NSW GOVERNMENT

WestConnex M4-M5 Link

Rozelle Interchange – Modification: Iron Cove ventilation underground

Modification report

Appendix E

Groundwater drawdown and potential surface settlement

Roads and Maritime Services

WestConnex - M4-M5 Link

Iron Cove Ventilation Underground Modification Report

Modification report

Appendix E Groundwater drawdown and potential surface settlement

November 2019

Prepared for

Roads and Maritime Services

Prepared by

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1 Introduction

1.1 Purpose

This report has been prepared by WSP/Arcadis Joint Venture (WAJ) to provide an overview of the predicted project-induced surface settlement and potential impacts to existing structures associated with the proposed modification to underground the ventilation ancillary facilities at Iron Cove Link.

The Planning Approval (SSI 7485) for the M4-M5 Link Project sets out requirements that must be met with respect to geotechnical modelling, settlement predictions and impact assessment and management. Pertinent to this report are Planning Approval Conditions E101 to E104 which detail requirements relating to geotechnical modelling, settlement criteria and monitoring. Planning Approval Conditions E105 to E109 set out requirements relating to pre- and post-building dilapidation surveys and a mechanism for addressing property damage disputes. The conditions require the Proponent to take account of ground settlement as a result of the Rozelle Interchange project (the project) works and undertake the design and construction of the project to limit the potential impacts on existing and approved buildings and other surface and sub-surface infrastructure.

Potential settlement associated with the proposed modification is currently being assessed as part of the project-wide settlement modelling and impact assessment processes and will be finalised during detailed design. The settlement criteria adopted for the project and the assessment and monitoring processes to be adopted by JHCPB in designing and constructing the Rozelle Interchange (Stage 2) of the M4-M5 Link Project are in accordance with the Planning Approval and are described within this report. This process includes:

- Review of ground conditions including soil and rock types and natural fluctuations in groundwater levels
- Calculation of predicted ground movement as a result of tunnel construction
- Development of a detailed ground settlement model which addresses the short-term and long-term settlement expected
- Identification of buildings and surface and sub-surface infrastructure which may be considered as sensitive and potentially at risk based on the expected settlement
- Monitoring of baseline conditions and any actual ground movement.

As tunnel excavation progresses, the results of the surface monitoring of settlement will be reviewed against the model to verify predications and, if required, refinements made to the design and/or construction methodology.

1.2 Structure of this report

This report is structured as follows:

- A description of the proposed modification is provided in Section 2
- An overview of the assessment of the potential settlement impacts of the project included in the Environmental Impact Statement (EIS) is set out in Section 3 along with extracts from the former Department of Planning and Environment's Environmental Assessment Report (EA Report) on the M4-M5 Link Project
- The potential impacts of the proposed modification are set out in Section 4
- An overview of the tunnel design, modelling and building impact assessment development and approval process is provided in Section 5
- An overview of settlement monitoring to be undertaken prior to and during construction is set out in Section 6
- Conclusions are documented in Section 7.

2 The proposed modification

The EIS described an electrical substation and ventilation exhaust facility located in separate buildings on the surface in the vicinity of Callan and Springside Streets, Rozelle, that together would comprise the Iron Cove Motorway Operations Complex (MOC 4).

The proposed modification would relocate MOC4 underground, including the electrical substation and ventilation facilities (the ventilation outlet will remain above ground in the same location as illustrated in the EIS) A switch room, high voltage regulators, an alternative Operational Motorway Control System (OMCS) room and a separate stair access leading down to the ventilation tunnel would be required on the surface on the western side of Victoria Road between Toelle and Callan Streets.

The following points provide an overview of the proposed ventilation tunnel and caverns:

- Construction of about 340 metres of ventilation tunnel with connections to the main Iron Cove Link tunnel on the western side of the tunnel portals and south of Moodie Street, between Waterloo and Cambridge Streets. This ventilation tunnel would be on average about 10 metres wide. The depth of the ventilation tunnel would vary from about eight metres (from ground level to tunnel crown) at its shallowest to about 25 metres (from ground level to tunnel crown) at its deepest
- The ventilation tunnel would include two caverns for the housing of ventilation equipment and the electrical substation
- The ventilation cavern would contain four ventilation fans laid horizontally, with associated attenuators and dampers. The dimensions of the exhaust fan cavern would be about 25 metres wide, 15 metres high and 70 metres long
- The cavern containing the electrical substation would be parallel to the cavern containing the ventilation. The dimensions of the substation cavern would be about 20 metres wide, 10 metres high and 65 metres long
- A five-metre wide and 20-metre long access tunnel, to facilitate personnel access from the exhaust fan cavern into the substation cavern
- The Iron Cove cut and cover area would include a side access for the vent tunnel to connect to the cut and cover about 7 metres wide and 17 metres long. This area would also accommodate the access stairs to the surface.

The ventilation tunnel and caverns would be constructed in sound rock (i.e. sandstone) and would be excavated as described for the M4-M5 Link Project's other ventilation tunnels in Section 6.4.2 of the EIS. The ventilation tunnel and caverns would be drained and a sprayed shotcrete lining, consistent with the other ventilation tunnels and caverns to be constructed as part of the approved project. The tunnel lining would be installed progressively with the tunnel excavation.

The alignment of proposed new ventilation tunnel and caverns at Iron Cove is shown in Figure 1. The approved Iron Cove Link road tunnels are shown in orange, with the approved cross passages shown in brown.

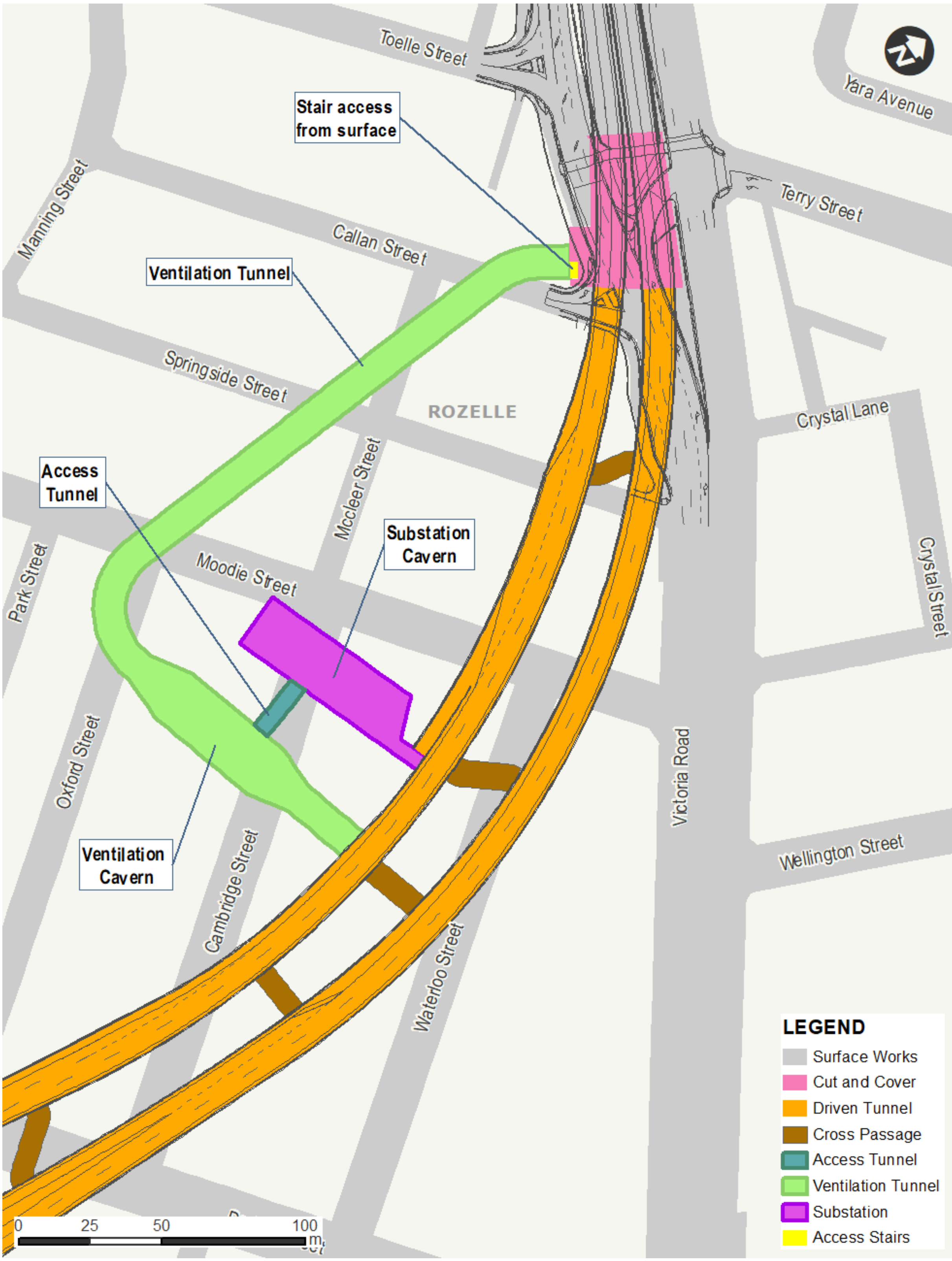

Figure 1 Alignment of proposed new ventilation tunnel and caverns at Iron Cove

3 EIS findings, independent assessment and Planning Approval Conditions

3.1 Overview of EIS findings on ground movement

The EIS identifies two causes of potential ground movement associated with the construction of the project:

- Tunnel excavation induced ground movement, which is the slight movement of the soil and rock around the tunnel as a result of the tunnel excavation removing material. This is a short-term effect, which happens as soon as the tunnel is excavated and can cause heave and/or settlement
- Soil consolidation (soil shrinkage) and rock compression due to the groundwater drawdown due to inflow into underlying tunnels. This is a longer-term effect, which may take some time to occur and causes settlement only.

These aspects are assessed separately in Chapters 12 and 19 of the EIS.

EIS Chapter 12 notes that the areas most likely to be affected by settlement are usually where tunnelling is closest to the ground surface (shallowest), around the tunnel portals and entry and exit ramps, and where soils are more likely to be compressible and thus have more voids which can compress. The EIS states that induced ground movement due to the tunnel excavation would occur primarily during the construction phase. Generally, settlement would be greatest in magnitude directly above the tunnel centreline, reducing with increased distance from both the tunnel sides and ahead of the tunnel face.

The EIS notes that the manner in which a building or structure responds to ground movement also depends on its size, design, materials, foundations and age. For instance, the EIS states that a timber or steel framed structure may be flexible, deflecting as the ground moves whereas a masonry building if subject to similar ground movement may behave differently. The EIS notes that other relevant factors may include the overall height (number of storeys) of the building and whether the building has basement levels.

The EIS adopts settlement criteria applied to other WestConnex projects and notes that preliminary geotechnical investigations and the assessment of potential settlement impacts have been carried out to inform the development of the concept design documented in the EIS. The preliminary assessment documented in the EIS shows that over the majority of the tunnel alignment predicted ground movement is less than 20 millimetres, which would be consistent with the criteria for sensitive buildings. The assessment focuses on areas where the tunnel was shallower and identified some areas where predicted ground movement would be greater than 20 millimetres.

The EIS concludes that further assessment including hydrogeological modelling would be undertaken during detailed design to determine the level of predicted settlement impacts.

Potential impacts associated with groundwater drawdown were addressed in EIS Chapter 19. The EIS notes that groundwater levels are impacted by both natural external influences such as rainfall permeation and drought and built elements including existing development and construction works including tunnel excavation.

The EIS documents rates of operational groundwater inflows monitored in recent years from several tunnels in the Sydney area designed to allow limited inflow of groundwater (referred to as drained structures) with similar geology, hydrogeology and construction to that proposed by the M4-M5 Link Project. The EIS noted that the groundwater inflow for these projects including the Eastern Distributer, M5 East Motorway, Epping to Chatswood Rail Line, Lane Cove Tunnel and Cross City Tunnel vary from 0.6 litres per second per kilometre to up to 1.7 litres per second per kilometre.

The EIS notes that the short-term inflow during construction would be dependent upon a number of factors including tunnelling progress, tunnelling construction methodology, fractured zones intersected, localised groundwater gradients and storability (the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer).

The EIS states that initial inflows to tunnels can be large, because of the large hydraulic gradients that initially develop near the tunnel walls; however, these gradients would reduce in time as drawdown impacts extend to greater distances from the tunnels and inflows approach steady state conditions. The EIS identifies that higher inflow rates are likely from zones of higher permeability, where saturated geological structural features are intersected by the tunnels. During construction, high permeability zones that are likely to have higher inflows over the longer term would be grouted to reduce the inflow rate. Grouting is the process of pumping grout into the rock mass by drilling and the injection of cement to reduce the permeability of the rock.

Initial groundwater inflows to the tunnels during construction are estimated in the EIS to range between 0.45 megalitres per day and 2.87 megalitres per day. The EIS concludes that the maximum inflows are predicted to peak towards the end of construction in 2021 at 2.45 megalitres per day or 0.77 litres per second per kilometre. This prediction is below the overall WestConnex tunnel operational inflow criterion of one litre per second per kilometre for any kilometre length of the tunnel.

The EIS concludes that during construction, the regional extent of drawdown impacts due to tunnel construction would be minimal, even though initial groundwater inflows are high. This is due to the generally low hydraulic conductivity of the Ashfield Shale and the Hawkesbury Sandstone restricting the extent of drawdown during the relatively short construction timeframe.

With respect to potential impacts on existing groundwater users, the EIS groundwater model predicted that no registered bore within two kilometres of the project footprint would be drawn down more than two metres (the minimum impact criterion under the NSW Aquifer Interference Policy) during the project construction program.

The EIS notes additional groundwater modelling would be conducted during construction using measured tunnel inflow rates and monitored groundwater drawdown to better calibrate the model and predict impacts. The EIS also notes that monitoring of settlement throughout the construction program would be undertaken. The EIS concludes that a geotechnical model of representative geological and groundwater conditions would be prepared prior to excavation and tunnelling for the project. The model would be used to assess predicted settlement impacts and ground movement caused by excavation and tunnelling on adjacent property and infrastructure.

The EIS identifies a range of options that are available to minimise settlement in areas where ground movement in excess of the relevant settlement screening criteria are predicted including:

- Review of the proposed tunnel design including the proposed tunnel support system and the tunnel lining
- Review of the construction methodology such as the rate of tunnel advance and consideration of ground improvement options.

The EIS concludes that it is anticipated that a combination of the abovementioned options would be sufficient to ensure that ground movement associated with the project is less than the relevant settlement criteria.

3.2 Department of Planning and Environment's Environmental Assessment Report and Planning Approval

The Environmental Assessment Report (EA Report) prepared by the former Department of Planning and Environment (now Department of Planning, Industry and Environment) dated March 2018 noted there is potential for settlement due to tunnel excavation and groundwater drawdown. The EA Report acknowledged the EIS findings that areas most likely to be affected are where the tunnel would be closer to surface level or intersect paleochannels.

The EA Report noted that further modelling is required during detailed design of the project to confirm settlement predictions.

The EA Report proposed a number of measures to manage settlement in areas identified as likely to be affected by settlement, including building conditions surveys, the implementation of a settlement monitoring program and rectification of any property damage caused by settlement. Additional numerical modelling will also be undertaken during detailed design to refine the spatial extent of potential settlement impacts. The EA Report considered that the design outcomes for the project should be guided by strict and contemporary settlement criteria similarly imposed on projects such as the WestConnex New M5 project (recently modified in relation to settlement).

Relevant Conditions in the Planning Approval for the M4-M5 Link and Revised Environmental Management Measures (REMMs) are set out in Appendix A and B.

4 Potential impacts of the proposed modification

As noted in Section 3, cumulative settlement impacts include the combined impacts of settlement from tunnel excavation induced ground movement and groundwater drawdown.

The new ventilation tunnel and caverns would equate to a total length of about 425 metres and would be excavated below residences not identified in the EIS as being near the tunnel alignment. This calculation is based on a length of about 340 metres for the ventilation tunnel alignment and the ventilation fan cavern, 65 metres for the substation cavern and about 20 metres of access tunnel connecting the two caverns. It is important to note that Rozelle Interchange (which is Stage 2 of the M4-M5 Link Project) includes excavation of approximately 23 kilometres of tunnels and that the proposed modification is limited to the construction of about 425 metres of additional tunnels and caverns, which represents a very small increase in the extent of tunnelling.

Areas most likely to be affected by settlement are where tunnelling is closest to the ground surface (shallowest), and where soils are more likely to be compressible because they have more voids which can compress. In Iron Cove, the depth to Hawksbury Sandstone is very shallow, with overlaying soils generally less than two metres in depth.

The depth of the proposed new ventilation tunnel and caverns would vary from about eight metres (from ground level to tunnel crown) at its shallowest to about 25 metres (from ground level to tunnel crown) at its deepest (see Figure 2).

Figure 2 Indicative depth from ground level to crown of ventilation tunnel and caverns

The proposed new ventilation tunnel and caverns would be located within Hawksbury Sandstone which is a highly competent bedrock. A cross-section of the geotechnical profile in Iron Cove which illustrates the proposed tunnel and ventilation cavern is provided in Figure 3. The crown (top) of the tunnel and ventilation cavern is marked in orange and the base is marked in blue.

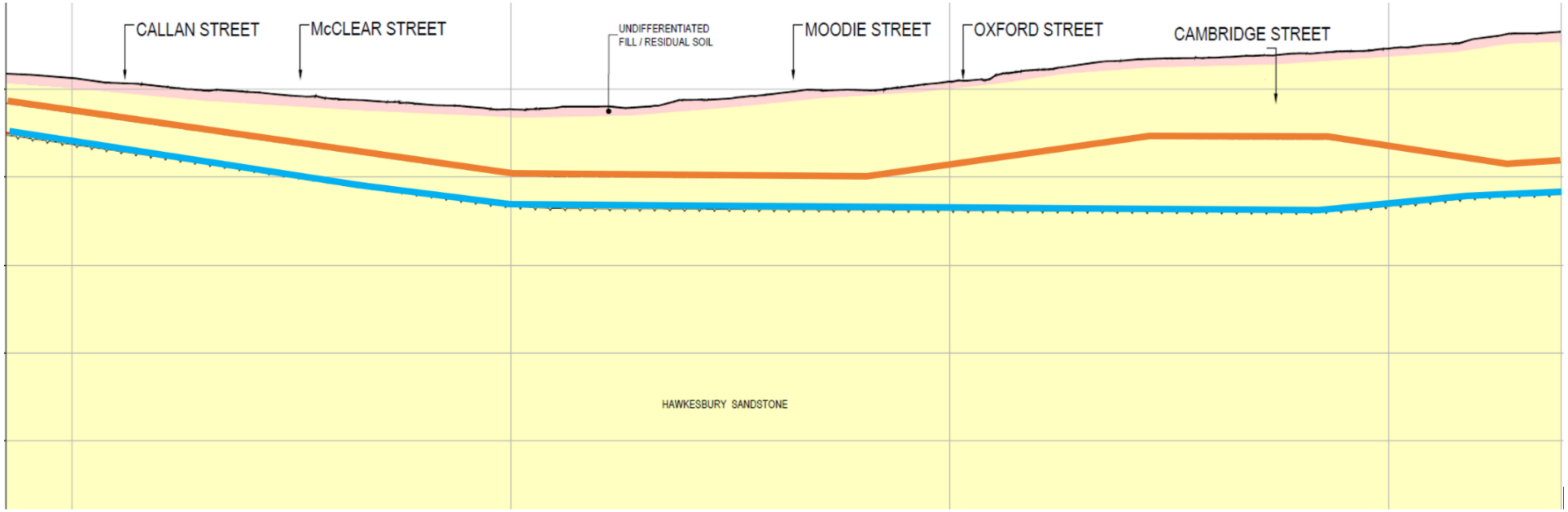

Figure 3 Iron Cove ventilation tunnel geological cross-section. Orange represent the top of the tunnel and blue represent the base of the tunnel.

Even the shallowest section of the proposed new tunnel would have substantial rock cover above the crown of the tunnel. It is also noted that the wider cavern excavations are generally located at depths greater than 15 metres. The ventilation tunnel and caverns connect to the Iron Cove Link road tunnel alignment and are therefore located at similar depths.

Consistent with the EIS findings, tunnel excavation induced ground movement is anticipated to be the prevalent mechanism causing ground movement. Risks associated with groundwater drawdown and associated induced settlement within Hawkesbury Sandstone is considered low because of the geotechnical properties of the rock. As groundwater is removed from this rock type the structural integrity and strength of the rock remains due to its competent nature. As a result, the cumulative settlement impacts are not anticipated to be an issue for tunnels excavated in the Hawkesbury Sandstone which would include the proposed new ventilation tunnel and caverns at Iron Cove.

The findings of the EIS described in Chapter 19 regarding groundwater would be consistent with the implementation of the proposed modification. Tunnel groundwater inflow criteria would not be altered. The proposed new ventilation tunnel and caverns, as noted above, are located in Hawksbury Sandstone. Hawksbury Sandstone has low permeability and predicted groundwater inflows and groundwater induced settlement associated with the proposed modification would be minimal.

With respect to potential impacts on existing groundwater users, there no registered bores within two kilometres of the footprint of the proposed modification and no impacts are therefore anticipated for existing groundwater users as a result of the proposed modification.

Planning Approval Condition E190 requires the Proponent to take all practicable measures to limit operational groundwater inflows into each tunnel to no greater than one litre per second per km length of tunnel. Based on the preliminary analysis completed to date on the concept design, the total groundwater inflow that would be expected for the proposed modification in steady state would be about 0.4 litre per second per kilometre length. During construction this may increase by about 0.1 litre per second to about 0.5 litres per second per kilometre length.

The preliminary settlement analysis completed to date, which combines both predicted excavation induced, and short and long-term groundwater drawdown settlement is illustrated in Figure 4. This assessment is based on the concept design and the predicted ground settlement ranges from 0 to 20 millimetres, which is consistent with settlement screening criteria set out in Planning Approval Condition E103 of the Infrastructure Approval (see Table 1).

Table 1 Comparison of preliminary settlement analysis against the screening criteria in Condition E103

Surface and Sub-Surface Structures	Maximum Settlement	Maximum Angular Distortion	Limiting Tensile Strain (percent)*	Compliance
Buildings – Low or non-sensitive properties (i.e. ≤ 2 levels and carparks)	30 mm	1 in 350	0.1	✓
Buildings and pools – High or sensitive properties (i.e. ≥ 3 levels and heritage items)	20 mm	1 in 500	0.1	✓
Roads and parking areas	40 mm	1 in 250	n/a	✓
Parks	50 mm	1 in 250	n/a	✓

* As defined in Burland et al. 'Building response to tunnelling – Case studies from construction of the Jubilee Link Extension', London, Thomas Telford (2001)

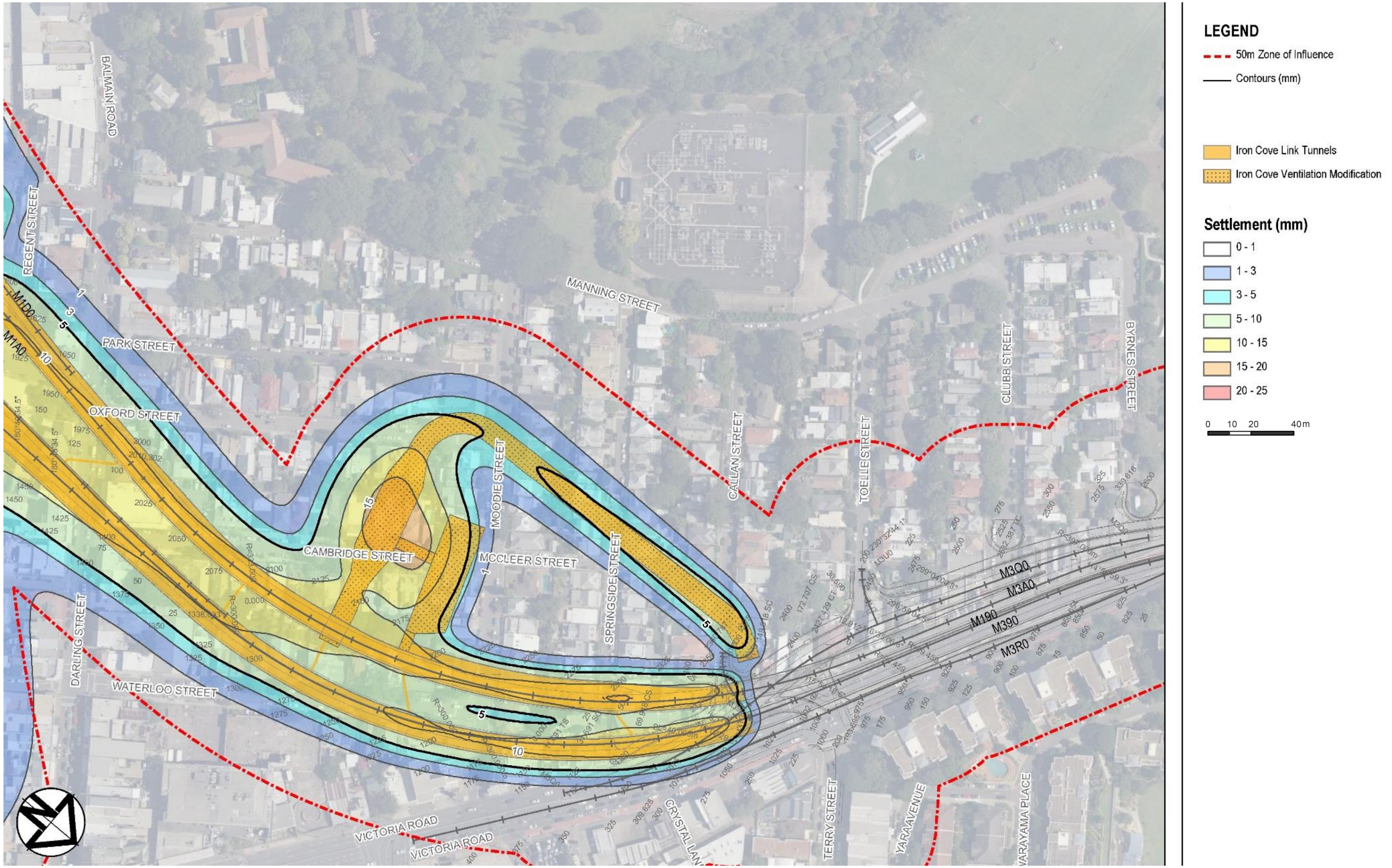

Figure 4 Preliminary settlement analysis of proposed modification (note this is subject to design development)

Based on the preliminary settlement analysis and building and structure impact assessment undertaken to date which has taken into consideration rock type, tunnel depth and building types (number of storeys and basement and foundation extents), it is not anticipated that the settlement screening criteria set out in Planning Approval Condition E103 would be triggered during excavation of the proposed new ventilation tunnel and caverns at Iron Cove.

As a result of the proposed modification, the subsurface stratum acquisition requirements and areas potentially subject to surface settlement would alter accordingly. The potential excavation-induced and groundwater drawdown impacts of the proposed ventilation tunnel and caverns would be consistent with those already identified in the EIS as:

- The proposed ventilation tunnels and caverns would be excavated in Hawkesbury sandstone
- The proposed ventilation tunnels and caverns are being constructed at a similar depth to the main road tunnel alignment for the Iron Cove Link
- The same tunnelling methodology is proposed for the construction of the proposed ventilation tunnel and caverns.

The Conditions in the Planning Approval set in place comprehensive requirements to ensure the potential impacts of the detailed design and construction methodology of the project, including the proposed modification, are assessed and potential impacts on property are minimised.

5 Tunnel design and modelling development and building assessment

5.1 Design development and approval

The design of the tunnel is subject to a staged engineering approval process that incorporates internal checking, quality assurance and external review and certification before any construction can begin. The design will be steadily developed through from concept to the final level of detail required to construct it.

An Independent Certifier has been appointed to the project to certify the design.

The tunnel design is broken down into packages to cover discreet geographical areas of the tunnel, to account for the shape of the tunnel and ground conditions at those areas and the construction program. Each tunnel design package is developed based on:

- Review of ground conditions and natural ground water parameters
- Calculation of predicted ground movement as a result of the tunnel construction
- Development of a detailed ground settlement model which addresses the short-term and long-term settlement expected (see Section 5.2)
- Identification of buildings and infrastructure which may be considered as sensitive and potentially at risk based on the expected settlement (see Section 5.3).

The Independent Certifier for the project and Roads and Maritime Services (RMS) comment on the design at each stage of its development and check its compliance with the project requirements including the Planning Approval. These comments are then reviewed by the designer and the contractor and any changes required are incorporated in the next stage of the design. The design is only issued to the contractor for construction to begin after completion of this detailed review process and when all comments have been closed out and the Independent Certifier issues a certificate to confirm that the design meets the requirements of the contract, including the requirements set out in the Planning Approval.

5.2 Settlement prediction methodology

Ground movement is predominantly associated with short-term impacts during construction and long-term ground settlement. Outcomes are predicted by the following methods:

- Short-term settlements are estimated by adding the tunnel excavation induced settlements and the groundwater drawdown induced settlements during the construction period (typically two to five years). Settlement associated with tunnelling induced ground loss (mined tunnels) and the movement of earth retaining walls (cut and cover tunnels) are derived by performing numerical modelling and by empirical methods
- Long-term settlements are derived by adding the tunnel excavation induced settlements and groundwater drawdown induced settlements for 50 years when indicated that the steady state condition is reached. This will include the time dependent consolidation of the soft layers and compression of the hard layers.

Figure 1 shows construction induced impact assessment flowchart.

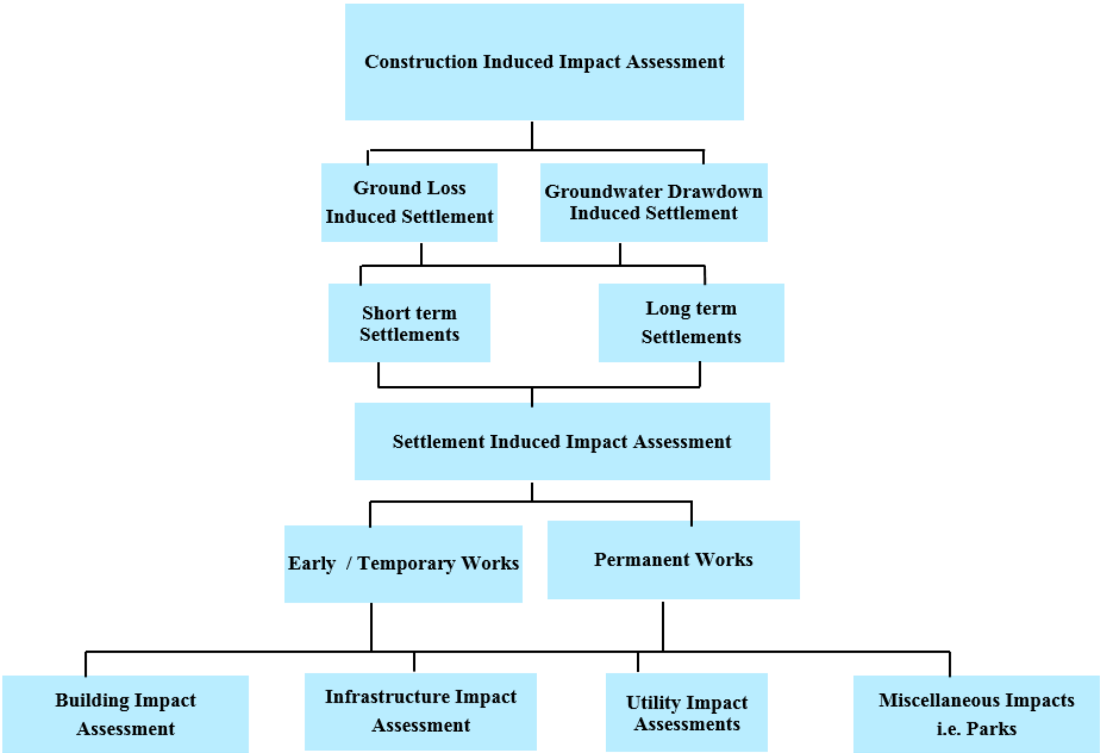

Figure 1 Construction Impact Assessment Flowchart

Settlement induced by mined tunnel excavation using road headers, rock hammers and if adopted surface miners and drill and blast is predicted using empirical methods and validated by performing detailed numerical modelling, giving consideration to the expected construction sequences.

Tunnelling induced ground loss values are assumed based on past projects in similar ground conditions and validated based on numerical analysis results. Three-dimensional models are developed to account for the complex nature of the project alignment, characterized by interacting tunnels. This is a proven approach that is being used by the tunnelling industry worldwide.

During construction and long-term operation of a drained underground structure (which allows the controlled inflow of groundwater), there is potential for groundwater to drain into the excavation, resulting in lowering of the natural/baseline groundwater table. This groundwater drawdown results in an increased effective weight of the ground, which will induce elastic compression of the ground in the short term and consolidation settlement in the long term. Tunnel excavation induced groundwater drawdown has been predicted for the both short- and long-term condition using numerical analysis tools. The zone of influence adopted for the assessment of potential groundwater drawdown impact has been developed based on previous experience and precedence from other recent tunnelling projects in Sydney. Buildings and infrastructure located beyond the zone of influence are considered to have “negligible” or no impact as a result of ground movements from the work. No further assessment is undertaken when existing infrastructure is outside the zone of influence defined above as the settlement beyond this limit is negligible and therefore the effect dissipates.

Preliminary settlement contours are presented in Figure 4 and these settlement contours will be refined and updated as the design development progresses and include the results of the excavation and groundwater induced settlement modelling and indicate any locations(s) where the settlement screening criteria in Planning Approval Condition E103 and determined under Planning Approval Condition E102 are predicted to be exceeded for further assessment.

5.3 Building and structure impact assessment

Each structure including buildings, swimming pools, utilities and roads within the potential zone of influence corridor is to be evaluated for potential impact due to settlement resulting from the project. Tunnelling (excavation) induced settlements and sub-surface movements can induce changes in the stresses and strains within existing buildings and structures which, depending on the magnitude, may lead to damage. The impact of the ground movement on a building or structure is influenced by:

- The nature of its construction
- The form of its foundations
- The magnitude of the ground movement
- The proximity of the building to the ground movement
- The dimensions
- Its geometrical relationship to the works
- The associated change in strains and stresses in the building or structure.

In addition to the settlement screening criteria set out in Planning Approval Condition E103 of the Infrastructure Approval, individual criteria will be developed for other surface and subsurface structures where required in consultation with the asset owner.

A staged approach will be adopted with an initial conservative overestimation of settlement to identify and eliminate from further consideration those structures at low risk of damage. A more refined analysis will be undertaken for buildings and structures that are identified as potentially at higher risk of damage. This works to focus the assessment on the buildings and structures potentially most susceptible to damage, with second and third stage detailed evaluation carried out on buildings and structures where a higher potential for damage is predicted in the initial assessment.

As noted in Section 4, based on the preliminary settlement analysis and building and structure impact assessment undertaken to date, it is not anticipated that the settlement screening criteria set out in Planning Approval Condition E103 would be triggered during excavation of the proposed new ventilation tunnel and caverns at Iron Cove.

Based on the findings of detailed settlement modelling pre-dilapidation and subsequent post-dilapidation surveys are offered to property and asset owners in advance of and following tunnel excavation in accordance with Planning Approval Conditions E105 to E107.

The tunnel excavation commences only following:

- Comprehensive settlement modelling
- Building and structure impact assessment
- Design development and refinement by specialist consultants and designers
- RMS review and Independent Certifier approval.

This process will work to ensure the project requirements including in the Planning Approval have been met.

An Independent Property Impact Assessment Panel (IPIAP) has been established by RMS in accordance with Planning Approval Condition E109. The Panel is composed of independent geotechnical and engineering specialists with experience in conducting property damage assessments. The purpose of the IPIAP is to independently review and resolve property damage disputes at the request of either the affected owner or RMS.

6 Settlement monitoring

Ground settlement will be monitored prior to and during excavation and impacts assessed in order to validate the modelling set out in Section 5.2. Monitoring and assessment will be carried out with the primary function of collating baseline data on natural groundwater fluctuations prior to the commencement of tunnelling and checking that actual ground movements are consistent with the predicted ground movements during excavation, and that design assumptions and predicted effects on third party assets are acceptable. Monitoring and assessment will include:

- Monitoring ground levels (surface and subsurface) and effects on adjacent and overlaying structures
- Providing an indication and warning of any impending instability, excessive deformation or failure
- Investigating ground behaviour and the response of structures and other property
- Determining pre-construction behaviour of existing structures
- Evaluating critical design assumptions and validating design models
- Developing and implementing contingency plans if the actual behaviour significantly deviates from the acceptable criteria
- Providing assurance to third party building and infrastructure owners and other stakeholders that the impacts of construction are as predicted and acceptable.

The monitoring program will identify trigger values to ensure that if the monitoring data indicates changes in what was predicted, then processes will be put in place to ensure review of the data is undertaken. For each aspect being monitored the trigger level will vary, but a common approach ensures that any changes to expected ground behaviour is captured early with an appropriate level of response implemented. This will include review by appropriately qualified specialists. Contingency actions may include additional monitoring, assessment of potential causes and if required design and/or construction methodology refinement.

Figure 2 shows how monitoring is carried out, starting from the design outcome (predicted effects), establishing trigger levels and baseline readings, monitoring review and reporting cycles, contingency measures and protection measures, if required.

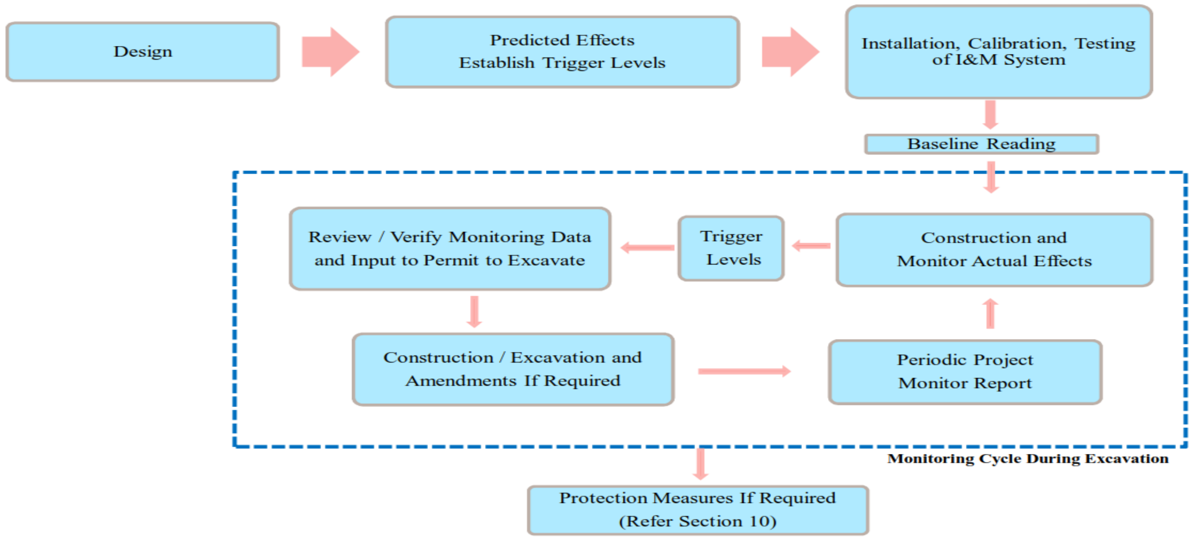

Figure 2 Monitoring Design Strategy Flowchart

7 Conclusion

The EIS included a preliminary assessment of potential settlement impacts from excavation and groundwater drawdown separately. This report summarises information and processes to provide an overall understanding of the geotechnical and settlement compliance program to be implemented during design and construction.

The preliminary settlement prediction and impact assessment indicates that the proposed modification is not anticipated to cause ground settlement above the criteria set out in the Planning Approval. The reasons for this are consistent with the EIS and include:

- The ventilation tunnels and caverns would be excavated in Hawkesbury sandstone
- The ventilation tunnels and caverns are being constructed at a similar depth to the main road tunnel alignment for the Iron Cove Link
- The same tunnelling methodology is proposed for the construction of the proposed ventilation tunnel and caverns.

The design will be reviewed as it is developed and approved by the Independent Certifier prior to construction. Comprehensive ground movement predictions that take into account the cumulative impacts of potential excavation induced ground movements and groundwater drawdown will be undertaken during design development in accordance with the Planning Approval. The findings of this modelling will be used to identify and assess buildings adopting a risk based approach as required under the Planning Approval.

The settlement monitoring program will identify trigger values to ensure that if the monitoring data indicates changes in what was predicted, then processes will be put in place to ensure review of the data is undertaken. For each aspect being monitored the trigger level will vary, but a common approach ensures that any changes to expected ground behaviour is captured early with an appropriate level of response implemented. This will include review by appropriately qualified specialists. Contingency actions may include additional monitoring, assessment of potential causes and if required design and/or construction methodology refinement.

Combined with other Planning Approval requirements including building condition surveys and the Independent Property Impact Assessment Panel, the Planning Approval sets in place comprehensive requirements to ensure the potential impacts of the detailed design and construction methodology are assessed and impacts on property are minimised. The proposed modification can be constructed in accordance with the existing Planning Approval and does not require any modifications to either the Conditions of Approval or the REMMs to successfully manage potential settlement or groundwater drawdown impacts.

Appendix A Planning Approval Compliance Matrix

There are a number of conditions in the Planning Approval for the M4-M5 Link that are applicable to groundwater and settlement. The below table references where in this report each of these conditions is discussed.

<table>
<tr><th>No.</th><th>Requirement</th><th>Reference</th></tr>
<tr><td>E101</td><td>A geotechnical model of representative geological and groundwater conditions must be prepared prior to excavation and tunnelling to identify geological structures and groundwater features. The model must include details of proposed excavations and tunnels, construction staging, and identify surface and sub-surface structures, including any specific attributes, which may be impacted by the CSSI. The Proponent must use this model to assess the cumulative predicted settlement, ground movement, stress redistribution and horizontal strain profiles caused by excavation and tunnelling, including groundwater drawdown and associated impacts, on adjacent surface and sub-surface structures.</td><td>Section 5</td></tr>
<tr><td>E102</td><td>The Proponent must undertake a review of surface and sub-surface structures at risk from damage to determine appropriate criteria to prevent damage, prior to excavation and tunnelling works that may pose a settlement risk. Criteria for surface and sub-surface structures which are not included in Condition E103 (Table 9) must be determined in consultation with the owner(s) of the surface and sub-surface structures prior to commencement of any excavation or tunnelling works potentially affecting the surface and sub-surface structures.</td><td>Section 5</td></tr>
<tr><td>E103</td><td>In the case of buildings, roads, parking areas and parks, the appropriate criteria which governs the greatest risk of damage are to be selected from Table 9 (Maximum Settlement, Maximum Angular Distortion or Limiting Tensile Strain) unless the Proponent has determined more stringent criteria as a result of Condition E102.
Table 9: Settlement criteria
<table>
<tr><th>Surface and Sub-Surface Structures</th><th>Maximum Settlement</th><th>Maximum Angular Distortion</th><th>Limiting Tensile Strain (percent)*</th></tr>
<tr><td>Buildings – Low or non-sensitive properties (i.e. ≤ 2 levels and carparks)</td><td>30 mm</td><td>1 in 350</td><td>0.1</td></tr>
<tr><td>Buildings and pools – High or sensitive properties (i.e. ≥ 3 levels and heritage items)</td><td>20 mm</td><td>1 in 500</td><td>0.1</td></tr>
<tr><td>Roads and parking areas</td><td>40 mm</td><td>1 in 250</td><td>n/a</td></tr>
<tr><td>Parks</td><td>50 mm</td><td>1 in 250</td><td>n/a</td></tr>
</table>
* As defined in Burland et al. 'Building response to tunnelling – Case studies from construction of the Jubilee Link Extension', London, Thomas Telford (2001)</td><td>Section 5</td></tr>
<tr><td>E104</td><td>Should the geotechnical model in Condition E101 identify exceedances of the relevant criteria established by Conditions E102 and E103, the Proponent must implement an instrumentation and monitoring program to measure settlement, distortion or strain as required. The Proponent must also identify and implement appropriate mitigation measures in consultation with the owner(s) of the relevant surface and sub-surface structures prior to excavation and tunnelling works to ensure where possible that the surface and sub-surface structures will not experience exceedances of the relevant criteria.
The adopted criteria does not remove any responsibility from the Proponent for the protection of existing surface and sub-surface structures or for rectifying any damage to surface and sub-surface structures resulting from the CSSI.</td><td>Section 5</td></tr>
</table>

No.	Requirement	Reference
E105	The Proponent must offer pre-dilapidation surveys and must undertake and prepare pre-dilapidation reports where the offer is accepted, on the current condition of surface and sub-surface structures identified as at risk from settlement or vibration by the geotechnical model described in Condition E101. The pre-dilapidation surveys and reports must be prepared by a suitably qualified and experienced person(s) and must be provided to the owners of the surface and sub-surface structures for review prior to the commencement of potentially impacting works.	Section 5
E106	Where pre-dilapidation surveys have been undertaken in accordance with Condition E105, subsequent post-dilapidation surveys must be undertaken to assess damage to the surface and sub-surface structures that may have resulted from the construction of the CSSI within three (3) months of the completion of construction.	Section 5
E107	The results of the surveys must be documented in a Condition Survey Report for each surface and sub-surface structure surveyed. Copies of the Condition Survey Reports must be provided to the owner(s) of the structures surveyed within three (3) weeks of completing the surveys and no later than four (4) months following the completion of construction.	Section 5
E108	Where damage has been determined to occur as a result of the project, the Proponent must carry out rectification at its expense and to the reasonable requirements of the surface and sub-surface structure owner(s) within three (3) months of completion of the post-dilapidation surveys unless another timeframe is agreed with the owner of the affected surface or sub-surface structure.	Section 5
E109	The Proponent must establish an Independent Property Impact Assessment Panel before works that have the potential to result in property impacts commence. The Panel must comprise geotechnical and engineering experts independent of the design and construction team. The Panel will be responsible for independently reviewing Condition Survey Reports undertaken under Conditions E105 and E106, the resolution of property damage disputes, and the establishment of ongoing settlement and vibration monitoring requirements. The Secretary must be informed of the Panel Members prior to property impact. Either the affected owner or the Proponent may refer unresolved disputes arising from potential and/or actual property impacts to the Panel for resolution. All costs incurred in establishing and implementing the Panel must be borne by the Proponent regardless of which party makes a referral to the Panel.	Section 5
E156	Identified impacts to heritage items and heritage conservation areas must be minimised through both detailed design and construction.	Section 5
E190	The Proponent must take all practicable measures to limit operational groundwater inflows into each tunnel to no greater than one litre per second across any given kilometre (1L/s/km). Compliance with this condition cannot be determined by averaging groundwater inflows across the length of the tunnel.	Section 5
E191	The Proponent must identify and commit to the implementation of ‘make good’ provisions for groundwater users in the event of a decline in water supply levels, quality and quantity from registered existing bores associated with groundwater changes from either construction and/or ongoing operational dewatering caused by the CSSI.	Section 3 and 4

No.	Requirement	Reference
E192	The Proponent must undertake further modelling of groundwater drawdown, tunnel inflows and saline water migration (using particle tracking) prior to finalising the design of the tunnels and undertaking any works that would impact on groundwater flows or levels. The modelling must be undertaken in consultation with DPI Water and include the results and hydrogeological analyses of at least 12 continuous months of current baseline groundwater monitoring data from bores identified in the EIS and SPIR. The modelling must also include data from any other existing monitoring bores identified in consultation with DPI Water, as required to supplement baseline data.	Section 5 and 6
E193	The results of the groundwater modelling must be documented in a Groundwater Modelling Report. The Groundwater Modelling Report must be finalised in accordance with the Australian Groundwater Modelling Guidelines (National Water Commission, 2012) and prepared in consultation with DPI Water. The Groundwater Modelling Report must include, but not be limited to: (a) justification for layer choice; (b) specification and justification of the grid based hydraulic conductivity and storage parameters (specific yield and specific storage) assigned to each layer and/or zone with reference to those values determined from data analyses and the literature; (c) an explanation of how groundwater flow was simulated within each model layer with reference to confined, unconfined or variably saturated flow solutions; (d) an explanation and justification of the drain-cell conductance term(s) applied to the tunnel boundaries to limit tunnel inflows; (e) an explanation and justification of the groundwater recharge values applied across the model domain, including around the modelled specific yield values and the water table fluctuations observed within the monitoring data in response to rainfall-fed groundwater recharge; (f) details (including figures) of the expected changes in groundwater flow directions in the vicinity of landfills, groundwater wells and surface water receptors; (g) cross-section diagrams of geology showing baseline groundwater levels in the monitoring piezometers, and for the predicted baseline condition groundwater levels in 2030 and 2100; (h) statistical evaluation of the model's calibration; (i) details of the groundwater monitoring data inputs (levels and quality); (j) details of the proposed groundwater model update and validation as additional data is collected; (k) assessment of impacts of groundwater drawdown, taking into consideration the NSW Aquifer Interference Policy (DPI, 2012), including potential impacts on licensed bores and groundwater dependent ecosystems; (l) a comparison of the results with the modelling results detailed in the documents referred to in Condition A1; and (m) documentation of any additional measures that would be implemented to manage and/or mitigate groundwater impacts not previously identified.	Section 5 and 6

Appendix B Revised Environmental Mitigation Measures Compliance Matrix

Revised Environmental Management Measures (REMMs) were included in the Preferred Infrastructure and Submissions Report. Relevant REMMs and where they are discussed in this report are shown in the below table.

<table>
<tr><th>Number</th><th>Requirement</th><th>Reference</th></tr>
<tr><td>PL6</td><td>Ground settlement will be managed to comply with the following criteria where possible
<table>
<tr><th>Beneath structure/facility</th><th>Maximum settlement</th><th>Maximum angular distortion</th><th>Limiting tensile strain (per cent)*</th></tr>
<tr><td>Buildings – Low or non-sensitive properties
(ie less than or equal to two levels and carparks)</td><td>30 mm</td><td>1 in 350</td><td>0.1</td></tr>
<tr><td>Buildings – High or sensitive properties
(ie greater than or equal to 3 levels and carparks)</td><td>20 mm</td><td>1 in 500</td><td>0.1</td></tr>
<tr><td>Roads and parking areas</td><td>40 mm</td><td>1 in 250</td><td>N/A</td></tr>
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</table>
* As defined in Burland et al. ‘Building response to tunnelling – Case Studies from construction
of the Jubilee Line Extension’, London, Thomas Telfor (2001)</td><td>Section 5.2 and 5.3</td></tr>
<tr><td>PL7</td><td>Further assessment of potential settlement impacts, including numerical modelling, will be undertaken during detailed design. In areas where ground movement in excess of settlement criteria are is predicted, an instrumentation and monitoring program to measure settlement, distortion or strain will be implemented. Feasible and reasonable measures will be investigated and implemented to ensure where possible that the predicted settlement is within the criteria. Measures that will be considered may include (but are not limited to):
Review of the proposed tunnel design including:
• the depth and alignment of tunnels
• the proximity of multiple tunnels to each other
• the proposed tunnel support system
• the tunnel lining to manage groundwater inflows
• Rationalising the layout of the proposed ventilation tunnels including the number, location an length of tunnels
• Review of the proposed construction methodology
• Consideration of ground improvement options.</td><td>Section 5.2 and 5.3</td></tr>
</table>

Number	Requirement	Reference
PL8	A Settlement Monitoring Program will be prepared that will provide details on: • Settlement criteria and predictions • Location of monitoring points • Duration of monitoring • Data collection (type and method) • Comparison of actual settlement with predictions • Triggers and corrective actions that will be implemented if, based on monitoring results, actual settlement is likely to exceed predictions or the relevant criteria, with the aim of complying with the criteria. The Settlement Monitoring Program will be endorsed the Independent Property Impact Assessment Panel (see PL11) prior to the commencement of any construction activities with the potential to result in settlement, as determined by the panel, unless otherwise agreed to by the Secretary.	Section 6
PL9	Settlement monitoring will be carried out for the period in accordance with the program starting prior to commencement of tunnel construction through to until all settlement has stabilised following completion of tunnel construction. The results of settlement monitoring will be compared to predicted settlement. The implementation and adequacy of the Settlement Monitoring Program will be monitored by the Independent Property Impact Assessment Panel	Section 6
GW1	Groundwater inflows within the tunnels will be minimised by designing the final tunnel alignment to minimise intersections with known palaeochannels and alluvium present in the project footprint.	Section 5
GW2	Appropriate waterproofing measures will be identified and included in the detailed design to permanently, where reasonable and feasible, reduce the inflow into the tunnels to below one litre per second per kilometre for any kilometre length of the tunnel.	Section 5
GW6	Potential impacts associated with subsurface components of the project intercepting and altering groundwater flows and levels will be considered during detailed design. Measures to reduce potential impacts will be identified and included in the detailed construction methodology and the detailed design as relevant.	Section 5
GW7	A detailed groundwater model will be developed by the construction contractor during detailed design. The model will be used to predict groundwater inflow rates and volumes within the tunnels and groundwater levels (including drawdown) in adjacent areas during construction and operation of the project.	Section 5
GW8	Groundwater inflow within and groundwater levels in the vicinity of the tunnels will be monitored during construction and compared to model predictions and groundwater performance criteria applied to the project. The groundwater model will be updated based on the results of the monitoring as required and proposed management measures to minimise potential groundwater impacts adjusted accordingly to ensure that groundwater inflow performance criteria are met.	Section 6
GW9	Further investigations will be carried out to identify areas where groundwater inflows to the tunnels are likely to be elevated, to guide the development of the detailed design and construction methodology. The investigations will be carried out prior to the commencement of excavations with the potential to result in groundwater inflow at each identified location.	Section 6

Number	Requirement	Reference
OGW9	A groundwater monitoring program will be prepared and implemented to monitor groundwater inflows in the tunnels and groundwater levels as well as groundwater quality in the three main aquifers and inflows during construction. The program will identify groundwater monitoring locations, performance criteria in relation to groundwater inflow and levels and potential remedial actions that will be considered to address any non-compliances with performance criteria. As a minimum, the program will include manual groundwater level and quality monitoring monthly and inflow volumes and quality weekly. The monitoring program will be developed in consultation with the NSW EPA, DPI-Fisheries, DPI Water, City of Sydney Council and Inner West Council.	Section 6