IN THE MATTER OF	the Fast-track Approvals Act 2024 ("FTAA")
AND	
IN THE MATTER OF	an application for approvals by **NZ Transport Agency Waka Kotahi** to construct, operate and maintain the State Highway 1 Wellington Improvements project

STATE HIGHWAY 1 WELLINGTON IMPROVEMENTS PROJECT
TECHNICAL REPORT #13
GEOTECHNICAL, NATURAL HAZARDS AND RESILIENCE ASSESSMENT

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1. INTRODUCTION

1. My full name is Pathmanathan Brabhaharan. I am the specialist engaged by the New Zealand Transport Agency Waka Kotahi (NZTA) to provide evidence on geotechnical engineering, natural hazards and resilience issues related to the Project. I work at WSP New Zealand Limited (WSP).

2. My colleague Dr Doug Mason, Principal Engineering Geologist at WSP, has contributed to the assessment of natural hazards and their effects; and Siva Arumugam, Principal Geotechnical Engineer at WSP has reviewed my report.

3. Eric Van Nieuwkerk, Technical Principal from WSP, has contributed to the assessment of groundwater issues and is also presenting evidence for this Project.

4. I have relied on the engineering assessments and preliminary design by staff from WSP and Tonkin and Taylor (T+T) for this Project.

Qualifications and experience

5. My qualifications relevant to this Project are:

   i. Bachelor of Science of Engineering with Honours, specialising in Civil Engineering, from the University of Peradeniya, Sri Lanka (1982)

   ii. Master of Science of Engineering in Foundation Engineering from the University of Birmingham, United Kingdom (1986)

   iii. Master of Business Administration from Deakin University, Australia (1998)

   iv. Chartered Professional Engineer in New Zealand

6. My professional affiliations are:

   i. Fellow of Engineering New Zealand

   ii. Fellow of the New Zealand Society for Earthquake Engineering (NZSEE)

   iii. Member of the New Zealand Geotechnical Society (NZGS), affiliated to the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) and the International Society for Rock Mechanics (ISRM)

   iv. Member of the Bridge Engineering Technical Society (BETS)

   v. Member of the Structural Engineering Society (SESOC)

   vi. Member of New Zealand Society on Large Dams (NZSOLD)

7. I am currently Immediate Past President of the New Zealand Society for Earthquake Engineering, following a 2-year term as President from April 2024 to May 2026.

8. A summary of my experience is:

   i. I have 43 years' experience in Geotechnical, Earthquake and Civil Engineering and Risk Management, in New Zealand, United Kingdom, Malaysia, Singapore and Sri Lanka

   ii. I have been based in Wellington and have practised in New Zealand over the past 37 years, and during this period have provided geotechnical advice, design, investigations, construction monitoring, assessment and strengthening for a variety of infrastructure, and in particular for motorways, expressways, highways, roads, tunnels and bridges

   iii. I was a member of the Learning from Earthquakes Team from the NZ Society for Earthquake Engineering that carried out reconnaissance of the damage to the built and natural environments in the Sichuan Province of China in the Richter Magnitude 8 Wenchuan Earthquake in May 2008, and in the Kyushu region of Japan following the Magnitude 7 Kumamoto Earthquake in April 2016, and presented findings to the profession on each occasion

   iv. I was engaged by NZTA to carry out field reconnaissance of damage to highways and bridges and to gather and report lessons on geotechnical aspects of the observed performance, following the 2010 Magnitude 7.1 Darfield Earthquake, the 2011 Magnitude 6.3 Christchurch Earthquake that affected Canterbury and the 2016 Kaikoura earthquake that affected the Kaikoura and Marlborough areas

v. I have been actively involved in the emergency response and recovery after the 2010-2011 Canterbury Earthquake Sequence, and the 2016 Kaikoura earthquake, and was involved in developing repair and reconstruction solutions

vi. I have carried out research and developed approaches to assess the resilience of transport networks and have over the past 27 years led the assessment of the resilience of the transport network in the Wellington Region, the national state highway network and other transport networks in New Zealand

vii. I led the Wellington Region Land Transport Resilience Business case for NZTA and GWRC during 2016-2019, and assessed the resilience to various natural hazard events, prioritised resilience risks and developed mitigation to enhance the resilience of the land transport system

viii. I led a theme on the performance of earthworks and slopes as a part of a 5-year research programme into earthquake induced landslides and other failures affecting the infrastructure in the 2016 Kaikoura Earthquake, in similar conditions as this Project

ix. I led the earthquake hazard assessment studies, including liquefaction and slope failure hazards for the Wellington region (1992-1995), which resulted in the publication of earthquake hazard maps for the Wellington region. This included the Terrace Tunnel to Kilbirnie area where the Project is located

x. I have also led a number of studies to assess the resilience and develop risk management strategies for the State highways in the Wellington Region and the local authority road networks in Kāpiti Coast, Wellington City, Hutt Valley, Upper Hutt, Porirua and the Wairarapa. The resilience of priority roads within the greater Wellington area under earthquake and / or storm conditions has been assessed as part of these studies

xi. I was involved in a study for NZTA to identify critical sections along SH1, SH2 and SH58 that would be affected in a major earthquake in the region, develop emergency response plans and in particular assess the likely time required to reopen the coastal route between Pukerua Bay and Paekākāriki

xii. I have advised the Wellington Lifelines Group in the consideration of emergency access following a major earthquake in the region

xiii. I have been involved in the management and rehabilitation of tunnels in New Zealand, scoping of new tunnels and in the construction of rock tunnels for a hydropower project

xiv. I also have experience in the investigation, assessment and management of the risk associated with underground cavities such as associated with abandoned underground mines, and the associated subsidence risk to the overlying built environment

9. My project experience relevant to this Project includes design and /or construction of large structures and earthworks in similar geological conditions including:

i. Long Tunnel Project, as Geotechnical and Natural Hazards Resilience Advisor, for the development of a concept for a long tunnel from north of the Terrace Tunnel to Kilbirnie

ii. Let’s Get Wellington Moving, as Principal Resilience and Geotechnical Advisor, for the development of options to enhance access and resilience through improvements to the state highway and public transport systems (2017-2022)

iii. Ngauranga to Airport Strategy, as Lead Geotechnical Engineer, including development of tunnel duplication concepts for the Terrace Tunnel and Mt Victoria Tunnel (2005-2007)

iv. Wellington Inner City Bypass, as Design Manager and Lead Geotechnical Engineer, for the development of concepts, detailed design, consenting and construction of the improvement of SH1 between the Terrace Tunnel and the Basin Reserve (1998-2007)

v. Mt Victoria Tunnel Strengthening, as Geotechnical Team Leader, involving strengthening of the portal structures (2008-2013)

vi. Terrace Tunnel Approach Retaining Walls, as Lead Engineer, investigating the history and construction, development of an asset management strategy, assessing the seismic performance of the walls and maintenance, testing of the anchors and walls (2004-2006)

vii. Shell Gully Seismic Assessment and Retrofit, as Geotechnical Reviewer, for the assessment and implementation of strengthening measures (2002-2005)

viii. Tunnel-Link project as Lead Geotechnical Engineer for a 1.2 km cut and cover tunnel between the Terrace Tunnel and Mt Victoria Tunnel, for development of the scheme; assessment of groundwater regime and interaction with proposed cut-and-cover tunnel, the bridge at the Basin Reserve and associated structures and earthworks (1989-1993)

ix. Wellington East Girls' College (above the Mt Victoria Tunnel), as Lead Geotechnical Engineer, for seismic assessment and master planning project, developing strengthening works and monitoring during construction at the school (2011-2018)

x. Southern Landfill Tunnel as Lead Geotechnical Engineer and Project Director, for the assessment of the condition and performance of the tunnel under proposed landfill loading as well as earthquakes, development of options to ensure effective passage of the stream, and presentation of expert evidence to the RMA hearing (2002-2024)

xi. Lead Geotechnical Engineer for the Petone to Grenada scheme development, including a transport interchange at Petone, Horokiwi and Tawa and development of options for large cut and fill slopes and tunnels. This included extensive geotechnical investigations and preliminary design concepts and mitigation of the liquefaction, landslide and fault rupture hazards (2012-2017)

xii. Transmission Gully expressway, as Expert and Geotechnical Team Leader, for the 27 km route, for geotechnical investigations, scheme development, development of designs for consents, assessment of effects and presentation of evidence at the Board of Inquiry; and development of tender design (2006-2013)

xiii. Christchurch Southern Motorway (liquefiable and compressible alluvium), as reviewer for the scheme development, detailed design and construction stages (2001-2010)

xiv. Peka Peka to Ōtaki Expressway (alluvium, sand and inter-dunal peat deposits), as lead geotechnical designer, for scoping, scheme assessment, presentation of evidence to the Board of Inquiry and provision of geotechnical advice during construction (2011-2020)

xv. SH2 Muldoon's Corner realignment, as lead geotechnical engineer the scheme development, detailed design and construction monitoring of up to 60 m high cuttings, 45 m high embankments and slope stabilisation works (2004-2012)

xvi. Newlands Interchange including overbridge, as lead geotechnical designer, for concept, scheme assessment, detailed design and construction (1994-1998)

xvii. Western Link Road including several bridges, between Raumati South and Waikanae (sand and inter-dunal peat deposits), for the design and consenting stages (2001-2010)

xviii. I have also been involved in the seismic assessment and retrofit of bridges in New Zealand including development of innovative retrofit solutions for abutments, either as lead geotechnical engineer or peer reviewer, including the Thorndon Overbridge seismic assessment and retrofit (preliminary assessment and then peer review)

xix. West Midlands UK abandoned underground limestone mine investigation, assessment of the risk of subsidence and development of risk mitigation measures

xx. Kotmale Hydropower Project in Sri Lanka involving the construction of long tunnels and underground power station caverns in rock

10. Site visits:

i. I have carried out numerous site visits to the corridor over the past 35 years, as part of the development of a number of concepts, schemes, investigations, design and construction

ii. I made specific site visits during the development of my evidence for this Project during October 2025 to February 2026

11. Extent of Involvement with the Project:

i. I provided advice during the Investment Case, reviewed the development of the site investigation programme at Mt Victoria East and its implementation, advised on and reviewed the Seismic Resilience Philosophy, participated in workshops to discuss the investment case concepts, challenge and review of the early concepts in the concept design case and advised on critical issues that must be resolved by the design team, and advised on alternative concepts and mitigation during the consent design stages. Given the risks that I identified during the early stages of my role, I proactively collaborated with the design team to identify the hazards and risks and facilitated the development of solutions that are more robust

ii. I have assessed the natural hazards and their potential impacts on resilience for the Project and developed this specialist report

Code of conduct

12. I confirm that I have read the code of conduct for expert witnesses contained in the Environment Court Practice Note 2023. This assessment has been prepared in compliance with that code, as if it were evidence being given in Environment Court proceedings. In particular, unless I state otherwise, this assessment is within my area of expertise, and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

Project description

13. The State Highway 1 (SH1) Wellington Improvements project (the Project) is a Road of National Significance (RoNS) which improves SH1 in Wellington City. The proposal includes the construction of improvements to SH1 within Wellington City, extending over 5 km through the city. The Project will provide for more efficient and reliable access on SH1 and includes duplicate new tunnels at The Terrace and Mount Victoria, a new layout at the Basin Reserve as well as improvements along the remainder of the SH1 corridor from north of the Terrace Tunnel to the intersection of Cobham Drive and Evans Bay Parade. The Project aims to attract traffic onto SH1, reduce traffic on other key routes, unblock critical bottlenecks on the state highway, maintain access for local movements and enable public transport growth.

Scope of assessment

14. My assessment addresses the following matters:

i. The methodology I have used to assess the effects on the built environment and resilience benefits of the Project

ii. The existing natural hazards environment

iii. Resilience context

iv. Effects of the natural hazards to the Project

v. Effects of the Project during operation

vi. Effects of the Project during construction

vii. Benefits of the Project

viii. Recommended measures to avoid, remedy or mitigate adverse effects

Assumptions and exclusions in this assessment

15. My assessment excludes the assessment of the effects on:

i. The groundwater regime, which is reported on separately by another specialist, **Eric Van Nieuwkerk**

ii. Offsite flooding beyond the resilience of the highway itself, which is reported on separately by another specialist, **Tom Bassett**

2. EXECUTIVE SUMMARY

Existing environment

16. The Project is in an area of complex geology, topography and natural hazards, with the SH1 crossing through the foothills of the Western Hills at The Terrace and at Mt Cook, and through Mt Victoria hills. The route also crosses the Terrace, Aotea and Mt Victoria East faults and low lying compressible and liquefiable areas with artesian groundwater pressures in the Basin Reserve. SH1 currently runs through 3 tunnels in this area, 2 of which are proposed to be duplicated through the Project.

17. Wellington is also in a high seismic environment, with the knowledge of seismicity enhanced by the publication of the 2022 National Seismic Hazard Model, which presents much higher seismic loads for Wellington than previously known, primarily because of the improved understanding of the seismicity associated with the Hikurangi Subduction zone along the east coast of the North Island which extends some 25 km under Wellington, in addition to the many active faults.

18. The government's National Policy Statement for Infrastructure 2025 (NPS-I) has an objective to ensure that infrastructure is well-functioning, resilient and compatible as far as practicable, and requires decision-makers to enable the upgrading of infrastructure where this will improve the resilience of infrastructure to risks from natural hazards and the effects of climate change. The Government Policy Statement for Land Transport emphasises the strategic priority to increase maintenance and resilience to effectively manage and reduce current and future risk and adapt to these challenges.

19. The National Policy Statement for Natural Hazards 2025 (NPS-NH) requires decision-makers to assess risk using a risk matrix and manage it proportionately. Very high risk must be avoided, and other risks managed through mitigation measures. Decisions must be based on the best available information, even where that information is uncertain or incomplete. However, the NPS-NH does not apply to infrastructure.

20. The Wellington transport system has poor resilience, and the 2018 regional transport resilience business case developed and adopted by the NZTA Board identified key vulnerabilities that need to be enhanced as part of future projects (such as the present Project). One such vulnerability expressly identified is the need to enhance the resilience of the existing approaches to the Mt Victoria Tunnel, which was identified as a key vulnerability in the city.

21. The presence of residential properties, heritage areas and the Town Belt add to the complexity and sensitivity of the environment.

Potential benefits of the Project

22. There are several potential benefits from the Project, and the primary ones that I have considered are the benefits of enhanced operational and natural hazards resilience.

23. The duplication of the two tunnels provides for enhanced operational resilience through providing redundancy for transport in the critical bottlenecks represented by the tunnels, which are vulnerable to closure due to incidents such as accidents, spills or fire. The separate second tunnels proposed for the Terrace Tunnel and Mt Victoria Tunnel enable the state highway network to continue to provide access, particularly for emergency vehicles, in the event of one of the tunnels being closed due to an incident.

24. Grade separation of (on the one hand) the state highway access to the airport and eastern suburbs and (on the other) local road access from the city to the Wellington Regional Hospital and Newtown provides for increased operational resilience of access to Wellington Airport and hospital, in the event of one of the routes being closed due to an incident in the critical Basin Reserve area. Other

local road connections enable both routes (or either one, in the event of disruption) to be able to provide access to both the regional hospital and the airport.

25. Enhancing the resilience of access at the currently vulnerable approaches to the Mt Victoria tunnel, through stabilisation of the existing approach cuttings, will help enhance the resilience of access between the city and Wellington Airport, particularly in the event of major earthquake or storm hazards. The proposed high cut slopes on the eastern approach to the tunnel will be designed to be resilient despite the presence of faults and associated unfavourable defects and poor rock.

Potential adverse effects ameliorated through design, without mitigation

26. There were several potential adverse effects associated with the early designs, and I have engaged collaboratively with the design team and provided advice to mitigate the effects through alternate design measures that mitigate the effects and infuse resilience into the infrastructure and access routes. The following measures are now incorporated into the Project:

    i. The northern access to the Terrace Tunnel crosses the Terrace Fault zone with very poor rock conditions, so enhanced ground stabilisation with pressure grouted anchors or nails are proposed to mitigate the risks to the resilience of access to the new tunnel and to the properties along The Terrace, associated with steep cut slopes

    ii. The risk of damage to the tunnel portals associated with high steep ground above the portals, has been mitigated using flatter stable slopes than initially proposed and ground stabilisation where necessary, to ensure that the access is not affected by slope failures from above the tunnel portal

27. The risk of damage to the proposed second Terrace Tunnel and resilience of access, in the event of modest displacement along the Terrace Fault which will be crossed by the tunnel, will be mitigated by providing movement joints or strengthening of the tunnel lining, so modest displacement along the Terrace Fault in sympathy to rupture of the active Wellington Fault does not affect the resilience of access along the new tunnel.

    i. The risk associated with the shallow ground cover over the southern part of the new tunnel will be mitigated through the introduction of a short section of cut and cover tunnel, where the ground is excavated with support measures, and the tunnel structure constructed and backfilled

    ii. There is a risk to properties and services overlying the broader area above the proposed second Terrace Tunnel, due to likely subsidence associated with the excavation for the tunnel and associated loss of ground, as well as to a lesser extent groundwater drawdown associated with construction of the drained tunnel. This risk will be mitigated through staged excavation and pre-stabilisation of the rock prior to excavation, and the residual risk will be mitigated through proactive actions, pre-construction, during construction and after construction

28. Any potential risks to the proposed tunnel due to uncontrolled development above the tunnel zone will be mitigated through protective measures associated with a subsurface designation, to preserve the integrity and avoid damage to the proposed tunnel from future development (in particular, development involving deep foundations).

29. The design and construction of earthworks and retaining walls associated with the ramp as well as the longer Ghuznee Street Bridge in poor alluvial ground underlain by rock with sub-artesian groundwater conditions will be mitigated through selection of appropriate forms of retaining walls, ground improvement and drainage measures to relieve artesian pressures.

30. Various options have been considered to provide grade separation between the local road and state highway at the Basin Reserve. The placement of Sussex Street in a trench under the state highway has been made robust in the consent design by the use of secant piled or diaphragm walls with floor level and temporary and permanent top props, given the poor ground and groundwater conditions, the high seismicity, and the potential for liquefaction.

    i. The highway related structures have been kept on the western side of the Basin given the presence of the Aotea Fault on the eastern side. This enables at grade access on the eastern side of the Basin to be restored quickly through minor earthmoving, in the event of rupture on this fault

31. The risk associated with earthworks and the settlement of the compressible ground and damage to the deep brick stormwater and sewers under Cambridge – Kent Terrace and the Basin Reserve have been considered. This will be mitigated by reducing the embankment load and use of a protection structure to reduce the load on the ground and resulting settlement.

32. The risk associated with construction of the second Mt Victoria tunnel with a relatively small (6 m) clearance to the existing 1930s tunnel in an earlier design iteration, has indicatively been mitigated by increasing the separation distance from 6 m to 9 m (a 50% increase). Various engineering solutions exist to ensure resilience of both tunnels, such as proactive measures to support the ground for both the cut and cover section using anchored piled walls, and measures such as rock anchors and consolidation grouting to stabilise the ground between the tunnels where poor rock is encountered.

33. The damage to the proposed second Mt Victoria tunnel and its resilience of access, in the event of modest displacement along the Mt Victoria East Fault which the tunnel will cross, will be mitigated by providing movement joints and strengthening of the tunnel lining. As a result, modest displacement along this fault in sympathy to a rupture of the active Aotea Fault will not affect the resilience of access along the new tunnel.

34. The very high risks associated with the formation of steep slopes in fault disturbed rock along the eastern approach to the Mt Victoria tunnels has been actively investigated and a stable cut slope profile and mitigation measures can be implemented.

35. There is an existing risk of disruption to access along the state highway due to flooding south of the Terrace Tunnel, at the Cambridge – Kent Terrace and Basin Reserve areas and along Ruahine Street. The Project proposes pumping to a buried tank south of the Terrace Tunnel to reduce the duration of such flooding. At Ruahine Street, modelling shows that the flooding will be mitigated by the proposed enhanced stormwater measures including a new stormwater pipe, and flood depth is limited and therefore any impact of this residual flooding on resilience will be lower, allowing important higher clearance vehicles to pass through the area. At the Basin Reserve, the existing flood hazard remains and could limit access, but this is likely to affect access for a limited period of less than 12 hours. This is an existing resilience risk for short durations, but important given that the route provides access to Wellington Airport.

Proposed measures to avoid, remedy or mitigate adverse effects, including conditions

36. I have summarised recommended measures to avoid, remedy or mitigate potential adverse effects:

i. Operational

I have identified potential mitigation measures to minimise the risks identified for the operation of the highway:

- Provide for traffic re-routing measures, so that traffic along both directions could be diverted through one tunnel in the event of one of the tunnels being closed due to a long duration incident, to provide for operational resilience
- Provide for traffic re-routing measures, to enable traffic to be diverted along sections of local roads where the highway is affected by surface flooding, for example along Moxham Avenue if there is flooding along Ruahine Street

ii. Construction

I have also identified measures to mitigate the risks during construction:

- Proactive monitoring of the subsidence of the ground overlying the proposed tunnels, and development of an action plan to mitigate the effects of the construction of the tunnel. This includes identification of the area that could be potentially affected by subsidence during detailed design, pre-construction condition survey of the buildings in the identified areas (Annexure A), pre-construction mitigation of any buildings that have significant vulnerability, monitoring of the subsidence of the ground during and for a period after construction, setting of alarm levels to trigger actions required to mitigate the subsidence, and proactive tunnel construction measures to limit subsidence, and repairs to any structures or services affected

- Proactive measures to monitor the groundwater regime and ground subsidence adjacent to the Basin Reserve area as illustrated in Annexure A, and an action plan to mitigate the effects. This includes refinement of the area that could be potentially affected by subsidence during detailed design, pre-construction condition survey of the buildings in the identified area, pre-construction mitigation of any buildings that have significant vulnerability, monitoring of the subsidence of the ground during and for a period after construction, setting of alarm levels for actions required to mitigate the effects of subsidence, and proactive measures to limit subsidence, and repairs to any structures or services affected

- There are a few heritage buildings that are located in the affected area, and are shown on the maps in Annexure A. Some of those adjacent to the Basin Reserve and Mt Victoria areas are planned to be relocated. The remaining heritage buildings are not expected to suffer severe damage. But some of these may experience minor damage, and these will be carefully evaluated during detailed design to consider if any prior mitigation measures are required, or if any potential minor damage can be readily repaired

37. I summarise as follows my conclusions regarding the Project, subject to these measures to avoid, remedy, and/or mitigate adverse effects being implemented.

38. The Project will provide resilience benefits for Wellington's transport network, including:

i. The duplication of the Terrace and Mt Victoria Tunnels will bring operational resilience due to being able to operate one tunnel even if one of the tunnels is closed due to incidents in the tunnel

ii. The grade separation of the arterial Cambridge / Kent Terrace – Adelaide Road connection from the state highway traffic will enable one route to operate even if the other is closed due to incidents or maintenance activities

iii. Constructing the new tunnels with allowance for fault rupture will enable them to be quickly recovered as the tunnel lining will include movement joints and strengthening to minimise downtime and hence provide resilience of access

39. The strengthening of the Mt Victoria Tunnel approaches, especially at the east approach with the adoption of stable slopes and stabilisation measures for the proposed and existing cuttings, will facilitate the access to the Mt Victoria tunnel being able to be maintained or quickly restored in significant to major storm or earthquake hazard events. Additional geotechnical investigations have been carried out, and the results facilitate a resilient design of the proposed cut slopes.

40. A number of potential hazards were identified early in the design process and actioned qualitatively with the design team to minimise the associated risk and enhance resilience:

41. Potential hazards associated with the crossing of the Terrace Fault and Mt Victoria tunnel East Fault strands within both tunnels and on the approaches to the tunnels were considered, and measures identified to reduce the risk and enhance resilience.

42. The Sussex Street / Basin Reserve trench concept, in an area of poor ground, has adopted a more resilient trench piled wall and temporary and permanent props as necessary to enhance its robustness. The embankment will be minimised and incorporate structural measures to protect the vulnerable deep brick stormwater pipes, with other services being diverted.

43. There are existing flood hazard risks in a large storm event south of the Terrace Tunnel, at the Basin Reserve – Cambridge / Kent Terrace area, and along Ruahine Street. The flood hazard south of the Terrace Tunnels will be somewhat mitigated by the incorporation of measures to pump the flood waters to a storage tank. The lower depth of flooding along Ruahine Street will be able to be accessed by vehicles with a higher base including emergency vehicles. The flooding at the Basin

Reserve is an existing hazard and is expected to be of short duration of hours and therefore is a short duration resilience impact.

44. Proactive measures will be taken to manage the risk of damage to properties and services above and adjacent to the new Terrace Tunnel, Basin Reserve improvements and the new Mt Victoria Tunnel (albeit to a lesser extent, due to lower risk and lower sensitivity of the area at Mt Victoria), due to subsidence of the ground. These measures include enhanced tunnel construction methodologies, pre-construction surveys, underpinning of critical buildings monitoring, setting of alarm levels, and repairs to buildings where necessary. There are a few heritage buildings in these areas, and the risk to them is low and would be similarly managed during construction.

45. The subsurface designation above the Terrace Tunnel corridor will ensure that future development does not affect the tunnels (as will associated acquisition of subsurface property rights under the Public Works Act 1981).

46. Additional geotechnical investigations have been carried out to better characterise the ground conditions along the approaches to the Mt Victoria Tunnel and this information will be used to ensure that the approach cut slopes are stable in storms and earthquakes and ensure the route remains open or can be quickly restored.

47. The NPS-I as well as the Government Policy Statement on Transport 2024 (GPS), both require that the functional and operational needs of transport infrastructure are key drivers for economic growth and productivity, and improving the resilience to climate change and natural hazards is a priority. This includes upgrading of infrastructure where this will improve resilience to the risks from natural hazards and effects of climate change. I consider the Project is well aligned with these policies because of the operational and natural hazard resilience benefits it will provide to the state highway route.

3. ASSESSMENT FRAMEWORK

NZTA technical publications or guidance documents

48. NZTA technical publications relevant to the project are:

    i. Bridge Manual, 4th Edition

    ii. Risk Management Practice Guide (Minimum Standard Z/44)

    iii. TAN #26-02 Seismic resilience of new State Highway Bridges and Soil Structures

Industry best practice or management guidance

49. Industry guidance relevant to the project are:

    i. GNS Science (2022). National Seismic Hazard Model

    ii. MBIE | NZ Geotechnical Society (2021). Geotechnical Modules

    iii. New Zealand Geotechnical Society (2023). Draft Ground Anchor Guidelines

    iv. New Zealand Geotechnical Society (2025). Draft Slope Stability Guidelines

    v. New Zealand Geotechnical Society (2026). Draft Climate Change Considerations for Geo Professionals

    vi. New Zealand Society for Earthquake Engineering (2023). Designing for Uncertainty

50. Resilience and hazard planning guidance are addressed in Section 5 of this report.

4. EXISTING ENVIRONMENT

Introduction

51. The Project involves the upgrade of a section of SH1 which skirts around the base of the western hills from Thorndon to Mount Cook, crosses the Te Aro valley and Mount Victoria and runs along the eastern side of the hill towards Kilbirnie and Wellington Airport, see Figure 1. SH1 currently runs through 3 tunnels, the Terrace Tunnel crossing under The Terrace, the Arras Tunnel under the foothills of Mount Cook and Mount Victoria Tunnel towards Hataitai.

Figure 1 – Aerial view of part of the Project area

Site description

Geology

52. Wellington is underlain by Mesozoic age greywacke rock overlain by Pleistocene age and more recent Holocene age sediments (GNS Science, 1996 and 2000), see Figure 2. The greywacke rock comprises sandstone, siltstone and argillite, with varying levels of weathering. The rocks are intensely fractured given the tectonic environment, with several active faults crossing the area.

53. There are several faults in the region, together with the subduction zone beneath Wellington that give rise to a high seismicity, see Figure 2. The route crosses a few faults, some of which are active and others less active, as discussed below.

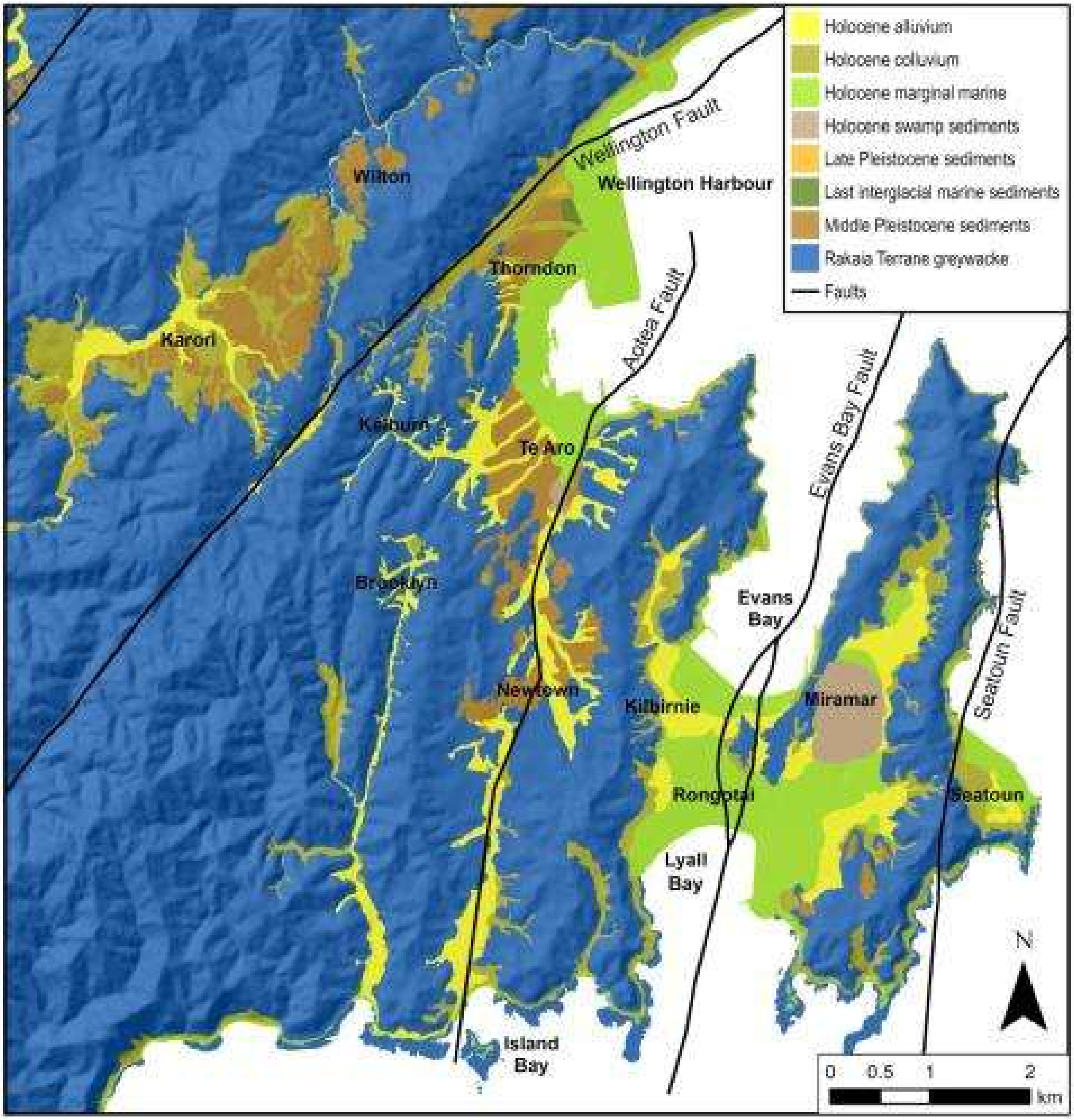

Figure 2 – Geology of the Wellington area (after Hill et al 2002)

Geomorphology

54. Wellington City Council commissioned geomorphological mapping of the area, which is presented on its website, and an extract is presented in Figure 3.

55. The geomorphology map confirms our knowledge that the Terrace Tunnel and Mt Victoria Tunnel constructed through rock, the Te Aro and Ruahine Street sections of the route crosses areas of fill, colluvium and alluvium, and the Basin Reserve area is underlain by fill, alluvium and colluvium.

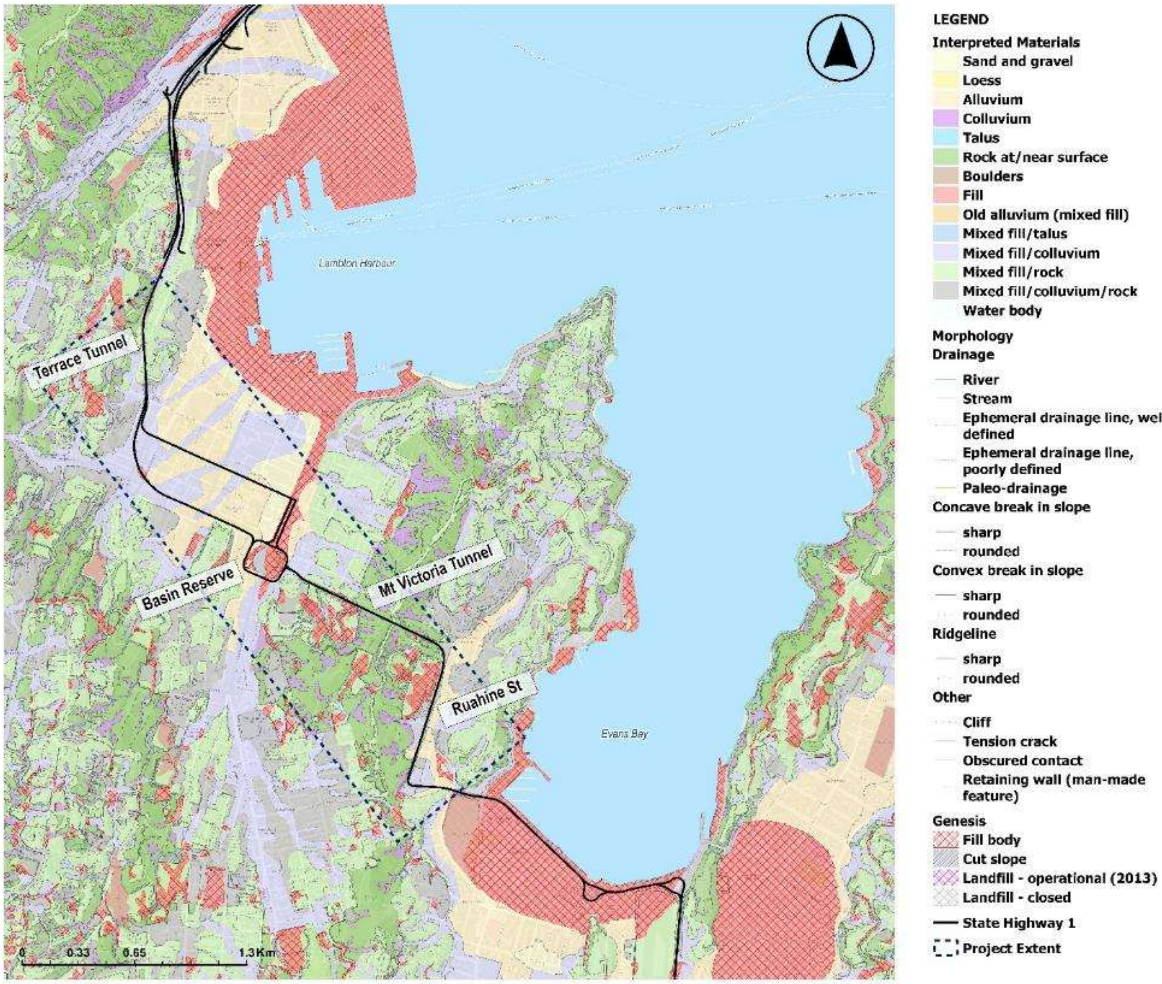

Figure 3 – Geomorphology of the Wellington area (after GNS, 2020)

Natural Hazards

Natural Hazards Context

56. The predominant natural hazard along the route is from earthquakes, which can cause:

    i. Active fault rupture
    ii. Ground shaking in earthquakes
    iii. Tsunami inundation
    iv. Liquefaction and lateral spreading
    v. Earthquake induced landslides
    vi. Failure of existing infrastructure along the route
    vii. Potential building damage and collapse, closing the corridor due to safety concerns

57. The following climatic hazards also have the potential to affect the route:

    i. Landslides triggered by rainfall
    ii. Local flooding
    iii. Inundation with sea level rise associated with potential climate change

Active Fault Rupture

58. The geological maps and active fault database show active faults as well as faults not considered to be active in the Wellington area, see Figure 4. The faults in red (Wellington Fault and Evan Bay Fault) were considered to be active at the time of preparation of the geology maps in 1996-2000.

Figure 4 – Active and other faults in the Wellington CBD and eastern suburbs (after GNS, 2000)

59. The fault line through the Basin Reserve area was considered at the time to be not active and hence was shown as a black line and passing through the western part of the Basin Reserve.

60. Figure 5 from Kaiser et al (2019) indicates that the fault is located more towards the eastern part of the Basin Reserve. This more easterly location is also consistent with the geotechnical investigations carried out by WSP (Opus, 2012) which identified a fault, but then it was not considered to be active.

61. However, more recent studies (Kaiser et al, 2019) including offshore studies by NIWA (Barnes et al, 2019) indicate the fault through the Basin Reserve area to be active, see Figure 5 and Figure 6, and is now known as the Aotea Fault.

62. Figure 4 also shows a fault on the eastern side of Mt Victoria, which was previously not considered to be active (later investigations and research indicate that this may be active as discussed later in this report). The location of this fault on the eastern side of Mt Victoria tunnel is shown to cross Ruahine Street and run through the suburb of Hataitai, and then cross Wellington Road near the southern end of this project, see the dashed black line in Figure 7. This was further investigated as this could potentially cross the alignment of the existing as well as the proposed second Mt Victoria tunnel.

63. A review of LiDAR images indicates that there are other lineaments as shown in green on the same Figure 7. These lineaments cross the existing Mt Victoria Tunnel and the adjacent pilot tunnel to the north. The recent assessment indicates that a more accurate location of the fault shown as a black dotted line on Figure 6 may be the locations shown in green.

64. The location of this fault sub-parallel to and between the active Aotea and Evans Bay faults, as well as the recent discovery of offshore active fault segments trending towards this fault at the harbour edge (see

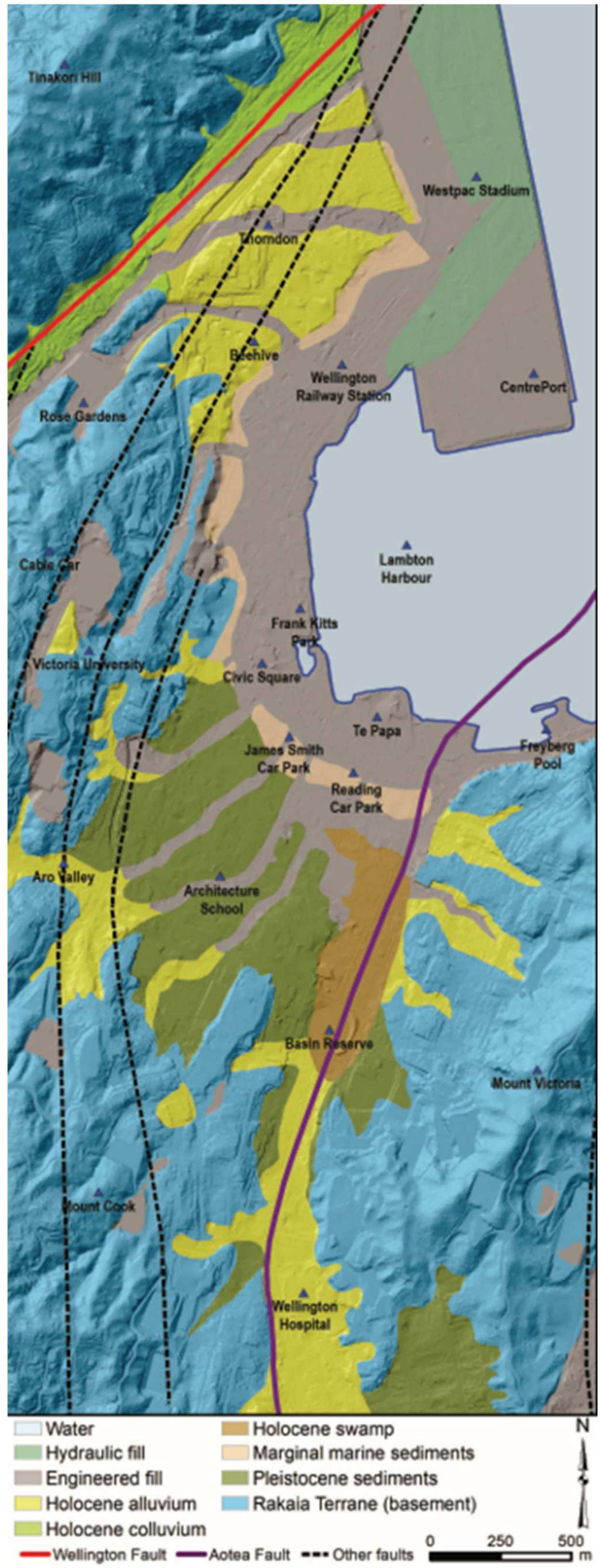

Figure 5 – Aotea Fault crossing the Basin Reserve area (shown in purple, after Kaiser et al, 2019)

Figure 6 from Barnes et al, 2019) indicate that there is a possibility that this fault may also be active. Further investigations are being carried out to confirm the location of the fault and its activity.

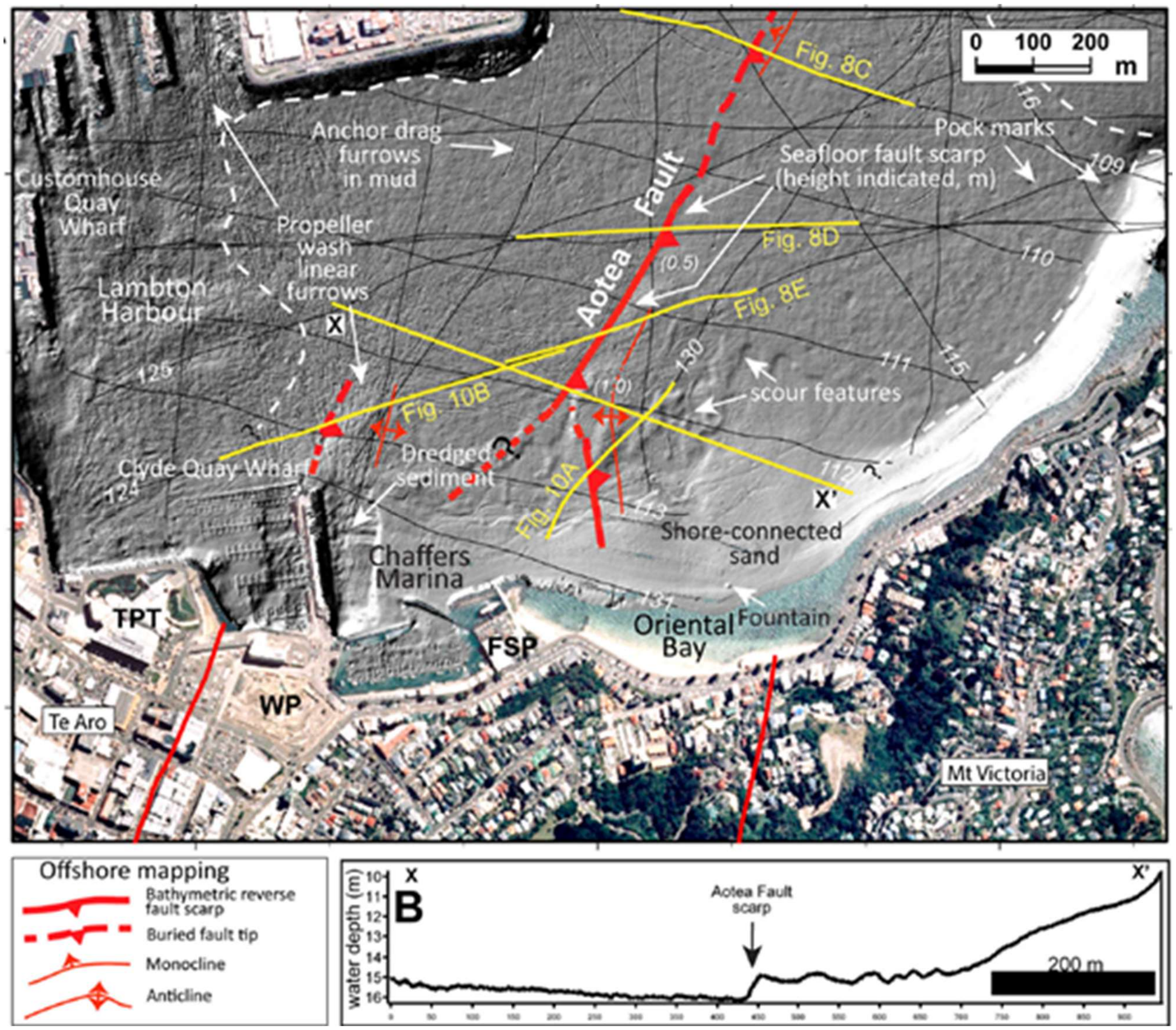

Figure 6 – Active faults from Offshore Investigations by NIWA (after Barnes et al, 2019)

Figure 7 – Location of Fault, east of Mt Victoria (black), and lineaments from LiDAR

Ground shaking

65. This section of SH1 where the proposed Project is located is in Wellington where there is potential for intense ground shaking from earthquakes. Such ground shaking could give rise to the effects of liquefaction, landslides, damage to infrastructure and buildings, as discussed below.

66. The site-specific seismic hazard study (WSP, 2025) provides the levels of ground shaking expected for shallow rock sites (Terrace and Mt Victoria Tunnels) and deep soil sites (Basin Reserve) for the Project.

Liquefaction and lateral spreading

67. Liquefaction hazard maps and consequent ground damage hazard maps were prepared by Works Consultancy Services (Brabhaharan, 1994) and published by the Wellington Regional Council (1993).

68. An extract from liquefaction hazard maps for the Wellington City area from the current Greater Wellington Regional Council website is reproduced in Figure 8.

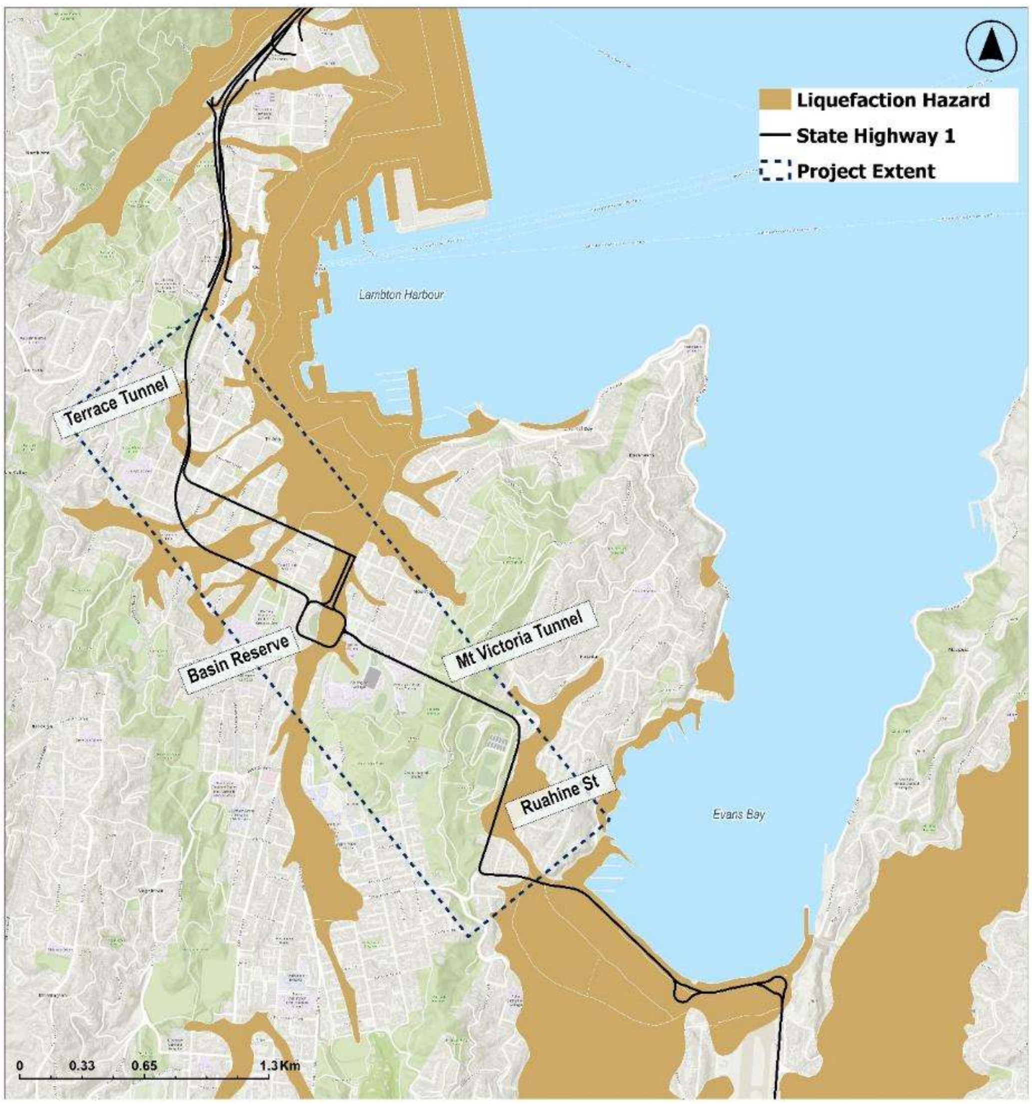

Figure 8 – Liquefaction hazard in Wellington CBD and eastern suburbs (after Greater Wellington Regional Council)

69. The maps show the liquefaction hazards in parts of the Te Aro flats, in the Basin area, particularly to the north and east and sections of Ruahine Street and Wellington Road. The investigations for previous projects in the area indicate that the soils are predominantly fine-grained silts with some sand layers which could liquefy.

70. An assessment by Opus (2012) indicated subsidence in the order of 250 mm at the Basin Reserve area, with a third of that from the upper 10 m of soil profile. The current state highway along the south and western parts of the Basin is on higher ground and is less prone to liquefaction and associated ground damage.

Tsunami inundation

71. Tsunami inundation and evacuation zones have been published by the Wellington Region Emergency Management Group, and an extract from that is reproduced in Figure 9. The map shows that the Basin Reserve and Vivian Street are in a yellow evacuation zone, ie likely to be inundated in a very large tsunami event. The Mt Victoria tunnel to Wellington Road areas will be located outside the red, orange and yellow zones for evacuation. However, the Wellington Road area will end in an orange zone for tsunami evacuation.

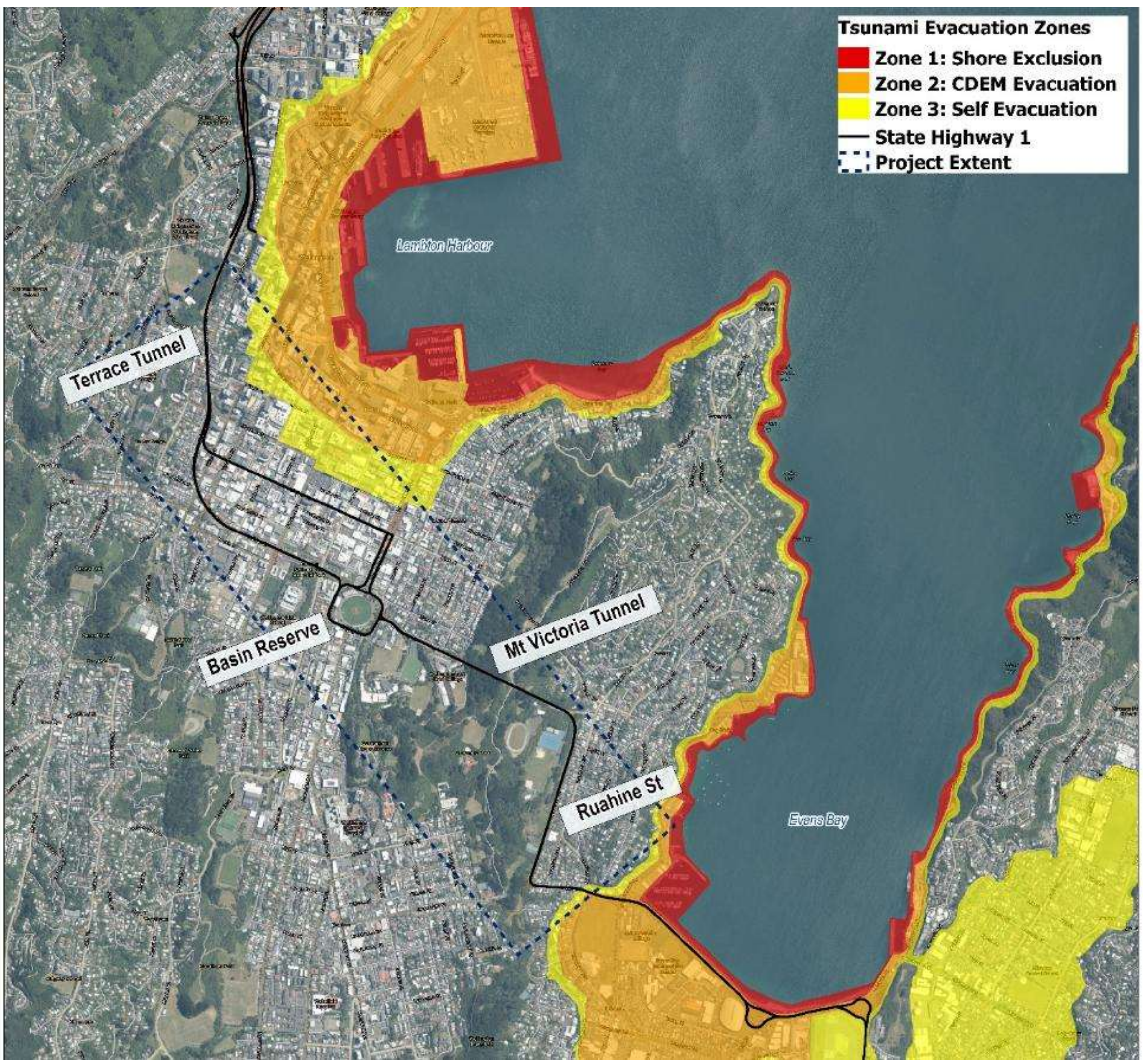

Figure 9 – Tsunami Evacuation Zones in Wellington CBD and Eastern Suburbs (after Wellington Region Emergency Management Office)

Earthquake induced landslides

72. SH1 crosses Mount Victoria through the Mount Victoria Tunnel between the Basin Reserve and the suburb of Hataitai in the east. The areas prone to earthquake induced failures are around both west and east portals of the existing tunnel, in particular the cut slopes which have been formed at very steep slopes of greater than 70 degrees and the hillsides to the north and south of eastern portal.

73. The earthquake induced landslide hazard study (Brabhaharan et al, 1995) shows the landslide hazard in the area, see Figure 10.

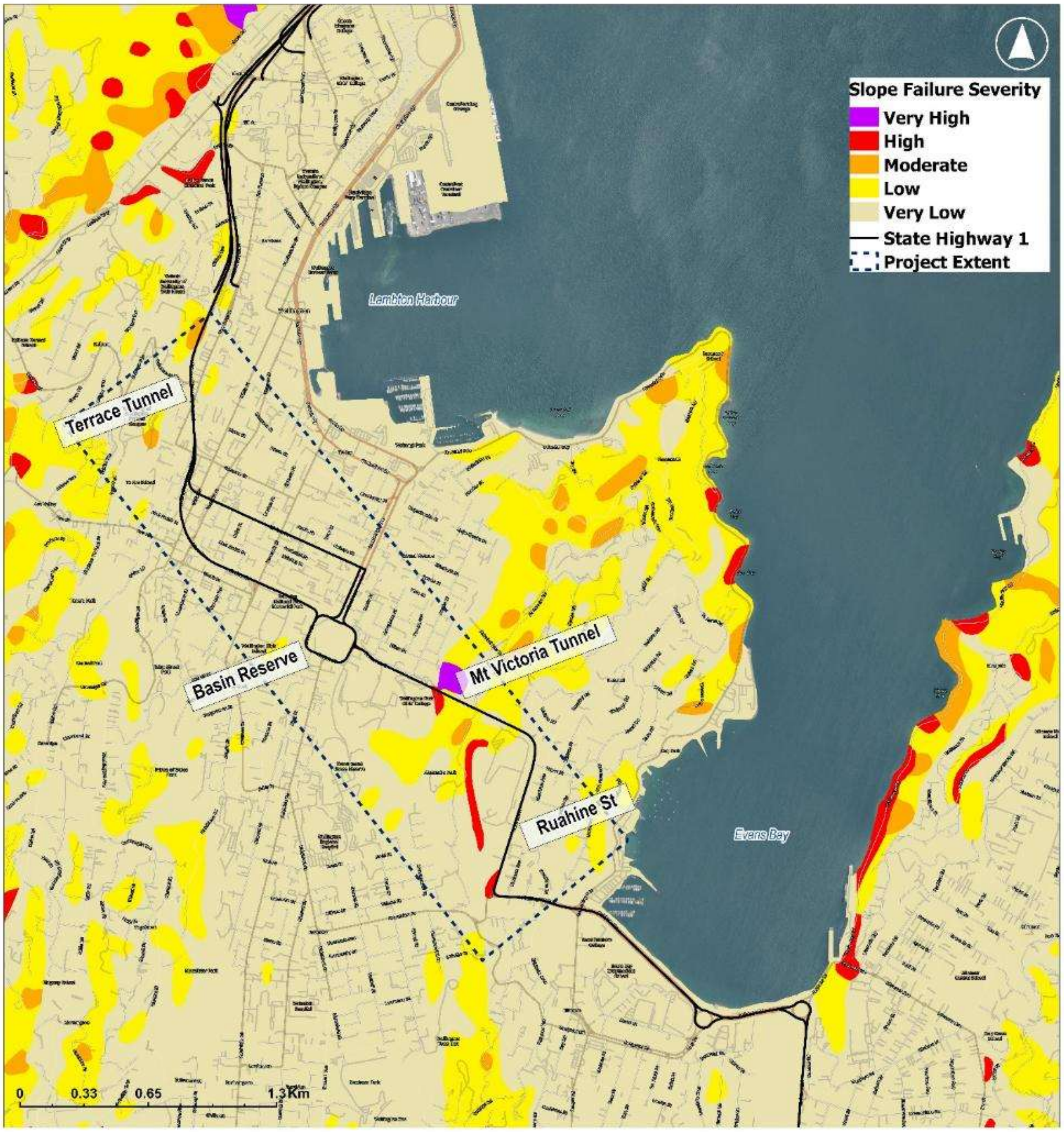

Figure 10 – Earthquake induced landslide hazard in Wellington CBD and eastern suburbs (after Greater Wellington Regional Council)

74. The integrated Wellington region transport resilience study (Opus, 2012) indicated that the slopes around the Mt Victoria tunnel portals are expected to fail in a large earthquake closing the tunnel access leading to significant outage.

75. It is understood that geotechnical investigations for the Memorial Park tunnel (Arras Tunnel) project in the sloping area near the intersection of Sussex Street and Buckle Street exposed veins filled with sand, and this was considered to be an indication of potential past slope instability and cracking of the ground that may have been filled subsequently with sand deposits or liquefaction and ejection of sand. This indicated the potential for slope instability in this area.

Post-earthquake building damage hazard

76. A key observation from the 2010-2011 Canterbury earthquake sequence which reinforced overseas observations was that access along inner-city transport routes was closed due to damage or collapse of buildings and safety hazards from buildings damaged by the earthquakes and aftershocks. Considering this observation, the post-earthquake availability state of inner-city roads was assessed considering the type and height of buildings along the routes, and the likely impact on accessibility considering potential building collapse, damage and safety hazards for road users (Brabhaharan, 2021). Higher and more vulnerable building topologies could cause more disruption due to damage or safety concerns.

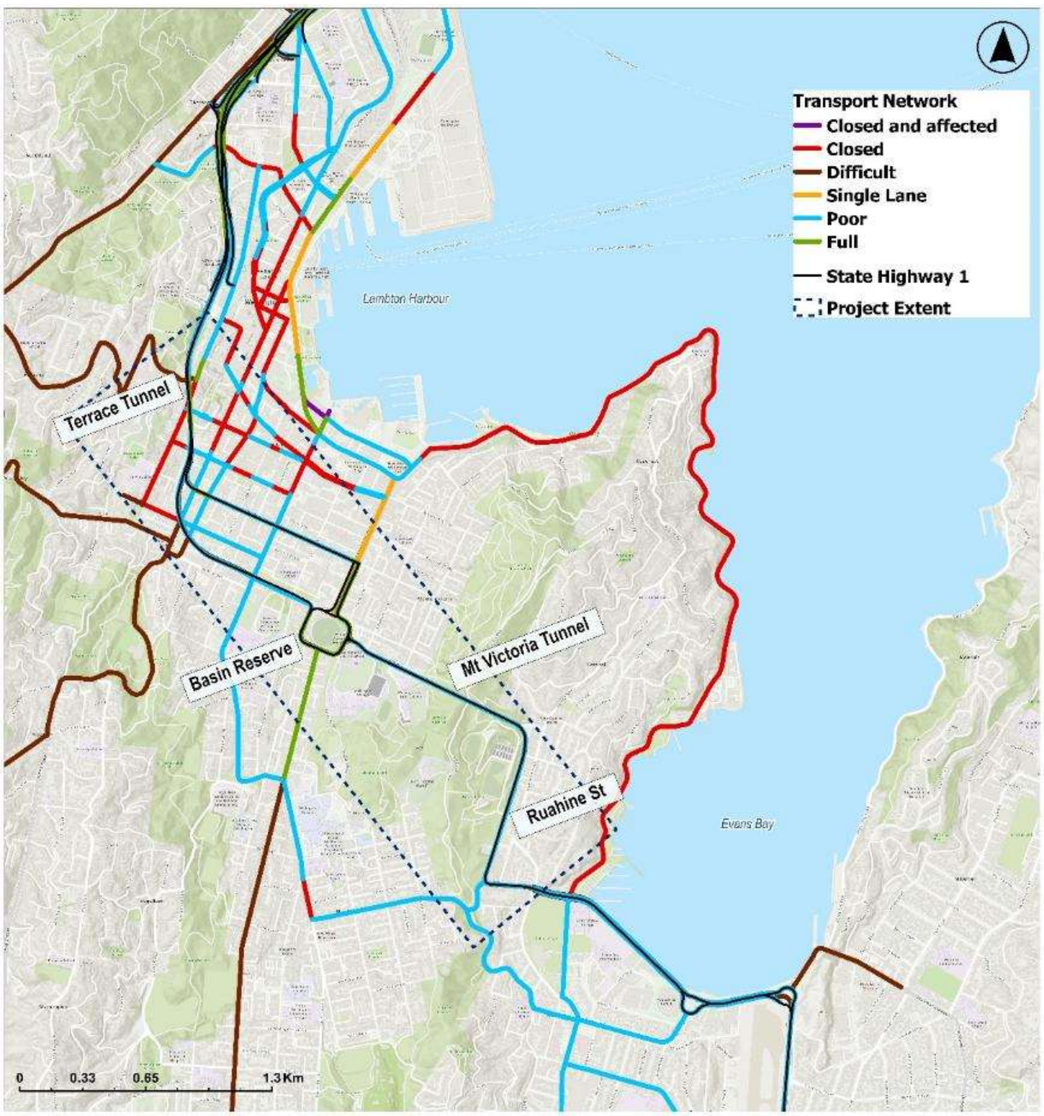

Figure 11 – Resilience of transport network after a major earthquake in inner-city Wellington due to collapse or damage to buildings along the routes (after Brabhaharan 2018)

77. The expected availability state of the inner-city transport routes in the Wellington central business district is shown on Figure 11. This assessment shows that although the roads in the flat inner-city areas themselves are unlikely to be damaged by the earthquake sufficiently to cause closure, they could still be closed due to earthquake damage to or collapse of adjacent buildings. It is noted that damage to large buildings along Cambridge and Kent Terraces could lead to closure of access for safety reasons.

Flooding

78. Wellington CBD has flood hazards that could cause flooding inundation following periods of heavy rainfall. The areas of potential flooding and priorities for action are shown on Figure 12, reproduced from the Wellington City Council geospatial hazard maps in the district plan. The map shows the potential for flooding south of the Terrace Tunnel, and along parts of the Te Aro flats, Cambridge - Kent Terrace, Basin Reserve and Ruahine Street corridors.

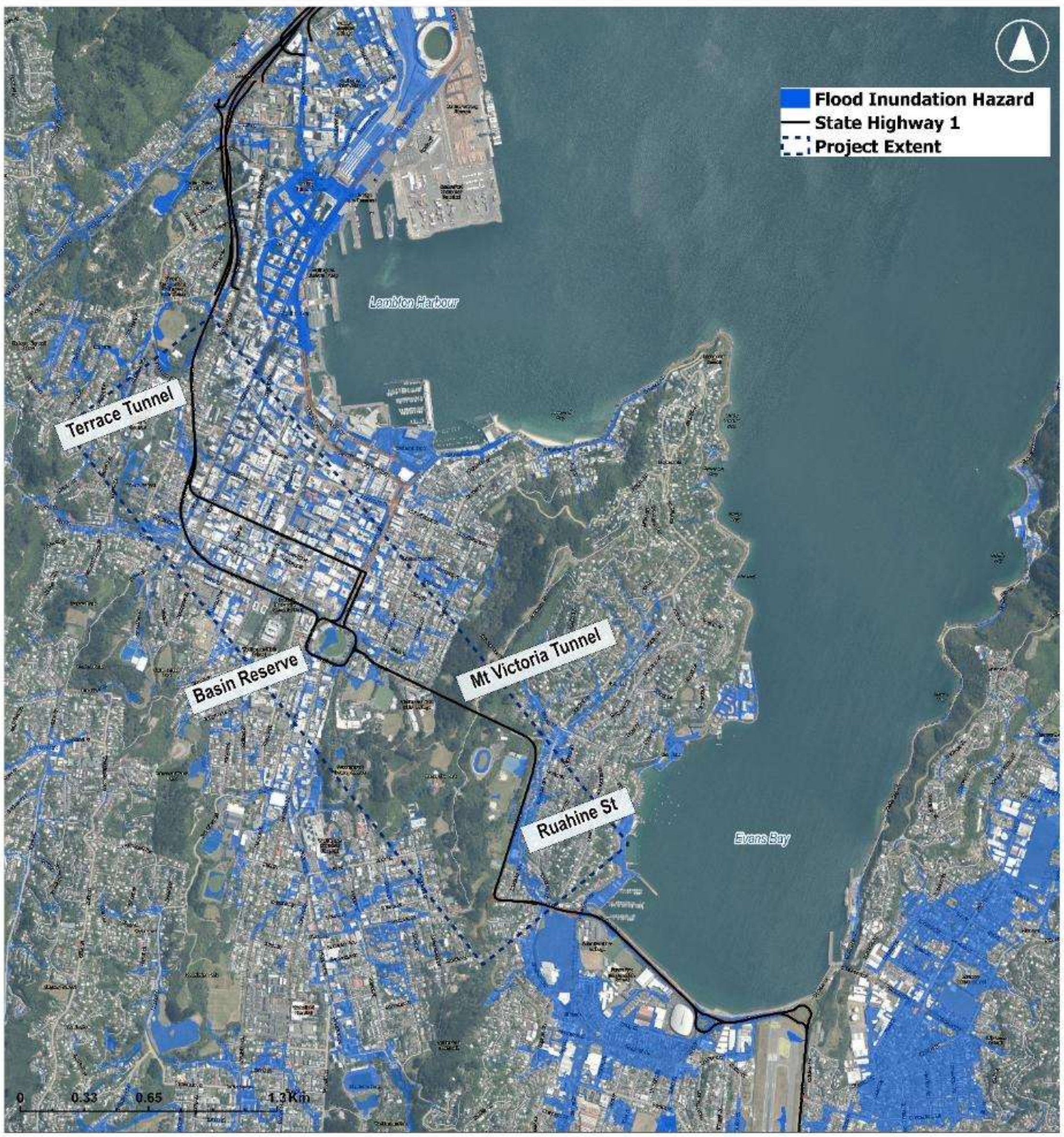

Figure 12 – Flood hazards and action priorities in Wellington City (after Wellington District Plan, 2026)

79. A more detailed modelling of the flood hazard has been carried out as part of this project taking into consideration climate change, assuming an RCP 6 level of climate change. The flooding hazard has been assessed and classified (Figure 13) for critical areas and are presented in Figure 14 and Figure 15 for the current state and post-construction of this Project. The hazard classification is in accordance with Australian Rainfall and Runoff Methodology (Engineers Australia, 2019), see Figure 13.

80. A more detailed close up of the flood hazards assessed in three of the critical areas are shown on Figure 16 through Figure 18.

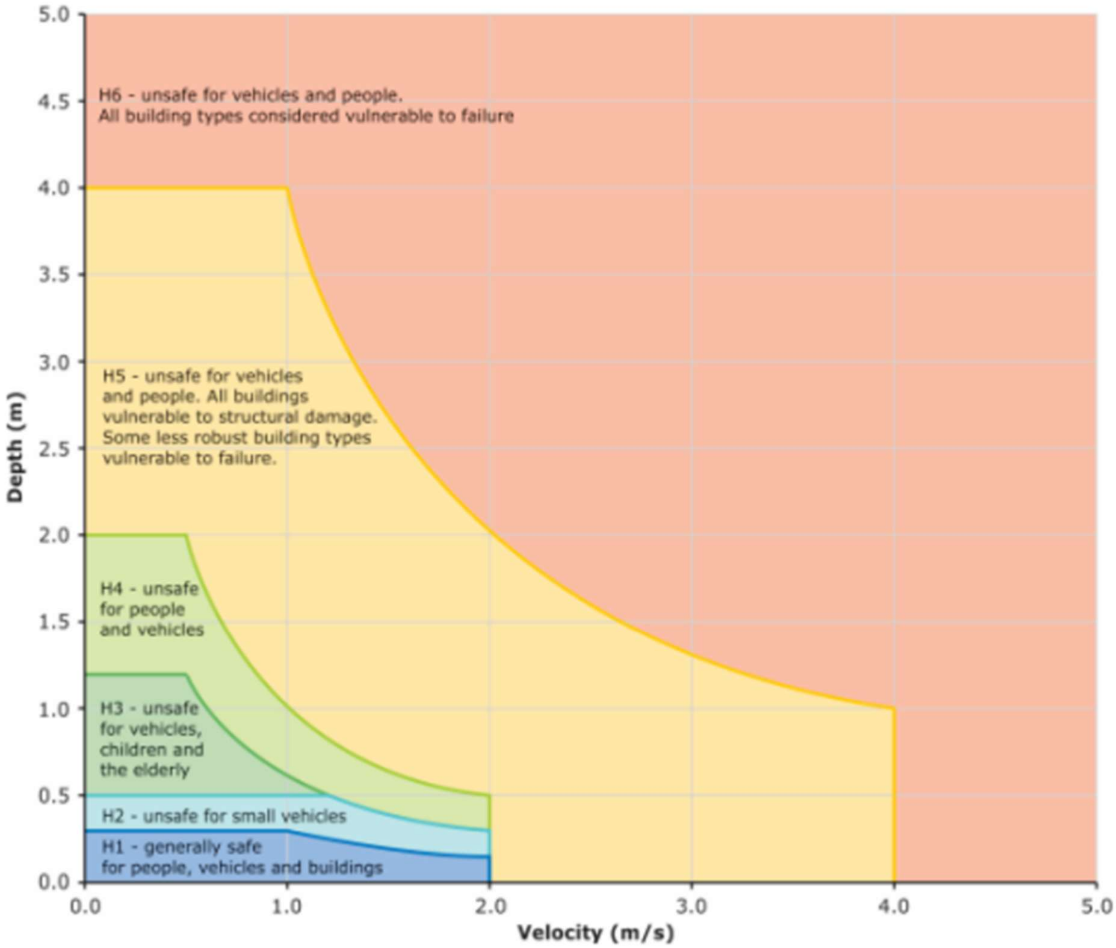

Figure 13 – Flood hazard rating

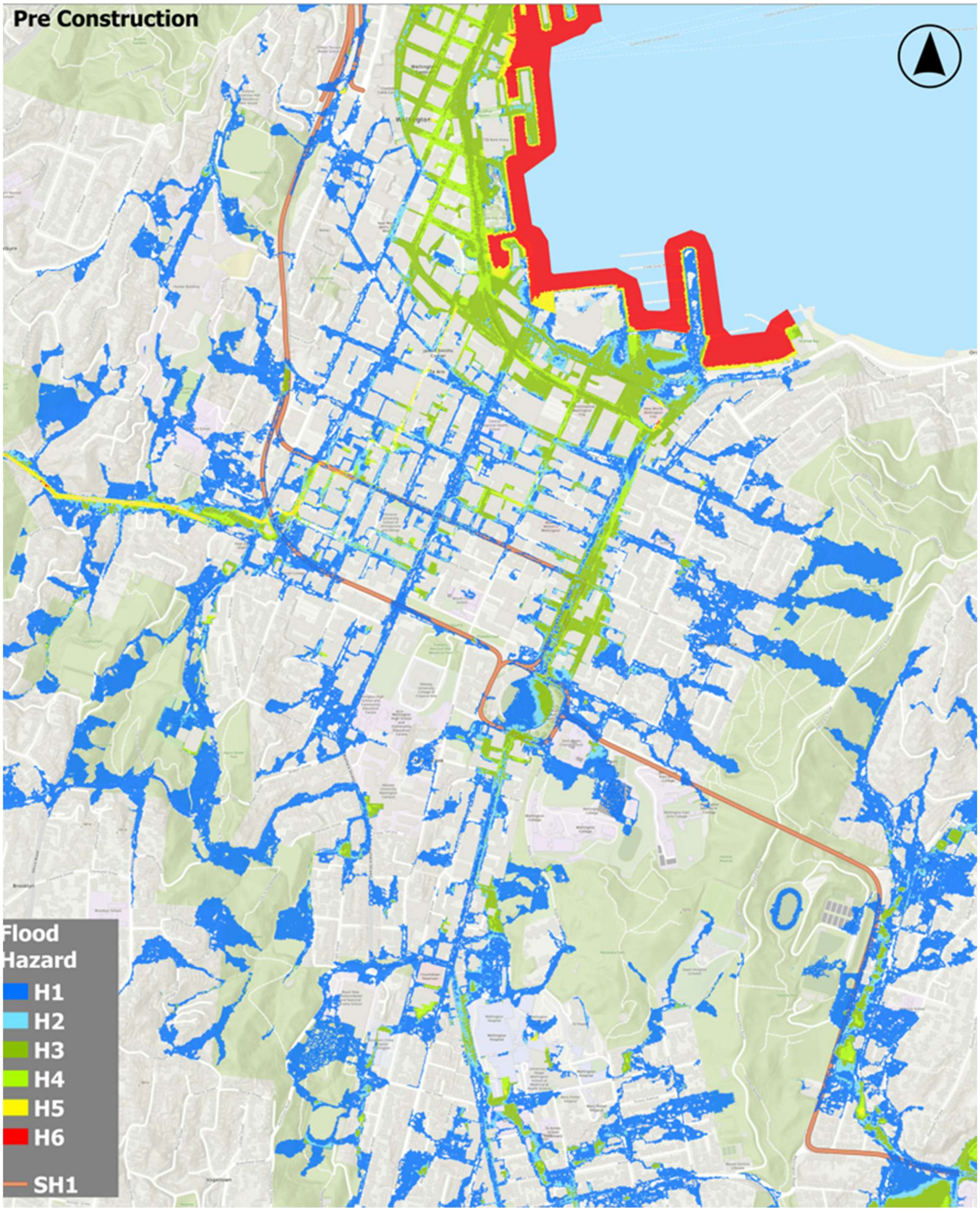

Figure 14 – Flood hazards – Pre – construction (1% AEP with climate change)

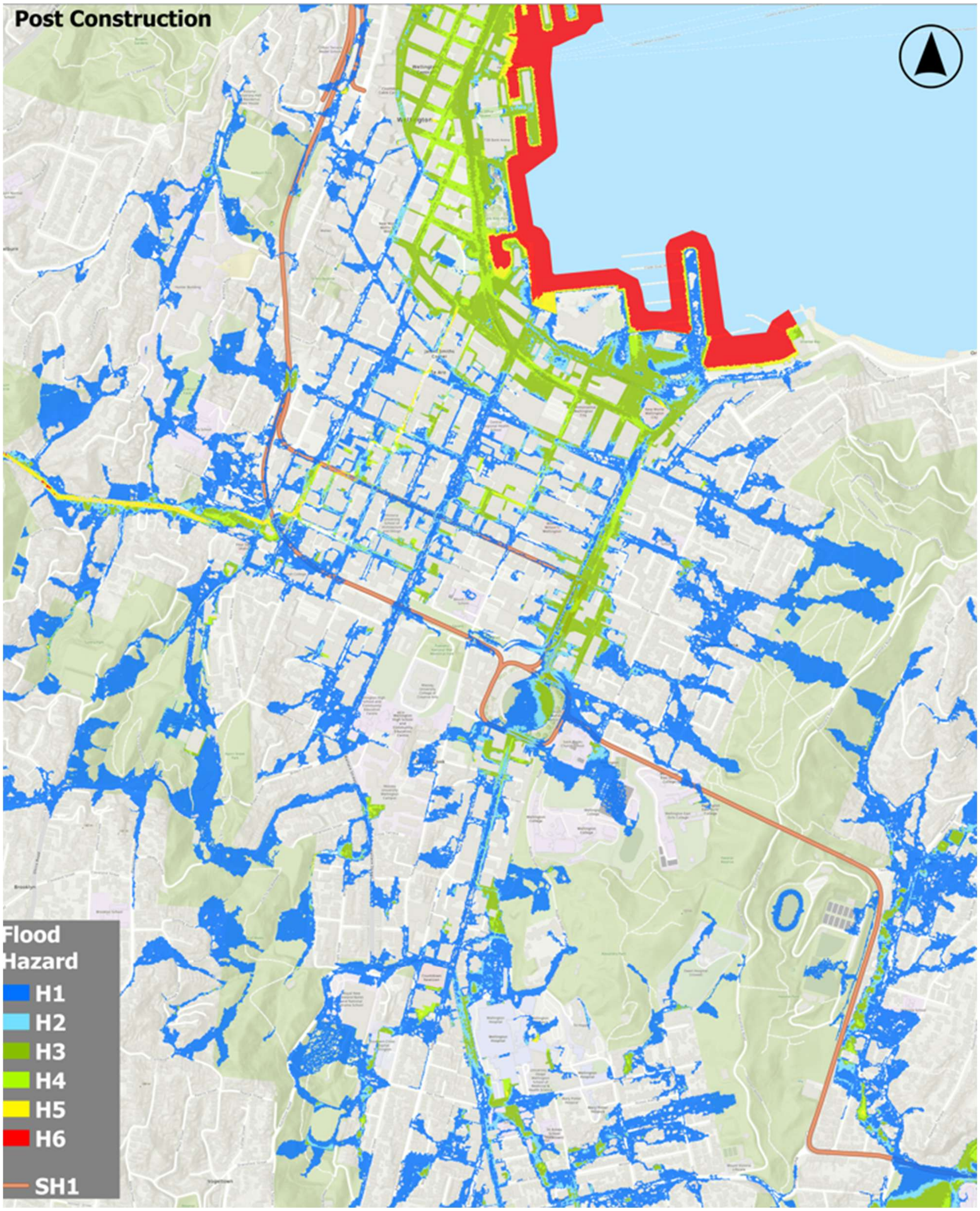

Figure 15 – Flood hazard – post-construction (1% AEP with climate change)

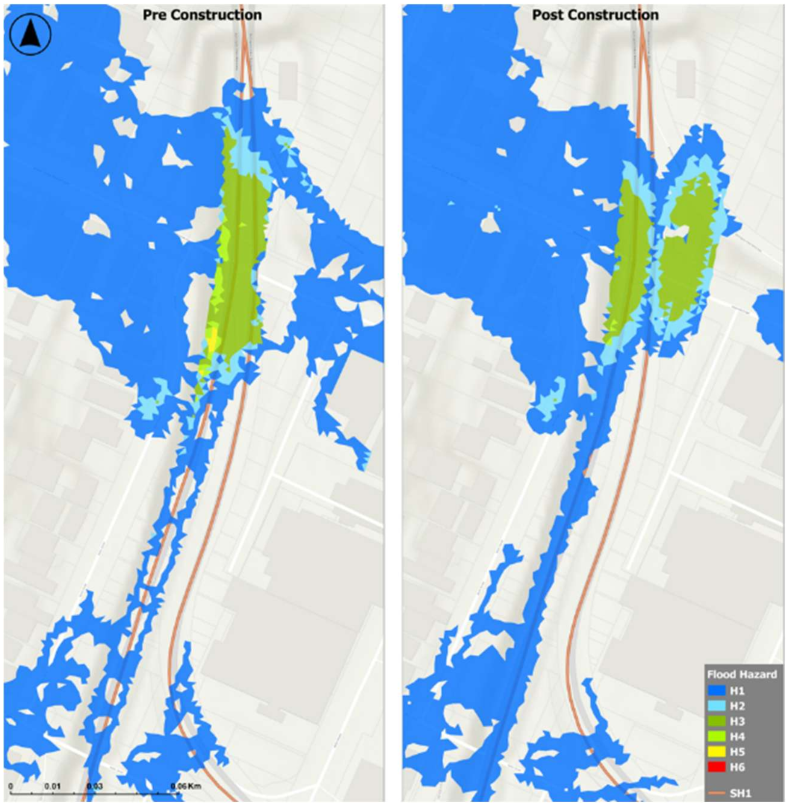

Figure 16 – Flood hazard south of the Terrace Tunnel before and after construction (1% AEP with climate change)

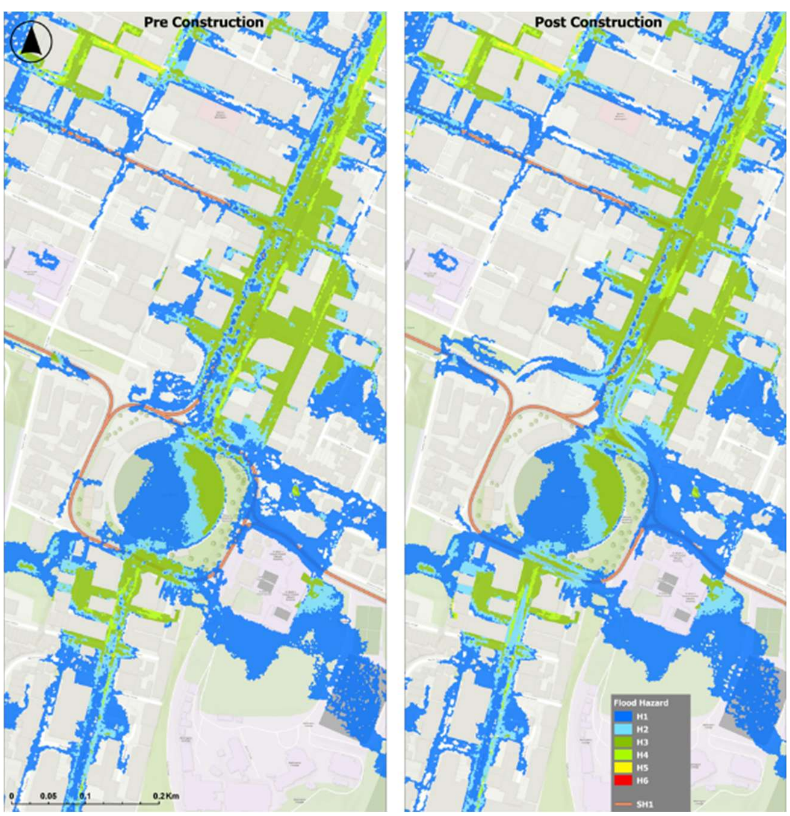

Figure 17 – Flood hazard assessed at Cambridge / Kent Terrace and the Basin Reserve area, before and after construction (1% AEP with climate change)

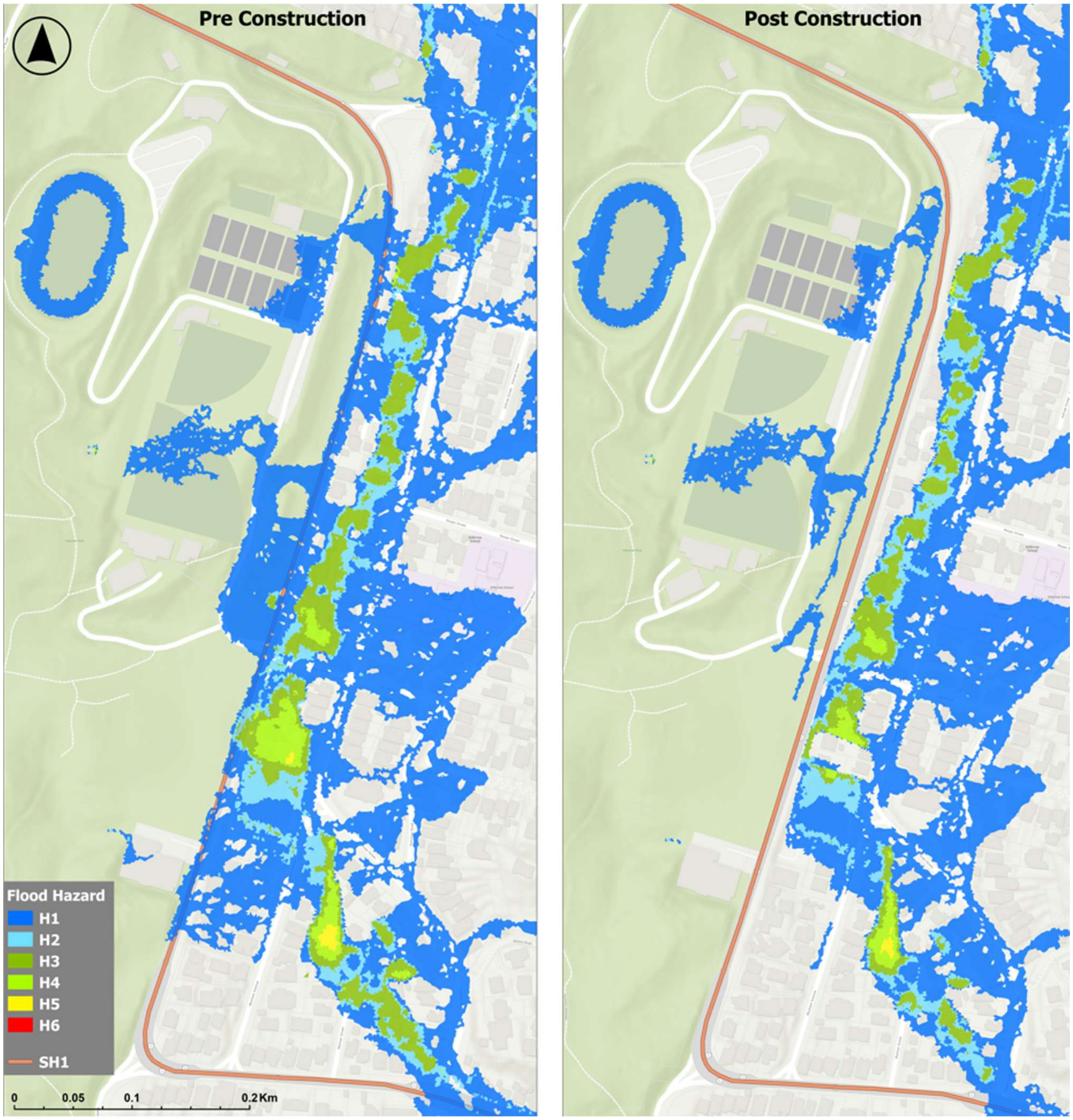

Figure 18 – Flood hazards assessed along Ruahine Street (1% AEP with climate change)

Sea level rise

81. Climate change is expected to lead to sea level rise due to the higher global temperatures and the associated melting of the ice shelves and thermal expansion of sea water.

82. The potential for sea level rise and recommendations for local authorities by the Ministry for the Environment (MfE, 2017) indicates the expected rise in sea level over the next 100 years (to 2120) varies between a low 0.6 m rise, to a high 1.4 m rise. MfE recommends that for major new infrastructure, the higher hazard scenario be adopted, which would be about 1.4 m. A rise of 0.6 m will have minimal immediate inundation effects for the city, but a 1.4 m rise will have a large impact on Wellington City, see Figure 19. Sea level rise is unlikely to affect the Basin Reserve to Wellington Road corridor under consideration in this project but would affect Cobham Drive immediately to the east of Wellington Road, outside the Project area.

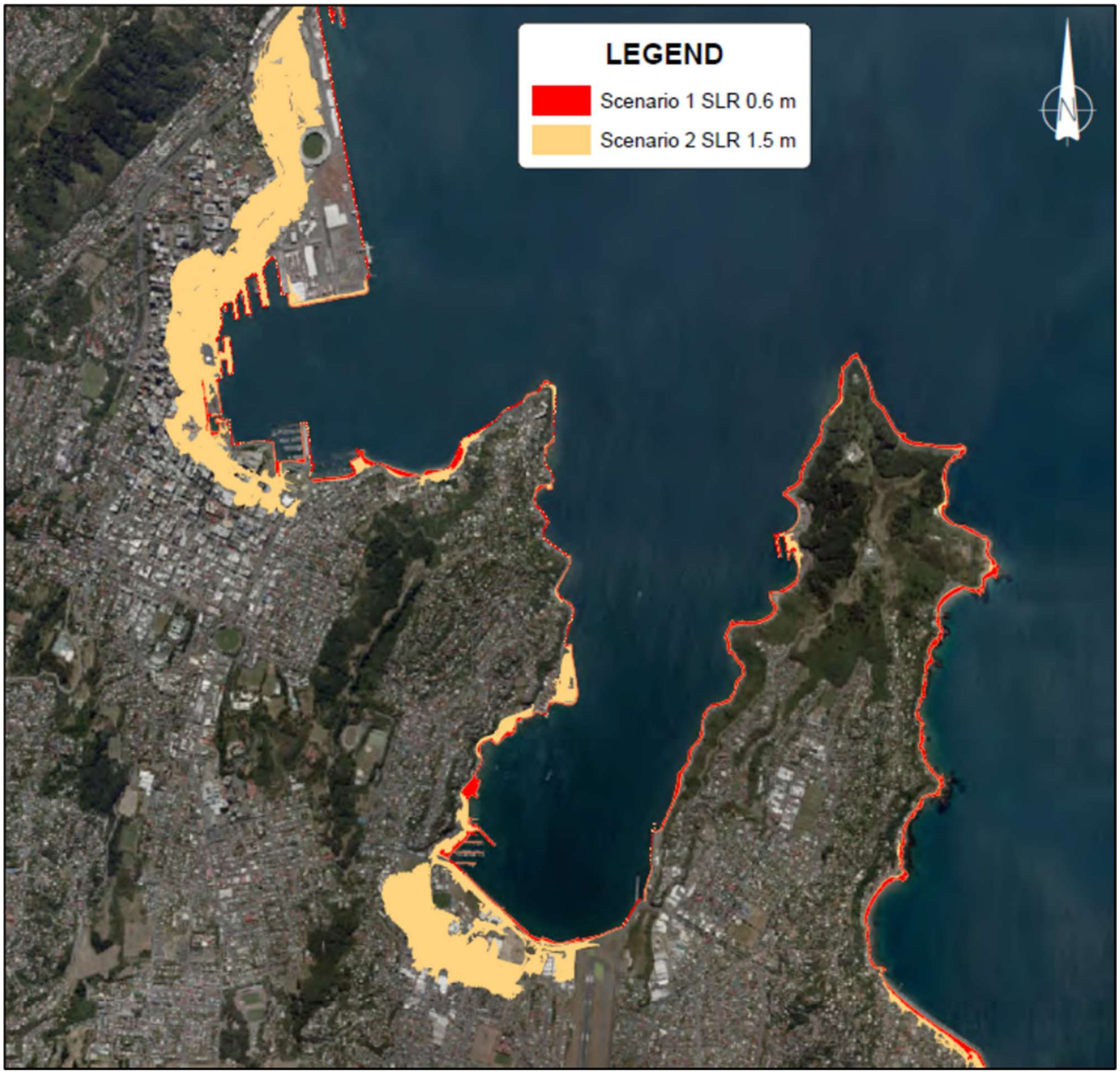

Figure 19 – Sea level rise impact on Wellington CBD (after Wellington City Council, 2014)

5. Resilience Context

Introduction

83. In carrying out an assessment of the natural hazards and resilience, the overarching transport and policy context has been considered, particularly in relation to resilience.

84. As described below the SH1 corridor through Wellington City is a strategic transport link in the region, and the national and regional policies require resilience be taken into consideration as key priorities in the development of transport infrastructure.

85. The NPS-I and the GPS, as well as resilience studies for the Wellington land transport system and Planning Emergency Levels of Service (PELOS) studies, as discussed below, require that resilience is a key consideration in the development of transport projects, and is important for the functionality of the Wellington Region in the event of natural hazard and operational events.

Strategic Transport Network

86. The SH1 Wellington corridor is the primary land transport link between Wellington CBD and the rest of the Wellington Region, and the Wellington International airport and eastern suburbs, see Figure 20.

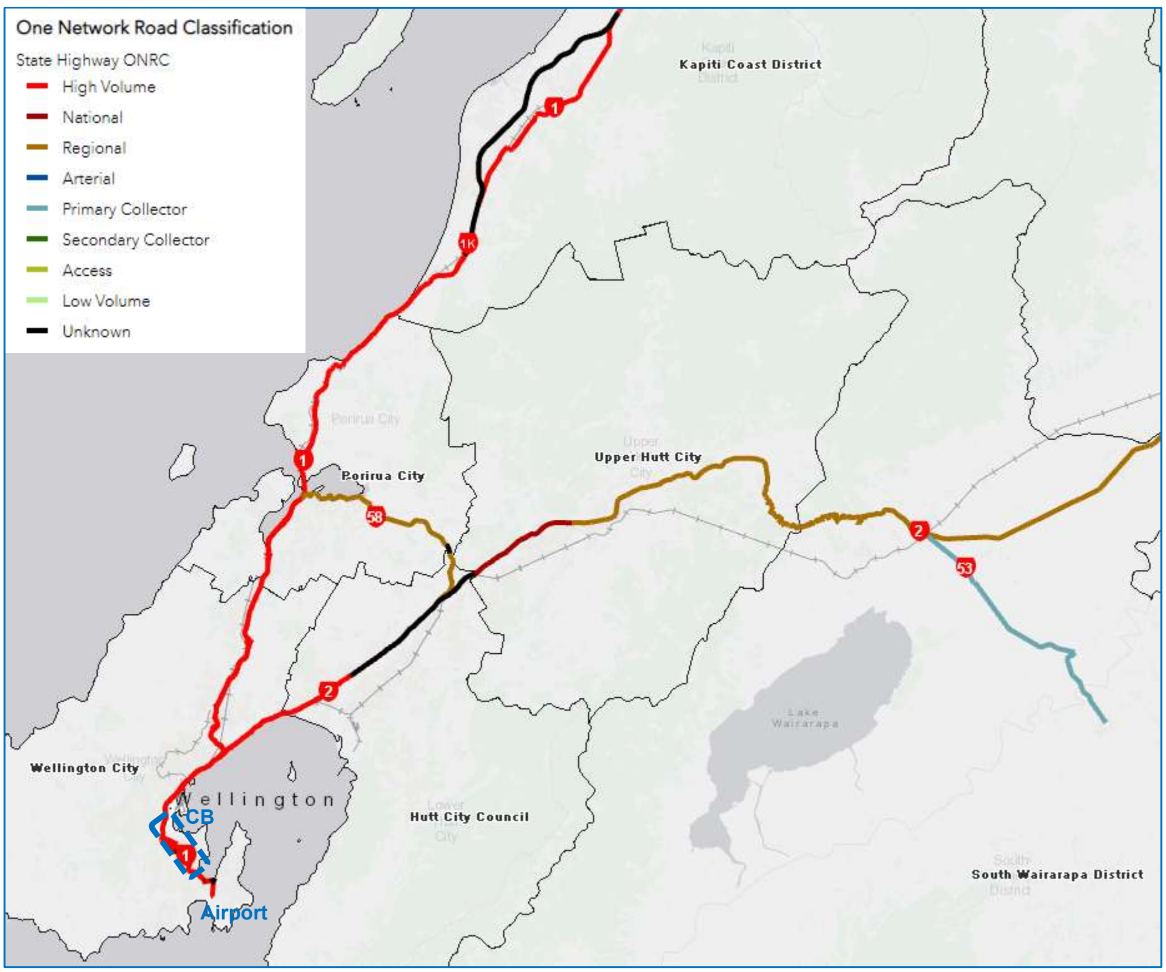

Figure 20 – Transport Routes – One Network Road Classification (ONRC) [the Project area is shown as dashed blue box]

National Policy Statement for Natural Hazards

87. The NPS-NH requires decision-makers to assess risk using a risk matrix and manage it proportionately. Very high risk must be avoided, and other risks managed through mitigation measures. Decisions must be based on the best available information, even where that information is uncertain or incomplete. The NPS-NH does not apply to infrastructure and focuses on land development.

National Policy Statement for Infrastructure

88. The NPS-I provides national direction under the Resource Management Act 1991 (RMA) to guide the efficient development, management, and upgrading of infrastructure across New Zealand, including in relation to natural hazards. It has an objective to ensure that infrastructure is well-functioning, resilient and compatible (as far as practicable) with other activities.

89. NPS-I Policy 1 requires decision makers to recognise that the benefits of infrastructure also include: (f) supporting New Zealand's emissions reduction targets and mitigating the effects of climate change; and (g) reducing the risks from, and improving resilience to, natural hazards and climate change.

90. Policy 2 requires decision makers to recognise that the operational and functional needs of infrastructure include the need to (e) locate where services are required, including in areas at risk to natural hazards, whether the infrastructure has been spatially identified in advance, and (f) manage risks from natural hazards.

91. Policy 4 Enabling the efficient and timely operation and delivery of infrastructure activities, requires that decision makers must (f) enable the upgrading of infrastructure where this will (i) improve the resilience of infrastructure to the risks from natural hazards and effects of climate change.

Government Policy Statement on Land Transport

92. The GPS outlines the Government's strategy to guide land transport investment over the next 10 years. It also provides guidance to decision-makers about where the Government will focus resources. The GPS operates under the Land Transport Management Act 2003, which sets out the scope and requirements for the GPS. The GPS influences decisions on how money from the National Land Transport Fund (the Fund) will be invested across activity classes, such as state highways and public transport. It also guides NZTA and local government on the type of activities that should be included in Regional Land Transport Plans and the National Land Transport Programme.

93. The GPS sets out four key strategic priorities:

    i. Economic Growth and Productivity

    ii. Increased Maintenance and Resilience

    iii. Safety

    iv. Value for Money

94. The GPS for Land Transport emphasises the strategic priority to increase maintenance and resilience to effectively manage and reduce current and future risk and adapt to these challenges.

95. The overarching strategic priority of economic growth and productivity also requires operational resilience of the transport network and a network resilience to natural hazards including the increasing frequency and severity of weather events attributable to climate change.

96. The second Mt Victoria Tunnel and Basin Reserve upgrade are identified in the GPS as Roads of National Significance upgrades to the state highway network under the GPS 2024.

97. In summary, the NPS-I as well as the GPS, both require that the functional and operational needs of transport infrastructure are key drivers for economic growth and productivity, and improving the resilience to climate change and natural hazards is a priority. This includes upgrading of infrastructure where this will improve resilience to the risks from natural hazards and effects of climate change.

Resilience

98. Resilience is the ability to recover and return to functionality after shock events or ability to adapt to progressive events. Resilience can be diagrammatically represented by Figure 21 for shock events that compromise functionality and the time for return to functionality (Brabhaharan, 2006).

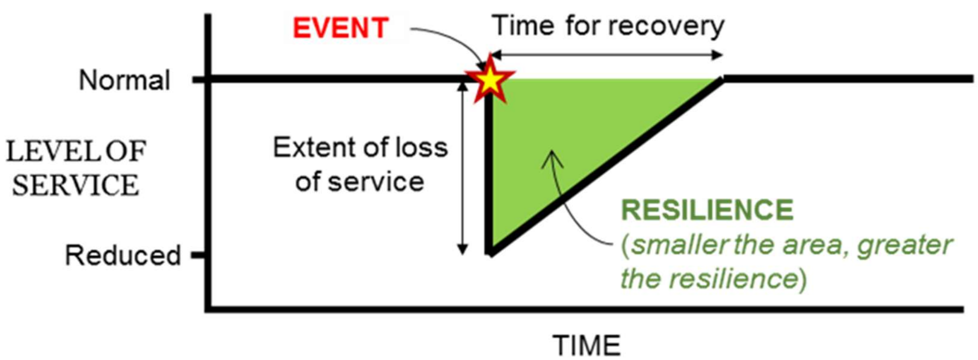

Figure 21 – Diagrammatic representation of Resilience for lifelines. (after Brabhaharan, 2006)

99. Though the diagram maintains simplicity and shows recovery from a shock event as a straight line, in reality the recovery is likely to be in stages, with the reduced state of functionality remaining for a period of time before response, and intermediate stages of recovery of functionality before full recovery, for example opening of the road for four-wheel drive access or single lane access.

100. There are several aspects that need to be considered for the resilience of transport systems and networks, and these are:

i. Route resilience – robustness of the route to remain functional or be able to be rapidly returned to functionality after shock events

ii. Network resilience

- Redundancy – availability of alternate routes, if one or more routes are closed by shock events
- Interconnectivity – ability of the network to readily allow users to move from one route to the other to avoid areas of impact or closures

iii. Maintenance and operations – ability to remain functional in maintenance and operational incidents

101. It is also important to consider the resilience to a range of events such as:

i. Different levels of natural hazards from frequent lower intensity hazards to infrequent high impact events

- Operational events
- Low impact, high probability events (LIHP)
- High impact, low probability events (HILP)

ii. Anthropogenic hazards, such as:

- Operational events, such as accidents and maintenance
- Transport of hazardous substances such as petroleum

102. The different hazards and the resilience of the options are considered in the assessment of the resilience of the option that have been developed by the Project team.

Wellington Transport Resilience Context

Wellington Transport Resilience Business Case

103. The Wellington Transport Resilience programme business case (Transport Resilience PBC) led by NZTA (WSP Opus, 2018) and approved by its Board sets the resilience context of land transport in the region, including Wellington city, identified important routes, prioritises resilience risks for the system, provides measures to enhance resilience of the Wellington Region land transport system, and provides recommendations for implementation to improve resilience over time. This is therefore a critical landmark study to consider in the development of any transport initiatives in the Wellington region.

104. The Transport Resilience PBC identifies the relative importance of land transport routes in the region as shown in Figure 22.

105. Critical facilities that are important to consider for this part of the network are:

  i. Wellington Regional Hospital
  ii. Wellington Airport
  iii. Wellington Port and Ferry Terminals

106. The Transport Resilience PBC identifies the following routes relevant to this current Project as being very important for the region, as these routes provide access to critical facilities such as the Wellington Regional Hospital and Wellington Airport.

  i. Wellington CBD to Wellington Airport (via the Basin Reserve and Mt Victoria Tunnel)
  ii. Basin Reserve to Wellington Regional Hospital (in Newtown)

107. The Transport Resilience Business case also identifies critical journeys in the region that are important to the functionality of the Wellington region. In the context of this project, the following critical journeys are identified in the resilience business case:

  i. Airport to Wellington CBD
  ii. Porirua and Hutt Valley to Regional Hospital, Newtown
  iii. Porirua and Hutt Valley to Wellington Airport, Rongotai
  iv. Wellington CBD to Wellington Airport, Rongotai
  v. Wellington CBD to Regional Hospital, Newtown

108. The functionality and resilience of the transport system need to be considered at different levels of hazards to provide operational functionality. The Wellington Transport Resilience PBC considered three levels of events:

  i. Frequent business as usual events
  ii. Low impact, high probability events (LIHP)
  iii. High impact, low probability events (HILP)

109. The Transport Resilience PBC identifies critical resilience risks in the region, which need to be addressed as part of resilience initiatives and future transport projects. For the Project area and corridors in the vicinity, the critical resilience risks identified as very high resilience risks that must be considered and addressed as part of the Project are:

  i. Mt Victoria tunnel portals (vulnerable to failure of the slopes in the portal areas)
  ii. Cobham Drive (vulnerable to liquefaction, lateral spreading and tsunami)

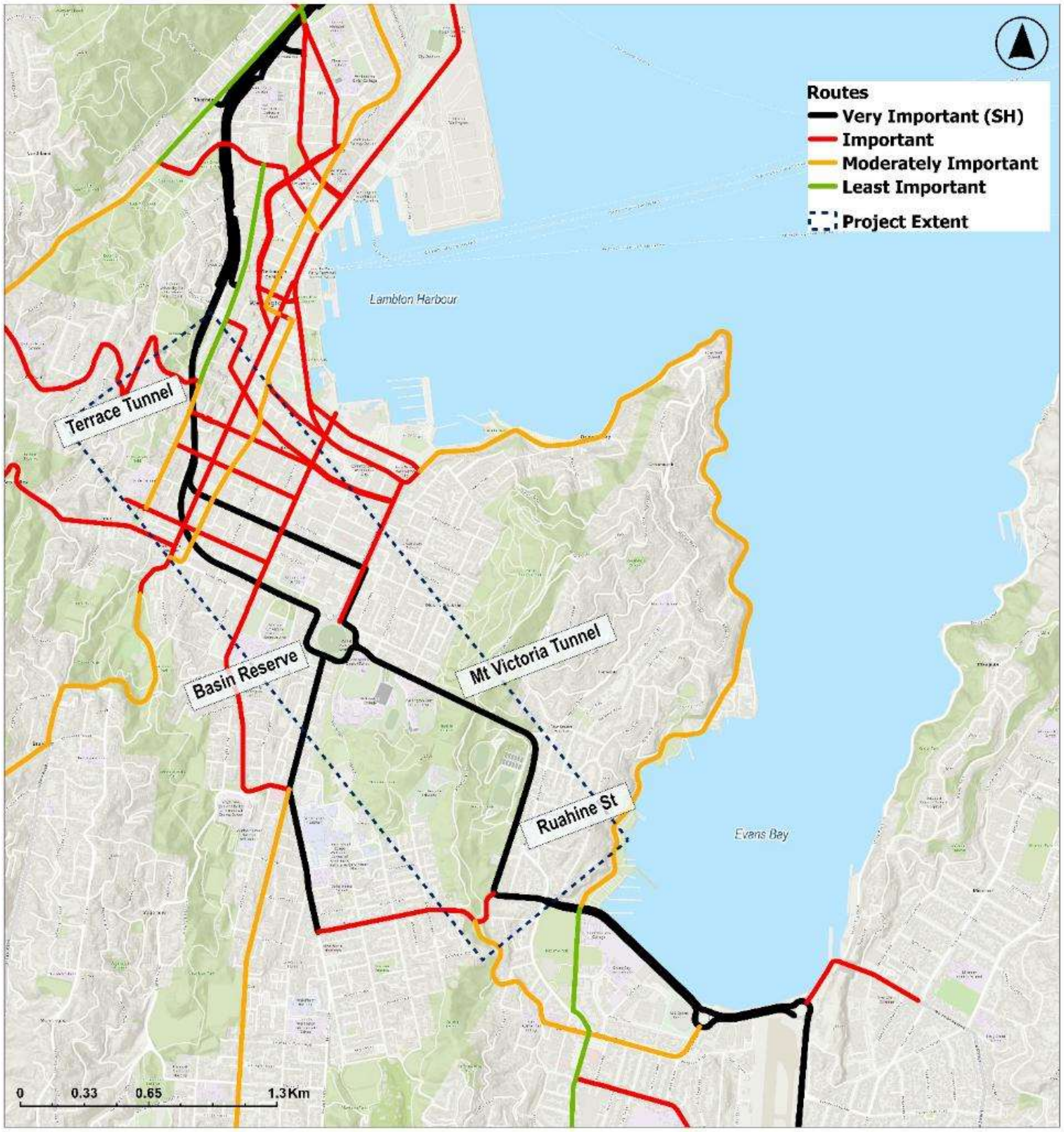

Figure 22 – Importance of routes from Wellington Transport Resilience PBC (WSP Opus, 2018)

Emergency Levels of Service for Priority Routes in the Wellington Area

110. Planning Emergency Levels of Service (PELOS) are goals for the delivery of infrastructure services following a major hazard event, such as an earthquake or flood. A study by Mowll et al (2023) which involved consultation with a wide range of emergency management, road controlling authority and infrastructure professionals characterised the planning emergency levels of service for a range of lifeline facilities including road networks in the Wellington Region. Though the study considered that human needs are hazard-agnostic, the framework was considered for a major regional hazard event, noting that much of the emergency management planning has been based on a "worst case" earthquake such as a rupture of the Wellington Fault, recognising that the system is able to absorb disruptions from smaller events. The Wellington Fault has a recurrence interval in the order of 500 to 1000 years, and therefore the PELOS considered appropriate for Wellington can be considered to be relevant for an earthquake with a return period of 500 to 1000 years.

111. The PELOS for road access developed by the study for Wellington are:

i. Week 1 - Priority 1 routes or immediate alternative routes are to remain open to emergency vehicles during the first week after a major earthquake or other hazard event

ii. First Month - Priority 1 routes are open to emergency and non-emergency vehicles, but the latter vehicles may have restrictions to manage safety issues, during the remaining first month after an event. Priority 2 routes or immediate alternative routes are open to emergency vehicles

iii. Second and third months - Priority 1 and 2 roads are open and managed, Priority 3 and 4 roads or alternates are open for emergency vehicles only and, where resources allow, some public transport services run

iv. Beyond – Full functionality towards a new normal

112. The study noted that road access was a key enabler for other infrastructure sectors to carry out inspections and repairs to other critical infrastructure networks to ensure their functionality. In the context of the SH1 Wellington route, considered as part of this Project, the route provides access into Wellington from the north, as well as access to and from Wellington Airport and Wellington Regional Hospital. Observations from past earthquakes indicate that access to the hospital is critical to ensure that the injured can be taken to hospital following a major natural disaster such as an earthquake. Similarly, with road access from outside the region likely to be cut off for the initial period both along SH1 along the northern corridor and SH2 from east, and Wellington port likely to be out of operation due to earthquake damage exacerbated by liquefaction and lateral spreading, airport access is critical.

113. The northern part of the Wellington Airport runway is on rock and is likely to remain functional, and access to the airport would be critical from the immediate aftermath of a major earthquake to bring in emergency response and recovery personal and medical supplies to treat the potentially large number of casualties. Therefore, the performance of the Terrace Tunnel, the Basin Reserve area (which provides access to both the hospital and airport) and Mount Victoria Tunnels will be critical from the early hours after a major earthquake.

114. A study of the priority routes in the event of an emergency was carried out by Opus (2015) for Wellington City Council. The study showed that the SH1 route between Thorndon and Wellington Airport as well as the local road route to Wellington Hospital are critical for recovery, as reflected in the Very Important routes on Figure 22. These can be considered as Priority 1 routes for recovery after a major event such as a large earthquake.

115. Therefore, from a resilience perspective, this Project which involves upgrading the SH1 route between Thorndon and the airport including the critical areas of the Terrace Tunnel, Basin Reserve and Mt Victoria Tunnel and approaches, as well as the north-south local arterial road connectivity to the hospital through the Basin Reserve is important to enhance the resilience of access both in operational events as well as for providing emergency access in the event of a disaster such as a major earthquake affecting Wellington.

Resilience expectations for the Project

116. Table 1 below sets out appropriate resilience expectations for this Project (as a Priority 1 route), based on the Wellington transport resilience context and the PELOS developed for the Wellington region. These expectations reflect the functionality required to support response and socioeconomic recovery of the region following hazard events of varying severity.

Table 1: Resilience Expectations for the Project

Event | Recurrence Interval	State	Week 1	Remaining 1st Month	2nd and 3rd months	Beyond 3 months
Operational	Full economic functionality	Full functionality	Full functionality	Full functionality	Full functionality

1 in 250 years [LIHP]	Access is important for economic functionality	Continued functionality within 4 hours.	Full functionality	Full functionality	Full functionality
1 in 500 years [Intermediate Event]	Access critical for emergency response.	Accessible by Emergency vehicles within 12 hours.	*Managed access for vehicles.	*Managed access for vehicles.	Near full functionality
1 in 1000 years [HILP | design event]	Access is critical for emergency response and assistance.	Accessible by Emergency vehicles within 2 days.	Accessible by Emergency vehicles.	*Managed access for vehicles.	Recovery towards full functionality.
1 in 2500 years [HILP | Collapse Avoidance]	Access is critical for emergency response and assistance.	Accessible by emergency vehicles within few days.	Accessible by Emergency vehicles.	*Managed access for vehicles.	Managed access for vehicles, with gradual recovery towards full functionality.

Notes:

i. Table focuses on resilience rather than damage

ii. *Managed access to cater for safety issues

117. The resilience expectations in Table 1 are framed around maintaining access along the transport network rather than the performance of individual “structures”. As event severity increases through the design event and beyond, progressively greater physical damage to infrastructure is to be expected. However, the focus is on the resilience (functionality and outage time, see Figure 21) of the transport network following such events.

6. BENEFITS OF THE PROJECT (POSITIVE EFFECTS)

118. The NPS-I and GPS identify that the functional and operational needs of transport infrastructure are key drivers for economic growth and productivity, and improving the resilience to climate change and natural hazards is a priority. Therefore, I have considered the effects of the Project on the resilience of the transport system.

Operational Resilience

119. The duplication of the Terrace Tunnel and Mt Victoria Tunnel will have operational resilience benefits in the event of incidents in the tunnel. Incidents inside a closed environment pose risks in confined space and can lead to closure of the tunnels and disruption of traffic in both directions. Of particular concern is the disruption to the flow of emergency services to and from the hospital or airport. Having two tunnels allows traffic to flow in at least one direction. In the event of a closure that lasts for a longer period, traffic management could allow the open tunnel to be reconfigured to allow traffic in both directions, if necessary, depending on the time of the day. Therefore, the duplication of the tunnel provides significant operational resilience for the state highway. This would be a regional benefit as the tunnels provide access to the Wellington Regional hospital (Terrace Tunnel) and the Wellington Airport (Terrace and Mt Victoria Tunnels).

120. The grade separation of the state highway (providing access to the airport and eastern suburbs) and local road (Cambridge - Kent Terrace - Sussex Street) enhances operational resilience in the Basin Reserve area, as any incidents on one of the routes may not restrict travel access along the other. Through the back roads in Newtown (Constable Street – Wellington Road), the available route (either state highway or Sussex Street) will enable some access to both the airport and the hospital, if the other route is closed. Therefore, the Basin Reserve enhancements will enhance operational resilience. This will be of regional benefit as it provides access to the Regional Hospital and Airport used by users from around the Wellington region and somewhat beyond.

121. The direct exit from the eastbound Mt Victoria tunnel lanes (via Taurima Street, after exiting the proposed new tunnel) to Moxham Avenue will allow eastbound traffic to use Moxham Avenue / Kupe Street to the airport in the event of incidents affecting SH1 along Ruahine Street. Likewise, the interchange and onramp near Goa Street will allow access along Kupe St / Moxham Avenue / Goa St to provide access from the airport in the event of closure of the southern part of Ruahine St or Wellington Road. The new local road connections with the state highway route therefore provide some redundancy to the Ruahine St - Wellington Road section of SH1 and thus improve operational resilience.

122. Therefore, the Project will significantly enhance operational resilience, in particular to and from the Wellington Airport and Wellington Regional Hospital and therefore would benefit the region as a whole and probably further afield (such as from Horowhenua and Tararua Districts). To maximise these benefits, the detailing of traffic lane configurations should allow ease of redirection of flow through a single tunnel (Terrace and Mt Victoria) in the event of incidents or to maintain access during maintenance closures.

Natural Hazards Resilience

Terrace Tunnel

123. In a Low Impact High Probability (LIHP) earthquake and storm events, both the existing and new tunnels are expected to perform well, and therefore the LIHP event resilience would be similar.

124. In High Impact Low Probability (HILP) events such as a large earthquake, the existing and new tunnels are expected to perform well. In the event of an HILP event involving displacement along

the Terrace Fault in sympathy to movement along the active Wellington Fault, the new tunnel which will be detailed with movement joints will minimise damage to the tunnel lining and enable the tunnel to be opened more quickly, reducing outage time, and thereby enhancing the resilience of access along through the Terrace Tunnels. The existing tunnel lining may experience more damage and it may take more time to restore access through it.

125. Also, in HILP events, the performance of the tunnel portals and approaches may be different between the existing and new tunnels. The duplication of the tunnels will facilitate access through the approaches and tunnel along one of the northbound or southbound routes and can be reconfigured to provide access in both directions, albeit with a lower capacity. Access is more critical than capacity in HILP events.

Terrace Tunnel Approaches

126. There are large retaining walls and slopes above the existing northwestern approach to the Terrace Tunnel. While the existing retaining walls are supported by large anchors and anchored to an anchor drive and hence are expected to provide resilience in earthquakes, some failure of the slopes above the existing retaining walls could be expected in a large HILP earthquake or storm event, see Figure 23. The further easterly approach to the second Terrace Tunnel would provide critical access to and from the airport if such slopes fail and close the access to the existing Terrace Tunnel.

127. The eastern slopes would still have significant high retained slopes, but the ground is flat above the retained slopes, and the retained slopes will be designed to modern seismic design standards (noting that the slopes will be in the Terrace Fault Zone). This would enhance the resilience of access through the Terrace Tunnel to the regional hospital and international airport. It should be noted that the inner-city streets including the waterfront route will be vulnerable to closure due to liquefaction and lateral spreading towards the harbour where the waterfront is close to Waterloo Quay / Jervois Quay, as well as due to damage and collapse of large, tall vulnerable buildings in a large HILP earthquake event, see Figure 11.

Figure 23 – Retaining wall and slopes above northwestern approach to the Terrace Tunnel

Mt Victoria Tunnel

128. In LIHP earthquake and storm events, both the existing and new Mt Victoria tunnels will perform well, and therefore the LIHP event resilience would be similar.

129. In HILP events such as a large earthquake, the existing and new tunnels are expected to perform well, though the unreinforced lining in the existing Mt Victoria tunnel may experience some cracking and possible fall of isolated concrete blocks. In the event of displacement along the Mt Victoria East Fault in sympathy to movement along the active Aotea Fault, the new tunnel which will be detailed with movement joints will minimise damage to the tunnel lining and enable the tunnel to be opened more quickly, reducing outage time, and thereby enhancing the resilience of access along through the Mt Victoria Tunnels. The existing tunnel lining may experience more damage, and it may take more time to restore access through it. Also, in HILP events, the performance of the tunnel portals and approaches may be different between the existing and new tunnels. The duplication of the tunnels will facilitate access through the approaches and tunnel along one of the northbound or southbound routes and can be reconfigured to provide access in both directions, albeit with a lower capacity. Access is more critical than capacity in HILP events.

Mt Victoria Tunnel Approaches

130. There are high shotcrete lined steep slopes adjacent to the existing Mt Victoria Tunnel, see Figure 24. The slopes are unreinforced and are vulnerable to failure in large earthquake or storm events. The failure of the slopes, particularly the higher slopes and adjacent faults on the eastern approach to the tunnel, would close the access to the existing tunnel, until the debris can be cleared and slopes made safe. The Wellington Transport Resilience business case recommended that these slopes be stabilised as part of the proposed duplication of the Mt Victoria tunnel.

Figure 24 – Shotcrete surfaced slopes above eastern approach to the Mt Victoria Tunnel

131. Given the increased separation between the existing and new tunnels in the consent design, failure of the high slopes on the southern side of the eastern approach to the existing tunnel is less likely to

encroach into the access to the new tunnel, and any debris that does encroach into the southbound carriageway can be cleared quickly to restore access.

132. The proposed second Mt Victoria Tunnel will significantly enhance resilience through the construction of an engineered slope, which is expected to perform well, despite the presence of adjacent fault zones and defects. The recent geotechnical investigations have confirmed that the soil overburden is very shallow and most of the cutting will be in rock. This will facilitate the engineering of a flatter and much more stable slope, with lesser need for reinforcement, and therefore enhance resilience.

133. The slopes on the western approach are of lower height and will be supported by engineered retaining walls to ensure resilience of access to the new tunnel.

Basin Reserve

134. The structures for the Basin Reserve area enhancements will be located at the western edge of the basin and therefore are less likely to be affected in the event of rupture along the Aotea Fault. The bridge over the Sussex Street trench is proposed to be a simply supported single span bridge, and therefore any damage can be repaired quickly and access restored along the highway. The at-grade carriageways around the eastern half of the Basin Reserve will experience damage in the event of fault rupture, and access can be quickly restored by re-levelling and restoring access with temporary road surfacing. Therefore, the highway would have good resilience in the event of rupture along the Aotea Fault.

Local Flooding

135. Flood assessments for the project indicate that there is expected to be local flooding along parts of the route, which will be exacerbated over time by climate change, see Figure 14. This hazard exists without the Project being implemented and will continue to be an issue after the Project is implemented, see Figure 15.

136. Local flooding is expected to predominantly affect the following areas (see Figure 14 through Figure 18):

    i. Shallow flooding less than 300 mm depth (Classification H1, Figure 13):
        - Vivian Street
        - Basin Reserve eastern part
        - Karo Drive, between Willis Street and Cuba Street
        - Ruahine Street

    The flooding will generally remain the same, and high base vehicles may be able to gain access for the short durations of flooding, providing some limited resilience

    ii. Moderate depth flooding, 500 mm to 1200 mm depth (Classification H3, Figure 13):
        - South of Terrace Tunnel
        - Cambridge | Kent Terrace
        - Basin Reserve
        - Ruahine Street, small sections

137. The flooding will again generally remain the same, and the highway will unlikely to be accessible during the periods of flooding. The photograph on Figure 25 shows flooding around the Basin Reserve on 20 April 2026.

138. Pumping to a local holding tank is proposed south of the Terrace Tunnel to somewhat mitigate the effects of local flooding at this location.

139. The additional stormwater management measures and proposal for a larger stormwater pipe will reduce the flooding along Ruahine Street, see Figure 18.

140. Overall, the local flooding will generally be unaffected or locally reduced by the Project, and the resilience effects from flooding will remain. The increasing frequency and severity of rainfall events associated with climate change means that the flood events are likely to become worse and more severe over time, with associated reduced levels of resilience in such events. The duration of flooding is likely to be short over a period of hours to a day, rather than many days.

Figure 25 - Flooding around the Basin Reserve, 20 April 2026 (Photo courtesy The Guardian, 21 April 2026)

Overall Resilience

141. In summary, the Project will facilitate enhancement of the overall resilience to the Wellington land transport network, through:

    i. Enhanced operational resilience by providing duplication of the critical Terrace Tunnel and Mt Victoria Tunnel sections, by enabling one way traffic flow in the event of an incident or maintenance in one of the tunnels, and in case of longer duration closure being able to reroute two-way traffic through one of the tunnels, albeit with a lower flow capacity. This will ensure the transport system to continue to operate albeit at lower capacity, and importantly for emergency services to be able to have access to critical facilities such as the Wellington Regional Hospital

    ii. Operational resilience will also be enhanced by grade separating the east-west state highway traffic and the north-south local access to the Regional Hospital through the Basin Reserve area; and enabling the local routes through Haitaitai to be available in the event of closure on the Ruahine Street section of SH1

    iii. Emergency access, in the aftermath of major natural hazard disasters such as a large earthquake, to the Wellington Airport and Wellington Regional Hospital would be enhanced through the design and construction of the second Terrace and Mt Victoria tunnels with enhanced design and stabilisation of the high cut slopes at the portals and approaches to the tunnels, so that the tunnels remain functional in the event of major earthquakes. Currently the poor resilience of access to the Mt Victoria Tunnel is a major constraint in the access to the Wellington Airport because of landslides at the eastern portal and approaches are expected to close access to the tunnel and therefore to the airport

142. The Project is expected to provide the resilience expectations for this Priority 1 transport corridor provided in Table 1 assuming the mitigation measures developed for the Project are carried through the detailed design and construction phases.

143. I consider the Project is well aligned with the NPS-I and the GPS because of the operation and natural hazard resilience benefits it will provide to the state highway route.

7. Assessment of Construction Effects

Introduction

144. Construction effects related to geotechnical issues are considered in this section. The general construction issues and effects on traffic flows are not considered in this report and are addressed by Mr Duncan Tindall in Technical Report #5 Integrated Transport Assessment. The construction effects associated with geotechnical issues that are important are considered for the following sections of the Project:

i. North of Terrace Tunnel

ii. Terrace Tunnel

iii. Basin Reserve

iv. Mount Victoria Tunnel Western Approach

v. Mount Victoria Tunnel

vi. Mount Victoria Tunnel Eastern Approach

North of Terrace Tunnel

145. The critical issue for this section is the effects of construction of the approach cuts and portals and on the adjacent properties along The Terrace.

146. The proposed route for the northbound carriageway deviates towards the second Terrace Tunnel immediately south of the Shell Gully Bridges / Boulcott Street interchange and crosses the base of the terrace scarp below The Terrace, see Figure 26.

Figure 26 – Properties above the northern approach to the Terrace Tunnels

147. Cut slopes up to 25 m in height are proposed into the scarp of The Terrace along the northern approach to the tunnel, with the cutting being highest adjacent to the north portal of the tunnel. The terrace scarp slope is underlain by colluvium and weathered greywacke bedrock. The Terrace Fault crosses this area, and previous investigations show the fault zone to underlie the terrace scarp through which the proposed cuttings will be formed, see Figure 27. There are also likely to be zones of sheared, crushed and shattered rock and weak persistent shear zones adjacent to the Terrace Fault, which could have a significant influence on stability, see indicative section on Figure 28, and as discussed in Section 8.

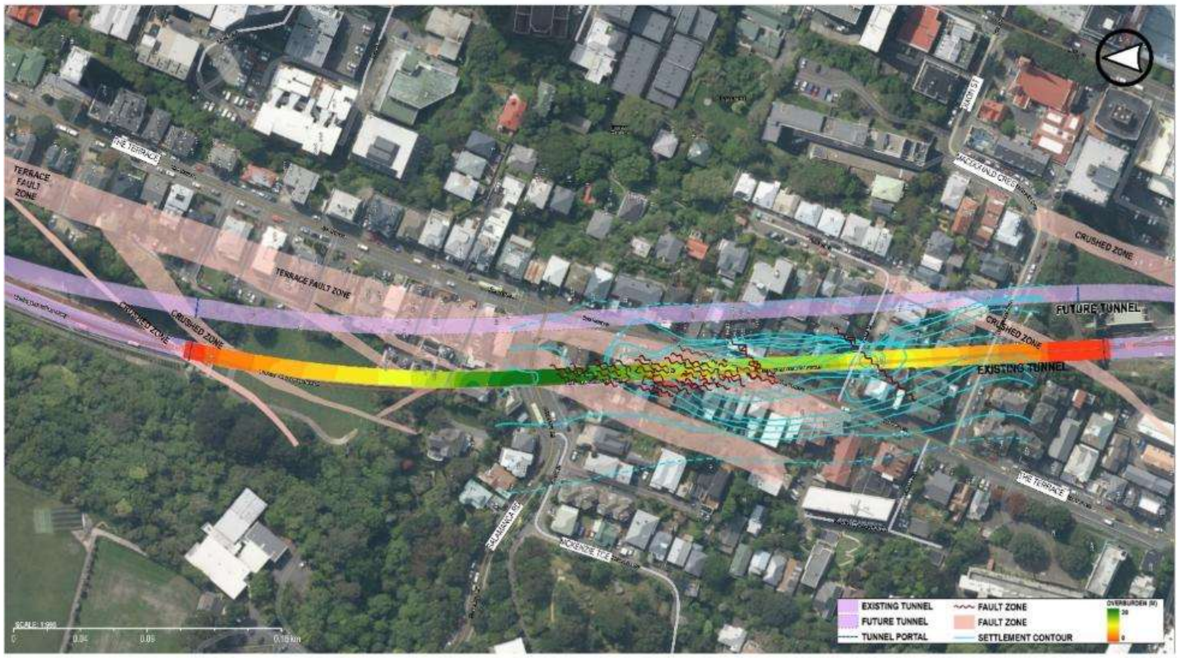

Figure 27 – Subsidence contours overlain on the expected Terrace Fault zones

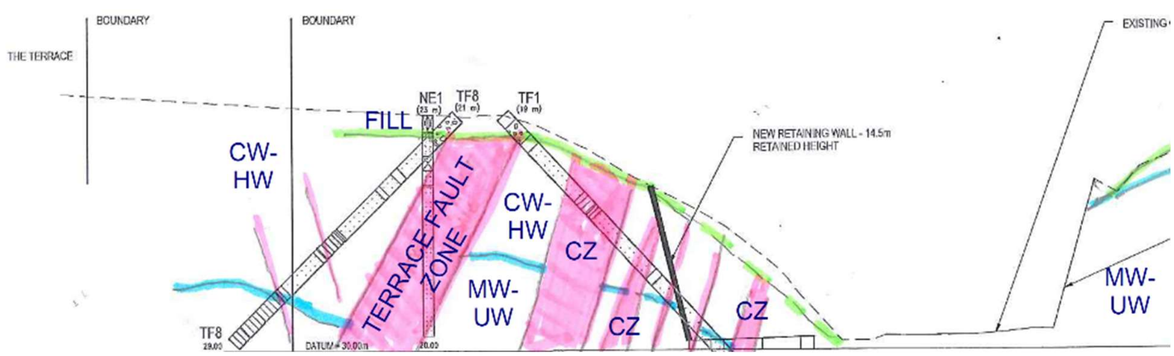

Figure 28 – Indicative section looking south showing the presence of the Terrace Fault zone and associated sheared and crushed zones where the northern approach cuttings will be formed

148. A block of flats and about 12 other residential properties are located along the western side of The Terrace along this approach and the tunnel portal, see Figure 26.

149. Excavation of the steep cut slopes required for the northern access to the second Terrace Tunnel in the weak fault disturbed ground conditions could potentially lead to ground deformation or failures during construction. To mitigate potential effects of such ground movements, generally shallow slope angles will be used to form stable cuttings along the northern part of the approach. Towards the south, the cut slopes required become higher steeper slopes. These slopes will be stabilised with soil nails or rock anchors, and sub-horizontal drainage holes drilled to relieve the porewater

pressures in the ground to ensure that the slopes are stable. To ensure stability and minimise ground movements, a top-down construction methodology is proposed for the construction of these cuttings. With such an approach, the upper part of the slope would be excavated and stabilised with soil nails and / or rock anchors, before further excavation and stabilisation.

150. A monitoring regime will be put in place to monitor ground movements and groundwater pressures along the cut slopes and at the properties behind to continuously monitor the ground and groundwater pressures. Larger and longer anchors / soil nails with high pressure post grouting can be used to enhance the anchor / soil nail capacities and minimise displacements and any associated risk from unacceptable ground displacements that may affect the residential properties along The Terrace.

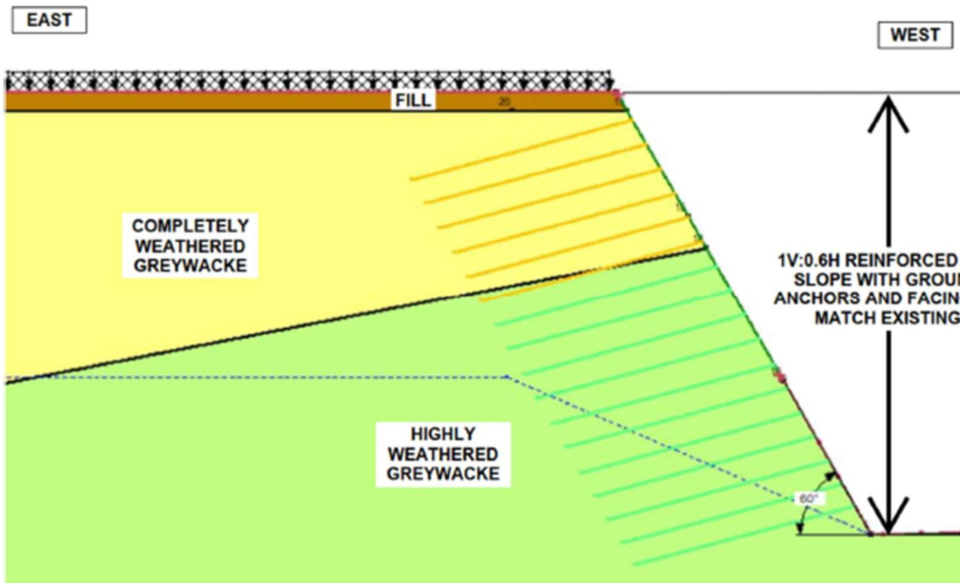

Figure 29 – Indicative section showing stabilisation of slopes with soil nails | ground anchors

Terrace Tunnel

Subsidence

151. Tunnelling can lead to ground subsidence due to two principal mechanisms:

i. Excavation of the tunnel allows groundwater to drain into the tunnel where the groundwater level is above the tunnel, which can often be the case. Lowering of the groundwater leads to an increase in the effective stress in the ground, and this increased stress within the ground could cause consolidation of compressible ground, and lead to ground surface subsidence

ii. Excavation and removal of ground leads to relaxation and displacement of ground towards the tunnel and this progresses towards the ground surface, leading to ground subsidence, where the ground surface moves downwards

152. Subsidence occurs without any load imposed on the ground, such as from structures. (Conversely settlement requires an imposed load). Therefore, the subsidence will affect ground both below buildings as well as open ground, roads and associated utility services.

153. In this instance, the adjacent existing tunnel that was constructed over 50 years ago would have led to some lowering of the groundwater level, and this has been observed through ongoing groundwater inflows from drains observed during tunnel maintenance. Therefore, the additional groundwater drawdown would be limited but would likely extend further west beyond where the second tunnel would be constructed.

154. In addition, the tunnel is overlain by moderately to highly weathered and completely weathered rock which would not have much compressibility, and there is only a limited thickness of soil overlying bedrock. The older alluvium soils which are present over bedrock (the overburden) are also likely to be of low compressibility given their age, and the investigations indicate that the groundwater level is well below the overburden soil layers.

155. Due to the low groundwater levels likely because of the existing tunnel and the presence of low compressibility soils and rock, the subsidence due to groundwater drawdown can be expected to be small and this has been confirmed by assessment. However, it is noted that the proposed tunnel crosses the Terrace fault zone as discussed, and groundwater could be impounded behind the lower permeability fault zones which are likely to be drained when the tunnel is constructed. The fault zone could be associated with more compressible ground. Therefore, some localised subsidence could be expected in the zone where the fault zone(s) are crossed.

156. The subsidence caused by removal of the ground (rock) within the tunnel envelope is expected to be more pronounced. The vertical and horizontal pressures from the overlying ground would squeeze the tunnel void as the ground is removed, and this will result in the ground moving downwards towards the tunnel, and this downward movement progresses up towards the ground surface. If the tunnel is very deep, the expression of this downward movement would be small, but with shallower tunnels the downward movement will be expressed as greater subsidence at the ground surface. The magnitude of subsidence will also depend on the strength and stiffness of the ground.

157. The squeezing of tunnel subsidence can be limited by excavation and supporting the tunnel in stages, thereby enhancing tunnel stability, but also reducing the downward movement. Such staged excavation and tunnel support was carried out when the existing Terrace Tunnel was constructed in the early 1970s, see Figure 30. However, the overall tunnel void, lining and support measures are likely to be not as stiff as the original rock, and therefore some squeezing would be inevitable. Where the overburden ground above the tunnel is small (shallow overburden) and weak, then this would be expressed as greater subsidence at the ground surface.

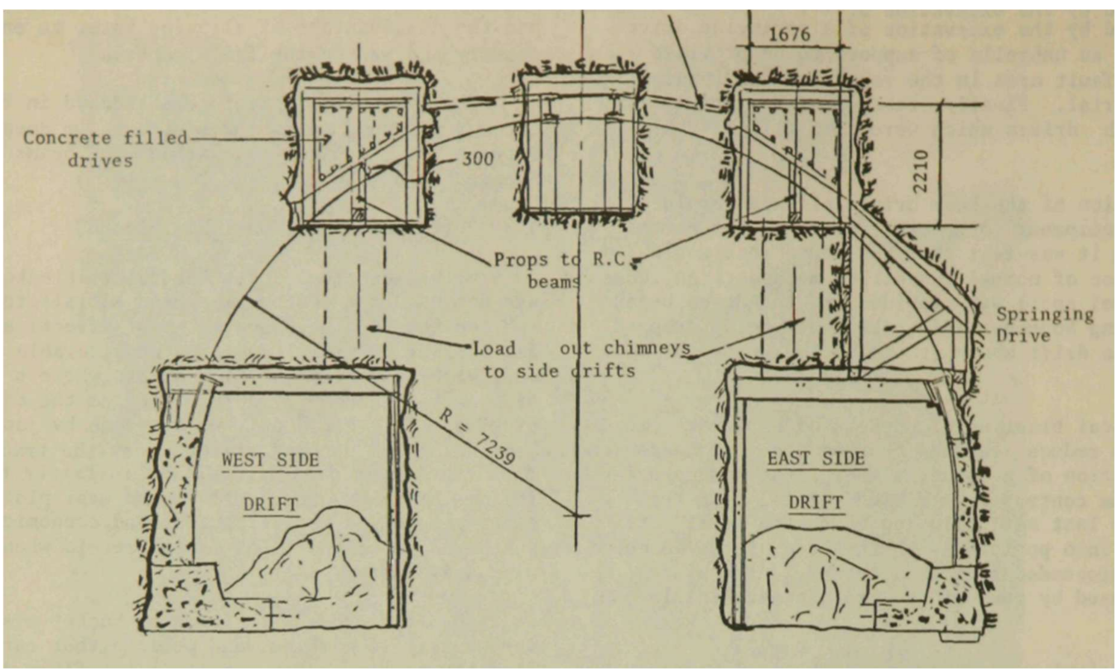

Figure 30 – Staged excavation during construction of the existing tunnel (Newsome, 1981)

158. I have considered the records from the experience of the construction of the existing tunnel in the 1970s. Ground subsidence did occur, and this has been recorded, and subsidence contours have been drawn (Newsome, 1981), see Figure 31. Larger ground subsidence was observed when the

tunnel was excavated through the Terrace Fault zone and is reported to have led to minor damage to the houses and the breakage of water and gas mains along Dixon Street and The Terrace. This is despite the precautions taken during tunnelling like limiting the excavation and support to 600 mm at a time through the Terrace Fault zone. I also discussed this with Mr Newsome some years ago and understand that ground subsidence affected overlying houses leading to sticking of windows and doors, and they had a team of carpenters to plane them so that they could continue to be opened and closed.

159. In the worst case where the tunnel is shallow with low overburden and the ground is weak, the tunnel void can progress quickly before it is supported leading to "crown holes" at the ground surface. It is understood that at MacDonald Crescent (near the southern portal of the tunnel) where the overburden was very shallow, a hole opened up on the road during construction and was quickly filled with concrete (Atkinson – pers comm). This may have been a crown hole but is unconfirmed. In modern tunnel construction such incidents can be avoided by pre stabilising the ground with consolidation grouting and fore poling before tunnel excavation or by adopting a cut and cover section where the overburden is very shallow.

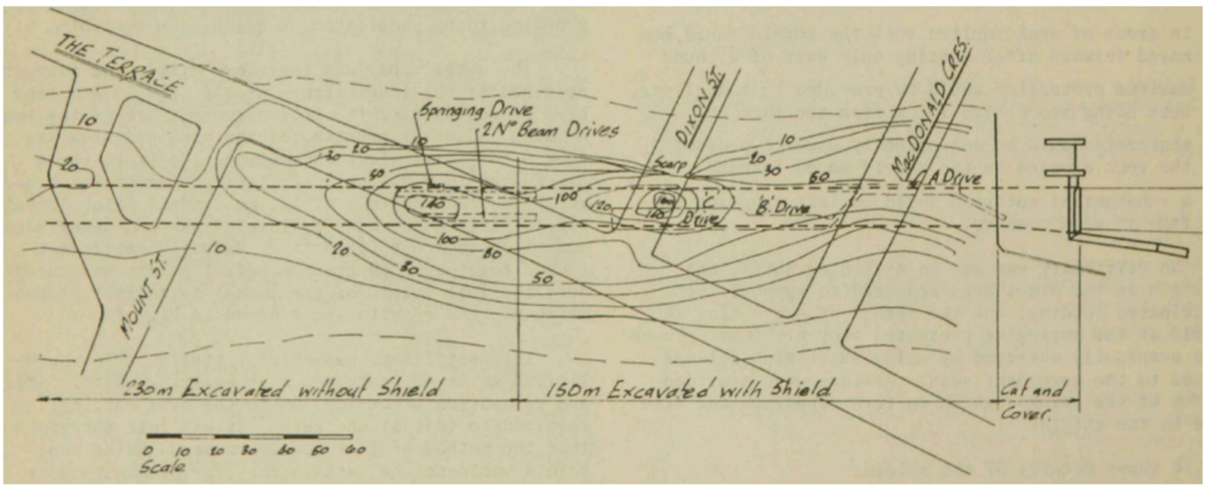

Figure 31 – Contours of subsidence in the 1970s construction of the existing tunnel (Newsome, 1981)

160. The subsidence contours from the 1970s construction of the existing tunnel have been overlain on the current ground surface, as shown on Figure 32, to understand the relationship between the distribution of the recorded subsidence and the Terrace Fault.

161. The map on Figure 32 also shows the variation of overburden above the tunnel with shallower overburden in orange to red, and thicker overburden in yellow to dark green colours. This indicates that the magnitude of subsidence was more related to the geology than overburden thickness.

162. It can be observed that the maximum subsidence occurred where the tunnel crossed under Dixon Street where a fault zone was encountered (Newsome, 1981) and under The Terrace where weak ground associated with the Terrace Fault zones was present. It can also be noted from the subsidence contours that the subsidence extended a significant distance from the footprint of the tunnel on the western side of the tunnel compared to the eastern side of the tunnel. The subsidence reduced sharply on the eastern side (with potentially associated larger angular distortions which causes building damage). The investigations have indicated that the Terrace Fault dips at an angle of 70 to 80 degrees (to the horizontal) towards the east. This means that the surface expression of the fault is likely to be further west than where the fault was recorded in the tunnel excavation and shown on Figure 32.

163. It appears that the weaker ground associated with Terrace Fault has allowed the subsidence to progress further away from the tunnel towards the west, compared to the east as the subsidence was recorded further west at the ground surface as illustrated diagrammatically in Figure 33. This

shows the dominant effect of the Terrace Fault on the magnitude and extent of the subsidence observed, and the angular distortion.

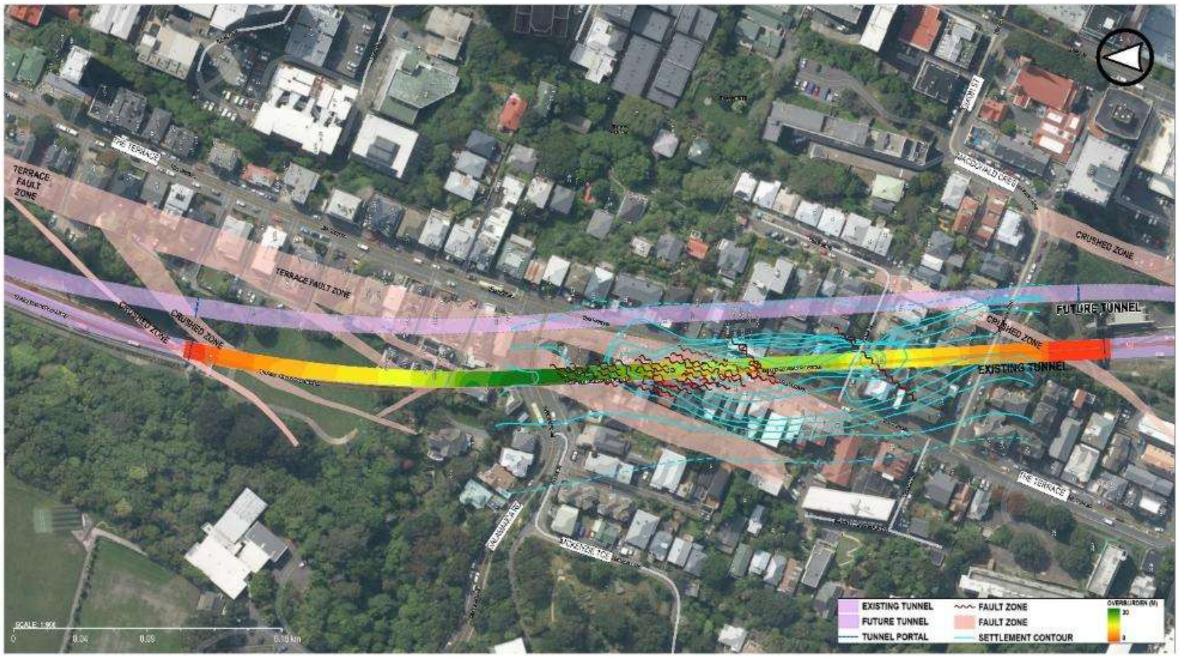

Figure 32 – Subsidence contours overlain on the expected Terrace Fault zones

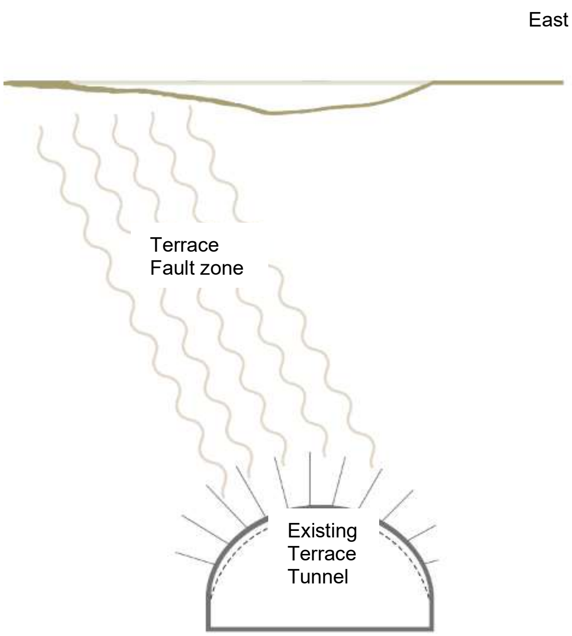

Figure 33 – Diagrammatic indication of the extent of subsidence in relation to the Terrace Fault

164. Numerical modelling has been carried out by the design team to understand the quantum and distribution of the subsidence associated with construction of the proposed second tunnel, which indicates that the subsidence would be greatest near the tunnel portals, and the magnitude of the subsidence would be limited to 60 mm at the north portal and 115 mm at the south portal, and the subsidence would be symmetrical in relation to the location of the tunnel, see Figure 34. The variation of overburden thickness above the tunnel is shown, with darker green to yellow showing overburden above 25 m and red and orange indicating overburden thickness less than about 15 m.

165. However, such symmetrical distribution of subsidence was not recorded during the construction of the 1970s construction of the existing tunnel, and the magnitude of the subsidence was greater where the tunnel crossed fault zones rather than near the portals where the overburden was shallower. An assessment of the observations indicate that the subsidence is unlikely to be symmetrical and could extend further to the west. The presence of the Terrace Fault could have a significant influence on not only the quantum of subsidence, but also the extent and distribution of the subsidence, and therefore the properties that may be affected. This illustrates the limitation of numerical modelling, and the importance of understanding the local geological conditions.

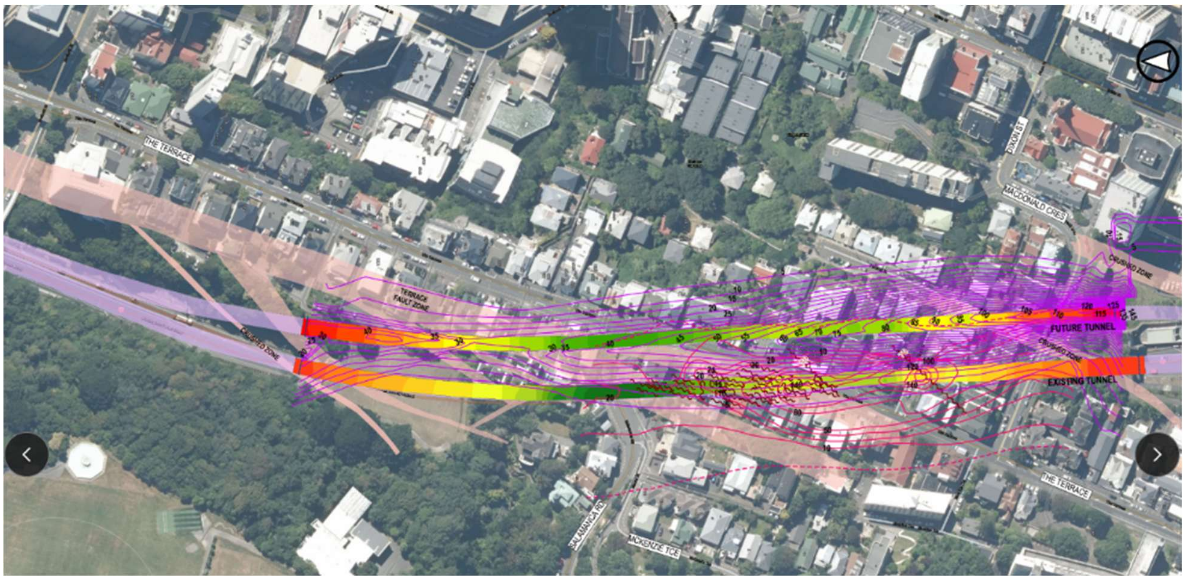

Figure 34 – Distribution of subsidence predicted by numerical modelling

166. Taking into consideration the extent of subsidence and its distribution observed from the construction of the existing tunnel in the 1970s, the construction of the second Terrace Tunnel could lead to greater subsidence where the second tunnel crosses the Terrace Fault, see Figure 34. My experience in assessing the surface effects from abandoned underground mine workings indicate that where the overburden is shallow the surface manifestation is more likely to be “crown holes” opening up at the surface, and where the overburden is thicker the consequence is more likely to be surface ground subsidence. Also, the progression of surface effects is generally controlled by the geological features. The observations from the construction of the existing Terrace Tunnel appears to follow this approach. The location and extent of the Terrace Fault will be better detailed during the detailed design and construction of the Project and this information would be used to manage the effects of the fault crossing. The subsidence could extend further towards the west. This would also allow the area affected by subsidence to be defined and managed.

167. Following identification of potential issues associated with shallow overburden and weaker weathered rock, a section of cut and cover tunnel construction has been adopted at the southern end of the Terrace Tunnel, and this would alleviate concerns about potential crown holes. With cut and cover construction, the ground will be excavated with support measures, the tunnel structure constructed and then backfilled over the preconstructed tunnel section.

168. In modern day tunnel construction, there are measures that can be taken to pre-stabilise the ground when tunnelling through the Terrace Fault and other areas of weak ground or shallow overburden. The staging of the excavation and rate of tunnelling can also be managed to limit subsidence. However, the magnitude and distribution of the subsidence will be difficult to predict with certainty.

169. The variation of the magnitude of subsidence at the surface is likely to affect buildings and services, rather than the absolute subsidence. Angular distortion is used as a parameter to understand the

damage that could be caused by subsidence (Burland and Burbridge, 2010: CIRIA 2016). It should be noted that these assessments have been based on consideration of more rigid brick buildings rather than the predominantly timber buildings that are present above the Terrace Tunnel. Timber buildings are generally more accommodating of subsidence, except where there are more rigid floors, driveways, steps and retaining walls. The timber buildings generally experience “sticking” of doors and floors, as was experienced during the construction of the existing Terrace Tunnel some 50 years ago.

170. There is an apartment building which is of reinforced concrete walls and floors on shallow strip footings. In such buildings subsidence could lead to noticeable cracking that is expected to be largely superficial but requiring repairs. The expected subsidence and angular distortion would be considered during detailed design, and where necessary mitigation measures would be implemented.

Basin Reserve

171. SH1 crosses the primary arterial road Cambridge / Kent Terrace – Sussex Street – Adelaide Road corridor which provides access to Newtown and the Wellington Regional Hospital. Currently SH1 runs around the Basin Reserve Cricket Ground, which includes a cricket museum along the northern side and grandstand along the northwest corner, see Figure 35. Various options have been considered over the years to grade separate the key arterial road corridor from SH1 and provide improved connectivity to the hospital.

Figure 35 – Basin Reserve Area and adjacent Buildings

172. The Basin Reserve is located in a low-lying area between the foothills of Mt Cook on the west and Mt Victoria to the east, with the active Aotea Fault running through the eastern part of the basin and with a significant potential for liquefaction in moderate to large earthquake. The geography, geology, ground conditions and natural hazards are presented in further detail in Section 8.

173. A key feature of the proposed construction in this area is the Sussex Street underpass, see Figure 36. As discussed in Section 8, a variety of options can be considered to grade separate the state highway corridor from the Kent Terrace to Sussex St – Adelaide Rd corridor. This underpass takes Sussex Street along the north-south arterial road Cambridge-Kent Terrace to Adelaide Road corridor towards the hospital, below the east-west state highway corridor, see Figure 36. The proposed design at the Basin Reserve area comprises placing Sussex Street in a deep cut and joining with

Kent Terrace immediately to the north of the Basin, see Figure 36. SH1 running east is raised on an embankment, crosses the Sussex St trench on a single span bridge and joins with Dufferin Street north of the Basin. The Sussex Street trench has been kept shallow adjacent to the Cricket Museum to minimise the effects on the structure.

174. To ensure a robust trench, it will be supported by a secant pile wall with floor level props and for the deeper trench section, overhead steel temporary and permanent props as necessary similar to the solution adopted for the Inner-City Bypass south of the Terrace Tunnel. This more robust solution has been adopted for this location instead of soil nailed slopes to minimise displacements during construction to protect adjacent properties, as well as ensure good performance in earthquakes. Through this approach, the effects on adjacent properties will be minimised.

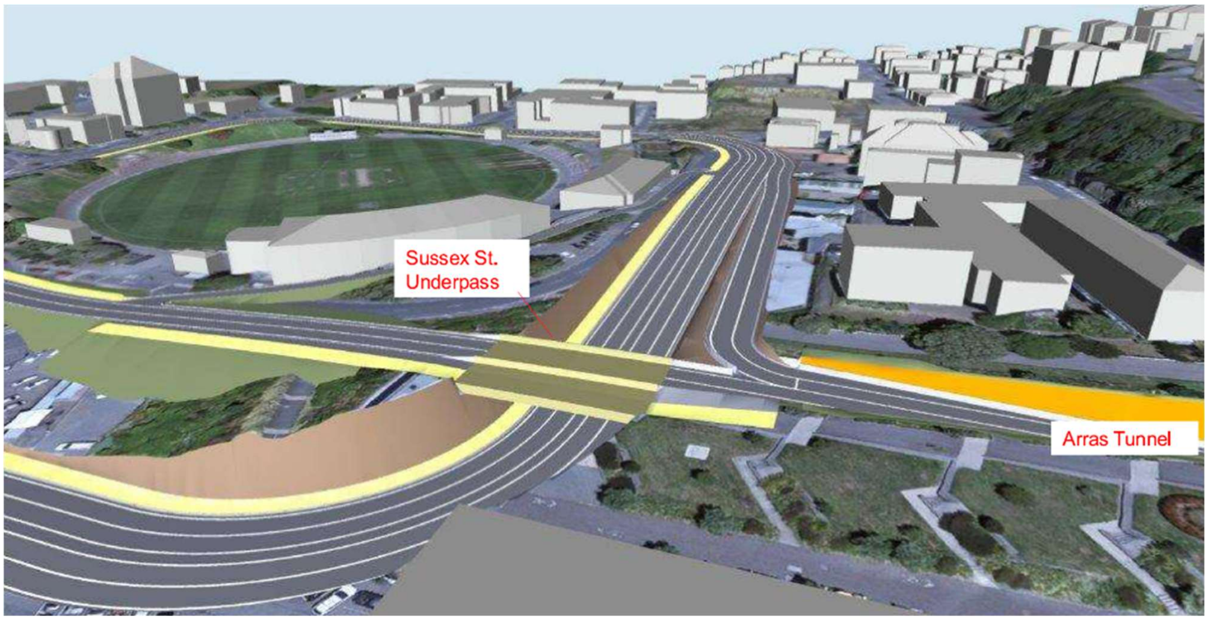

Figure 36 – Sussex Street Underpass proposed in the Basin Reserve area

Settlement due to Embankment Construction

175. The design also involves construction of an embankment next to SH1 immediately north – northwest of the Basin Cricket grounds (connecting to the land/green bridge forming an extension to Pukeahu), on the very poor ground with high groundwater levels near surface and artesian groundwater below. This could, if not managed appropriately, cause settlement of the ground under the weight of the embankment fill and cause a settlement trough extending beyond the embankment footprint during construction.

176. There are a number of services, including deep brick stormwater drains running along the median between Cambridge | Kent Terrace and below the middle of the Basin Reserve cricket grounds. The extent of the embankment could be reduced during construction, to reduce the quantum and areal extent of the subsidence and its effect on the deep brick stormwater services. Alternatively, during detailed design, the old brick stormwater drains would be protected from the subsidence effects by supporting the embankment on a structure, thus reducing the load of the embankment on the ground, and thereby reducing the settlement of the ground and impact on the deep brick stormwater drains during construction.

177. The settlement effects affect the road corridor and are not expected to cause wider settlement affecting surrounding buildings.

Subsidence from Sussex Street Underpass and Trench Construction

178. The construction of the Sussex Street underpass and trench could cause lowering the groundwater regime and relaxation of the ground, causing subsidence of the surrounding area. The subsidence has been estimated to be up to approximately 80 mm, and its effects on adjacent buildings have been assessed by the design team based on subsidence estimates at the locations of significant individual buildings. Some of the buildings closest to the Sussex Street trench are identified for demolition for the Project.

179. The subsidence affecting the Museum Stand is expected to be of the order of 10 mm and could cause superficial cracking, which is expected to be readily repairable. The subsidence at the RA Vance Stand in the Basin Reserve is expected to be of the order of 10 mm and given that the building is on piles founded in denser gravel strata, therefore it is expected that there would be only minor deformations across the structure. Therefore, more intensive mitigation measures are not considered to be necessary for these structures.

180. The Archives building at 169-179 Tory Street is of reinforced concrete construction with reinforced concrete shear walls and moment frames supporting precast concrete hollowcore and rib and infill floors. Foundations for the building are a mixture of reinforced concrete piles (western half and southern edge) and shallow pad/raft footings. Subsidence estimates indicate values ranging from none at the centre of the building, to 20 mm at the southeast increasing to 55 mm at the southeast corner of the building.

181. Building assessment by the design team indicates that the seismically separate northwestern, northeastern, and southwestern structures are expected to experience a negligible impact from ground subsidence associated with the Project, but the southeast structure could be affected, particularly at the southeast corner. Mitigation measures such as underpinning will be considered during detailed design and implemented during construction.

Mt Victoria Tunnel and Approaches

Mt Victoria Tunnel Western Approach

182. The existing cuttings along the western approach to the Mt Victoria Tunnel are of relatively low height and either comprise a large wall (northern side) or a shotcrete surfaced moderate height cutting less than 15 m high. The wall will be removed to allow construction of the second tunnel with a new engineered wall further to the north. This is proposed to be an anchored wall constructed by top-down construction in good ground and therefore will cause little issues to the surrounding area during construction.

183. The new cut and cover structure proposed at the western end of the proposed second tunnel would be constructed using secant pile walls, props and anchors to minimise the effects during excavation to build the tunnel and could use a piled wall with props and ground anchors.

Mt Victoria Tunnel

184. Greywacke rocks at Mt Victoria tunnel are much stronger but are typically highly fractured. The risk associated with construction of the second Mt Victoria tunnel with just 6 m clearance to the existing 1930s tunnel has been mitigated by increasing the separation distance by 50% to an indicative 9 m, and proactive measures are planned to support the ground for both the cut and cover section with anchored piled walls, and to stabilise the ground between the tunnels with rock anchors and consolidation grouting where poor rock is present. These measures will mitigate risks to the surrounding area during construction of the tunnel.

185. The stability of the greywacke rock in Wellington is typically controlled by the presence of dominant and persistent defects such as faults, shear zones and crushed zones rather than the strength of the greywacke rock or even the rock mass strength. In this case there are a number of fault strands located either side of Mount Victoria and have been mapped within the pilot tunnel. The indicative provision of the wider 9 m tunnel separation and allowance for strengthening the rock between the existing and new tunnel where poor ground associated with the fault is present will facilitate the construction minimising potential effects on the existing tunnel. The floor level of the proposed second tunnel could be optimised during detailed design to provide further resilience.

186. It is anticipated that the tunnel will be constructed using a road header, which is used for excavation, given that road headers of greater capacity are now available compared to when the existing Terrace Tunnel was constructed in the 1970s. The Greywacke rocks at Mt Victoria tunnel are much stronger, but the rock is typically highly fractured, facilitating the excavation using a road header. However, there is the possibility that sections of less fractured and strong rocks are present along the tunnel alignment, which cannot not be excavated effectively by a road header, requiring blasting. Therefore, provision for blasting has been allowed for in planning the construction works. Blasting is likely to require temporary closure of the existing tunnel during the blast, and a follow up inspection of the tunnel to ensure there are no hazards such as loose concrete, which is very unlikely.

187. Vibration from tunnel construction is considered by the noise and vibration specialist **Siiri Wilkening**.

Mt Victoria Tunnel Eastern Approach

188. Cut slopes of over 30 m in height are proposed at the eastern approach to the proposed new Mt Victoria second tunnel, see Section 8 for further details. Currently, the cut is proposed at steep slopes of up to 65 degrees slope angle with anchoring of the slope. There will also be cuttings above the tunnel portal.

189. Faulted zones observed in cuttings at the eastern tunnel portal and approach have significantly lower rock mass strength than the surrounding un-faulted greywacke, based on engineering geological logging of the pilot tunnel in the 1970s and surface mapping of the eastern portal slopes in 2014. These faulted zones will present instability issues for the cut slopes at the portal and approach for the new Mount Victoria Tunnel. Bedding planes and sheared zones with adverse orientations for the new cut slopes at the eastern portal were observed in the pilot tunnel.

190. To mitigate these conditions during construction (as well as in the long-term during earthquakes), the cut slopes are proposed to be stabilised with rock anchors or rock nails to avoid failure along unfavourable defects in the rock. To ensure stability, a top-down construction methodology is proposed for the construction of the cuttings. With such an approach, the upper part of the slope would be excavated and stabilised with rock anchors or rock nails, before further excavation and stabilisation.

191. As discussed in Section 8, recent investigations showed that there is only a very thin soil cover above bedrock. Given that the soil cover is thin, moderately steep cut slopes with lesser stabilisation measures may be considered during detailed design. Either way, the recently completed geotechnical investigations provide confidence that a stable cut slope can be designed and constructed for the new cut slope on the northern side of the eastern approach to the new tunnel.

Subsidence

192. The less weathered and stronger greywacke rock at Mt Victoria Tunnel and the general absence of buildings above the tunnel means that the subsidence issues are much less at Mt Victoria above the bored tunnel, and will be more near the western portal area with shallower overburden above the tunnel and presence of residential and school buildings, see Figure 37.

Figure 37 – Buildings in the Mt Victoria Tunnel West Area

193. Landscape Apartments is a reinforced concrete structure with reinforced concrete shear walls, beams, columns and floors, with a combination of shallow strip and pad footing foundations. The design team has estimated subsidence to be of the order of 10 mm, and though the building is of robust reinforced concrete construction, subsidence could cause superficial cracking of the east and west facades. This could be mitigated by underpinning the southern edge of the building and would be considered further during detailed design.

194. The Wellington East College East Block originally comprised a two-storey construction with reinforced concrete floors, reinforced concrete frames (beams and columns), and reinforced concrete walls Foundations comprise shallow strip footings and pad footings. The extension in 2022 is formed with structural steel frames, a posi-strut timber truss floor and rod-bracing providing lateral stability. A magnitude of subsidence varying from none at the west edge to 20 mm at the eastern edge, and the potential for superficial cracking at the eastern ends was assessed by the design team. Mitigation measures such as underpinning could be considered to mitigate the risk of cracking.

195. The two-storey Science Block at the school has reinforced block masonry walls with in situ concrete floor slabs and is supported by a mix of shallow strip footings and reinforced concrete piles with shallow embedment. The building was strengthening in 2024. The design team has assessed that the ground settlements vary from none at the western edge to about 10 mm at the northeast corner and could result in superficial cracking at the eastern ends of the north and south walls. The cracking can be easily repaired with grout injection.

Management of Subsidence Effects

196. Potential subsidence could affect the area over and adjacent to the proposed second Terrace Tunnel, near the Sussex Street trench in the Basin Reserve area and over and adjacent to the western end of the proposed second Mt Victoria Tunnel. It is important that the subsidence and effects are proactively managed during detailed design and construction.

197. Subsidence of the ground associated with the construction of the tunnels and underpasses and potential damage to overlying and adjacent buildings and services is not uncommon in road construction and can be carefully managed. There is always some uncertainty as to the magnitude,

distribution and consequences associated with such subsidence induced damage to buildings and services associated with tunnelling and trench construction.

198. The risk to the built environment would be managed proactively through a variety of measures. The following measures would be taken by NZTA in the future stages of this project to manage the risk:

i. Detailed design stage geotechnical investigations would be used to improve the characterisation of the ground conditions above the tunnel, and particularly the location of the weak zones associated with the Terrace Fault to refine the subsidence, and angular distortion estimates that have been made as part of the consent design work

ii. Detailed development of the design and tunnel support sequence and stabilisation measures to minimise subsidence, recognising that it may not be practical to eliminate subsidence damage

iii. Characterisation of the building stock in the potentially affected area and use that to assess the vulnerability of the buildings to subsidence and associated angular distortion

iv. Use the characterisation of the buildings and their vulnerability to identify actions to manage the risk. Identify buildings that may require pre-construction stabilisation measures such as underpinning, and services that may need to be replaced or strengthened

v. A Groundwater and Subsidence Monitoring and Contingency Plan (GSMCP) would be developed to refine the area affected by subsidence and angular distortion along with the location of subsidence and groundwater monitoring points. Institute a comprehensive programme of monitoring, alarm levels and response measures, using a trigger-action-response-plan (TARP) regime

vi. Based on the monitoring results, take proactive measures to adapt the tunnel construction progress and stabilisation measures to reduce subsidence if required

vii. Effective communication with potentially affected property owners, occupiers and service authorities, so the uncertainty and associated risk is better understood by all the parties

viii. Proactively communicate with property owners, occupiers and service owners during construction

199. The proactive programme of subsidence effects management will enable the subsidence risk to the surrounding built environment to be effectively managed during construction of the Project, and in particular the two tunnels and the trench and underpass at the Basin Reserve.

200. There are a few heritage buildings in the potentially affected areas, and the effects on these buildings also need to be carefully managed during the design and construction of the Project. These heritage buildings are discussed in the next section.

Heritage Buildings

Terrace Tunnel Area

201. The area of subsidence management (in yellow) and the heritage buildings in the Terrace Tunnel area (hatched) are shown on Figure 38, and also in Annexure A.

Figure 38 – Area of potential subsidence and heritage buildings near the proposed second tunnel

202. These heritage structures are timber residential buildings that generally perform well when subjected to subsidence as discussed above. They generally experience “sticking” of doors and floors as observed during the construction of the existing tunnel. The subsidence and associated risk to these heritage buildings will be able to be better assessed during detailed design and will be managed as discussed above.

Basin Reserve Area

203. The area of subsidence management (in yellow) and the heritage buildings in the Basin Reserve area (hatched) is shown on Figure 39, and also in Annexure A. Two heritage structures are located within the subsidence management area at the Basin Reserve.

204. The creche is a robust concrete structure north of Buckle Street, and is a heritage building as shown in Figure 39. This structure is proposed to be relocated during construction and could be easily relevelled during relocation. This structure was also previously relocated during construction of the Wellington Inner City Bypass in c2006-2007.

205. The other heritage structure is the Basin Reserve Museum Stand (which also houses the cricket museum), see Figure 39 and Figure 40, which was designed and constructed in the 1920s, and was seismically strengthened in 2019. The structure is comprised of primarily reinforced concrete walls, floors and columns, supported by shallow strip footings and pad foundations, see Figure 40. As discussed above, the subsidence affecting the Museum Stand is expected to be of the order of 10 mm and could cause superficial cracking expected to be readily repairable.

Figure 39 – Area of potential subsidence and heritage buildings at the Basin Reserve area

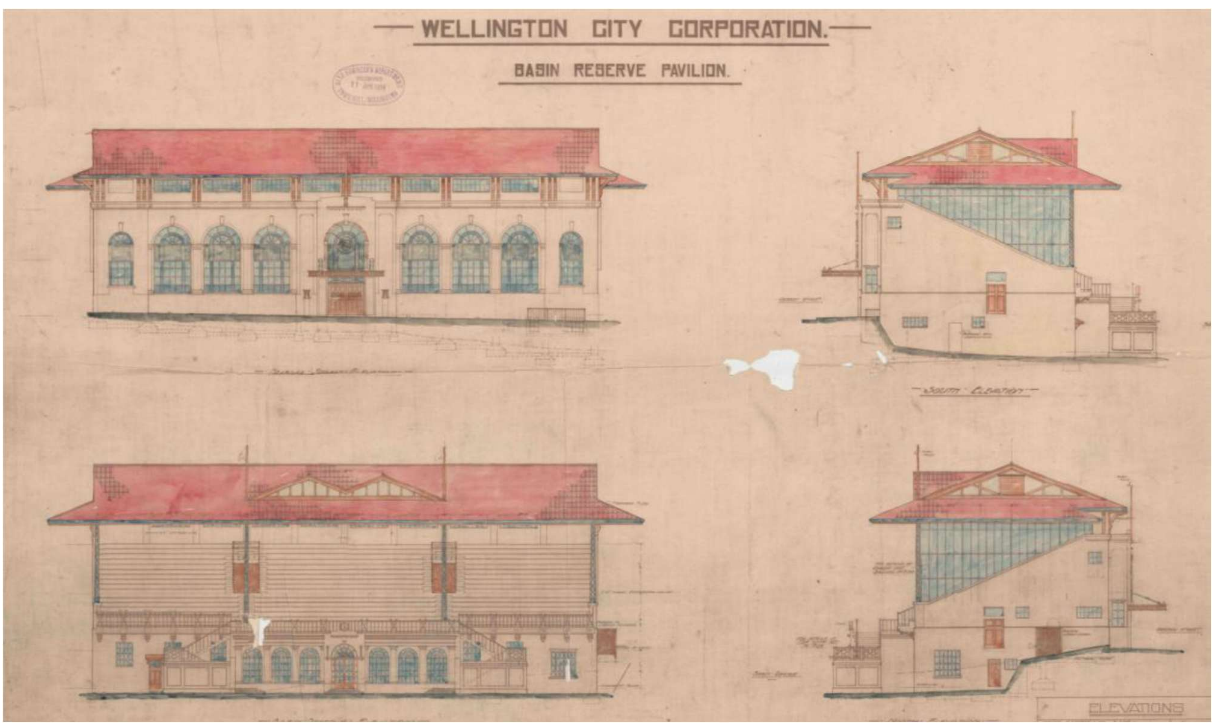

Figure 40 – Elevations of the Museum Stand from the original Architectural drawings

Mt Victoria Tunnel Area

206. There are two timber residential heritage buildings identified in the subsidence management area (in yellow) near the Mt Victoria Tunnel, see Figure 41. These structures are Ettrick Cottage (19 Paterson Street) and 140 Austin Street, which are proposed to be removed during construction and repositioned on reformed Paterson Street at the end of the Project works. These buildings can be relevelled when they are relocated/repositioned as part of this process.

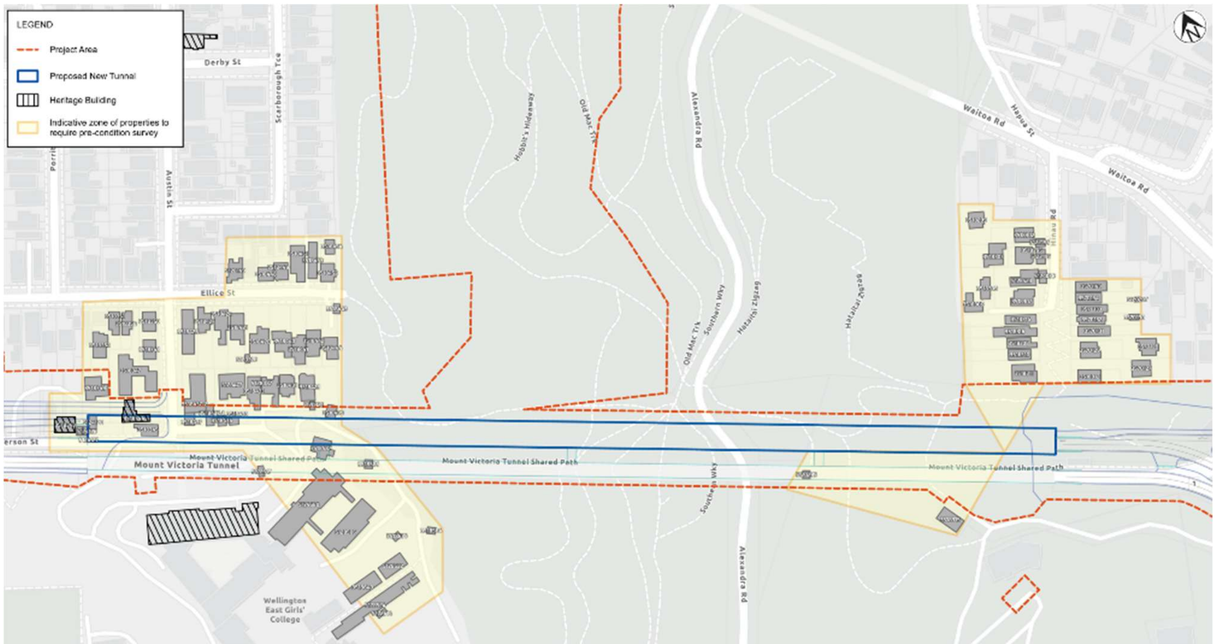

Figure 41 – Area of potential subsidence and heritage buildings at the Mt Vitoria tunnel area

8. ASSESSMENT OF OPERATIONAL EFFECTS

Introduction

207. The effects of the Project are considered in relation to the region's functional requirements and expectations for SH1. The effects are localised with respect to each sector, and cumulative effects are discussed in the final section. The effects are considered in relation to the following sections:

i. North of Terrace Tunnel

ii. Terrace Tunnel

iii. Terrace Tunnel South Portal to Vivian Street

iv. Vivian Street

v. Cambridge Terrace / Kent Terrace

vi. Basin Reserve

vii. Mount Victoria Tunnel Western Approach

viii. Mount Victoria Tunnel

ix. Mount Victoria Tunnel Eastern Approach

x. Ruahine Street – Wellington Road

208. I have focussed on the critical issues in each sector, that have the potential to cause significant life safety, environmental, social and resilience risks to society. The routine design issues would be addressed through normal design practices.

North of Terrace Tunnel

209. The critical issue for this section is the stability of the approach cuts and portals and has been the focus of this assessment.

210. The proposed route for the northbound carriageway deviates towards the second Terrace Tunnel immediately south of the Shell Gully Bridges / Boulcott Street interchange and crosses the base of the terrace scarp below The Terrace, see Figure 42 and Figure 43.

Figure 42 – Northern approach to the Terrace Tunnels

211. The terrace rises about 25 m above the level of the northern approach to the tunnel, and the proposed southbound route cuts into this terrace with cut heights up to 25 m along the approach, with the cutting being highest adjacent to the north portal of the tunnel.

212. A block of flats and about 12 other residential properties are located along the western side of The Terrace along this approach and the tunnel portal, see Figure 43.

Figure 43 – Oblique view of Terrace Tunnel and northern approach

213. The terrace scarp slope is underlain by colluvium and weathered greywacke bedrock. The Terrace Fault crosses this area, and the geological map prepared as part of the investigations for the duplication of the Terrace Tunnel in about 2015 shows the fault zone to underlie the terrace scarp through which the proposed cuttings will be formed, see Figure 44. There are also likely to be zones of sheared, crushed and shattered rock and weak persistent shear zones adjacent to the Terrace Fault, which could have a significant influence on stability, see indicative section on Figure 45.

214. A variety of slope reinforcement and support measures can be used for the cut slopes. Steep slopes of up to 25 m high and up to 65 degrees slope angle are required; these slopes can be reinforced with soil nailing and anchoring into this slope. The weak zones associated with the fault will likely control the stability of the steep slopes, rather than the strength of the weak or weathered rock mass. Larger and longer anchors / soil nails with high pressure post grouting can be used to enhance the anchor / soil nail capacities and minimise displacements. The groundwater regime could also be locally complex with groundwater pressures behind low permeability fault zones, and higher pressures in fractured zones associated with the presence of the fault. Sub-horizontal drainage holes would be drilled into the slope to relieve the groundwater pressures. The longer anchors / soil nails would be accommodated by obtaining sub-surface rights for the critical properties into which the subsurface anchors will encroach.

Figure 44 – Terrace fault zone along the proposed northern approaches to the southbound tunnel (after Beca, 2015)

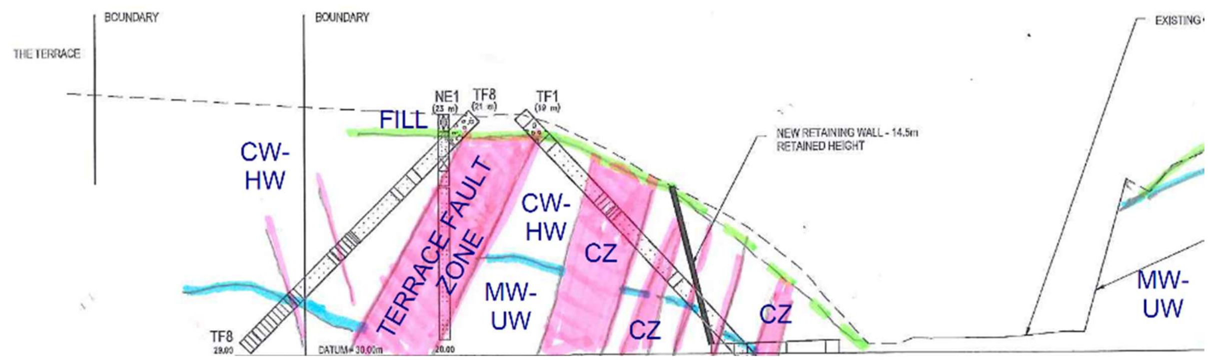

Figure 45 – Indicative section looking south showing the presence of the Terrace Fault zone and associated sheared and crushed zones

215. The slopes will be designed for the design earthquake loads in moderate to large earthquake events, considering the high seismicity in the Wellington region and associated topographical amplification in the upper part of the high steep cut slopes (Brabhaharan et al 2018), with the stabilisation measures designed to minimise displacements. The measures would ensure that the high slopes do not fail and lead to closure of the access to the tunnel but accommodate limited displacements.

216. The slope above the north tunnel portal would be in potentially very weak rock associated with the Terrace Fault, see Figure 44. Therefore, the slope would be formed at a flatter slope or reinforced with soil nails and or ground anchors, to ensure that the access to the tunnel remains open in a large earthquake event.

Terrace Tunnel

217. The issues that I have identified as being critical for this sector of the Project and having an impact on the environment are:

   i. Performance of the proposed tunnel given that it will obliquely cross the Terrace Fault zone

ii. Subsidence associated with construction of the tunnel and damage to overlying buildings, roads and services, as discussed in Section 7

iii. Restriction to future development due to the need to preserve the integrity of the tunnel

Terrace Fault Crossing

218. The Terrace Fault is identified as having various levels of activity, with some maps identifying it as inactive and some as Class II active, which means it has a lower level of activity than the Class I active faults such as the Wellington Fault. The Terrace Fault is identified as branching off the main Wellington Fault (Figure 4), and some displacement during the rupture of the main Wellington Fault may be accommodated by smaller displacements along the Terrace Fault.

219. The Wellington Fault is generally considered to be associated with horizontal (strike-slip) displacements of the order of 4 m to 5 m, and vertical displacements of the order of 1 m to 2 m. The displacements along the Terrace Fault could be an order of magnitude smaller, say few hundred millimetres. The tunnel width and height would be sized so that such displacement could be accommodated to continue to provide the required lane widths.

220. In the 2016 Kaikoura earthquake, rupture of the Hope Fault across a rail tunnel led to cracks and small displacements but was able to be repaired and the tunnel was stable except for localised displacement and cracking of the lining. Displacement along the fault would be accommodated by allowing movement joints and locally strengthening the tunnel lining, and any steps in the floor could be quickly relevelled to allow access through the tunnel for post-earthquake response and recovery.

221. The likelihood of such displacement along the Terrace Fault is rare, and the consequences can be effectively managed through design.

222. The crossing of the Terrace Fault is likely to be associated with poor rock conditions and inflow of groundwater preferentially channelled along more permeable fracture zones impounded by low permeability fault gouge zones. Drainage holes will be drilled from the tunnel excavation during construction to relieve the groundwater pressures and flows channelled into tunnel drainage systems. Construction measures such as fore poling,1 pre-grouting and steel supports have been allowed for in the Project design and construction methodology. This is not unusual to be encountered in tunnel construction.

Effect of Tunnel(s) on Future Development

223. The presence of the tunnel will have some effect on future development of the overlying land and will be an effect on the built environment. For example, high rise development, basements and in particular use of deep piles may cause some effects on the tunnel and its integrity and performance. Given that bedrock is at shallow depth, such effects are likely to be limited but nevertheless there are areas of weak rock associated with the Terrace Fault and areas of shallow overburden that need to be considered. This will have some effect on future development.

224. I understand the following mitigation measures are being implemented by NZTA to manage this risk:

i. Identifying areas that are likely to impact on the tunnel and associated stabilisation measures. This will be broader than just the tunnel footprint

ii. Development of criteria to mitigate any risks in the future

[1] Forepoling (or spilling) is a pre-support tunneling method used to stabilize weak, loose, or broken ground by creating a protective canopy ahead of the excavation face. It involves driving steel pipes, rods, or timber into the ground at an angle, often accompanied by grouting to prevent collapse and control ground subsidence.

iii. Agree with property owners and put in place sub-surface easements where needed to manage the risk associated with future development

225. This will enable the effects to be proactively managed with appropriate planning and legal measures.

Terrace Tunnel South Portal to Vivian Street

226. This section will involve the construction of a new Ghuznee Street Bridge with associated abutments and retaining walls to support the off ramp from the new tunnel to Vivian Street. There are also large buildings in the general area.

227. From my previous experience in the design and construction of the Inner-City Bypass in this section, I am aware that the ground conditions are generally poor with soft and loose alluvium and artesian groundwater in the underlying bedrock.

228. The retaining walls and abutment will be detail-designed using appropriate design and construction techniques taking into consideration the poor ground conditions and presence of adjacent large buildings.

229. Excavation behind the existing propped concrete walls | trough structure ('U' shaped structure) has been avoided or minimised as the structural design relies on the passive pressure of the ground behind where the off ramp is located.

Vivian Street

230. There are no significant engineering measures proposed along this existing road.

231. However, it should be noted that the presence of buildings may pose a risk to access after a major earthquake given damage to buildings may pose a safety hazard, and therefore the resilience of access along the highway. Given that the buildings are generally low rise, limited access is likely to be able to be maintained along the route.

Cambridge Terrace / Kent Terrace

232. Eastbound access along SH1 will be along a section of Cambridge Terrace. No significant engineering measures are proposed along this section.

233. It should be noted that this road is located in an area susceptible to significant flooding, liquefaction in earthquakes, and fault rupture hazard from the Aotea Fault. The Project does not exacerbate this existing risk.

234. The earthquake induced liquefaction maps from Greater Wellington Regional Council indicate areas of moderate liquefaction in the Cambridge | Kent Terrace corridor between Vivian Street and the Basin Reserve as shown on Figure 8. The liquefaction susceptibility assessed at borehole locations in presented in Figure 37. Liquefaction is likely to be triggered by modest earthquakes with a peak ground acceleration of about 0.15g to 0.35g for the different soil layers underlying the site. The high liquefaction susceptibility assessed is consistent with the liquefaction and consequent ground damage assessment I carried out for Greater Wellington Regional Council in 1992-1993 (Brabhaharan, 1993), see Figure 38, which indicated a high liquefaction ground damage susceptibility for the corridor. Given that the liquefiable deposits are present at shallow depth, ejection of sand and silt with sand boils could lead to additional subsidence of the ground that what is assessed from volumetric consolidation. Liquefaction could lead to subsidence in the range of 150 mm to 200 mm.

235. Significant liquefaction occurred in Christchurch during the 2010-2011 Canterbury Earthquake Sequence, with ground conditions more susceptible to liquefaction than in the Cambridge | Kent

Terrace and Basin areas. Except where there was significant lateral spreading of the ground towards free surface such as those associated with Avon and Heathcote Rivers, liquefaction in the flat areas of Christchurch did not lead to loss of access along roads, although cracking and uneven road surfaces resulted from liquefaction. Road access was able to be maintained and repaired over a period of years.

236. The Cambridge | Kent Terrace corridor is a generally flat area with no significant free surfaces associated with streams or rivers. Therefore, liquefaction is expected to lead to subsidence of the ground and associated cracking and uneven road surface. Road access can be maintained albeit at lower speeds and can be repaired over a period of time. It is not practical or economical to mitigate the risk of liquefaction over long sections of road, and it is prudent to accept some road damage, maintain access and carry out repairs after the event.

Basin Reserve Area

Context and Ground Conditions

237. SH1 crosses the primary arterial road Cambridge / Kent Terrace – Sussex Street – Adelaide Road corridor which provides access to Newtown and the Wellington Regional Hospital. Currently SH1 runs around the Basin Reserve Cricket Ground, which includes a cricket museum along the northern side and grandstand along the northwest corner, see Figure 46. Various options have been considered over the years to grade separate the key arterial road corridor from SH1 and provide improved connectivity to the hospital.

238. The Basin Reserve area and the area between Cambridge - Kent Terraces to the north were originally designated as a canal between the road leading to an inland basin where ships could come and unload-load freight. However, the 1855 Wairarapa earthquake was associated with the land being uplifted by some 1.5 m and dried up the basin and led to the inland port idea being abandoned. However, the basin remains as a low-lying area with high groundwater levels and poor ground.

239. This is also geologically a very complex area, including the following features:

i. Variable depth of alluvial deposits which are very loose to medium dense overlying dense silty sand and gravel, overlying bedrock, see Figure 47

ii. The active Aotea Fault crosses this area, leading to the variable depth to bedrock and weak permeable bedrock. The Aotea Fault is located in the middle to eastern part of the Basin, and also poses a fault rupture hazard, see Figure 5

iii. Artesian ground pressure at moderate to deep depth, probably contributed by the adjacent Mount Victoria hills and fractured zones associated with the Aotea Fault. Artesian pressures are equivalent to the order of 6 m above ground level

iv. Highly liquefiable soils which are likely to liquefy in moderate to large earthquakes

Figure 46 – Oblique view of the Basin Reserve area

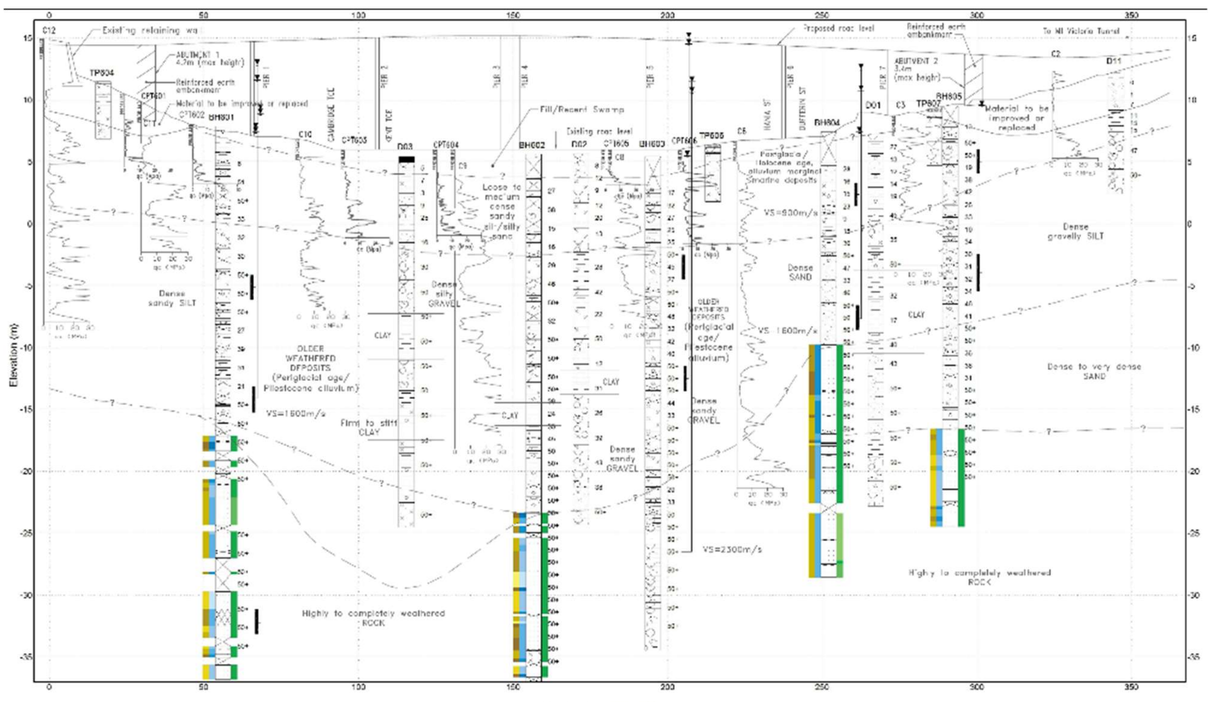

Figure 47 – Geological section through the Basin Reserve area, showing the complex geology

Liquefaction Effects of Project

240. The earthquake induced liquefaction maps from Greater Wellington Regional Council indicate areas of moderate liquefaction as shown on Figure 8, which shows that only the eastern part of the Basin is susceptible to liquefaction. However, information gleaned during my involvement in prior projects for NZTA and the Council indicates that the whole low lying Basin area is vulnerable to liquefaction and associated subsidence and lateral spreading where there are slopes, see the liquefaction susceptibility assessed at borehole locations in Figure 48.

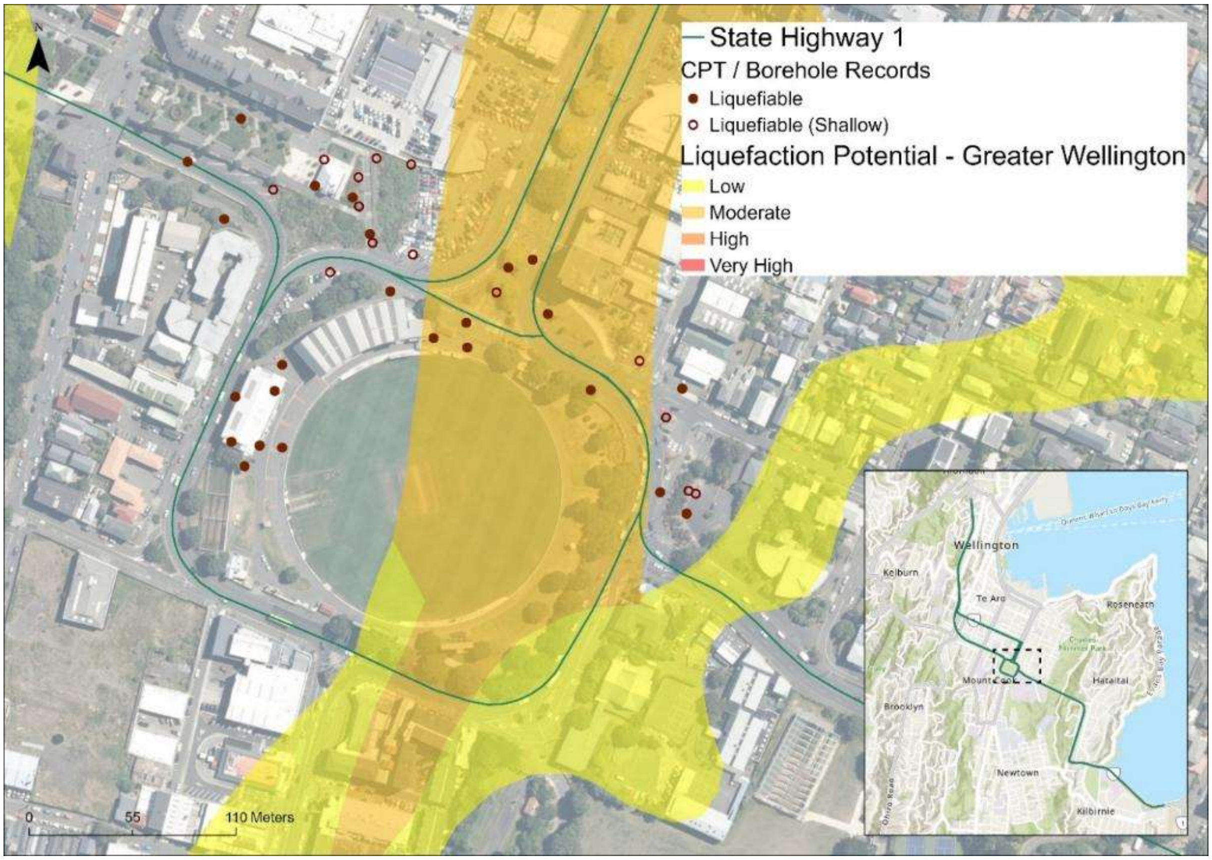

Figure 48 – Liquefaction Susceptibility, with assessed liquefaction at borehole locations

241. Liquefaction is likely to be triggered by modest earthquakes with a peak ground acceleration of about 0.15g to 0.35g for the different soil layers underlying the site. The high liquefaction susceptibility assessed is consistent with the liquefaction and consequent ground damage assessment I carried out for Greater Wellington Regional Council in 1992-1993 (Brabhaharan, 1993), see Figure 49, which indicated a high liquefaction ground damage susceptibility for the Basin Reserve area.

242. Given that the liquefiable deposits are present at shallow depth, ejection of sand and silt with sand boils could lead to additional subsidence of the ground than what is assessed from volumetric consolidation. Liquefaction could lead to subsidence in the range of 150 mm to 250 mm.

243. North of the Basin, along the Cambridge – Kent Terrace corridor, liquefaction induced subsidence in a large earthquake could be of the order of 150 mm to 200 mm.

244. The Basin Reserve corridor is a generally flat area with no significant free surfaces associated with streams or rivers. Therefore, liquefaction is expected to lead to subsidence of the ground and associated cracking and uneven road surface. Road access can be maintained albeit at lower speeds and can be repaired over a period of time. To minimise road damage, the road will be reconstructed with geotextile and geogrid base layers to minimise the different subsidence and cracking. It is not practical or economical to mitigate the risk of liquefaction over long sections of

road, and it is prudent to accept some road damage, maintain access and carry out repairs after the event.

245. Where embankments are proposed, they will be reinforced with geogrids and a geotextile and geogrid base layer to minimise displacements due to liquefaction of the ground below. The road surfaces supported by the embankments could be repaired after a large damaging earthquake event that causes liquefaction and / or embankment displacement from severe ground shaking.

246. In moderate to large earthquakes, the ground is susceptible to liquefaction, and liquefaction would lead to subsidence as well as lateral spreading and failure of the embankment constructed for the SH1 route. The embankment will be reinforced with geogrids to ensure that the embankment would not fail, and any settlement of the embankment due to subsidence of the ground below can be readily repaired after an earthquake to provide resilience of access.

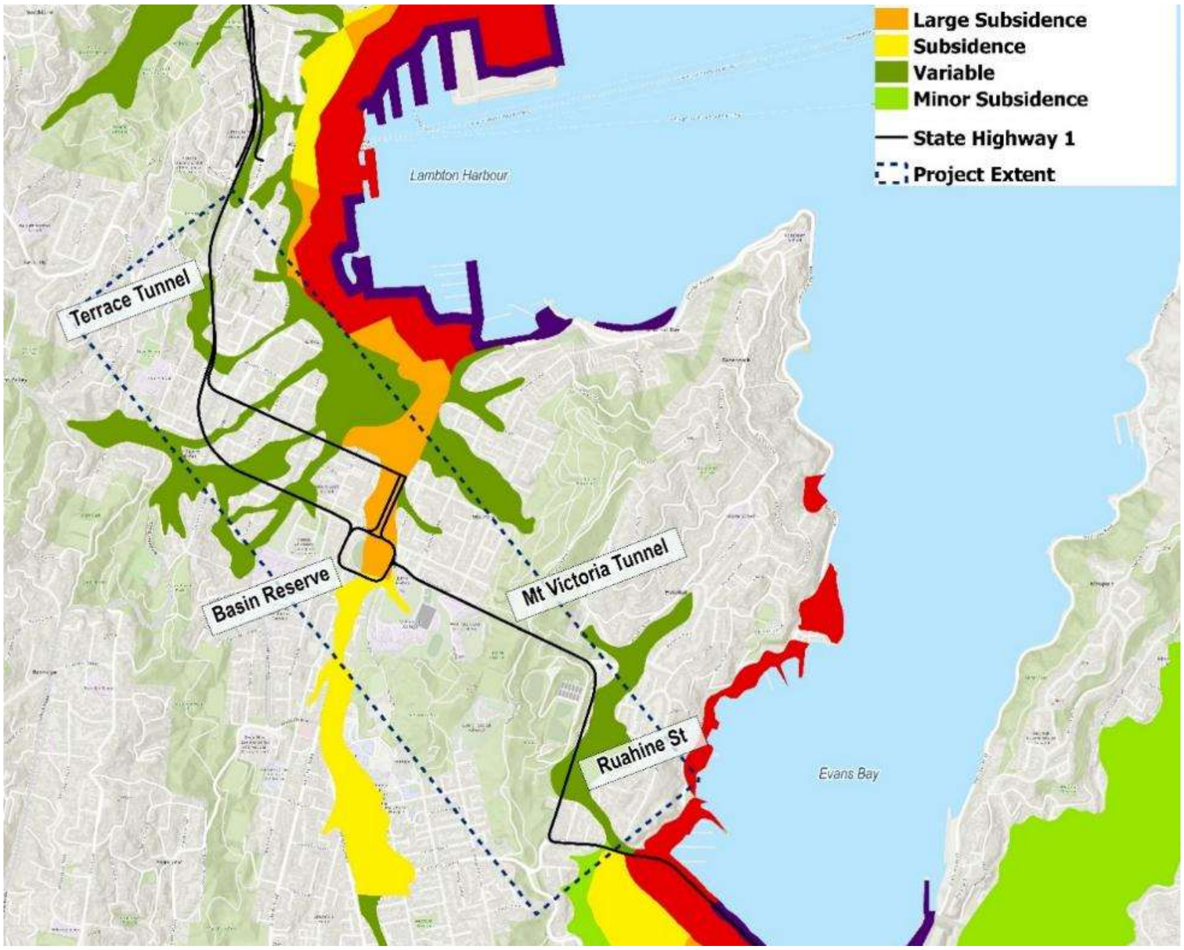

Figure 49 – Liquefaction susceptibility in Wellington City (Brabhaharan, 1993)

Sussex Street Trench and Underpass

247. There are a variety of options previously considered to grade separate the state highway corridor from the Kent Terrace to Sussex St – Adelaide Rd corridor towards the hospital. The proposed design at the Basin Reserve area comprises placing Sussex Street in a deep cut and joining with Kent Terrace immediately to the north of the Basin, see Figure 50. SH1 running east is raised on an embankment, crosses the Sussex St trench on a single span bridge and joins with Dufferin Street north of the Basin.

248. To ensure a robust trench, it will be supported by a secant pile wall with floor level props and for the deeper trench section, overhead steel temporary and permanent props as necessary similar to the solution adopted for the Inner-City Bypass south of the Terrace Tunnel, see Figure 51. This more robust solution has been adopted for this location instead of soil nailed slopes to ensure good performance in earthquakes as well as minimise displacements during construction and in earthquakes, to protect adjacent properties.

249. Secant pile walls or reinforced soil walls or a combination will be adopted to the bridge abutment, and where necessary ground improvement used to strengthen the ground, noting that the ground conditions at the Sussex Street underpass location are better than in the lower lying Basin area.

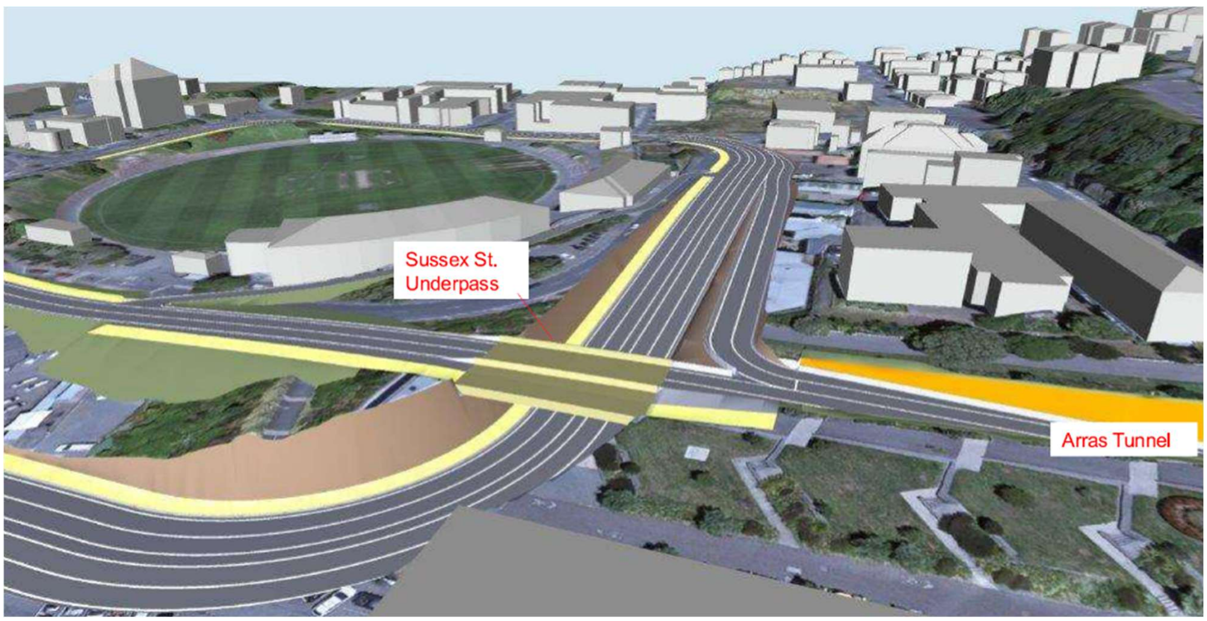

Figure 50 – Proposed improvements concept at Basin Reserve

Embankment

250. As noted in Section 7, the design also involves construction of an embankment next to SH1 immediately north – northwest of the Basin Cricket grounds (connecting to the land/green bridge forming an extension to Pukeahu), on the very poor ground with high groundwater levels near surface and artesian groundwater below.

251. In moderate to large earthquakes, the ground is susceptible to liquefaction, and liquefaction would lead to subsidence as well as lateral spreading and failure of the embankment constructed for the SH1 route. The embankment will be reinforced with geogrids to ensure that the embankment would not fail, and any settlement of the embankment due to subsidence of the ground below can be readily repaired after an earthquake to provide resilience of access.

Figure 51 – Similar existing propped trench at the Inner City Bypass, south of the Terrace Tunnel

Fault Rupture through Basin Reserve Area

252. The Aotea Fault runs through the Basin Reserve, and this is an active fault with a recurrence interval of about 2500 years. Rupture of the fault would cause severe damage to any structures built through the Basin corridor. The Aotea Fault runs on the eastern side of the Basin (see Figure 5), and the design avoids the construction of any structures on the eastern side, and therefore any damage due to rupture of the fault where the highway will be at grade can be readily repaired to ensure access for emergency vehicles. This will provide resilience by reducing the time for recovery, as illustrated in Figure 41. The blue triangle illustrates how the level of service or functionality (access) can be recovered quickly by keeping the state highway at grade where rupture of the Aotea Fault is likely.

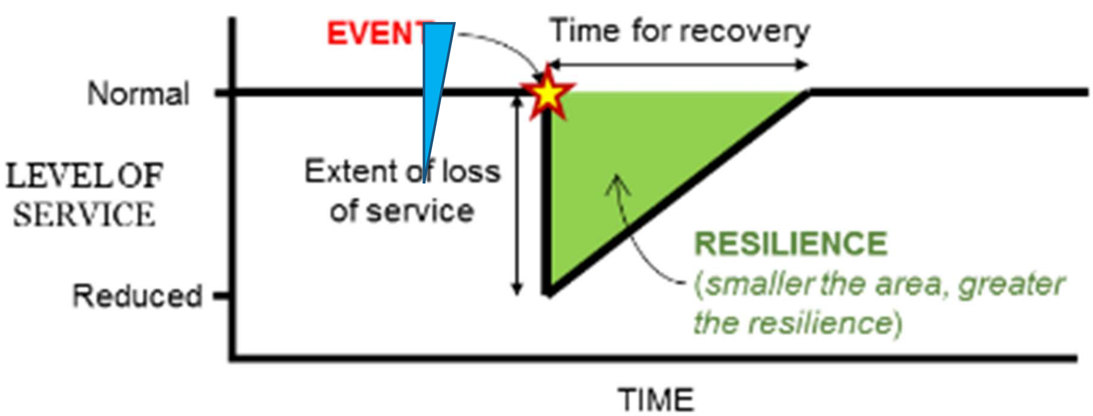

Figure 52 – Diagram illustrating resilience through enabling quick recovery after an event

253. Therefore, the Project will provide good performance and resilience of transport access at the Basin Reserve grade separation.

Mt Victoria Tunnel Western Approach

254. The existing cuttings along the western approach to the Mt Victoria Tunnel are of relatively low height and either comprise a large wall (northern side) or a shotcrete surfaced moderate height cutting less than 15 m high, see Figure 53.

Figure 53 – Oblique view of the Western Approach to the Mt Victoria Tunnel

255. The wall on the northern side will be removed to allow construction of the second tunnel with a new engineered wall further to the north. The existing slope on the south side could be strengthened. Even if the existing cutting on the south side fails in a large earthquake, it would only generate a small quantity of landslide debris, and this can be quickly cleared to restore access to the existing tunnel.

256. The new cut and cover structure proposed at the western end of the proposed second tunnel would be constructed using secant pile walls, props and anchors to minimise the effects during excavation to build the tunnel and could use a piled wall with props and ground anchors.

Mount Victoria Tunnel

Geology and Faulting

257. An examination of aerial photographs, LiDAR maps and historical photographs indicate geomorphic lineaments on both sides of Mount Victoria, see Figure 54.

258. On the eastern side of Mount Victoria, the lineaments are expressed as pronounced notches on spurs and incised linear gullies. A pronounced linear gully trending northeast to southwest lies to the northeast of the Hataitai bus tunnel. South of the bus tunnel, this lineament bifurcates into several strands. The main (i.e. most prominent) strand maintains a northeast to southwest trend, parallel to the crest of the ridgeline of Mount Victoria towards Constable Street. The other strands follow a north-to-south trend through Hataitai Park towards Kilbirnie. The alignments of the most strongly preserved lineaments are approximately parallel to the active Wellington and Aotea Faults mapped by Earth Sciences NZ, whereas the less distinct lineaments to the south of Mount Victoria Tunnel are approximately parallel to inactive faults in the area, see Figure 55.

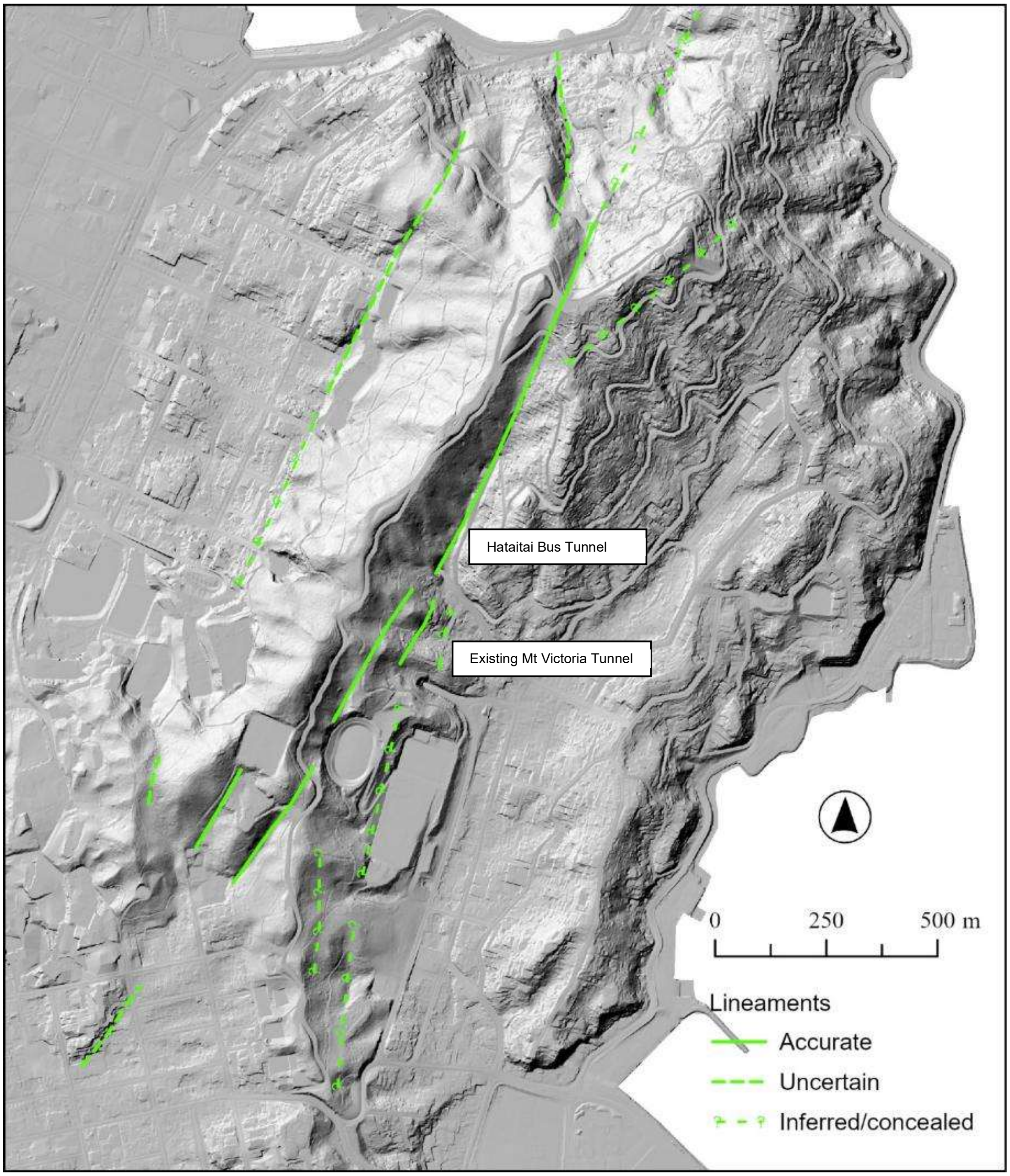

Figure 54 – Lineaments in the geomorphic terrain indicate faults on both sides of Mount Victoria

259. Faulted and crushed zones in the greywacke bedrock were observed in cuttings for the Mount Victoria Tunnel eastern approach (Figure 56) and were logged in the pilot tunnel. The lineaments identified at the ground surface coincide with the up-slope projection of these faulted zones. The harbour end of this fault was identified by NIWA to be active (Barnes et al., 2018), see Figure 6. If the presence of faulted zones within the tunnel and the spatial connection to preserved geomorphic features is an indication of an active fault on the eastern side of Mount Victoria, then the potential for fault rupture displacement of the Mount Victoria Tunnel should be considered. Assuming a length of approximately 6 km to 12 km, the potential surface displacement could be on the order of 0.5 to 1 m in magnitude using published relationships between surface rupture length and fault displacement (Nicol et al., 2022). This magnitude of displacement is consistent with previous estimates of surface displacement for rupture of the Aotea and Evans Bay faults (Barnes et al., 2018).

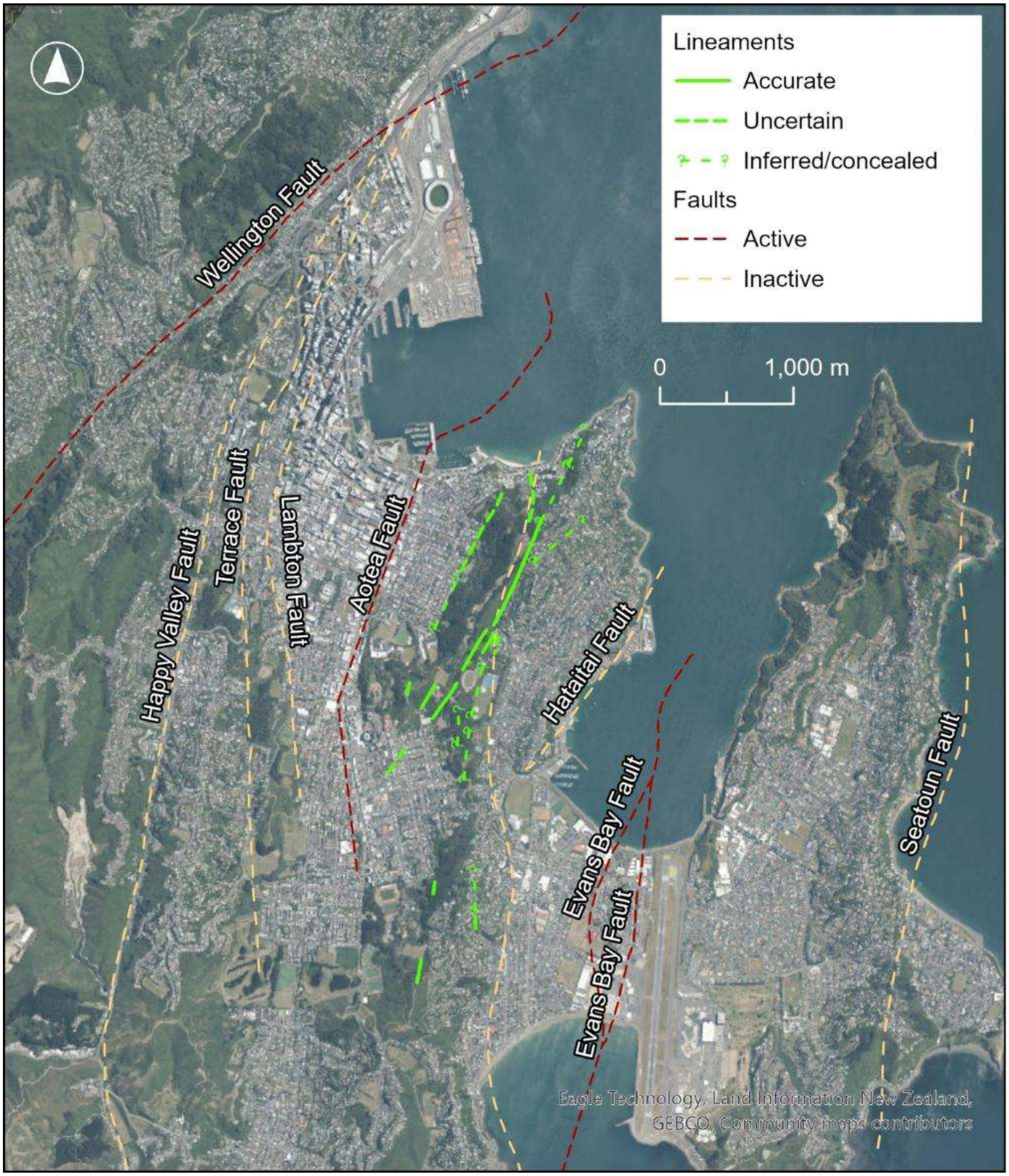

Figure 55 – Lineaments at Mt Victoria in the context of faults in Wellington city

260.

Figure 56 – Faulting in exposed bedrock cut slopes in historical photographs

Low separation distance

261. The risk associated with construction of the second Mt Victoria tunnel with just 6 m clearance to the existing 1930s tunnel has been mitigated by increasing the separation distance by 50% to an indicative 9 m, and proactive measures are planned to support the ground for both the cut and cover section with anchored piled walls, and to stabilise the ground between the tunnels where poor rock is encountered with rock anchors and consolidation grouting.

262. The stability of the greywacke rock in Wellington is typically controlled by the presence of dominant and persistent defects such as faults, shear zones and crushed zones rather than the strength of the greywacke rock or even the rock mass strength. In this case there are a number of fault strands located either side of Mount Victoria and have been mapped within the pilot tunnel. The indicative provision of the wider 9 m tunnel separation and allowance for strengthening the rock between the existing and new tunnel where poor ground associated with the fault is present will facilitate the construction minimising potential effects on the existing tunnel. The floor level of the proposed second tunnel could be optimised during detailed design to provide further resilience.

Mt Victoria East Fault Crossing

263. The tunnel will be crossing a fault that is identified as a potentially active fault, with a lower level of activity and displacement compared to the Wellington Fault or Aotea Fault. The Mt Victoria East fault is identified as being potentially able to cause fault rupture displacements of the order of 0.5 m to 1 m horizontally and potentially smaller vertical displacements. The likelihood of such displacement along the Mt Victoria East Fault is rare.

264. Displacement along the fault zone, which the tunnel crosses, can lead to cracking of the tunnel lining and small steps in the tunnel. The tunnel width and height will be sized so that in the event of such fault rupture induced displacement, the movement could be accommodated without compromising the lane widths and can be repaired to continue to provide access.

265. In the 2016 Kaikoura earthquake, rupture of the Hope Fault across a rail tunnel led to cracks and small displacements but was able to be repaired and the tunnel was stable except for localised displacement and cracking of the lining. Displacement along the fault would be accommodated by allowing movement joints and locally strengthening the tunnel lining, and any steps in the floor could be quickly relevelled to allow access through the tunnel for post-earthquake response and recovery.

266. The likelihood of such displacement along the Mt Victoria East fault is rare, and the consequences can be effectively managed through the detailed design process.

267. The crossing of the fault is likely to be associated with poor rock conditions and inflow of groundwater preferentially channelled along more permeable fracture zones impounded by low permeability fault gouge zones. Drainage holes will be drilled from the tunnel excavation during construction to relieve the groundwater pressures and flows channelled into tunnel drainage systems. Construction measures such as fore poling, pre-grouting and steel supports have been allowed for in the project design and construction methodology. This is not unusual to be encountered in tunnel construction.

Mt Victoria Tunnel Eastern Approach

268. Cut slopes of over 30 m in height are proposed at the eastern approach to the proposed new Mt Victoria second tunnel, see Figure 57. Currently, the cut is proposed at steep slopes of up to 65 degrees slope angle with anchoring of the slope, see Figure 58. There will also be cuttings above the tunnel portal.

269. Faulted zones observed in cuttings at the eastern tunnel portal and approach have significantly lower rock mass strength than the surrounding un-faulted greywacke, based on engineering geological logging of the pilot tunnel in the 1970s and surface mapping of the eastern portal slopes in 2014. These faulted zones will present instability issues for the cut slopes at the portal and approach for the new Mount Victoria Tunnel. Bedding planes and sheared zones with adverse orientations for the new cut slopes at the eastern portal were observed in the pilot tunnel.

Figure 57 – High cut slopes proposed along the eastern approach to the new second tunnel

270. The presence of the fault could mean much weaker rock, low capacities for the proposed soil nails | rock anchors and significant displacements or failure associated with these high steep slopes. The groundwater regime could also be locally complex with groundwater pressures behind low permeability fault zones, and higher pressures in fractured zones associated with the presence of the fault. The weak zones associated with the fault will likely control the stability of the steep slopes, rather than the strength of the weak or weathered rock mass.

271. During an earthquake, a range of slope failure mechanisms could develop, particularly combinations of shallow-seated disaggregated rock mass failures and kinematic failure mechanisms including structurally controlled slides and joint-controlled step-path slides. These will be exacerbated by the topographical amplification and failures affecting the upper parts of cut slopes in particular or larger defect-controlled failures. Observations of earthquake-induced slope failures in Torlesse greywacke in the Kaikōura earthquake show that co-seismic slope displacement can lead to rapid failure and collapse due to the brittle nature of the greywacke rock mass (Mason and Brabhaharan, 2023). The runout of potential slope failures from the cut slopes and the natural hillslopes above the cut could lead to inundation of the eastern access to not only the new tunnel but also the existing tunnel.

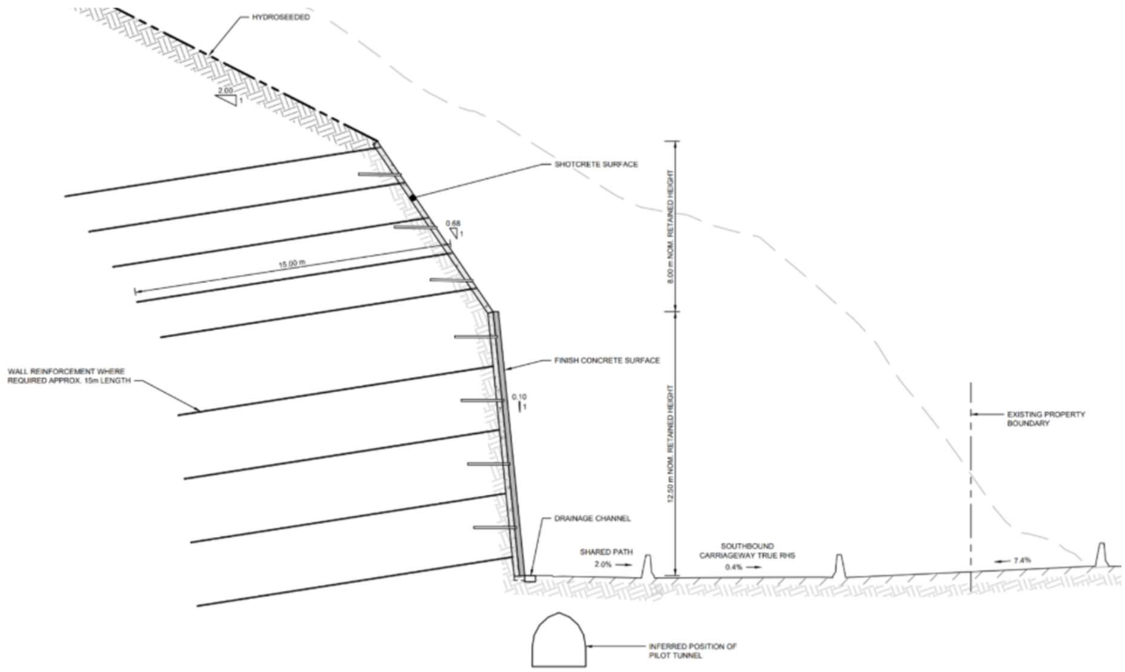

Figure 58 – Steep anchored slopes proposed along the eastern approach to the second tunnel

272. Additional geotechnical investigations have been carried out in the eastern part of the Mt Victoria tunnel and approaches to better understand the ground and groundwater conditions. These recent investigations included vertical and inclined cored boreholes, supplemented by downhole acoustic televiewer logging to obtain information on the rock defects. The investigations showed that there is only a very thin soil cover above bedrock, and the highly to moderately weathered rock has defects that are likely to influence stability. Given that the soil cover is thin, there is no need for a significant height of 2H:1V slope at the upper part of the cutting, and a moderately steep cut slopes with lesser stabilisation measures may be considered during detailed design. Either way, the recently completed geotechnical investigations provide confidence that a stable cut slope can be designed and constructed for the new cut slope on the northern side of the eastern approach to the new tunnel, to provide resilience of access to the new tunnel.

273. In addition, the steep cut slope that is covered with a thin layer of shotcrete, on the south side of the eastern approach to the existing tunnel (see Figure 59) could also fail in an earthquake inundating the exiting approach as well as the approach to the new tunnel, closing access through the tunnels.

274. The Transport Resilience PBC concluded that this risk could be mitigated as part of the design and construction of a second tunnel, e.g. through reprofiling the slope to a flatter slope angle. These works are being considered by NZTA but are not part of the current Project.

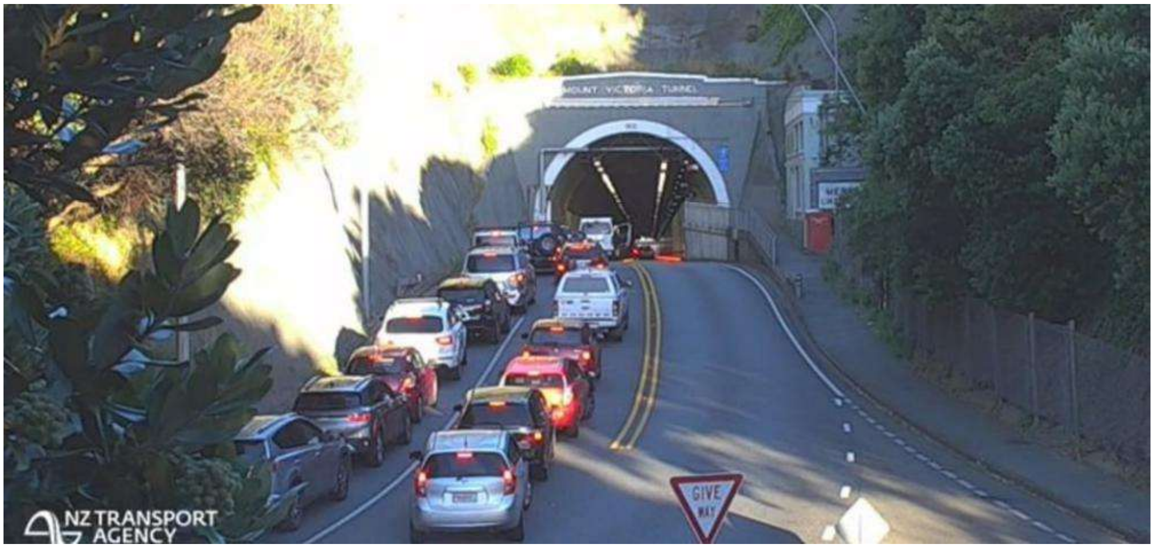

Figure 59 – Oblique view of the Eastern Approach to the Mt Victoria Tunnel

Ruahine Street

275. It is understood that the SH1 route along Ruahine Street is prone to local flooding. However, flood modelling carried out as part of this project indicates that the additional stormwater management measures and proposal for a larger stormwater pipe will reduce the flooding along Ruahine Street, see Figure 18. Any residual flooding will be of low depth allowing vehicles to pass through, perhaps at a slower speed. This flooding would affect access for a short duration of hours to a day or so. Therefore, the flood hazard would be less than the current situation.

9. CONSULTATION

277. A community engagement survey was held for the Project. The community survey was part of the wider engagement on the proposed SH1 improvements project with the community and stakeholders. The survey was developed to get community feedback to help future project development.

278. Comments included concerns about potential subsidence issues and damage to property that might occur because of tunnel construction. I have assessed these impacts in Section 7.

279. A previous version of this report was provided to Wellington City Council (WCC) for an initial review, and their comments included the following:

280. For the Terrace Tunnel, WCC noted that while the Terrace Fault Zone is recognised as a critical feature controlling northern approach cuttings, with weak zones governing stability rather than overall rock mass strength, stability analyses were currently not included. WCC indicated they were happy for these analyses to be provided in the next phase of Project design.

   i. Additional geotechnical investigations were required and a ground subsidence management plan with trigger levels, monitoring and property-specific mitigation strategies was sought. A Groundwater and Settlement Monitoring and Contingency Plan (GSMCP) is proposed, which will apply to the areas identified in Annexure A. Indicative content for this plan is set out in the Groundwater Assessment report

   ii. A full liquefaction assessment for key areas including Sussex Street, the SH1 embankment, and Cambridge-Kent Terrace corridor was also requested, which has been added into Section 8 (paragraphs 221 to 227) above

   iii. WCC also requested that their own geomorphic mapping is incorporated into the assessment, and this is now included in Section 4, Figure 3

281. The location of the heritage buildings/structures should be mapped and the impact on them assessed. This is included in Section 7 and Annexure A.

282. The NPS-NH could also be considered along with detailed construction methodology assessments including building tolerance criteria and contingency measures. However, I understand that the NPS-NH does not apply to infrastructure projects, so this is not relevant in this case. Rather, the geotechnical assessment has been updated to evalute alignment with the (NPS-I provisions relating to natural hazard resilence. The relevant policies are set out in Section 5and the technical evaluation relevant to these policies is outlined in Section 6.

10. CONCLUSION AND RECOMMENDATIONS

283. The Project will provide resilience benefits along this important route, and the risks associated with construction of the Project can be managed through engineering measures during detailed design and construction.

284. The resilience benefits that the Project brings to the region can be felt regionally and nationally – that is, in my view they are regionally significant (if not nationally so, given the important function performed by this part of SH1) – and are summarized below:

i. The duplication of the Terrace and Mt Victoria Tunnels will bring operational resilience due to being able to operate one tunnel even if one of the tunnels is closed due to incidents in the tunnel

ii. The grade separation of the arterial Cambridge / Kent Terrace – Adelaide Road connection from the state highway traffic will enable one route to operate even if the other is closed due to incidents or maintenance activities

iii. The new tunnels with allowance for fault rupture will enable these to be quickly recovered as the tunnel linings will include movement joints and strengthening to minimise downtime and hence resilience of access

285. Strengthening of the Mt Victoria Tunnel approaches, especially at the east approach with the adoption of stable slopes and stabilisation measures will facilitate access to the Mt Victoria tunnel being able to be maintained or quickly restored in significant to major storm or earthquake hazard events.

286. A number of potential hazards were identified early in the design process and actioned qualitatively with the design team to minimise the associated risk and enhance resilience:

i. Potential hazards associated with the crossing of the Terrace Fault and Mt Victoria tunnel East Fault strands within both tunnels and the approaches will proactively incorporate measures to reduce risk and enhance resilience

ii. The Basin Reserve trench concept has adopted more resilient piled wall and props to enhance its robustness, and the embankment will be minimised and incorporate structural measures to protect vulnerable deep brick stormwater pipes, other services being diverted

iii. There are existing flood hazards in a large storm event south of the Terrace Tunnel, at the Basin Reserve – Cambridge Kent Terrace area and along Ruahine Street. The flood hazard south of the Terrace will be somewhat mitigated by the incorporation of measures to pump the flood waters to a storage tank, and the additional stormwater measures and pipe proposed along Ruahine Street will significantly reduce the flooding along this section of the highway. Flood hazards at the Basin Reserve area will remain as existing, and continue to affect access resilience, but only for a short duration, likely less than 12 hours

iv. Proactive measures will be taken to manage the risk of damage to properties and services above the new Terrace Tunnel and to a lesser extent the Mt Victoria Tunnel, due to subsidence of the ground, through enhanced tunnel construction methodologies, pre-construction surveys, underpinning of critical buildings monitoring, setting of alarm levels, and repairs to buildings where necessary

v. The subsurface easements above the Terrace Tunnel corridor will incorporate conditions to ensure that future development does not affect the tunnels

vi. Additional geotechnical investigations have been carried out to better characterise the ground conditions along the approaches to the Mt Victoria Tunnel and this information will be used to ensure that the approach cut slopes are stable in storms and earthquakes and ensure the route remains open or can be quickly restored

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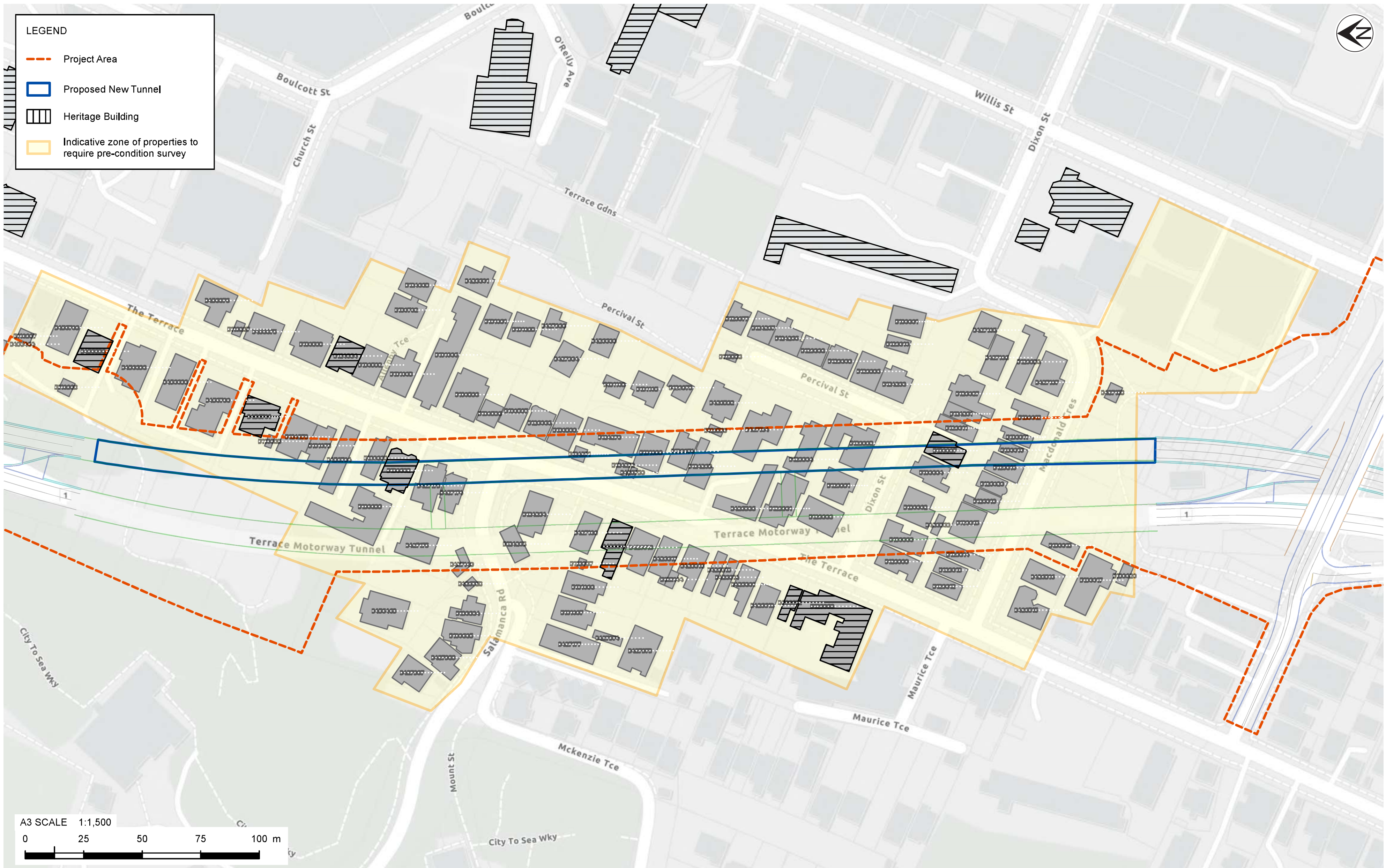
ANNEXURE A - Indicative areas for subsidence management



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REV	DESCRIPTION	GIS	CHK	DATE
0	First version	JORB	RANI	26/02/26
1	Second version - Heritage buildings and pre-condition survey zone added	JORB	RANI	15/06/26

LOCATION PLAN: Wellington

PROJECT No.	1097483	
DESIGNED	KELE	JUN.26
DRAWN	JORB	JUN.26
CHECKED	RANI	JUN.26
APPROVED	JRN	21/07/26

CLIENT: NEW ZEALAND TRANSPORT AGENCY (NZTA)

PROJECT: SH1 WELLINGTON IMPROVEMENTS CONSENT DESIGN

TITLE: TERRACE: PROPOSED TUNNEL DUPLICATION - POTENTIAL SETTLEMENT EFFECTS - BUILDINGS AND STRUCTURES

SCALE (A3) 1:1,500   FIG No. FIGURE A4.   REV 2

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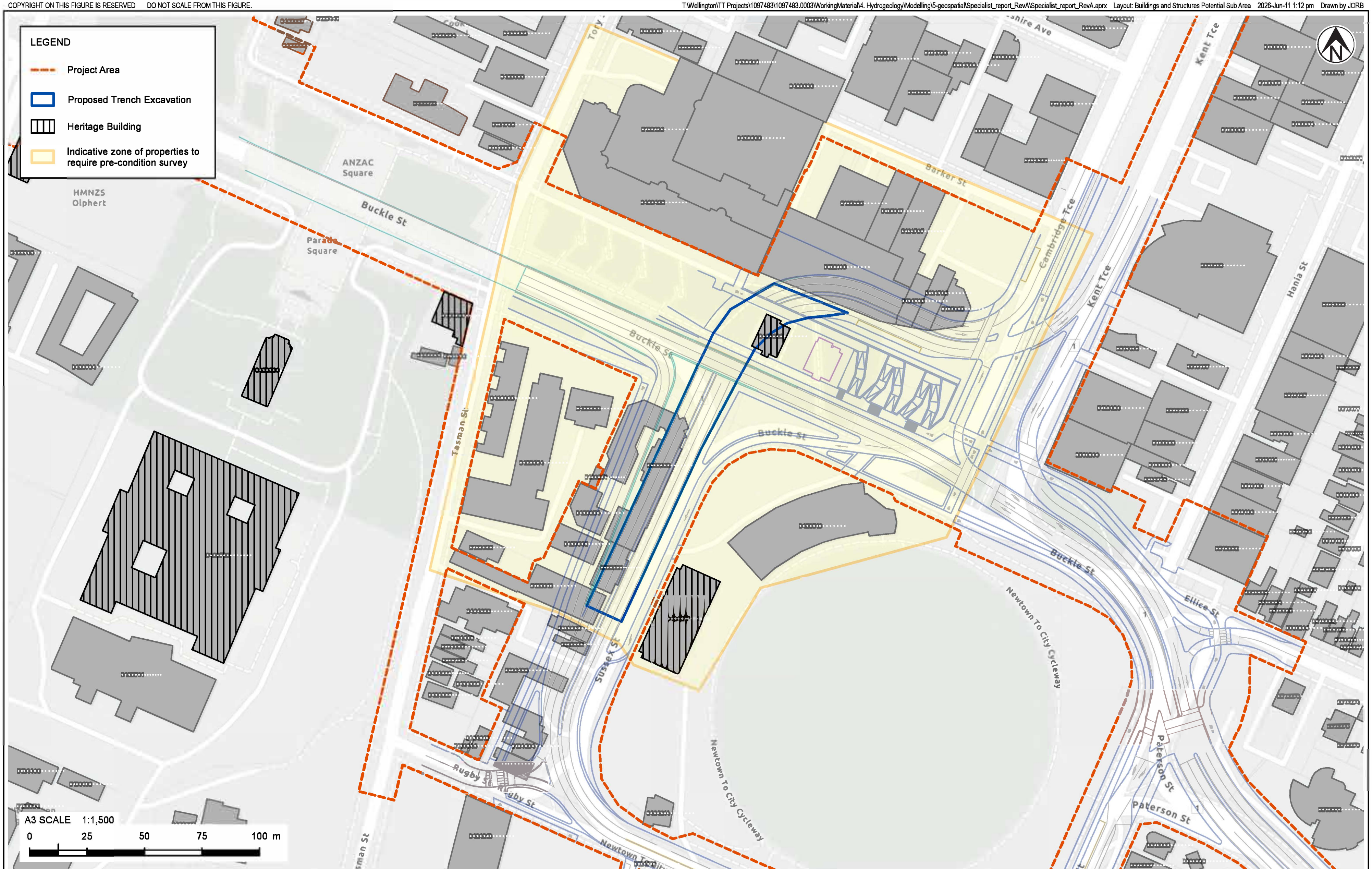

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APPROVED	JRN	21/07/26

CLIENT NEW ZEALAND TRANSPORT AGENCY (NZTA)

PROJECT SH1 WELLINGTON IMPROVEMENTS CONSENT DESIGN

TITLE BASIN RESERVE: PROPOSED TRENCH EXCAVATION - POTENTIAL SETTLEMENT EFFECTS - BUILDINGS AND STRUCTURES

SCALE (A3) 1:1,500 FIG No. FIGURE B4. REV 2

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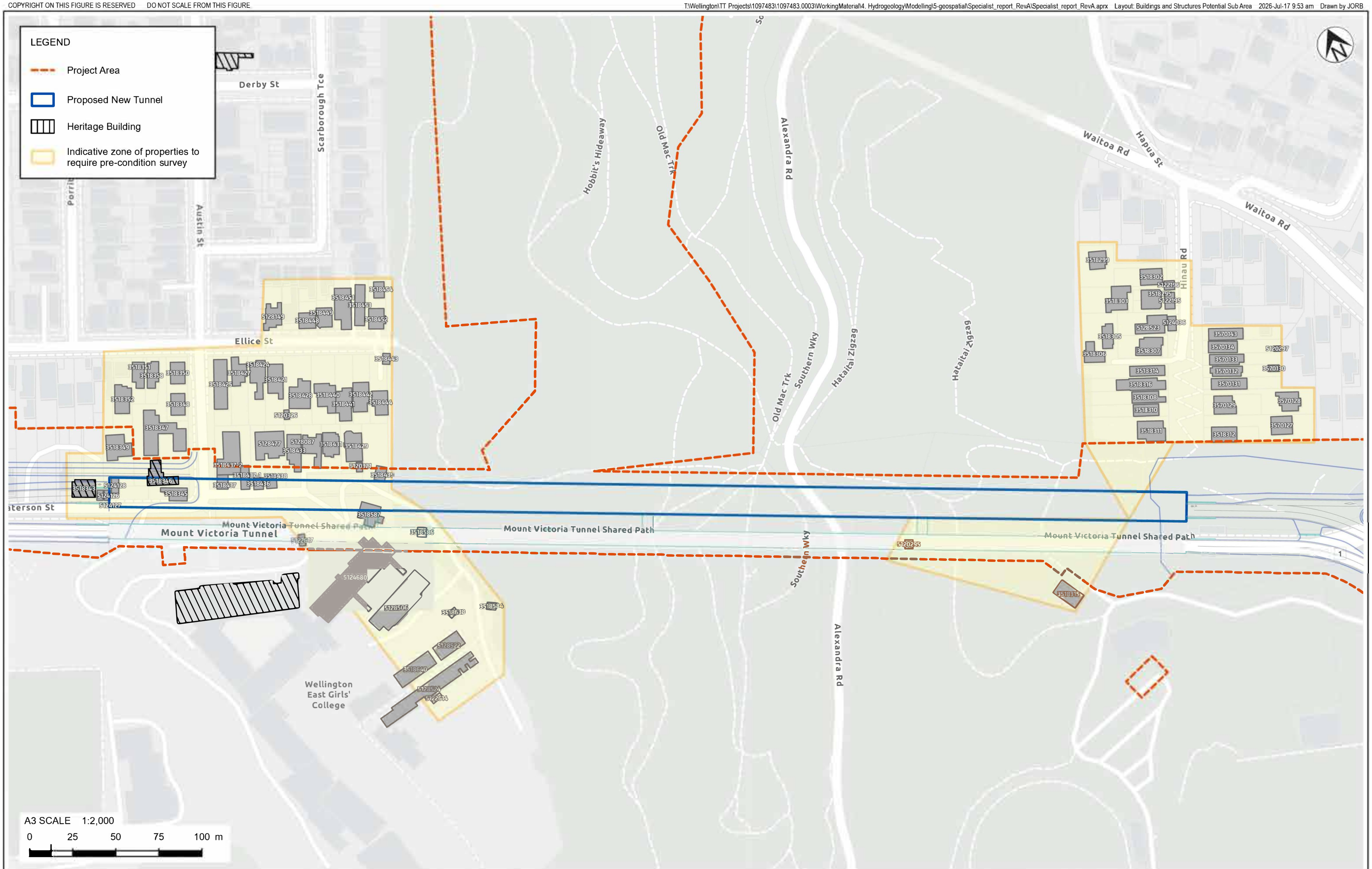

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REV	DESCRIPTION	GIS	CHK	DATE
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1	Second version - Heritage buildings and pre-condition survey zone added	JORB	RANI	22/07/26

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DRAWN	JORB	JUL.26
CHECKED	RANI	JUL.26
APPROVED	JRN	23 Jul 2026

CLIENT **NEW ZEALAND TRANSPORT AGENCY (NZTA)**
PROJECT **SH1 WELLINGTON IMPROVEMENTS CONSENT DESIGN**
TITLE MOUNT VICTORIA: PROPOSED TUNNEL DUPLICATION - POTENTIAL SETTLEMENT EFFECTS - BUILDINGS AND STRUCTURES
SCALE (A3) 1:2,000 FIG No. FIGURE C4. REV 2