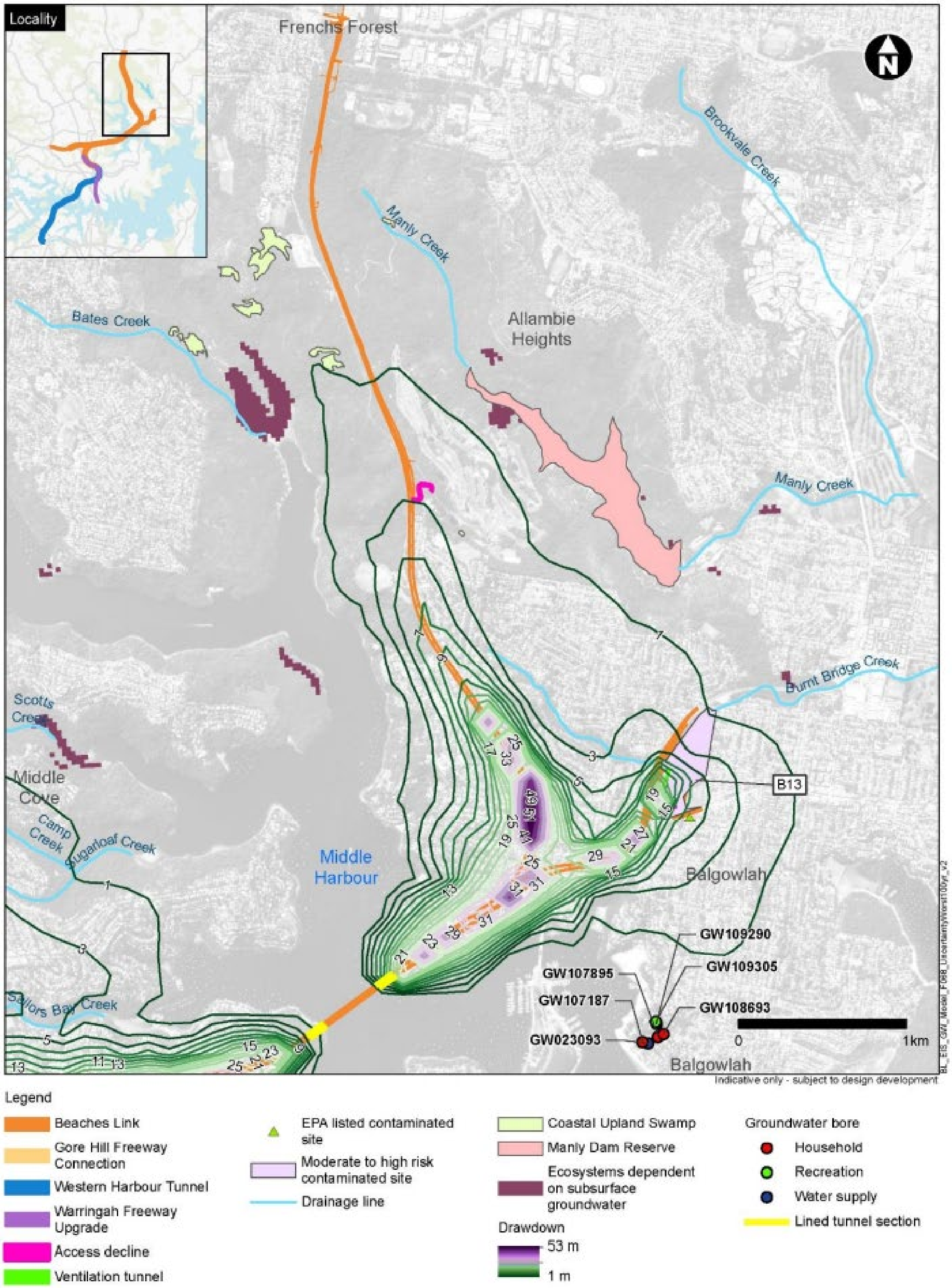


**Figure 3-4: Predicted cumulative (all projects) drawdown in the water table after 100 years of operation (north), 2128, for Scenario A**

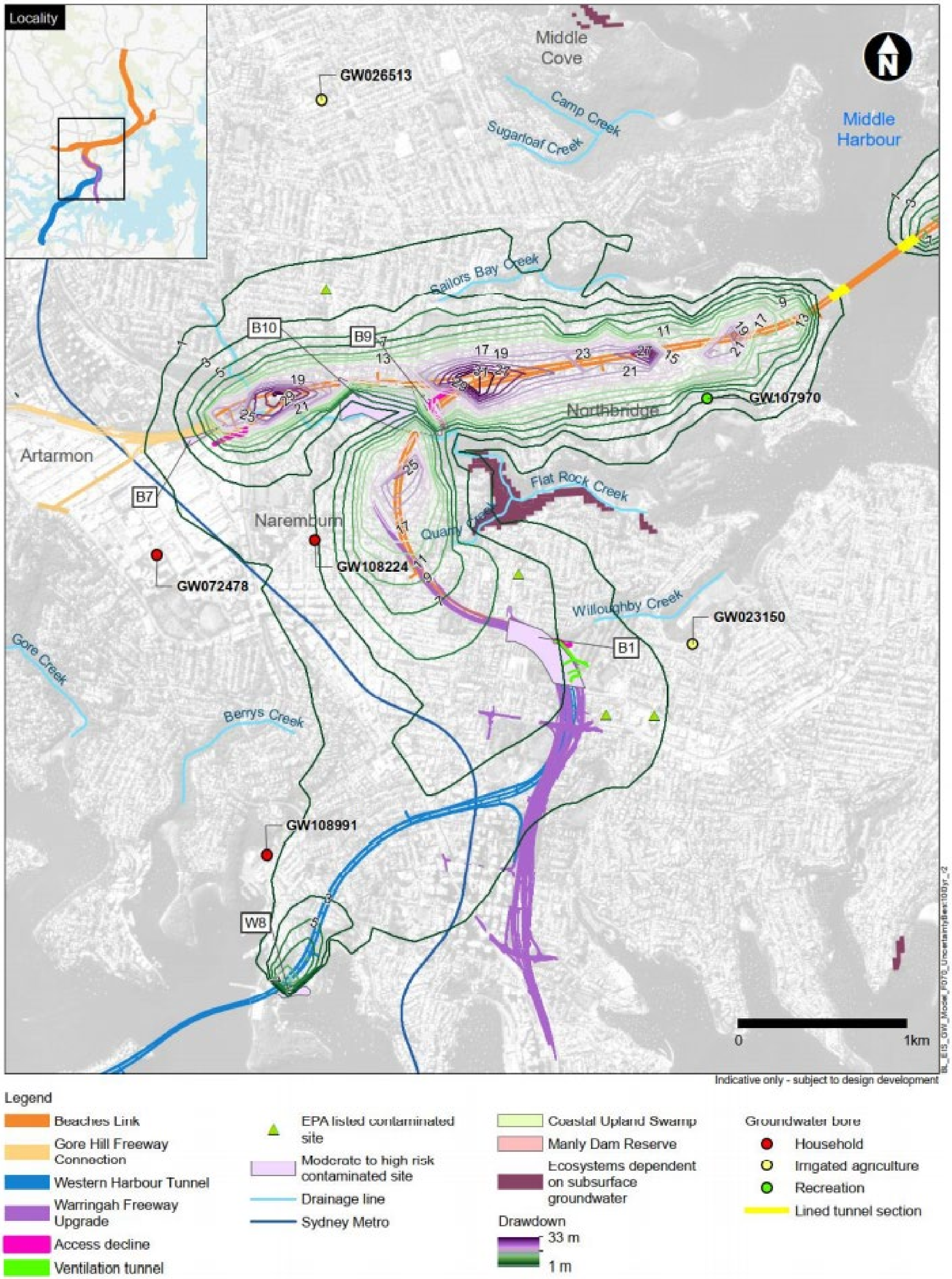


**Figure 3-5: Predicted cumulative (all projects) drawdown in the water table after 100 years of operation (south), 2128, for Scenario B**

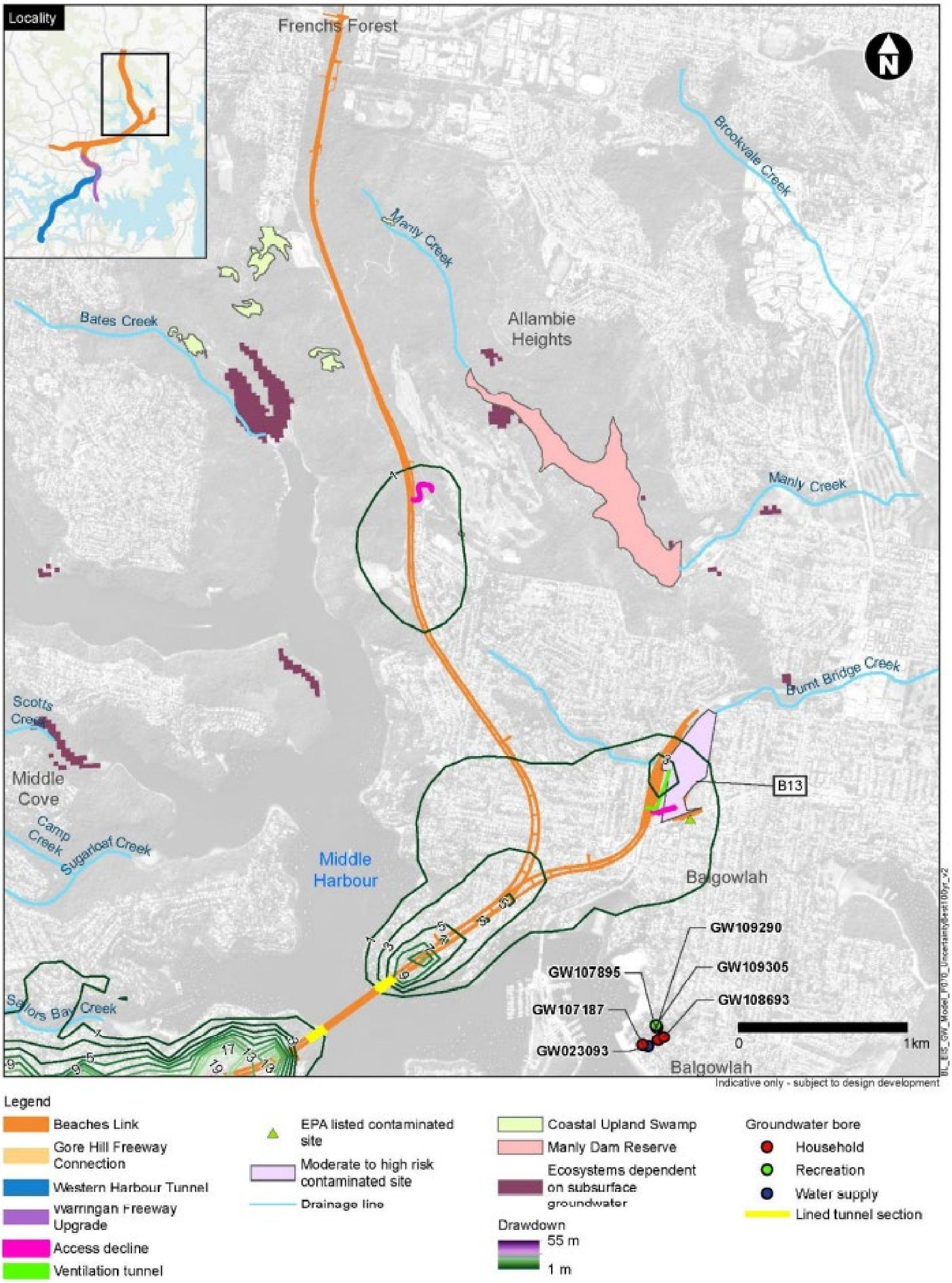


**Figure 3-6**: **Predicted cumulative (all projects) drawdown in the water table after 100 years of operation (north), 2128, for Scenario B**

### 3.2 Predicted impacts

Potential impacts resulting from the predicted groundwater level drawdown associated with operation of the project are discussed in the following sections. Drawdown for each receiver is rounded up to the nearest metre and assessed against the NSW Aquifer Interference Policy requirements.

#### 3.2.1 Groundwater supply bores

Where existing groundwater users are using bores that target the water table the water table drawdown has been considered. Where bores are targeting deeper horizons, a conservative approach has been adopted to assess the impacts by considering the maximum drawdown across all model layers.

For the Base case, of the 21 groundwater users identified, all bores except GW023150, GW026513, GW072478, GW107970, GW108224 and GW108991 are predicted to experience less than one metre of drawdown during operation and would therefore not be impacted by the project.

Table 3-1 summarises the predicted cumulative drawdown at groundwater receivers during operation (2128).

**Table 3-1 Predicted cumulative drawdown and impact at receivers during operation (2128)**

| Bore ID | Bore depth (m BGL) | Cumulative drawdown in 2128 (m) | | |
|---|---|---|---|---|
| | | Base case | Scenario B | Scenario A |
| GW023093 | 2.4 | Less than 1 | Less than 1 | Less than 1 |
| GW023150 | 1.8 | Up to 2 | Less than 1 | Less than 1 |
| GW026513 | 64 | Up to 2 | Less than 1 | Up to 3 |
| GW029731 | 21.6 | Less than 1 | Less than 1 | Up to 2 |
| GW033631 | 14 | Less than 1 | Less than 1 | Less than 1 |
| GW033711 | 13.4 | Less than 1 | Less than 1 | Less than 1 |
| GW065075 | 150 | Less than 1 | Less than 1 | Less than 1 |
| GW072478 | 180.5 | Up to 2 | Up to 2 | Up to 4 |
| GW102744 | 39 | Less than 1 | Less than 1 | Less than 1 |
| GW103127 | 138 | Less than 1 | Less than 1 | Less than 1 |
| GW103133 | 46 | Less than 1 | Less than 1 | Less than 1 |
| GW107187 | 8 | Less than 1 | Less than 1 | Less than 1 |
| GW107757 | 162.6 | Less than 1 | Less than 1 | Up to 2 |
| GW107895 | 4 | Less than 1 | Less than 1 | Less than 1 |
| GW107970 | 199 | Up to 13 | Up to 13 | Up to 11 |
| GW108224 | 132.4 | Up to 11 | Up to 8 | Up to 10 |
| GW108693 | 4 | Less than 1 | Less than 1 | Less than 1 |
| GW108792 | 174 | Less than 1 | Less than 1 | Less than 1 |
| GW108991 | 168 | Up to 4 | Up to 3 | Up to 2 |
| GW109290 | 6.1 | Less than 1 | Less than 1 | Less than 1 |

| Bore ID | Bore depth (m BGL) | Cumulative drawdown in 2128 (m) | | |
|---|---|---|---|---|
| | | Base case | Scenario B | Scenario A |
| GW109305 | 6.1 | Less than 1 | Less than 1 | Less than 1 |

Note: BGL means below ground level
Drawdown for each receiver is rounded up to the nearest metre

Bore GW023150 is recorded in the Department of Planning, Industry and Environment (Water) database as being less than two metres deep. Modelling predicts that the cumulative water table drawdown at this bore would be up to three metres in 2128. If this bore were to rely on shallow groundwater, water availability at this bore could be impacted.

Bore GW026513 is recorded in the Department of Planning, Industry and Environment (Water) database as being 64 metres deep, with a water level of about six metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to two metres in 2128, which equates to about three per cent of available drawdown (water head) within the bore and is therefore anticipated to cause negligible impact to the groundwater supply.

Bore GW072478 is recorded in the Department of Planning, Industry and Environment (Water) database as being 180.5 metres deep with a water level of about 48 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to two metres in 2128, which equates to about five per cent of available drawdown (water head) within the bore and is therefore anticipated to cause negligible impact to the groundwater supply.

Bore GW107970 is recorded in the Department of Planning, Industry and Environment (Water) database as being 199 metres deep with a water level of 110 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to 13 metres in 2128, which equates to about 15 per cent of available drawdown and is therefore not anticipated to cause significant impact to the groundwater supply.

Bore GW108224 is recorded in the Department of Planning, Industry and Environment (Water) database as being 132.4 metres deep with a water level of 35 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to 11 metres in 2128, which equates to about 11 per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

Bore GW108991 is recorded in the Department of Planning, Industry and Environment (Water) database as being 168 metres deep with a water level about 13 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to four metres in 2128 (cumulative case), which equates to less than three per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

For Scenario B, all bores are predicted to experience similar (or slightly lower) drawdown than the Base case. This suggests that under hydrogeological conditions that are less likely to induce groundwater level drawdown, these potential impacts identified under the Base case would be similar.

For Scenario A, bores GW026513, GW029731, GW072478 and GW107757 are predicted to experience greater drawdown than the Base case. However, the greater predicted drawdown under Scenario A scenario is no more than two additional metres of drawdown at these bores. This equates to less than an additional three per cent reduction in the available groundwater drawdown (head) within these bores.

Therefore, the predicted impacts under Scenario A and B are not expected to be significantly different to those predicted for the Base case during operation.

### 3.2.2 Areas of environmental interest for contamination

The following potential impacts may arise from areas of environmental interest for contamination:

- Where there is existing groundwater contamination altered hydraulic gradients may change the speed and direction of contaminant migration. Drawdown of the groundwater table may also act to disconnect the contaminant plume from the contaminant source
- Where there is existing soil contamination that has not yet migrated to the groundwater table lowering of the groundwater table would act to mitigate, or delay, the potential migration of contamination through groundwater.

Predicted cumulative drawdown at areas of environmental interest for contamination (AEI) within 500 metres of the project alignment and with moderate or high risk are summarised in Table 3-2.

**Table 3-2 Predicted cumulative (all projects) drawdown of water table at areas of environmental interest for contamination after 100 years of operation (2128)**

| Reference | Area of environmental interest (AEI) | Contaminated groundwater risk ranking | Cumulative drawdown in 2128 (m) | | |
|---|---|---|---|---|---|
| | | | Base case | Scenario A | Scenario B |
| B1 | Unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray | Moderate | Up to 19 | Up to 5 | Up to 30 |
| B7 | Punch Street at Artarmon | Moderate | Up to 21 | Up to 19 | Up to 21 |
| B9 | Flat Rock Reserve at Northbridge | Moderate | Up to 25 | Up to 27 | Up to 25 |
| B10 | Willoughby Leisure Centre and Bicentennial Reserve at Willoughby | High | Up to 27 | Up to 34 | Up to 20 |
| B13 | Balgowlah Golf Course at Balgowlah | Moderate | Up to 11 | Up to 23 | Up to 3 |
| W8 | Waverton Park – Woolcott Road, Waverton | High | Up to 13 | Up to 9 | Up to 12 |

Note: Drawdown for each receiver is rounded up to the nearest metre

For the Base case, significant drawdown was predicted at the unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray (AEI B1); Punch Street, Artarmon (AEI B7); Flat Rock Reserve at Northbridge (AEI B9); the Willoughby Leisure Centre and Bicentennial Reserve (AEI B10); and Balgowlah Golf Course at Balgowlah (AEI B13).

The levels of drawdown at Waverton Park (AEI W8) during construction would be largely due to the effect of the Western Harbour Tunnel and Warringah Freeway Upgrade project (cumulative Base case).

Groundwater drawdown predictions for Scenario A and B are similar to, or less than, the Base case drawdown predictions at many of the AEI in the vicinity of the project. The exceptions are for Scenario A predictions at Flat Rock Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10) and Balgowlah Golf Course at Balgowlah (AEI B13); and Scenario B predictions at the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1).

Depending on the nature of the soil and groundwater contamination present and the location and proximity of the tunnel, the Scenario B uncertainty analysis results suggest that the potential impacts associated with areas of environmental interest for contamination could exceed those reported in Appendix N (Technical working paper: Groundwater) for the unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray (AEI B1), Flat Rock Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), and Balgowlah Golf Course at Balgowlah (AEI B13).

However, any contaminants from these sites already present in the groundwater (due to contact) would be expected to travel towards the tunnels. The rate of contaminant migration would depend predominantly on the hydraulic conductivity at the area of environmental interest for contamination, contaminant viscosity/dispersion/solubility and the hydraulic gradient at the site. Furthermore, where existing soil contamination was present that had not yet migrated to the groundwater table, lowering of the groundwater table would act to mitigate, or delay, the potential migration of contamination through groundwater.

Depending on the nature and extent of any leachate contaminated groundwater associated with the former landfill at Bicentennial Reserve at Willoughby (AEI B10), groundwater inflows to the adjacent sections of tunnel could potentially pose a human health risk. Any volatile compounds (if present and in sufficient quantities) could potentially affect tunnel users. All groundwater inflows would be collected and treated at the operational wastewater treatment plants. Any contaminants (if present and in sufficient quantities) could pose a risk to the operation of the water treatment processes and associated operational personnel.

The NSW Aquifer Interference Policy states that the beneficial use of a groundwater source 40 metres away from the activity must not be reduced. Contaminant migration caused by drawdown from the tunnel has the potential to degrade water quality more than 40 metres from the tunnel.

There are no groundwater supply bores that lie between the relevant AEI and the tunnels. Therefore, the water quality at groundwater supply bores is not expected to be impacted by the project. The only groundwater dependent ecosystem in the vicinity of these AEI is that which is present at the upper reaches of Flat Rock Creek and Quarry Creek in the vicinity of the Willoughby Leisure Centre and Bicentennial Reserve ie Terrestrial groundwater dependent ecosystem - Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest. This groundwater dependent ecosystem is not expected to be impacted by contaminant migration since the potentially contaminated fill area at this area of environmental interest is immediately overlying the tunnels and would therefore migrate vertically towards the tunnels and away from the groundwater dependent ecosystem, which would satisfy the requirements of the Aquifer Interference Policy.

### 3.2.3 Surface water systems

Further investigations and assessment of predicted groundwater baseflow reductions, and the potential impacts to surface water systems, are provided in Appendix E of this submissions report.

The predicted drawdown at watercourses after 100 years of operation (2128) is provided in Table 3-3 and the predicted volumetric and percentage reduction in groundwater baseflow to various watercourses and water bodies is provided in Table 3-3.

**Table 3-3 Predicted cumulative (all projects) water table drawdown at watercourses after 100 years of operation**

| Watercourse | Location | Base case drawdown (m) | Scenario A drawdown (m) | Scenario B drawdown (m) |
|---|---|---|---|---|
| Flat Rock Creek | Northbridge | Up to 29 | Up to 32 | Up to 21 |
| Quarry Creek | Cammeray | Up to 18 | Up to 9 | Up to 8 |
| Willoughby Creek | Cammeray | Up to 7 | Up to 3 | Up to 3 |
| Burnt Bridge Creek | North Balgowlah | Up to 6 | Up to 10 | Up to 3 |
| Sailors Bay Creek | Castlecrag | Up to 5 | Up to 6 | Up to 4 |
| Manly Dam | Manly Vale/Allambie Heights | Less than 1 | Less than 1 | Less than 1 |
| Berrys Creek | Longueville | Up to 2 | Up to 2 | Less than 1 |
| Gore Creek | Longueville | Less than 1 | Up to 2 | Less than 1 |
| Tambourine Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Tannery Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Stringybark Creek | Lane Cove | Less than 1 | Up to 2 | Less than 1 |
| Swaines Creek | Lane Cove | Less than 1 | Up to 2 | Less than 1 |
| Blue Gum Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Scotts Creek | Castlecrag | Less than 1 | Up to 2 | Less than 1 |
| Camp Creek and Sugarloaf Creek | Castlecrag | Up to 2 | Up to 3 | Less than 1 |

Note: Drawdown for each receiver is rounded up to the nearest metre

**Table 3-4: Predicted cumulative (all projects) baseflow reduction at watercourses after 100 years of operation**

| Watercourse | Location | Maximum cumulative baseflow reduction (kL/day) | | | Maximum cumulative flow reduction (per cent) | | |
|---|---|---|---|---|---|---|---|
| | | Base case | Scenario A | Scenario B | Base case | Scenario A | Scenario B |
| Flat Rock Creek | Northbridge | 84.7 | 630.0 | 7.9 | 39.0 | 87.0 | 5.5 |
| Quarry Creek | Cammeray | 11.4 | N/A | 0.1 | 69.0 | N/A | 0.5 |
| Willoughby Creek | Cammeray | Neg | N/A | Neg | Neg | N/A | Neg |
| Burnt Bridge Creek | North Balgowlah | 16.8 | N/A | 0.6 | 96.0 | N/A | 0.9 |
| Sailors Bay Creek | Castlecrag | Neg | N/A | Neg | Neg | N/A | Neg |
| Manly Dam | Manly Vale/Allambie Heights | 1.2 | N/A | Neg | 2.0 | N/A | Neg |
| Berrys Creek | Longueville | Neg | N/A | Neg | Neg | N/A | Neg |
| Gore Creek | Longueville | Neg | N/A | Neg | Neg | N/A | Neg |
| Tambourine Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Tannery Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Stringybark Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Swaines Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Blue Gum Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Scotts Creek | Castlecrag | Neg | N/A | Neg | Neg | N/A | Neg |
| Camp Creek and Sugarloaf Creek | Castlecrag | 0.2 | N/A | Neg | 4.0 | N/A | Neg |

Notes: Neg means negligible, N/A means not applicable as there would be no baseflow under the Base case with the adopted parameter set

The model was also used to predict potential groundwater baseflow reduction. Groundwater baseflow refers to the groundwater contribution to total streamflow, of which it is one part. The predicted baseflow reduction is a total for the stream system as a whole.

The baseflows predicted from the Base case model at the creeks nearest to the proposed tunnel alignment (Flat Rock Creek, Quarry Creek and Burnt Bridge Creek) were significantly less than streamflows measured during an extended dry period during the 2018 drought. As described in Annexure F of Appendix N (Technical working paper: Groundwater), preliminary streamflow measurements were carried out at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek in May 2018, following a period of two weeks without rain. The measured streamflow for the three creeks during this extended dry period was up to one order of magnitude higher than modelled baseflow. For example, measured Flat Rock Creek total streamflow was 1,590 $m^3$ per day compared to a modelled baseflow (Base case) of approximately 215 $m^3$ per day after 100 years of operation. The comparison of modelled baseflow (groundwater contribution to streamflow) and measured total streamflow during an extended dry period during a drought indicates that baseflow is a small proportion of streamflow, even during periods of low rainfall runoff.

The model indicates that baseflow reduction to Flat Rock Creek during operation under Scenario A would be significantly greater (above a 20 per cent loss in baseflow) than for the Base case and for Scenario A uncertainty scenario.

It is therefore possible that where hydrogeological conditions are consistent with those of the Base case or Scenario A, baseflow reduction to Flat Rock Creek is likely to be significant during operation.

The reduction in baseflow to Flat Rock Creek under Scenario A has the potential to impact the groundwater dependent ecosystem at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) to a greater extent than under the Base case. The reduction in baseflow to Flat Rock Creek under Scenario B has the potential to impact the groundwater dependent ecosystems at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) to a lesser extent than under the Base case.

For all other watercourses, the baseflow reduction for Scenario A is represented as not applicable ("N/A") (Table 3-4). This is because when Scenario A parameter values are applied to the model, the watercourses become 'losing streams', dominated by leakage loss from the watercourse to the groundwater system ie the groundwater table would be below the base of the watercourse and there would, therefore, be no associated groundwater contributions to streamflow.

It should be noted that the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction for the following reasons:

- The modelled groundwater inflows to the tunnels are controlled by the formation permeability, which for some tunnel sections resulted in inflow predictions to the tunnels greater than 1 L/s/km. However, a design criterion for the project is that the tunnel inflows do not exceed 1 L/s/km for any given kilometre of tunnel, and the tunnels would be constructed to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. Potential baseflow reduction to watercourses and waterbodies would therefore be less than predicted and discussed here
- The conceptual hydrogeological model assumes that there is continuous saturation between the tunnel and the shallow water table at the location of watercourses (i.e. there is a single connected groundwater system beneath the creek and the proposed underlying tunnel). It is assumed that the groundwater system is stratified, with permeability of the modelled layers decreasing with depth. In terms of baseflow reduction calculations, this means that there would be no baseflow contribution from any location along the watercourse where any groundwater drawdown is predicted, no matter how small. However, in reality, the hydrogeological conditions within the project area may consist of multiple vertically

(hydraulically) disconnected groundwater systems separated by low permeability hydrogeological units. The predicted maximum drawdowns beneath the creek are therefore unlikely to be realised. Also, the predicted extents of drawdown would be less and might not affect (cause baseflow reductions in) as much of the watercourses compared to current drawdown predictions. The predicted reductions in baseflows are therefore conservative

The results of the uncertainty analysis indicate that adopting an alternative conceptual hydrogeological model consisting of multiple hydraulically disconnected vertical groundwater systems would result in less predicted drawdown beneath watercourses and much lower baseflow reduction. For example, Base case model results presented in Figure 3-2 show predicted water table drawdown of approximately one metre beneath a significant portion of the Burnt Bridge Creek segment located to the north-west of the proposed tunnel branch to Balgowlah. Baseflow reduction of greater than 90 per cent is predicted for this segment of Burnt Bridge Creek. However, Scenario B model results presented in Figure 3-6 indicate drawdown of less than one metre for the headwaters segment of Burnt Bridge Creek with negligible baseflow reduction.

- For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. At the time of modelling, there was no information on the nature of creek bed conditions for Willoughby Creek and Sailors Bay Creek. Even with this assumption, estimated baseflow reductions due to groundwater drawdown are insignificant for these watercourses. If any of these watercourses are lined, the baseflow reduction would be less than that predicted
- Groundwater inflows to the tunnels would be collected, treated and discharged to Flat Rock Creek. Any discharge to the waterways would act to offset flow reduction due to reduced groundwater contribution.

### 3.2.4 Groundwater dependent ecosystems and sensitive environments

Further investigations and assessment of predicted groundwater baseflow reductions, and the potential impacts to groundwater dependent ecosystems, are provided in Appendix E of this submissions report.

Table 3-5 summarises the predicted cumulative drawdown of the water table at groundwater dependent ecosystems and sensitive environments after 100 years of operation (2128).

For the Base case, drawdown is predicted to be less than one metre at the Coastal Upland Swamp, the vegetation at Quarry Creek and the groundwater dependent ecosystem at Manly Dam Reserve. Cumulative water table drawdown up to 12 metres was predicted at the groundwater dependent ecosystems at Flat Rock Creek and Quarry Creek. The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity Development Assessment Report). The other groundwater dependent ecosystems in the project area are outside the predicted drawdown extents.

For both Scenario A and B, drawdown at these ecosystems is predicted to be similar to, or less than, that predicted under the Base case. Based on this, the predicted drawdown under the Base case, as reported in the environmental impact statement, can be considered a conservative assessment.

**Table 3-5: Predicted cumulative (all projects) drawdown of water table at groundwater dependent ecosystems and sensitive environments after 100 years of operation (2128)**

| Receiver | Location | Cumulative drawdown in 2128 (m) |
|---|---|---|

| | | Base case | Scenario A | Scenario B |
|---|---|---|---|---|
| Vegetation at Flat Rock Creek and Quarry Creek | Northbridge | Up to 12 | Up to 6 | Up to 4 |
| Vegetation at Bates Creek | Bates Reserve/Garigal National Park | Less than 1 | Less than 1 | Less than 1 |
| Manly Dam Reserve | Manly Dam Reserve | Less than 1 | Less than 1 | Less than 1 |
| Coastal Upland Swamp | Bates Reserve/Garigal National Park | Less than 1 | Less than 1 | Less than 1 |

Note: Drawdown for each receiver is rounded up to the nearest metre

## 4. At the completion of construction

### 4.1 Water table drawdown

Water table drawdown would occur because groundwater would flow into the tunnels and reduce groundwater pressures (and groundwater levels) in the surrounding aquifer. Figure 4-1 and Figure 4-2 show the predicted water table drawdown at the end of tunnel construction for the Base case as shown in Appendix N (Technical working paper: Groundwater).

The predicted drawdown is up to a maximum of around 28 metres overlying the tunnel cross passages in the Artarmon area. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 0.5 kilometres northwards in the Willoughby/Chatswood area and extending southwards up to around 0.4 kilometres in the Crows Nest area.

North of Middle Harbour, the drawdown would be slightly lower, with maximum predicted drawdown of 16 metres between Seaforth and Balgowlah. The drawdown is predicted to reach the harbour on both sides of Middle Harbour as well as at Berrys Bay and Balls Head Bay.

Figure 4-3 and Figure 4-4 show the predicted water table drawdown at the end of tunnel construction for Scenario A.

For Scenario A, the magnitude and extent of predicted drawdown is significantly greater than the Base case to the south of Middle Harbour, with a maximum of around 41 metres immediately overlying the tunnel centreline in the Northbridge area. Predicted drawdown propagates away from the tunnels, with the drawdown extending up to around 1.8 kilometres northwards in the Willoughby/Chatswood area, around 1.8 kilometres westwards across Artarmon, and around 3.4 kilometres southwards to North Sydney. North of Middle Harbour, the predicted drawdown is greater than the Base case, with maximum predicted drawdown of 35 metres between Seaforth and Balgowlah. The extent of predicted drawdown for Scenario A north of Middle Harbour is slightly larger than for the Base case.

Figure 4-5 and Figure 4-6 show the predicted water table drawdown at the end of tunnel construction for Scenario B.

For Scenario B, the predicted drawdown is generally less than the drawdown for the Base case, with the exception of some local anomalies due to the method of selection of model parameter values. The lateral extent of predicted drawdown is generally less than the lateral extent of predicted drawdown for the Base case. North of Middle Harbour, significantly less drawdown (a maximum predicted drawdown of 11 metres between Seaforth and Balgowlah) and significantly less lateral extent of drawdown is predicted for Scenario B compared to the Base case.

As noted earlier, the method of choosing the model parameter values for the uncertainty analysis and the fact that the model is not then calibrated can lead to some local anomalies in terms of drawdown. In addition, some model parameters, and the magnitude of variation, have a greater influence over other parameters when assessing drawdown effects in certain areas of the model e.g. for Scenario A, high hydraulic conductivity can override the drawdown effects of low storage, resulting in broader but shallower drawdown in certain parts of the model. However, the likely impacts and the appropriateness of the recommended environmental management measures can be considered based on the general observations from the additional uncertainty scenarios.

It should be noted that the modelled groundwater inflows to the tunnels were controlled by bulk rock and fracture permeability, which for certain sections of the proposed tunnels, causes inflows to the tunnels to be greater than 1 L/s/km. However, a design criterion for the project is that the tunnel inflows do not exceed 1 L/s/km for any given kilometre of tunnel, and measures would be taken to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling for the Base case and Scenario A.

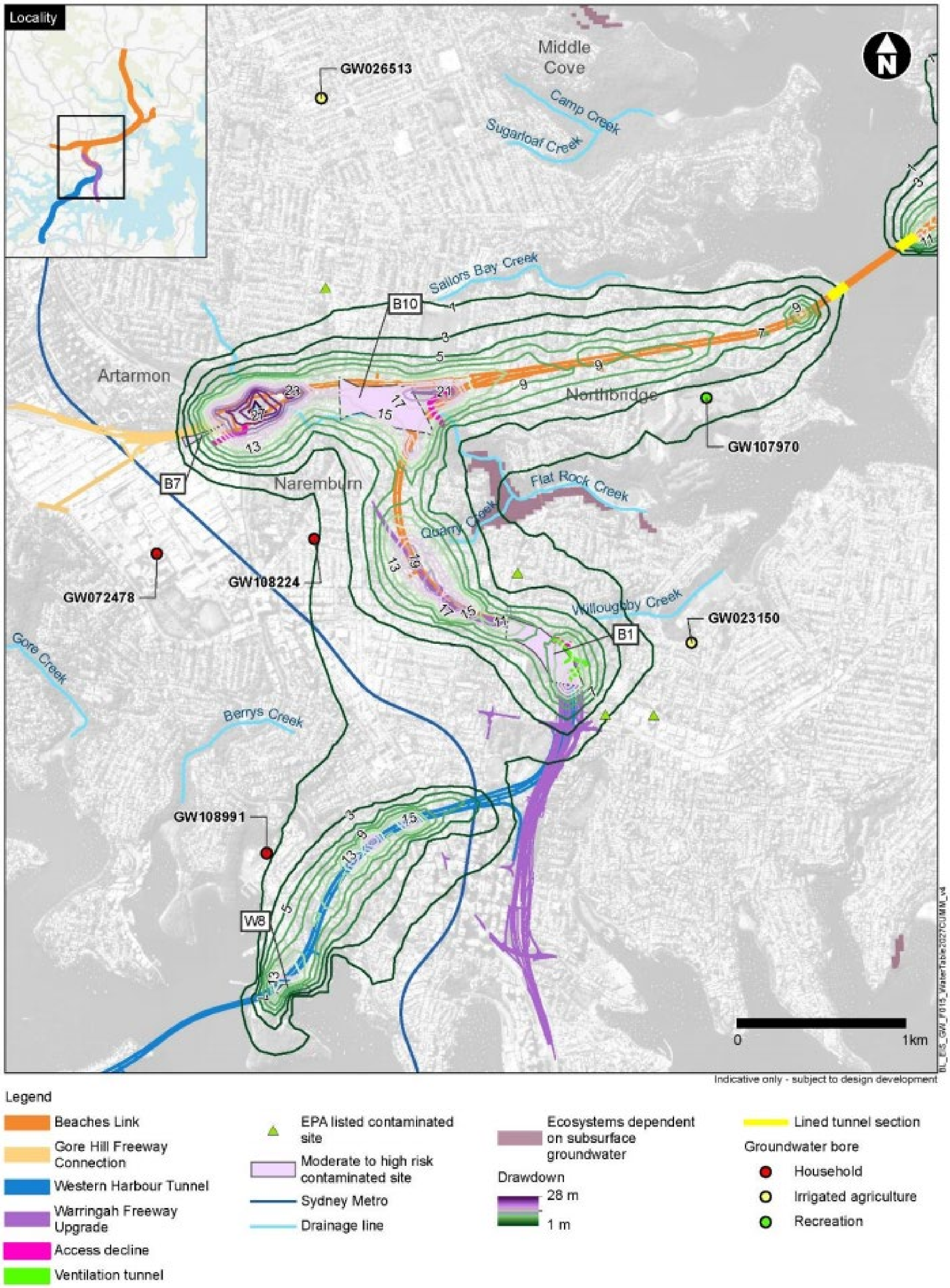


**Figure 4-1: Predicted cumulative (all projects) drawdown in the water table at the end of tunnel construction (south), June 2028, for the Base case (source: Figure 6-3 of Appendix N (Technical working paper: Groundwater))**

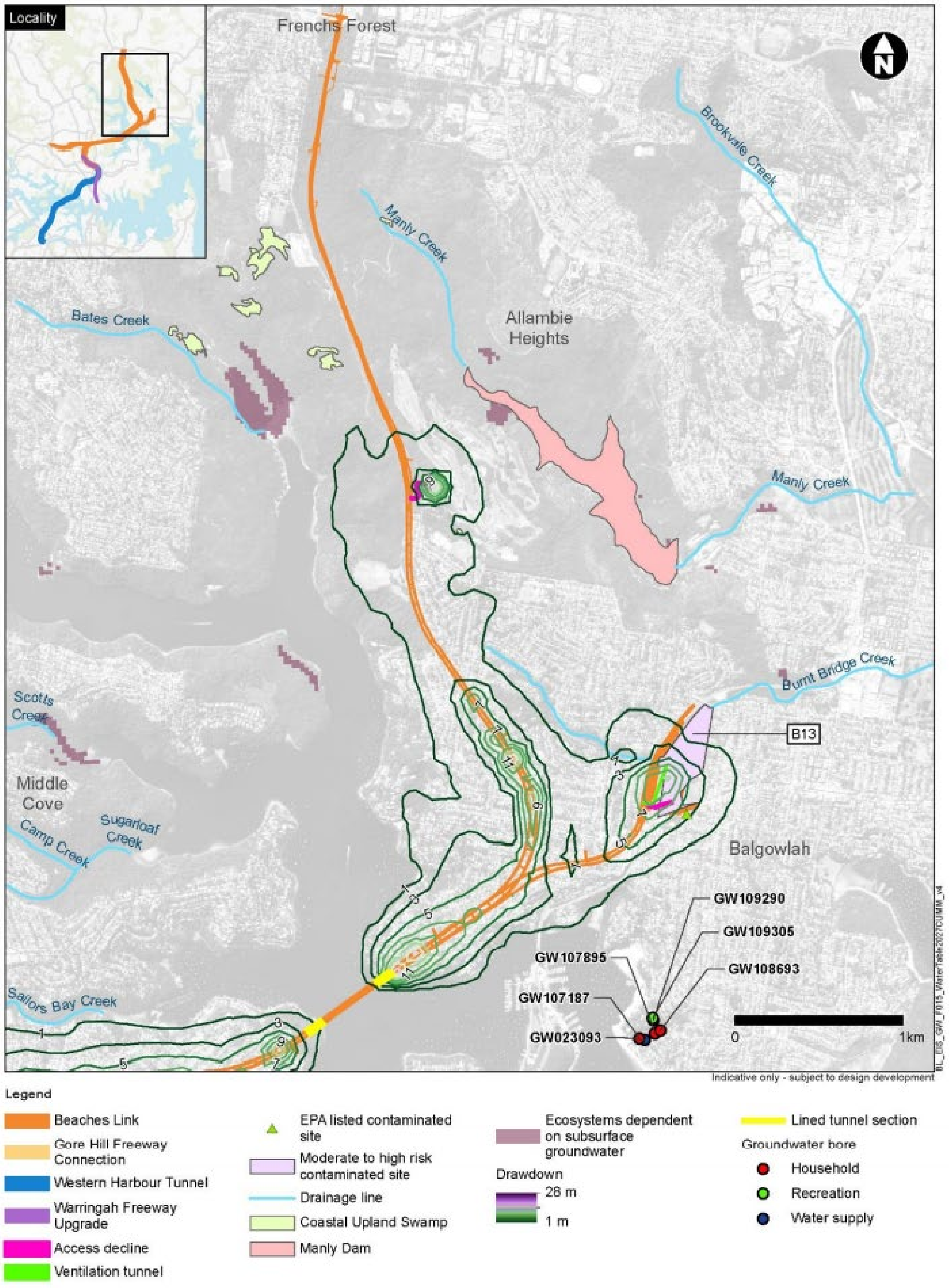


**Figure 4-2: Predicted cumulative (all projects) drawdown in the water table at the end of tunnel construction (north), June 2028, for the Base case (source: Figure 6-4 of Appendix N (Technical working paper: Groundwater))**

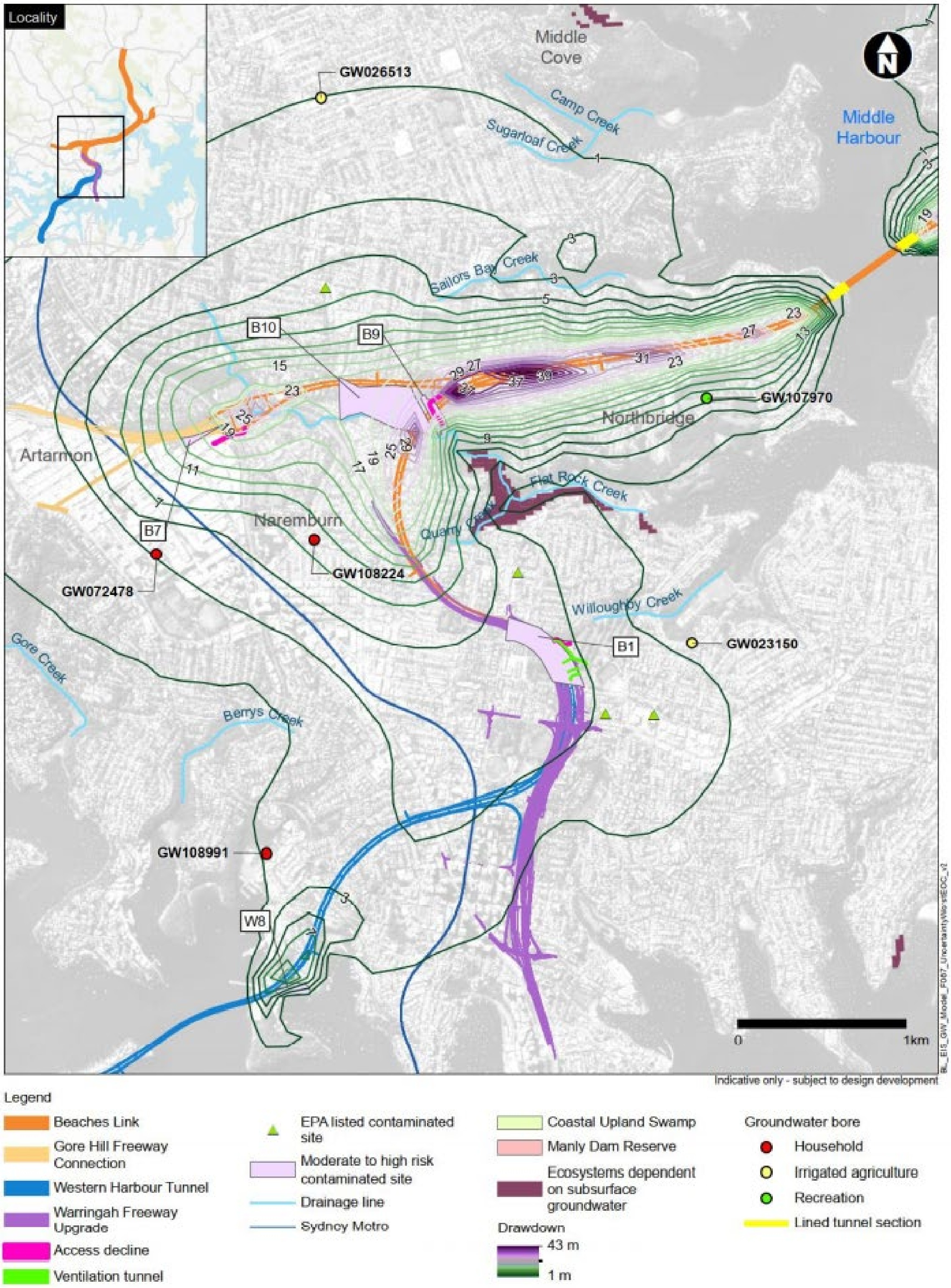


**Figure 4-3: Predicted cumulative (all projects) drawdown in the water table at the end of tunnel construction (south), June 2028, for Scenario A**

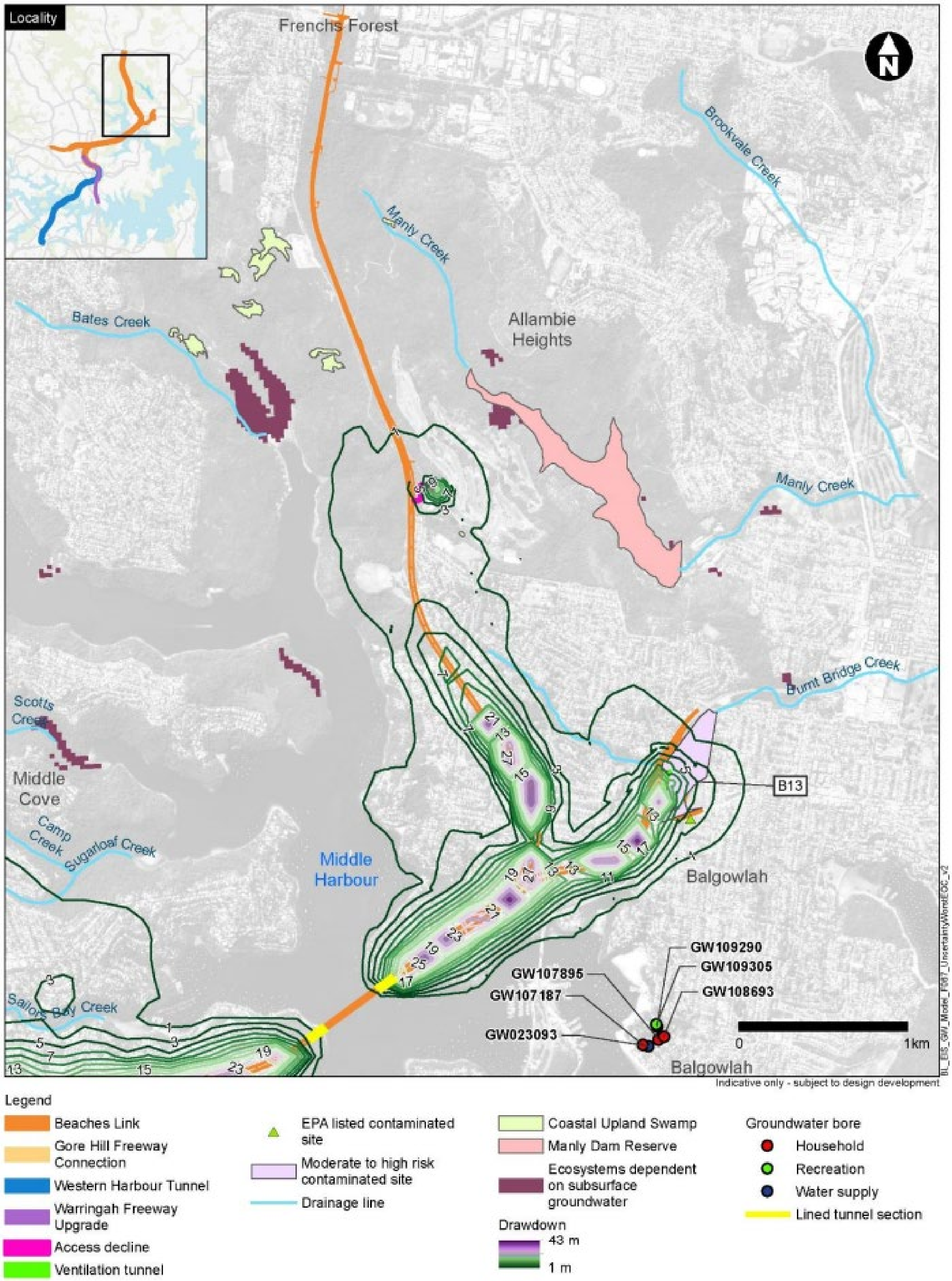


**Figure 4-4**: **Predicted cumulative (all projects) drawdown in the water table at the end of tunnel construction (north), June 2028, for Scenario A**

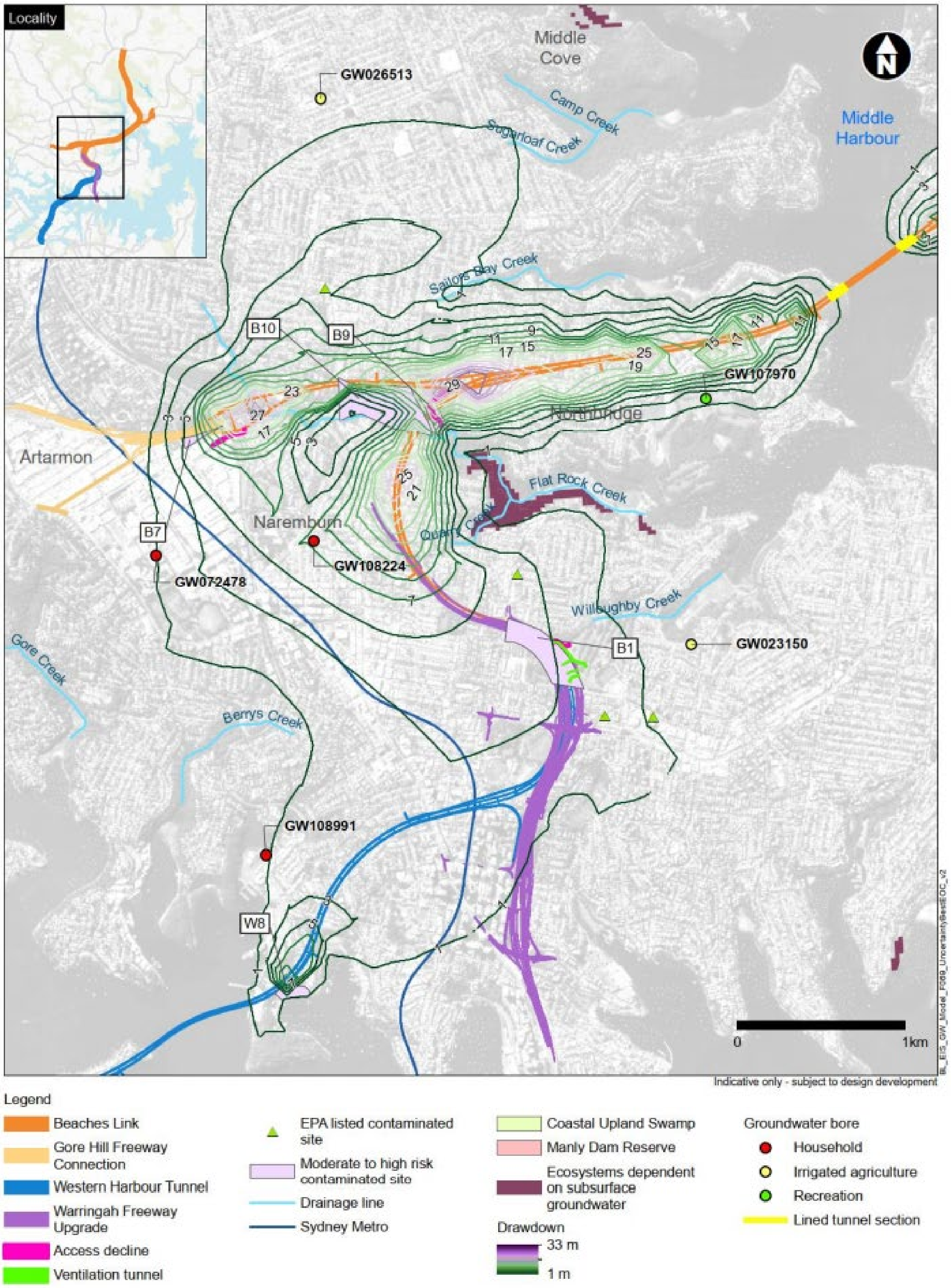


**Figure 4-5: Predicted cumulative (all projects) drawdown in the water table at the end of tunnel construction (south), June 2028, for Scenario B**

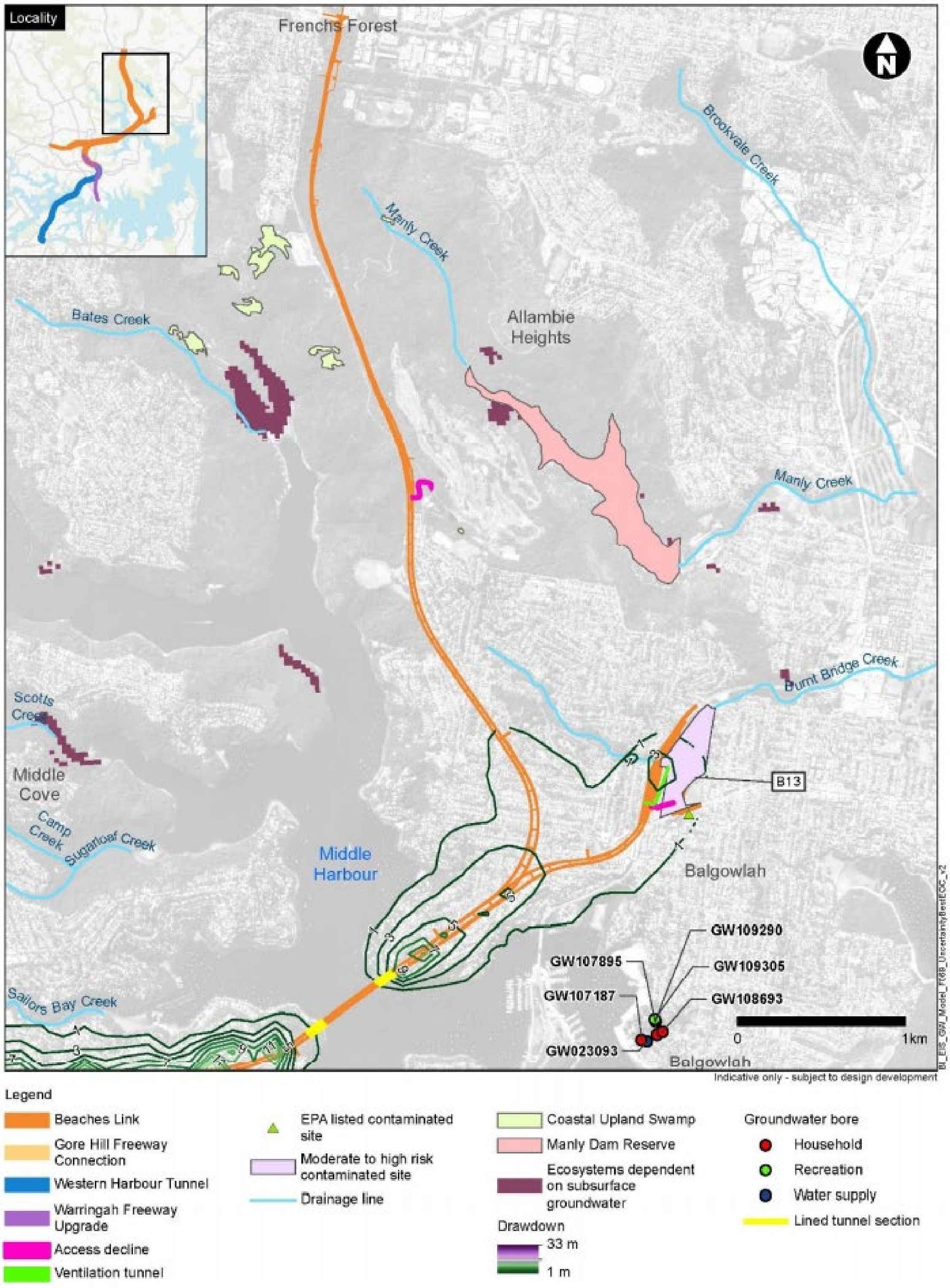


**Figure 4-6: Predicted cumulative (all projects) drawdown in the water table at the end of tunnel construction (north), June 2028, for Scenario B**

## 4.2 Predicted impacts

Potential impacts resulting from the predicted groundwater level drawdown associated with construction of the project are discussed in the following sections. Drawdown for each receiver is rounded up to the nearest metre and assessed against the NSW Aquifer Interference Policy requirements.

### 4.2.1 Groundwater supply bores

Where existing groundwater users are using bores that target the water table the water table drawdown has been considered. Where bores are targeting deeper horizons, a conservative approach has been adopted to assess the impacts by considering the maximum drawdown across all model layers.

For the Base case, of the 21 groundwater users identified, all bores except GW107970, GW108224, GW108991 are predicted to experience less than one metre of drawdown at the end of construction and would therefore not be impacted by the project.

Predicted cumulative (all projects) drawdown and impact at receivers at the end of construction (2028)Table 4-1summarises the predicted cumulative drawdown at groundwater receivers at the end of construction (2028).

**Table 4-1 Predicted cumulative (all projects) drawdown and impact at receivers at the end of construction (2028)**

| Bore ID | Bore depth (m BGL) | Cumulative drawdown in 2028 (m) | | |
|---|---|---|---|---|
| | | Base case | Scenario B | Scenario A |
| GW023093 | 2.4 | Less than 1 | Less than 1 | Less than 1 |
| GW023150 | 1.8 | Less than 1 | Less than 1 | Less than 1 |
| GW026513 | 64 | Less than 1 | Less than 1 | Less than 1 |
| GW029731 | 21.6 | Less than 1 | Less than 1 | Less than 1 |
| GW033631 | 14 | Less than 1 | Less than 1 | Less than 1 |
| GW033711 | 13.4 | Less than 1 | Less than 1 | Less than 1 |
| GW065075 | 150 | Less than 1 | Less than 1 | Less than 1 |
| GW072478 | 180.5 | Less than 1 | Less than 1 | Up to 4 |
| GW102744 | 39 | Less than 1 | Less than 1 | Less than 1 |
| GW103127 | 138 | Less than 1 | Less than 1 | Less than 1 |
| GW103133 | 46 | Less than 1 | Less than 1 | Less than 1 |
| GW107187 | 8 | Less than 1 | Less than 1 | Less than 1 |
| GW107757 | 162.6 | Less than 1 | Less than 1 | Less than 1 |
| GW107895 | 4 | Less than 1 | Less than 1 | Less than 1 |
| GW107970 | 199 | Up to 7 | Up to 2 | Up to 10 |
| GW108224 | 132.4 | Up to 5 | Up to 8 | Up to 9 |
| GW108693 | 4 | Less than 1 | Less than 1 | Less than 1 |
| GW108792 | 174 | Less than 1 | Less than 1 | Less than 1 |

| Bore ID | Bore depth (m BGL) | Cumulative drawdown in 2028 (m) | | |
|---|---|---|---|---|
| | | Base case | Scenario B | Scenario A |
| GW108991 | 168 | Up to 3 | Less than 1 | Up to 2 |
| GW109290 | 6.1 | Less than 1 | Less than 1 | Less than 1 |
| GW109305 | 6.1 | Less than 1 | Less than 1 | Less than 1 |

Notes: BGL means below ground level
Drawdown for each receiver is rounded up to the nearest metre

Bore GW107970 is recorded in the Department of Planning, Industry and Environment (Water) database as being 199 metres deep with a water level of 110 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to seven metres in 2028, which equates to about eight per cent of available drawdown and is therefore not anticipated to cause significant impact to the groundwater supply.

Bore GW108224 is recorded in the Department of Planning, Industry and Environment (Water) database as being 132.4 metres deep with a water level of 35 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at the bore would be up to five metres in 2028, which equates to about five per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

Bore GW108991 is recorded in the Department of Planning, Industry and Environment (Water) database as being 168 metres deep with a water level about 13 metres below ground surface. Modelling predicts that the cumulative maximum drawdown at this bore would be up to three metres in 2028, which equates to less than two per cent of available drawdown and is therefore anticipated to cause negligible impact to the groundwater supply.

For Scenario B, the predicted drawdown is lower than the Base case for bores GW072478 and GW107970, but three metres greater for bore GW108224. For bore GW108224, this equates to about seven per cent of available drawdown, compared to about five per cent under the Base case. This suggests that under hydrogeological conditions consistent with Scenario B, the potential impacts identified under the Base case would be similar.

For Scenario A, bores GW072478, GW107970 and GW108224 are predicted to experience greater drawdown than the Base case. However, the greater predicted drawdown under Scenario A is no more than four additional metres of drawdown at any one of these bores, with an equivalent reduction in the available groundwater drawdown (head) at any one of these bores of less than 11 per cent.

Therefore, groundwater supply bores under Scenario A conditions are not expected to be significantly different to those under the Base case, and construction of the project is anticipated to cause negligible impact to water availability at groundwater supply bores.

### 4.2.2 Areas of environmental interest for contamination

The following potential impacts may arise from areas of environmental interest for contamination:

- Where there is existing groundwater contamination, altered hydraulic gradients may change the speed and direction of contaminant migration. Drawdown of the groundwater table may also act to disconnect the contaminant plume from the contaminant source
- Where there is existing soil contamination that has not yet migrated to the groundwater table, lowering of the groundwater table would act to mitigate, or delay, the potential migration of contamination through groundwater.

Predicted drawdown at areas of environmental interest for contamination (AEI) within 500 metres of the project alignment and with moderate or high risk are summarised in Table 4-2.

**Table 4-2 Predicted cumulative (all projects) drawdown of water table at areas of environmental interest for contamination at the end of construction (2028)**

| Reference | Area of environmental interest (AEI) | Contaminated groundwater risk ranking | Cumulative drawdown in 2028 (m) | | |
|---|---|---|---|---|---|
| | | | Base case | Scenario A | Scenario B |
| B1 | Unsealed areas next to Warringah Freeway – Eastern side (Cammeray Golf Course) at Cammeray | Moderate | Up to 17 | Up to 5 | Up to 5 |
| B7 | Punch Street at Artarmon | Moderate | Up to 19 | Up to 15 | Up to 19 |
| B9 | Flat Rock Reserve at Northbridge | Moderate | Up to 21 | Up to 27 | Up to 22 |
| B10 | Willoughby Leisure Centre and Bicentennial Reserve at Willoughby | High | Up to 22 | Up to 34 | Up to 19 |
| B13 | Balgowlah Golf Course at Balgowlah | Moderate | Up to 11 | Up to 27 | Up to 3 |
| W8 | Waverton Park – Woolcott Road, Waverton | High | Up to 12 | Up to 9 | Up to 9 |

Note: Drawdown for each receiver is rounded up to the nearest metre

For the Base case, significant drawdown was predicted at the unsealed areas next to Warringah Freeway (eastern side by Cammeray Golf Course) at Cammeray (AEI B1); Punch Street, Artarmon (AEI B7); Flat Rock Reserve at Northbridge (AEI B9); the Willoughby Leisure Centre and Bicentennial Reserve (AEI B10); and Balgowlah Golf Course at Balgowlah (AEI B13). The levels of drawdown at Waverton Park (AEI W8) during construction would be largely due to the effect of the Western Harbour Tunnel and Warringah Freeway Upgrade project (cumulative Base case).

Scenario A and B predict lesser drawdown at these sites, with the exception of the predicted Scenario A drawdown at Flat Rock Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10) and Balgowlah Golf Course at Balgowlah (AEI B13), and Scenario B at Flat Rock Reserve at Northbridge (AEI B9). Depending on the nature of the soil and groundwater contamination present and the location and proximity of the tunnel, the Scenario B uncertainty analysis results suggest that the potential impacts associated with areas of environmental interest for contamination could exceed those reported in

Appendix N (Technical working paper: Groundwater) at Flat Rock Reserve at Northbridge (AEI B9), Willoughby Leisure Centre and Bicentennial Reserve at Willoughby (AEI B10), and Balgowlah Golf Course at Balgowlah (AEI B13).

However, any contaminants from these sites already present in the groundwater (due to contact) would be expected to travel towards the tunnels. The rate of contaminant migration would depend predominantly on the hydraulic conductivity at the area of environmental interest for contamination, contaminant viscosity/solubility/dispersion and the hydraulic gradient at the site. Furthermore, where existing soil contamination was present that had not yet migrated to the groundwater table, lowering of the groundwater table would act to mitigate, or delay, the potential migration of contamination through groundwater.

The quality of groundwater inflows could pose a potential human health risk (due to the potential migration of potential volatile contaminants into the tunnel system from AEI B10). All groundwater inflows would be collected and treated at the construction wastewater treatment plant.

The NSW Aquifer Interference Policy states that the beneficial use of a groundwater source 40 metres away from the activity must not be reduced. Contaminant migration caused by drawdown from the tunnel has the potential to degrade water quality more than 40 metres from the tunnel.

There are no groundwater supply bores that lie between AEI and the tunnels. Therefore, the water quality at groundwater supply bores is not expected to be impacted by the project.

The only groundwater dependent ecosystem in the vicinity of these AEI is that which is present at the upper reaches of Flat Rock Creek and Quarry Creek in the vicinity of the Willoughby Leisure Centre and Bicentennial Reserve (i.e., Terrestrial groundwater dependent ecosystem - Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest). This groundwater dependent ecosystem is not expected to be impacted by contaminant migration since the potentially contaminated fill area at this area of environmental interest is immediately overlying the tunnels and would therefore migrate vertically towards the tunnels and away from the groundwater dependent ecosystem, which would satisfy the requirements of the Aquifer Interference Policy.

### 4.2.3 Surface water systems

Further investigations and assessment of predicted groundwater baseflow reductions, and the potential impacts to surface water systems, are provided in Appendix E of this submissions report.

The groundwater model was used to predict the groundwater drawdown at the surface watercourses. The maximum predicted groundwater drawdown at watercourses at the end of construction (2028) is provided in Table 4-3 and the predicted volumetric and percentage reduction in groundwater baseflow to various watercourses and water bodies is provided in Table 4-3. The predicted baseflow reduction is a total for the stream system as a whole.

**Table 4-3 Predicted cumulative (all projects) water table drawdown at watercourses at the end of construction (2028)**

| Watercourse | Location | Base case drawdown (m) | Scenario A drawdown (m) | Scenario B drawdown (m) |
|---|---|---|---|---|
| Flat Rock Creek | Northbridge | Up to 28 | Up to 31 | Up to 16 |
| Quarry Creek | Cammeray | Up to 9 | Up to 8 | Up to 6 |

| Watercourse | Location | Base case drawdown (m) | Scenario A drawdown (m) | Scenario B drawdown (m) |
|---|---|---|---|---|
| Willoughby Creek | Cammeray | Up to 4 | Up to 3 | Up to 2 |
| Burnt Bridge Creek | North Balgowlah | Up to 5 | Up to 9 | Up to 3 |
| Sailors Bay Creek | Castlecrag | Less than 1 | Up to 6 | Up to 3 |
| Manly Dam | Manly Vale/Allambie Heights | Less than 1 | Less than 1 | Less than 1 |
| Gore Creek | Longueville | Less than 1 | Less than 1 | Less than 1 |
| Tambourine Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Tannery Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Stringybark Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Swaines Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Blue Gum Creek | Lane Cove | Less than 1 | Less than 1 | Less than 1 |
| Scotts Creek | Castlecrag | Less than 1 | Less than 1 | Less than 1 |
| Camp Creek and Sugarloaf Creek | Castlecrag | Less than 1 | Up to 2 | Less than 1 |

Note: Drawdown for each receiver is rounded up to the nearest metre

**Table 4-4 Predicted cumulative (all projects) baseflow reduction at watercourses at the end of construction (2028)**

| Watercourse | Location | Maximum cumulative baseflow reduction (kL/day) | | | Maximum cumulative flow reduction (per cent) | | |
|---|---|---|---|---|---|---|---|
| | | Base case | Scenario A | Scenario B | Base case | Scenario A | Scenario B |
| Flat Rock Creek | Northbridge | 43.6 | 631.0 | 29.5 | 20.0 | 85.7 | 20.4 |
| Quarry Creek | Cammeray | 4.1 | N/A | 0.1 | 23.0 | N/A | 0.5 |
| Willoughby Creek | Cammeray | Neg | N/A | Neg | Neg | N/A | Neg |

| Watercourse | Location | Maximum cumulative baseflow reduction (kL/day) | | | Maximum cumulative flow reduction (per cent) | | |
|---|---|---|---|---|---|---|---|
| | | Base case | Scenario A | Scenario B | Base case | Scenario A | Scenario B |
| Burnt Bridge Creek | North Balgowlah | 16.7 | N/A | 0.5 | 79.0 | N/A | 0.7 |
| Sailors Bay Creek | Castlecrag | Neg | N/A | N/A | Neg | N/A | N/A |
| Manly Dam | Manly Vale/ Allambie Heights | 1.9 | N/A | 0.2 | 2.0 | N/A | 0.5 |
| Gore Creek | Longueville | Neg | N/A | Neg | Neg | N/A | Neg |
| Tambourine Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Tannery Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Stringybark Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Swaines Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Blue Gum Creek | Lane Cove | Neg | N/A | Neg | Neg | N/A | Neg |
| Scotts Creek | Castlecrag | Neg | N/A | Neg | Neg | N/A | Neg |
| Camp Creek and Sugarloaf Creek | Castlecrag | Neg | N/A | Neg | Neg | N/A | Neg |

Note: Neg means negligible, N/A means not applicable as there would be no baseflow under the Base case with the adopted parameter set

The model was also used to predict potential groundwater baseflow reductions. Groundwater baseflow refers to the groundwater contribution to total streamflow, of which it is one part.

The baseflows predicted from the Base case model at the creeks nearest to the proposed tunnel alignment (Flat Rock Creek, Quarry Creek and Burnt Bridge Creek) were significantly less than streamflows measured during an extended dry period during the 2018 drought. As described in Annexure F to Appendix N (Technical working paper: Groundwater) preliminary streamflow measurements were carried out at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek in May 2018, following a period of two weeks without rain. The measured streamflow for the three creeks during this extended dry period was up to one order of magnitude higher than modelled baseflow. For example, measured at Flat Rock Creek, total streamflow was 1,590 $m^3$ per day compared to a modelled baseflow (Base case) of approximately 216 $m^3$per day at end of construction. The comparison of modelled baseflow (groundwater contribution to streamflow) and measured total streamflow during an extended dry period during a drought indicates that baseflow is a small proportion of streamflow, even during periods of low rainfall runoff.

The model indicates that baseflow reduction to Flat Rock Creek at the completion of construction under Scenario A would be significantly greater than for the Base case.

Based on the available information, it is therefore likely that the baseflow to Flat Rock Creek would be reduced at the completion of construction.

The reduction in baseflow to Flat Rock Creek under Scenario A has the potential to impact the groundwater dependent ecosystems at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) to a greater extent than under the Base case. The reduction in baseflow to Flat Rock Creek under Scenario B has the potential to impact the groundwater dependent ecosystems at those locations (Coastal Sandstone Gully Forest, Sandstone Riparian Scrub and Coastal Sandstone Gully Forest) to a lesser extent than under the Base case.

For all other watercourses, the baseflow reduction for Scenario A is represented as not applicable ("N/A") (Table 4-4). This is because when Scenario A parameter values are applied to the model, the watercourses become 'losing streams', dominated by leakage loss from the watercourse to the groundwater system ie the groundwater table would be below the base of the watercourse and there would, therefore, be no associated groundwater contributions to streamflow.

It should be noted that the assessment of baseflow reduction is conservative and is likely to overestimate actual baseflow reduction for the following reasons:

- The modelled groundwater inflows to the tunnels were controlled by the formation permeability, which for some tunnel sections, resulted in inflow predictions to the tunnels greater than 1 L/s/km. However, a design criterion for the project is that the tunnel inflows do not exceed 1 L/s/km for any given kilometre of tunnel, and the tunnels would be constructed to ensure that this is the case. Therefore, the predicted tunnel inflows and associated groundwater level drawdown would be less than predicted by the modelling. Potential baseflow reduction to watercourses and waterbodies would therefore be less than predicted and discussed here
- The conceptual hydrogeological model assumes that there is continuous saturation between the tunnel and the shallow water table at the location of watercourses ie there is a single connected groundwater system beneath the creek and the proposed underlying tunnel). It is assumed that the groundwater system is stratified, with permeability of the modelled layers decreasing with depth. In terms of baseflow reduction calculations, this means that there would be no baseflow contribution from any location along the watercourse where any groundwater drawdown is predicted, no matter how small. However, in reality, the hydrogeological conditions within the project area may consist of multiple vertically (hydraulically) disconnected groundwater systems separated by low permeability hydrogeological units. The predicted maximum drawdown beneath the creeks are therefore unlikely to be realised. Also, the predicted extents of drawdown would be less and might not affect (cause baseflow reductions in) as much of the watercourses compared to current drawdown predictions. The predicted reductions in baseflow are therefore conservative
- For watercourses and waterbodies other than Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, the whole length or area at the base of the creek or dam is considered to be unlined. At the time of modelling, there was no information on the nature of creek bed conditions for Willoughby Creek and Sailors Bay Creek. Even with this assumption, estimated baseflow reductions due to groundwater drawdown are insignificant for these watercourses. If any of these watercourses were lined, the baseflow reduction would be less than predicted
- Groundwater inflows to the tunnels would be collected, treated and discharged to local waterways (Willoughby Creek, Flat Rock Creek, Burnt Bridge Creek). Any discharge to the waterways would act to offset flow reduction due to reduced groundwater contribution.

#### 4.2.4 Groundwater dependent ecosystems and sensitive environments

Further investigations and assessment of predicted groundwater baseflow reductions, and the potential impacts to groundwater dependent ecosystems, are provided in Appendix E of this submissions report.

There are four areas of vegetation considered to be groundwater dependent ecosystems or sensitive environments within the area of predicted drawdown. Table 4-5 summarises the predicted cumulative drawdown of the water table at groundwater dependent ecosystems and sensitive environments at the end of construction (2028).

For the Base case, drawdown at the following ecosystems is predicted to be less than one metre over the construction period: vegetation at Bates Creek, vegetation at Manly Dam Reserve, and the Coastal Upland Swamp south of Frenchs Forest. Drawdown is predicted to be up to five metres at the vegetation at Flat Rock Creek and Quarry Creek. The potential significance of these impacts is discussed in Appendix S (Technical working paper: Biodiversity Development Assessment Report). The other groundwater dependent ecosystems in the project area are outside the predicted Base case drawdown extents.

For Scenario A, drawdown at the vegetation at Bates Creek, the vegetation at Manly Dam Reserve and the Coastal Upland Swamp south of Frenchs Forest is predicted to be equal to or less than the drawdown predicted for the Base case. Drawdown at the vegetation at Flat Rock Creek and Quarry Creek is predicted to be greater than for the Base case.

For Scenario B, drawdown at the vegetation at Bates Creek, the vegetation at Manly Dam Reserve, the Coastal Upland Swamp south of Frenchs Forest. and the vegetation at Flat Rock Creek and Quarry Creek is predicted to be equal to or less than the drawdown predicted for the Base case. Under the hydrogeological conditions adopted for Scenario B, impacts to groundwater dependent ecosystems are therefore predicted to be the same as, or similar to, the Base case.

**Table 4-5 Predicted cumulative (all projects) drawdown of water table at groundwater dependent ecosystems and sensitive environments at the end of construction (2028)**

| Receiver | Location | Cumulative drawdown in 2028 (m) | | |
|---|---|---|---|---|
| | | Base case | Scenario A | Scenario B |
| Vegetation at Flat Rock Creek and Quarry Creek | Northbridge | Up to 5 | Up to 6 | Up to 3 |
| Vegetation at Bates Creek | Bates Reserve/Garigal National Park | Less than 1 | Less than 1 | Less than 1 |
| Manly Dam Reserve | Manly Dam Reserve | Less than 1 | Less than 1 | Less than 1 |
| Coastal Upland Swamp | Bates Reserve/Garigal National Park | Less than 1 | Less than 1 | Less than 1 |

Note: Drawdown for each receiver is rounded up to the nearest metre

## 5. Conclusion

Appendix N (Technical working paper: Groundwater) provides an assessment of the potential groundwater impacts of the project on the basis of a conservative groundwater model developed following feedback from regulators and based on information available at the time.

Groundwater modelling was used to estimate potential changes in groundwater levels due to the project and associated impacts on various environmental and anthropogenic features. However, given that the available data used to develop the model was limited by the early stage of design, there is an element of uncertainty in the groundwater modelling results and therefore the potential impacts.

To address this uncertainty, the groundwater modelling report in Annexure F of Appendix N (Technical working paper: Groundwater) contained an uncertainty analysis prepared in accordance with the Australian groundwater modelling guidelines (Barnett et al, 2012). The purpose of the uncertainty analysis modelling was to investigate the sensitivity of model predictions to parameter values assigned to the groundwater model. The uncertainty analysis involved targeted sensitivity analyses to assess potential groundwater-related impacts, identifying key factors of high and low range hydraulic parameter values. This analysis estimated the potential changes in groundwater table drawdown under extreme parameter value modelling conditions. The uncertainty analysis described in Annexure F of Appendix N (Technical working paper: Groundwater) provides results of the uncertainty analysis relating to potential water table drawdown and a brief summary of the assessed range in environmental impacts based on the predictions of the extreme parameter value conditions that were modelled in the uncertainty analysis. This memorandum presents further detail of the uncertainty analysis and predicted impacts on environmental features.

The results of this uncertainty analysis indicate that:

- **Groundwater supply bores**: Under the extreme parameter value conditions (Scenarios A and B), drawdown at identified groundwater supply bores is not expected to be significantly different to the drawdown predicted for Base case scenario conditions (as reported in the environmental impact statement). Consistent with the environmental impact statement conclusions, construction and operation of the project are therefore anticipated to cause negligible impact to water availability at groundwater supply bores
- **Areas of environmental interest (AEI) for contamination**: Uncertainty Scenarios A and B generally predict lesser drawdown than the Base case at areas of environmental interest for contamination sites, although drawdown of over one metre is predicted to occur within the footprint of each AEI for contamination. As noted in the environmental impact statement, any contaminants from these sites already present in the groundwater (due to contact) would be expected to travel towards the tunnels. The quality of groundwater inflows could pose a potential human health risk (due to the potential migration of potential volatile contaminants into the tunnel system). All groundwater inflows would be collected and treated at the construction wastewater treatment plant. Groundwater supply bores and groundwater dependent ecosystems are not expected to be impacted by contaminant migration. It is also worth noting that drawdown of the groundwater table due to the project may act to disconnect the contaminant plume from the contaminant source. Where there is existing soil contamination that has not yet migrated to the groundwater table, lowering of the groundwater table would act to mitigate, or delay, the potential migration of contamination through groundwater. The potential impacts identified by the uncertainty analysis scenarios do not differ in nature to those identified in the environmental impact statement, and the mitigation and management measures listed in the environmental impact statement would similarly address the potential impacts as identified by the uncertainty analysis
- **Groundwater dependent ecosystems**: The drawdown predicted by the uncertainty analysis scenarios at groundwater dependent ecosystems is the same or less than the drawdown predicted in the environmental impact statement, with the exception that the drawdown at the vegetation at Flat Rock Creek and Quarry Creek was predicted to be one metre more at the end of construction. This confirms

that the potential impacts to groundwater dependent ecosystems identified by the environmental impact statement may be considered conservative

- **Surface water systems**: The results of the uncertainty analysis suggest that potential baseflow reduction to creeks could be either much lesser or much greater than was predicted by the environmental impact statement. Reducing the uncertainty associated with the assessment of potential impacts to creeks can only be addressed through additional hydrogeological/hydrological/ecological field investigations.

Transport for NSW has conducted further investigations and assessment of predicted groundwater baseflow reductions and the potential environmental impacts. The additional investigations and analysis completed, including the freshwater ecology and groundwater dependent ecosystem impacts at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, are provided in Appendix E of this submissions report.

## 6. References

Arup and WSP (2020), Western Harbour Tunnel and Beaches Link, Tunnels – Settlement Assessment, Report prepared by Arup Pty Ltd and WSP Australia Pty Ltd, Document No. WHTBL-BL20-TU-MEM-0066 Revision 2.0, 21 October 2020.

Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A, (2012), Australian groundwater modelling guidelines

Bureau of Meteorology (2018), Australian Groundwater Explorer, available at http://www.bom.gov.au/water/groundwater/explorer/map.shtml.

Rau, G. C., Acworth, R. I., Halloran, L. J. S., Timms, W. A., & Cuthbert, M. O. (2018), Quantifying compressible groundwater storage by combining cross-hole seismic surveys and head response to atmospheric tides, Journal of Geophysical Research: Earth Surface, 123. https://doi.org/10.1029/2018JF004660

Serov P, Kuginis L, Williams J.P., (2012). Risk assessment guidelines for groundwater dependent ecosystems, Volume 1 – The conceptual framework, NSW Department of Primary Industries, Office of Water, Sydney.

WaterNSW (2020), Continuous monitoring network data, available at https://realtimedata.waternsw.com.au/, formerly published by the NSW Department of Primary Industries Water.