Transport for NSW

Beaches Link and Gore Hill Freeway Connection

Appendix E –
Further information on predicted groundwater drawdown, baseflow reductions and related environmental assessment

November 2021

E Further information on predicted groundwater drawdown, baseflow reductions and related environmental impact assessment

Contents

Annexures

1 Introduction

1.1 Background

An environmental impact statement for the Beaches Link and Gore Hill Freeway Connection project ('the project') was placed on public exhibition on 9 December 2020, with an exhibition closing date of 1 March 2021.

Public exhibition provided the community, interested parties and key stakeholders (including Government agencies and Councils) with an understanding of the project and the opportunity to make a submission on the environmental impact statement. A description of the project can be found in Section A1.2 of the submissions report. One of the key issues raised in submissions by agencies and the community was in relation to the predicted groundwater drawdown, baseflow reductions and the related environmental impacts. In particular, concerns were raised with regards to potential long-term impacts on Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

The following components of the environmental impact statement provide important context for the revised assessment presented in this report:

- Groundwater was assessed in Chapter 16 (Geology, soils and groundwater) of the environmental impact statement and Appendix N (Technical working paper: Groundwater), including Annexure F (Groundwater modelling report)
- Surface water quality was assessed in Chapter 17 (Hydrodynamics and water quality) of the environmental impact statement and Appendix O (Technical working paper: Surface water quality and hydrology)
- Groundwater dependent ecosystems were assessed in Chapter 19 (Biodiversity) of the environmental impact statement and Appendix S (Technical working paper: Biodiversity development assessment report) including Annexure D (Freshwater ecology impact assessment)
- Social values were assessed in Chapter 21 (Socio-economic) of the environmental impact statement and Appendix U (Technical working paper: Socio-economic assessment).

1.2 Summary of key feedback

A range of issues were raised during the submissions process, as outlined in Section A3 of the submissions report. Many issues have interrelated components across a number of environmental aspects.

A number of stakeholders, including the Department of Planning, Industry and Environment (Water), Department of Planning, Industry and Environment (Environment, Energy and Science Group), Northern Beaches Council, and Willoughby City Council , as well as community members raised concerns regarding the predicted long-term groundwater baseflow reductions at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, and associated environmental issues.

Key concerns include:

- The environmental impacts of the predicted long-term reduction in baseflow are understated
- The level of uncertainty of the groundwater model predictions and methodology due to the manner in which the model was developed historically
- The consequent level of uncertainty related to impacts on freshwater ecology and groundwater dependent ecosystems as a result of the predicted groundwater drawdown and groundwater baseflow reductions to streams

- The lack of detail regarding the surface water quality impacts that would potentially result from the predicted groundwater drawdown and baseflow reductions
- Concern that there is insufficient consideration of the social impacts of the groundwater baseflow reductions in Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

Individual summaries and detailed responses to issues raised can be found in Part B (response to key stakeholder submissions) and Part C (response to community submissions) of the submissions report.

To address the concerns raised by stakeholders and community members in relation to the groundwater modelling and associated potential environmental impacts, it was determined that additional work would be carried out to be able to provide more detail in the responses, to provide context for the information presented in the environmental impact statement and to update the groundwater model predictions based on more recent investigations.

More detail on the uncertainty associated with the groundwater modelling has been provided in Appendix D of the submissions report.

1.3 Purpose

This report has been prepared to respond to submissions raised by Government agencies and the community and to update the findings of the environmental impact statement including:

- Revised groundwater drawdown predictions and baseflow reductions based on additional field investigations
- Expressing the revised baseflow reductions in terms of a reduction in streamflow
- Additional assessment of environmental issues, based on the revised baseflow reductions
- Any new or revised environmental management measures, if required.

The environmental impact statement did not include a definition of groundwater baseflow to explain that groundwater baseflow is only one component of streamflow. This report provides further detail of the relationship between streamflow and groundwater baseflow and expresses the revised baseflow reductions as an indicative reduction in streamflow to provide stakeholders with a broader appreciation of the potential impact of the project on Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. A clarification is also provided in Section A5.1.15 of the submissions report on this definition.

1.4 Outline of revised assessments

As a result of the submissions received, and through discussions with the Department of Planning, Industry and Environment, some of the assessments in the environmental impact statement have been updated since public exhibition to inform the submissions report. These have focussed on the hydrological systems at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek as these are the creeks that have the potential to be most impacted by the project. The potential impacts of the project on groundwater baseflows and streamflow in Flat Rock Creek and Burnt Bridge Creek have also been reassessed.

The following assessments have been carried out:

- Additional field survey of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to assess the nature of each creek's streambed and the potential for interaction between surface water and groundwater

- Revised groundwater modelling for the Flat Rock Creek, Quarry Creek and Burnt Bridge Creek systems based on the results of the additional field survey
- Expressing the revised baseflow reductions as an indicative reduction in streamflow based on historical streamflow measurements to provide stakeholders with a broader appreciation of the potential impact of the project on Flat Rock Creek, Quarry Creek and Burnt Bridge Creek
- Targeted field survey of freshwater ecology at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to inform a revised assessment of potential impacts on freshwater ecology
- Targeted field survey and assessment of groundwater dependent ecosystems at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to inform a revised assessment of potential impacts on groundwater dependent ecosystems
- Additional analysis of findings relating to surface water quality at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, and a revised assessment of potential surface water quality impacts as result of the expected baseflow changes
- Additional analysis of community values in relation to Flat Rock Creek, Quarry Creek and Burnt Bridge Creek and revised assessment of potential social impacts as a result of the expected changes to waterways at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

2 Assessment approach

2.1 Key considerations

2.1.1 Definition of streamflow and groundwater baseflow

The water flowing in creeks and watercourses is known as streamflow. Streamflow is the combination of water from several sources including rainfall run-off, direct rainfall into the stream, discharge from stormwater pipes and groundwater contributions. The proportion of streamflow that comes from groundwater is referred to as groundwater baseflow. While the boundary of each of these sources of water is difficult to distinguish in reality, a schematic showing the basic elements of streamflow is provided in Figure 2-1.

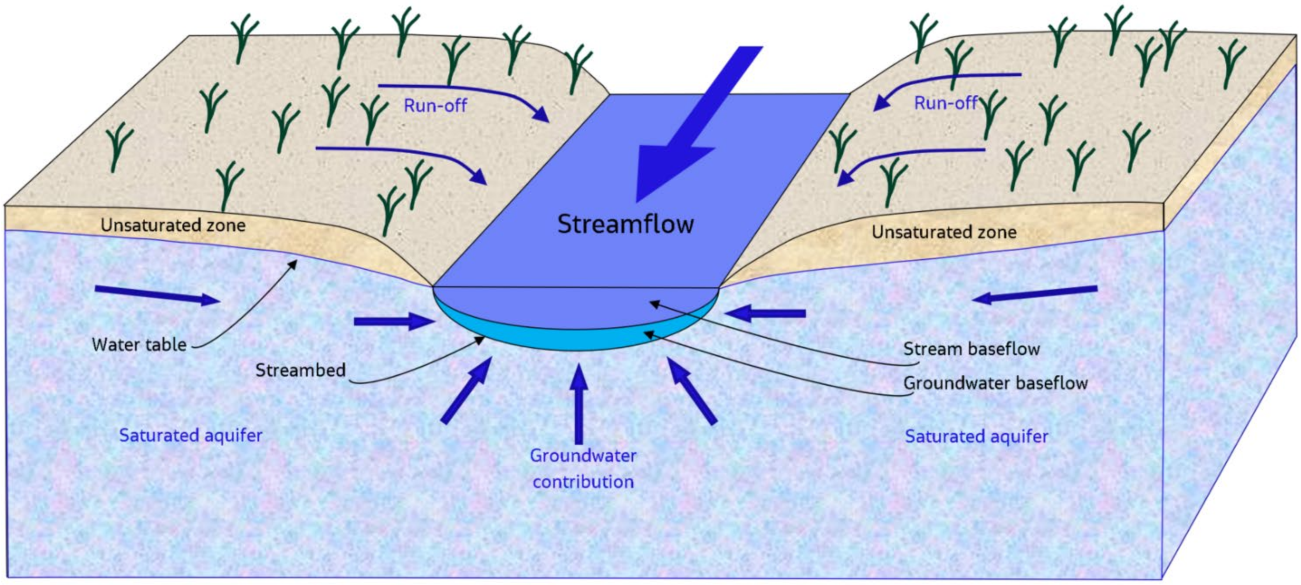


Figure 2-1 Basic elements of streamflow (modified from United States Geological Survey (USGS) (2001))

As groundwater baseflow is just one component of streamflow, it follows that the impact of a reduction in groundwater baseflow would be proportionate to its contribution to streamflow.

2.1.2 Interaction between groundwater and surface water

Streams are surface features that can be a point of interaction between groundwater and surface water. Streams can gain or lose water from the surrounding groundwater system as shown in Figure 2-2a and Figure 2-2b respectively. Losing streams can be connected to the groundwater system by a continuous saturated zone as shown in Figure 2-2b or disconnected from the groundwater system by an unsaturated zone as shown in Figure 2-2c (USGS, 2001). These conditions are identified by groundwater levels in contrast to the stream water level. Where the surrounding groundwater level is higher than the stream water level, the stream is considered a gaining stream. Where the surrounding groundwater level is lower than the stream water level, the stream is considered a losing stream.

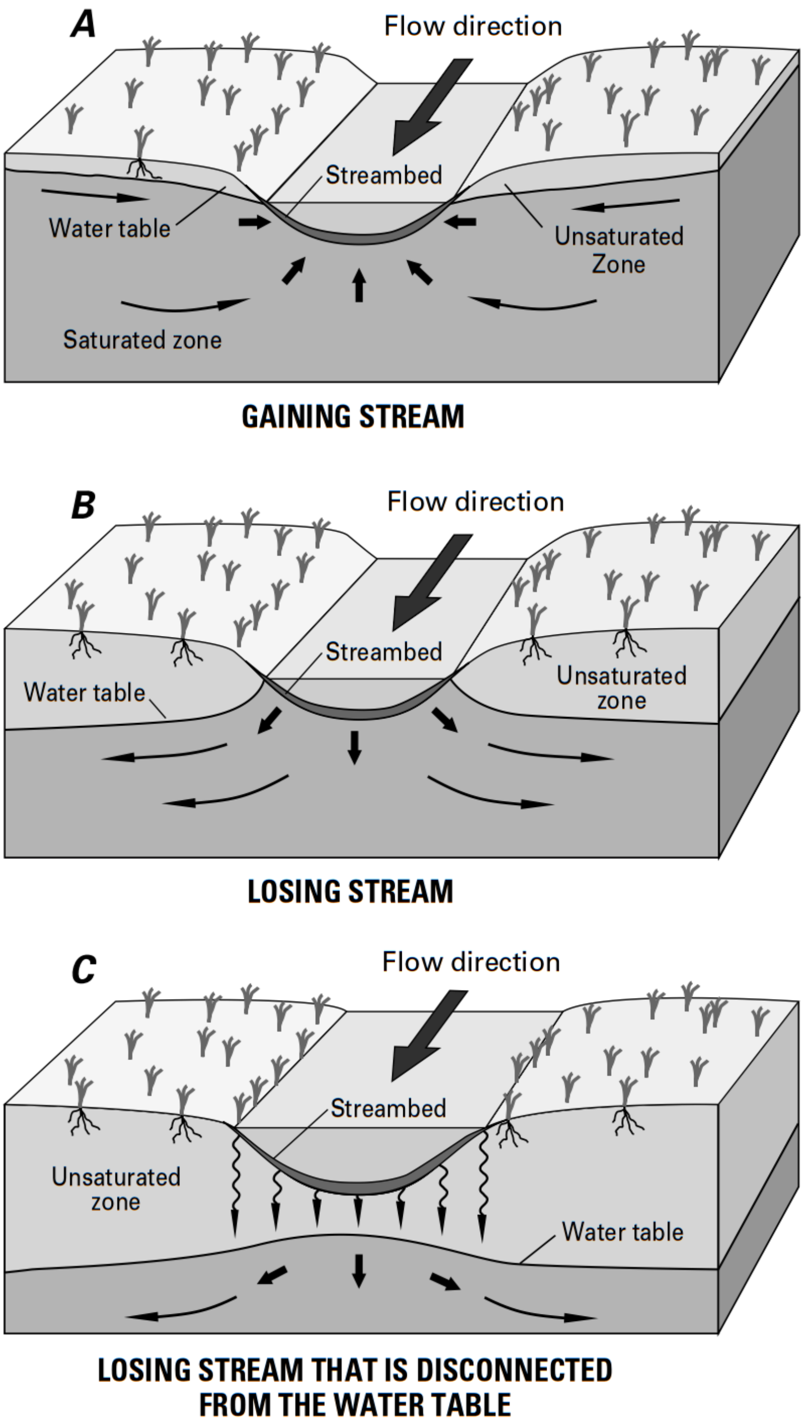


Figure 2-2 Interactions of a stream and a groundwater system (modified from USGS, 2001)

In some cases, stream beds consist of low hydraulic conductivity materials that can be natural or of human origin. A low hydraulic conductivity streambed can reduce the interaction between surface water and groundwater in both losing and gaining streams. Natural low conductivity material can include compacted fine sediments such as clay and silt and/or layered organic material. Many streams in urban areas have been lined with concrete or channelled into pipes to reduce flooding. These types of streambed materials can also alter the interaction between surface water and groundwater.

Near to the proposed alignment of the Beaches Link tunnels, the groundwater levels are assumed to generally be higher than the stream levels and so groundwater contributes a proportion of streamflow. The contribution of groundwater to streamflow is dependent on the hydraulic conductivity of the aquifer that is exposed in the stream bed and the condition and permeability of any potential lining in the stream bed. Localised groundwater seepage points were identified in watercourses during the additional field survey of the streambeds of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek mentioned in Section 1.4 above. However, the conductivity of the outcropping sandstone is considered to be relatively low, so the contribution of groundwater to streamflow is considered relatively low. Also, some of the streams in the project area are lined with concrete, culverted and filled over or channelled into underground pipes, which further limits the contribution of groundwater to surface water as noted above. Assumptions made about the permeability of creek beds and the level of connectivity between surface water, groundwater and the tunnel affects predictions of inflows to the tunnel and the magnitude of groundwater drawdown. Further information on these assumptions is provided in sections 2.1.3 and 2.2.1 below.

2.1.3 Inherent groundwater model conservatism

The potential groundwater impacts of the project were assessed in Appendix N (Technical working paper: Groundwater). The assessment used groundwater modelling to estimate potential changes in groundwater levels and groundwater baseflow due to the project. Details of the groundwater model are contained in a groundwater modelling report in Annexure F of Appendix N (Technical working paper: Groundwater).

The groundwater modelling was designed to meet Class 2 requirements of the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012) and conservative assumptions were made during its development taking into account experience from other recent major tunnel infrastructure projects in Sydney. The assessment of groundwater impacts in the environmental impact statement was inherently conservative, and is likely to have overestimated actual impacts for the following reasons:

- There was limited, site-specific geotechnical information available on which to base assumptions concerning the permeability of geological strata between the watercourses and the tunnels. It was therefore necessary to assume that there was a single connected groundwater system (aquifer) between the watercourses and the underlying tunnels. The groundwater model assumes continuous saturation (and hydraulic connectivity) between the tunnel and the shallow water table beneath the creeks. Under this assumption, all drawdown at tunnel depth would be realised at the surface, which could result in baseflow reductions in watercourses. In reality, the geology would be stratified, possibly with disconnected sections of the aquifer ie limited potential for vertical movement of groundwater. This means that the subsurface drawdown at tunnel depth might not result in the same (or any) drawdown in the shallow water table and might reduce actual drawdown substantially compared to the predictions so the predicted groundwater drawdown are unlikely to be fully realised in all locations
- To reduce the likelihood of underestimating potential tunnel groundwater inflows, there was a requirement for the model to simulate tunnels in a fully drained state ie with no controls in place to limit groundwater inflows to the tunnel. Put another way, the groundwater inflows to the tunnels were controlled by the permeability of the surrounding geological formation. As indicated in Table 7-1 and Table 7-2 of Annexure F of Appendix N (Technical working paper: Groundwater), this results in some situations where groundwater inflows to the tunnels exceed a design criterion limiting tunnel inflows in any one kilometre section of tunnel to a maximum of one litre per second per kilometre. In reality, measures will be implemented during construction to ensure that groundwater inflows into each tunnel during the operation phase do not exceed one litre per second per kilometre across any given kilometre, as required by revised environmental management measure SG16 (refer to Table D2-1 of the submissions report). As the tunnels would be designed and constructed to ensure this design criteria is met, the predicted levels of groundwater drawdown in surrounding areas would be less than modelled.

When the environmental impact statement was being prepared there was limited information available on the state of the streambeds and specifically, whether they were conducive to water movement between the stream and the underlying aquifer. Due to this limited information, conservative assumptions were made in the groundwater modelling reported in the environmental impact statement. Transport for NSW has now carried out field surveys to inspect the condition of streambeds and gathered information that was not available when the environmental impact statement was prepared, as discussed in Section 2.2 below.

Consistent with the environmental impact statement, the revised groundwater modelling assumed that no tunnel lining would be provided to reduce groundwater inflow to the tunnels with the exception of a 125 metre section on either side of Middle Harbour and that groundwater inflows to the tunnels would be constrained by the permeability of the geological formation.

2.2 Revised groundwater modelling

Transport for NSW has carried out additional field investigations at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek since the environmental impact statement was finalised to gather further information regarding these creeks. Additional information was sought on these three creeks because they are the watercourses that were predicted in the environmental impact statement to experience a greater reduction in groundwater baseflow in 2128 after 100 years of operation than other watercourses near to the project area, as discussed in Section 17.4.5 of the environmental impact statement and Section 6.1.3.5 of Appendix N (Technical working paper: Groundwater). The groundwater modelling carried out for the environmental impact statement was based on the creek bottom surfaces shown in Figure A1-14 and A1-15 of Attachment 1 of Annexure F of Appendix N (Technical working paper; Groundwater) and described in Table 9-2 of Annexure F of Appendix N (Technical working paper; Groundwater).

The additional information collected in field investigations has enabled Transport for NSW to carry out additional environmental impact assessment to address concerns regarding the groundwater modelling results relating to surface water-groundwater interactions presented in the environmental impact statement.

Transport for NSW has carried out the following:

- Additional field survey of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to assess the nature of the creek streambed and the potential for interaction between creek surface waters and groundwater
- Revising the groundwater modelling carried out for the environmental impact statement, including updating the numerical groundwater model and revised predictions of groundwater level drawdown at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

As part of the above, the predicted baseflow reductions along individual, discrete sections of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek were recalculated to facilitate a more detailed analysis of potential impacts. These more detailed predictions of baseflow reductions were used to reassess the potential impacts to freshwater ecology, groundwater dependent ecosystems, surface water quality and social amenity.

To provide appropriate context for the predicted groundwater baseflow reductions and to make them readily understandable and tangible to the community, the revised predictions of groundwater baseflow reduction have also been expressed as a percentage reduction in streamflow using streamflow data collected in May 2018 during the 2017 to 2019 drought period (Bureau of Meteorology, 2021). Presenting the potential impact in terms of a reduction in streamflow is expected to make it easier for stakeholders including the community to understand the magnitude of any potential impact.

While the revised groundwater modelling and groundwater baseflow reduction predictions are based on the additional information on streambed lining obtained during the May 2021 field survey and therefore there is less uncertainty about the predictions, the conservative assumptions applied to the groundwater modelling and groundwater baseflow reduction predictions in the environmental impact statement that were discussed in Section 2.1 above continue to apply.

2.2.1 Field survey

A field survey of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek was carried out during the week of 10 May 2021. The full length of each creek was surveyed by a principal hydrogeologist. Survey observations included the nature of the creek bed and banks and identification of groundwater seepage. Streamflows were also observed but not measured.

Based on the field observations, unique sections of each creek were classified in line with the descriptions provided in Table 2-1. Examples of each creek section classification are provided in Figure 2-3 to Figure 2-10.

Table 2-1 Classification of creek sections

Classification	Description	Example figures
Unlined	Locations where a creek flows over natural media and there is potentially free interaction between surface water and groundwater.	Figure 2-3
Unlined underground	Locations where a creek flows over natural media and there is potentially free interaction between surface water and groundwater, but the creek has been channelled into an underground culvert with no floor.	Figure 2-4
Unlined bedrock with springs	Locations where a creek is flowing over exposed bedrock, with localised groundwater seepage points.	Figure 2-5
Unlined bedrock, banks with baseflow	Locations where a creek is flowing over exposed country rock/basement rock with the creek banks contributing seepage to groundwater.	Figure 2-6
Constructed surface creek	Locations where a creek has been modified by human actions.	Figure 2-7
Constructed surface creek, banks with baseflow	Locations where a creek has been modified by human actions, with the creek banks contributing seepage to groundwater and to baseflow.	Figure 2-8
Lined underground	Locations where a creeks flows through a concrete pipe or culvert and the interaction between surface water and groundwater is likely to be minimal.	Figure 2-9
Lined contributing baseflow	Locations where a creek flows through a concrete pipe or culvert, and there are cracks, weep holes or other features that allow seepage and interaction between surface water and groundwater.	Figure 2-10

Figure 2-3 Example of a section of Burnt Bridge Creek classified as unlined or natural near Baringa Avenue at Seaforth (BBC005)

Figure 2-4 Example of a section of Flat Rock Creek classified as unlined underground under Willoughby Road bridge at Naremburn (FRC016)

Figure 2-5 Example of a section of Burnt Bridge Creek classified as unlined bedrock with springs near Baringa Avenue at Seaforth (BBC007)

Figure 2-6 Example of a section of Flat Rock Creek classified as unlined bedrock, banks with baseflow, about 100 metres east of Flat Rock Drive at Willoughby (FRC027)

Figure 2-7 Example of a section of Burnt Bridge Creek classified as a constructed surface creek at the end of Quirk Road at Balgowlah (BBC027)

Figure 2-8 Example of a section of Flat Rock Creek classified as constructed surface creek, banks with baseflow, in Flat Rock Reserve at Northbridge (FRC023)

Figure 2-9 Example of a section of Burnt Bridge Creek classified as lined underground at Kitchener Street bridge at Balgowlah (BBC017)

Figure 2-10 Example of a section of Flat Rock Creek classified as lined contributing baseflow near Glenview Road at Naremburn (FRC015)

The observation points along each creek and the resulting classification of each creek section are shown in Figure 2-11 to Figure 2-14.

The key differences between the creeks modelled in the environmental impact statement and the results from the field survey are:

- Additional sections in the upper reaches of Flat Rock Creek were identified and added to the groundwater model
- The upper reach of Flat Rock Creek is not lined where it is within a box culvert and instead, is in direct connection with the underlying sandstone bedrock, whereas modelling carried out for the environmental impact statement assumed there was no groundwater contribution from this section of the creek
- The underground box culvert within the upper reaches of Flat Rock Creek to the east of the Gore Hill Freeway was observed to potentially have groundwater contributing to it, whereas modelling carried out for the environmental impact statement assumed there was no groundwater contribution to this section of the creek
- Sections of Burnt Bridge Creek immediately west of the Burnt Bridge Creek Deviation and between the Burnt Bridge Creek Deviation and Manly West Park were previously assumed to be lined and therefore have no groundwater contribution. However, during the field survey theses sections of the creek were observed to have possible groundwater contribution.

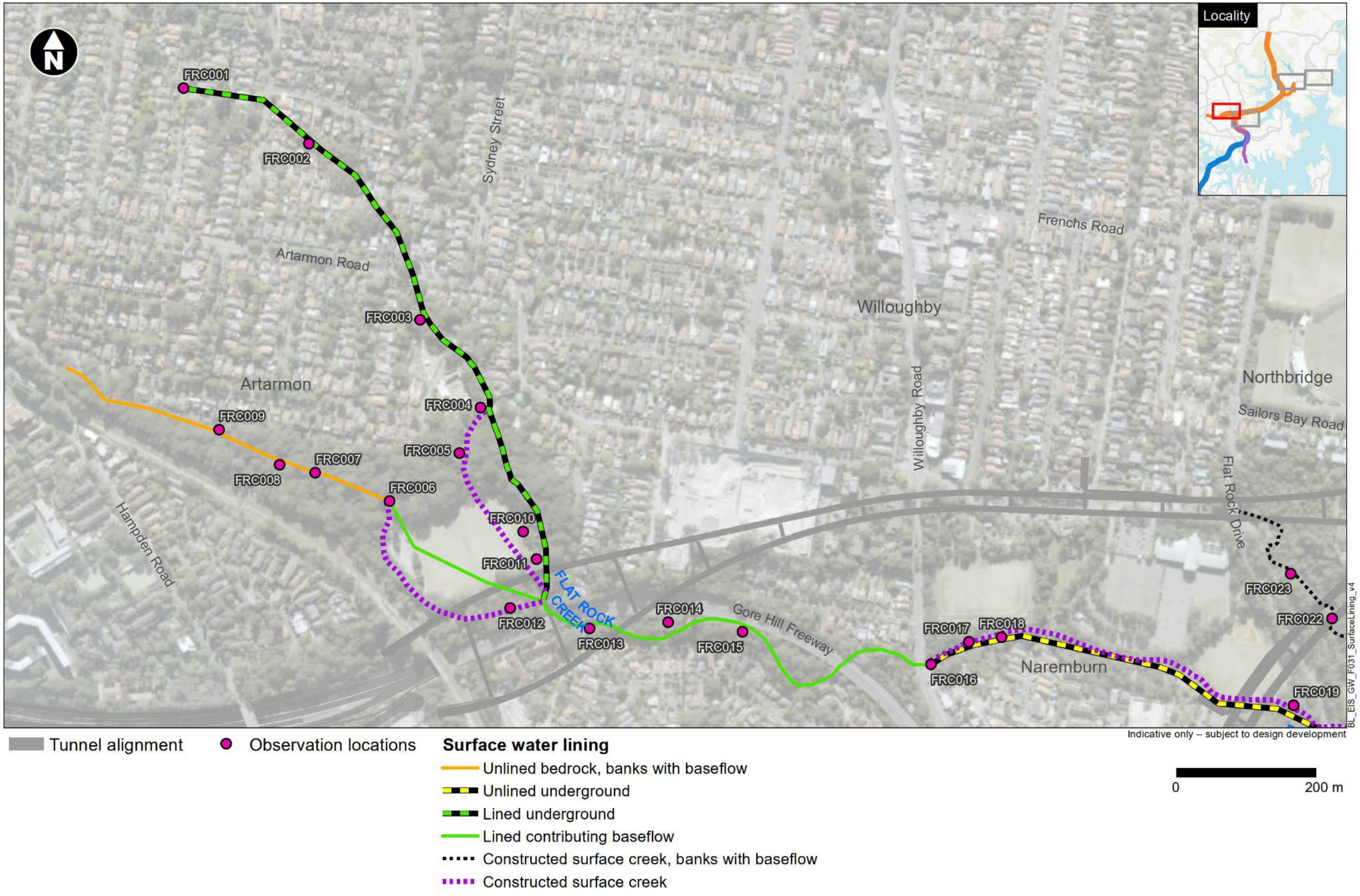


Figure 2-11 Classification of sections of Flat Rock Creek between Artarmon and Bicentennial Park

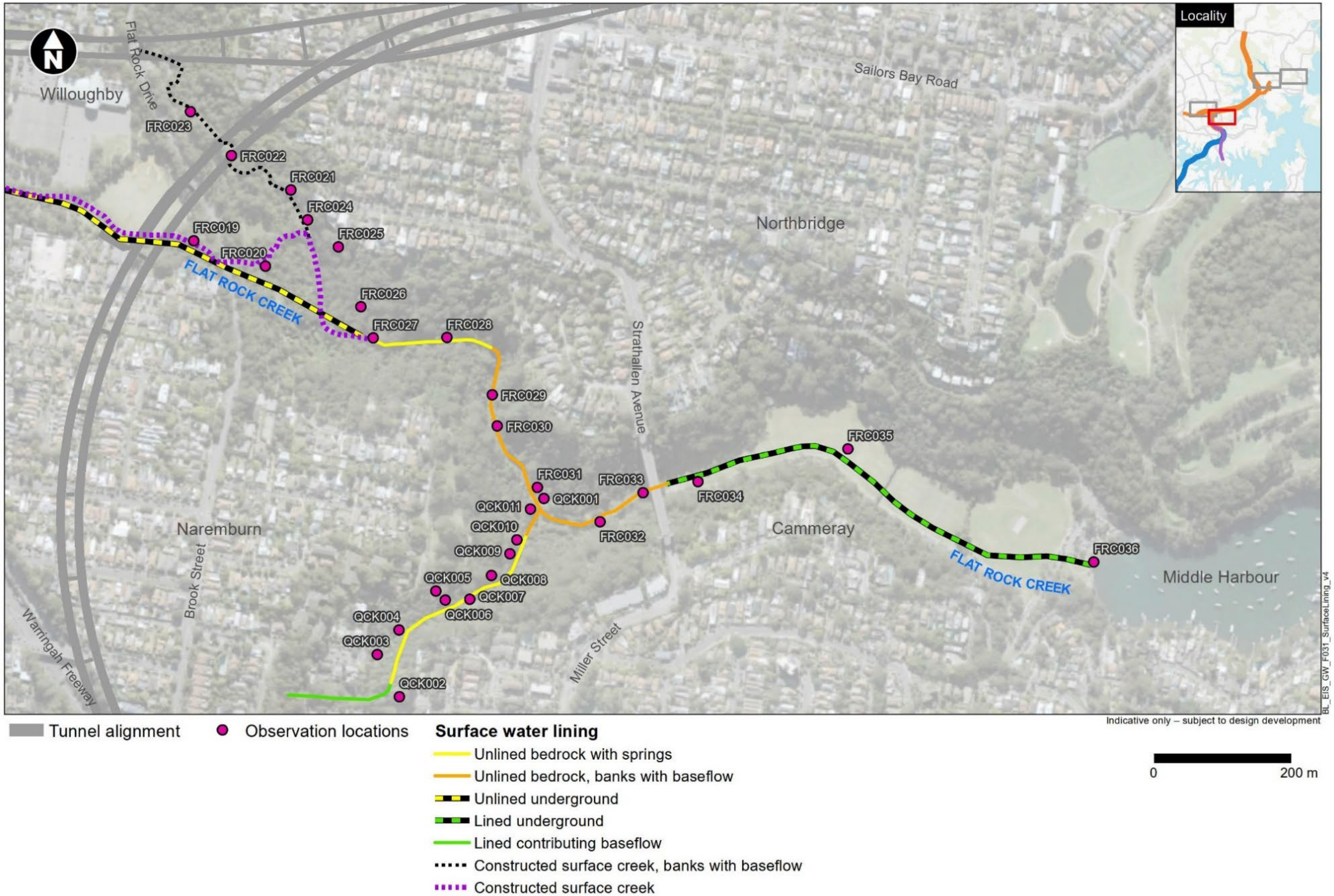


Figure 2-12 Classification of sections of Flat Rock Creek and Quarry Creek between Bicentennial Park and Middle Harbour

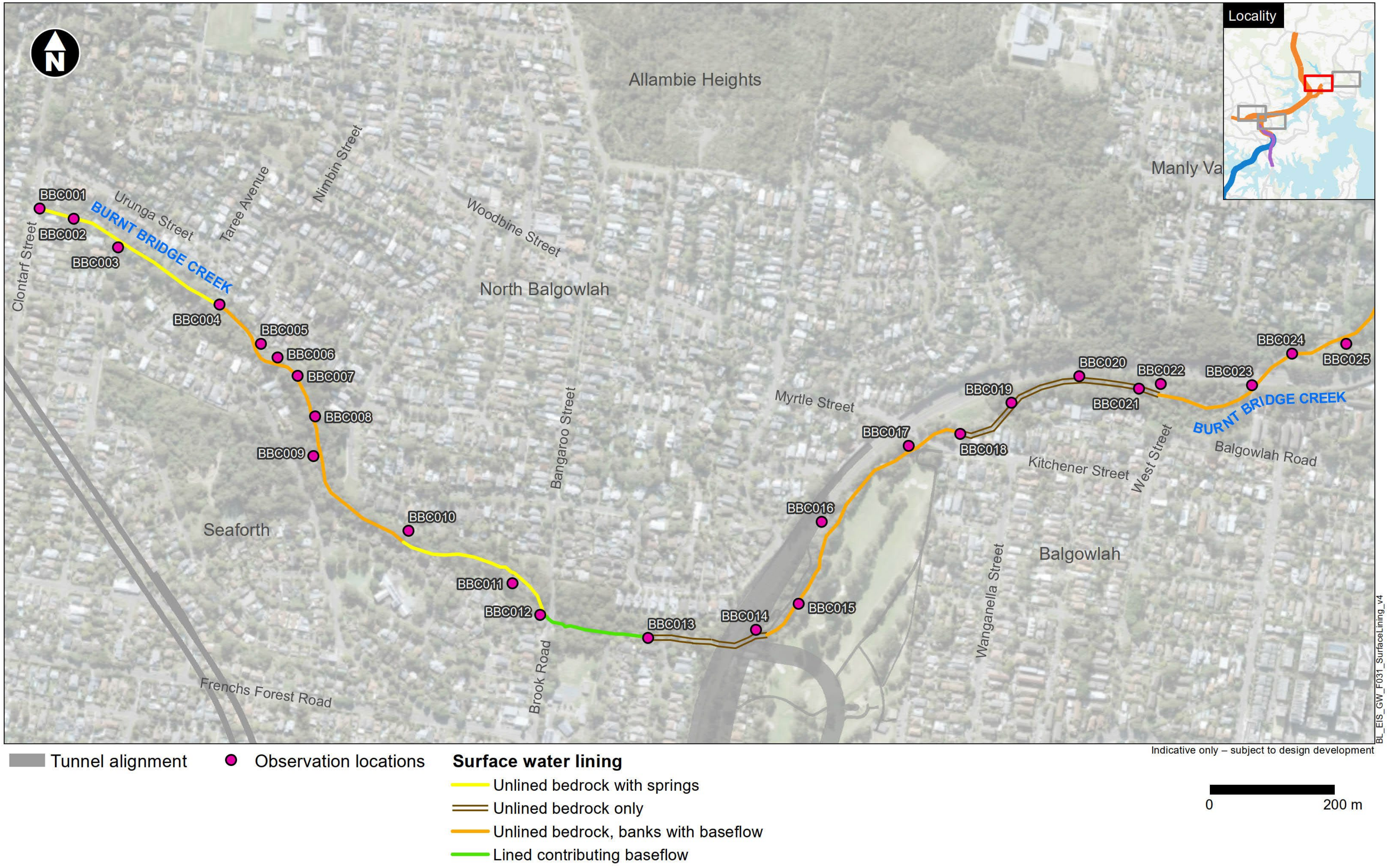


Figure 2-13 Classification of sections of Burnt Bridge Creek between North Balgowlah and Balgowlah

Figure 2-14 Classification of sections of Burnt Bridge Creek between Balgowlah and Fairlight

2.2.2 Groundwater modelling

Transport for NSW has revised the groundwater predictions for the project based on the results of the field survey described above. The revised groundwater modelling was carried out using the MODFLOW-USG (Unstructured Grid) model that is described in Section 4.4 of Appendix N (Technical working paper: Groundwater).

The revised groundwater modelling carried out involved:

- Assigning revised riverbed conductance term values to represent the groundwater-surface water interaction at unlined sections of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek based on a literature review of conductance for similar conditions. Riverbed conductance term values are discussed in Section 2.2.3
- Updating the no project and project numerical groundwater models to reflect the uniquely characterised sections of each creek based to enable baseflow to be separately analysed for each discrete section of the creeks
- Predicting groundwater level drawdown and baseflow changes at each uniquely characterised creek section. Given stakeholders' concerns about long-term impacts to baseflow, the revised modelling focused on these impacts after 100 years of operation of the project ie in the year 2128
- Expressing the revised baseflow reductions as an indicative reduction in streamflow based on historical streamflow measurements to provide a better appreciation of the potential impact of the project on each creek (refer to Section 2.2.4 below).

The revised groundwater modelling was carried out for the 'cumulative scenario', which considers the cumulative impact on groundwater of the project together with the Western Harbour Tunnel and Warringah Freeway Upgrade project and the Sydney Metro City & Southwest project as discussed in Section 16.4.5 of the environmental impact statement.

As previously indicated, to aid comprehension of the predicted changes to groundwater baseflow, the predictions are also presented in relation to relative changes to streamflow. Refer to Section 2.1for a discussion on streamflow components and their interrelationship.

2.2.3 Riverbed conductance

Riverbed conductance is a parameter used in MODFLOW to measure the flow of water between a riverbed/creek and the underlying aquifer, as discussed in Section 3.9.3 of Annexure F of Appendix N (Technical working paper: Groundwater). Riverbed conductance is defined in MODFLOW as the hydraulic conductivity (K) of the riverbed materials divided by the vertical thickness (T) of the riverbed materials, multiplied by the cross sectional area of the river ie width (W) of the river multiplied by the length (L) of the river being analysed, as shown in the equation below:

$$\text{Riverbed conductance} = (K/T)*W*L$$

The higher a riverbed conductance value, the greater the assumed flow of water between the river and the aquifer.

The vertical thickness (T) of the bed sediments of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek was assumed to be one metre, as discussed in Section 3.9.3 of Annexure F of Appendix N (Technical working paper: Groundwater).

The hydraulic conductivity (K) was conservatively based on the horizontal hydraulic conductivity of the cell containing the creek model boundary.

A conductance value of 0.001 m^2/day was used for channels in the F6 Extension Stage 1 Groundwater Modelling Report (RPS Australia West, 2018) prepared for the F6 Extension Stage 1 environmental impact statement (now known as the M6 Stage 1 project). The same conductance value has been adopted in the revised groundwater modelling for the project for consistency and given the regional proximity to the M6 Stage 1 project. This conductance value was used to represent sections of creek where the creek bed is not in full hydraulic connection with the underlying ground, but where groundwater baseflow (seepage) to the creek was observed. A conductance value of 100 m^2/day represents sections of creek where the creek bed is in full hydraulic connection with the underlying ground, and the flow between the creek and the underlying ground is controlled by the formation permeability. A conductance value of zero means there is no connection between groundwater and surface water.

2.2.4 Streamflow measurements

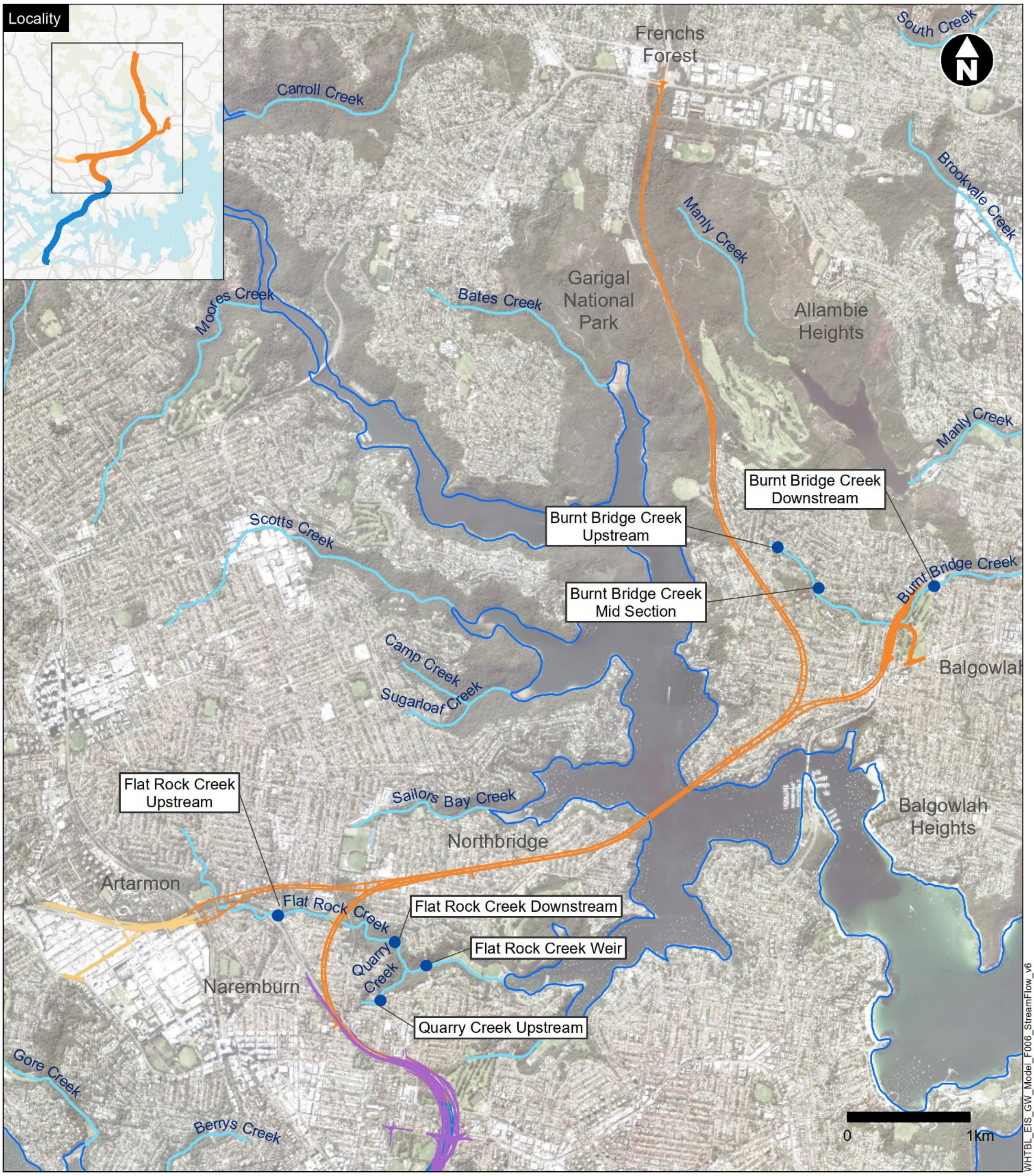
Estimated flow measurements were carried out at Flat Rock Creek, Quarry Creek (a tributary to Flat Rock Creek) and Burnt Bridge Creek in May 2018, as noted in Section 2.3 of Annexure F of Appendix N (Technical working paper: Groundwater). Streamflow was measured using a portable flow meter where applicable or was otherwise indirectly measured using either a velocity-cross sectional area relationship or measuring the time to fill a discrete volume. The locations where streamflow was estimated in May 2018 are shown in Figure 2-15.

The streamflow measurements in May 2018 were taken after two weeks of no rain. Estimated flow rates are listed in Table 2-2. The table also nominates a ‘confidence’ rating for these estimates, with greater accuracy assigned where a flow meter was used and the streambed geometry was well defined and lesser accuracy assigned where flow velocity was used and the streambed geometry was not well defined. Measurements considered to have relatively greater accuracy have higher confidence.

Table 2-2 Estimated creek streamflows – May 2018

Location	Estimated streamflow (kilolitres per day)	Confidence
Flat Rock Creek downstream	1908	High
Flat Rock Creek weir	2337	Low
Quarry Creek upstream	178	High
Burnt Bridge Creek midsection	130	Moderate
Burnt Bridge Creek downstream	1242	Low

These streamflow measurements provide a basis for calculating indicative impacts to streamflow from the revised predicted reductions in baseflow (refer to Section 3.3 below).



Legend

- Beaches Link
- Gore Hill Freeway Connection
- Western Harbour Tunnel
- Warringah Freeway Upgrade
- Surface water flow monitoring site
- Drainage line
- Coastline

Figure 2-15 Streamflow measurement locations – May 2018

2.3 Related environmental impacts

The revised groundwater modelling predictions were used to revise the assessments of the impacts of the predicted groundwater drawdown at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek on freshwater ecology, groundwater dependent ecosystems, surface water quality and social and community values. The methodologies for revising these assessments are summarised below.

2.3.1 Freshwater ecology

The entire reaches of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek between the headwaters and the downstream estuaries were inspected between 26 - 28 May 2021 to identify habitat sensitivity, riparian condition and the proportion of shallow pools, deep pools or riffles/cascades.

Data was collected on the following:

- Instream features – within sections of each creek, visual estimates were made of the proportion of creek length that contained shallow pools (less than two metres depth), deep pools (more than two metres depth) or riffles/cascades. The type of substratum in pools (bare rock, earth, silt, sand, gravel or detritus) was also noted
- Quality of fish habitat - assessed with reference to the criteria in *Policy and guidelines for fish habitat conservation and management* (Department of Primary Industries, 2013)
- Riparian condition – assessed using a modified version of the Riparian, Channel, and Environmental (RCE) inventory method (Peterson, 1992, Chessman et al. 1997). This assessment involved evaluation and scoring of the characteristics of the various components of the riparian corridor, including adjacent land, condition of riverbanks, channel and bed of the watercourse, and degree of disturbance evident at each site. The maximum score indicates a stream with little or no obvious physical disruption and the lowest score indicates a heavily channelled stream without any riparian vegetation that is considered to be in poor condition. RCE scores were assigned to sections of the creeks, with boundaries occurring where there was a visible change in the riparian condition (eg a change in riparian native vs exotic trees/shrubs, channel form or riffle/pool sequence).
- Fish sampling – catch and release of fish using collapsible bait traps in line with Cardno's scientific collection permit F86/670(A)-8.2
- Macroinvertebrates – semi-quantitative Australian River Assessment System (AUSRIVAS) rapid assessment sampling method in pools with suitable representative edge habitat
- Water quality – measured in situ in line with Australian Guidelines: Australia, New Zealand Environment Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) 2000.

This data, and the revised groundwater modelling predictions, were analysed and used to revise the assessment of the potential impacts of the project on freshwater ecology at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

Further details of the methodology used for the freshwater ecology survey are provided in Section 2 of Annexure A.

2.3.2 Groundwater dependent ecosystems

The assessment of the potential impacts of the project on groundwater dependent ecosystems was revised in line with the *Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (Department of Primary Industries, 2012) and *Information Guidelines Explanatory Note: Assessing groundwater-dependent ecosystems* (Doody et al., 2019).

Ecologists conducted a rapid assessment survey of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek in June 2021 to confirm the vegetation, structure and landscape features and classify the plant community types and presence of groundwater dependent ecosystems.

The assessment of the potential impacts of the project on groundwater dependent ecosystems was revised by:

- Identifying and classifying the potentially impacted groundwater dependent ecosystems
- Assessing the level of dependence of these ecosystems on groundwater
- Identifying high value ecological components of the groundwater dependent ecosystems and their overall ecological value
- Reviewing the potential impact of the project on the aquifer based on the revised groundwater drawdown predictions from the groundwater model
- Assessing the risk magnitude to the groundwater dependent ecosystems as a result of the revised groundwater drawdown predictions
- Applying the groundwater dependent ecosystem risk matrix, derived from Serov et al. (2012) to identify both the level of management action required and the timeframe in which this action needs to be implemented, based on the identified ecological values.

Further detail of the risk assessment process adopted for the groundwater dependent ecosystems assessment is provided in Section 2 of Annexure B.

2.3.3 Surface water quality

The desired performance outcome for the project in relation to surface water quality identified in the Secretary’s environmental assessment requirements, is that:

“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)”.

The Australian and New Zealand Guidelines (ANZG) (2018) and ANZECC & ARMCANZ (2000) water quality guidelines and objectives applied in the assessment of surface water quality are identified in Table 2.1 of Appendix O (Technical working paper: Surface water quality). These guidelines and objectives are dependent on nominated environmental values. The nominated environmental values for Flat Rock Creek, Quarry Creek and Burnt Bridge Creek are the protection of freshwater ecosystems, visual amenity and secondary contact recreation.

A qualitative approach was used to revise the assessment of the potential impacts of the project on surface water quality at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, which included:

- Reviewing water quality data used in the environmental impact statement and from additional water quality monitoring carried out in January and February 2021 at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek
- Reviewing the revised groundwater modelling predictions and the revised freshwater ecology assessment
- Qualitatively assessing whether the revised groundwater modelling predictions would result in any potential impacts to the identified water quality objectives.

2.3.4 Social and community values

The following tasks were carried out to revise the assessment of the potential impacts of the project on social amenity:

- Identify and confirm community values relevant to Flat Rock Creek, Quarry Creek and Burnt Bridge Creek based on consultation completed for the environmental impact statement
- Review of community feedback received through the submission process relevant to social values and potential impacts on Flat Rock Creek, Quarry Creek and Burnt Bridge Creek
- Review the specialist findings of the revised groundwater drawdown impacts on Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to identify any changes in potential impacts on identified community values
- Consider if any changes to the identified environmental management measures would be required.

3 Revised groundwater modelling predictions

The groundwater model for the project was revised based on the streambed lining observations made during the May 2021 field surveys of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek (refer to Section 2.2.1).

The revised groundwater modelling predictions are discussed and presented in the following sections.

3.1 Maximum groundwater drawdown

The groundwater model was used to predict the maximum groundwater drawdown based on unconstrained inflows into the tunnel. This is a conservative assumption as explained above in Section 2.1.

The predicted maximum groundwater drawdown at Flat Rock Creek, Quarry Creek, Burnt Bridge Creek and the groundwater dependent ecosystems at Flat Rock Creek and Quarry Creek in 2128 after 100 years of operation of the project is provided in Table 3-1. This table also includes the groundwater drawdown predictions for these creeks that were outlined in Table 6-9 and Table 6-10 of Appendix N (Technical working paper: Groundwater).

Table 3-1 Predicted maximum groundwater drawdown in 2128

Feature	Predicted maximum groundwater drawdown in 2128 (metres)	
	Reported in the environmental impact statement	Revised groundwater modelling
Creeks		
Flat Rock Creek	Up to 29 metres	Up to 28 metres
Quarry Creek	Up to 18 metres	Up to 19 metres
Burnt Bridge Creek	Up to 6 metres	Up to 3 metres
Groundwater dependent ecosystems		
Vegetation at Flat Rock Creek and Quarry Creek	Up to 12 metres	Up to 12 metres

Contour maps showing the predicted groundwater drawdown in 2128 following 100 years of operation of the project based on the revised groundwater modelling for the sections of the project south and north of Middle Harbour are provided in Figure 3-1 and Figure 3-3 respectively. Similar contour maps based on the groundwater modelling carried out for the environmental impact statement are also reproduced below in Figure 3-2 and Figure 3-4.

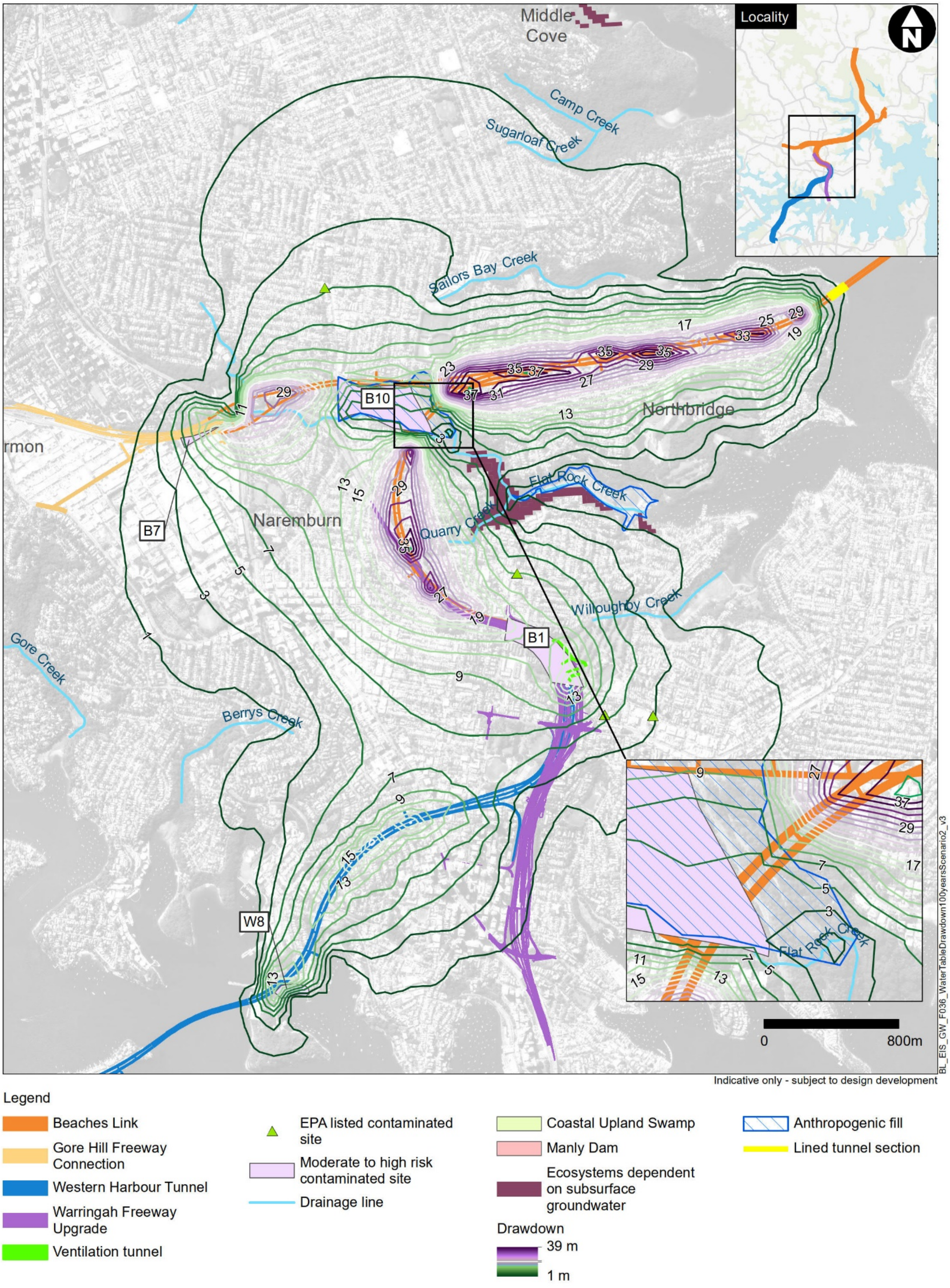


Figure 3-1 Predicted maximum groundwater drawdown south of Middle Harbour based on the revised groundwater modelling

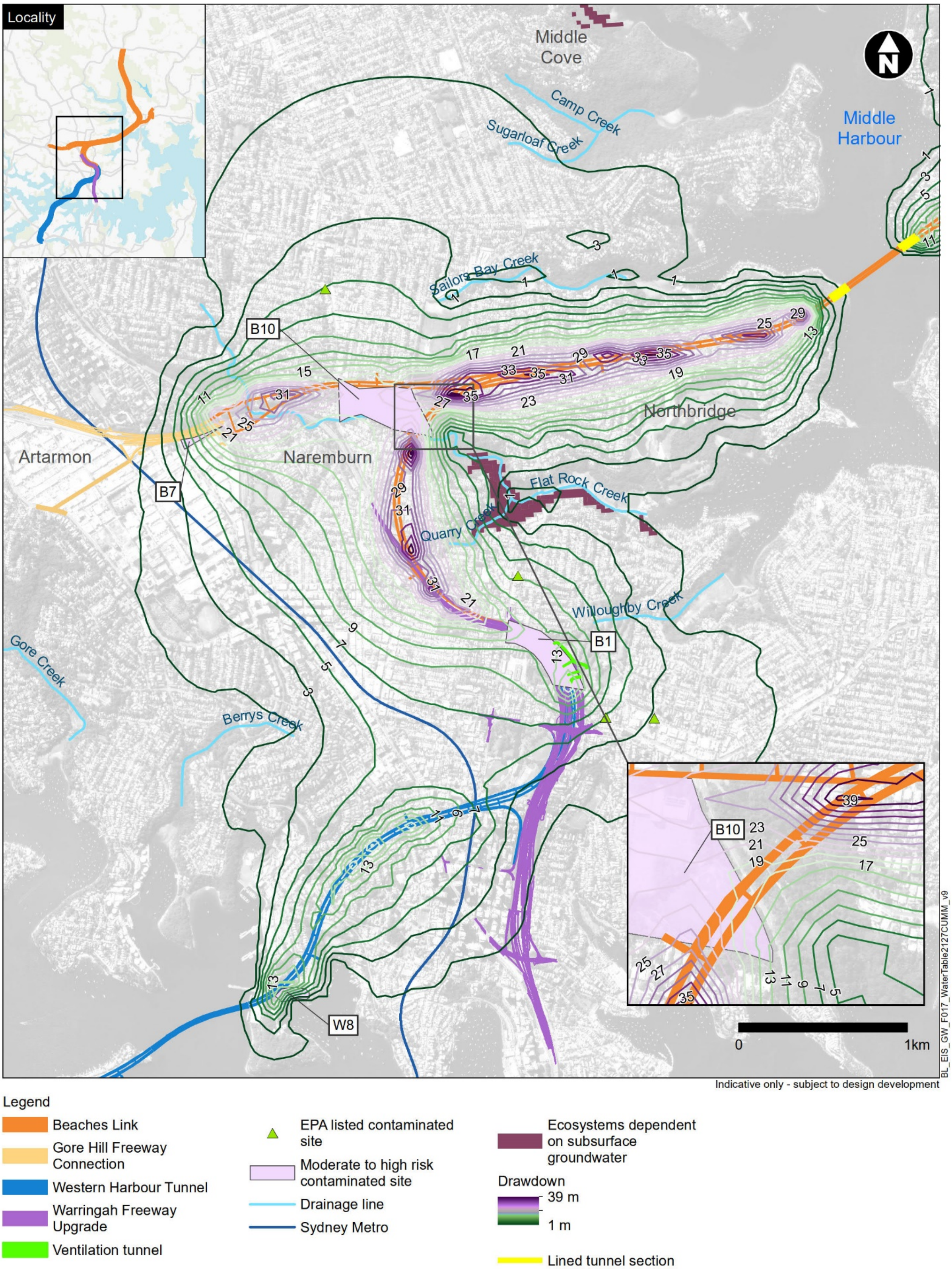


Figure 3-2 Predicted maximum groundwater drawdown south of Middle Harbour as shown in Figure 6-7 of Appendix N (Technical working paper: Groundwater)

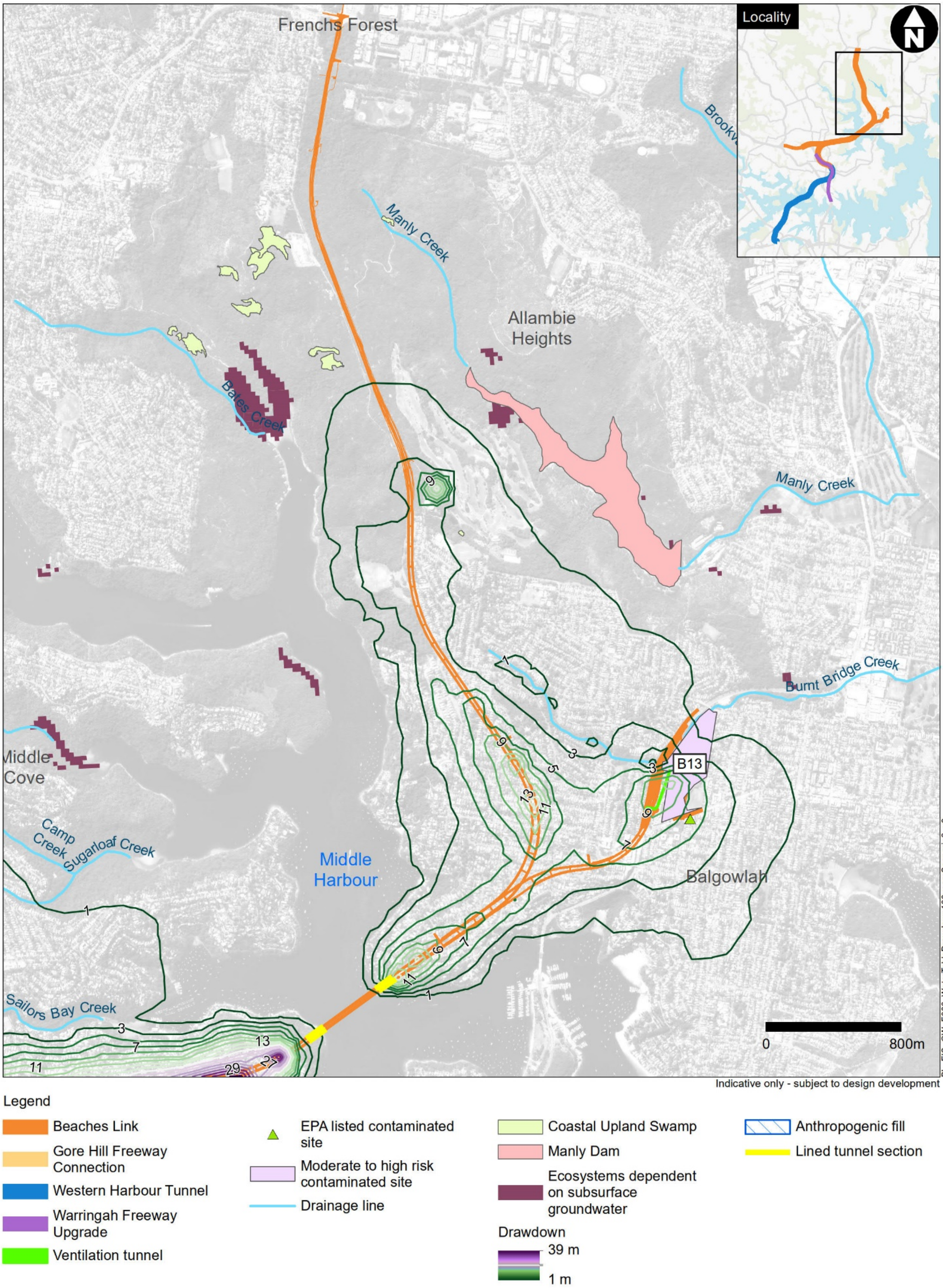


Figure 3-3 Predicted maximum groundwater drawdown north of Middle Harbour based on the revised groundwater modelling

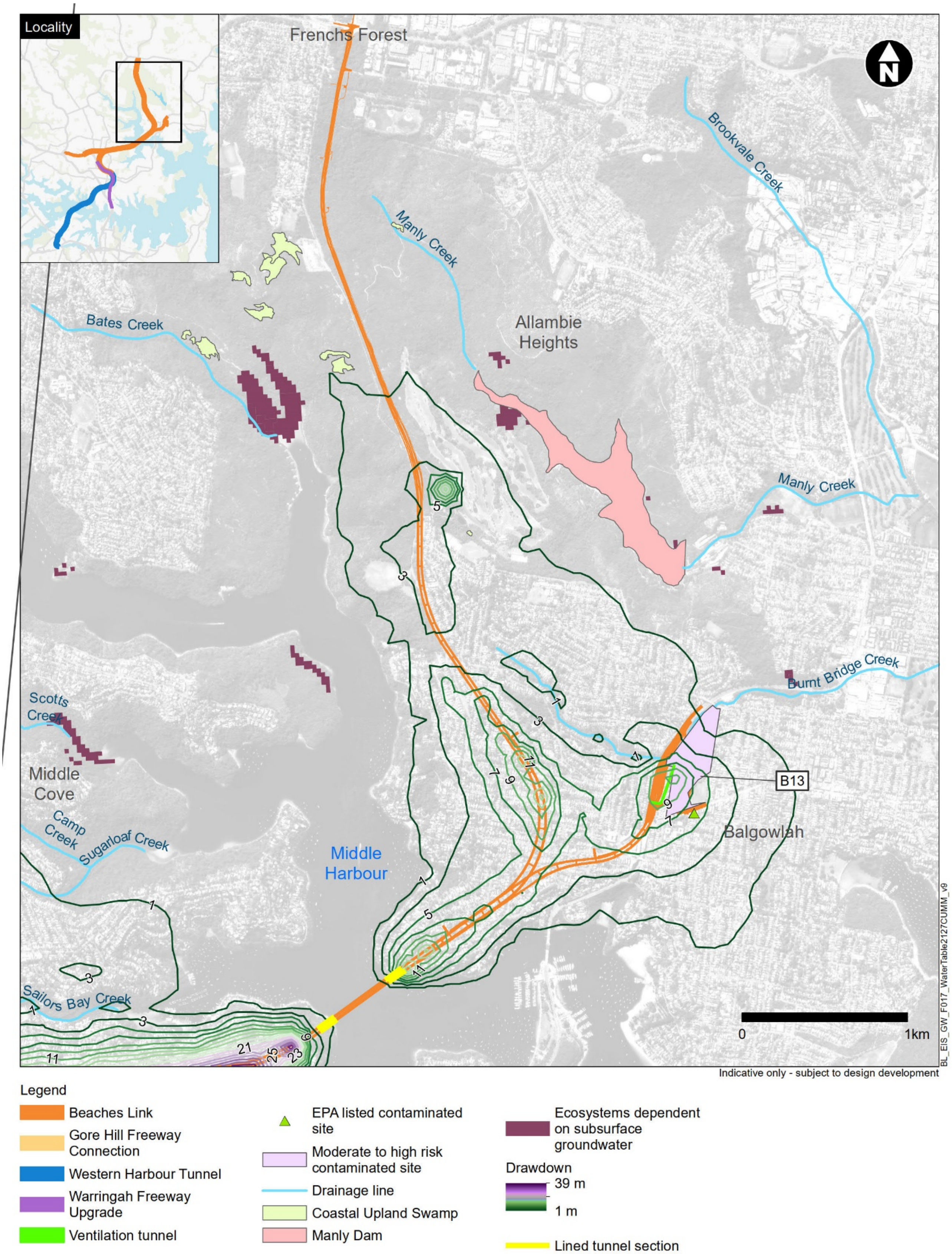


Figure 3-4 Predicted maximum groundwater drawdown north of Middle Harbour as shown in Figure 6-8 of Appendix N (Technical working paper: Groundwater)

The revised groundwater drawdown predictions at Flat Rock Creek, Quarry Creek, Burnt Bridge Creek and the groundwater dependent ecosystem at Flat Rock Creek and Quarry Creek are very similar to those presented in the environmental impact statement as demonstrated in Figure 3-1 to Figure 3-4.

The maximum drawdown predicted at any point along Flat Rock Creek, Quarry Creek, Burnt Bridge Creek and at the groundwater dependent ecosystem at Flat Rock Creek and Quarry Creek based on the revised groundwater modelling is also similar to the predictions contained in the environmental statement as indicated in Table 3-1. This indicates that the additional creek sections added to the model and the changes to creek linings observed during the recent field survey, have had only a minor effect on the groundwater drawdown predictions.

3.2 Changes to groundwater baseflow

Groundwater baseflow was analysed in the environmental impact statement for the entire lengths of creeks by averaging the groundwater baseflow predicted in the groundwater modelling, as discussed in Section 6.2.3.5 of Appendix N (Technical working paper: Groundwater). A similar approach was applied to the revised groundwater modelling completed.

Groundwater baseflows in Flat Rock Creek, Quarry Creek and Burnt Bridge Creek in 2128 with and without the project have been predicted based on the revised groundwater modelling and are presented in Table 3-2. The table also includes the predicted groundwater baseflows in 2128 with and without the project from the modelling carried out for the environmental impact statement to enable easy comparison between the two sets of predictions.

Table 3-2 Predicted groundwater baseflow in 2128 with and without the project

Creek	Predicted groundwater baseflow to creeks in 2128 (kilolitres per day)			
	Reported in the environmental impact statement		Revised groundwater modelling	
	Without the project	With the project	Without the project	With the project
Flat Rock Creek	215	131	1748	1222
Quarry Creek	17	5	17	6
Burnt Bridge Creek	18	1	34	14

The project is predicted to result in a reduction in groundwater baseflow in Flat Rock Creek, Quarry Creek and Burnt Bridge Creek in 2128 as indicated by the ‘without the project’ predictions in Table 3-2 being higher than ‘with the project’ predictions for both the revised groundwater modelling and the groundwater modelling carried out for the environmental impact statement. The difference between the predictions reported in the environmental impact statement and the revised groundwater modelling is due to the additional reaches of Flat Rock Creek identified in the May 2021 field survey that were not previously included in the modelling, as well as changes to the streambed classifications of some sections of both Flat Rock Creek and Burnt Bridge Creek and consequently, the contribution of groundwater baseflow to these creek sections.

Table 3-3 Predicted reduction in groundwater baseflow in 2128 with the project

Creek	Predicted reduction in groundwater baseflow to creeks in 2128			
	Reported in the environmental impact statement		Revised groundwater modelling	
	kilolitres per day	%	kilolitres per day	%
Flat Rock Creek	85	39%	526	30%
Quarry Creek	11	69%	11	63%
Burnt Bridge Creek	17	96%	20	60%

The predicted baseflow reductions for Flat Rock Creek and Quarry Creek based on the revised groundwater modelling are similar to the predicted baseflow reductions for these creeks contained in the environmental impact statement. For Burnt Bridge Creek, less baseflow reduction is predicted with the revised groundwater modelling, which reflects the presence of creek linings observed during the field survey.

The groundwater baseflow reduction predictions in Table 3-3 are calculated by summing the predictions for discrete sections of each creek. The discrete creek sections used in the revised groundwater modelling are based on the classifications of creek sections shown in Figure 2-11 to Figure 2-14. The cumulative baseflow reductions for the discrete creek sections are provided in Figure 3-5 for Flat Rock Creek and Quarry Creek and Figure 3-6 for Burnt Bridge Creek.

Figure 3-5 Predicted cumulative reduction in groundwater baseflow along sections of Flat Rock Creek and Quarry Creek

Figure 3-6 Predicted cumulative reduction in groundwater baseflow along sections of Burnt Bridge Creek

3.3 Changes to streamflow

As indicated in Section 2.1.1, groundwater baseflow is difficult to distinguish from other sources of water and makes up only a portion of streamflow that is observed in creeks. Therefore, the predicted groundwater baseflow reductions have also been presented in the context of overall streamflow using measurements made in May 2018 at Flat Rock Creek weir and Burnt Bridge Creek downstream to better illustrate the tangible effects of the project on these creeks.

The contribution of baseflow to streamflow is predicted to vary considerably along the length of the creeks, for example it is predicted to comprise about one per cent of streamflow at Flat Rock Creek upstream, about 79 per cent of streamflow at Flat Rock Creek downstream and 67 per cent of streamflow at Flat Rock Creek Weir, while baseflow is predicted to comprise about six per cent of streamflow at Burnt Bridge Creek midsection and two per cent of streamflow at Burnt Bridge Creek downstream,

Flat Rock Creek weir is the most downstream location at which streamflow was measured in May 2018. The predicted groundwater baseflow contribution to streamflow at Flat Rock Creek weir in 2128 without the project is about 1562 kilolitres per day, which is about 67 per cent of the streamflow measured at the weir in May 2018. Groundwater baseflow is predicted to reduce to 1041 kilolitres per day at Flat Rock Creek weir in 2128 with the project, which is about 45 per cent of the streamflow measured at the weir in May 2018. The predicted reduction in streamflow at Flat Rock Creek weir in 2128 as a result of groundwater baseflow reductions caused by the project is therefore 521 kilolitres per day or about 22 per cent as shown in Table 3-4 and illustrated in Figure 3-7. Flat Rock Creek weir is located downstream of the confluence of Quarry Creek and Flat Rock Creek, so it includes streamflow contribution from both creeks.

A similar analysis of the potential impact of the project on streamflow in Burnt Bridge Creek has been carried out and is presented in Table 3-4 and illustrated in Figure 3-7. It is predicted that in 2128 after 100 years of operation, the project would result in a one per cent reduction (20 kilolitres per day) in streamflow at Burnt Bridge Creek due to the predicted groundwater baseflow reduction at this location.

Table 3-4 Reduction in streamflow due to the predicted reduction in groundwater baseflow in 2128 based on the revised groundwater modelling

May 2018 streamflow measurement		Predicted groundwater baseflow				Predicted reduction in streamflow	
Location	Streamflow (kilolitres per day)	Without the project		With the project		With the project	
		(kilolitres per day)	% of streamflow	(kilolitres per day)	% of streamflow	(kilolitres per day)	%
Flat Rock Creek weir[1]	2337	1562	67%	1041	45%	-521	-22%
Burnt Bridge Creek downstream	1242	29	2%	9	1%	-20	-1%

Notes

[1] Flat Rock Creek weir is located downstream of the confluence of Quarry Creek and Flat Rock Creek, therefore it includes streamflow from both creeks.

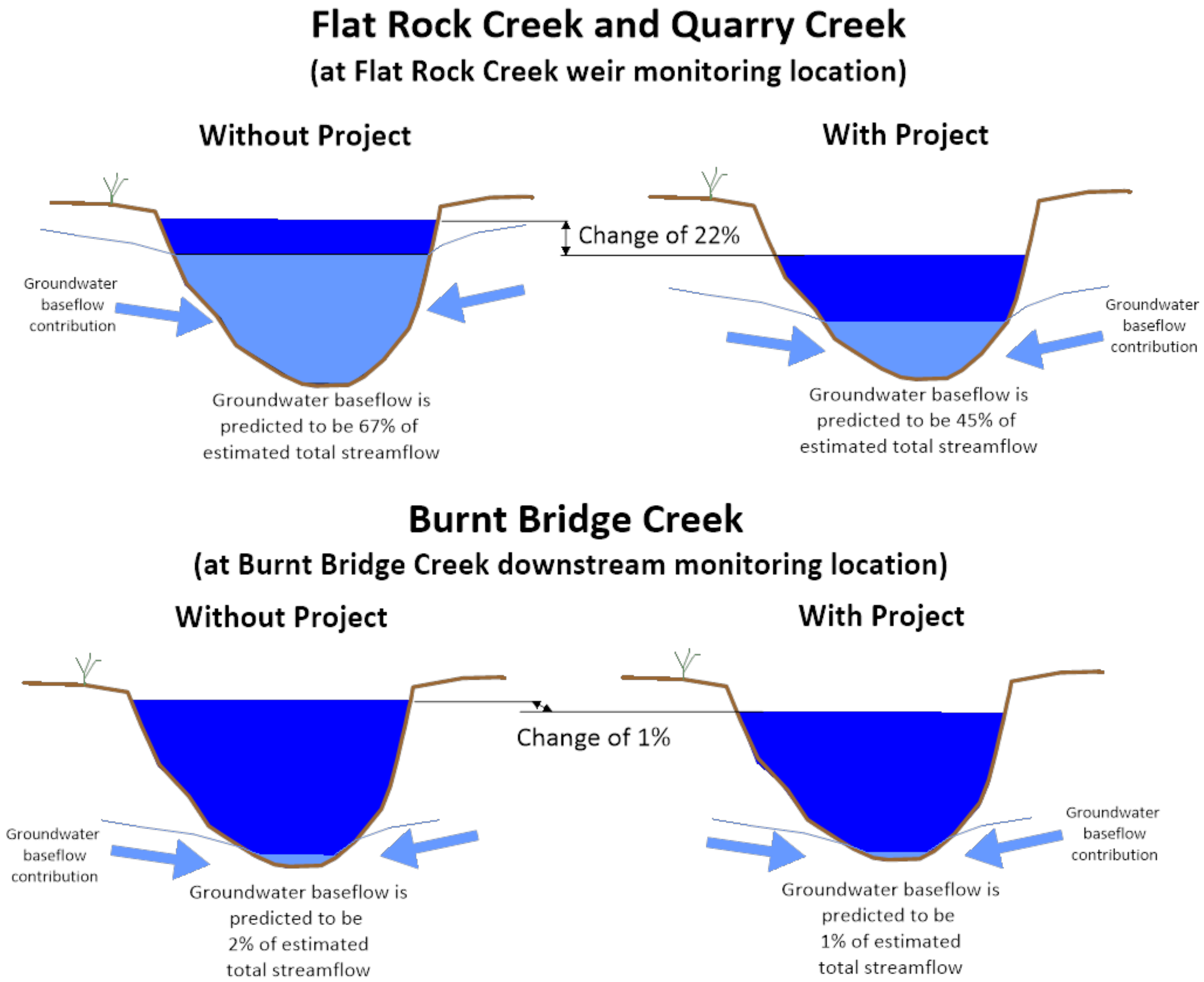


Figure 3-7 Illustration of the effect of the predicted reduction in groundwater baseflow on streamflow in 2128 (based on May 2018 streamflow measurements)

3.4 Environmental management measures

Transport for NSW has developed a suite of environmental management measures to mitigate the potential impacts of the construction and operation of the project and these are detailed in Table D2-1 of the submissions report. Environmental management measures that will be implemented to mitigate the potential impacts to groundwater include:

- As more information becomes available on groundwater levels and contamination through ongoing groundwater monitoring, groundwater modelling will be updated to refine the predictions. Inflow predictions will be updated prior to finalising detailed design and will include designed tunnel linings, and the detailed design will be updated based on the updated operational inflow and impact predictions.

  If refined predictions of groundwater levels and drawdown indicate that impacts would be greater than the impacts presented in the environmental impact statement, feasible and reasonable mitigation measures will be incorporated into the detailed design and implemented.

Groundwater modelling will be conducted considering *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012), including sensitivity analysis and consideration of future climate change, as required (refer to revised environmental management measure SG2)

- Following completion of environmental management measure SG2, a focussed study will be carried out in consultation with Department of Planning, Industry and Environment (Environment, Energy and Science Group) to confirm potential groundwater drawdown and associated baseflow reductions at Burnt Bridge Creek, Flat Rock Creek and Quarry Creek due to tunnelling, and confirm potential impacts on freshwater ecology in the affected watercourses and nearby groundwater dependent ecosystems. The study will consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where ecological impacts are predicted to be worse than that presented as part of the environmental impact statement/submissions report, feasible and reasonable mitigation measures to address the impacts will be identified in consultation with a suitably qualified and experienced specialist, incorporated into the detailed design, and implemented during construction. The mitigation measures considered will include tunnel linings (refer to revised environmental management measure SG6)
- Measures will be implemented during tunnel construction to ensure that groundwater inflows into each tunnel during the operation phase do not exceed 1L/s/km across any given kilometre (refer to revised environmental management measure SG16).

No changes to the environmental management measures listed in Table D2-1 of the submissions report are considered necessary based on the results of the revised groundwater modelling.

In addition to the above environmental management measures, during operation of the project, the proposed Gore Hill Freeway wastewater treatment plant would discharge into Flat Rock Creek via the local stormwater system at a rate of up to about 1425 kilolitres per day as outlined in Table 6-1 of Appendix O (Technical working paper: Surface water quality and hydrology). The proposed operational wastewater treatment plant discharge to Flat Rock Creek may offset the impact of the predicted reduction in baseflow to this creek given that the expected daily discharge volume to Flat Rock Creek from the wastewater treatment plant exceeds the revised predicted reduction in baseflow (526 kilolitres per day, refer to Table 3-3 above).

4 Revised environmental impact predictions

4.1 Freshwater ecology

A report to revise the findings in the environmental impact statement regarding the predicted reduction in groundwater baseflows to the freshwater ecology of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek has been prepared by Cardno and is provided in Annexure A. A summary of the findings is presented below.

4.1.1 Existing environment

•

Flat Rock Creek

Flat Rock Creek is a first order waterway upstream of the Quarry Creek confluence and a second order waterway downstream. It drains the Flat Rock Creek catchment into Middle Harbour and flows in a generally easterly direction from Marlow Road at Artarmon into Middle Harbour at Tunks Park at Cammeray. It is considered to be freshwater upstream of its confluence with Quarry Creek and estuarine downstream. At the time of inspection, moderate flow was observed downstream of Flat Rock Drive. Low flow was observed at its source but the creek was dry in some of its upper parts. There are many stormwater outlets along the length of Flat Rock Creek and at the time of inspection, these had low or non-existent flow. Flat Rock Creek is generally unlined and this includes the dry areas of the upper parts of the creek. Much of the middle section of the creek is lined with concrete as is the far downstream area flowing to an underground weir at Tunks Park.

Flat Rock Creek includes a mixture of shallow and deep pools and riffle/cascade zones in its upper and middle reaches before reaching the estuarine section.

The Riparian, Channel, and Environmental (RCE) scores for all of Flat Rock Creek were generally high. Where it is not underground or concrete lined, much of Flat Rock Creek has evidence of active bush regeneration and is dominated by native trees and shrubs. The riparian condition of much of the creek is either quasi-natural or only partly modified.

Quarry Creek

Quarry Creek is a second order waterway. It drains into the Flat Rock Creek catchment and subsequently into Middle Harbour. It generally flows in a north-easterly direction from Bridgeview Avenue, Cammeray into Tunks Park, Cammeray. It appears to be estuarine downstream of its confluence with Flat Rock Creek. Quarry Creek is shorter than Flat Rock Creek, has no stormwater outlets along its length and apart from the upper section, generally flows down a steep gradient. At the time of inspection, moderate flow was observed. Quarry Creek is generally unlined apart from the far upper part of the creek. Quarry Creek generally consists of riffle/cascade zones with few shallow or deep pools.

Most of Quarry Creek is among natural bushland and the RCE scores for all of Quarry Creek were generally good. The riparian condition of much of the creek is either quasi-natural or only partly modified.

Burnt Bridge Creek

Burnt Bridge Creek is a first order waterway in the Burnt Bridge Creek catchment which flows in a generally easterly direction from Clontarf Street, Seaforth to Kenneth Road, Manly where it enters Manly Lagoon. At the time of inspection, low flow was observed at its source. There are numerous stormwater outlets along the length of Burnt Bridge Creek and at the time of inspection, these had low or non-existent flow.

Burnt Bridge Creek is generally unlined apart from a small section upstream of the Burnt Bridge Creek Deviation and within the Balgowlah industrial area. It includes a mixture of shallow and deep pools and riffle/cascade zones in its upper and middle reaches before flowing into a concrete-lined culvert when it reaches the Balgowlah industrial area.

The RCE scores for Burnt Bridge Creek ranged from 17 (in the lower reaches within the Balgowlah industrial area) to 41 (in the upper reaches). Upstream of the Burnt Bridge Creek Deviation, the riparian corridor is considered quasi-natural. This area has evidence of active bush regeneration and is dominated by native trees and shrubs with frequent long deep pools, riffles and cascades. The riparian condition of the middle and downstream areas of the creek is either partially or highly modified. None of the riparian zones of Burnt Bridge Creek are dependent, either entirely or in part, on the presence of groundwater for their health and/or survival (refer to Appendix S (Technical working paper: Biodiversity development assessment report)).

Fish

No native fish species were caught or observed. Schools of the pest species Mosquito Fish (*Gambusia holbrooki*) were caught in the two collapsible bait traps deployed at site BB03 in Burnt Bridge Creek (ie the long, deep pool upstream of the weir, immediately downstream of the Burnt Bridge Creek Deviation).

Macroinvertebrates

The number of macroinvertebrate taxa collected in the Australian River Assessment System (AUSRIVAS sampling sites ranged between 10 and 36. Both the Observed to Expected ratio (OE50 - provides a measure of biological impairment at the site) and Stream Invertebrate Grade Number (SIGNAL2 – a scoring system for macroinvertebrates which gives an indication of water quality) scores indicated assemblages at all creeks were either severely or extremely impaired and suffered from severe pollution.

Water quality

Some sections of the creeks have undergone significant modifications to the original bedrock channel or alterations from natural channels to artificial, hard (concrete-lined) channels to accommodate higher volumes and flow velocities after rain, from an increase in urban, impervious surfaces. This hydrological alteration from natural conditions would be expected to promote the transport of sediments and contaminants to downstream receiving environments (eg Middle Harbour and Manly Lagoon).

Detailed analysis of water quality for Flat Rock Creek, Quarry Creek and Burnt Bridge Creek carried out for the environmental impact statement is provided in Appendix O (Technical working paper: Surface water quality and hydrology). The water quality of these three creeks was considered likely to be substantially influenced by the surrounding urban development. Sources of contaminants, such as suspended sediments, heavy metals and persistent organic pollutants include stormwater, wastewater overflows and leachate from contaminated lands.

Recent investigations of the water quality of Flat Rock Creek and Burnt Bridge Creek were carried out in March 2021 by ERM during a period of rainfall. These investigations confirmed the presence of some heavy metals and that nutrients (total nitrogen, reactive nitrogen and total phosphorous) were in excess of the ANZECC & ARMCANZ 2000 default guideline values for slightly to moderately disturbed ecosystems, defined as ecosystems in which “aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity" (Chapter 3 of ANZECC & ARMCANZ (2000)).

Further discussion on surface water quality is provided in Section 4.3.

Summary

The freshwater sections of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek all have depauperate (ie lacking in numbers of variety of species) assemblages of macroinvertebrates, non-existent assemblages of native fish and generally very few, if any, native macrophytes. The AUSRIVAS results suggest the freshwater ecology of the creeks is generally partially or severely impaired and affected by severe pollution. Sensitive macroinvertebrate groups such as *Ephemeroptera, Trichoptera* and *Plecoptera* were absent from all creeks. This is despite the riparian habitat of many parts of all of the creeks being in reasonable to good condition. Hence, although much of the freshwater reaches of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek appear to look healthy, the effect is aesthetic only and the freshwater ecology is considered to be generally poor.

The reasons for freshwater ecology being in such poor condition are likely to be a consequence of the following:

- Generally high levels of some nutrients and dissolved metals in the creeks (refer to Section 5 of Appendix N (Technical working paper: Groundwater))
- Regular scouring after heavy rain from torrents of stormwater (ie bare substratum in most shallow pools and a lack of aquatic habitat for macroinvertebrates in most pools generally, such as fine sand, gravel and detritus)

The presence of weirs in Flat Rock Creek and Burnt Bridge Creek, and steep cascades in all creeks, would prevent some species from colonising middle to upper reaches of creeks from downstream areas.

4.1.2 Impact assessment

Impact of groundwater drawdown to freshwater ecology

The revised groundwater modelling has allowed estimates of the project's predicted effects to the baseflow of the creeks to be refined. The refined estimates indicate baseflow would still be expected to be reduced by as much as 30 per cent to 63 per cent after 100 years, depending on the creek. Notwithstanding this, additional information about the relative contribution of baseflow to total streamflow suggests that for the most part, baseflow only represents a small proportion of total streamflow and reductions in streamflow would be less. The exception would be for some parts of Flat Rock Creek, but given there are significant stormwater inflows and an operational discharge into the creek of up to about 1425 kilolitres per day of good quality water from the project wastewater treatment plant during operation, there would be a net increase in flow in this creek.

Annexure D of Appendix S (Technical working paper: Biodiversity development assessment report) considered that there would still be some (low) flow along the entirety of the creeks between rainfall events and additional studies have confirmed this would be the case after the effects of the project on baseflow are considered. The additional survey completed in May 2021 indicates the presence of pool habitats in most reaches of the creeks and that even in periods of low flow in dry periods in summer, it would be expected that many of these pools would be deep enough to retain water and therefore freshwater habitat. Notwithstanding the finding that assemblages of aquatic macroinvertebrates and fish are generally depauperate in the creeks, even in extremely dry times, some pools would be deep enough to provide refuge for aquatic macroinvertebrates, albeit only those species that are most tolerant to low flows.

Based on the evidence that changes to baseflow caused by groundwater drawdown would not substantially alter the flow regime after 100 years of operation in any of the creeks to the extent that it would alter instream habitat to already depauperate assemblages of aquatic macroinvertebrates, fish and macrophytes, it was concluded that the project would not significantly impact the freshwater ecology of Flat Rock Creek, Quarry Creek or Burnt Bridge Creek.

Impact of groundwater drawdown on riparian habitat

Where the creeks are not diverted underground, the general findings of the study indicate the riparian corridors of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek appear to be in good condition, with native vegetation dominating apart from the middle and downstream areas of Burnt Bridge Creek. Ongoing efforts of bush regeneration in the upper parts of Flat Rock Creek and Burnt Bridge Creek appear to have removed much of the weeds that had previously been noted in these areas during investigations for the environmental impact statement. Much of the riparian vegetation of Quarry Creek and in downstream areas of Flat Rock Creek depend on groundwater. It is expected that the additional creek flows from treated water from the operational wastewater treatment plant could partially feed the surrounding groundwater system. None of the riparian zones of Burnt Bridge Creek, including the project exclusion zone in its middle section, are dependent, either entirely or in part, on the presence of groundwater for their health and/or survival (refer to Appendix S (Technical working paper: Biodiversity development assessment report)).

4.1.3 Environmental management measures

As no impacts are expected on the freshwater ecology of Flat Rock Creek, Quarry Creek or Burnt Bridge Creek as a result of the revised predictions of groundwater baseflow reductions, no additional environmental management measures beyond those identified in Table D2-1 of the submissions report are required to manage these impacts.

4.2 Groundwater dependent ecosystems

A report to revise the finding in the environmental impact statement regarding the predicted reduction in groundwater baseflows to groundwater dependent ecosystems near the project has been prepared by Eco Logical Australia (refer to Annexure B). A summary of the findings is presented below.

4.2.1 Existing environment

A detailed account of the geology and hydrogeology of the project area is provided in Section 5.3 and Section 5.5 respectively of Appendix N (Technical working paper: Groundwater). Groundwater dependent ecosystems are discussed in Appendix S (Technical working paper: Biodiversity development assessment report).

The following groundwater dependent ecosystems are the focus of this revised assessment:

- Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, and Coastal Sand Forest in the mid reaches of Flat Rock Creek, about 280 metres south-east of the tunnel alignment and the Flat Rock Drive construction support site (BL2). These have been mapped as having a moderate to high potential for groundwater dependence (Bureau of Meteorology, 2018)
- A small patch of Coastal Upland Swamp in the Sydney Basin Bioregion, which is an endangered ecological community under the *Biodiversity Conservation Act 2016* and the *Environment Protection and Biodiversity Conservation Act 1999*. This is not mapped in the Groundwater Dependent Ecosystems Atlas (Bureau of Meteorology, 2018), but is potentially sensitive to changes in groundwater flow (Arcadis, 2020). Three patches occur in the project area: two about 95 metres west of the Wakehurst Parkway in Garigal National Park, and one north of Bantry Bay Oval, about 135 metres south-east of the construction footprint.

Most of the project area is underlain by the Hawkesbury Sandstone, with a small amount of localised fill or Quaternary sediment near Flat Rock Creek.

The Hawkesbury Sandstone is an unconfined aquifer at the surface, but becomes increasingly confined with depth because of the highly stratified nature of the sandstone and interbedded shales. Groundwater flow occurs mostly via secondary permeability and bedding.

The regional water table generally mimics the surface topography, with groundwater moving from high areas to low areas where they discharge to surface drainage lines. The water table varies from close to ground surface to 100 metres below ground level.

The Hawkesbury Sandstone was deposited in a fluvial paleo-environment, likely by a large braided river and as such is highly stratified. Localised perched water tables occur as a result of the stratified nature of the sandstone, which can be interspersed with lenses of low permeability that restrict the downward draining of water. This can mean that at some locations throughout the project area there are shallow perched water tables overlying a deeper water table.

Fractures in the sandstone create preferential flow paths for groundwater. Shallow or perched groundwater systems may discharge to surface water via shallow fracture networks, or may emerge from the sides of bare sandstone as springs.

Baseline ecological value and ecological condition

The value of a groundwater dependent ecosystem is determined by the biota it supports, as well as the processes performed by the ecosystem (Serov et al., 2012). Biota includes the flora, fauna and microbiota, while the processes performed include nutrient processing, hydrological filtration, and other biological, hydrological, physical, and chemical processes.

The ecological conditions of groundwater dependent ecosystems in the project area have been determined from information contained in Appendix S (Technical working paper: Biodiversity development assessment report) and subsequent field survey by the project terrestrial ecologists in June 2021.

Flat Rock Creek, Quarry Creek and Burnt Bridge Creek are all considered to be in a poor ecological condition, as they have a depauperate macroinvertebrate fauna, no native fish community, and very few if any native macrophytes (Cardno, 2021).

Flat Rock Creek

In the upstream reaches, Flat Rock Creek is modified and alternates between above and below-ground sections and has reaches where it is lined with either concrete or bedrock. In addition, this area is dominated by stormwater flows which have shaped the creek form. This part of the creek is not considered key fish habitat (Cardno, 2020; Cardno 2021). The channel is natural as it flows through Flat Rock Reserve, with the bed made of sandstone in the upstream section of reserve, and alluvium downstream. There are occasional ripples and pools, and the banks are steep in places, and range from three to 10 metres above the creek bed. The invertebrate fauna of Flat Rock Creek consists of 16-36 taxa which indicates that the creek is either severely or extremely impaired, and therefore is in poor ecological condition (Cardno, 2021).

Riparian vegetation is densely vegetated with generally native overstorey and an understorey of native and exotic species. Vegetation consists of PCT 1841 Smooth-barked Apple-Turpentine-Blackbutt tall open forest on enriched sandstone slopes and gullies of the Sydney region, with infestations of weeds and exotics in disturbed areas. The vegetation is likely to only provide marginal quality habitat for disturbance-tolerant species of amphibians, reptiles, mammals, invertebrates and birds (Cardno, 2020). There are numerous impediments to fish passage including underground sections bedrock bars and narrow pipe culverts, and there is little fauna habitat present in the form of logs, leaf litter or rocks. In the lower reaches of the creek immediately upstream of the Quarry Creek confluence, there is a small amount of instream timber that may provide fish habitat. Flat Rock Creek is considered to be in poor ecological condition (Cardno, 2021); therefore it is a low ecological value groundwater dependent ecosystem.

Downstream of the Quarry Creek confluence, Flat Rock Creek becomes estuarine and continues to receive stormwater discharge (like the mid to upper reaches). The bed consists of unconsolidated sediments and there is some channel and bank erosion. It remains aboveground.

Quarry Creek

Quarry Creek is a short (500 metre) waterway that joins Flat Rock Creek at Flat Rock Reserve. Quarry Creek begins at an altitude of 50 metres Australian Height Datum (AHD) and descends over a distance of 300 metres to an altitude of 10 metres AHD. The creek crosses the modelled groundwater contour (Jacobs, 2020) at an altitude of 30 metres, indicating that the final 300 metres of the creek is fed to varying degrees by groundwater.

Upstream of the confluence, Quarry Creek is a first order stream that flows through an underground culvert reach into a natural bedrock channel as part of Flat Rock Reserve. Vegetation along Quarry Creek is similar to that along Flat Rock Creek. Quarry Creek has a depauperate community of aquatic macroinvertebrates (10-25), with those taxa present indicating extreme or severe levels of impact on the ecology (Cardno, 2021). The creek is considered a low ecological value groundwater dependent ecosystem.

Burnt Bridge Creek

Burnt Bridge Creek is a first order waterway that is intermittent and receives stormwater input from multiple locations. It was not identified as being groundwater dependent in the *Groundwater Dependent Ecosystems Atlas* (Bureau of Meteorology, 2018), but receives some of its contribution from groundwater (Jacobs, 2020). The creek has low dissolved oxygen concentration and elevated heavy metal and nutrient concentrations (Cardno, 2020). The channel consists of bedrock with sand and silt patches and rocky outcrops. Pools are partially connected and contain exotic in-stream vegetation and moderate riparian shading. Burnt Bridge Creek is likely to provide only marginal quality habitat suitable for disturbance tolerant species. There is minimal structural habitat (rocks, logs, leaf litter) and water quality is poor (Cardno, 2020). The freshwater ecology of Burnt Bridge Creek is severely or extremely impaired, with 14-24 taxa (Cardno, 2021). Therefore it is considered a low ecological value groundwater dependent ecosystem.

Riparian vegetation ranges in width from 0 to 30 metres and consists of Water Gum-Coachwood riparian scrub that has a mix of native and exotic species. The area has been significantly disturbed and contains weeds and large areas of exposed ground.

Groundwater dependent vegetation communities of Flat Rock Reserve

A patch of Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest extends for about one kilometre in the middle reaches of Flat Rock Creek. The vegetation is in moderate to good condition and contains mostly native species (*Eucalyptus spp., Angophora costata, Allocasuarine littoralis*) on the upper or mid-slopes, but is dominated by exotic species in the flatter areas beside the creek. Vegetation in the gully closer to the creek is sheltered and appears to be in good condition with no signs of stress. Palms and ferns occur on the lower flat beside the creek. This groundwater dependent ecosystems is considered a moderate ecological value groundwater dependent ecosystem.

Coastal Upland Swamps

Coastal Upland Swamps in the Sydney Basin Bioregion are listed as an endangered ecological community under the *Biodiversity Conservation Act 2016* and the *Environment Protection and*

Biodiversity Conservation Act 1999. This makes them a high ecological value groundwater dependent ecosystem. This vegetation community occurs on poorly permeable sandstone plateaux in low relief headwater valleys of streams and on sandstone benches with abundant seepage moisture (Department of the Environment, 2014). Coastal Upland Swamps generally occur in small patches of less than a hectare (Department of the Environment, 2014). There is small patch of swamp west of the Wakehurst Parkway in Garigal National Park, and another small patch north of Bantry Bay Oval. During a site visit to this swamp in 2021, ecologists found it difficult to delineate the swamp from the surrounding heathland.

4.2.2 Impact assessment

Terrestrial vegetation communities of Flat Rock Creek and Quarry Creek

About 10.5 hectares of Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest is within the area subject to groundwater drawdown around Flat Rock Creek as shown in Figure 4-1. Drawdown beneath this vegetation is predicted to be less than five metres at the upstream end of Flat Rock Creek, about 11 metres at the upstream end of Quarry Creek, and less than one metre at the confluence of Flat Rock Creek and Quarry Creek. Vegetation growing on the upper slopes of the sandstone ridges is likely to be supported by perched aquifers that are isolated from the regional water table. Drawdown in the regional aquifer is therefore likely to have minor spatial impacts on vegetation health, so the magnitude of risk would be small given that the vegetation community is not solely dependent on regional groundwater.

The small alluvial aquifer of Flat Rock Creek at the Quarry Creek confluence would be recharged by the releases of up to about 1425 kilolitres per day of treated water from the project operational wastewater treatment plant discharge into Flat Rock Creek at Artarmon. This may replace any baseflow losses and sustain vegetation communities dependent on groundwater in the shallow alluvium.

Coastal Upland Swamp

Groundwater drawdown beneath the section of coastal upland swamp beside Wakehurst Golf Club is modelled to be less than three metres. Regional water level is about 50 metres below ground level, so this swamp is likely to be connected to perched water tables rather than the regional aquifer. Perched aquifers are predominantly fed by localised rainwater, or from downward drainage from upslope aquifers. It is unlikely that this section of upland swamp would be affected by drawdown from the project.

Drawdown beneath the swamp west of the Wakehurst Parkway is modelled to be between zero and one metre by 2128. The groundwater dependence of this swamp is uncertain, as the water level is about 10 metres below ground level. The water table beneath this swamp may be affected by drawdown, but it is likely that the swamp also receives water from surface runoff and subsurface drainage from upslope perched aquifers, and that the availability of this water to support the swamp would not be affected.

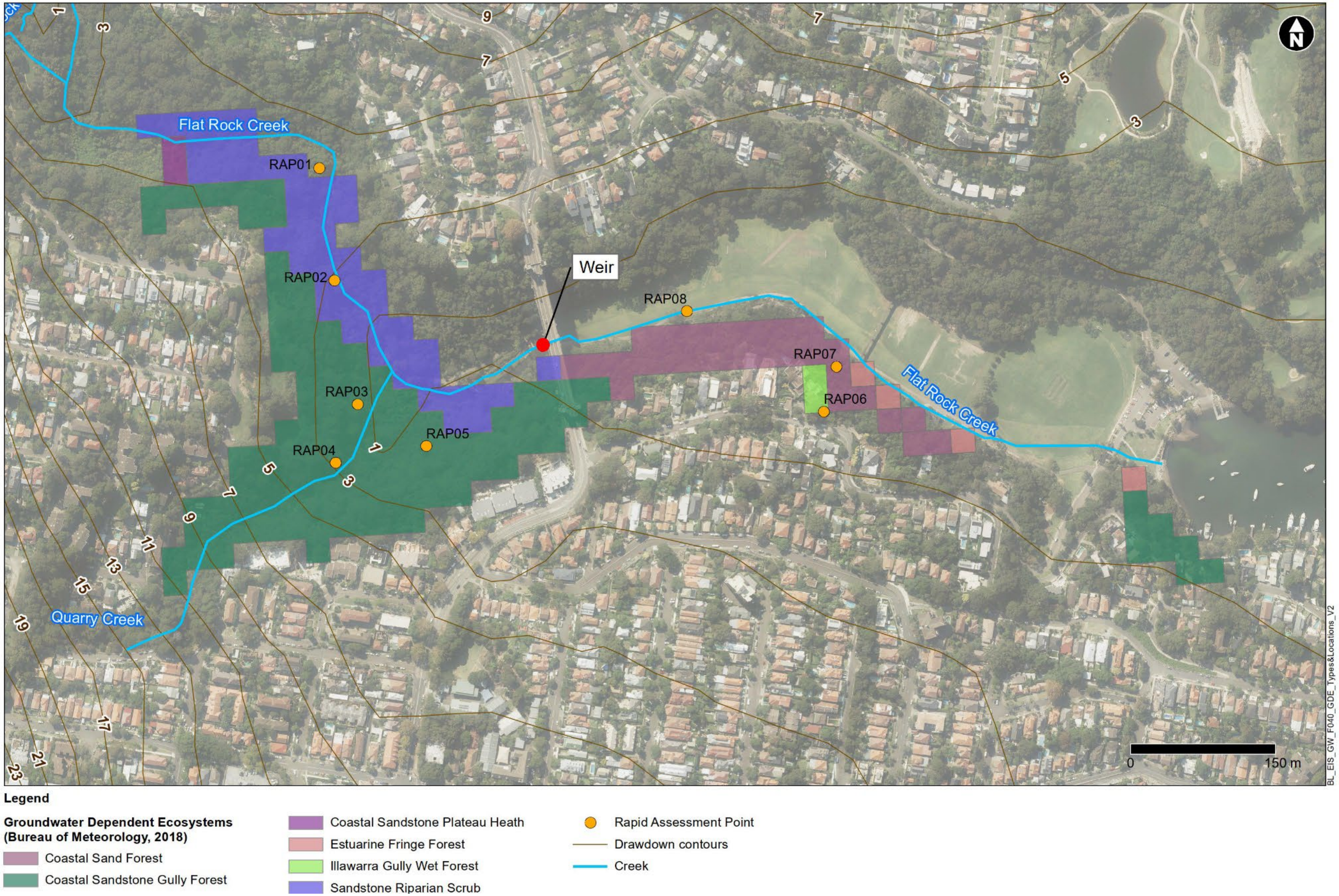


Figure 4-1 Groundwater dependent ecosystems at Flat Rock Creek and predicted groundwater drawdown after 100 years of operation

4.2.3 Environmental management measures

The risk assessment considered recommended management actions for the identified groundwater dependent ecosystems, taking into consideration the existing ecological conditions. The assessment found that:

- As the ecological condition of the creeks is already poor, the ongoing ecological monitoring of these waterways is unlikely to indicate whether baseflow loss would have an impact
- The release of treated water into Flat Rock Creek from the operational wastewater treatment plant at Artarmon would compensate for the water lost through groundwater drawdown and ensure that pool and riffle habitats in middle reaches of Flat Rock Creek, which are classified as Type 1 key fish habitat, are able to persist and maintain their ecological functions
- There is a very low risk that the Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, and Coastal Sand Forest ecosystems around Flat Rock Creek would be impacted by groundwater drawdown, particularly the vegetation growing close to the creek where flow would be supplemented from the operational wastewater treatment plant
- Vegetation communities on the sandstone slopes of Flat Rock Creek Gully are likely to be buffered against the impacts of groundwater drawdown by shallow perched aquifers. These aquifers are recharged by rainfall and surface runoff, and in the upper slopes of the gully, may be disconnected from the deeper regional aquifer
- Given the uncertainty of whether the two patches of Coastal Upland Swamp around Wakehurst Parkway are groundwater dependent, and the low likelihood that they will be impacted by the project, no specific monitoring of these ecosystems is recommended.

Further investigation and monitoring of the potential water table drawdown impacts on groundwater baseflow and groundwater dependent ecosystems will be carried out during further design development in line with revised environmental management measure SG6:

> *Following completion of environmental management measure SG2, a focussed study will be carried out in consultation with Department of Planning, Industry and Environment (Environment, Energy and Science Group) to confirm potential groundwater drawdown and associated baseflow reductions at Burnt Bridge Creek, Flat Rock Creek and Quarry Creek due to tunnelling, and confirm potential impacts on freshwater ecology in the affected watercourses and nearby groundwater dependent ecosystems. The study will consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where ecological impacts are predicted to be worse than that presented as part of the environmental impact statement/submissions report, feasible and reasonable mitigation measures to address the impacts will be identified in consultation with a suitably qualified and experienced specialist, incorporated into the detailed design, and implemented during construction. The mitigation measures considered will include tunnel linings.*

4.3 Surface water quality

4.3.1 Existing environment

An assessment of existing surface water quality and potential impacts from the construction and operation of the project was provided in Appendix O (Technical working paper: Surface water quality). The findings from the revised groundwater modelling predictions have been used to inform the revised assessment presented below.

Flat Rock Creek

Background water quality data collected during preparation of the environmental impact statement indicated that Flat Rock Creek experiences elevated nutrients (Oxidised Nitrogen (NO_x)), Total Nitrogen (TN), Total Phosphorus (TP) and metals (Copper and Zinc) at the upstream reach. Also, pH levels also frequently fell outside the ANZG (2018) guidelines limits of 6.5-8 due to elevated pH (>8.5). Downstream, pH levels were generally lower and compliant. However, nutrients and metals were still elevated, and generally higher downstream. Recent sampling carried out in January and February 2021 shows that pH is still elevated and exceeds upper limit for protection of freshwater ecosystems. Turbidity and total suspended solids concentrations were generally low which was complemented by clear, highly transparent water. Nutrients, whilst still exceeding the guidelines, were recorded in much lower concentrations than during previous investigations carried out for the environmental impact statement. Copper and zinc concentrations in January and February 2021 also exceeded the guidelines however were recorded in higher concentrations compared to previous monitoring. Zinc was generally double the median concentration previously recorded with the exception of the downstream site in February 2021 where concentrations in Flat Rock Creek were 100 times the guideline limit and 18 times greater than median concentrations previously recorded at this site during the environmental impact statement investigations.

Quarry Creek

Quarry Creek is a tributary of Flat Rock Creek which flows into Long Bay in Middle Harbour. Background water quality data collected during the environmental impact statement phase showed that similarly to Flat Rock Creek, Quarry Creek has elevated nutrient and metal concentrations with NO_x, TN, TP, copper and zinc all exceeding the recommended guideline limits (ANZG, 2018) for protection of estuarine aquatic ecosystems. Dissolved oxygen and iron were also recorded outside guideline limits on occasion. More recent monitoring has not been carried out at Quarry Creek.

Burnt Bridge Creek

Data collected during preparation of the environmental impact statement indicated that Burnt Bridge Creek exhibits poor water quality that does not meet the required limits for protection of freshwater ecosystems due to low dissolved oxygen concentrations, and elevated copper, zinc, TN and NO_x, with concentrations generally higher upstream. Additionally, lead, iron and TP also frequently exceeded the recommended limits at the upstream site in Burnt Bridge Creek.

Recent sampling carried out in January and February 2021 shows that dissolved oxygen levels are higher and pH is generally compliant with the recommended guideline limits (ANZG, 2018), with the exception of pH in February 2021 at the downstream site which exceeded the upper limit. Nutrient concentrations in Burnt Bridge Creek have decreased significantly, particularly at the downstream site since monitoring carried out during preparation of the environmental impact statement, although still exceeded the recommended guidelines for NOx and TN in February 2021, and TP in January and February 2021. Metal concentrations in Burnt Bridge Creek are generally compliant with the recommended guideline limits (ANZG, 2018) with the exception of copper and zinc which continue to exceed the recommended limits of protection of freshwater ecosystems. Copper concentrations were generally lower than median concentrations recorded in the investigations carried out during the preparation of the environmental impact statement.

4.3.2 Impact assessment

Impact of groundwater drawdown on surface water quality

The water quality of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek is generally poor due to elevated nutrients and metals as discussed in Section 4.3.1. As outlined in Section 3.2and Section 3.3, baseflow in Quarry Creek and Burnt Bridge Creek and the upstream section of Flat

Rock Creek is a very small proportion of surface flow. As such, the predicted drawdown estimated is unlikely to influence surface water quality at these sites.

Streamflow in Flat Rock Creek at the weir and downstream is made up of a greater proportion of groundwater baseflow which may influence the current water quality condition in the creek which is generally poorer downstream. Groundwater quality as reported in Appendix O (Technical working paper: Surface water quality and hydrology) documented that groundwater bores in the area exhibit elevated concentrations of metals and nutrients, which together with runoff, are the likely cause of the poor water quality observed. The predicted reduction in groundwater baseflow in this section of Flat Rock Creek may also result in a reduction of poor quality groundwater entering surface water which over time may result in a reduction of metal and nutrient concentrations in Flat Rock Creek. Additionally, Flat Rock Creek is to receive treated wastewater during the operation of the project that would be of a better quality than is currently observed. As a result, it would be expected that this could lead to improved water quality during the operational phase of the project.

Impact of groundwater drawdown on achieving the NSW Water Quality Objectives

During the operation of the project, there would be minimal change in baseflow reduction in Quarry Creek and Burnt Bridge Creek and upstream Flat Rock Creek. Therefore, the estimated drawdown in groundwater would not affect achieving the nominated water quality objectives of freshwater ecosystems, visual amenity and secondary contact recreation.

The predicted reduction in groundwater baseflow could result in a reduction of nutrient and metal concentrations in Flat Rock Creek. This reduction, combined with discharge of treated wastewater to a level that is consistent with the guidelines specified in revised environmental management measure WQ17 (refer to Table D2-1 of the submissions report), could slightly improve water quality and contribute to achieving the nominated water quality objectives of protection of aquatic ecosystems, visual amenity and secondary contact recreation.

4.3.3 Environmental management measures

No additional environmental management measures beyond those identified in Table D2-1 of the submissions report are considered necessary to manage the expected surface water quality impacts resulting from the project.

4.4 Social and community values

4.4.1 Existing environment

An assessment of existing social and community values and potential impacts from the construction and operation of the project was provided in Appendix U (Technical working paper: Socio-economic assessment).

The socio-economic assessment recognises the importance of Flat Rock Reserve to local communities and community concerns about potential impacts on water quality in Flat Rock Creek. The importance of this area for its local amenity and the physical and mental health and wellbeing of local and regional communities were reiterated in submissions made by community members on the environmental impact statement. Submissions on the EIS identified the importance of Flat Rock Reserve to local communities due to its active and passive recreation opportunities; the landscape, scenic and amenity values offered by the bushland, green space and waterways; and the habitat it provides for flora and fauna

Burnt Bridge Creek Bushland Reserve is a riparian corridor that runs along Burnt Bridge Creek between Seaforth and North Balgowlah. The reserve is important to local and regional communities for its natural, visual and recreational values (Manly Council, undated). This was confirmed in submissions on the environmental impact statement, which identified Burnt Bridge Creek as a place that is valued by the community for its natural environment and bushland, wildlife, contribution to local amenity, and recreational uses.

4.4.2 Impact assessment

Submissions on the environmental impact statement about Flat Rock Creek and Quarry Creek mainly related to concerns about potential impacts on aquatic habitats and groundwater dependent ecosystems. As confirmed in Section 4.1 and Section 4.2 above, the revised assessment has confirmed that the project would not result in negative impacts to the flora and fauna.

Submissions on the environmental impact assessment raised several issues relating to potential impacts on community values associated with changes in groundwater flow in Flat Rock Creek and Burnt Bridge Creek.

Socio-economic issues raised in submissions about potential impacts of the project on Flat Rock Creek included concerns about:

- Negative impact of construction activities on Flat Rock Creek water quality and the potential reduction in recreation opportunities
- Loss of greenspace and the recreational values of the natural environment at Flat Rock Reserve.

Socio-economic issues raised in submissions relating to Burnt Bridge Creek included concerns about:

- The loss of community values due to reduced flows in Burnt Bridge Creek
- Potential for water loss to impact local amenity, and the recreational values of the creek environment for dog walkers, commuters, and bike riders
- Impacts on the environment of Burnt Bridge Creek negatively affecting the well-being of local residents and resulting in the loss of lifestyle
- Cost associated with the removal of dead trees that result from water loss within the creek.

As discussed in Section 3, the revised groundwater modelling carried out for the project has found that changes to groundwater baseflow caused by groundwater drawdown would not substantially alter the flow regime within Flat Rock Creek, Quarry Creek and Burnt Bridge Creek and that adverse impacts on freshwater ecology, groundwater dependent ecosystems and surface water quality are not expected. As noted in Section 4.2.2, the small alluvial aquifer of Flat Rock Creek at the Quarry Creek confluence would be recharged by the releases of up to about 1425 kilolitres per day of treated water from the project operational wastewater treatment plant discharge into Flat Rock Creek at Artarmon. This may replace any baseflow losses and sustain vegetation communities dependent on groundwater in the shallow alluvium.

Consequently, impacts of the project associated with changes to groundwater baseflow on the natural environment and community values are not expected. Flat Rock Creek, Quarry Creek and Burnt Bridge Creek of Flat Rock Reserve would continue to provide local amenity and recreational uses and contribute to the physical and mental health and wellbeing of local and regional communities.

The socio-economic assessment in Section 21.4.5 of the environmental impact statement identified that there would be adverse changes in visual amenity, local character and health and wellbeing in some locations due to the presence of construction works and vegetation clearing within the construction footprint. As required by environmental management measure V11, all areas disturbed by construction and not required for operation of the project will be restored as soon as practicable to their existing condition or in accordance with the urban design and landscape plan where applicable (environmental management measure V1).

4.4.3 Environmental management measures

No additional environmental management measures beyond those identified in Table D2-1 of the submissions report are considered necessary to manage the potential socio-economic impacts resulting from the project.

5 Conclusion

5.1 Summary of findings

The revised groundwater modelling predicts groundwater drawdown levels and groundwater baseflow reductions at Flat Rock Creek and Quarry Creek that are similar to those presented in the environmental impact statement. The revised predicted groundwater drawdown level and groundwater baseflow reduction at Burnt Bridge Creek is less than that predicted in the environmental impact statement.

The revised assessments of impacts to freshwater ecology, groundwater dependent ecosystems, surface water quality and social and community values at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek are also similar to the findings in the environmental impact statement.

5.1.1 Revised groundwater modelling results

The revised groundwater modelling predicts groundwater baseflow reductions in 2128 with the project of 30 per cent, 63 per cent and 60 percent for Flat Rock Creek, Quarry Creek and Burnt Bridge Creek respectively. The revised predictions for Flat Rock Creek and Quarry Creek are similar to those contained in the environmental impact statement of 39 per cent and 69 percent respectively. The revised prediction for Burnt Bridge Creek is less than the 96 per cent groundwater baseflow reduction predicted for this creek in the environmental impact statement.

Considering the available streamflow data collected in May 2018 during a drought period, the predicted reduction in groundwater baseflow to Burnt Bridge Creek in 2128 would only result in about a one per cent reduction in streamflow, which is a negligible impact. Applying the same approach to the downstream reaches of Flat Rock Creek, the project would result in about a 22 per cent reduction in streamflow in 2128. In periods that had more rainfall leading up to and during May 2018, there would be more surface water runoff into the creeks and the predicted reduction in groundwater baseflow would result in a smaller reduction in streamflow than predicted.

While the revised groundwater modelling and groundwater baseflow reduction predictions are based on the additional information on streambed lining obtained during the May 2021 field survey, they remain conservative due to:

- Predicted inflows to the tunnels being controlled by the permeability of the surrounding geological formation
- Full hydraulic connectivity being assumed between the creek and the surrounding groundwater system at the tunnel depth.

The groundwater environmental management measures in Table D2-1 of the submissions report will address the potential impacts discussed in this assessment including:

- Following completion of environmental management measure SG2, a focussed study will be carried out in consultation with Department of Planning, Industry and Environment (Environment, Energy and Science Group) to confirm potential groundwater drawdown and associated baseflow reductions at Burnt Bridge Creek, Flat Rock Creek and Quarry Creek due to tunnelling, and confirm potential impacts on freshwater ecology in the affected watercourses and nearby groundwater dependent ecosystems. The study will consider how existing site features affect the interaction between surface water and groundwater along the affected reaches of these watercourses, and the hydraulic connectivity in the underlying geology. Where ecological impacts are predicted to be worse than that presented as part of the environmental impact statement/submissions report, feasible and reasonable mitigation measures to address the impacts will be identified in consultation with a suitably qualified and experienced specialist, incorporated into the detailed design, and implemented during construction. The mitigation measures considered will include tunnel linings. (refer to revised environmental management measure SG6)

- Measures will be implemented during tunnel construction to ensure that groundwater inflows into each tunnel during the operation phase do not exceed one litre per second per kilometre across any given kilometre (refer to revised environmental management measure SG16).

The small alluvial aquifer of Flat Rock Creek and at the Quarry Creek confluence would be recharged by the releases from the project operational wastewater treatment plant discharge into Flat Rock Creek at Artarmon. This would sustain vegetation communities dependent on groundwater in the shallow alluvium.

5.1.2 Freshwater ecology

The freshwater sections of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek all have depauperate (ie lacking in numbers of variety of species) assemblages of macroinvertebrates, non-existent assemblages of native fish and generally very few, if any, native macrophytes. The AUSRIVAS results suggest the freshwater ecology of the creeks was generally partially or severely impaired and affected by severe pollution. Sensitive macroinvertebrate groups such as *Ephemeroptera, Trichoptera* and *Plecoptera* were absent from all creeks.

The riparian habitat of many parts of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek is generally in reasonable, if not good condition. However, although much of the freshwater reaches of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek appear to look healthy, the effect is aesthetic only and the freshwater ecology is considered to be generally poor.

The revised groundwater modelling predictions have confirmed that changes to baseflow caused by groundwater drawdown would not substantially alter the flow regime in any of the creeks. Instream habitat is already in poor condition and is not expected to be altered by the predicted groundwater drawdown. Consequently, the project would not significantly impact the freshwater ecology of Flat Rock Creek, Quarry Creek or Burnt Bridge Creek.

5.1.3 Groundwater dependent ecosystems

As a consequence of the poor ecological condition of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, all three creeks have been assessed as being low ecological value groundwater dependent ecosystems. The groundwater dependent vegetation communities of Flat Rock Reserve are considered to be a moderate ecological value groundwater dependent ecosystem.

There are small patches of Coastal Upland Swamps west of the Wakehurst Parkway in Garigal National Park, and another small patch north of Bantry Bay Oval, which are considered to be high ecological value groundwater dependent ecosystem.

Drawdown in the regional aquifer is likely to have minor impacts on vegetation health, so the magnitude of risk to vegetation communities of Flat Rock Creek would be small given that the vegetation community is not solely dependent on groundwater.

The small alluvial aquifer of Flat Rock Creek at the Quarry Creek confluence would be recharged by the releases from the project operational wastewater treatment plant discharge into Flat Rock Creek at Artarmon. This would sustain vegetation communities dependent on groundwater in the shallow alluvium.

Due to the separation between regional water levels and the section of Coastal Upland Swamp beside Wakehurst Golf Club, it is unlikely that this section of upland swamp would be affected by drawdown from the project.

The groundwater dependence of the swamp west of the Wakehurst Parkway is uncertain, as the water level is about 10 metres below ground level. The water table beneath this swamp may be affected by drawdown, but it is likely that the swamp also receives water from surface runoff and subsurface drainage from upslope perched aquifers, and that the availability of this water to support the swamp would not be affected.

5.1.4 Surface water quality

The water quality of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek is generally poor due to elevated nutrients and metals. Baseflow in Quarry Creek and Burnt Bridge Creek and the upstream section of Flat Rock Creek is a very small proportion of surface flow and therefore is unlikely to influence surface water quality. As such, the minimal drawdown estimated is unlikely to influence surface water quality at these sites, and would not impact on achieving the nominated water quality objectives of freshwater ecosystems, visual amenity and secondary contact recreation.

The predicted reduction in baseflow in Flat Rock Creek at the weir and downstream may result in a reduction of poor quality groundwater entering surface water which over time may result in a reduction of metal and nutrient concentrations in Flat Rock Creek. Additionally, Flat Rock Creek is to receive treated wastewater during the operation of the project that would be of a better quality than is currently observed. Overall, it is expected that this could slightly improve water quality over time, which could contribute to achieving the nominated water quality objectives.

5.1.5 Social and community values

The revised groundwater modelling has found that changes to baseflow caused by groundwater drawdown would not substantially alter the flow regime within Flat Rock Creek, Quarry Creek and Burnt Bridge Creek and that adverse impacts on freshwater ecology, groundwater dependent ecosystems and surface water quality are not expected. Consequently, any changes in water flows are not expected to impact on the natural environment, residential amenity and recreational uses associated with these creeks.

5.2 Recommended environmental management measures

The revised groundwater modelling and associated revised environmental impact assessments have confirmed that the environmental management measures presented in Table D2-1 of the submissions report are sufficient to manage the potential impacts of the project. Therefore no additional environmental management measures are required.

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Annexure A. Assessment of baseflow changes in freshwater creeks (Cardno, 2021)

Executive Summary

Cardno (NSW/ACT) Pty Ltd, was commissioned by Transport for NSW to prepare a more detailed ecological assessment of the potential effects on aquatic ecosystems due to changes to baseflows at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek predicted to occur as a result of groundwater drawdown 100 years following the opening of the Beaches Link and Gore Hill Freeway Connection project (the project). This was in response to a number of agency and community submissions on the project's environmental impact statement which had queried the predicted groundwater impacts to these creeks.

The scope of work involved field investigations at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to:

> Assess the quantity, type and condition of aquatic habitat (eg pools and riffles) and riparian vegetation

> Assess the type and condition of assemblages of macrophytes, fish and macroinvertebrates.

This data from the field investigation was then interpreted in combination with existing water quality, surface flow, wastewater discharge volumes from operational waste water treatment plants and ecological information that had already been collected for the environmental impact statement, as reported in Appendix N (Technical working paper: Groundwater), Appendix O (Technical working paper: Surface water quality and hydrology), Annexure D of Appendix S (Technical working paper: Biodiversity development assessment report), recent investigations of surface water quality for Burnt Bridge Creek and Flat Rock Creek by ERM (2021) and further inputs from the project groundwater specialist.

Burnt Bridge Creek is generally unlined apart from a small section upstream of the Burnt Bridge Creek Deviation and within the Balgowlah industrial area. It includes a mixture of shallow and deep pools and cascade/riffle zones in its upper and middle reaches before becoming essentially a concrete-lined culvert that runs through the Balgowlah industrial area to Manly Lagoon. Upstream of the Burnt Bridge Creek Deviation the riparian corridor could be considered 'quasi natural, with frequent long deep pools, riffles and cascades. Ongoing efforts of bush regeneration appear to have removed much of the weeds that had previously been noted in this part of Burnt Bridge Creek during investigations for the environmental impact statement. The riparian condition of the middle and downstream areas of the creek is either partially or highly modified. Flat Rock Creek and Quarry Creek also include a mixture of shallow and deep pools and cascade/riffle zones in their upper and middle reaches before reaching the estuarine section. The riparian corridors of these two creeks are also generally good and the results of active bush regeneration in Flat Rock Creek were also notable.

Stormwater flows have a considerably large influence on all three creeks, generally scouring the bedrock base and removing coarse and fine sediments. Very few instream macrophytes were recorded in the creeks and there were no native fish observed or caught. AUSRIVAS analyses indicated macroinvertebrate assemblages at all creeks were either severely or extremely impaired and suffered from severe pollution.

Indicative dry period flow measurements taken in 2017 indicate that baseflow is generally small (<30 kilolitres per day) for many areas of the creeks. Baseflow only makes up less than one per cent of total stream flow in upstream areas of Flat Rock Creek and generally less than six per cent at Quarry Creek and Burnt Bridge Creek. In these areas, most of the total stream flow would be expected to be coming from stormwater input from various points. In dry periods, even though groundwater drawdown from the project is predicted to reduce baseflow by between 25 per cent and 67 per cent, this would generally equate to less than three per cent reduction to total stream flow for the upstream part of Quarry Creek and both the mid-stream and downstream parts of Burnt Bridge Creek. After rainfall, given baseflow is likely to be an insignificant proportion of the total stream flow, due to an increased contribution from stormwater, any changes from the project to baseflow in the upstream parts of Flat Rock Creek and Quarry Creek and for most parts of Burnt Bridge Creek would be negligible.

Along the downstream sections of Flat Rock Creek, baseflows are estimated to comprise larger proportions of total stream flow, at 67 per cent to 79 per cent respectively, meaning that any reductions to baseflow resulting from groundwater drawdown in these areas has potential to be a larger proportion of total stream flow than for upper Flat Rock Creek or for the other two creeks. During dry periods, at the downstream area of Flat Rock Creek and at the weir, groundwater drawdown in dry periods would be expected to reduce total stream flow by 27 per cent and 22 per cent respectively. Notwithstanding this, others factors would potentially mitigate or offset these effects. The high dry period stream flows in these areas mean that reasonable flows would be maintained despite the effects of groundwater drawdown, and, at the weir, where there is an estuarine influence, any changes to stream flow would be inconsequential relative to tidal influence.

Further, Flat Rock Creek would also receive a maximum of 1425 kilolitres per day of treated wastewater from the operational wastewater treatment plant. Although a portion of this discharge will potentially be directed to Council assets for external use, the remainder would be expected to result in a net increase in total stream flow generally from the project. The discharged wastewater will be treated to meet ANZG (2018) 95 per cent species protection levels for estuarine and lowland river ecosystems for toxicants generally, with the exception of those toxicants known to bioaccumulate, which would be treated to meet the ANZG (2018) 99 per cent species protection levels, and the draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water).

The freshwater sections of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek all had depauperate assemblages of macroinvertebrates, non-existent assemblages of native fish and generally very few, if any, native macrophytes. This is despite the riparian habitat of many parts of all of the creeks being in reasonable, if not good condition, and containing mostly native vegetation, again as a consequence of the effects of recent bush regeneration and weed management. Hence, although much of the freshwater reaches of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek appear to look good to the 'naked eye' due to reasonable or good quality riparian corridors, the effect is 'aesthetic only' and the aquatic ecology can be considered to be generally poor.

The reasons for aquatic ecology being in such poor condition are not clear but are likely to be a consequence of the following factors:

> Generally high levels of some nutrients and dissolved metals in the creeks (see Appendix N (Technical working paper: Groundwater) and recent investigations by ERM (2021))

> Regular scouring after heavy rain from torrents of storm water (ie bare substratum in most shallow pools and a paucity of aquatic habitat for macroinvertebrates in most pools generally, such as fine sand, gravel and detritus)

> The presence of weirs in Flat Rock Creek and Burnt Bridge Creek, and steep cascades in all creeks, that would prevent some species from colonising middle to upper reaches of creeks from downstream areas.

Annexure D of Appendix S (Technical working paper: Biodiversity development assessment report) considered that there would still be some (low) flow along the entirety of the creeks between rainfall events and additional studies have confirmed this would be the case after the effects of the project on baseflow are considered. Further, detailed field investigations indicate the presence of pool habitats in most reaches of the creeks and that even in periods of low flow in dry periods in summer it would be expected that many of these pools would be deep enough to retain water and hence aquatic habitat. Notwithstanding the finding that assemblages of aquatic macroinvertebrates and fish are generally depauperate in the creeks, even in extremely dry times some pools would be deep enough to provide refuge for aquatic macroinvertebrates, albeit only those species that are most tolerant to low flows.

It is noted that none of the riparian zones of Burnt Bridge Creek, including the exclusion zone in its middle section are dependent, either entirely or in part, on the presence of groundwater for their health and/or survival. Much of the riparian vegetation of Quarry Creek and in downstream areas of Flat Rock Creek depend on groundwater and a revised assessment of impacts to GDEs is provided in Annexure B of Appendix E of this submissions report.

Given the above, it is considered that changes to baseflow caused by groundwater drawdown would not substantially alter the flow regime after 100 years in any of the creeks to the extent that it would alter instream habitat to already depauperate assemblages of aquatic macroinvertebrates, fish and macrophytes. Based on this evidence, it can be concluded that the findings are generally consistent with the environmental impact statement and that the project would not significantly impact the aquatic ecology of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

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Attachments

Tables

Figures

1 Introduction

1.1 Background and previous investigations

As part of the environmental impact statement, predicted changes to the baseflows of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, as a result of groundwater drawdown during construction and operation of Beaches Link and Gore Hill Freeway Connection project (the project) were presented in Appendix N (Technical working paper: Groundwater). Cardno considered these changes in combination with investigations of the existing environment to make predictions of potential ecological impacts in the creeks (Annexure D of Appendix S (Technical working paper: Biodiversity development assessment report)). These studies were carried out to comply with the project Secretary's environmental assessment requirements dated 22 April 2020 which identified the following key issue and desired performance outcome in relation to aquatic biodiversity as:

"6. Biodiversity

The project design considers all feasible measures to avoid and minimise impacts on terrestrial and aquatic biodiversity."

Requirement 6(8) of the Secretary's environmental assessment requirements states:

"Impacts on biodiversity values that cannot be assessed using the Biodiversity Assessment Method (BAM) must also be otherwise assessed".

As described in Appendix N (Technical working paper: Groundwater), surface environmental water availability and flows have the potential to be reduced at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek as a result of worst case groundwater drawdown for the project by a maximum of:

> 20 per cent reduction in baseflow at Flat Rock Creek at the end of construction and 96 per cent reduction after about 100 years of operation

> 23 per cent reduction in baseflow at Quarry Creek at the end of construction and 69 per cent reduction after about 100 years of operation

> 79 per cent reduction in baseflow at Burnt Bridge Creek at the end of construction and 96 per cent reduction after about 100 years of operation.

As groundwater inflows to tunnels during project construction and operation would be collected, treated and discharged to Flat Rock Creek, and during construction to Burnt Bridge Creek, this was expected to largely offset baseflow reduction to these watercourses at those times (see Appendix N (Technical working paper: Groundwater)). The environmental impact statement considered that given baseflows in Flat Rock Creek, Quarry Creek and Burnt Bridge Creek would not be reduced completely, it would not cause the complete loss of any aquatic habitat. The conclusion was based on the assumption that pool habitats within the creeks would be largely unaffected given there would still be some (low) flow along the entirety of the waterways between rainfall events. Outside of the pool areas, substantially reduced flows between rainfall events would be expected to alter assemblages of freshwater biota in Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to generally include only those species that are most tolerant to low flows.

Notwithstanding this, a number of agency and community submissions on the environmental impact statement queried the predicted project groundwater impacts to the ecology of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. As such, Transport for NSW requested that Cardno prepare a more detailed assessment of the effects on the aquatic ecology of these creeks, following updated predictions of groundwater drawdown (as presented in Appendix E of this submissions report).

1.2 Scope of works

The aim of this study has been to provide further support for the findings in the environmental impact statement regarding the effect of altered baseflows to freshwater ecology of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, principally from groundwater drawdown as a consequence of construction and operation of the project.

The scope of work included field investigations of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek:

> Assess the quantity, type and condition of aquatic habitat (eg pools and riffles) and riparian vegetation

> Assess the type and condition of assemblages of macrophytes, fish and macroinvertebrates.

This data from the field investigation was then interpreted in combination with existing water quality, surface flow, wastewater discharges volumes from operational waste water treatment plants and ecological information that had already been collected for the environmental impact statement (as reported in Appendix N (Technical working paper: Groundwater), Appendix O (Technical working paper: Surface water quality and hydrology) and Annexure D of Appendix S (Technical working paper: Biodiversity development assessment report)) , recent investigations of surface water quality for Flat Rock Creek and Burnt Bridge Creek by ERM (2021) and further inputs from the project groundwater specialist. Further groundwater inputs, as documented in Appendix E of this submissions report, include:

- Confirmation of creek form
- Reassessment of conductance values
- Remodelling to refine localised changes in baseflow and assessment against total streamflow.

2 Methodology

2.1 Study area

The study area for this report included the following creeks within the Willoughby, North Sydney and Northern Beaches local government areas:

- Flat Rock Creek
- Quarry Creek
- Burnt Bridge Creek (see **Figure 2-1**).

2.2 Aquatic habitat and riparian condition

Field investigations of the entire reaches of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek (between the headwaters and the downstream estuaries) were inspected between 26 - 28 May 2021 to determine habitat sensitivity, riparian condition and the proportion of shallow or deep pools or riffles/cascades.

2.2.1 Instream features

Within sections of each creek, visual estimates were made of the proportion of creek length that contained shallow pools (<2 metres depth), deep pools (>2 metres depth) or riffles/cascades**.** The type of substratum in pools (bare rock, earth, silt, sand, gravel or detritus) was also noted.

The quality of fish habitat in the watercourses was determined with reference to the criteria in **Table 2-1** and **Table 2-2** in accordance with the *Policy and Guidelines for Fish Conservation and Management* (NSW DPI, 2013).

2.2.2 Riparian condition

The condition of riparian habitat in creeks was assessed using a modified version of the riparian, channel and environmental (RCE) inventory method (Peterson, 1992; Chessman, *et al*. 1997). This methodology was developed by Peterson (1992) but modified for Australian conditions by Chessman *et al*. (1997) by combining some of the descriptors, modifying some of the associated categories and simplifying the classifications from 1 to 4 (**Table 2.3**, **Annexure A**).

This assessment involved evaluation and scoring of the characteristics of the various components of the riparian corridor, including adjacent land, condition of riverbanks, channel and bed of the watercourse, and degree of disturbance evident at each site. The maximum score (52) indicates a stream with little or no obvious physical disruption and the lowest score (13) indicates a heavily channelled stream without any riparian vegetation that can be considered to be in poor condition. RCE scores were assigned to sections of the creeks, with boundaries occurring where there was a visible change in the riparian condition (eg a change in riparian native vs exotic trees/shrubs, channel form or riffle/pool sequence)**.**

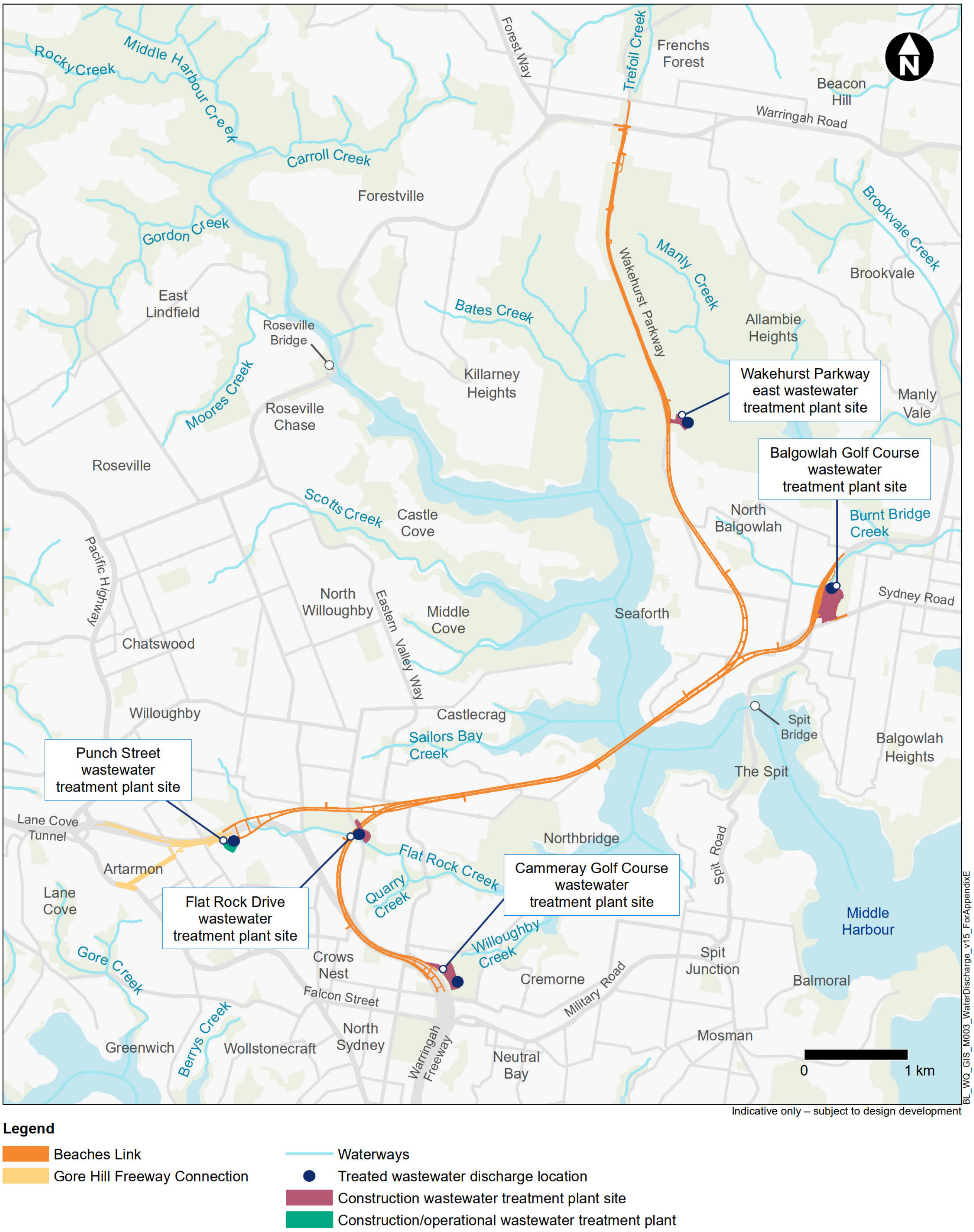

Figure 2-1 Construction footprint, relevant temporary construction support sites, wastewater treatment plant discharge locations and associated waterways

Table 2-1 Classification of waterways for fish passage (NSW DPI, 2013)

Classification	Habitat type
Class 1 – Major key fish habitat	Major permanently or intermittently flowing waterway (eg river or major creek), habitat of a threatened fish species.
Class 2 – Moderate key fish habitat	Named permanent or intermittent stream, creek or waterway with clearly defined bed and banks with semi - permanent to permanent waters in pools or in connected wetland areas. Marine or freshwater aquatic vegetation is present. Known fish habitat and/or fish observed inhabiting the area.
Class 3 – Minimal key fish habitat	Named or unnamed waterway with intermittent flow and potential refuge, breeding or feeding areas for some aquatic fauna (eg fish, yabbies). Semi - permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or recognised aquatic habitats.
Class 4 Unlikely key fish habitat	Named or unnamed waterway with intermittent flow following rain events only, little or no defined drainage channel, little or no flow or free standing water or pools after rain events (eg dry gullies or shallow floodplain depressions with no permanent aquatic flora present).

Table 2-2 Key fish habitat and associated sensitivity classification scheme (NSW DPI, 2013)

Classification	Habitat type
Type 1 – Highly sensitive key fish habitat	– Freshwater habitats that contain in-stream gravel beds, rocks greater than 500 mm in two dimensions, snags greater than 300 mm in diameter or 3 metres in length, or native aquatic plants – Any known or expected protected or threatened species habitat or area of declared 'critical habitat' under the NSW *Fisheries Management Act 1994* – Mound springs.
Type 2 – Moderately sensitive key fish habitat	– Freshwater habitats and brackish wetlands, lakes and lagoons other than those defined in Type 1 – Weir pools and dams up to full supply level where the weir or dam is across a natural waterway.
Type 3 – Minimally sensitive key fish habitat	– Freshwater habitats not included in Types 1 or 2 – Ephemeral aquatic habitat not supporting native aquatic or wetland vegetation.
Not considered key fish habitat	– First and second order streams on gaining streams (based on the Strahler method of stream ordering) – Farm dams on first and second order streams or unmapped gullies – Agricultural and urban drains – Urban or other artificial ponds (eg evaporation basins, aquaculture ponds) – Sections of stream that have been concrete-lined or piped (not including a waterway crossing) – Canal estates.

Table 2-3 RCE ratings (Peterson, 1992; Chessman, *et al*. 1997)

Degree of modification	Score / rating	Description	Colour coding
Quasi natural	41-52 / 4	Creek is not modified and resembles natural state. Vegetation is mainly native with minimal weeds. Can include active vegetation rehabilitation. Features include: – Adjacent to undisturbed native vegetation – Width of riparian strip more than 30 m – Native trees/shrubs present – Banks fully stabilised by trees/roots, no undercutting – Channel form deep (width/depth ratio less than 7:1) – Frequent alternation of riffles and pools – Many large boulders and/or debris – Little or no accumulation of loose sediments, stream bottom mainly clean stones – Detritus mainly unsilted wood, bark and leaves Eg Natural creek	
Partly modified	27-40 / 3	Creek may be modified and some non-native and/or weeds present. Features include: – Adjacent mixed native vegetation and pastures/exotics – Width of riparian strip between 5-30 m – Banks firm, undercutting present on curves/constrictions – Channel form medium (width/depth ratio 8:1 to 15:1); – Long pools with infrequent short riffles – Rocks/logs present, limited damming effect – Some gravel bars, stream bottom mainly stones – Much fine detritus. Eg Partly natural with sections of modifications.	
Highly modified	14-26 / 2	Creek is modified and vegetation is a mix of native and non-native plants and/or weeds. Features include: – Adjacent pasture, crops or plantation land use – Width of riparian strip less than 5 m – Banks loose, frequent undercutting – Channel form shallow (width/depth ratio greater than 15:1) – Natural channel form without riffle/pool sequence – Rocks/logs present, but unstable – Bars of sand and silt common, heavily silted bottom – Mainly fine detritus. Eg lined beds/banks.	
Completely modified or underground	1-13 / 1	Creek is highly and/or totally modified and vegetation is mostly non-native and/or weeds. Features include: – Adjacent urban land use – No woody vegetation – Exotic grasses/weeds only – Banks unstable, with bank collapse common – Artificial channel form with no riffle/pool sequence – Stream with few retention devices. Eg cuverts (open/underground), stormwater.	

2.3 Fish

Fish were sampled using two collapsible bait traps (40 centimetres x 20 centimetres x 20 centimetres with 2-3 millimetre mesh, tapering to a 3 centimetres entrance) in accordance with Cardno's scientific collection permit F86/670(A)-8.2. Bait traps were deployed at two sites in each of Flat Rock Creek and Quarry Creek and three sites in Burnt Bridge Creek and for up to 30 minutes and all caught fish identified. If native species were caught, they were released unharmed, while non-native species were euthanised humanely.

2.4 Macroinvertebrates

2.4.1 Sample collection

Semi-quantitative AUSRIVAS sampling was carried out in pools with suitable representative edge habitat (eg detritus, overhanging vegetation, macrophytes and substrate present). Sampling was carried out at the end of the AUSRIVAS sampling season (autumn).

Aquatic macroinvertebrates were collected using the AUSRIVAS rapid assessment methodology (RAM) (Turak *et al*. 2004) at two sites in each of Flat Rock Creek and Quarry Creek and three sites in Burnt Bridge Creek (**Figure 2-2**). Samples were collected in pool edge habitat with dip nets (250 micrometres mesh) over a period of 3-5 minutes from a 10 metres length of habitat within a 100 metres reach of the creek at each site. The dip net was used to agitate and scoop up material from vegetated river edge habitats. Where the habitat was discontinuous, patches of habitats with a total length of 10 metres were sampled over the 100 metres reach.

Each RAM sample was rinsed from the net onto a white sorting tray from which animals were 'picked' live using forceps and pipettes. Each tray was picked for a minimum period of forty minutes, after which they were picked at ten-minute intervals either until no new specimens had been found or total of 60 minutes (eg the initial 40 minutes plus up to another 20 minutes). Care was taken to collect cryptic and fast moving animals in addition to those that were conspicuous and/or slow. The animals collected at each site were placed into a labelled jar containing 70 per cent alcohol/water for subsequent taxonomic identification in Cardno's laboratory.

Environmental variables, including alkalinity, modal river width and depth, percentage boulder or cobble cover, latitude and longitude were recorded in the field. Distance from source, altitude, and land-slope were determined from appropriate topographic maps. Mean annual rainfall was determined in the laboratory from the regional precipitation maps presented in the AUSRIVAS sampling and processing manual (Turak *et al*., 2004). All of these variables are required for running the autumn AUSRIVAS predictive model for (pool) edge habitat to give an estimate of the 'health' of the creek with the derived output as OE50 and SIGNAL2 scores. OE50 provides a measure of biological impairment, while SIGNAL2 is a simple biotic index for macroinvertebrates that uses the pollution tolerance levels of different macroinvertebrate types.

Figure 2-2 AUSRIVAS sampling sites. FRC01 (top, left), FRC02 (top, right), QC01 (second row, left) and QC02 (second row, right), BBC01 (third row, left), BBC02 (third row, right), BBC03 (bottom row left), see Figure 3-9 and Figure 3-20 in Section 3 for locations of sampling sites (Photos collected: 26/5/2021 - 28/05/2021)

2.5 Water quality

Water quality was measured *in situ* with a YSI 6920 water quality probe that was calibrated prior to sampling. Water quality was measured before aquatic fauna were sampled to avoid disturbance to the waterway. The following variables were recorded:

- Temperature (°C)
- Electrical conductivity (EC) (µs/cm)
- pH
- Dissolved oxygen (DO) (mg/L and percentage saturation)
- Oxidation reduction potential (ORP) (millivolts [mV])
- Turbidity (NTU).

Two replicate readings of each variable were taken in accordance with Australian Guidelines: Australia, New Zealand Environment Conservation Council 2000 (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand 2000 (ARMCANZ).

Mean water quality measurements were compared with the ANZECC/ARMCANZ 2000 default guideline values for protection of aquatic ecosystems for physical and chemical stressors for slightly to moderately disturbed lowland rivers in southeast Australia. The Sydney Harbour and Parramatta River Water Quality and Flow Objectives were also used as a comparison.

3 Results

3.1 Aquatic habitat and riparian condition

3.1.1 Flat Rock Creek

Flat Rock Creek is a first order waterway upstream of the Quarry Creek confluence and a second order waterway downstream. It drains the Flat Rock Creek catchment into Middle Harbour and flows in a general easterly direction from Marlow Road at Artarmon into Middle Harbour at Tunks Park at Cammeray. It is freshwater upstream of its confluence with Quarry Creek and estuarine downstream. There are numerous stormwater outlets along the length of Flat Rock Creek and at the time of inspection these had low or non-existent flow. At the time of inspection, moderate flow was observed downstream of Flat Rock Drive. Low flow was observed at its source but the creek was dry in some of its upper parts (Table 3-1**)**. Flat Rock Creek is comprised of unlined above ground sections, some above ground lined sections and some underground tunnels (**Figure 3-1, Figure 3-2**). The dry areas of the upper parts of the creek were unlined (**Figure 3-1**).

Flat Rock Creek includes a mixture of shallow and deep pools and cascade/riffle zones in its upper and middle reaches before reaching the estuarine section (Table 3-1**, Figure 3-3** to **Figure 3-8**)**.**

Stormwater flows appear to have had a large influence along this waterway, generally scouring the bedrock base and removing coarse and fine sediments. No instream macrophytes were recorded in the creek however, moss was observed in some reaches.

The RCE scores for all of Flat Rock Creek were generally high (Table 3-2**, Figure 3-9** to **Figure 3-10**). Wherever it was not underground or concrete lined, much of Flat Rock Creek has evidence of active bush regeneration and many areas are dominated by native trees and shrubs. Although there are small pockets where exotic vegetation occurs among native plants, the recent efforts of bush regeneration have contributed to much of the creek having riparian condition scores that range between quasi natural or only partly modified (Table 3-2).

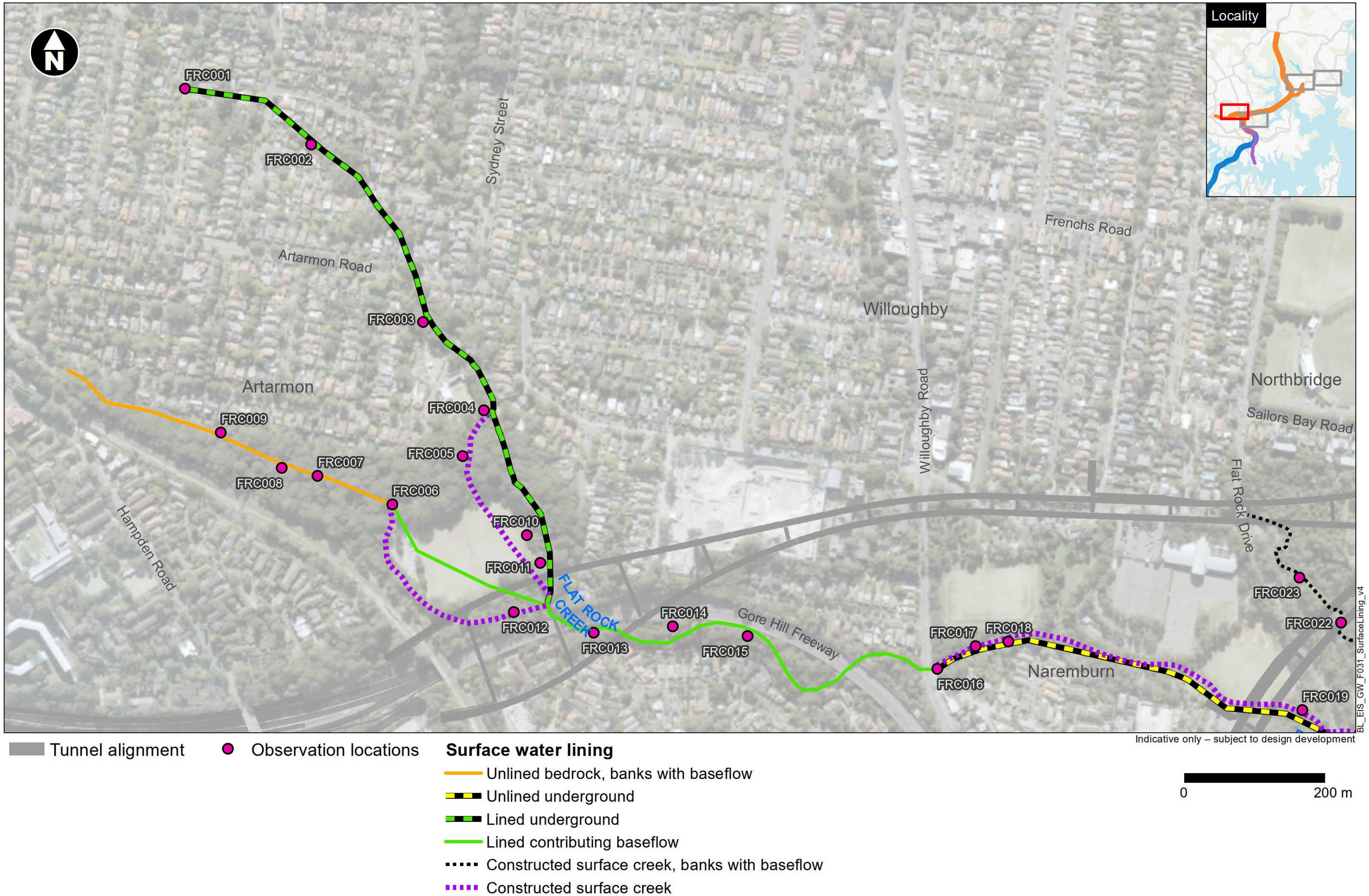

Figure 3-1 Flat Rock Creek (upstream extent) surface lining (Source: Jacobs, 2021)

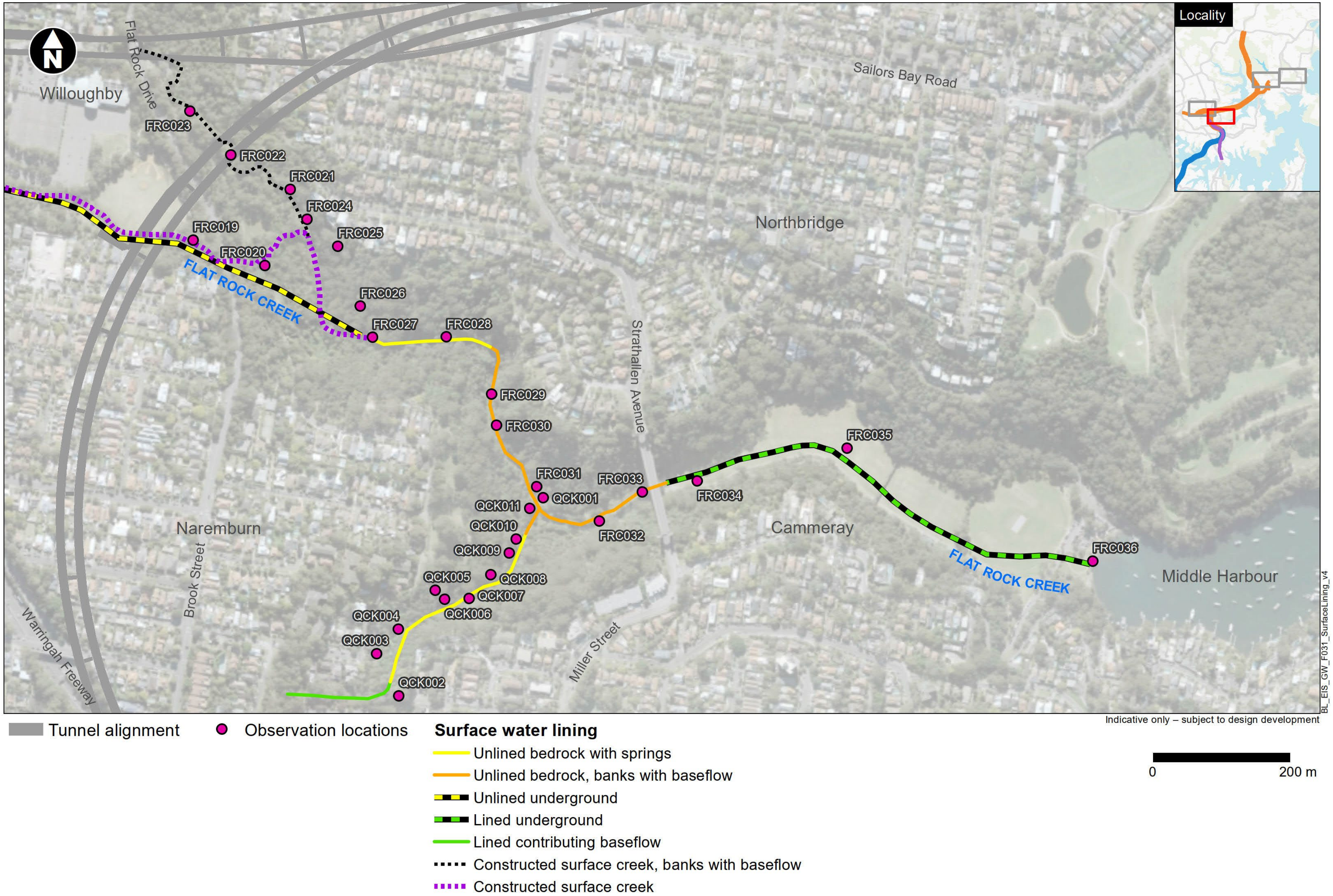

Figure 3-2 Flat Rock Creek (downstream extent) and Quarry Creek surface lining (Source: Jacobs, 2021)

Figure 3-3 Flat Rock Creek concrete lined areas (left) and along the underground channel (right) (Photo date: 27/05/2021).

Figure 3-4 Existing aboveground watercourse within the northern extent of Flat Rock Reserve looking downstream from the Small Street roundabout culvert (Photo date: 27/05/2021).

Figure 3-5 Examples of pools and scoured bedrock along the existing aboveground watercourse within the northern extent of Flat Rock Reserve(Photo date: 27/05/2021).

Figure 3-6 Wilksch Walk crossings along the existing aboveground watercourse of Flat Rock Creek (Photo date: 27/05/2021).

Figure 3-7 Flat Rock Creek at the downstream site looking downstream (left) and upstream (right) (Photo date: 27/05/2021).

Figure 3-8 Flat Rock Creek at the estuarine site looking downstream (left) and looking at the right bank (right) (Photo date: 28/05/2021).

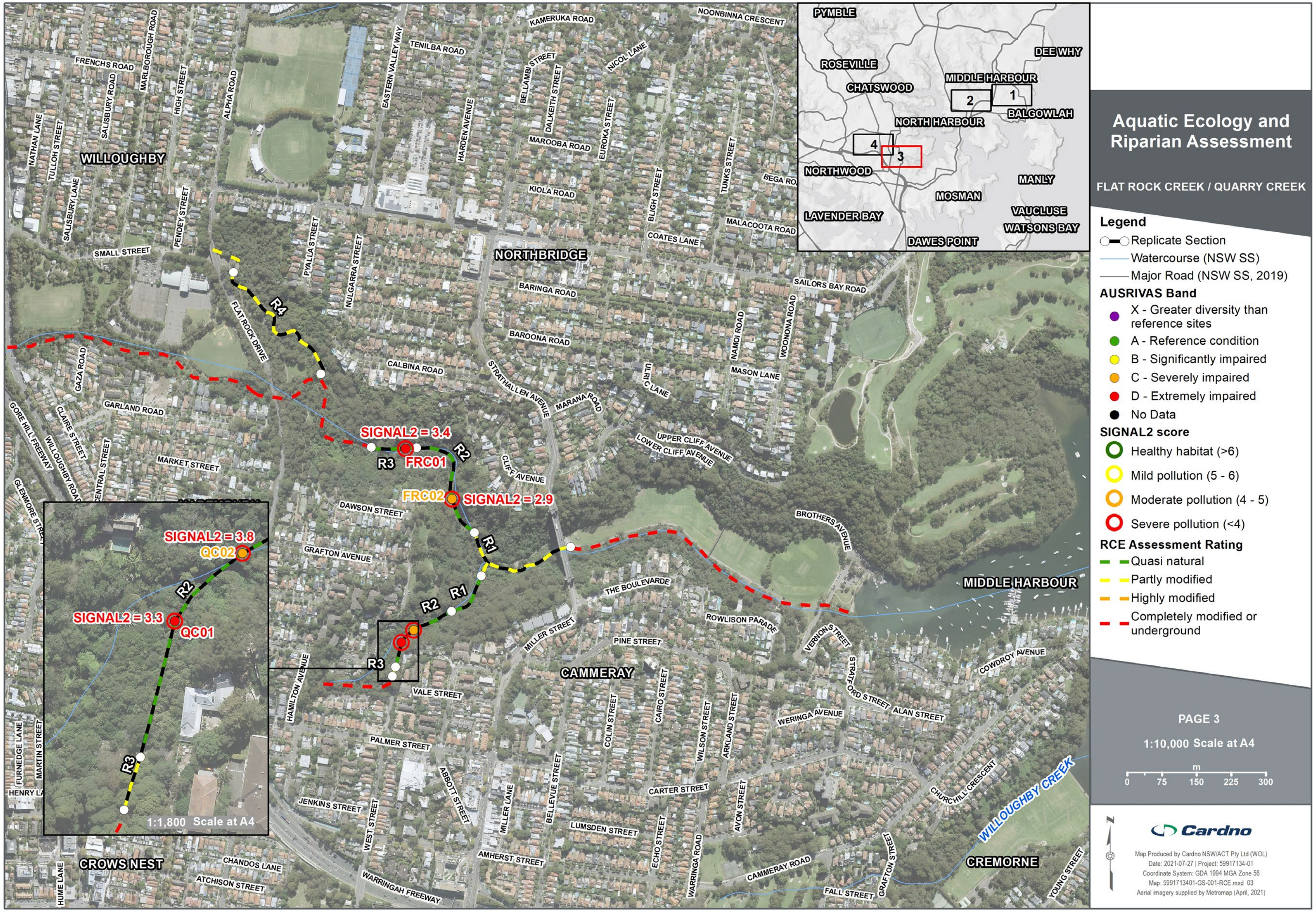

Figure 3-9 Flat Rock Creek and Quarry Creek aquatic ecology and RCE assessment ratings (downstream extent)

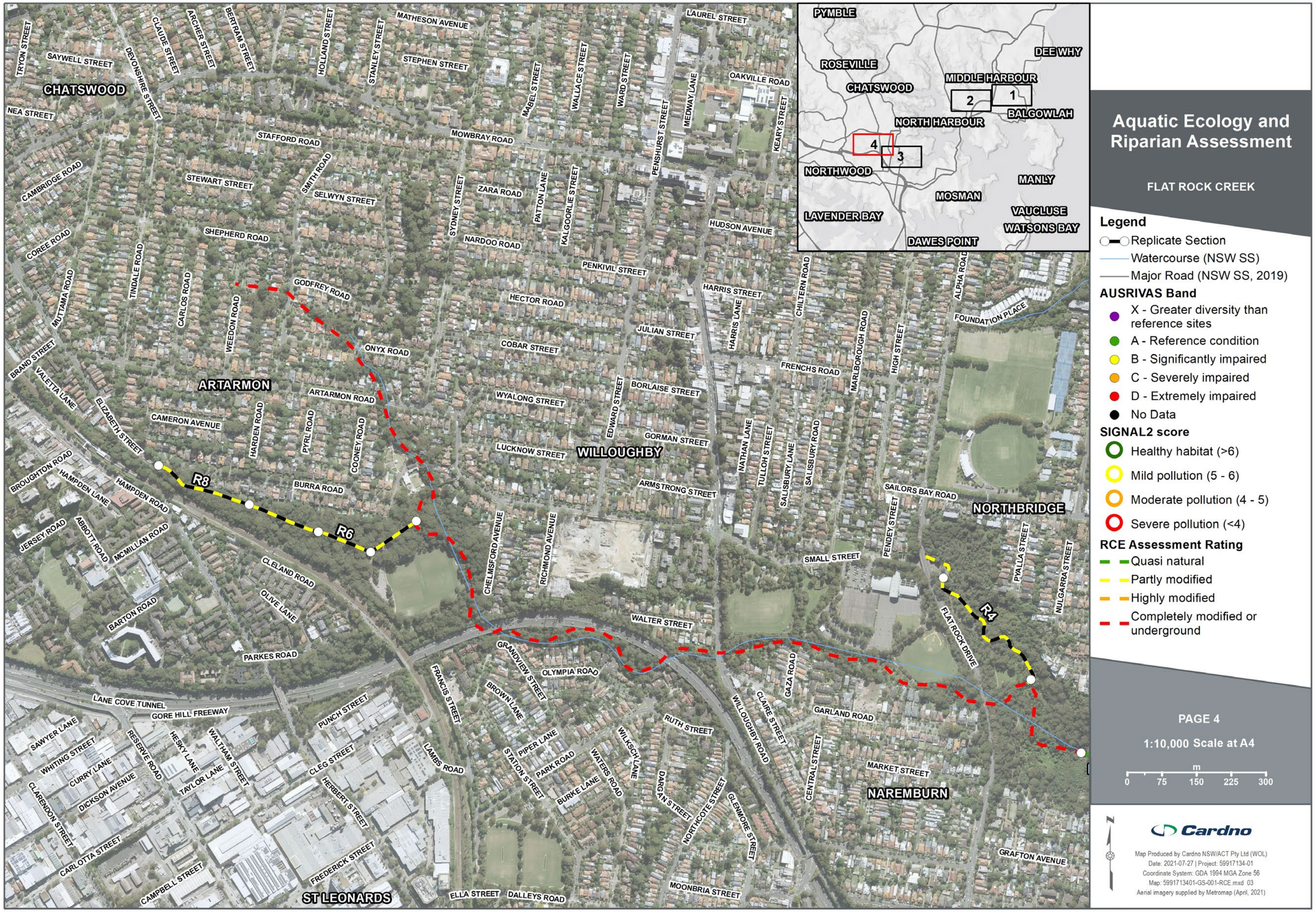

Figure 3-10 Flat Rock Creek aquatic ecology and RCE assessment ratings (upstream extent)

3.1.2 Quarry Creek

Quarry Creek is a second order waterway. It drains into the Flat Rock Creek catchment and further into Middle Harbour. It generally flows in a north-easterly direction from Bridgeview Avenue, Cammeray into Tunks Park, Cammeray. It is estuarine downstream of its confluence with Flat Rock Creek. Quarry Creek is shorter than the other two creeks, has no stormwater outlets along its length and apart from the top section generally flows down a steep gradient. At the time of inspection, moderate flow was observed (Table 3-1). Quarry Creek is generally unlined apart from the far upper part of the creek (**Figure 3-2**).

Quarry Creek generally consists of cascade/riffle zones with few shallow or deep pools (Table 3-1**, Figure 3-11**)**.**

Stormwater flows appear to have had a large influence along this waterway, generally scouring the bedrock base and removing coarse and fine sediments apart from one large deep pool. No instream macrophytes were recorded in the creek, however moss was observed in some reaches.

Most of Quarry Creek is among natural bushland and the RCE scores for all of Quarry Creek were generally good (Table 3-2). Hence the riparian condition of much of the creek is either quasi natural or only partly modified (**Table 3-2, Figure 3-11**).

Figure 3-11 Quarry Creek cascades and boulder instream features (left). Quarry Creek large deep pools upstream of the confluence of Quarry Creek and Flat Rock Creek (right) (Photo date: 28/05/2021).

3.1.3 Burnt Bridge Creek

Burnt Bridge Creek is a first order waterway in the Burnt Bridge Creek catchment which flows in a general easterly direction from Clontarf Street at Seaforth to Kenneth Road where it enters Manly Lagoon. At the time of inspection, low flow was observed at its source. There are numerous stormwater outlets along the length of Burnt Bridge Creek and at the time of inspection these had low or non-existent flow.

Burnt Bridge Creek is generally unlined apart from a small section upstream of the Burnt Bridge Creek Deviation and within the Balgowlah industrial area (**Figure 3-12** and **Figure 3-13**). It includes a mixture of shallow and deep pools and cascade/riffle zones in its upper and middle reaches before flowing into a concrete-lined culvert when it reaches the Balgowlah industrial area (Table 3-1**, Figure 3-14** to **Figure 3-19**)**.**

Stormwater flows appear to have had a large influence along this waterway upstream of the Burnt Bridge Creek Deviation, generally scouring the bedrock base and removing coarse and fine sediments. The gradient of the creek lessens at the middle reach of Burnt Bridge Creek (immediately south of Burnt Bridge Creek Deviation) and here it has been modified and realigned in the past and the upper extent of this reach was defined by one large continuous deep pool behind a weir, with cobble/gravel, silt and detritus substratum (**Figure 3-15**). Established exotic macrophytes lined much of the banks. Downstream of the weir there are pools connected with cascades before Burnt Bridge Creek traverse's north-east underneath the Burnt Bridge Creek Deviation. Further downstream in the Balgowlah industrial area the creek becomes an artificial channel form with no riffle/pool sequence.

The RCE scores for Burnt Bridge Creek ranged from 17 (lower reaches within the Balgowlah industrial area) to 41 (in the upper reaches). Upstream of the Burnt Bridge Creek Deviation the riparian corridor could be considered quasi natural, mostly as a consequence of the results of recent active bush regeneration and weed management in the area (Table 3-2**, Figure 3-21**). The area is dominated by native trees and shrubs with frequent long deep pools, riffles and cascades. The riparian condition of the middle and downstream areas of the creek, where a project exclusion zone occurs, was either partially or highly modified (Table 3-2**, Figure 3-20**). None of the riparian zones of Burnt Bridge Creek are dependent, either entirely or in part, on the presence of groundwater for their health and/or survival (see Appendix S (Technical working paper: Biodiversity development assessment report)).

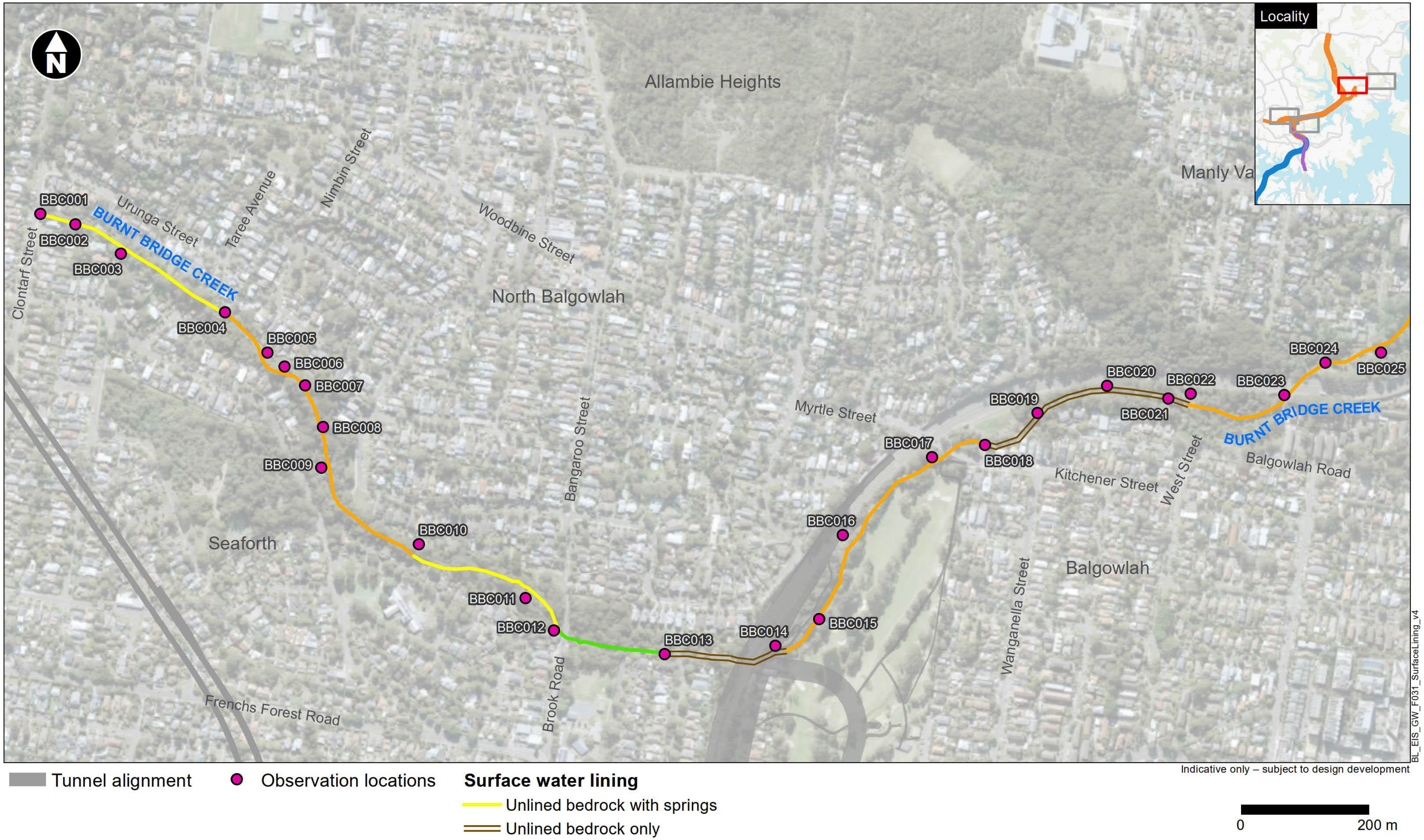

Figure 3-12 Burnt Bridge Creek surface lining (upstream and mid section extent) (Source: Jacobs, 2021)

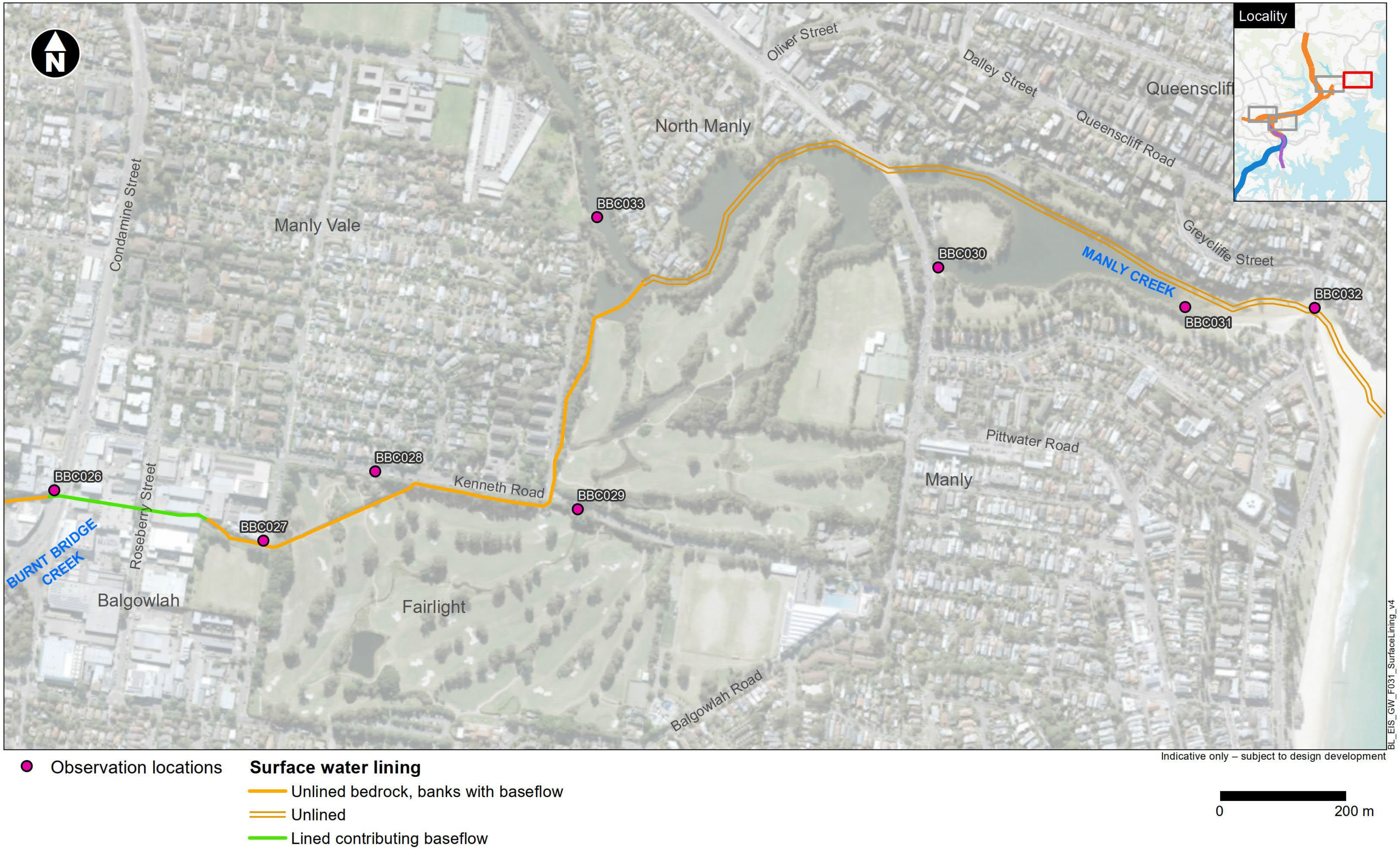

Figure 3-13 Burnt Bridge Creek surface lining (downstream extent) (Source: Jacobs, 2021)


Figure 3-14 AUSRIVAS BB01 sampling site (right). Upstream reach of Burnt Bridge Creek scoured bedrock with cascades (left). Pooled water with aquatic habitat eg cobbles, gravels detritus, macrophytes (right) (Photo date: 26/05/2021).


Figure 3-15 Burnt Bridge Creek spilling weir with deep pool (left). Constricted middle reach downstream (north of Balgowlah Road), heavily constricted by exotic weeds and trees (right) (Photo date: 26/05/2021).


Figure 3-16 Burnt Bridge Creek along the stretch between the culverts at Burnt Bridge Creek Deviation and Kitchener Street looking upstream (left) and downstream (right) (Photo date: 26/05/2021).

Figure 3-17 Highly modified section of Burnt Bridge Creek prior to tracking underground into the Balgowlah industrial area (Photo date: 26/05/2021).

Figure 3-18 Modified sections of Burnt Bridge Creek near Manly Golf Course (Photo date: 26/05/2021).

Figure 3-19 Estuarine sections of Burnt Bridge Creek near Manly Golf Course (Photo date: 26/05/2021).

Figure 3-20 Burnt Bridge Creek aquatic ecology and RCE assessment ratings (downstream extent)

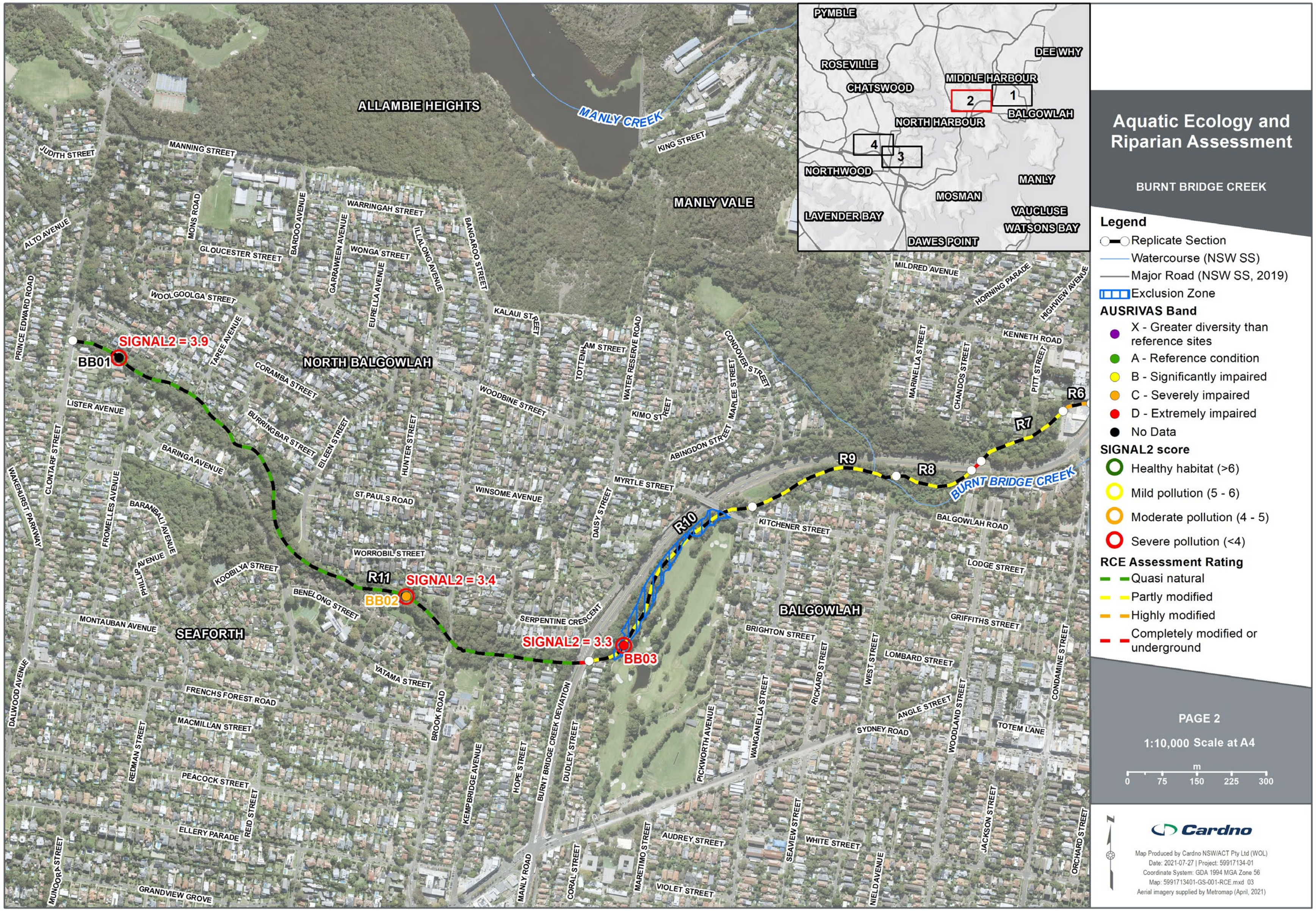

Figure 3-21 Burnt Bridge Creek aquatic ecology and RCE assessment ratings (upstream and mid section extent)

Table 3-1 Instream features and waterway/key fish habitat classification

Creek	Reach	Estuarine or Freshwater	Flow	Instream habitat			Waterway class	KFH level
				Shallow pools (depth <0.2 m)	Deep pools (depth >0.2m)	Cascades / riffles		
Flat Rock Creek	R1	Estuarine	Tidal	-	100%	-	1	1
	R2	Freshwater	Mod	-	50%	50%	3	Not KFH
	R3	Freshwater	Mod	-	20%	80%	3	Not KFH
	R4	Freshwater	Low.	10%	-	80%	3	Not KFH
	R5	Freshwater	Dry	-	-	-	3	Not KFH
	R6	Freshwater	Dry	-	-	-	3	Not KFH
	R7	Freshwater	Low	50%	-	50%	3	Not KFH
	R8	Freshwater	Low	-	60%	40%	3	Not KFH
Quarry Creek	R1	Freshwater	Mod	20%	20%	60%	3	Not KFH
	R2	Freshwater	Mod	-	30%	70%	3	Not KFH
	R3	Freshwater	Mod	10%	-	90%	3	Not KFH
Burnt Bridge Creek	R1-R4	Estuarine	Tidal	-	100%	-	1	1
	R5	Freshwater	Low	100%	-	-	3	Not KFH
	R6	Freshwater	Low	-	100%	-	3	Not KFH
	R7	Freshwater	Low	80%	-	20%	3	Not KFH
	R8	Freshwater	Low	100%	-	-	3	Not KFH
	R9	Freshwater	Low	20%	-	80%	3	Not KFH
	R10	Freshwater	Low	-	100%	-	3	Not KFH
	R11	Freshwater	Low	25%	25%	50	3	Not KFH

Table 3-2 RCE assessment scores

Creek	Reach	RCE score	RCE rating
Flat Rock Creek	R1	39	Partly modified
	R2	44	Quasi natural
	R3	46	Quasi natural
	R4	31	Partly modified
	R5	35	Partly modified
	R6	30	Partly modified
	R7	42	Quasi natural
	R8	35	Partly modified
Quarry Creek	R1	46	Quasi natural
	R2	42	Quasi natural
	R3	34	Partly modified
Burnt Bridge Creek	R1	30	Partly modified
	R2	38	Partly modified
	R3	36	Partly modified
	R4	33	Partly modified
	R5	23	Highly modified
	R6	17	Highly modified
	R7	38	Partly modified
	R8	31	Partly modified
	R9	35	Partly modified
	R10	37	Partly modified
	R11	41	Quasi natural

3.2 Fish

No native fish species were caught or were observed. Schools of the pest species Mosquito Fish (*Gambusia holbrooki)* were caught in the two collapsible bait traps deployed at site BB03 in Burnt Bridge Creek (ie the long, deep pool upstream of the weir, immediately downstream of the Burnt Bridge Creek Deviation).

3.3 Macroinvertebrates

3.3.1 AUSRIVAS samples

The number of macroinvertebrate taxa collected in AUSRIVAS sampling sites ranged between 10 and 36. OE50 refers to the observed to expected ratio of the number of invertebrate families observed at the site to the number of invertebrate families expected at that site. Both the OE50 and SIGNAL2 scores indicated assemblages at all creeks were either severely or extremely impaired and suffered from severe pollution (**Table 3-3** and see **Figure 3-9, Figure 3-10, Figure 3-20, Figure 3-21**).

Table 3-3 AUSRIVAS OE50 scores and SIGNAL2 grades for AUSRIVAS sites

Creek	Site	Band	Autumn OE50 score	SIGNAL2 grade	Number of taxa
Flat Rock Creek	FRC01	D (Extremely impaired)	0.08	3.4 (Severe pollution)	36
	FRC02	C (Severely impaired)	0.19	2.9 (Severe pollution)	16
Quarry Creek	QC01	D (Extremely impaired)	0.09	3.3 (Severe pollution)	25
	QC02	C (Severely impaired)	0.18	3.8 (Severe pollution)	10
Burnt Bridge Creek	BB01	N/A[1]	N/A[1]	3.9 (Severe pollution)	18
	BB02	C (Severely impaired)	0.37	3.4 (Severe pollution)	24
	BB03	D (Extremely impaired)	0.09	3.3 (Severe pollution)	14

1 indicates the site is outside the experience of the model

3.4 Water quality

3.4.1 Rainfall

Rainfall recorded by the bureau of meteorology (BOM) weather station at Observatory Hill (nearest available) is presented in **Table 3-4**. A total of 66.6 mm was recorded in May 2021, with the largest event of 25.4 mm on 6 May 2021. No rainfall was recorded during the survey period, with the most recent period of rainfall occurring between 22 to 25 May 2021 (5.2 mm in total). Mean annual rainfall derived from the BOM indicates the study area receives a mean annual rainfall 1,213.4 mm.

Table 3-4 Rainfall (month prior to survey) (BOM, 2021)

BOM observation Site (ID)	Total May rainfall (mm) / largest event (mm-date)	Most recent rainfall (mm-date)
Observatory Hill (066037)	66.6 / 25.4 - 6/05/2021	5.2 / 22-25/05/2021

3.4.2 Physical and chemical parameters

Some sections of the creeks have undergone significant modifications to the original bedrock channel or alterations from natural channels to artificial, hard (concrete-lined) channels to accommodate higher volumes and flow velocities, after rain, due to an increase in urban, impervious surfaces. This hydrological alteration from natural conditions would be expected to promote the transport of sediments and contaminants to downstream receiving environments (eg Middle Harbour and Manly Lagoon).

Detailed analysis of water quality for Flat Rock Creek, Quarry Creek and Burnt Bridge Creek carried out for the environmental impact statement is given in Appendix O (Technical working paper: Surface water quality and hydrology)**.** In summary, the water quality of these three creeks was considered likely to be substantially influenced by the surrounding urban development. Sources of contaminants, such as suspended sediments, heavy metals and persistent organic pollutants, include stormwater, wastewater overflows and leachate from contaminated lands. Recent investigations in March 2021 (ERM, 2021) of the water quality of Flat Rock Creek and Burnt Bridge Creek, carried out during a period of rainfall, confirmed the presence of some heavy metals and that nutrients (total nitrogen, reactive nitrogen and total phosphorous) were in excess of the ANZECC &

ARMCANZ 2000 default guideline values for slightly to moderately disturbed ecosystems (defined as ecosystems in which "*aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity*" (Chapter 3 of ANZECC, 2000)).

The results of in-situ water quality sampling done for field investigation on 26 - 28 May 2021 (this study) are given in **Table 3-5**. The results indicated exceedances of the default guideline values for the measured parameters only for dissolved oxygen (DO) at AUSRIVAS site BB01.

Table 3-5 Average water quality parameters compared to ANZECC & ARMCANZ 2000 / Sydney Harbour Water Quality Objectives

Creek	Site	pH	EC (uS/cm)	ORP (mV)	DO (%Sat.)	DO (mg/L)	Salinity (ppt)	Turbidity (ntu)	Temp (°C)	Alkalinity (mg/L)[1]
Flat Rock Creek	FC01	7.8	414.5	176.2	91.8	9.6	0.2	19.5	13.3	15
	FC02	7.7	586.5	162.5	**71.7**	7.6	0.3	14	12.7	13
Quarry Creek	QC01	7.6	595	188.1	**83**	8.7	0.3	2.3	13	13
	QC02	7.7	511	196.1	87.2	9.2	0.3	1.9	12.8	13
Burnt Bridge Creek	BB01	7.3	565	142.5	**78.4**	8.2	0.3	0.8	13.4	15
	BB02	7.2	354	136.5	91	9.6	0.2	0.9	13.1	15
	BB03	7.3	357.5	123.8	87.6	9.2	0.2	1.2	12.6	17

Note: Bold indicates exceedance of ANZECC & ARMCANZ 2000 and/or Sydney Harbour Water Quality Objectives for lowland rivers

4 Impact assessment

4.1 Impact of groundwater drawdown to baseflow and total stream flow

As described in **Section 1.1**, modelled changes to baseflow of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek, as given in Appendix N (Technical working paper: Groundwater) informed the predictions of potential ecological impacts in the creeks made in Annexure D of Appendix S (Technical working paper: Biodiversity development assessment report). Discharges from wastewater treatment plants were also considered as to the extent to which these flows would offset reductions to baseflow.

Additional groundwater modelling has since been carried out to refine predictions about the levels to which the project would potentially alter the contribution of baseflow to total stream flow at Flat Rock Creek, Quarry Creek and Burnt Bridge Creek. This additional information is summarised in Table 4-1. These results, which had been measured/derived during a dry period of low rainfall, indicate that, during dry periods, baseflow is generally small (<30 kilolitres per day) for many areas of the creeks. Baseflow makes up only less than one per cent of total stream flow in upstream areas of Flat Rock Creek and generally less than six per cent at and Quarry Creek and Burnt Bridge Creek. In these areas, most of the total stream flow would be expected to be coming from stormwater input from various points. Hence, even though groundwater drawdown from the project is predicted to reduce baseflow by between 25 per cent and 67 per cent, this would only equate to less than three per cent reduction of total stream flow for most parts of Burnt Bridge Creek and the upstream part of Quarry Creek (Table 3-1). Notably, these predictions are indicative of low rainfall periods. After rainfall, given baseflow is likely to be an insignificant proportion of the total stream flow, due to an increased contribution from stormwater runoff any changes from the project to baseflow for upstream parts of Flat Rock Creek and Quarry Creek and for most parts of Burnt Bridge Creek would be negligible.

Along the downstream sections of Flat Rock Creek, baseflows are estimated to comprise larger proportions of total stream flow, at 67 per cent to 79 per cent respectively, meaning that any reductions to baseflow resulting from groundwater drawdown in these areas has potential to be a larger proportion of total stream flow than for upper Flat Rock Creek or for the other two creeks (Table 4-1). Indeed, during dry periods, at the downstream area of Flat Rock Creek and at the weir, groundwater drawdown in dry periods would be expected to reduce total stream flow by 27 per cent and 22 per cent respectively. Notwithstanding this, others factors would potentially mitigate or offset these effects. The high dry period stream flows in these areas mean that reasonable flows would be maintained despite the effects of groundwater drawdown, and, at the weir, where there is an estuarine influence, any changes to stream flow would be inconsequential relative to tidal influence.

Further, Flat Rock Creek would also receive a maximum of 1425 kilolitres per day of treated wastewater from the Gore Hill Freeway operational wastewater treatment plant. Although a portion of this discharge would potentially be directed to Council assets for external use, the reminder would be expected to result in a net increase in total stream flow generally from the project. The discharged wastewater will be treated to meet ANZG (2018) 95 per cent species protection levels for estuarine and lowland river ecosystems for toxicants generally, with the exception of those toxicants known to bioaccumulate, which would be treated to meet the ANZG (2018) 99 per cent species protection levels, and the draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water), in accordance with environmental management measure WQ17 (refer to Table D2-1 of this submissions report).

Table 4-1 Indicative daily dry period total stream flow (as measured in 2017) and baseflow after 100 years

Creek	Site	Measured (Total) stream flow (kL/d)	Baseflow (kL/d)		Change in baseflow (%)	Baseflow as a % of (Total) stream flow		Change in baseflow as a % of (Total) stream flow
			With no project	After 100 years of operation of the project		With no project	After 100 years of operation of the project	
Flat Rock Creek	Upstream	1589	13	7	-54%	0.8%	0.4%	0.4%
	At the weir	2337	1563	1041	-67%	67%	45%	22%
	Downstream	1908	1503	992	-66%	79%	52%	27%
Quarry Creek	Upstream	178	0.08	0.02	-25%	0.05%	0.01%	0.04%
Burnt Bridge Creek	Mid-section	130	8	4	-50%	6%	3%	3%
	Downstream section	1242	29	9	-31%	2%	1%	1%

4.2 Impact of groundwater drawdown to aquatic ecology

4.2.1 Aquatic ecology

The freshwater sections of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek all have depauperate assemblages of macroinvertebrates, non-existent assemblages of native fish and generally very few, if any, native macrophytes. The AUSRIVAS results suggest the aquatic ecology of the creeks was generally partially or severely impaired and affected by severe pollution. Sensitive macroinvertebrate groups such as Ephemeroptera, Trichoptera and Plecoptera (EPT taxa) were absent from all creeks. This is despite the riparian habitat of many parts of all of the creeks being in reasonable, if not good condition. Hence, although much of the freshwater reaches of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek appear to look good to the 'naked eye', the effect is 'aesthetic only' and the aquatic ecology can be considered to be generally poor.

The reasons for aquatic ecology being in such poor condition are not clear but are likely to be a consequence of the following factors:

> Generally high levels of some nutrients and dissolved metals in the creeks (see Appendix N (Technical working paper: Groundwater))

> Regular scouring after heavy rain from torrents of storm water (eg bare substratum in most shallow pools and a paucity of aquatic habitat for macroinvertebrates in most pools generally, such as fine sand, gravel and detritus)

> The presence of weirs in Flat Rock Creek and Burnt Bridge Creek, and steep cascades in all creeks, that would prevent some species from colonising middle to upper reaches of creeks from downstream areas.

The additional groundwater modelling (**Section 4.1**) has allowed estimates of the project's predicted effects to the baseflow of the creeks to be refined. New estimates indicate baseflow would still be expected to be reduced by as much as 25 per cent – 67 per cent after 100 years, depending on the creek. Notwithstanding this, new information about the relative contribution of baseflow to total stream flow suggests that for the most part, baseflow only represents a small proportion of total stream flow. The exception would be some parts of Flat Rock Creek, but given there is stormwater inflow and an operational discharge into the creek of good quality water from the project's Gore Hill Freeway wastewater treatment plant during operations (see above) there would be a net increase in flow in this creek. Annexure D of Appendix S (Technical working paper: Biodiversity development assessment report) considered that there would still be some (low) flow along the entirety of the creeks between rainfall events and additional studies have confirmed this would be the case after the effects of the project on baseflow are considered. The additional studies presented here also indicate the presence of pool habitats in most reaches of the creeks and that even in periods of low flow in dry periods in summer it would be expected that many of these pools would be deep enough to retain water and hence aquatic habitat. Notwithstanding the finding that assemblages of aquatic macroinvertebrates and fish are generally depauperate in the creeks, even in extremely dry times, some pools would be deep enough to provide refuge for aquatic macroinvertebrates, albeit only those species that are most tolerant to low flows.

Based on the assessment that changes to baseflow caused by groundwater drawdown would not substantially alter the flow regime after 100 years in any of the creeks to the extent that it would alter instream habitat to already depauperate assemblages of aquatic macroinvertebrates, fish and macrophytes it can be concluded that the project would not significantly impact the aquatic ecology of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek.

4.3 Impact of groundwater drawdown on riparian vegetation

Where the creeks are not diverted underground, the general findings of the study indicate the riparian corridors of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek appear to be in good condition, with native vegetation dominating apart from the middle and downstream areas of Burnt Bridge Creek. Ongoing efforts of bush regeneration in the upper parts of Flat Rock Creek and Burnt Bridge Creek appear to have removed much of the weeds that had previously been noted in these areas during investigations for the environmental impact statement. Much of the riparian vegetation of Quarry Creek and in downstream areas of Flat Rock Creek depend on groundwater. It is expected that the additional creek flows from treated water from the construction and operational wastewater treatment plants could partially feed the surrounding groundwater system during construction and ongoing operation.

None of the riparian zones of Burnt Bridge Creek, including the exclusion zone in its middle section (see **Section 3.1.1**), are dependent, either entirely or in part, on the presence of groundwater for their health and/or survival. They are most likely supported by rainfall and hence groundwater drawdown would not be expected to affect these vegetation communities.

A revised assessment of impacts to groundwater dependent ecosystems is provided in Annexure B to Appendix E of this submissions report.

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Attachment

A

RCE CRITERIA

Descriptor and category	Score	Descriptor and category	Score
1. Land use pattern beyond the immediate riparian zone		8. Riffle / pool sequence	
Undisturbed native vegetation	4	Frequent alternation of riffles and pools	4
Mixed native vegetation and pasture/exotics	3	Long pools with infrequent short riffles	3
Mainly pasture, crops or pine plantation	2	Natural channel without riffle / pool sequence	2
Urban	1	Artificial channel; no riffle / pool sequence	1
2. Width of riparian strip of woody vegetation		9. Retention devices in stream	
More than 30 m	4	Many large boulders and/or debris dams	4
Between 5 and 30 m	3	Rocks / logs present; limited damming effect	3
Less than 5 m	2	Rocks / logs present, but unstable, no damming	2
No woody vegetation	1	Stream with few or no rocks / logs	1
3. Completeness of riparian strip of woody vegetation		10. Channel sediment accumulations	
Riparian strip without breaks in vegetation	4	Little or no accumulation of loose sediments	4
Breaks at intervals of more than 50 m	3	Some gravel bars but little sand or silt	3
Breaks at intervals of 10 - 50 m	2	Bars of sand and silt common	2
Breaks at intervals of less than 10 m	1	Braiding by loose sediment	1
4. Vegetation of riparian zone within 10 m of channel		11. Stream bottom	
Native tree and shrub species	4	Mainly clean stones with obvious interstices	4
Mixed native and exotic trees and shrubs	3	Mainly stones with some cover of algae / silt	3
Exotic trees and shrubs	2	Bottom heavily silted but stable	2
Exotic grasses / weeds only	1	Bottom mainly loose and mobile sediment	1
5. Stream bank structure		12. Stream detritus	
Banks fully stabilised by trees, shrubs etc.	4	Mainly un-silted wood, bark, leaves	4
Banks firm but held mainly by grass and herbs	3	Some wood, leaves etc. with much fine detritus	3
Banks loose, partly held by sparse grass etc.	2	Mainly fine detritus mixed with sediment	2
Banks unstable, mainly loose sand or soil	1	Little or no organic detritus	1
6. Bank undercutting		13. Aquatic vegetation	
None, or restricted by tree roots	4	Little or no macrophyte or algal growth	4
Only on curves and at constrictions	3	Substantial algal growth; few macrophytes	3
Frequent along all parts of stream	2	Substantial macrophyte growth; little algae	2
Severe, bank collapses common	1	Substantial macrophyte and algal growth	1
7. Channel form			
Deep: width / depth ratio < 7:1	4		
Medium: width / depth ratio 8:1 to 15:1	3		
Shallow: width / depth ratio > 15:1	2		
Artificial: concrete or excavated channel	1		

Annexure B. Groundwater dependent ecosystems assessment (Eco Logical Australia, 2021)

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1. Introduction

The Beaches Link and Gore Hill Freeway Connection environmental impact statement was placed on exhibition between 9 December 2020 and 1 March 2021. In the environmental impact statement, specific impacts to groundwater dependent ecosystems (GDEs) were considered in Appendix S (Technical working paper: Biodiversity development assessment report) and Appendix N (Technical working paper: Groundwater).

The Department of Planning, Industry and Environment and other agencies have requested additional consideration of impacts associated with groundwater drawdown and tunnel inflows. Eco Logical Australia Pty Ltd has been engaged by Transport for NSW to provide further assessment on potential impacts to GDEs, specifically with respect to:

- Baseflow reductions in ecologically poor sections of Flat Rock Creek, Quarry Creek, and Burnt Bridge Creek
- Groundwater dependent vegetation communities in moderate ecological condition adjacent to the middle to lower reaches of Flat Rock Creek, including Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest
- A small patch of Coastal Upland Swamp north of Bantry Bay Oval, about 135 metres to the south-east of the construction footprint, which is in relatively poor ecological condition but considered as high ecological value because the community is listed as an endangered ecological community.

This assessment is based on information included in the environmental impact statement, as well as supplementary assessments carried out since the exhibition period in response to agency and Department of Planning, Industry and Environment feedback as follows:

- Longitudinal surveys of Flat Rock Creek, Quarry Creek and Burnt Bridge Creek to confirm the structural nature of reaches along the creeks, specifically whether creek beds were unlined bedrock or lined with concrete, and whether they contained springs
- An update of existing groundwater models to reflect the structural nature of the creek beds (following detailed inspection), and re-run of the base case and null predictive numerical models to predict baseflow reduction and groundwater drawdown, for distinct sections of the creeks
- Revised maps showing the updates in modelled drawdown and baseflow reduction
- An inspection of potential groundwater dependent terrestrial ecology sites carried out by Arcadis on 16 June 2021 (Arcadis, 2021)
- An assessment of potential impacts to aquatic ecology from changes to baseflow (Cardno, 2021).

2. Risk assessment process

This assessment follows the framework outlined in the *Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (Serov et al, 2012), which summarises the steps needed for GDE risk assessment in New South Wales. The assessment also follows the *Information Guidelines Explanatory Note: Assessing groundwater-dependent ecosystems* (Doody et al, 2019). This assessment only considers those impacts relevant to changed groundwater conditions such as groundwater drawdown, flow paths or changes to water quality. Surface activities such as vegetation clearing or altered surface hydrology due to increases in impermeable surfaces, are not likely to impact on GDEs, so are not considered here. More details of impacts to terrestrial ecology are considered in Appendix S (Technical working paper: Biodiversity development assessment report).

The steps used in the GDE assessment process were as follows:

- Identify and classify the GDEs
- Assess the level of dependence on groundwater
- Identify high value ecological components of the GDE and its overall ecological value
- Determine the impact of the project on the aquifer
- Determine risk magnitude to the GDE
- Apply the GDE Risk Matrix
- Determine the appropriate management actions, including mitigation measures.

The GDE Risk Matrix (Table 1) is a method of outlining appropriate management responses for an environmental value under a particular activity.

The matrix consists of a vertical axis that plots ecological value, and a horizontal axis that plots the level of risk of an activity. The ranking of both ecological values and risk is divided into a three-category system of “High, Medium, and Low” values. The comparative terms, low, medium and high are defined in the context of the project and the nature and value of the ecological value. This will also be influenced by the level of data available and confidence in the activity impacts.

Table 1. GDE Risk Matrix (Serov et al., 2012)

	Category 1: Low Risk	Category 2: Moderate Risk	Category 3: High Risk
Category 1: High Ecological Value (HEV) Sensitive Environmental Area (SEA)	A	B	C
Category 2: Moderate Ecological Value (MEV) Sensitive Environmental Area (SEA)	D	E	F
Category 3: Low Ecological Value (LEV)	G	H	I

The Risk Matrix management action table (Table 2) identifies both the level of management action required and the time frame in which this action needs to be implemented (Action Priority). The management action is aligned with ecological value and does not vary with changes in risk (i.e. the rules for the management of high ecological value ecosystems or aquifers are the same whether the risk is high or low). However, the timing of the management action is aligned with and determined by the level of risk and specific actions will be determined on a site by site basis.

Table 2. Risk Matrix Management Actions (Serov et al., 2012)

Risk Matrix Box	Descriptor	Management action		
		Short term	Mid-term	Long term
A	High value/Low risk	Protection measures for aquifer and GDEs.	Continue protection measures for aquifers and GDEs.	Adaptive management. Continue monitoring.
		Baseline Risk monitoring.	Periodic monitoring and assessment.	
B	High value/Moderate Risk	Protection measures for aquifer and GDEs.	Protection measures for aquifer and GDEs.	Adaptive management. Continue monitoring.
		Baseline Risk monitoring. Mitigation action.	Monitoring and periodic assessment of mitigation.	
C	High Value/High Risk	Protection measures for aquifer and GDEs.	Protection measures for aquifer and GDEs.	Adaptive management. Continue monitoring.
		Baseline Risk monitoring. Mitigation.	Monitoring and annual assessment of mitigation	
D	Moderate Value/Low Risk	Protection of hotspots.	Protection of hotspots.	Adaptive management. Continue monitoring.
		Baseline Risk monitoring.	Baseline Risk monitoring.	
E	Moderate Value/Moderate Risk	Protection of hotspots.	Protection of hotspots.	Adaptive management. Continue monitoring.
		Baseline risk monitoring.	Monitoring and periodic assessment of mitigation.	
F	Moderate Value/High Risk	Protection of hotspots.	Protection of hotspots.	Adaptive management. Continue monitoring.
		Baseline risk monitoring. Mitigation action.	Monitoring and annual assessment of mitigation.	
G	Low value/Low risk	Protect hotspots (if any).	Protect hotspots (if any).	Adaptive management. Continue monitoring.
		Baseline risk monitoring.	Baseline risk monitoring.	
H	Low Value/Moderate Risk	Protect hotspots (if any).	Protect hotspots (if any).	Adaptive management. Continue monitoring.
		Baseline risk monitoring. Mitigation action.	Monitoring and periodic assessment of mitigation.	
I	Low Value/High Risk	Protect hotspots (if any).	Protect hotspots (if any).	Adaptive management. Continue monitoring.
		Baseline risk monitoring. Mitigation action.	Monitoring and periodic assessment of mitigation.	

3. Current environment

3.1. Summary of groundwater condition

A detailed account of the geology and hydrogeology of the project area is given in Appendix N (Technical working paper: Groundwater). Information relevant to GDEs present in the project area is summarised below.

The majority of the project area is underlain by Hawkesbury Sandstone, with a small amount of localised fill or Quaternary sediment near Flat Rock Creek that consists of silty to peaty quartz sand, silt and clay.

The Hawkesbury Sandstone was deposited in a fluvial paleo-environment, likely by a large braided river and as such is highly stratified. Localised perched water tables occur as a result of the stratified nature of the sandstone, which can be interspersed with lenses of low permeability that restrict the downward draining of water. This can mean that at some locations throughout the study area there are shallow perched water tables overlying deeper water table (e.g. near Wakehurst Parkway, Jacobs, 2020).

Fractures in the sandstone create preferential flow paths for groundwater. Shallow or perched groundwater systems may discharge to surface water via shallow fracture networks or, may emerge from the sides of bare sandstone as springs.

The Hawkesbury Sandstone is thus an unconfined aquifer at the surface, but becomes increasingly confined with depth because of the highly stratified nature of the sandstone and interbedded shales. Groundwater flow occurs mostly via secondary permeability, fractures and along bedding planes.

The regional water table generally mimics, but in a subdued fashion, the surface topography, with groundwater moving from high topographic areas to low areas where it discharges to surface drainage lines. The water table varies from close to ground surface in topographic lows to 100 metres below ground level beneath hills.

3.2. Groundwater dependent ecosystems identified in the project area

The following GDEs were identified in the environmental impact statement as part of Appendix S (Technical working paper: Biodiversity development assessment report) and the Appendix N (Technical working paper: Groundwater).

The National Atlas of GDEs (BOM, 2018) was used to identify the location of GDEs for the region and these are shown in relation to the project in Figure 1. However, only those in or close to the project assessment area were considered further. These include:

- Coastal Sandstone Gully Forest
- Sandstone Riparian Scrub
- Coastal Sand Forest
- Coastal Sandstone Plateau Heath
- Illawarra Gully Wet Forest
- Estuarine Fringe Forest in the middle to lower reaches of Flat Rock Creek, approximately 280 metres south-east of the tunnel alignment and the Flat Rock Drive construction support site (BL2).

These vegetation communities are mapped as having a moderate to high potential for groundwater dependence, and occur in isolated patches throughout the Sydney region.

- A small patch of Coastal Upland Swamp in the Sydney Basin Bioregion, which is an Endangered Ecological Community (EEC) under the *Biodiversity Conservation Act 2016* and the *Environment Protection and Biodiversity Conservation Act 1999,* whilst not mapped in the National Atlas of GDEs, is potentially sensitive to changes in groundwater flow (Arcadis, 2020). Three patches occur in the assessment area: two approximately 95 metres west of Wakehurst Parkway in Garigal National Park, and one north of Bantry Bay Oval, about 135 metres south-east of the construction footprint.

In addition to these identified communities, varying levels of groundwater discharge contributes to river baseflow ecosystems in Flat Rock Creek, Quarry Creek, and Burnt Bridge Creek (Jacobs, 2020). These are described in Section 3.3.1.

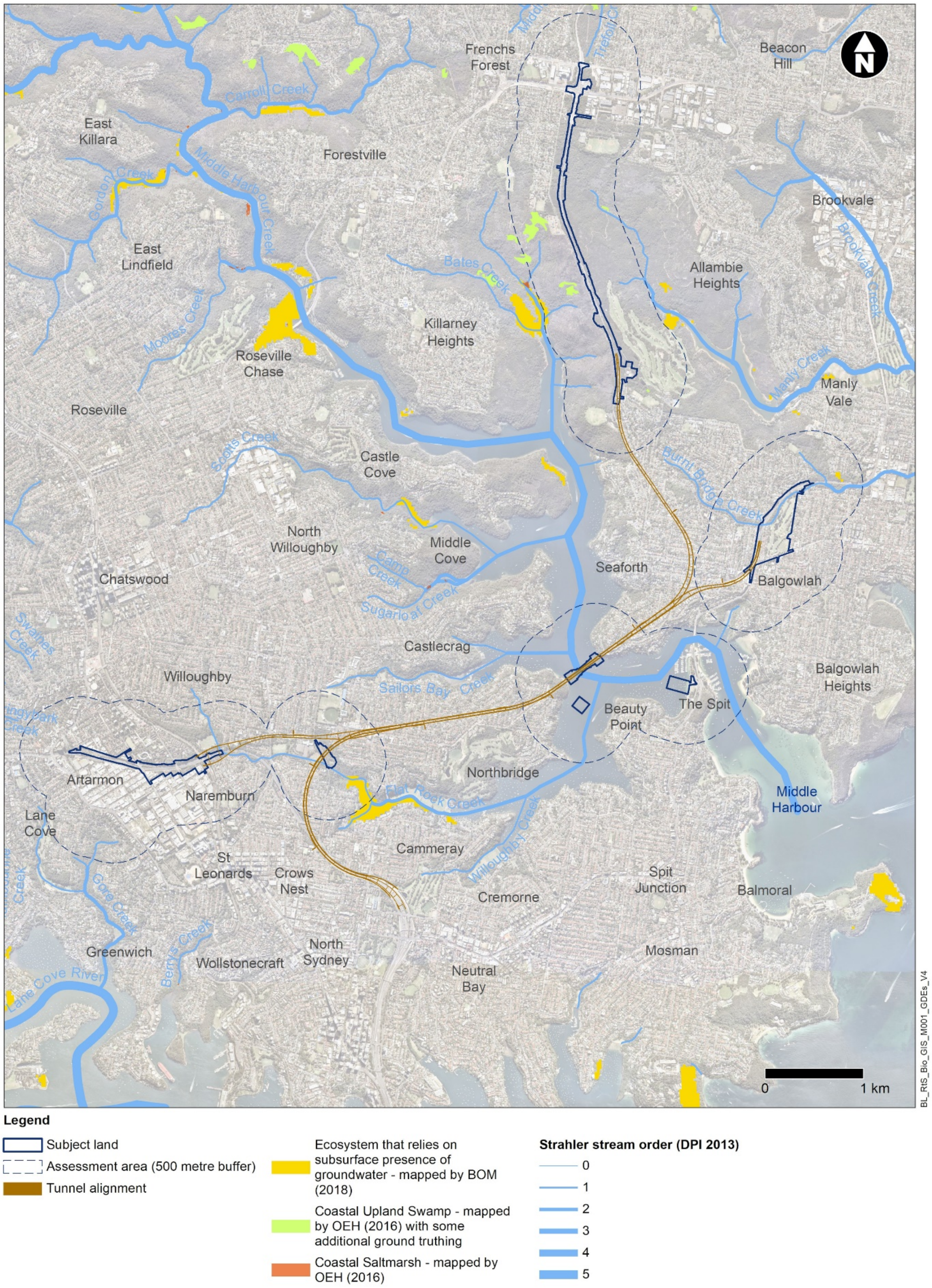

Figure 1. Location of regional groundwater dependent ecosystems represented in the National Atlas of GDEs (from Arcadis, 2020)

3.3. Level of groundwater dependence in ecosystems

3.3.1. River baseflow ecosystems

Streamflow is made up of a number of components, principally including baseflow, sourced from groundwater aquifers, and quickflow, sourced from surface runoff. River channel precipitation and evapotranspiration also contributes to the overall flow in waterways, but are generally small and indistinguishable from other components of streamflow. Distinguishing between each of these sources of water is difficult in practice and is commonly derived through modelling.

Strict definitions of baseflow are difficult to formulate. Conceptually, however, baseflow represents river flow sourced from groundwater aquifers. Groundwater and surface water interaction varies spatially and temporally and can occur from the stream to groundwater, vice versa or in both directions at different times and places, depending on relative river and groundwater levels and hydrogeologic conditions.

Groundwater is recognised to contribute to the baseflow component of stream flow in Flat Rock, Quarry and Burnt Bridge Creeks.

Flat Rock Creek

Flat Rock Creek intersects the groundwater table near where it is crossed by the M1 at Artarmon, approximately at 54 meters AHD, and groundwater interacts with the stream for most of its length downstream, including in the estuarine reaches. In the upstream reaches of Flat Rock Creek, near Willoughby Road, baseflow is estimated to contribute 0.8 per cent to the entire volume of streamflow, with the remaining contribution from surface runoff and direct rainfall. Further downstream at Flat Rock Creek reserve the baseflow contribution is 79 per cent, and at Flat Rock Creek Weir it is 67 per cent. However, overall flow in Flat Rock Creek is dominated by stormwater contribution and this has a stronger influence over aquatic ecology than groundwater.

Groundwater is likely to enter the creek channel, either through springs or as diffuse seepage through porous bedrock, when the stream bed or banks intersect the water table. Figure 2 indicates that Flat Rock Creek is currently a gaining stream (i.e. receives upwelling groundwater) downstream of Hampden Road and Artarmon Park. Most flow in this reach of Flat Rock Creek, upstream of Flat Rock Drive, originates from overland flow or from shallow groundwater in perched aquifers emerging as springs, rather than from the regional Hawkesbury Sandstone aquifer which is predicted to be affected by drawdown during development.

Immediately upstream of Willoughby Road, Flat Rock Creek is lined, though is still able to receive baseflow through cracks and seepage (Figure 4). Downstream of Willoughby Road, the creek is unlined and flows underground for about 900 metres before emerging as an unlined bedrock channel with springs and baseflow. Downstream of Strathallen Avenue it becomes a lined underground channel until it flows into Middle Harbour (Figure 5).

Quarry Creek

Quarry Creek is a gaining stream for its entire length and connected to groundwater (Figure 2). The upper 200 metres is lined, but is still able to receive groundwater contributions to baseflow (Figure 5). For this reach, baseflow makes up approximately 0.5 per cent of stream flow. Unlined bedrock with springs occur along most of its length, until just before its confluence with an unlined reach of Flat Rock Creek. The percentage of groundwater baseflow in the lower reaches is likely to be approximately 79 per cent - similar to that of the mid-reach of Flat Rock Creek.

Burnt Bridge Creek

The upper reach of Burnt Bridge Creek is unlined bedrock with springs and baseflow until Brook Road, where is becomes lined for approximately 200 metres but still receives baseflow contributions (Figure 3, Figure 6). For 200 metres downstream of this point, the creek is an unlined bedrock channel with no baseflow, however baseflow contributions resume for most of the length downstream to Manly Creek (Figure 7). The mid-section of Burnt Bridges Creek, near Baringa Ave, baseflow contributes six per cent to streamflow. This decreases to two per cent downstream of the Balgowlah Golf Course.

Figure 2. Areas of lined, gaining and losing sections of Flat Rock and Quarry Creeks

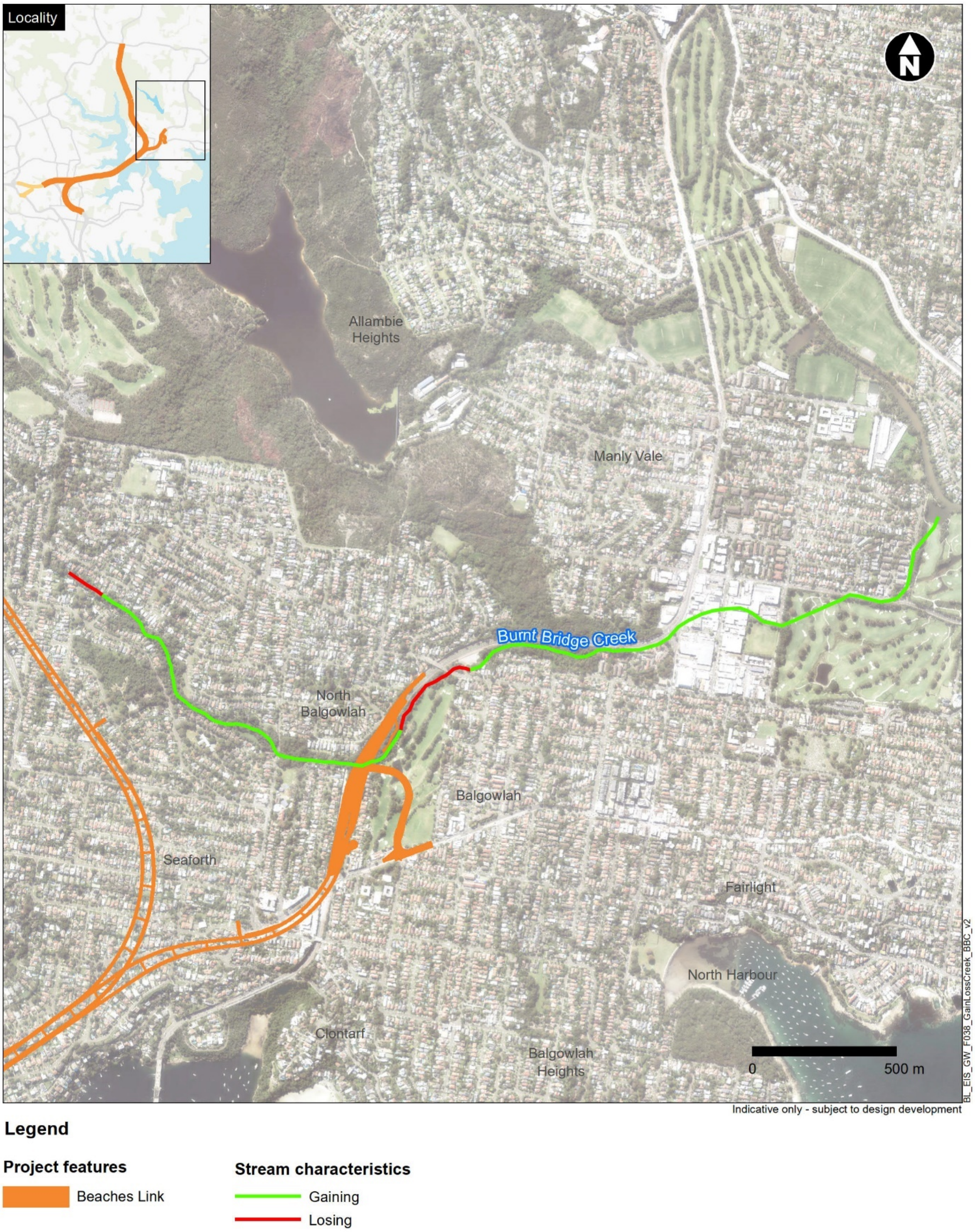

Figure 3. Areas of gaining and losing sections of Burnt Bridge Creek

Figure 4. Waterway lining type- upper to mid reaches of Flat Rock Creek

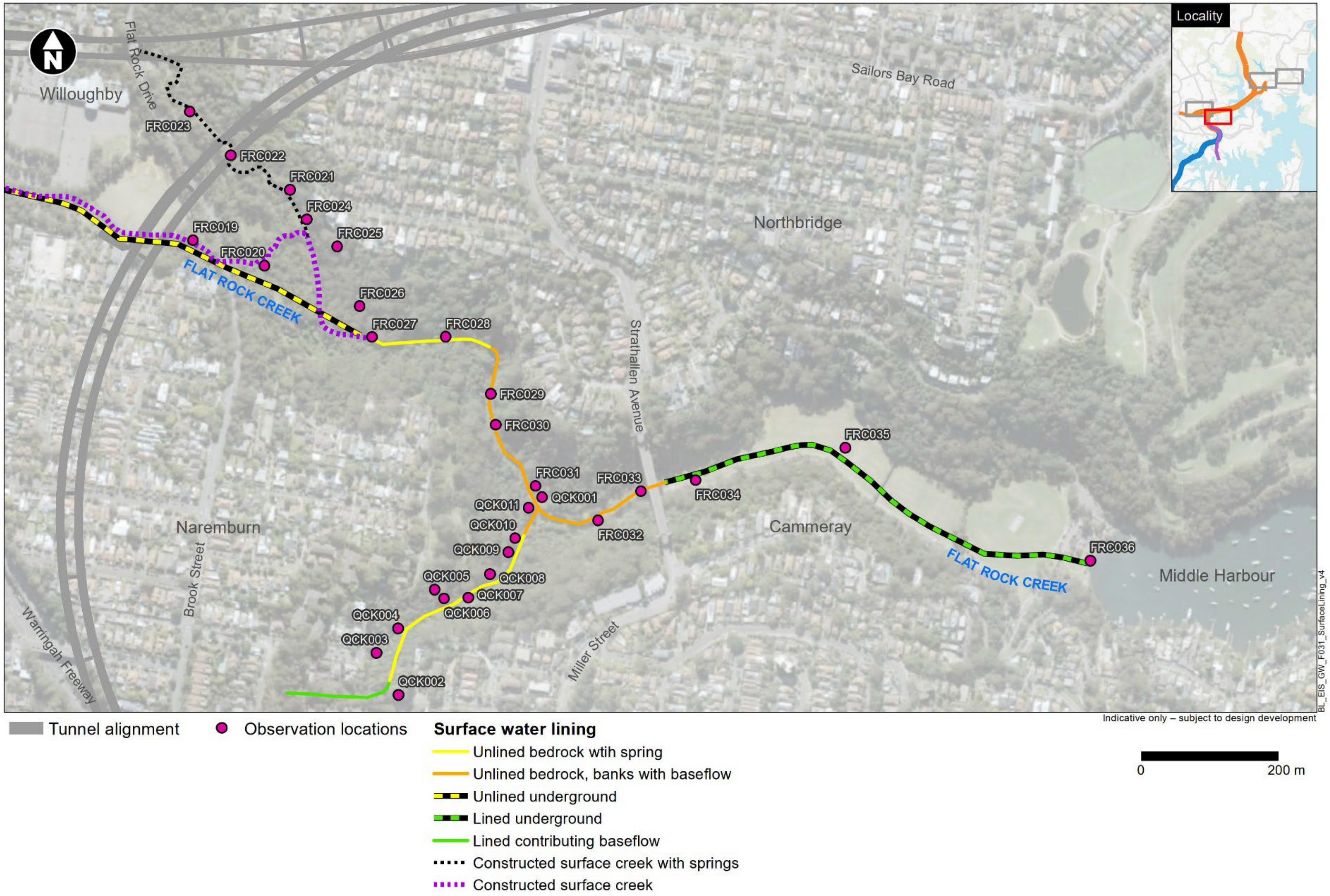

Figure 5. Waterway lining type- mid to lower reaches of Flat Rock Creek, including Quarry Creek

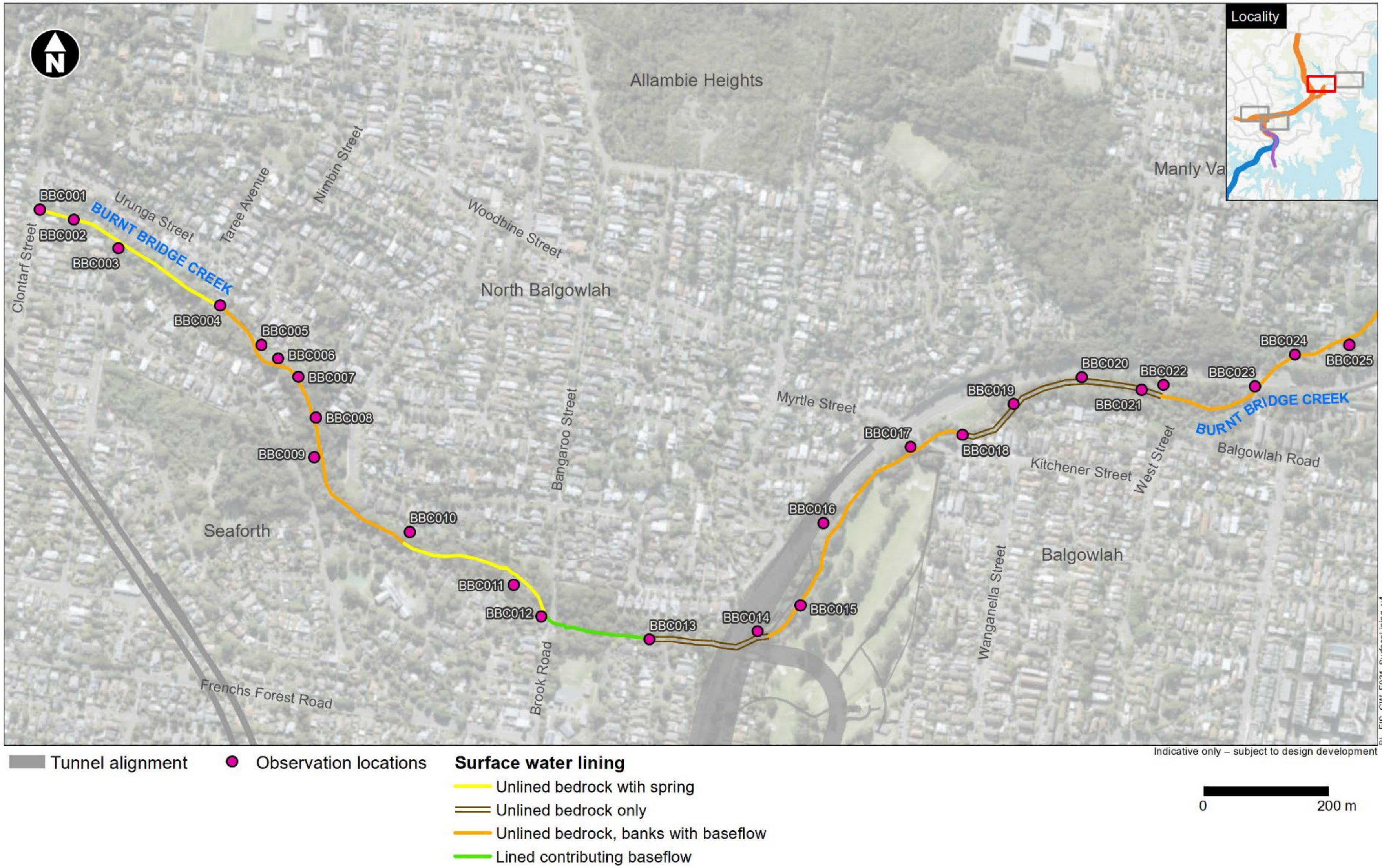

Figure 6. Waterway lining type- upper reach of Burnt Bridge Creek

Figure 7. Waterway lining type - lower reach of Burnt Bridge Creek

3.3.2. Groundwater dependent vegetation

Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest in the middle to lower reaches of Flat Rock Creek are all mapped on the National Atlas of GDEs (Figure 8; BOM, 2018) as having a moderate to high potential for groundwater interaction (Figure 9; BOM, 2018). Vegetation upstream of Long Gully Bridge is mapped as having a moderate likelihood of groundwater interaction, while vegetation on the southern sides of the gully overlooking Tunks Park, is mapped as having a high potential for groundwater interaction (Figure 9).

Vegetation upstream of Long Gully Bridge extends from elevations of 4 metres AHD close to Flat Rock Creek, up to 40 metres AHD on the gully slopes[1]. The extent of interaction with the regional water table in these vegetation communities is likely to become less with increasing distance up the gully slope. Vegetation in elevated areas is more likely to depend on perched aquifers and water stored in fractures, since fractures are required for root penetration of the rock. Examples of fracturing in the Hawkesbury Sandstone near the Flat Rock Drive construction support site (BL2) are shown in Figure 10.

[1] Measured with www.maps.six.nsw.gov.au

Figure 8. Groundwater dependent vegetation communities as mapped by Groundwater Dependent Ecosystems Atlas (Arcadis 2021)

Figure 9. Potential for groundwater interaction as mapped by the Groundwater Dependent Ecosystem Atlas (Arcadis 2021)

Figure 10. Examples showing horizontal fractures and stratification in Hawkesbury Sandstone, Tunks Park

3.3.3. Coastal Upland Swamp

Coastal Upland Swamp mainly occurs on impermeable sandstone plateau where there are shallow groundwater aquifers, impeded drainage lines, and on benches with seepage moisture (Jacobs, 2020). A small section of Coastal Upland Swamp south of the Wakehurst Golf Course sits at an elevation of approximately 110 metres AHD[2]. At this location, the modelled composite groundwater contour is approximately 40 metres AHD (Jacobs, 2020). A larger section of swamp occurs in Garigal National Park to the west of Wakehurst Parkway at an altitude of 110 metres AHD. Beneath the swamp the composite groundwater contour is between 100 and 110 metres AHD.

The level of groundwater dependence at these swamps is unclear. The swamp near Wakehurst Golf Course does not appear to be connected to the regional water table, but may be dependent on shallow perched water tables. The swamp west of Wakehurst Parkway sits above a shallower section of groundwater table and may be connected, although neither of these swamps are mapped on the National Atlas of GDEs (BOM, 2018).

3.4. Baseline ecological value and ecological condition

The value of a GDE is determined by the biota it supports, as well as the processes performed by the ecosystem (Serov et al., 2012). Biota includes the flora, fauna and microbiota, while the processes performed include nutrient processing, hydrological filtration, and other biological, hydrological, physical and chemical processes.

A GDE with high ecological value is one that is in a natural or near-natural state and meets the following criteria (Serov et al., 2012):

[2] As indicated in topographic mapping on www.maps.six.nsw.gov.au

- Groundwater dependent communities where a slight to moderate change in groundwater hydrology would result in a substantial change in distribution, species composition or health
- Ecosystems that have already been identified as important by other State, Commonwealth, or International agencies, or are a recognised high conservation area
- Any GDE that is habitat for endemic, relictual, rare, or endangered plant of animal as listed under the *Biodiversity Conservation Act 2016*, *Fisheries Management Act 1994*, or the *Environment Protection and Biodiversity Conservation Act 1999*.

The ecological conditions of GDEs in the project area have been determined from information contained in Appendix S (Technical working paper: Biodiversity development assessment report) and information gathered subsequently by Arcadis during a site inspection (Arcadis, 2021).

3.4.1. River baseflow ecosystems

Flat Rock Creek

Flat Rock Creek is a first order fresh waterway upstream of the Quarry Creek confluence, and an estuarine second order creek downstream of the confluence. In the upstream reaches, the channel is modified and alternates between above- and below-ground sections and has reaches where the channel is lined with either concrete or bedrock. In addition, this area is dominated by stormwater flows which have shaped the creek form. This part of the creek is not considered key fish habitat (Cardno, 2020; Cardno, 2021). The channel is natural as it flows through Flat Rock Reserve, with the bed made of sandstone in the upstream section of reserve, and alluvium downstream. There are occasional ripples and pools, and the banks are steep in places, ranging from 3 to 10 metres above the creek bed. The invertebrate fauna of Flat Rock Creek consists of 16-36 taxa and indicates that the creek is either severely or extremely impaired.

Riparian vegetation is densely vegetated with generally native overstorey and an understorey of native and exotic species. Vegetation consists of PCT 1841 Smooth-barked Apple-Turpentine-Blackbutt tall open forest on enriched sandstone slopes and gullies of the Sydney region, with infestations of weeds and exotics in disturbed areas. The vegetation is likely to only provide marginal quality habitat for disturbance-tolerant species of amphibians, reptiles, mammals, invertebrates and birds (Cardno, 2020). There are numerous impediments to fish passage including underground sections, bedrock bars, and narrow pipe culverts, and there is limited fauna habitat present in the form of logs, leaf litter or rocks. In the lower reaches of the creek immediately upstream of the Quarry Creek confluence there is a small amount of instream timber that may provide fish habitat.

Given the depauperate invertebrate community, and considering the poor quality of habitat present, Flat Rock Creek is considered to be in poor ecological condition (Cardno, 2021), and therefore it is a **low ecological value** GDE.

Downstream of Quarry Creek confluence, Flat Rock Creek becomes estuarine and continues to receive stormwater discharge (as do the mid to upper reaches). The bed consists of unconsolidated sediments and there is some channel and bank erosion. It remains aboveground until Strathallen Avenue, then flows underground though a lined channel into Middle Harbour.

Quarry Creek

Quarry Creek is a short (500 metres) waterway that joins Flat Rock Creek at Flat Rock Reserve. Quarry Creek begins at an altitude of 50 metres AHD and descends over a distance of 300 metres to an altitude of 10 metres AHD. The creek crosses the modelled water table contour (Jacobs, 2020) at an altitude of 30 metres AHD, indicating that the final 300 metres of the creek is fed to varying degrees by groundwater.

Upstream of the confluence, Quarry Creek is a first order waterway that flows through an underground culvert reach into a natural bedrock channel as part of Flat Rock Reserve. Vegetation along Quarry Creek is similar to that along Flat Rock Creek. Quarry Creek has a depauperate community of aquatic macroinvertebrates (10-25 taxa), with those taxa present indicating extreme or severe levels of impact on the ecology (Cardno, 2021). The creek is therefore considered to be a **low ecological value** GDE.

Burnt Bridge Creek

Burnt Bridge Creek is a first order waterway that is intermittent and receives stormwater input from multiple locations. It was not identified as being groundwater dependent in the GDE Atlas, but receives some of its contribution from groundwater (Jacobs, 2020). The creek has low dissolved oxygen concentration and elevated heavy metal and nutrient concentrations (Cardno, 2020). The channel consists of bedrock with sand and silt patches and rocky outcrops. Pools are partially connected and contain exotic in-stream vegetation and moderate riparian shading. Burnt Bridge Creek provides only marginal quality habitat suitable for disturbance tolerant species. There is minimal structural habitat (rocks, logs, leaf litter) and water quality is poor (Cardno, 2020). The aquatic ecology of Burnt Bridge Creek is severely or extremely impaired, with 14-24 taxa (Cardno, 2021), and is therefore considered to be of **low ecological value** GDE.

Riparian vegetation ranges in width from 0 to 30 metres and consists of Water Gum-Coachwood riparian scrub that has a mix of native and exotic species. The area has been significantly disturbed and contains weeds and large areas of exposed ground.

3.4.2. Groundwater dependent vegetation communities of Flat Rock Reserve

Patches of Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest extend for approximately one kilometre in the middle to lower reaches of Flat Rock Creek. The vegetation is in moderate to good condition and contains mostly native species (*Eucalyptus* sp., *Angophora costata*, *Allocasuarine littoralis*) which grow on the upper or mid-slopes, but is dominated by exotic species in the flatter areas beside the creek (Arcadis, 2021). Vegetation in the gully closer to the creek is sheltered and appears to be in good condition with no signs of stress (Arcadis, 2021). Palms and ferns occur on the lower flat beside the creek. This GDE is considered to be a **moderate ecological value** GDE.

3.4.3. Coastal Upland Swamps

Coastal Upland Swamps in the Sydney Basin Bioregion are listed as an EEC under the *Biodiversity Conservation Act 2016* and the *Environment Protection and Biodiversity Conservation Act 1999*. Therefore, this GDE is considered to be a **high ecological value** GDE. This vegetation community occurs on poorly permeable sandstone plateaux in low relief headwater valleys of streams and on sandstone benches with abundant seepage moisture (OEH, 2017). Coastal Upland Swamps generally occur in small patches of less than a hectare (OEH, 2017). There is a small patch of swamp located west of Wakehurst

Parkway in Garigal National Park, and another small patch north of Bantry Bay oval. During a site visit to this swamp in 2021, Arcadis ecologists found it difficult to delineate the swamp from the surrounding heathland (Arcadis, 2021).

4. Potential impacts

4.1. Creek baseflow loss

Assessments of baseflow loss determined for the Beaches Link and Gore Hill Freeway Connection environmental impact statement are likely to be overestimates as groundwater models were developed using a conservative approach that assumed tunnels were fully unlined and that there is full hydraulic connectivity between the deep tunnels and surface. In reality, tunnels would be lined with shotcrete at a minimum, grouting would be carried out to limit groundwater inflows to within approval limits and stratification and fracturing of sandstone would result in actual hydraulic conductivity in the rocks being less than that used for modelling purposes.

Further, under the environmental management measures, the project is required to limit groundwater inflows into the tunnel to less than 1L/km/s during operation. Additional modelling was carried out to account for the different creek linings, which are shown in Figure 4 toFigure 4 Figure 7.

While Flat Rock Creek, Quarry Creek, and Burnt Bridge Creek are predicted to lose some water from the baseflow component of their streamflow, the ecology of all three creeks is already highly disturbed, and the taxa present are considered to be robust and able to tolerate small changes in flow volume. There are no sensitive species present and it is expected that there would be negligible impact on aquatic communities.

4.1.1. Flat Rock Creek

Groundwater modelling estimates a maximum fall in groundwater level of 27 metres beneath Flat Rock Creek near Artarmon at the (approximate) start of the gaining reach of Flat Rock Creek shown in Figure 11. However, at this location, the current contribution to streamflow is only estimated as 0.8 per cent. Drawdown continues to affect the creek for most of the distance downstream, reducing to between 3 and 5 metres at Flat Rock Reserve, and 1 metre where Flat Rock Creek reaches Quarry Creek (Figure 11). This drawdown regime results in an average reduction in baseflow of 30 per cent across the whole creek, comprised of a reduction in streamflow of 0.4 per cent in the upstream reaches, 27 per cent at Flat Rock Reserve, and 22 per cent at Flat Rock Creek Weir (Jacobs, 2021).

This estimated drawdown is based on the conservative modelling approach considering the tunnel being unlined and having no mitigation measures to limit inflow. Considering the modelled drawdown, the point at which Flat Rock Creek intersects the groundwater table would migrate downstream due to the project. Without supplemental flow or storm water input, this means that Flat Rock Creek may become more ephemeral for this reach, and experience longer and more frequent periods of low or no flow. However, the impacts of this would be offset by supplemental flows from the project operational water treatment plant that discharges into Flat Rock Creek in the Artarmon area (refer to Section 17.5.3 of the environmental impact statement). These supplemental flows would prevent the creek from drying out and provide enough connectivity between pools for aquatic habitats in the creek to be sustained.

4.1.2. Quarry Creek

Drawdown beneath the gaining reaches of Quarry Creek is predicted to be approximately 13 metres (Figure 11) in the upper section and one metre just upstream of the Flat Rock Creek confluence. This drawdown would result in a loss of 63 per cent of baseflow contribution to the creek (Jacobs, 2021). In the upstream reaches of Quarry Creek, the predicted loss in baseflow would equate to a decline in stream flow of 0.04 per cent (Jacobs, 2021).

Most flow in the upper reaches of Quarry Creek comes from surface contribution. A reduction of 0.04 per cent is not expected to have a significant impact on aquatic ecology. In the downstream reaches, where Quarry Creek flows through a small floodplain and into Flat Rock Creek, the impact to baseflow is expected to be minor. This is because the alluvial floodplain aquifer would be recharged from water released from the project operational water treatment plant discharging into Flat Rock Creek at Artarmon. Therefore, the resultant impact to aquatic ecology would be negligible.

4.1.3. Burnt Bridge Creek

Drawdown beneath Burnt Bridges Creek is predicted to be between one and three metres for most of the reach upstream of Kitchener Street, and less than one metre downstream (Figure 12). This equates to an overall baseflow reduction of 60 per cent along the whole creek (Jacobs, 2021) and a reduced total streamflow of three per cent in the mid-section and two per cent in the downstream section.

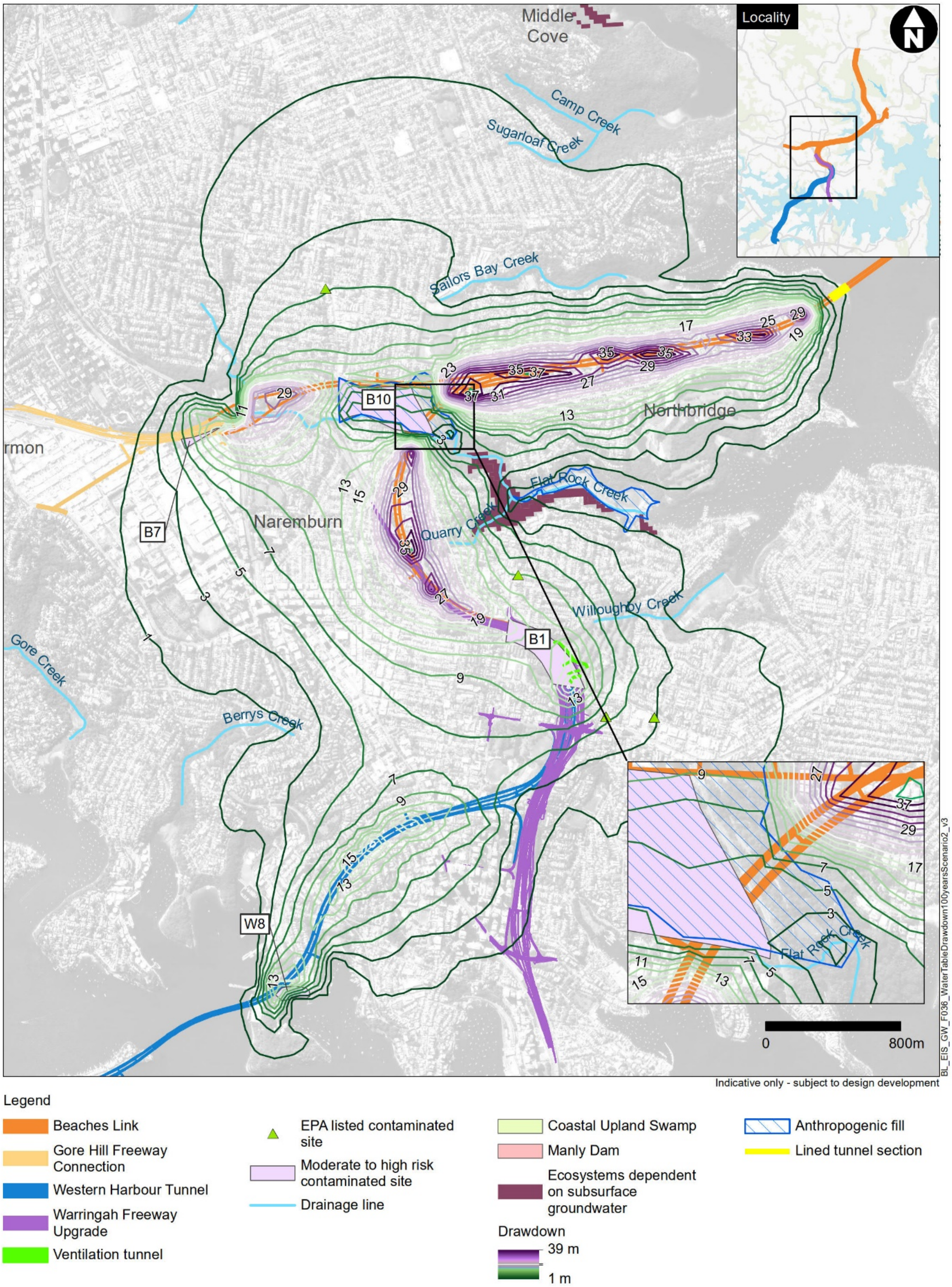

Figure 11. Water table drawdown beneath Flat Rock and Quarry Creeks after approximately 100 years of operation for the Western Harbour Tunnel and Beaches Link program

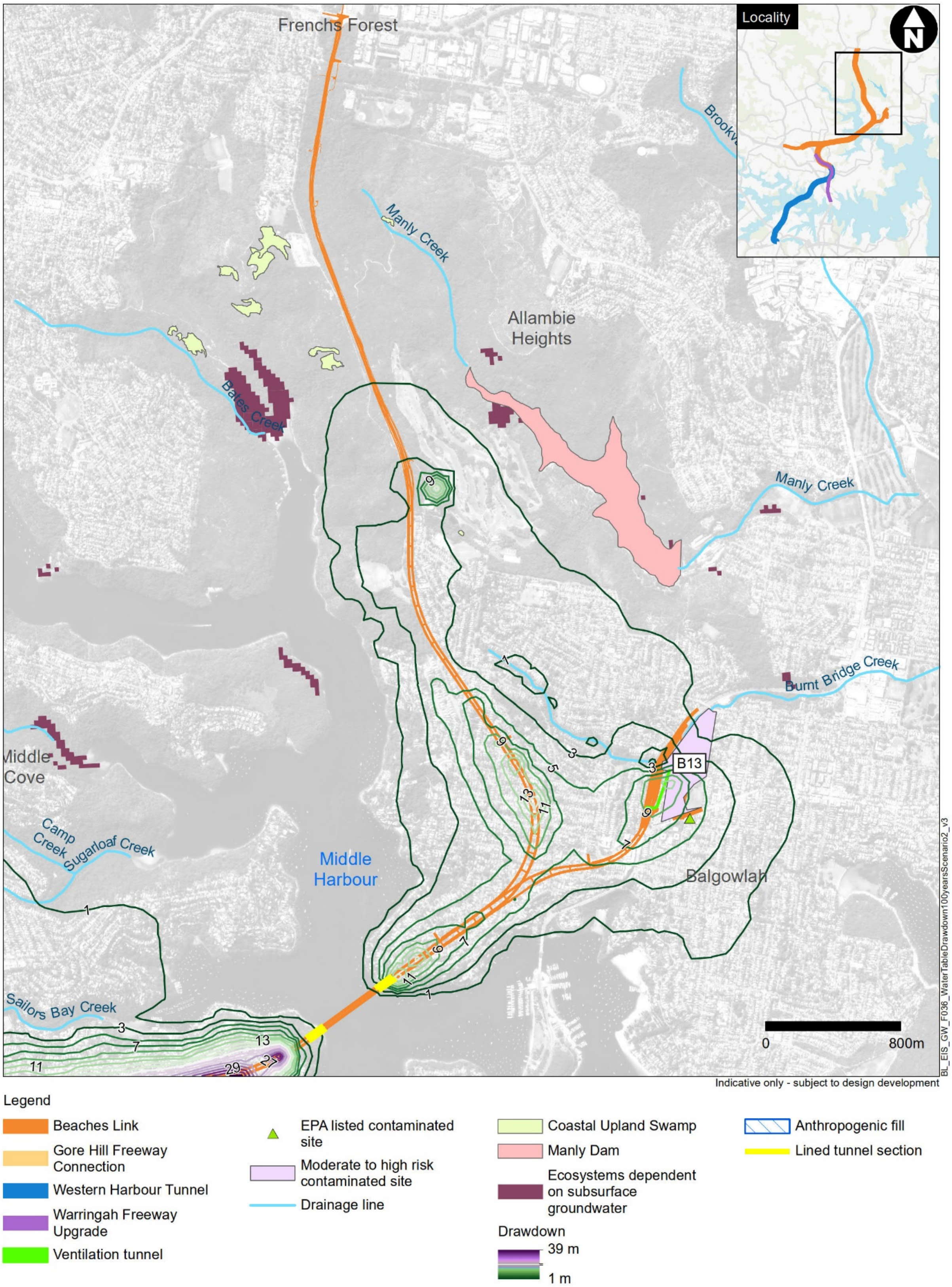

Figure 12. Water table drawdown beneath Burnt Bridge Creek after approximately 100 years of operation for the Western Harbour Tunnel and Beaches Link program.

4.2. Groundwater dependent vegetation communities of Flat Rock Creek

Approximately 10.5 hectares of Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest is within the area predicted to experience drawdown around Flat Rock Creek. Drawdown beneath this vegetation is modelled to be less than five metres at the upstream end, and less than one metre downstream of the Quarry Creek confluence (Figure 11).

Vegetation growing on the upper slopes of the sandstone ridges are likely to be supported by perched aquifers that are isolated from the regional water table. These are constrained by the stratification and fracturing in the Hawkesbury Sandstone. Drawdown in the regional aquifer is therefore likely to have minor spatial impacts on vegetation health, so the magnitude of risk is small given that the vegetation community is not solely dependent on regional groundwater.

The small alluvial aquifer of Flat Rock Creek and at the Quarry Creek confluence would also be recharged by releases from the project water treatment plant into Flat Rock Creek at Artarmon. This is expected to replace any baseflow losses and sustain vegetation communities dependent on groundwater in the shallow alluvium.

4.3. Coastal Upland Swamp

Groundwater drawdown beneath the section of coastal upland swamp beside Wakehurst Golf Course is modelled to be less than three metres. This regional water level is approximately 50 metres below ground level, so this swamp is likely to be connected to perched water tables, rather than the regional aquifer. Perched aquifers are predominantly fed by localised rainwater, or from downward drainage from upslope aquifers. It is therefore unlikely that this section of upland swamp would be affected by drawdown from the project.

Drawdown beneath the swamp west of Wakehurst Parkway is modelled to be between zero and one metre by 2028 and for the subsequent 100 modelled years. The groundwater dependence of this swamp is uncertain, as the water level is currently approximately 10 metres below ground level. The water table beneath this swamp may be affected by drawdown, but it is likely that the swamp receives water from surface runoff and subsurface drainage from upslope perched aquifers, and that the availability of this water to support the swamp would not be affected.

5. Risk assessment

The aquatic ecosystems supported by Flat Rock, Quarry, and Burnt Bridge Creeks are all highly modified and support a depauperate aquatic biota, typical of highly-disturbed small streams in the Sydney region (Cardno, 2021). The biological community of these creeks are robust and would not be impacted by the anticipated levels of disturbance expected from the project. There are few aquatic macrophytes in the creeks and the native fish communities are in poor condition. As such, these creeks have a **low ecological value**.

The local Coastal Upland Swamps, however, are listed as endangered, hence the two patches of this ecosystem are considered to have a **high ecological value**.

Modelled baseflow losses are estimated at between 30 and 63 per cent across the three creeks predicted to be impacted by the project. This constitutes approximately 2 to 27 per cent of daily total stream flow. Most of the water in these creeks is thus derived from surface runoff and stormwater discharge, so would be minimally affected by groundwater drawdown. The percentage of potential baseflow loss can be considered as posing a **low level of risk** in Quarry and Burnt Bridge Creeks, and a **moderate level of risk** in Flat Rock Creek.

Drawdown of the regional groundwater table beneath the Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest along Flat Rock Creek, and beneath the Coastal Upland Swamp, is not expected to negatively affect these vegetation communities because they are likely supported by rainfall and shallow, perched aquifers. They are considered of **moderate ecological value** and at a **low level of risk**.

Outcomes against the GDE risk matrix are presented in Table 3, and the associated recommended management actions are discussed in Section 6 below.

Table 3. Risk Matrix assessment characteristics for GDEs

Potential GDE	Ecological Value	Level of Risk	Risk Matrix outcome
Flat Rock Creek	Low	Moderate	H
Quarry Creek	Low	Low	G
Burnt Bridge Creek	Low	Low	G
Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest	Moderate	Low	D
Coastal Upland Swamp	High	Low	A

6. Proposed management actions and mitigation measures

For ecosystems in category H (low value/moderate risk) and G (low value/low risk) of the GDE Risk Matrix, the recommended management actions include protecting hotspots (if any) and monitoring ecological condition. As there are no areas of high biodiversity that could be considered hotspots in any of the creeks affected by baseflow loss, there are no sections that need particular protection. The ecological condition of the creeks is already very poor, so is not likely to be impacted further by the potential baseflow loss. Ongoing ecological monitoring of these waterways would not be sensitive enough to detect the minor (if any) impacts from reduced baseflow, so this is not recommended.

Environmental management measures as listed in the environmental impact statement and submissions report would be sufficient to maintain the current ecological condition of all groundwater dependent ecosystems in the project area. Specifically, releases from wastewater treatment plants will replace and augment local streamflows.

The release of water into Flat Rock Creek from the Gore Hill Freeway operational wastewater treatment plant at Artarmon would compensate for any water lost due to groundwater drawdown. Prior to release, water will be treated to comply with the relevant physical and chemical stressors from ANZECC/ARMCANZ (2000) and the ANZG (2018) 95 per cent species protection levels for toxicants generally, with the exception of those toxicants known to bioaccumulate, which would be treated to meet the ANZG (2018) 99 per cent species protection levels, and the draft ANZG default guideline values for iron (in fresh and marine water) and zinc (in marine water), in accordance with environmental management measure WQ17 (refer to Table D2-1 of the submissions report). This would ensure that pool and riffle habitats in middle reaches of Flat Rock Creek are able to persist and maintain their ecological functions. Water released down Flat Rock Creek would also recharge the shallow alluvial aquifer of the creek and support riparian vegetation on the narrow floodplain at the bottom of Flat Rock Gully.

Baseflow loss in Burnt Bridge Creek would be supplemented by discharges from the wastewater treatment plant only during the construction phase. During the operational phase, the current modelled reduction in streamflow due to groundwater drawdown is only 2-3 per cent. These figures are based on the conservative scenario of tunnels being unlined with no mitigation measures in place to limit groundwater inflows. Once the construction contractor has a detailed tunnel design, which includes inflow mitigation measures at strategic locations, it is likely that revised groundwater modelling would indicate an even lesser impact on streamflow. Given the level of disturbance already apparent in Burnt Bridge Creek, the small reduction in streamflow is unlikely to have a significant impact, so no monitoring is considered necessary.

For Coastal Sandstone Gully Forest, Sandstone Riparian Scrub, Coastal Sand Forest, Coastal Sandstone Plateau Heath, Illawarra Gully Wet Forest and Estuarine Fringe Forest ecosystems, classified as D under the risk matrix, the recommended management actions include the protection of hotspots, ongoing monitoring, and adaptive management. There is a very low risk that these ecosystems would be impacted by groundwater drawdown, particularly the vegetation growing close to the creeks where flow is supplemented from the water treatment plant.

Vegetation communities on the sandstone slopes of Flat Rock Gully are likely to be buffered against the impacts of groundwater drawdown by water received from shallow perched aquifers. These aquifers are recharged by rainfall and surface runoff, and in the upper slopes of the gully are likely disconnected from the deeper regional aquifer. Given the highly disturbed condition of the vegetation community, it would be difficult to attribute any decline in vegetation condition to a decline in regional groundwater level.

For the Coastal Upland Swamps, the risk management matrix outcome was A, as they are considered EECs. Management actions for these ecosystems include the protection of the GDE and aquifer and monitoring to detect potential impacts. However, the extent of dependence on the potentially impacted regional aquifer for both of these patches of swamp is uncertain, and it is difficult to determine if there would be any impact from regional water table drawdown. Coastal Upland Swamps generally occur on areas of poorly permeable sandstone (OEH, 2017), so at least some of the water they rely on is expected to come from overland flow or rainfall that is prevented from draining away by rock beneath the swamp.

The area of swamp north of Bantry Bay Oval is also surrounded by a modified landscape, including a sportsground that drains directly into the swamp area. For the area of Coastal Upland Swamp in Garigal National Park, meanwhile, the predicted drawdown of less than 1 metre is unlikely to have a significant impact on the vegetation community. Given the likelihood that the two patches of Coastal Upland Swamp are not dependent on the regional groundwater table, and the low likelihood that they would be impacted by the project, no specific monitoring of these ecosystems is recommended.

Environmental management measure SG2 (refer to Table D2-1 of the submissions report) specifies that, “during the development of the detailed design and once a contractor is engaged, additional geotechnical investigations and groundwater monitoring would be completed”. This information would be used, along with the updated detailed tunnel design, to carry out any additional groundwater modelling, which would provide more detailed predictions of groundwater drawdown. If the updated predictions indicate that the impacts would be greater that those presented in the environmental impact statement, additional mitigation measures should be developed.

As current modelling is conservative and assumes that the tunnels are unlined with no mitigation measures in place to limit groundwater inflows, and assumes there would be continuous saturation (and hence hydraulic connectivity) between the tunnel and the water table, the incorporation of more refined geotechnical information and inflow mitigation measures at strategic locations into the models is expected to reduce the predicted level of groundwater drawdown.

Following completion of any updated modelling, environmental management measure SG6 (refer to Table D2-1 of the submissions report) requires “a focussed study, in consultation with Department of Planning, Infrastructure and Environment, to confirm potential groundwater drawdown and baseflow reduction in the three creeks due to tunnelling, and confirm potential impacts on freshwater ecology in the affected watercourses and nearby GDEs”. This would entail further, detailed hydrological and geological studies and would provide improved appreciation of potential impacts to GDEs in the project area. If unacceptable impacts are predicted, appropriate additional mitigation measures would be identified to address these impacts.

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