Chapter 4

Chapter 4

Project development and alternatives

January 2020

4 Project development and alternatives

This chapter describes the alternatives that were considered as part of the project development process and explains the selection of the preferred alternative. The preferred alternatives presented in this chapter are based on technical, environmental and planning considerations. Stakeholder and community considerations which have been incorporated into the project development process are outlined in Chapter 7 (Stakeholder and community engagement). Design refinements for particular elements of the project are also outlined.

The Secretary's environmental assessment requirements as they relate to the project development and alternatives, and where in the environmental impact statement these have been addressed, are detailed in Table 4-1.

Table 4-1 Secretary's environmental assessment requirements - Project development and alternatives

Secretary's requirement	Where addressed in EIS
Environmental impact statement	
1. The EIS must include, but not necessarily be limited to, the following: e. an analysis of any feasible alternatives to the project	An analysis of strategic alternatives is provided in **Section 4.3**.
f. a description of feasible options within the project, including: - alternative methods considered for the construction of the project, including the tunnels; and - staging of the proposal	Alternative construction methods are detailed in **Section 4.5.1**. Further detail on staging is included in **Chapter 6** (Construction work)
g. a description of how alternatives to and options within the project were analysed to inform the selection of the preferred alternative/option. The description must contain sufficient detail to enable an understanding of why the preferred alternative to, and options(s) within, the project were selected, including: - details of the short-listed route and tunnel options considered, and the criteria that was considered in the selection of the preferred route and tunnel design - details of the alternative construction methods that were considered for tunnel construction, particularly those areas spanning Sydney Harbour - the alternative tunnel design and ventilation options considered to meet the air quality criteria for the proposal - a justification for the preferred proposal taking into consideration the objects of the *Environmental Planning and Assessment Act 1979* (EP&A Act)	The assessment of alternatives is detailed in **Section 4.4** and **Section 4.5**. A description of the benefits of the overall program of works and the justification for the project is provided in **Chapter 3** (Strategic context and project need). Justification for the preferred proposal taking into consideration the objects of the *Environmental Planning and Assessment Act 1979* is presented in **Chapter 28** (Synthesis of the environmental impact statement).

Secretary's requirement	Where addressed in EIS
i. a demonstration of how the project design has been developed to avoid or minimise likely adverse impacts.	Project design development is detailed in **Section 4.4** and **Section 4.5**, and **Chapter 5** (Project description).

4.1 Overview

The project has undergone extensive evaluation of alternatives from pre-feasibility and strategic investigations through to design development and refinement, as outlined in Figure 4-1.

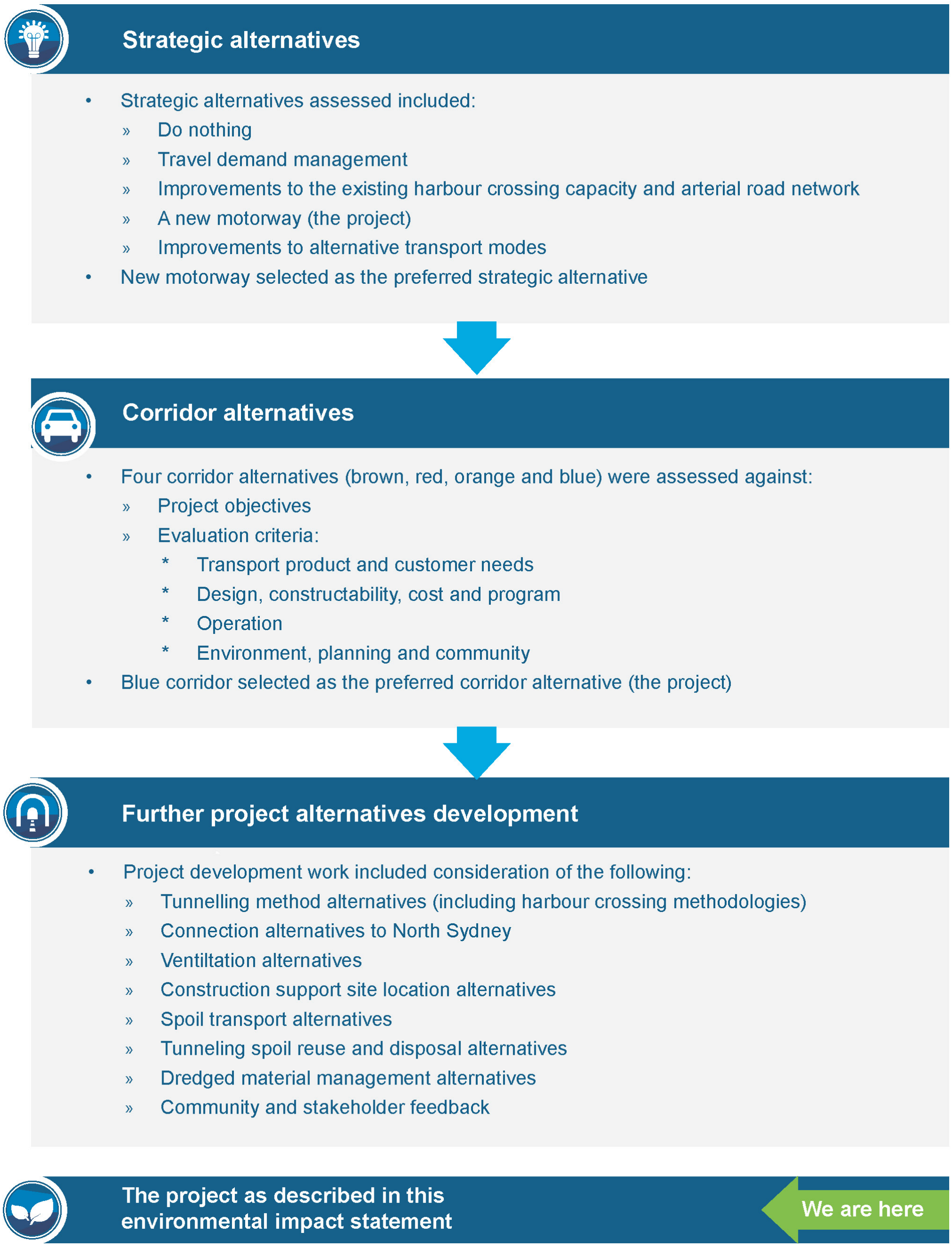


Figure 4-1 Alternatives development process

4.2 Historical context

The origins of the Western Harbour Tunnel and Beaches Link program of works extend back to the 1930s when the need for additional cross–Sydney Harbour transport capacity was identified as part of the development of the Warringah Transport Corridor.

A timeline for the historical development of the Warringah Transport Corridor and an additional harbour crossing as precursors to the Western Harbour Tunnel and Beaches Link program of works is provided in Figure 4-2.

1930s

Plans were developed for a new Warringah Transport Corridor, including an additional harbour crossing, to the Northern Beaches.

1951 - 1953

Planning for the Warringah Expressway (now Freeway) began in 1951. The Warringah Transport Corridor was adopted by the State Government as part of the *Main Road Development Plan 1953.*

1953

County of Cumberland Road Reservation prescribed. Included an inner ring-route, including a second crossing of Sydney Harbour (Greenwich-Birchgrove) and the Warringah Freeway crossing Middle Harbour between Sugarloaf Point and Pickering Point.

1959

Two tram tracks on Harbour Bridge converted to road lanes to improve road capacity.

1962

Cahill Expressway completed, helping to cope with traffic flows to/from the east.

1964

Opening of the Gladesville Bridge provided an additional harbour crossing to the west of the Harbour Bridge.

1968

The first stage of the Warringah Expressway opened in 1968. A review of the *Main Road Development Plan 1953* was carried out in the *Sydney Regional Outline Plan* (NSW State Planning Authority, 1968) and further studies were recommended.

1972

Western Distributor opened.

1974

The Sydney Area Transportation Study recommended that the Warringah Freeway be part of the long term road network in Sydney.

1978

Warringah Freeway extended.

Late 1970s

Government made formal call for suggestions to solve capacity issues at the crossing of Sydney Harbour. Submissions received included tunnels and bridges – most of which were west of the Sydney Harbour Bridge and required significant property acquisition for the approaches. Subsequently all formally rejected in 1982.

1981

The NSW Government established a Second Harbour Crossing Inquiry which presented alternative proposals for public comment including a route linking Greenwich to Birchgrove with a bridge or tunnel west of the Sydney Harbour Bridge. Due to strong community and stakeholder opposition the government abandoned the Second Harbour Crossing Inquiry without further analysis into the feasibility of the proposals.

1981

The Warringah Transport Corridor Inquiry starts, considering the proposal for the corridor to extend from the Warringah Freeway, across Middle Harbour at Castlecrag, to Seaforth and Balgowlah.

1983

The Commission of Inquiry into the Warringah Transport Corridor found that a new surface road to the Northern Beaches in the identified corridor would result in unacceptable levels of community and environmental impacts and would not deliver material transport benefits without addressing the constraint of the existing Sydney Harbour crossing, which was not part of the proposal. The Inquiry noted that the feasibility of the proposal would be improved by future tunnelling technology alleviating some of the potential environmental and community impacts.

1992

Opening of the Sydney Harbour Tunnel provided an additional harbour crossing.

1999

Eastern Distributor opens, providing an eastern bypass of the CBD.

2012

The NSW Government's *NSW Long Term Transport Master Plan* (Transport for NSW, 2012) proposed a new harbour crossing to the west of the CBD identifying it as a key 'missing link' in the Sydney motorway network. It also proposed a bus tunnel bypassing Military Road.

2014

Commitments were made in the *NSW State Infrastructure Strategy Update 2014* (Infrastructure NSW, 2014) that the Government would commence work on an additional harbour crossing and would further review and develop Beaches Link.

2015 - 2016

Transport for NSW carried out preliminary work to establish the viability and high level conceptual design for the Western Harbour Tunnel and Beaches Link program of work.

2015

Transport for NSW commence development of the B-Line program, to provide more frequent and reliable bus services between the Northern Beaches and Sydney CBD. Beaches Link and Western Harbour Tunnel would provide opportunity for express bus services into the CBD, and reduce pressure on Military Road for existing services.

2016

The draft *North District Plan* (Greater Sydney Commission, 2017b) and draft *Eastern City District Plan* (Greater Sydney Commission, 2017a) released by the Greater Sydney Commission identified the Western Harbour Tunnel and Beaches Link program of works as important initiatives to improve connections and access to and from northern Sydney.

2017

In March 2017, the NSW Government announced the commencement of a community engagement program to inform the development of designs for the Western Harbour Tunnel and Beaches Link program of works, including an additional harbour crossing. Transport for NSW commences community and stakeholder consultation, technical, environmental and heritage site investigations and more detailed design development for the Western Harbour Tunnel, Warringah Freeway and Beaches Link.

2018

The *Greater Sydney Region Plan – A Metropolis of Three Cities* (Greater Sydney Commission, 2018a) references the Western Harbour Tunnel and Beaches Link program of works as infrastructure that would further improve accessibility from the Northern Beaches to the Harbour CBD and reduce through traffic in the Harbour CBD ensuring the economic strength and global competitiveness of the Harbour CBD.

2018

The *Future Transport Strategy 2056* (NSW Government, 2018), the *NSW State Infrastructure Strategy 2018-2038* (Infrastructure NSW, 2018), the *Greater Sydney Region Plan - A Metropolis of Three Cities* (Greater Sydney Commission, 2018a), the *North District Plan* (Greater Sydney Commission, 2018b) and the *Eastern City District Plan* (Greater Sydney Commission, 2018c) released. These strategies reference the Western Harbour Tunnel and Beaches Link projects as a transport initiative that will improve connections and accessibility across Sydney.

2018

The Infrastructure Priority List (Infrastructure Australia, 2018) identifies the Western Harbour Tunnel and Beaches Link program of works as a priority initiative in recognition of its importance in addressing urban congestion on Sydney's arterial road network, augmenting critical cross-harbour capacity and Northern Beaches connectivity.

Figure 4-2 Historical development of additional cross-harbour capacity

4.3 Strategic alternatives

The project aims to provide additional transport capacity, to relieve pressure on existing crossings and to improve the efficiency and reliability for journeys across Sydney Harbour. Further information on the strategic context for the project and the transport needs addressed are provided in Chapter 3 (Strategic context and project need).

The *NSW Long Term Transport Master Plan* (Transport for NSW, 2012a) and subsequent *Future Transport Strategy 2056* (NSW Government, 2018) set the 40 year vision, strategic directions and outcomes for customer mobility in NSW. These plans identify the transport challenges that will need to be addressed to support NSW's economic and social performance and establish a number of short, medium and long-term actions to address those challenges.

Giving consideration to future land use, population density and transport requirements, both of these strategic plans identified road based transport, including improvements to bus services, as important modes to meet the needs of the Northern Beaches region. Furthermore, the need for additional core motorway capacity at the crossings of Middle and Sydney Harbour was identified as key to development of an appropriate multi-modal Sydney transport network – and specifically identified the Western Harbour Tunnel and Beaches Link program as transport projects required to support the plan.

Considering the identified requirements of the *NSW Long Term Transport Master Plan* and the *Future Transport Strategy 2056*, a number of strategic alternatives were considered for delivering the required road capacity, as follows:

- Do nothing
- Travel demand management
- Improvements to the existing harbour crossing capacities and road network
- A new motorway crossing of Sydney Harbour (the project)
- Improvements to alternative transport modes.

These strategic alternatives are described and evaluated in the following sections.

4.3.1 Do nothing

This alternative is to do nothing to the existing crossings of Sydney Harbour and adjoining motorway network and rely on the continued operation of existing transport networks and other transport projects currently proposed to meet future transport demands.

The Sydney Harbour Bridge and Warringah Freeway has been identified as one of Australia's 30 most congested road corridors, generating a congestion cost of $65,000 per day in 2016 (Infrastructure Australia, 2019). If no action is taken, this is forecast to rise to $98,000 per day by 2031. This congestion results in the existing road network being vulnerable to extensive network delays creating long and unreliable journey times.

The Sydney Harbour Bridge and Warringah Freeway corridor is integral to Sydney's Eastern Economic Corridor, which contributed two thirds of the NSW economic growth for the 2015/16 financial year (Greater Sydney Commission, 2018b). As Sydney's population and economy continue to grow, so will the pressure on access to this corridor. The network's vulnerability to congestion and significant delay will worsen with significant congestion incidents likely to become more frequent. Consequently, improvements to existing transport networks and creation of new transport connections will be essential for Sydney to continue to be a competitive global city.

The do nothing alternative has been rejected as an undesirable strategic alternative because it would not address the identified project need. For example, future traffic modelling (refer to Chapter 9 (Operational traffic and transport)) indicates that without the project, this alternative would be unable to accommodate forecast growth during the peak periods without unacceptable delays across the Sydney road network.

The do nothing alternative would adversely impact on:

- Future economy and opportunities for economic growth, particularly with regard to ongoing congestion costs and access to jobs and services
- Amenity and environment, including air quality, noise, visual and traffic related impacts resulting from traffic congestion.

These impacts would result in a reduction in Sydney’s performance and desirability as a global city.

4.3.2 Travel demand management

Travel demand management is a measure that focuses on minimising or avoiding the need to invest in new motorway infrastructure, such as the project, by reducing individual trip lengths, reducing peak traffic volumes and making alternative transport mode options more viable. Demand management initiatives may include:

- Land use planning policies which promote urban consolidation and the establishment of town ‘centres’ to reduce the need for travel. For example, the *NSW Long Term Transport Master Plan* (Transport for NSW, 2012a), *Future Transport Strategy 2056* (NSW Government, 2018) and *Greater Sydney Regional Plan: A Metropolis of Three Cities* (Greater Sydney Commission, 2018a) aim to bring jobs closer to homes and to areas of increasing population
- Augmenting existing public transport and integrating urban regeneration around transport nodes
- Implementing policies which restrict parking provisions in new developments to encourage alternative modes of transport
- Flexible working arrangements to reduce the number of trips during peak hours.

To have a major impact on road traffic, travel demand management measures would require considerable changes in social attitudes, travel behaviour and government policy and can take many years to achieve. Further, Sydney’s population is forecast to grow from six million to eight million people over the next 40 years. An expanded road network would be required to accommodate this population growth, even with significantly reduced per-capita travel demand through demand management. Travel demand management changes alone are therefore not a viable strategic alternative to the project. They are, however, viewed as complementary initiatives, together with the project, to reduce the level of demand on Sydney’s road network as population grows.

4.3.3 Improvements to the existing harbour crossing capacities and road network

To provide additional transport capacity across Sydney Harbour and increase the resilience of the road network in Sydney, improvements to the existing arterial road network, including the Sydney Harbour Bridge and Sydney Harbour Tunnel, have been considered.

Ways to increase road capacity across Sydney Harbour have been considered for many years (refer to Section 4.2). Options to provide additional capacity have included investigations into adding new lanes to the Sydney Harbour Bridge and developing new harbour crossing locations. Increases to road capacity of the Sydney Harbour Bridge have not proved to be feasible due to engineering and physical constraints limiting the additional load carrying capacity of the bridge, and the significant heritage, visual and tourist values of the Sydney Harbour Bridge limiting the feasibility of major modifications to increase capacity.

Improvements to the Sydney Harbour Tunnel to provide additional capacity along this strategic route are also not feasible due to engineering challenges and physical constraints.

Increasing capacity of the existing crossings would also have limited benefit due to the constraints imposed by existing roads on the southern side of the harbour, including the Western Distributor and ANZAC Bridge.

Transport for NSW has an extensive program of upgrades to existing roads across Sydney to address congestion and to improve travel times. Information on these projects can be found on the Transport for NSW website (https://roads-maritime.transport.nsw.gov.au). These projects are considered complementary because they would maximise the capacity of Sydney's existing motorway and arterial road network, but they would not relieve cross-harbour congestion or address the need to upgrade the Warringah Freeway to improve separation of through traffic and bypass functions (refer to Chapter 3 (Strategic context and project need) for additional details on these two functions).

Accordingly, substantial new improvements to the existing cross harbour capacities and road network have been rejected as a strategic alternative. It is not feasible to add additional lanes to the existing Sydney Harbour Bridge or Sydney Harbour Tunnel, and the impacts of substantial capacity increases to either connection are unlikely to be acceptable.

4.3.4 A new motorway crossing of Sydney Harbour

Options for new road crossings of Sydney Harbour have been considered for many decades. These have included concepts for new bridges and tunnels at several locations along the harbour. Since the release of the *NSW Long Term Transport Master Plan* (Transport for NSW, 2012) and *State Infrastructure Strategy Update 2014* (Infrastructure NSW, 2014), investigations into alternative harbour motorway crossings have focused on tunnelled solutions to provide a western CBD bypass of the Sydney CBD.

A new tunnelled motorway west of the CBD would address the project need of providing additional transport capacity across Sydney Harbour to relieve congestion and improve reliability on existing crossings. Importantly, it would:

- Increase road capacity on the critical north–south harbour crossing by 50 per cent, providing journey time and reliability benefits to users of the new route, as well as users of the existing crossings
- Provide an alternative western bypass of the CBD, reducing pressure on the heavily congested ANZAC Bridge and Western Distributor corridor
- Improve performance, reliability and resilience of the adjoining arterial road network, which is heavily affecting performance of the existing harbour crossings
- Improve travel times between key centres for all road users, including a significant number of bus users, service vehicles and freight
- Re-establish road hierarchy for the harbour crossings (refer to Chapter 3 (Strategic context and project need) for additional information on the three crossings strategy).

4.3.5 Improvements to alternative transport modes

Alternative transport modes to the project, and their effectiveness in meeting the project need, are described in the following sections.

The NSW Government, through Transport for NSW, is currently planning and delivering a series of new and upgraded transport projects and initiatives, consistent with the *Future Transport Strategy 2056* (NSW Government, 2018). The key public transport projects in the Greater Sydney area are shown in Figure 4-3.

Information on these projects can be found on the Transport for NSW website (transport.nsw.gov.au/projects/current-projects).

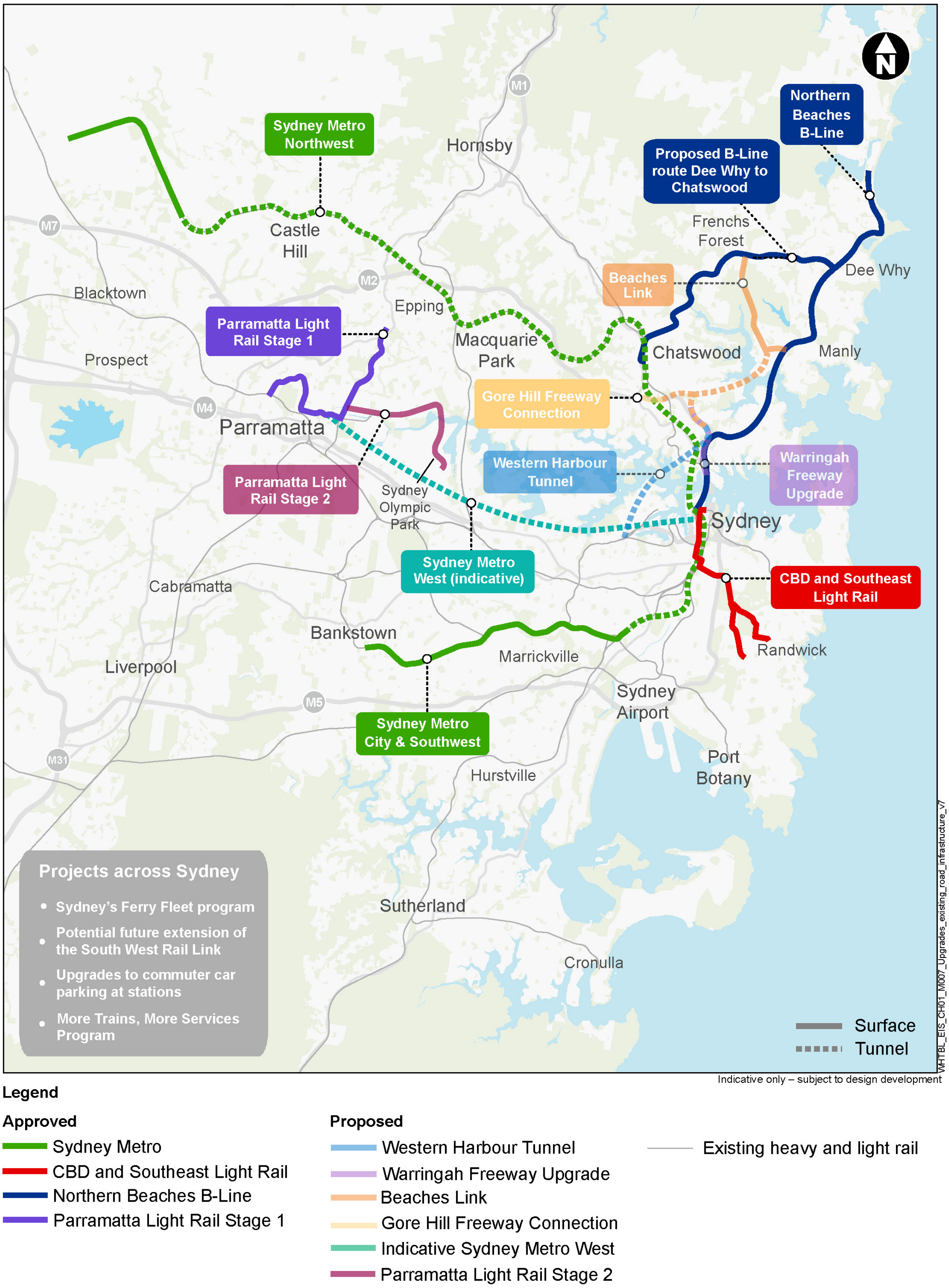


Figure 4-3 Improvements to public transport

Improvements to the Sydney bus network

Improvements to the Sydney bus network as a strategic alternative to the project include additional bus routes, additional buses on existing routes and bus priority measures.

Buses play a crucial role in Sydney's public transport system. They can be put into service more quickly, cheaply and to more places than any other type of public transport. Sydney's bus network currently includes more than 600 routes. For more than 90 per cent of residents within Sydney, local bus routes are within 400 metres of home and offer connections to neighbourhood shops and services, major centres and the wider public transport system. Figure 4-4 illustrates the number of bus passengers that rely on the Sydney CBD arterial road network in the AM peak.

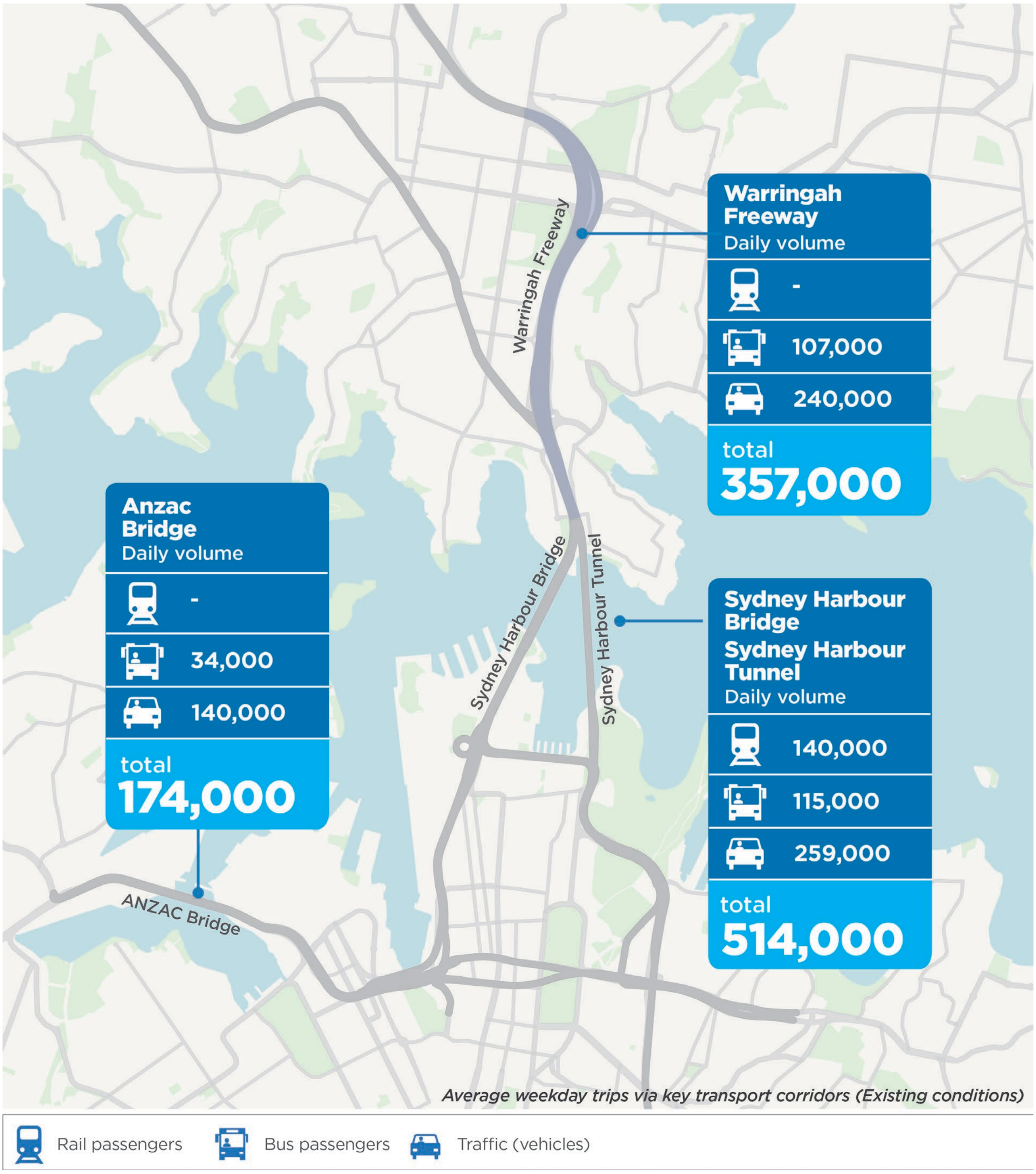


Figure 4-4 Average weekday trips via key transport corridors (existing conditions)

Sydney's Bus Future (Transport for NSW, 2013b) acknowledges that improvements to the bus network are essential to meet changing customer needs, including access to major centres outside the Sydney CBD. *Sydney's Bus Future* aims for seamless connection to other transport modes to deliver the right mix of services. In response to changing passenger needs and an increase in demand, additional services have already been added to the bus network. However, without measures to improve journey times by increasing the road efficiency or capacity, the addition of more buses to the network can contribute to congestion, making bus services less effective at meeting customer needs.

Sydney's Bus Future proposes major changes to the Sydney bus network to meet current and future demands by providing rapid service routes to connect major centres along transport routes with mass transit demand. Suburban and local service routes would build on the foundation of the rapid routes to improve access to local, neighbourhood destinations. Bus initiatives relevant to the project include the B-Line for the Northern Beaches (which commenced operation in 2017).

Despite the importance of the bus network in Sydney's transport future and the complementary nature of the aforementioned projects, improved bus services alone would not be sufficient to provide the level of additional cross-harbour capacity that is required. This is in part due to the wide range of purposes and destinations associated with cross harbour trips and the limited ability for buses to cater for these. The ability for the bus network to provide extra capacity is also strictly limited by the capacity of the road network itself.

Improvements to the rail network

The effect of proposed improvements to the Sydney rail network have been considered as strategic alternatives to the project. Rail initiatives relevant to the project include the Sydney Metro City & Southwest project; a 30 kilometre extension of metro rail from the end of Sydney Metro Northwest at Chatswood, under the Sydney Harbour, through new CBD stations and south west to Bankstown, which is currently under construction.

Sydney Harbour crossing capacity is a major transport constraint for all modes. The Sydney Metro City & Southwest project will deliver much needed cross harbour capacity for commuters, connect new nodes, and deliver faster and more reliable train journeys to and from the north-west of Sydney. Whilst this project will contribute to reducing congestion on the existing cross-harbour road connections it is only one part of an integrated transport network that is required to service the needs of a very diverse range of origins, destinations and journey purposes.

The array of journey patterns and trip purposes within Sydney, and the dispersed nature of origin and destination points for an individual journey mean that roads remain a critical element in the integrated transport network, servicing buses, freight, commercial and many other individual journey needs. Strategic transport modelling completed by Transport for NSW indicates that there will still be need for additional road transport capacity at the crossing of Sydney Harbour to cater for future demands post Sydney Metro City & Southwest.

Improvements to the freight rail network would assist with the efficient distribution of freight, particularly for freight travelling longer distances. However, a significant proportion of Sydney's freight, commercial, and services tasks require distribution of goods and services to customers within the Sydney basin. This requires a diverse and dispersed point-to-point transport system that is most efficiently provided by the road network.

Improvements to the ferry network

Additional ferry services were considered as a strategic alternative to the project. Additional ferry services would provide an improved cross-harbour public transportation link and would contribute to relieving congestion on existing cross-harbour road connections. While this would contribute to reducing congestion on the existing road network, it would not resolve the existing cross-harbour road congestion and capacity constraints. This is due to comparatively small number of journeys currently using these crossings that would be transferable to the ferry network.

Improvements to active transport

Improvements to active transport that could be considered as strategic alternatives to the project included additional cycling and pedestrian routes and facilities as identified in *Sydney's Cycling Future* (Transport for NSW, 2013c) and *Sydney's Walking Future* (Transport for NSW, 2013d).

Sydney's Cycling Future aims to make cycling a safe, convenient and enjoyable transport option for short trips by:

- Investing in separated cycleways and providing connected bicycle networks to major centres and transport interchanges
- Promoting better use of the existing network
- Engaging with stakeholders across government, councils, developers and bicycle users.

The strategy aims to increase the mode share of cycling in the Sydney metropolitan area for short trips that can be an easy 20 to 30 minute ride. The strategy aims to improve access to towns and centres, reduce congestion and increase capacity on the public transport system by investing in connected bike routes within five kilometres of major centres and public transport interchanges. The strategy commits to expanding bike route connectivity within 10 kilometres of major centres in the longer term. The 'Bike and Ride' initiative would make it convenient for customers to ride to transport hubs, leave their bikes securely locked up and transfer to public transport to continue their journey.

Sydney's Walking Future complements *Sydney's Cycling Future*. The actions set out in *Sydney's Walking Future* propose to make walking the transport choice for quick trips under two kilometres and help people access public transport. Encouraging and enabling more people to make walking trips would ease pressure on public transport, reduce congestion on roads and promote a healthier transport alternative.

As outlined in *Sydney's Cycling Future* and *Sydney's Walking Future*, journeys made by cycling and walking are generally for short trips only, which would not meet the project need of improving cross-harbour capacity or resilience. Improvements to cyclist and pedestrian infrastructure alone would not cater for the diverse travel demands within the project footprint that are best met by road infrastructure. Further improvements to cyclist and pedestrian infrastructure alone would not support long-term economic growth through improved motorway access or enhance the productivity of commercial and freight generating land uses. The active transport network is therefore complementary to other modes of transport as part of an integrated transport solution.

As part of an overarching integrated transport network, the project includes the development of new or improved active transport links in a number of locations, generally associated with surface works for the project. These links would improve connectivity between communities, open space areas, public transport modes and the existing active transport network. This is described in further detail in Chapter 5 (Project description) and Chapter 9 (Operational traffic and transport).

Summary

As outlined in the previous sections, alternative transport modes, including bus, rail, ferry and active transport, could be considered as strategic alternatives to the project. While many of these modes and upgrades are complementary to the project as part of a broader integrated transport network, none of the proposed initiatives negate the need to provide additional cross-harbour motorway capacity.

The array of journey patterns and trip purposes within Sydney, and the dispersed nature of origin and destination points for an individual journey mean that roads remain a critical element in the integrated transport network, servicing bus, freight, commercial and many other journey needs.

While improvements to the freight rail network would reduce pressure on the core motorway network, Sydney's freight, commercial and services tasks require distribution of goods and services within the Sydney basin, which relies on diverse and dispersed point-to-point transport network that is most efficiently provided by the road network. Providing high-quality motorway links to meet this need is key to growing Sydney's economic prosperity while reducing surface traffic through communities.

Extending the underground motorway network to address capacity, efficiency and reliability issues on critical road corridors would not only provide faster, more efficient and more reliable journeys for users who would use this network, but would also deliver much broader benefits through reduced congestion on existing surface networks.

The project would materially improve the functionality and performance of the bus network, in particular the reliability and optionality for both long distance and inner North Shore services, and efficiency of the Warringah Freeway and Sydney Harbour Bridge southbound bus lane, which services about 57,500 bus commuters each week.

The project would improve active transport links through the provision of a new dedicated bicycle path along the eastern side of the Warringah Freeway between Miller Street at Cammeray and Ernest Street, as well as a number of new and upgraded shared user bridges which would provide connectivity across the Warringah Freeway.

4.3.6 Preferred strategic alternative

When considering the strategic alternatives and complementary projects discussed in previous sections, it was concluded that the construction and operation of a new tunnelled motorway crossing of Sydney Harbour (the project) was the preferred solution. This would provide additional transport capacity across Sydney Harbour to relieve congestion on existing crossings and improve the efficiency and reliability for all non-rail journeys across Sydney Harbour.

The project is part of a suite of current and future transport initiatives outlined in *Future Transport 2056* that would work together to provide the cross-harbour transport capacity required to cater for a diverse array of journeys and future population growth. Further, as discussed in Chapter 3 (Strategic context and project need), a new harbour crossing would also provide capacity to deliver new strategic connections to the north, including new express bus routes, to be developed.

4.4 Corridor alternatives

Following identification of a new motorway tunnel as the preferred strategic alternative, a design development process was carried out to determine the most appropriate alignment and construction method to deliver the tunnel. The process for selection of the preferred tunnel alignment and construction method included consideration of 10 strategic corridors and over 15 different combinations of tunnelling methods.

Options were developed and assessed by a multidisciplinary team including design engineers, construction engineers, transport planners and environmental advisors with direct experience in delivering major transport infrastructure in NSW, Australia and internationally. Selection of the preferred corridor required consideration of various technical and environmental factors including:

- Strategic traffic demands and how they define the required connectivity to achieve transport outcomes
- Results of geotechnical, groundwater and contamination investigations
- Basements and foundations of major structures in North Sydney
- Marine heritage, biodiversity and marine ecology
- Turbidity and hydrodynamic monitoring and modelling for Sydney Harbour
- Opportunities for viable temporary intermediate tunnelling sites that minimise community, environmental and heritage impacts
- Physical and operational interfaces with other major infrastructure (eg Sydney Metro Tunnels, Rozelle Interchange, the Warringah Freeway)
- Integration with the proposed Beaches Link and Gore Hill Freeway Connection project in the future
- Horizontal alignments and waterway crossing methodologies that allow the tunnel to achieve acceptable vertical gradients to achieve the desired transport product, reduce whole of life emissions, operational costs, and improve safety outcomes
- Interfaces with commercial and recreational maritime traffic
- Construction and operational costs.

4.4.1 Description of shortlisted corridor alternatives

Following preliminary technical and environmental analysis, four corridor alternatives were shortlisted for a new tunnelled motorway connection between Rozelle and the northern side of Sydney Harbour (refer to Figure 4-5). The shortlisted corridor alternatives were termed the brown, red, orange and blue alternatives.

Brown corridor alternative

The brown corridor alternative included a crossing of Sydney Harbour between Rozelle and North Ryde, broadly under the Victoria Road and Gladesville Bridge corridor. The tunnel would provide connection to the M2 Hills Motorway/Lane Cove Tunnel corridor around East Ryde and would bypass the Lane Cove Tunnel and Warringah Freeway.

When compared to options that connect to the Warringah Freeway, this option would:

- Slightly reduce traffic volumes on the Lane Cove Tunnel, Gore Hill Freeway and a portion of the Warringah Freeway through to Cammeray
- Result in poorer traffic outcomes on the existing harbour crossings, ANZAC Bridge and Western Distributor corridor. This is because the connectivity provided would not be attractive for the high number of users with origins and destinations east of the Lane Cove Tunnel, including areas such as Chatswood, Lane Cove, North Sydney and the Northern Beaches catchment. This reduces the usage, and hence benefits, of the new tunnel
- Require construction of 50 per cent more tunnel, increasing the number of intermediate construction support sites, heavy haulage trips, construction cost and operational cost
- Expose the tunnel alignment to poor geology due to increased harbour and river crossings, increasing construction complexity and cost and requirements for intermediate construction support sites.

Red corridor alternative

The red corridor alternative included tunnels between the Rozelle Interchange and the Warringah Freeway near Cammeray, crossing Sydney Harbour between Balmain East and McMahons Point via Goat Island.

The alignment would include main tunnel connections to the Warringah Freeway and underground connections to the future Beaches Link and Gore Hill Freeway Connection project tunnels at Cammeray. Ramps would connect the Western Harbour Tunnel to North Sydney at Arthur Street (for vehicles travelling northbound via Western Harbour Tunnel) and from North Sydney at Berry Street (for vehicles travelling southbound via the Western Harbour Tunnel).

The alignment of this option, combined with the poor geology at the harbour crossing, force the main tunnels to pass under the Sydney Metro City & Southwest tunnels beneath North Sydney. Given the depth of the Metro tunnels, the Western Harbour Tunnel would need to adopt long spiral ramps to provide the required connectivity at North Sydney.

These ramps would significantly degrade the user experience, increasing the distance that users must travel via the tunnel to reach their destination, reducing speed, and impacting wayfinding. These long loop ramps would also significantly increase the amount of tunnelling, and hence heavy haulage trips, construction costs and operational costs for the Western Harbour Tunnel.

Furthermore, the red alignment would require temporary construction support sites at Goat Island and Sawmillers Reserve. The use of these two sites would be particularly challenging given their limited size combined with access and heritage constraints.

Orange corridor alternative

The orange corridor alternative was similar to the red corridor alternative at the Sydney Harbour crossing, with the key difference being the main tunnel connection was moved further to the north to connect to the Gore Hill Freeway near Naremburn rather than the Warringah Freeway at Cammeray. The intent of this alignment would be to extend the Western Harbour Tunnel to bypass the constrained section of the Gore Hill Freeway and Warringah Freeway through Naremburn.

Topography and constraints such as the Artarmon Reserve, the T1 North Shore and Northern rail line, flooding and existing traffic operations make connecting the Western Harbour Tunnel to the Gore Hill Freeway near Artarmon very challenging. This would result in significantly increased disruption, cost and property impacts.

Further to the challenges of integrating this alignment with the existing network, extending the Western Harbour Tunnel through to the Gore Hill Freeway would significantly increase tunnel lengths and costs. Providing the required connectivity for the future Beaches Link and Gore Hill Freeway Connection project would also be significantly more difficult and costly.

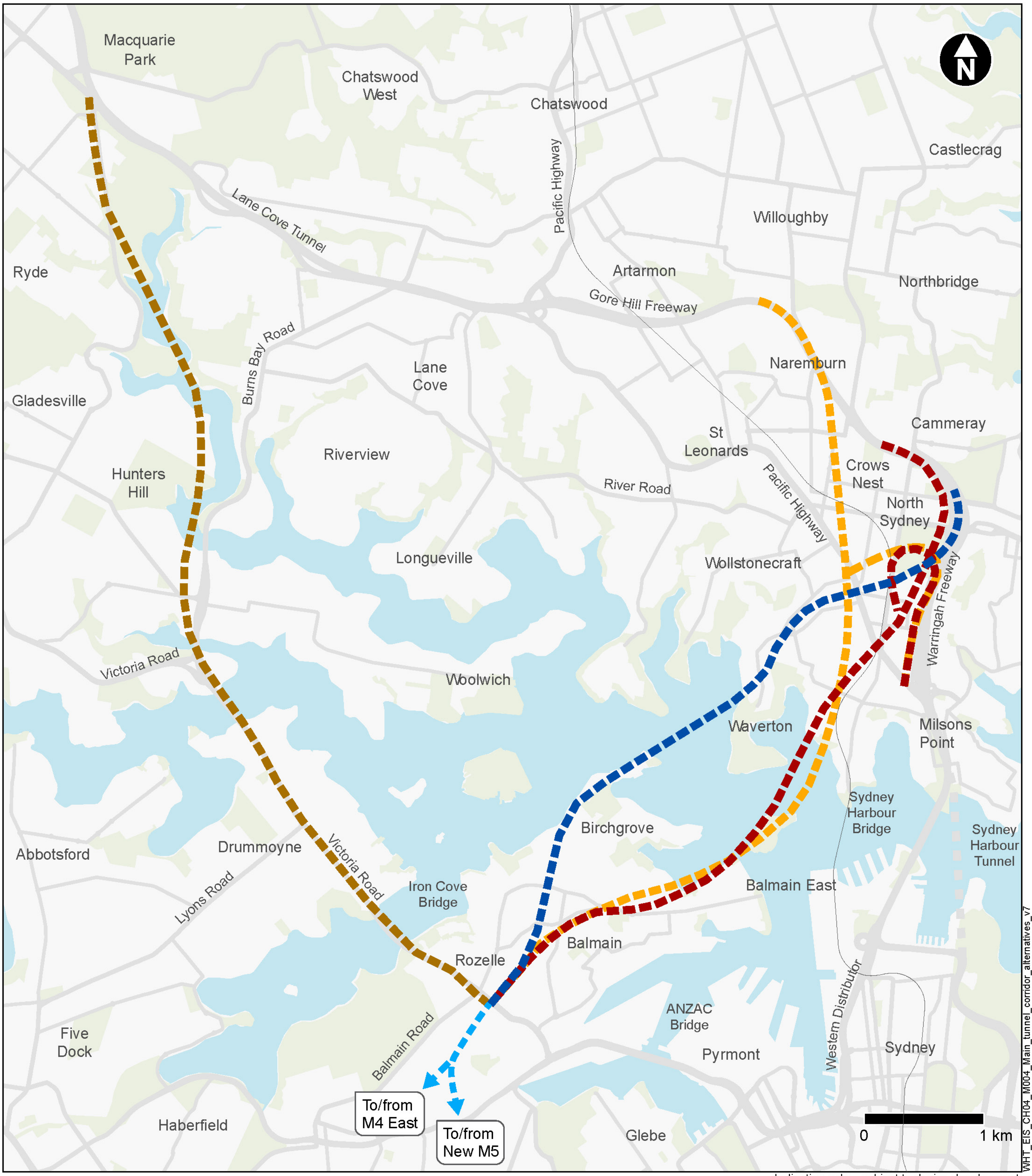
Blue corridor alternative

The blue corridor alternative included a tunnel connection across Sydney Harbour between Birchgrove and Waverton. The mainline tunnels would connect directly to the Warringah Freeway near the Cammeray Golf Course and the Beaches Link and Gore Hill Freeway Connection project (via underground ramps). Ramps would also connect the Western Harbour Tunnel with North Sydney at Falcon Street (northbound Western Harbour Tunnel traffic) and Berry Street (southbound Western Harbour Tunnel traffic).

This alignment would take advantage of a relatively shallow harbour crossing combined with the favourable geometry offered by the Waverton Peninsula and an alignment passing north-west of the major structures in the North Sydney CBD to allow the proposed tunnels to pass over the Sydney Metro City & Southwest tunnels north of the Victoria Cross station. This would in turn allow efficient direct connections to the Warringah Freeway near Cammeray and for the connections to and from North Sydney and the future Beaches Link and Gore Hill Freeway Connection project tunnels.

Widening at the Cammeray Golf Course would allow for construction of the Western Harbour Tunnel portals with minimal impacts to property and reduced disruption to the critical Warringah Freeway corridor.

This alignment would also result in the shortest harbour crossing, reducing exposure to poor geology, and presents the opportunity to establish viable construction support sites on Government-owned land, significantly reducing property impacts, and creating the opportunity to enhance the amenity of these spaces post construction.



Indicative only – subject to design development

Legend

- Western Harbour Tunnel Blue corridor alternative
- Western Harbour Tunnel Brown corridor alternative
- Western Harbour Tunnel Orange corridor alternative
- Western Harbour Tunnel Red corridor alternative
- WestConnex M4-M5 Link (indicative)
- Sydney Metro

Figure 4-5 Main corridor alternatives

4.4.2 Evaluation of corridor alternatives

The four shortlisted corridor alternatives were evaluated to identify the solution that best balanced technical, social and environmental outcomes while meeting the transport objectives. The evaluation criteria used were an expansion of the project objectives with the addition of design and constructability criteria to reflect the more detailed comparison required (Figure 4-6).

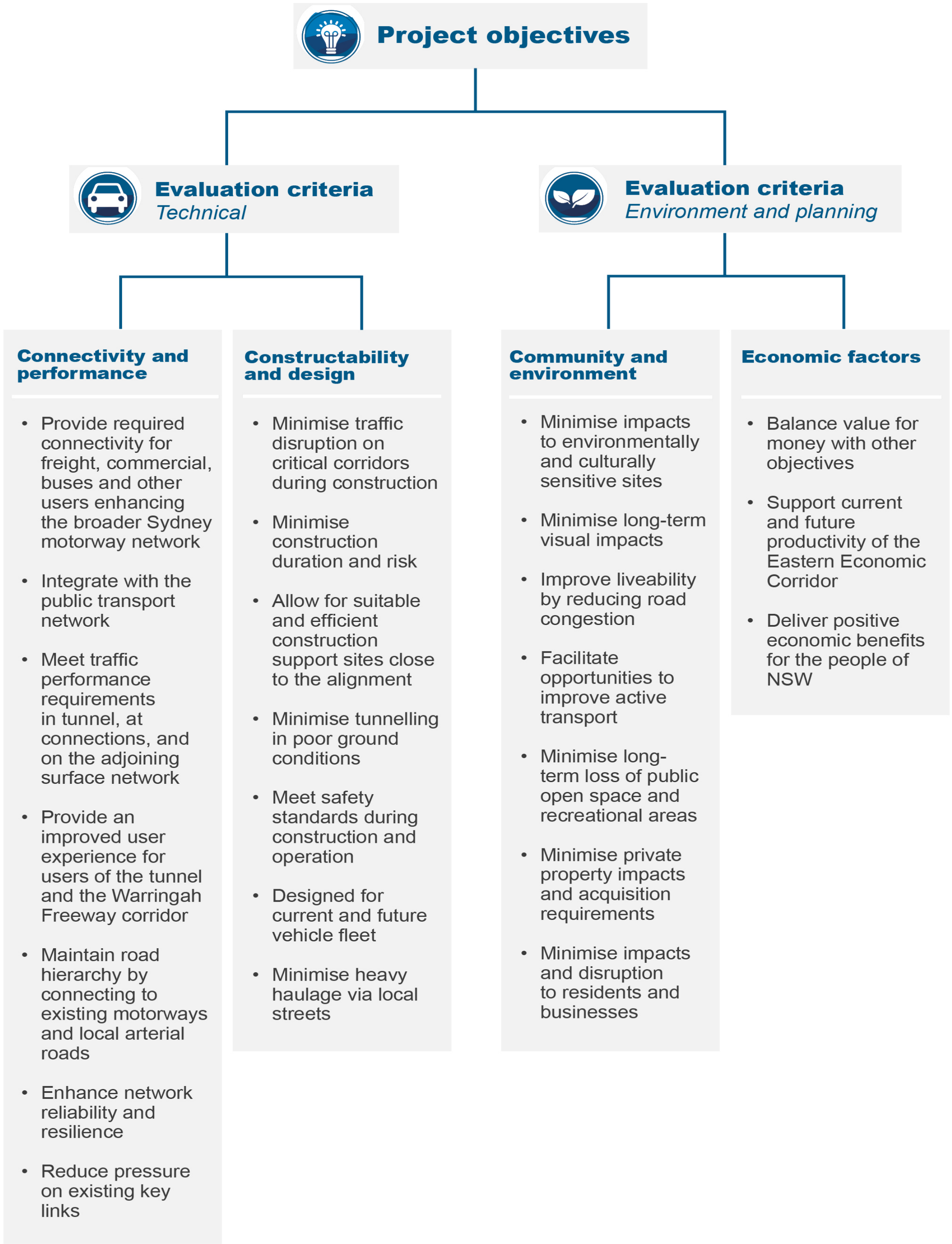


Figure 4-6 Evaluation criteria for corridor alternatives

A summary of the key strengths and weaknesses of each alignment with respect to the evaluation criteria, are shown in Figure 4-7 to Figure 4-10.

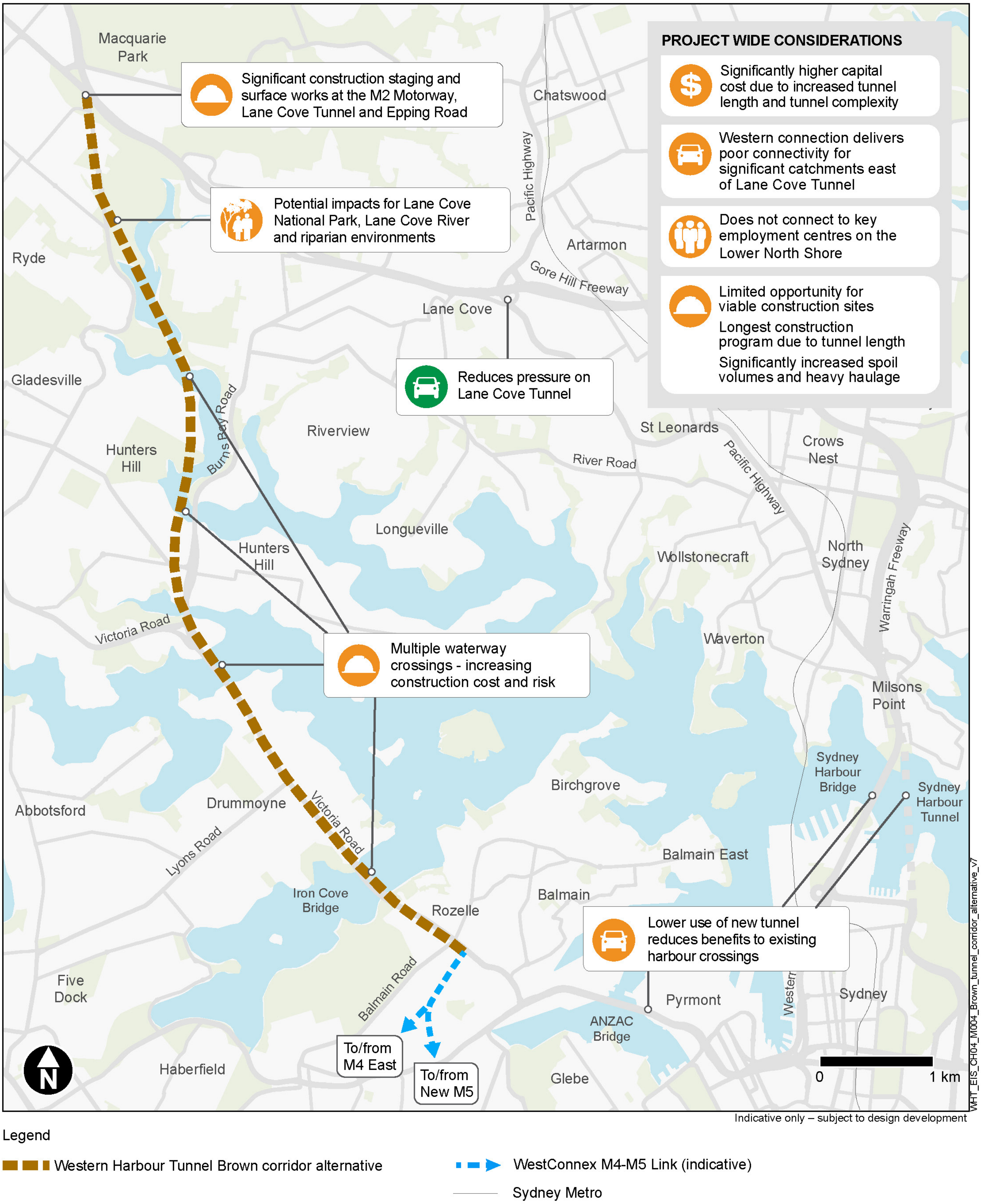
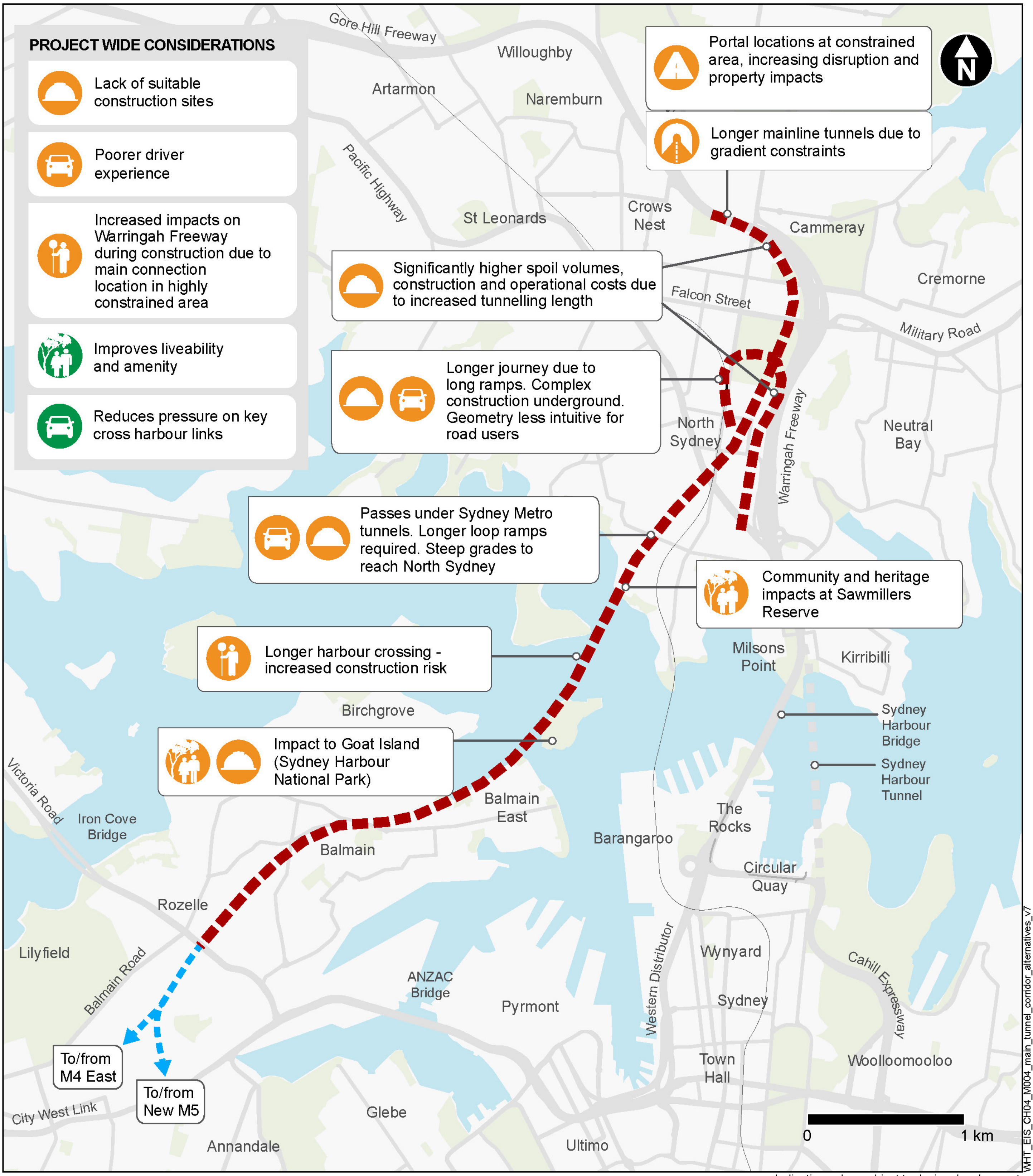


Figure 4-7 Brown corridor alternative



Indicative only – subject to design development

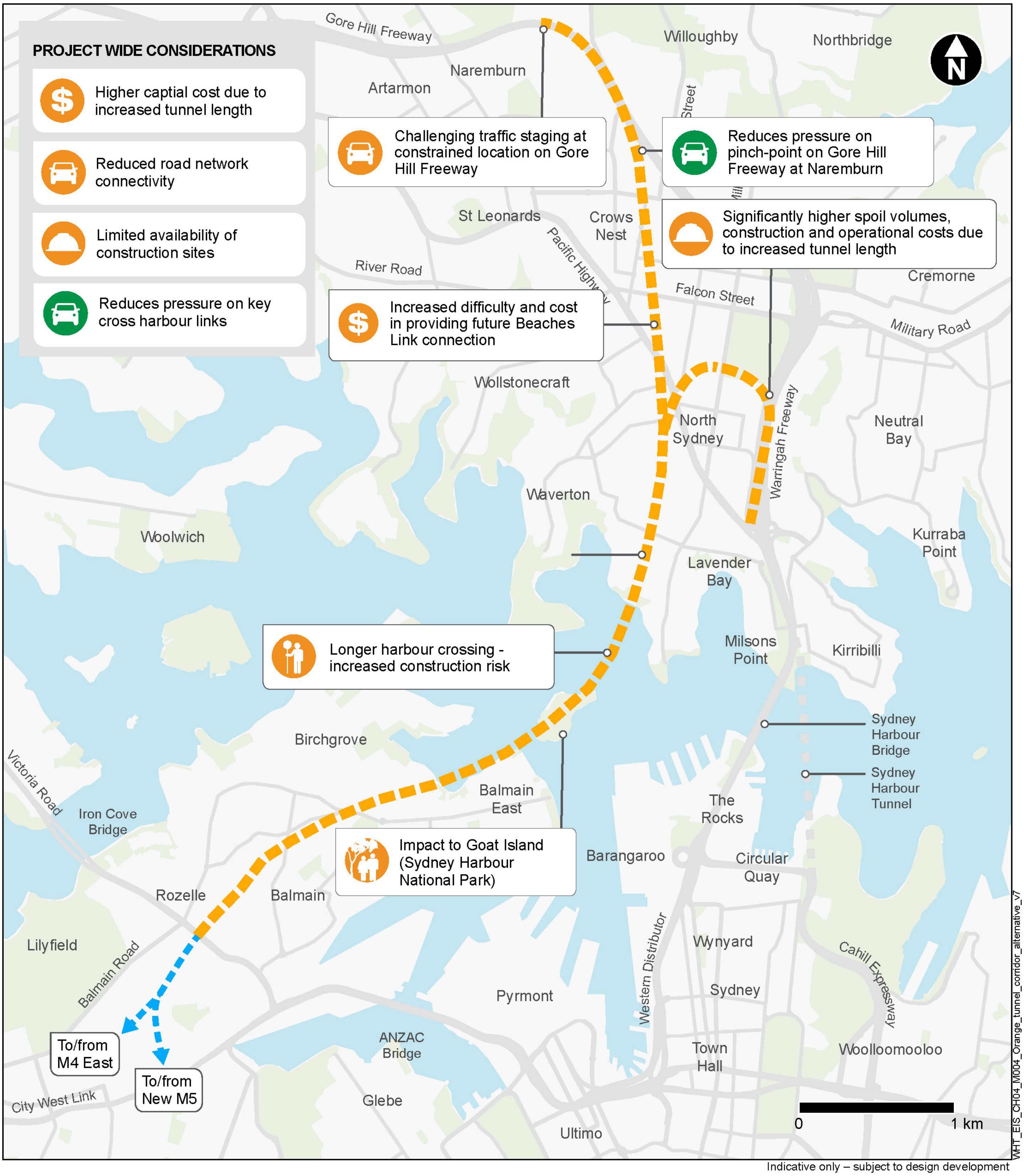
Legend

Western Harbour Tunnel red corridor alternative

WestConnex M4-M5 Link (indicative)

Sydney Metro

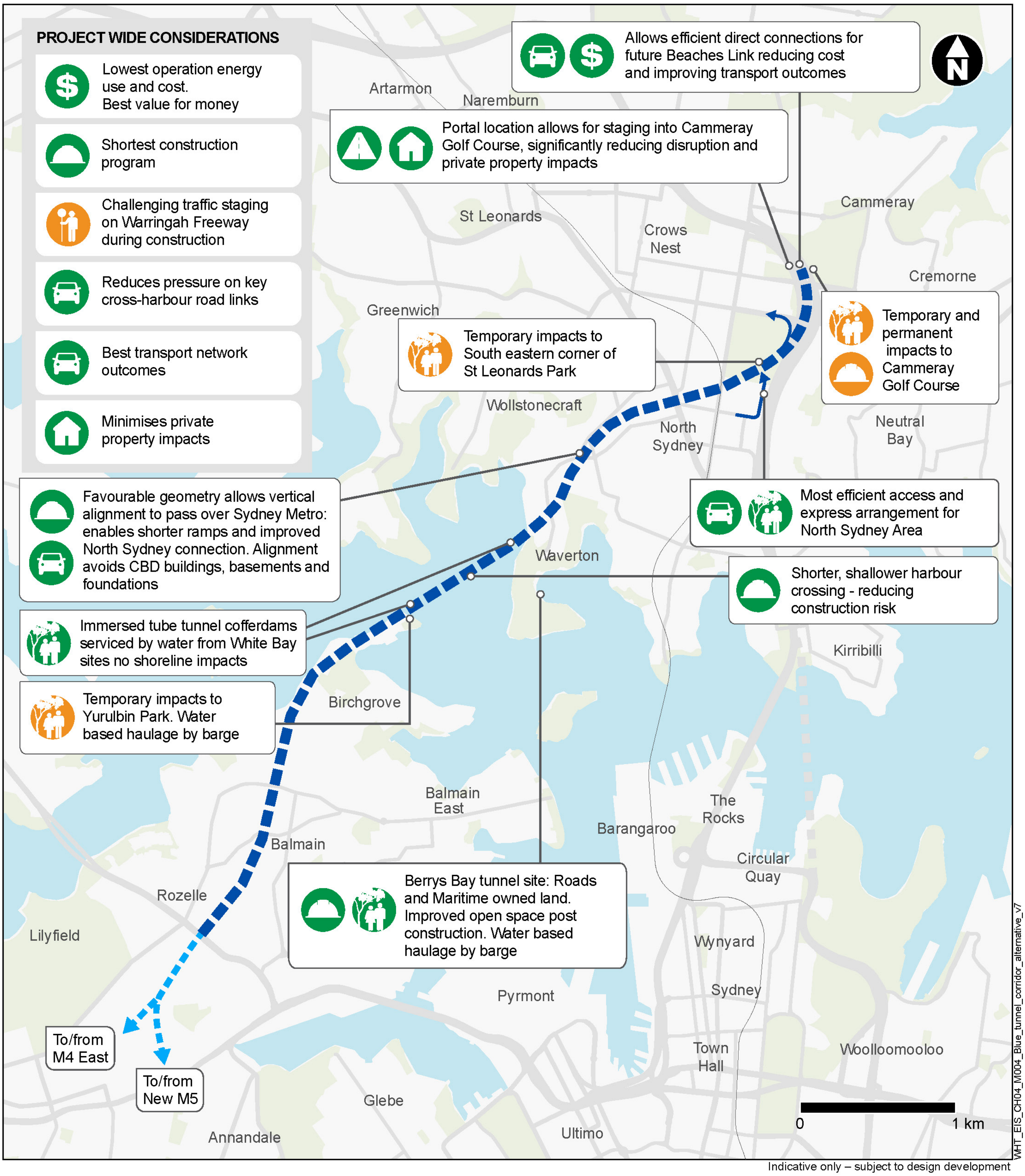
Figure 4-8 Red corridor alternative



Legend

- Western Harbour Tunnel orange corridor alternative
- WestConnex M4-M5 Link (indicative)
- Sydney Metro

Figure 4-9 Orange corridor alternative



Legend

Western Harbour Tunnel Brown corridor alternative

WestConnex M4-M5 Link (indicative)

Sydney Metro

Figure 4-10 Blue corridor alternative

4.4.3 Preferred corridor

On the basis of its superior performance relative to other alternatives, the blue corridor alternative was identified as the preferred corridor to be carried forward for further design development (refer to Section 4.5).

Key advantages of the blue corridor alternative include:

- Improved experience, safety and efficiency for users:
  - The blue corridor alternative would enable the mainline tunnels to pass over the Sydney Metro tunnels at North Sydney, removing the requirement for two kilometre long loop ramps as per the red and orange corridor alternatives
  - The blue corridor alternative would enable shorter, more direct and more legible connectivity between the Western Harbour Tunnel and North Sydney, providing long-term benefits for users
  - The blue corridor alternative would provide a 4.5 per cent maximum gradient (compared to the six per cent maximum gradient for the red alternative), which is a result of removing the need to pass under the Sydney Metro tunnels at North Sydney. This would also improve the driver experience and support more efficient traffic movements and reduced emissions generation over time
- Viable construction support sites on Government-owned land:
  - The blue corridor provides the opportunity to establish temporary construction support sites suitable for delivery of the infrastructure. This improves the efficiency of construction, reducing cost and duration of construction impacts
- Shortest harbour crossing:
  - Significantly reducing exposure to poor geology, reducing construction risk, cost and program duration
- Reduced community and environmental impacts during construction:
  - The blue corridor reduces impacts on environmentally sensitive areas including Goat Island (Sydney Harbour National Park), the Lane Cove National Park, and Artarmon Reserve
  - The ability to establish viable construction support sites on Government-owned land improves efficiency, reduces construction duration, and significantly reduces the number of private properties directly impacted by the project
  - The construction support sites identified along the blue corridor allow for direct arterial road access or viable marine access, minimising heavy haulage trips through local communities
  - The blue corridor minimises the amount of tunnelling required to deliver the requisite transport product, significantly reducing the raw materials, heavy haulage trips and energy required to construct and operate the infrastructure
  - Temporary construction support site at Berrys Bay presents the opportunity for remediation of this site and subsequent use as a public space with improved amenity
  - Widening at the Cammeray Golf Course minimises impacts on the large number of users of the Warringah Freeway corridor during construction, and also minimises direct property impacts and construction duration.

4.5 Further project development

Following identification of the blue corridor alternative as the preferred corridor for the project, further detailed project development work has been carried out, including:

- Community and stakeholder engagement to identify key local issues to be taken into account in the development of the project (refer to Chapter 7 (Stakeholder and community engagement))
- Detailed environmental and other site investigations along the corridor, including desktop and field investigations to identify key environmental issues
- Design development and value engineering to ensure benefits are realised, while reducing costs, program, constructability risks and community and environmental impacts where possible. This process also included consideration of community and stakeholder feedback and the outcomes of environmental and other site investigations.

This project development work included detailed consideration of the following, with further detail on these key issues provided in Sections 4.5.1 to 4.5.7:

- Tunnelling methods, both land-based and the preferred harbour crossing methods
- Location and configuration of the North Sydney connections
- Ventilation alternatives, including the ventilation system design and outlet locations
- Construction support site locations, layouts and alternatives
- Spoil transport, reuse and disposal alternatives.

Other factors considered during design development included:

- Detailed construction staging within the Warringah Freeway corridor to minimise disruption and optimising the corridor for future operations
- Construction staging and work methodologies to reduce impacts on surrounding communities and the environment
- Integration with and enhancements to the existing public transport infrastructure, particularly along the Warringah Freeway corridor
- Opportunities to integrate with and enhance walking and cycling routes
- Utilities impacts and relocation requirements
- Minimising interfaces with heritage items.

The development and evaluation of detailed components of the preferred corridor included consideration of options against a localised set of criteria that was consistent with the project objectives. These included connectivity, transport network performance, constructability, design, community, environmental, and economic criteria specific to the scope item and area being considered.

4.5.1 Tunnelling method alternatives

The methods used to deliver tunnels at different locations around the world varies significantly, primarily in response to the geology encountered and the cross section that is required along the alignment. Roadheader, tunnel boring machines, immersed tube tunnels, cut and cover tunnels, and the drill and blast methods are all used to deliver tunnels in different conditions around the world.

The process for selection of the preferred tunnel alignment and tunnel construction method for the project included the development and evaluation of over 15 different combinations of tunnelling methods.

These options were developed and assessed by a multidisciplinary team of design, constructability, and environmental specialists with direct experience in delivering major tunnels in international, Australian and NSW contexts.

The assessment considered various technical and environmental factors including:

- Strategic traffic demands and how they define the required connectivity to achieve transport outcomes
- Results of geotechnical and groundwater investigations
- Marine heritage, biodiversity and marine ecology surveys
- Contamination testing
- Turbidity and hydrodynamic monitoring and modelling
- Opportunities for viable temporary intermediate tunnelling sites that minimise impacts on sensitive vegetation, heritage sites, private property, local communities and the functionality of public open space
- Implications for physical and operational interfaces with other major infrastructure (for example Sydney Metro & Southwest tunnels, M4-M5 Link tunnels, the Beaches Link and Gore Hill Freeway Connection project and building foundations in North Sydney and along the Warringah Freeway)
- Horizontal alignments and waterway crossing methods that allow the tunnel to achieve acceptable vertical gradients to achieve the desired transport product, reduce whole of life emissions, operational costs, and improve safety outcomes
- Consultation with commercial and recreational maritime stakeholders
- Market engagement, including technical engagement with 14 construction contractors
- Construction and operational costs.

Given the major change in geology beneath Sydney Harbour, the following sections discuss the methodologies for the harbour crossing and the tunnels north and south of Sydney Harbour separately.

Tunnelling south and north of Sydney Harbour

Favourable tunnelling conditions are expected north and south of Sydney Harbour, with the majority of the tunnel alignment expected to be constructed in high-quality Hawkesbury Sandstone. This has led to the consideration of roadheader and tunnel boring machine construction methods for these segments. Examples of roadheaders and tunnel boring machines are shown in Figure 4-11.

Roadheaders are made up of rotating cutting heads mounted on a boom or similar structure. They are typically used where the rock being tunnelled through is very sound without being too hard. In these conditions roadheaders can be used to cut away the rock to form a tailored cross-section to match the exact cross-sectional area of the tunnel.

When using the roadheader method, multiple roadheaders are typically deployed via intermediate construction support sites along the alignment. This allows the tunnel to be constructed from multiple fronts, typically providing significantly reduced construction durations when compared to tunnelling from a single site.

The roadheader tunnelling method has been the preferred construction technique for all major motorway tunnels in Sydney, with the exception being the existing Sydney Harbour Tunnel, which was delivered using the immersed tube tunnel technique. The favourable Hawkesbury

Sandstone geology combined with the requirement for a wide but short cross-section are the key variables that have combined to make roadheader the most efficient and cost effective method for delivering motorway tunnels in Sydney.

Tunnel boring machines are significantly larger than roadheaders, and use a circular rotating cutting head that houses many individual cutting tools. Due to the circular cutting head, tunnel boring machines excavate and produce a circular tunnel cross-sectional area.

To allow for tunnelling in many different types of geology, there are many different types of tunnel boring machines. With no one type of machine ideally suited to tunnelling through both rock and soft ground major changes in geology, soft sediments, such as sediments found beneath Sydney Harbour, would require a different type of tunnel boring machine to the landside tunnels being constructed through Hawkesbury Sandstone.

This is best demonstrated by the construction method adopted for construction of the new Sydney Metro crossing of Sydney Harbour, where the poor geology under Sydney Harbour requires a different type of tunnel boring machine to the landside tunnels. Accordingly, the Sydney Metro project is using five tunnel boring machines – two north and two south of the harbour to complete tunnelling through rock, with one specialised machine for the crossing of Sydney Harbour. This requires the establishment of large shafts at Barangaroo and Blues Point to change tunnel boring machines for the harbour crossing.

Figure 4-11 Examples of a roadheader (left) and tunnel boring machine (right)

The indicative cross-sections of the Western Harbour Tunnel if roadheaders or tunnel boring machines are used are shown in Figure 4-12. This diagram demonstrates that the cross-section required for a modern motorway does not fit efficiently within the circular cross-section provided by a tunnel boring machine, resulting in significantly increased excavation and backfill requirements.

Options to build multi-level roadways within the one cross-section were also considered (for example two lanes above two lanes), but these would require even larger machine diameters.

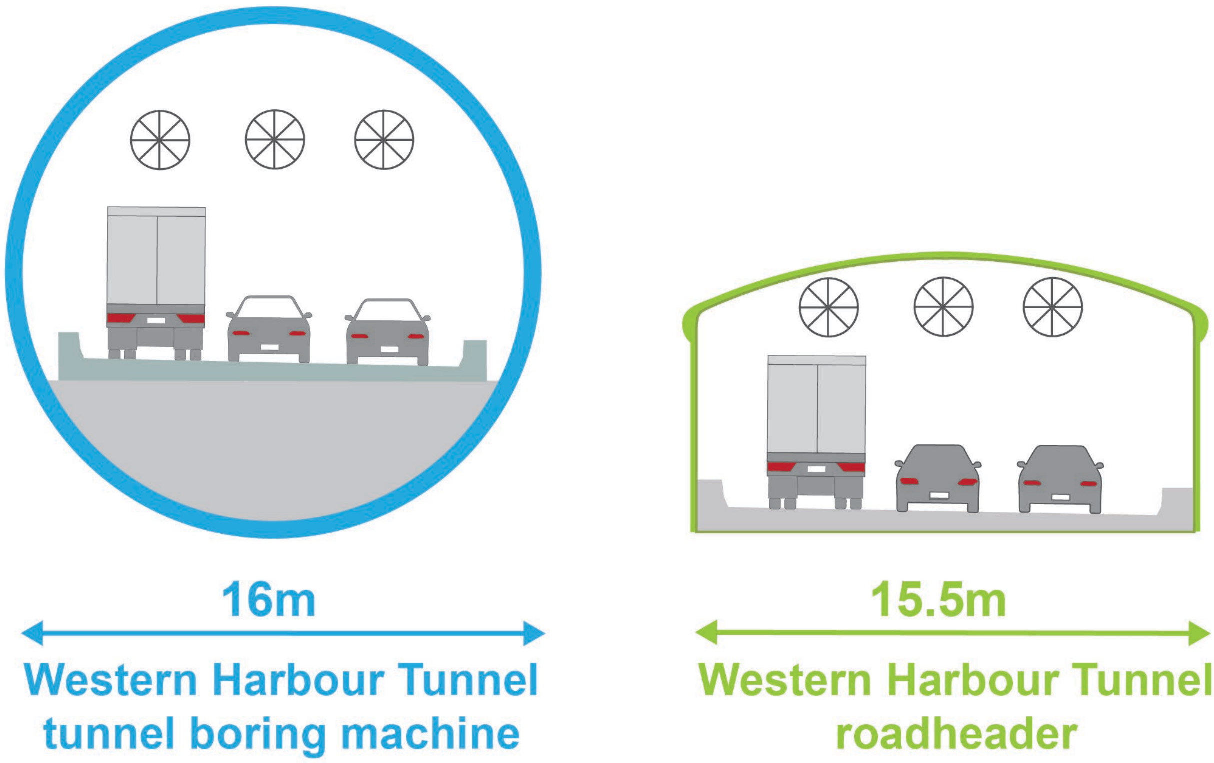


Figure 4-12 Comparison of tunnel cross-sections using a tunnel boring machine and a roadheader

A comparative evaluation of alternative tunnelling methods for tunnelling north and south of Sydney Harbour is summarised in Table 4-2.

Table 4-2 Alternative tunnelling methods

Method	Summary of evaluation
Roadheader (preferred method)	**Advantages:** • The technology required is well understood and has been proven to be most cost-effective for motorways in Sydney's geological conditions • All major road tunnels in Sydney to date have been built successfully by roadheader • Reduced construction risk relative to using a tunnel boring machine for a three lane road tunnel (further details below) • Ability to cut an exact cross-section reduces infrastructure or fill required within the tunnel to achieve desired road level • Significantly lower spoil volumes and heavy vehicle movements relative to using a tunnel boring machine • Machines are relatively inexpensive and readily available in the Sydney market • Roadheaders can generally be deployed much faster than tunnel boring machines, due to shorter procurement, establishment and commissioning times • Large trained workforce in Sydney, following recent major road tunnel projects. **Disadvantages:** • Tunnelling rate of roadheaders is less than tunnel boring machines when both reach peak production • Depending on the length of tunnel, roadheaders may require intermediate surface construction and access sites.

Method	Summary of evaluation
Tunnel boring machine	**Advantages:** • If the geology and cross-section are consistent, tunnel boring machines can usually construct much longer tunnels with fewer intermediate surface access points • Provides for faster excavation rates than roadheaders when the machine is ideally matched to the project geology and changes in cross-section along the tunnel are minimised • Provides safer tunnelling conditions in poor ground conditions when compared to roadheaders. **Disadvantages:** • Require larger tunnelling and access sites than roadheaders • Tunnel boring machines are significantly more expensive to procure and operate than roadheaders • The timeframe for procuring, commissioning and launching tunnel boring machines would be significantly longer than for roadheaders • A three lane motorway cross-section would require tunnel boring machines about 16 metres in diameter. These would be within the top five largest globally. Given that mega diameter machines are uncommon, machines of such size are likely to pose significantly more construction risk than a roadheader solution • Being a circular excavation, tunnel boring machines require significant over-excavation compared to roadheader construction. This results in significantly increased spoil volumes for the rock tunnelling and associated heavy vehicle hauling or barging and disposal, as well as a need to backfill within the tunnel to build the road level back up • Tunnel boring machines require long stretches of tunnel to outperform roadheaders on a cost and production basis. The maximum drive length for the Western Harbour Tunnel would be three kilometres; therefore, there would be minimal efficiencies from using tunnel boring machines • Roadheaders and intermediate sites would still be required to excavate interchanges and ramp connections ahead of tunnel boring machine arrival, as tunnel boring machines cannot accommodate these changes in cross-section • Major intermediate sites would be required at the northern and southern shorelines of Sydney Harbour to change machines if the project was to select tunnel boring machines that are matched to geology.

Sydney Harbour crossing

While the majority of the tunnelling for the project is expected to be constructed through high quality Hawkesbury Sandstone, the portion of tunnel crossing the Sydney Harbour presents particular challenges. These include:

- **Significant changes in elevation:** The project starts in Rozelle, at about three metres above the harbour water level, then travelling up to about 90 metres at the connections to North Sydney. In between, Sydney Harbour has a trench in the bedrock running along the northern side, with rock present at about 45 metres below the harbour bed level. This creates about a 145 metre elevation difference between rock level at the harbour and the surface level at North Sydney. Considering the elevation change between the rock level under the harbour and North Sydney it becomes apparent that there is significant pressure on the vertical grade of the proposed tunnel – with gradient having implications for long-term operations of the tunnel (safety and emissions)

- **Sydney Metro City & Southwest tunnels:** Adding to the challenge for the project are the new Sydney Metro tunnels. The project would need to be tunnelled either above or below the Sydney Metro City & Southwest tunnels at North Sydney (which are at a depth of more than 50 metres)
  - If the project were to tunnel under the Sydney Metro City & Southwest tunnels, connectivity at North Sydney would require steep, long, circular access ramps with adverse outcomes for traffic performance, emission generation, and project cost
  - If the project were to tunnel over the Sydney Metro City & Southwest tunnels, the ramps would become simple directional ramps, but with the increased challenge of achieving acceptable vertical grades under this design
- **Poor geology and rock fracturing at harbour crossings:** Geotechnical testing has been conducted for the proposed harbour crossing. At the northern side of the harbour, the top of the Hawkesbury Sandstone bedrock is approximately 45 metres below the harbour surface. Unlike the bedrock either side of the harbour, this rock is generally highly fractured. This fracture zone is likely to cause significant water ingress issues during construction using a mined or bored method as seen during the construction of the Northside Storage Tunnel and Greenwich to Woolwich Cable Tunnel. Above this fractured rock are layers ranging from stiff clay through to sand and sediment. Depending on the vertical alignment of the tunnels, they may need to be constructed through rock, through sediment, or a combination of these. Generally tunnelling through sediment is undesirable as it is prone to instability. However, high-quality Hawkesbury Sandstone is very deep beneath the harbour, giving rise to the need to balance between the preference to tunnel through rock and the gradient of the tunnels – with the gradient of the tunnels affecting traffic performance, emission generation, ventilation design, and long-term operational costs for the tunnel
- **Limited intermediate sites:** For most of its alignment, the proposed Western Harbour Tunnel would pass beneath harbourside suburbs like Balmain and Waverton, which are characterised by highly urbanised areas with very narrow streets. This presents as a significant challenge to the establishment of viable intermediate tunnelling sites as these would likely require acquisition of a significant number of private properties and/or unacceptable haulage routes via narrow streets. This is a particular challenge when considering the scale of sites required to support large diameter slurry shield or tunnel boring machines for the harbour crossing
- **Cross-section:** The cross-section required for a modern three lane motorway crossing of Sydney Harbour is about 16 metres wide. Given the poor geology (refer to Figure 4-13), this creates a significant challenge for tunnel boring machines or roadheader solutions. If using a tunnel boring machine, this would require one of the largest machines of its type ever used in the world – significantly increasing construction cost and risk.

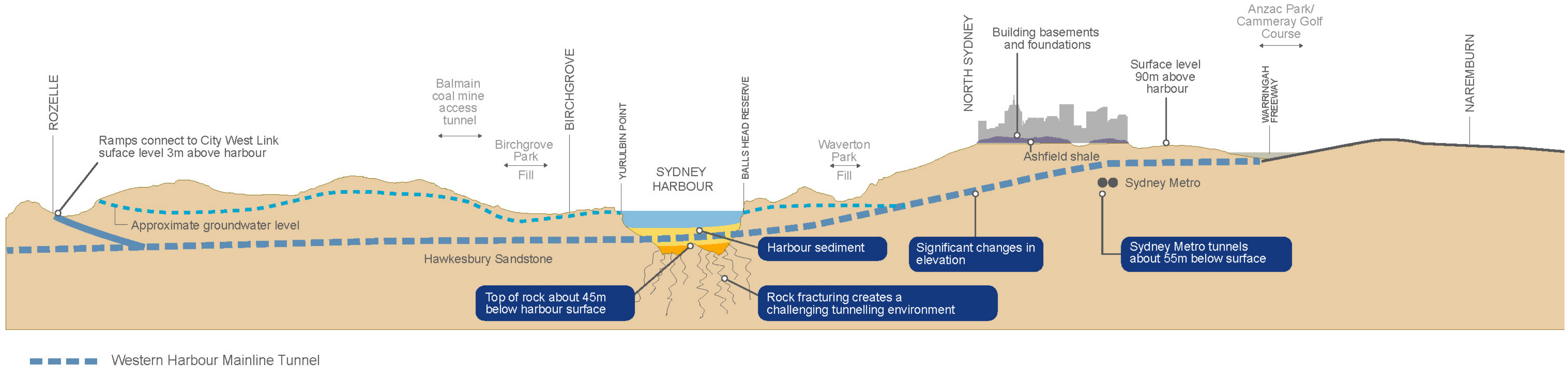


Figure 4-13 Indicative vertical alignment of the mainline tunnels

Design development for the project included a significant focus on evaluation of potential tunnelling methods for the crossing of Sydney Harbour. This analysis was carried out by a multidisciplinary team including design, construction, transport planning, and environmental specialists to ensure a comprehensive analysis. It included the consideration of the roadheader method, specialised slurry shield tunnel boring machines, and an immersed tube tunnel (similar to the existing Sydney Harbour Tunnel).

Roadheader options were discounted early in the process for the following reasons.

- The tunnel depth required to deliver this method beneath the harbour would significantly compromise the gradients of the mainline tunnel impacting the transport product, emissions generation, construction and operational cost
- The highly fractured geology beneath Sydney Harbour, which creates a risk of significant water ingress during construction if using the roadheader method.

Although tunnel boring machines are a viable alternative, the diameter and type of machines required for the crossing of Sydney Harbour cannot be considered a conventional solution. Depending on the depth of the alignment, the tunnel boring machines required to cross Sydney Harbour would need to be very large diameter slurry shield machines, as shown in Figure 4-14.

Slurry shield tunnel boring machines use clay slurry and compressed air to carefully control the pressure at the tunnelling face. This is required to maintain stability ahead of construction of the permanent concrete lining when tunnelling poor ground conditions, such as those expected beneath Sydney Harbour. The pressure at the face needs to be carefully controlled as the machine advances to respond to the ground conditions as they vary.

These are highly sophisticated and specialised machines, and have rarely been used for sub-sea tunnelling at the diameter that would be required for this project. These machines also require significant landside sites to accommodate:

- Segment production and storage
- Clay slurry production and processing
- High voltage power supply.

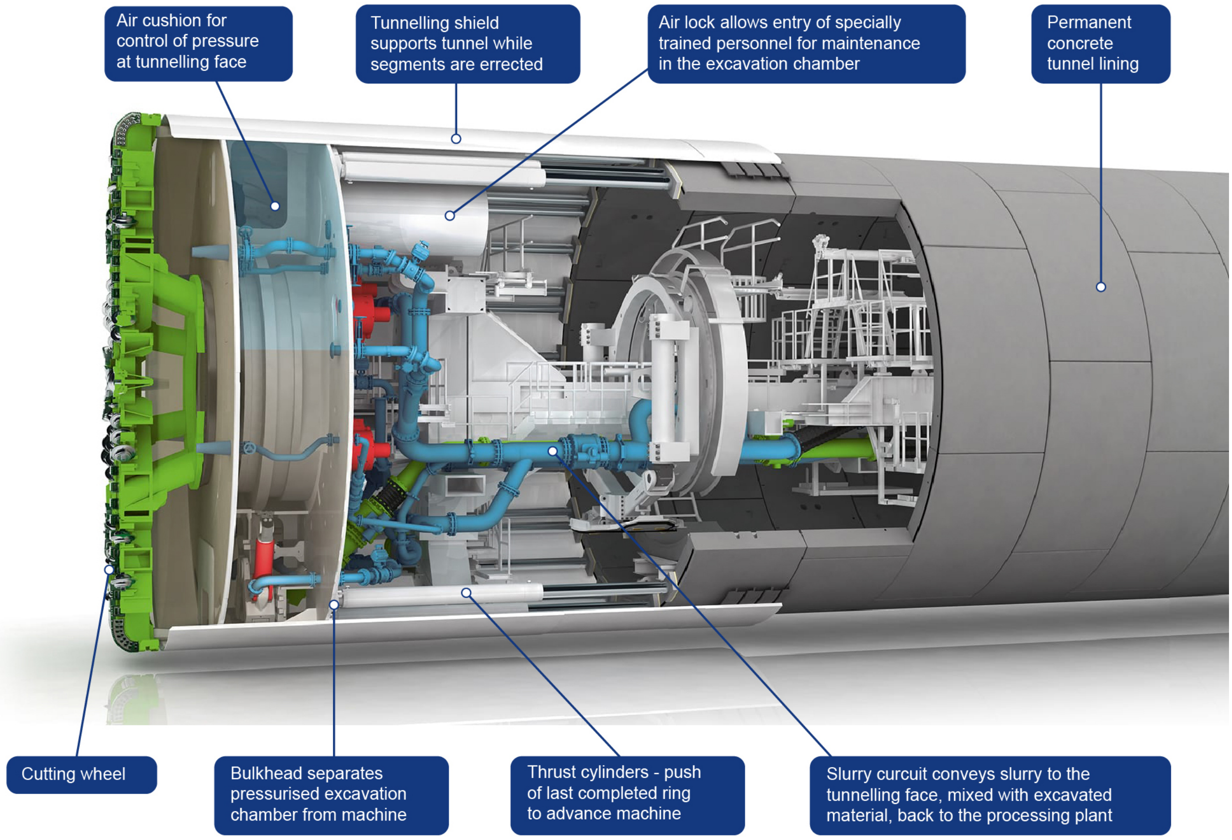


Figure 4-14 Example of a slurry shield tunnel boring machine

An alternative to tunnelling through rock or sediment using roadheaders or tunnel boring machines would be to place precast tunnel units on top, or within, the top layers of harbour rock and sediments. This method is known as an immersed tube tunnel and has been applied to over 150 major road and rail tunnels around the world to overcome similar combinations of geology, topography and cross-sectional challenges, including the existing Sydney Harbour Tunnel.

This alternative would involve excavation of the bed of the harbour and placement of immersed tube tunnel units within the excavated trench as shown in Figure 4-15.

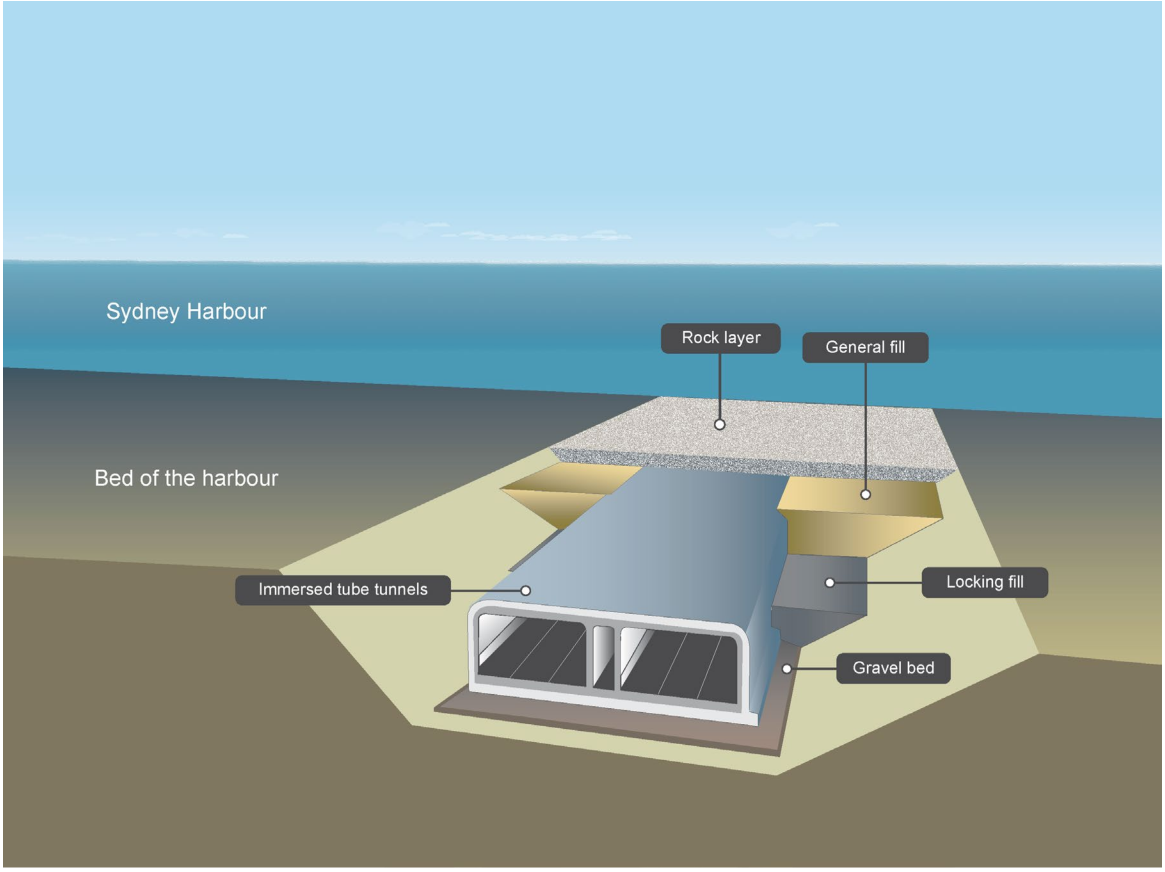


Figure 4-15 Example of an immersed tube tunnel

Figure 4-16 shows the four main options for the vertical alignment of the Sydney Harbour tunnels:

- A deep driven roadheader tunnel, completely within rock (grey)
- A shallower bored tunnel boring machine tunnel, with parts of the tunnel in softer, weathered rock or sediment (red and purple)
- An immersed tube tunnel lying on top, or within the top layers, of softer, weathered rock and sediments (green).

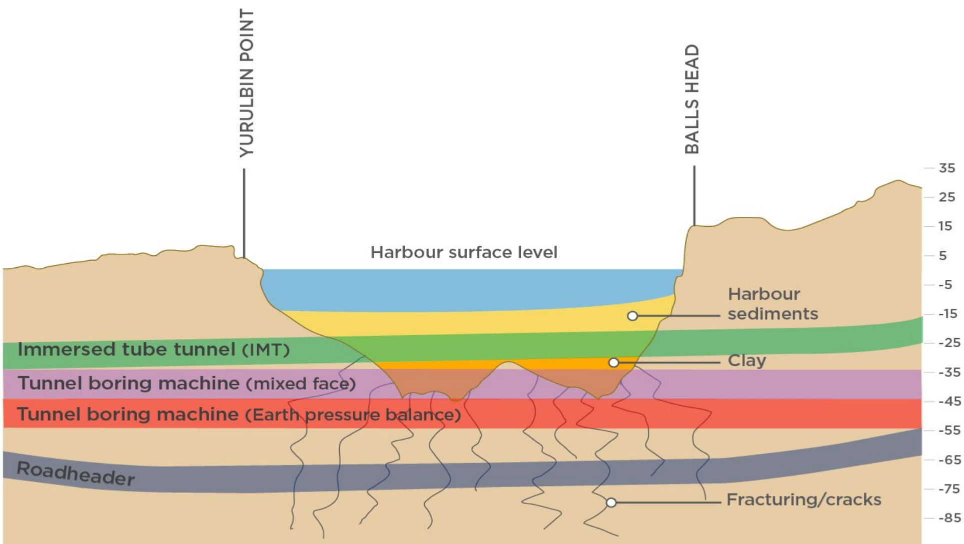


Figure 4-16 Main vertical alignment options for the harbour tunnels

When considering the performance of each of the potential methodologies against design, constructability, traffic performance, environmental and social criteria, the preferred method for crossing Sydney Harbour is via an immersed tube tunnel. The justification for selecting this alternative is summarised in Table 4-3.

Table 4-3 Preferred tunnelling method for the Sydney Harbour crossing

Preferred method	Summary of evaluation
Immersed tube tunnel	**Advantages:** • The technology required is proven, having been used on major contemporary infrastructure projects around the world, including the Sydney Harbour Tunnel • Provides the shallowest possible tunnel alignment at the Sydney Harbour crossing, enabling the best possible gradient and associated performance outcomes (eg safety, vehicle speeds, journey experience, long-term emissions) • Minimises tunnelling risks by reducing exposure to tunnelling through poor geology and reducing the time workers need to spend in high risk tunnelling environments • Lower construction and operational costs when compared to alternate methodologies • Minimises the size of waterside sites when compared to those required to launch large diameter tunnel boring machines • Significantly reduces haulage on land when compared to tunnel boring machine solutions • Takes advantage of marine logistics to minimise heavy haulage on roads • The preferred alignment avoids interfaces with sensitive marine ecology. **Disadvantages:** • Requires measures to be implemented to prevent migration of material during excavation of sediments, particularly areas with elevated levels of contaminants on the bed of Sydney Harbour • Interfaces with commercial and recreational maritime traffic during construction.

4.5.2 North Sydney connection alternatives

Connections to and from the North Sydney area that would link the North Sydney CBD and surrounding areas to the Western Harbour Tunnel service an important catchment area. Accordingly, these links were identified as critical connections for the project. The following key objectives were considered in the development of options for this connection:

- To service key origins and destinations around the North Sydney area, including the North Sydney CBD, Crows Nest and Waverton
- To ensure resilience of the North Sydney area transport network, including the ability to respond to changes to normal operating conditions
- To balance demands across established road corridors to avoid concentrating impacts in one area and diminishing network resilience and reliability
- To ensure the proposed connections integrate with the local arterial network, using established state road corridors where possible
- To provide accessibility of the ramps for the range of transport users including public transport, service vehicles, freight and private vehicles

- To minimise impacts on private property and public open space.

There were a number of challenges associated with the provision of a connection for the North Sydney area. The key challenges included high demands for traffic coming to/from North Sydney and the Crows Nest area, topography issues, and the limited number of parallel/alternate routes available in the area with connectivity to the motorway network.

Over 20 alternative arrangements have been considered for the Western Harbour Tunnel connections to and from the North Sydney area. Of the alternatives considered, three were shortlisted for further consideration, as shown in Figure 4-17:

- Connections to and from Pacific Highway (orange)
- Off ramp connecting to Arthur Street and an on ramp connecting from Berry Street (red)
- Off ramp connecting to Falcon Street and an on ramp connecting from Berry Street (blue).

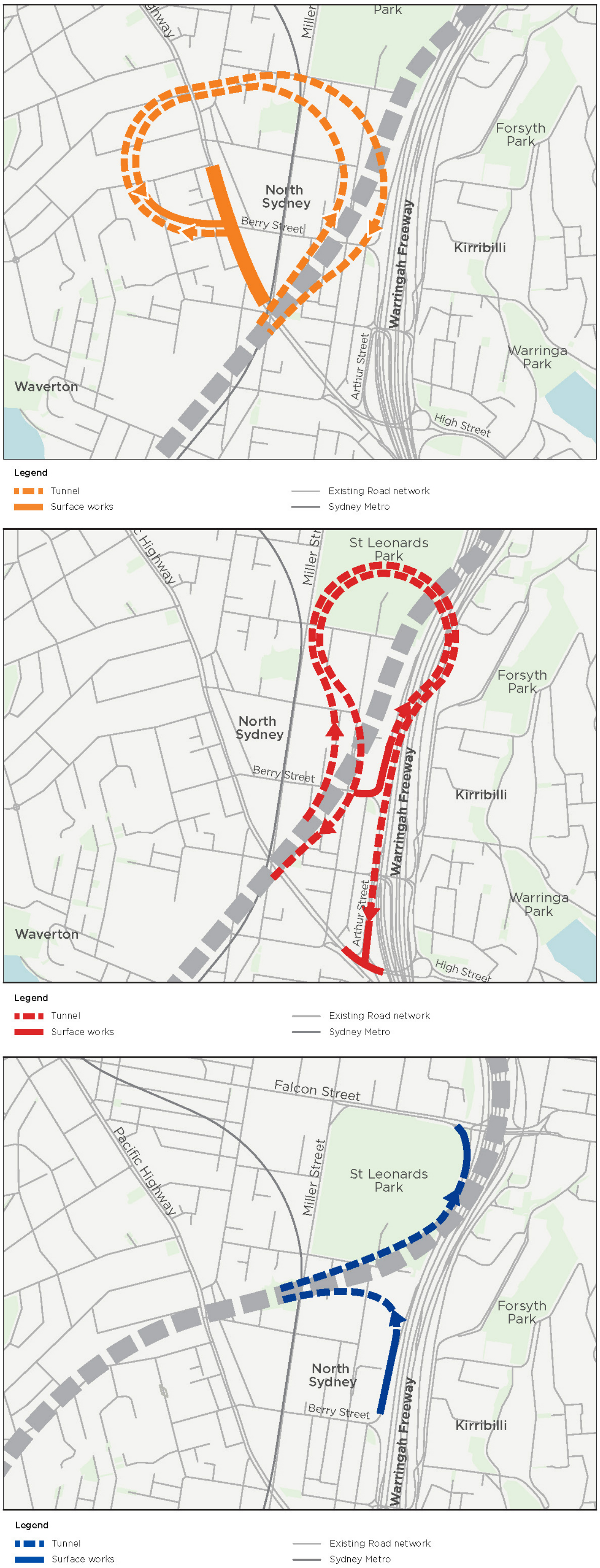


Figure 4-17 Connection alternatives at North Sydney

The preferred connection alternative for the North Sydney area includes an off ramp connecting to Falcon Street and an on ramp connecting from the existing Berry Street on ramp to the Warringah Freeway (Figure 4-17 (blue alternative)). These ramps would provide high-quality connectivity for the North Sydney area to accommodate current and future demands. Both ramps would connect to existing State Road corridors, which would result in good network performance outcomes and reduce impacts on local streets.

This option has minimal impacts on private property. Some impacts would occur to the south-eastern corner of St Leonards Park in the sloping area between the bowling greens and Warringah Freeway. However, this area is required during construction only, and would be reinstated following completion of the project.

This option also includes a new northbound ramp to the Warringah Freeway at High Street. This would enable better distribution of traffic across the North Sydney arterial network, with the primary northbound access to the Warringah Freeway and Gore Hill Freeway moved from the Berry Street ramp to the new High Street ramp. Berry Street would service a reduced number of destinations and would no longer provide access to Falcon Street or through to the Gore Hill Freeway.

An overview of the justification for selecting this alternative is summarised in Table 4-4.

Table 4-4 Summary of evaluation of North Sydney connection alternatives

Evaluation criteria	Reason for preferred alternative
Connectivity and network performance	• Provides the connectivity required to service key origins and destinations in the North Sydney area • Connectivity between North Sydney, surrounding areas and the Western Harbour Tunnel would be provided via existing State Road corridors (ie Berry Street and Falcon Street), which would provide appropriate capacity while minimising impacts on local streets • A new northbound on ramp to the Warringah Freeway from High Street would help to distribute trips across the existing surface arterial network, improving reliability and avoiding concentrating traffic flows into one area • Enables future connectivity for the Beaches Link and provides opportunities for integration of associated bus services with the Sydney Metro.
Constructability and design	• Both the Falcon Street off ramp and the Berry Street on ramp take advantage of local topography, geometry and geology to reduce tunnelling and minimise construction in poor ground conditions • Ramps would be located adjacent to the Warringah Freeway corridor, minimising impacts on operation of the freeway during project construction and enabling simpler integration • Suitable construction support sites are available on Government-owned land with direct arterial road access.
Community and environment	• The ramps are located on the western edge of the Warringah Freeway, avoiding major construction within the North Sydney CBD and minimising private property and business impacts • While there would be some impacts on St Leonards Park in the south-eastern corner between the bowling greens and the Warringah Freeway, the impacts would be temporary during construction. The construction support site would avoid significant vegetation and heritage items. Rehabilitation and landscaping works would also be undertaken following construction • Connections to existing State Road corridors would minimise impacts

Evaluation criteria	Reason for preferred alternative
	on local streets • Construction support site configurations minimise heavy haulage on local streets • No residential property acquisitions would be required for the construction of this connection option.
Economic factors	• Provides the required transport connectivity, which would improve the efficiency of freight, service vehicles, public transport and private trips • Significantly improves capacity, reliability and resilience of connectivity between the North Sydney area and other key business centres • Avoids major construction within the North Sydney CBD, minimising business impacts.

4.5.3 Ventilation alternatives

Ventilation system design

Tunnel ventilation systems must continuously, reliably and efficiently provide a safe environment for tunnel users and communities surrounding the infrastructure. The basic objectives of the tunnel ventilation systems are to:

- Maintain in-tunnel air quality
- Avoid portal emissions
- Manage smoke during fire incidents.

Most tunnels in NSW are unidirectional, meaning that traffic travels in one direction only within the tunnel. Usually two tunnels are constructed side by side (for example, the Lane Cove Tunnel), or one on top of the other (for example, the Eastern Distributor), to enable traffic to travel in both directions.

On an open roadway, vehicle emissions are diluted and dispersed by natural surface air flows. However, in a tunnel, mechanical ventilation can be required to ensure that air quality standards are maintained. This is achieved by providing fresh air to, and removing exhaust air from, the tunnel. The requirements for tunnel ventilation are determined by the vehicle emissions in the tunnel and the limits of pollutant levels set by regulatory authorities. Air quality is managed by ensuring that the volume of fresh air coming into the tunnel adequately dilutes emissions.

The movement of vehicles through a tunnel drives air flow, called the ‘piston-effect’, drawing fresh air in through the tunnel entrance, diluting the vehicle exhaust emissions. In short tunnels up to around one kilometre long, air flow resulting from the piston effect of the vehicles may be adequate to manage in-tunnel air quality.

In longer tunnels, the flow of fresh air can be supplemented by ventilation facilities which remove exhaust air and/or supply additional fresh air. The need for these features is dependent on tunnel size and length and the number and mix of vehicles using the tunnel. Fans may also be required when the piston effect is insufficient to maintain adequate air flow, such as during periods of low traffic or congested traffic conditions.

Elevated ventilation outlets are used for longer tunnels in urban areas in Australia to disperse tunnel air at a height that ensures compliance with ambient air quality criteria.

There are four broad types of road tunnel ventilation systems, and each of these was considered for application to the project:

- Natural ventilation
- Longitudinal ventilation
- Transverse ventilation
- Semi-transverse ventilation.

A number of alternatives for design of the ventilation system were considered. The advantages and disadvantages of the various systems are described below and shown in Figure 4-18.

Natural ventilation

Road tunnels with natural ventilation rely on vehicle movements, prevailing winds and differences in air pressure between the tunnel portals to move air through the tunnels without the assistance of mechanical ventilation (for example, through the use of fans). In the case of unidirectional naturally ventilated tunnels, the piston effect generated by traffic using the tunnels also assists in the movement of air. Because naturally ventilated tunnels do not have mechanical ventilation outlets, all air from within the tunnels is emitted via the tunnel portals.

Natural ventilation is only acceptable for use in relatively short tunnels (that is, less than one kilometre). This is because, without the assistance of mechanical ventilation, vehicle emissions can build up within the tunnels leading to unacceptable in-tunnel air quality under some traffic scenarios. Emergency smoke management considerations may also dictate a mechanical solution. Natural ventilation would not achieve acceptable in-tunnel air quality under low vehicle speed conditions or during emergencies and is therefore not a viable ventilation design for the project.

Longitudinal ventilation

The simplest form of ventilation for road tunnels is longitudinal ventilation, in which fresh air is drawn in at the entry portal and passes out through the exit portal with the flow of traffic. For longer tunnels, during normal operating conditions, most air would be forced through the tunnels by the movement of vehicles (the piston effect) and jet fans would be used to assist with the movement of tunnel air, to maintain acceptable in-tunnel air quality. The air pressure inside the exit portals would be maintained below atmospheric pressure to avoid the release of tunnel air from the portals. This air is then exhausted through an elevated ventilation outlet to maximise dispersion. All road tunnels longer than one kilometre built in Australia in the last 20 years have been designed and operated with longitudinal ventilation systems. This includes the NorthConnex, New M4, New M5 and M4-M5 Link tunnels, which are all under construction or complete.

Transverse ventilation

Another way to ensure adequate dilution of emissions is to provide fresh air inlets along the length of the tunnel along one side, with outlets on the opposite side. This system requires two ducts to be constructed along the length of the tunnel: one for the fresh air supply and one for the exhaust air. Transverse ventilation has been used in the past when vehicle emissions produced greater levels of pollutants than they do today. A transverse ventilation system is more expensive to construct because of the additional ducts that need to be excavated for each tunnel. This type of system is less effective than a longitudinal system for controlling smoke in the tunnel in case of a fire. It is also more energy intensive as more power is consumed to manage air flows.

Semi-transverse ventilation

Semi-transverse ventilation combines both longitudinal and transverse ventilation. Fresh air can be supplied through the portals and be continuously exhausted through a duct along the length of the tunnel. Alternatively, fresh air can be supplied through a duct and exhausted through the portals.

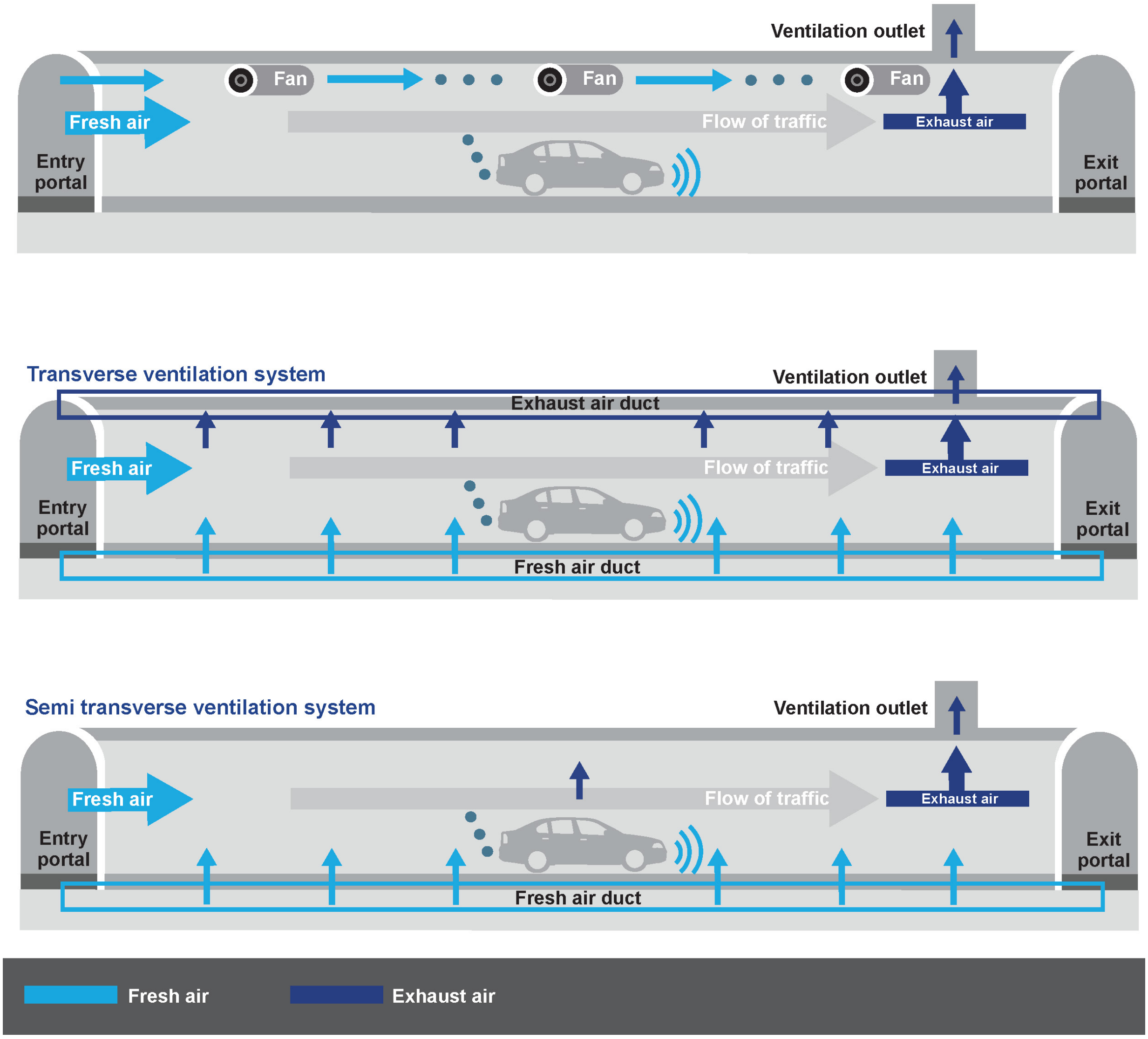


Figure 4-18 Ventilation system design alternatives

Preferred alternative

The development of cleaner vehicles in response to cleaner fuel and emissions standards has led to a significant reduction in vehicle emissions over the past 20 years. Where longitudinal ventilation was once not suitable for long tunnels, due to the need to supply large volumes of fresh air to dilute vehicle emissions, a well-designed longitudinal ventilation system can maintain acceptable air quality in long tunnels and is considered the most efficient and effective tunnel ventilation system (Advisory Committee on Tunnel Air Quality (ACTAQ), 2019).

Although all three mechanical ventilation systems described above could be designed to meet in-tunnel air quality criteria, a longitudinal system with elevated ventilation outlets has been selected as the preferred option for the project for the following reasons:

- It is less costly to construct and operate than transverse systems

- It is able to ensure emissions are dispersed and diluted so that there is minimal or no effect on ambient air quality
- It is considered to be more effective for the management of smoke in the tunnel in the event of a fire
- It is able to meet the requirement to avoid portal emissions.

The effectiveness of elevated ventilation outlets in dispersing emissions is well established. Chapter 12 (Air quality) presents the air quality assessments for both in-tunnel and external air quality. An overview of the ventilation system design and operation is provided in Chapter 5 (Project description).

Consideration of air filtration at the ventilation outlets

Only a small proportion of road tunnels around the world are fitted with air treatment systems. It has been shown that control of pollutants at the source is significantly more effective in improving local and regional air quality (ACTAQ, 2019; NHMRC, 2008a). Control measures include minimising road gradients, increasing tunnel height and providing a large tunnel cross-sectional area. The tunnel ventilation system for the project would be designed with appropriate levels of conservatism and redundancy to ensure compliance with air quality goals and limits.

No in-tunnel filtration system is proposed for the project because the modelling carried out demonstrates that the ventilation system would be effective in ensuring compliance with the in-tunnel air quality criteria. The inclusion of tunnel filtration was evaluated and found not to provide any material benefit to air quality or community health as discussed in Chapter 12 (Air quality).

The inclusion of filtration would result in no material change in air quality in the surrounding community when compared to the current project ventilation system and outlet design. Any predicted changes in the concentration of pollutants would be largely driven by changes in the surface road traffic.

Ventilation outlet locations

The contribution of the ventilation outlets is negligible for the expected traffic scenarios. This outcome can be achieved at nearly any location through appropriate outlet design. Therefore, the main factors when considering the location of the ventilation facilities and outlets were maintaining in-tunnel air quality, maximising operational efficiency and minimising surface disturbance.

Vehicles travelling through the tunnels create a piston effect which draws air in the direction of travel. As a result, the most efficient location for a ventilation outlet is above or adjacent to tunnel portal locations (that is, near the exit portal of the southbound tunnel in Rozelle and near the exit portal of the northbound tunnel in Cammeray). This minimises the length of tunnel where the air flow must be forced, by jet fans within the tunnels, against traffic flow back to the ventilation point. The reduced use of tunnel ventilation fans also increases the performance of the tunnels and reduces operational power consumption, thereby reducing the operational costs of the project and enhancing the sustainability outcomes.

The proposed ventilation outlet in Rozelle would be located within the Rozelle Interchange site alongside the M4-M5 Link ventilation building. The location of this facility was decided as part of the M4-M5 Link environmental impact statement assessment process.

For the ventilation outlet to the north of Sydney Harbour, the Warringah Freeway corridor was identified as the preferred location for the ventilation outlet. This location would provide the following key advantages:

- It would minimise the total project footprint, noting alternatives would require additional property acquisition external to the existing road corridor
- It would be immediately above the tunnel, with associated efficiencies.

4.5.4 Construction support site location alternatives

In addition to the surface disturbance areas required for the operation of the project, a number of construction support sites would be required along the project corridor. The construction support sites would be needed to support both tunnelling and surface works.

Construction support sites would include activities such as construction material and equipment storage and staging areas, spoil handling, component casting facilities, worker amenities and car parking.

Environmental investigations and community and stakeholder feedback were used to inform the identification of appropriate construction support sites. The primary driver for the location of these sites was the objective of minimising environmental and community impacts, while being suitably located to facilitate the construction activities of the project.

Key factors applied to identification of potential construction support sites included:

- Locating the construction support sites as close as possible to project construction areas
- Avoiding sensitive environmental and community locations where possible
- Avoiding material impacts on heritage sites or items
- Maximising opportunities for direct access to motorways and arterial roads or water transport opportunities for construction traffic, and avoiding the need to use local residential streets if possible
- Minimising direct and indirect property impacts and acquisition requirements, particularly in residential areas.

Where the identified construction support sites could not meet the criteria listed above, additional specific mitigation measures were identified to manage impacts associated with their use. Details of construction support sites are provided in Chapter 6 (Construction work) of this environmental impact statement.

4.5.5 Spoil transport alternatives

Most of the spoil generated by major transport infrastructure projects currently under delivery and development would be Virgin Excavated Natural Material (VENM). VENM is considered a desirable material for clean fill in development sites and major earthworks projects across Greater Sydney.

Securing spoil disposal sites to meet production throughout construction and during bad weather is critical to the delivery program of tunnelling projects. Most reuse arrangements are directly negotiated between construction contractors and councils or private developers – with major projects often using many sites to optimise haulage and cost.

Tunnel spoil generated from major projects in Sydney is generally transported via road due to the majority of reuse sites being within the Sydney basin and the desire to minimise double handling of material.

Options to reduce impacts of spoil haulage on the surface road network were considered during development of the project. The spoil transportation strategy for the project includes road haulage from all sites, with the exception of the construction support sites at Yurulbin

Point (WHT4) and Berrys Bay (WHT7), where water-based transportation has been adopted to minimise impacts on narrow streets through harbourside areas.

In addition to the mitigation measures adopted within the proposed construction strategy, additional options to reduce spoil haulage impacts have been considered, including rail or barge as outlined below.

Rail

Freight rail was considered as a mode of spoil transport that may offer the opportunity to move large volumes of material and reduce the number of heavy vehicle movements on the Sydney road network. However, when considering the location of the project and associated construction support sites, this method presents the following issues:

- The material would need to be at least double and, most likely, triple handled. Trucks would be required to move material from construction support sites to a suitable train loading facility, and from the rail terminus to the final disposal location. This would significantly undermine the benefits of any such arrangement, as heavy vehicles are typically on the motorway network shortly after leaving the proposed tunnelling construction support sites. Analysis of haulage to potential train loading facilities concluded that heavy haulage distances on non-motorways would actually increase if this option was adopted
- There are few spare timeslots for freight trains on the Sydney rail network, which presents a significant construction risk. If this material cannot be reliably moved, large spoil storage facilities would be required to ensure tunnelling operations are not interrupted
- Infrastructure upgrades would be necessary to develop an appropriate train loading facility to receive the material.

Barge

As with rail, the main benefit of barge transport is the potential to move large volumes of spoil, while reducing the number of heavy vehicle movements on sensitive areas of the Sydney road network. The benefits of this method are particularly pronounced on local roads near water-based construction support sites, which are generally not suitable for large numbers of heavy vehicle movements. This is the rationale for adopting this method for haulage from the proposed Yurulbin Point (WHT4) and Berrys Bay (WHT7) construction support sites.

However, beyond these two sites, this option presents a number of issues including:

- The material would need to be double (or possibly triple) handled, as trucks would be required to move material to a harbourside barge loading facility, and from the barge to its final disposal location
- Infrastructure upgrades would potentially be required to allow the barge loading facility to receive the material
- Given the final spoil disposal locations are likely to be within the Sydney Basin, this option is unlikely to increase heavy haulage impacts on local roads when considering that heavy vehicles are typically on the motorway network shortly after leaving the proposed tunnelling construction support sites.

Preferred alternative

A combination of trucks from most of the proposed construction support sites, and barging from the water-based construction support sites at Berrys Bay (WHT7) and Yurulbin Point (WHT4) is the preferred spoil transport method for the project. With major tunnelling construction support sites located near to the urban arterial network at Victoria Road and the

Warringah Freeway, or Sydney Harbour, this solution minimises impacts on the local road network, and would deliver a value for money solution.

Chapter 6 (Construction work) provides a summary of heavy vehicle movements, including spoil related haulage. Use of local roads would be avoided where possible, with the main haulage routes being via major arterial roads.

4.5.6 Tunnelling spoil reuse and disposal alternatives

As described in Chapter 24 (Resource use and waste management), spoil would be beneficially reused as part of the project before alternative spoil disposal options, such as other infrastructure or development projects, were pursued.

Most of the spoil generated by the project would be VENM, which is considered a desirable material for clean fill in development sites and major earthworks projects across Greater Sydney. Generally, VENM is not disposed of at licenced landfills, primarily due to the high cost of doing so in comparison to reuse at development sites.

Residual spoil waste which cannot be reused or recycled would be disposed of to a suitably licensed landfill or waste management facility. Potential opportunities for reuse of spoil within the project include use for the formation of embankments and earth mound noise barriers, site rehabilitation and landscaping, road upgrades and infill for temporary tunnel access shafts and declines.

Alternative and/or additional spoil reuse options may be identified by the construction contractor as the project progresses.

Determination of the final destination(s) for spoil from construction of the project would be made during further design development and may include more than one disposal site.

4.5.7 Dredged material management alternatives

The project would require material to be dredged from Sydney Harbour to allow for the construction of the immersed tube tunnel crossing between Birchgrove and Waverton. A number of options for the disposal and reuse of dredged material have been considered as part of the development of the project, including:

- Land disposal at a licensed waste management facility
- Offshore disposal.

A summary of the alternatives considered for the disposal and reuse of dredged material is provided below.

Land disposal at a licensed waste management facility

Disposal of all dredged material at a licensed waste management facility would require:

- Dewatering to a spadable condition prior to disposal, potentially requiring mixing of the material with additives to alter the consistency of the dredged material, enabling it to be transferred to land. Dewatering may require large areas of land, depending on the quantity of material, which may result in additional property acquisition, large and noisy machinery and potential impacts on nearby receivers
- Large volumes of marine vessel movements to transfer dredged material to land
- Potential odour impacts to nearby receivers

- Additional heavy vehicle movements to transfer material (once spadable) to a licensed waste management facility.

Disposal of this material at a licensed waste management facility would likely be at a landfill and would therefore require the use of landfill space. Given the potential environmental impacts associated with the disposal of all dredged material to a licensed waste management facility, this option was not considered feasible.

However, it is expected that the top 1.5 metres of material dredged from Sydney Harbour as part of the project may not be considered suitable for sea disposal. The reuse of this material is not an option and, given the smaller amount of material, disposal at a licensed waste management facility is considered an appropriate option.

Offshore disposal

An application for offshore disposal of suitable dredged material has been submitted to the Commonwealth Department of the Environment and Energy. Offshore disposal is regularly used by marine dredging projects in New South Wales, with licenced disposal grounds in operation off Sydney Harbour and Newcastle. These sites have been carefully selected by the Commonwealth to provide suitable disposal grounds for dredge material and minimise impacts on sensitive marine ecology. The designated offshore disposal site is over 20 square-kilometres in area and is a non-dispersive ground, meaning that material placed within the area generally does not migrate from that area.

Material disposed of at the designated offshore disposal site would comprise sediments removed from Sydney Harbour during the construction of cofferdams at Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6), and dredged material removed from Sydney Harbour as part of the construction of the immersed tube tunnels.

Disposal of suitable dredged material at the designated offshore disposal site would:

- Avoid disposal of spoil to land based site
- Avoid additional heavy vehicle movements on the road network
- Minimise some environmental impacts such as noise, odour and dust at sensitive receivers, by avoiding the need to carry out treatment, dewatering and land-based transport of a large quantity of dredged material
- Avoid the creation of a significant waste stream on land.

Material would be required to satisfy the requirements of the *National Assessment Guidelines for Dredging* (Department of Environment, Water, Heritage and the Arts, 2009) before being considered suitable for disposal at the designated offshore disposal site.

Preferred dredged material management option

The preferred option for the disposal and/or reuse of dredged material is a combination of offshore disposal and disposal at a licensed waste facility. To minimise the potential environmental impacts associated with the disposal and reuse of dredged material, where dredged material complies with the *Environment Protection (Sea Dumping) Act 1981*, it would be disposed of at the designated offshore disposal site. Where material is not suitable for offshore disposal, treatment, dewatering and disposal on land to a licensed waste management facility would be carried out.

Chapter 6 (Construction work) provides a summary of heavy vehicle and vessel movements relating to the transport of dredged material to land for disposal at a licensed waste management facility. Chapter 24 (Resource use and waste management) details the indicative quantities of material requiring disposal at a licensed waste management facility and suitable for disposal at the designated offshore disposal site.

Offshore disposal of dredged material would be conducted outside NSW and is therefore not regulated under the *Environmental Planning and Assessment Act 1979*. Daily maximum construction maritime traffic volumes and routes to navigational channels that lead to Sydney Heads, including offshore barge movements for dredged spoil, are summarised in Chapter 6 (Construction work) and considered in Chapter 8 (Construction traffic and transport) and Appendix F (Technical working paper: Traffic and transport). Noise impacts related to the loading and unloading of barges at water-based construction support sites have been considered in Chapter 10 (Construction noise and vibration) and Appendix G (Technical working paper: Noise and vibration).

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