



# Let's Get Wellington Moving

Resilience of Recommended Programme of Investment



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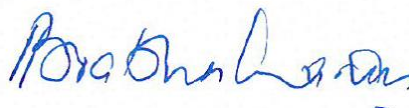
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Revision	Details
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## Acknowledgements

Advice from Bruce Maney and Scott Ney (WSP Australia) on LRT systems is acknowledged.

## Limitations

This report has been prepared for the NZ Transport Agency to meet its specific brief and requirements and inform the Let's Get Wellington Moving project.

Other parties shall not use this report for their purposes and should contact WSP Opus for specific advice for their needs.

# Summary

## Resilience Issues associated with the Recommended Programme of Investment

The Recommended Programme of Investment (RPI) proposes a number of strategies to enhance transport in Wellington City. The programme has been reviewed to identify the resilience issues associated with them based on known natural hazards. It is recognised that the programme has not progressed to the stage of developing mitigation measures through design. Therefore, this assessment considers the resilience of the recommended programme in place, with common standards of design and practical mitigation measures. Some resilience risks are impractical or very costly to mitigate through design and are best dealt with through route selection or form. Possible measures to enhance resilience are identified in this report.

The resilience issues associated with these investments are summarised in Table S.

Table S – Resilience Issues related to the Recommended Programme of Investment

Strategy	Investment Proposal	Associated Resilience Issues	Comments
Step change in public transport connection to the north	Increased bus priority on Hutt Road and Thorndon Quay	Hutt Road is vulnerable to closure from failure of retaining walls, slopes and possibly overbridge structures, due to earthquakes and landslides.	Parallel investment in enhancing resilience of Hutt Road is important.
	Increased rail network capacity and service	Rail network – Johnsonville line (landslides), NIMT (landslides, fault rupture and bridge damage), Hutt Valley line (landslides, flooding and coastal erosion along Petone to Ngauranga) are vulnerable to closure.	Improving resilience of feeder rail networks is critical to deliver benefits. This will include operational planning of alternate transport such as buses where roads are open.
Step change in public transport through Central City	Implementing dual spine PT through central city.	Enhances resilience by adding redundancy, particularly as both Golden Mile (damaged building safety) and the Waterfront Corridor (liquefaction lateral spreading) are vulnerable to earthquake hazards.	PT can also be added or relocated along Thorndon to Basin section of SH1 motorway to improve resilience, because of the vulnerability of the CBD routes to earthquakes.
Step change in public transport through Mass Transit	LRT from Railway Station to Newtown	LRT route along waterfront is vulnerable to liquefaction and lateral spreading. LRT cannot be reassigned (like rubber tyred mass transit) if a section of corridor is closed due to earthquake or other related hazards, see below.  Waterfront route not affected much in a low sea level rise scenario, and in a larger sea level rise scenario, all CBD routes will be affected	Alternate mass transit or incorporate resilience into LRT corridors. Note that SH1 motorway corridor will be more resilient to sea level rise and earthquakes; through Newtown, along Hanson Street – south Adelaide Road would give enhanced resilience (but recognise these routes are more distant from commuters).
	LRT from Newtown to Airport	LRT route through Kilbirnie and Cobham Drive is particularly vulnerable to liquefaction lateral spreading, tsunami and sea level rise. Further inland Kilbirnie will be less affected except in a very large tsunami.	Alternate route through Rongotai (middle of Kilbirnie – Lyall Bay Isthmus) and below the runway through an underpass. to the airport and then to Miramar would reduce resilience risks.



Strategy	Investment Proposal	Associated Resilience Issues	Comments
Improving bypass route from the North	Southbound widening of SH 1 between Ngauranga and Aotea Quay	Both existing motorway and Hutt Road in the network vulnerable to fault rupture, coastal hazards or landslides and bridge failures.  Eastern seaboard widening of SH1 motorway also exposes new lanes to earthquake, coastal and sea level risks.	Consider opportunities for enhancement of resilience through alternate widening on the western side, and alternate alignment for Wellington Fault crossing, together with current consideration of port, ferry terminal and connection to the transport network.
	Second Terrace Tunnel	Enhances resilience through redundancy in routine hazards and provides a secure alternate route not affected by building damage safety hazards in CBD local streets, or sea level rise.	Consider resilient design to seismic standards, particularly for approach structures and portals.
Improving bypass route through Te Aro	Cut and cover tunnel between Terrace Tunnel and Sussex Street.	Enhances resilience by providing redundancy for routine hazards and a secure alternate route not affected by building damage, safety hazards in CBD local streets and liquefaction/lateral spreading in earthquakes, or sea level rise.	Design to be resilient to groundwater issues including climate change effects.
Improving bypass route by grade separation at Basin Reserve	Sussex Street extension local road overbridge to grade separate.	The proposed bridge will straddle an area of liquefaction and lateral spreading down the terrace rise and expose SH1 to poor resilience, which requires significant investment in ground improvement of the area to mitigate these hazards.  The at-grade state highway north – northeast of the Basin will also continue to be vulnerable to liquefaction and flooding given the liquefiable ground and high groundwater pressures.  Pedestrian underpass from Cambridge / Kent Terrace corridor under SH1 at grade will be challenging and very difficult to impractical, given poor ground and groundwater conditions (high groundwater, artesian groundwater below and liquefaction hazard).	Consideration could be given to entrance from the west (Sussex Street) or south-east of the Basin Reserve.
Improving bypass route by better access to east	Second Mt Victoria Tunnel and widening Ruahine Street	Opportunity to provide redundancy and construct tunnel with more resilient approaches (tunnels themselves generally resilient).	Consider resilient design to seismic standards, particularly for approach structures and portals.

It should be noted that this review has not considered what services need to be relocated to allow construction of the recommended programme, or what measures may be considered to protect the city from sea level rise in the future. It is noted that there is an opportunity to carry out some flood hazard improvements in conjunction with the proposed Recommended Programme.

## Land Use and Urban Form

The RPI summary report suggests that there will be significant growth in the population living in the CBD and the eastern suburbs, and this would be encouraged in order to reduce the demand for private vehicle travel. While this is a sound strategy from a transport perspective, increased population in the CBD has led to a lower resilience for society because of the potential hazards in the CBD, such as the building stock being prone to damage from earthquakes and the lack of access into the CBD for response and recovery and supplies from outside the CBD for post-disaster sustenance. The growth in the residential population in Kilbirnie (facilitated by the proposed LRT route) could also lead to poorer community resilience because of the vulnerability of the area to earthquake liquefaction and tsunami hazards. These potential resilience issues need to be considered holistically, with appropriate types of land use adopted where such hazards exist.

## Other Interventions

A range of other interventions necessary to enhance the resilience of transport, within the area of the Let's Get Wellington Moving study, are presented for consideration. These interventions consider response and recovery after low impact - high probability events (e.g. routine storm events), high impact - low probability events (e.g. large earthquake) and sustaining socio-economic functionality of the city and the broader Wellington Region. These issues have been identified in the Programme Business Case for Wellington Land Transport Resilience, which is in the final stages of completion.

## Tyre-based mass transit v Light Rail Transit

Any mass transit systems, be it rubber-tyred or a fixed guideway such as a proposed Light Rail Transit (LRT), would potentially be adversely affected by earthquakes and the associated effects of liquefaction, damage to seawall and overbridge structures and building damage safety hazards.

After an earthquake causing liquefaction and lateral spreading, a rubber tyre-based system may be able to resume operations after localised repairs of the road or rerouted.

A fixed guideway system such as LRT which operates on a fixed structural track might take much longer to repair, depending upon the design of the structure. Repair times could potentially be reduced where ballasted tracks are used, however, this is not likely to be a viable option for an LRT operation within an urban city environment with shared users.

Any mass-transit systems will be equally affected by failure of structures or utility networks and safety hazards associated with damaged buildings.

Rubber tyre-based mass-transit systems can also potentially be rerouted to (temporarily) operate along alternative corridors such as the SH1 Wellington Urban Motorway and Karo Drive, whereas a fixed guideway option such as LRT does not have this flexibility.

Therefore, overall rubber tyre-based mass transit systems are more resilient than a fixed track based LRT system. However, while fixed track LRT systems are less resilient than rubber tyre-based mass transit systems, this is not a fatal flaw. Such systems would require additional development of measures to enhance the track form, foundations and ground improvement, to reduce its vulnerability to liquefaction induced subsidence and lateral spreading displacements and facilitate quicker repair and recovery. The adoption of mixed systems will provide diversity and facilitate alternate response to be provided such as using rubber tyre-based systems during periods of recovery after events such as a major earthquake.

## LRT: Waterfront route v Golden Mile / Featherston - Victoria Street Corridors

It is assumed that the waterfront sea wall and pedestrian overbridge structures would be strengthened as part of any LRT scheme along this route.

An LRT route along the waterfront would be more vulnerable to liquefaction and associated lateral spreading than the other routes as it is on reclaimed land and is closer to the waterfront sea walls. While liquefaction is likely to be restricted to greater depths because of generally liquefaction-resistant reclamation fills at shallow depths, lateral spreading will cause more deformation and cause damage to the LRT trackform.

An LRT route on Featherston Street – Victoria Street will also be damaged by liquefaction and subsidence, but to a lesser degree, and may still take a considerable time to restore. A Golden Mile route near the former shoreline may be damaged more than a Featherston Street route because of the shallow depth to the liquefiable marine sands.

However, a major earthquake causing extensive liquefaction and lateral spreading would also lead to damage of the built environment and consequently to much-reduced activity in the CBD and will take a significant time to recover. This would allow time for repair and restoration of the LRT route in parallel with other repair efforts. Repair of an LRT route would not only require consideration of the track and trackform structures where the vehicles operate, but also the supporting infrastructure including any overhead line / traction power equipment, stops, and signalling / communication equipment. All of these must be in safe working order prior to the LRT system resuming operations.

An LRT route along the Golden Mile and Featherston Street - Victoria Street route would be located in a much denser built up environment, and these corridors would be more likely to be closed due to safety hazards associated with damage or failure of buildings along the route, in the aftermath of earthquakes. Therefore, this route has been assessed to be much more vulnerable to closure from adjacent building damage. The Kaikōura earthquake of 2016, and the damage to some localised buildings and associated closure of adjacent roads for long periods of time, show that such building related closures can happen in moderate earthquakes, and not just major earthquakes. In such moderate earthquakes, the CBD will be largely functional, and the demand for public transport such as the LRT will remain. The whole inner city in Christchurch was closed due to building damage safety issues for many months following the 2010-2011 Canterbury earthquakes. The duration and nature of such a closure in Wellington is likely to be more complex given the resident population in the CBD and the potential building damage.

The waterfront has fewer buildings, mainly along the western fringe, and an LRT route located eastwards of the western fringe will be less likely to be closed due to building damage hazards.

Assuming a depot would be located on a property somewhere along the waterfront, regardless of the alignment chosen, it would be vulnerable regardless of the route alignment. The depot and stabling will need to be carefully located and designed to enhance its resilience, so that parked vehicles are secure and in safe working order prior to any resumption of services.

It is recognised that the liquefaction risk is greater along the waterfront route and the building damage safety risk is greater along the Golden Mile / Featherston Street routes. The liquefaction and associated lateral spreading is likely to cause severe damage only in large earthquakes with a long recurrence interval, and in such earthquakes the demand for LRT systems would be significantly less because of the widespread damage to the CBD. Damage to the tracks from liquefaction and lateral spreading can be limited by design measures (ground improvement, and more resilient track foundations).

However, transport corridor closures can also occur due to building damage in relatively moderate earthquakes, as observed in the distant Kaikōura earthquake, and in these events the demand for LRT systems are likely to remain. Even localised building damage-related closures could close the LRT operation, and this risk is likely to be uncontrollable by agencies designing or operating the LRT system. Therefore, an LRT system along the Golden Mile or Featherston Street – Victoria Street will have a lower level of resilience because of uncontrollable building damage-related closures than an LRT system on the waterfront that is well-designed to minimise damage from lateral spreading.



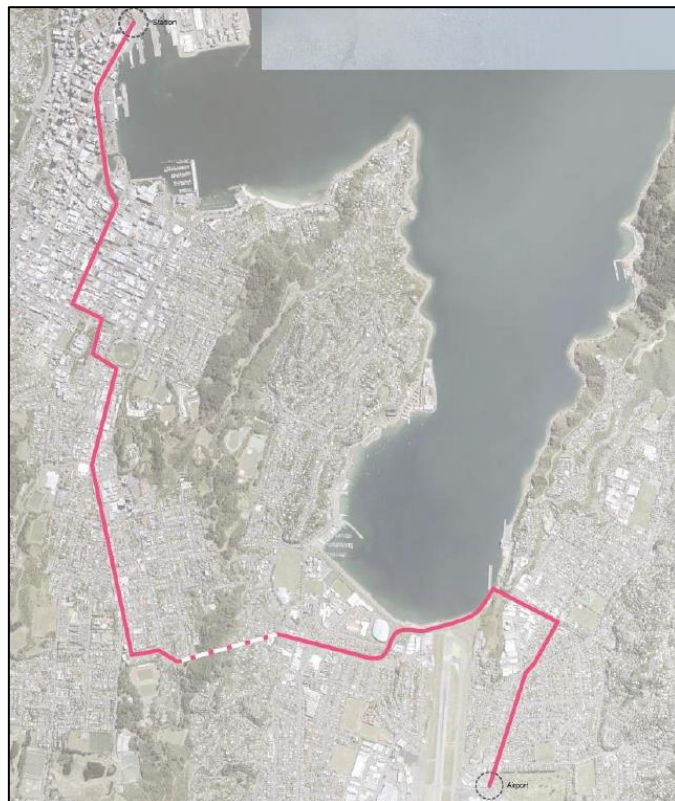
# 1 Introduction

The New Zealand Transport Agency and local Councils are developing a transport strategy for Wellington City. A Recommended Programme of Investment (RPI) has been developed, at strategy level, to enhance transportation in Wellington City (NZ Transport Agency – Greater Wellington – Wellington City Council, 2018).

The Agency has asked WSP Opus to provide brief advice on:

- 1) The engineering issues associated with operating LRT in a seismically active environment and how these can be addressed;
- 2) The resilience of LRT over tyre-based systems for Wellington, between the Railway Station and Newtown, see Figure 1;
- 3) The resilience of the waterfront route for mass-transit (LRT and multi-articulated buses) compared to the Golden Mile or Featherston / Victoria, and the evidence behind this;
- 4) The resilience of all major new assets in the RPI; and
- 5) Other types of interventions that could be progressed to address resilience risks and the resilience benefits of these, e.g. types of shorter term interventions.

The resilience assessment has been based on the document “DRAFT Recommended Programme of Investment. Summary Report – September 2018” (NZ Transport Agency – Greater Wellington – Wellington City Council, 2018). This report provides comments on the resilience of the transportation improvements proposed as part of the strategy.



*Figure 1: LRT Route under Consideration as part of the Let's Get Wellington Moving Project*  
(after NZ Transport Agency – Greater Wellington – Wellington City Council, 2018)

## 2 Resilience of Mass-Transit System Routes

### 2.1 Proposed Mass Transit System and Route

As part of this strategy a Light Rail Transport (LRT) is being considered between the Wellington Railway Station in Thorndon, the Wellington Regional Hospital in Newtown, the Airport and Miramar Peninsula, see Figure 1. The proposed LRT route runs close to the waterfront of the Wellington Harbour between the Wellington railway station and Cable Street, and then turns away from the harbour into Taranaki Street. It then runs across the Te Aro Flats along Taranaki Street, across to Tasman Street and skirts around Mr Cook to join Adelaide Road and Riddiford Street in Newtown. From Newtown, the route will extend through a tunnel in Mt Albert, Kilbirnie, and Miramar to the airport.

### 2.2 Description of Hazards along the Route

#### 2.2.1 *Natural hazards*

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

- Ground shaking in earthquakes;
- Tsunami inundation;
- Liquefaction and lateral spreading;
- Failure of existing infrastructure along the route; and
- Potential building damage and collapse, closing the corridor due to safety concerns.

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

- Landslides triggered by rainfall
- Local flooding; and
- Inundation with sea level rise associated with potential climate change.

#### 2.2.2 *Ground shaking*

The proposed LRT will be located in Wellington where there is potential for intense ground shaking. The ground shaking will give rise to the effects of liquefaction, damage to infrastructure and buildings, as discussed below. It is expected that the infrastructure associated with the LRT scheme will be designed for the expected earthquake shaking, noting that the characteristics of earthquake shaking will vary depending on the local ground conditions.

#### 2.2.3 *Tsunami Inundation*

Tsunami inundation and evacuation zones have been published by the Wellington Region Emergency Management Group, and a section is reproduced below in Figure 2.

The map shows that the LRT route in the CBD will be located outside the red zone for evacuation. However, the proposed LRT route, as well as possible alternate routes along the Golden Mile, Featherston Street and Victoria Street, will all be located within the orange zone for evacuation.

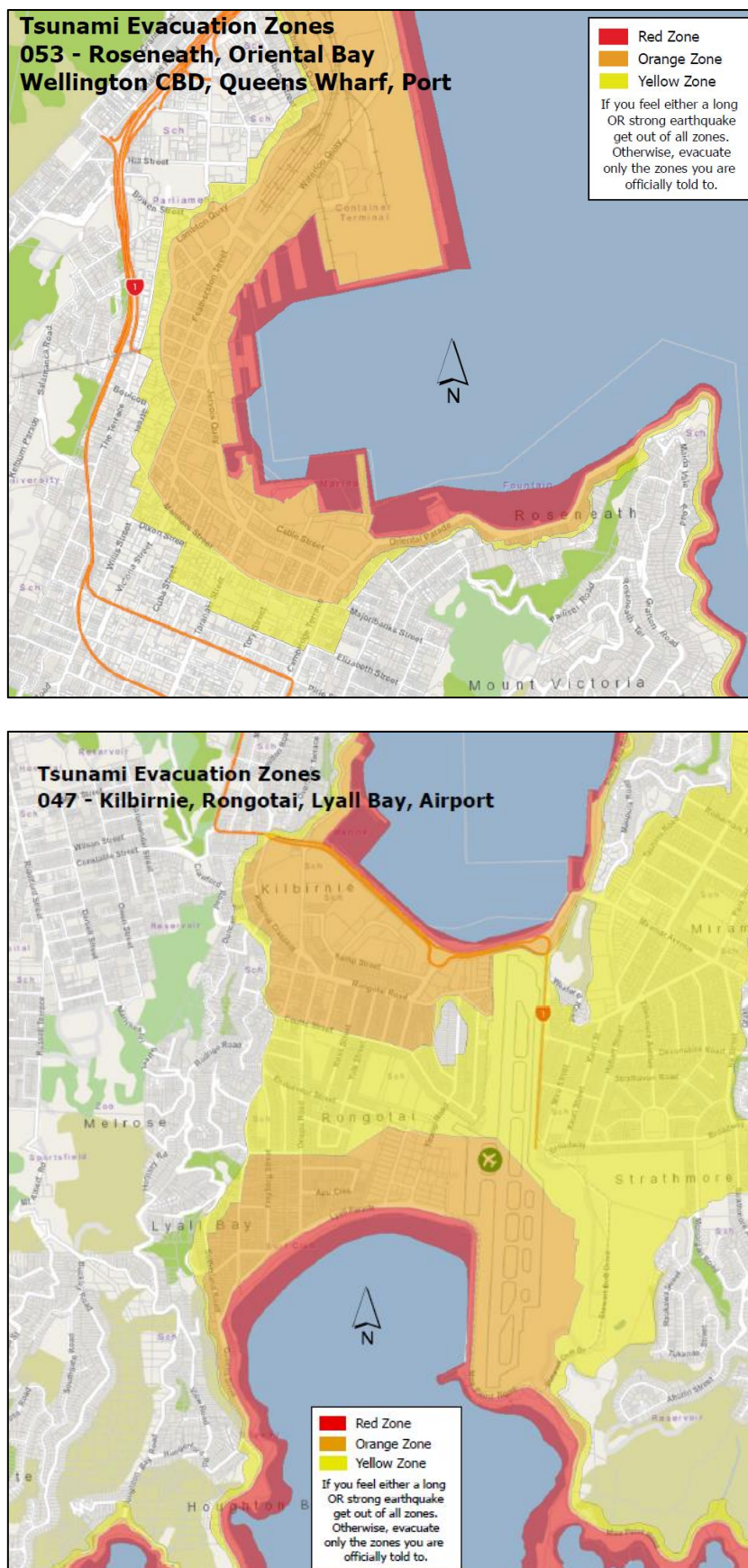


Figure 2: Tsunami Evacuation Zones in Wellington CBD and eastern Suburbs  
 (after Wellington Region Emergency Management Office)



The extension of the LRT route from Newtown to the Airport will be located in the red zone along the eastern end of Cobham Drive. Much of the remaining route through Kilbirnie will be in the Orange Zone for evacuation.

The duration of closure from such a tsunami will depend on the amount of debris mobilised by the tsunami. Given the location of the areas within the Wellington Harbour, the destructive power of a tsunami will be less than if it was exposed to waves from the open sea, if the source of the tsunami is outside the harbour. Kilbirnie will be exposed to the open sea in Lyall Bay and may thus be prone to more damage from a tsunami.

### 2.2.1 Liquefaction and lateral spreading

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). An extract from the liquefaction ground damage hazard maps for the Wellington City area is reproduced in Figure 3, with the LRT route superimposed.

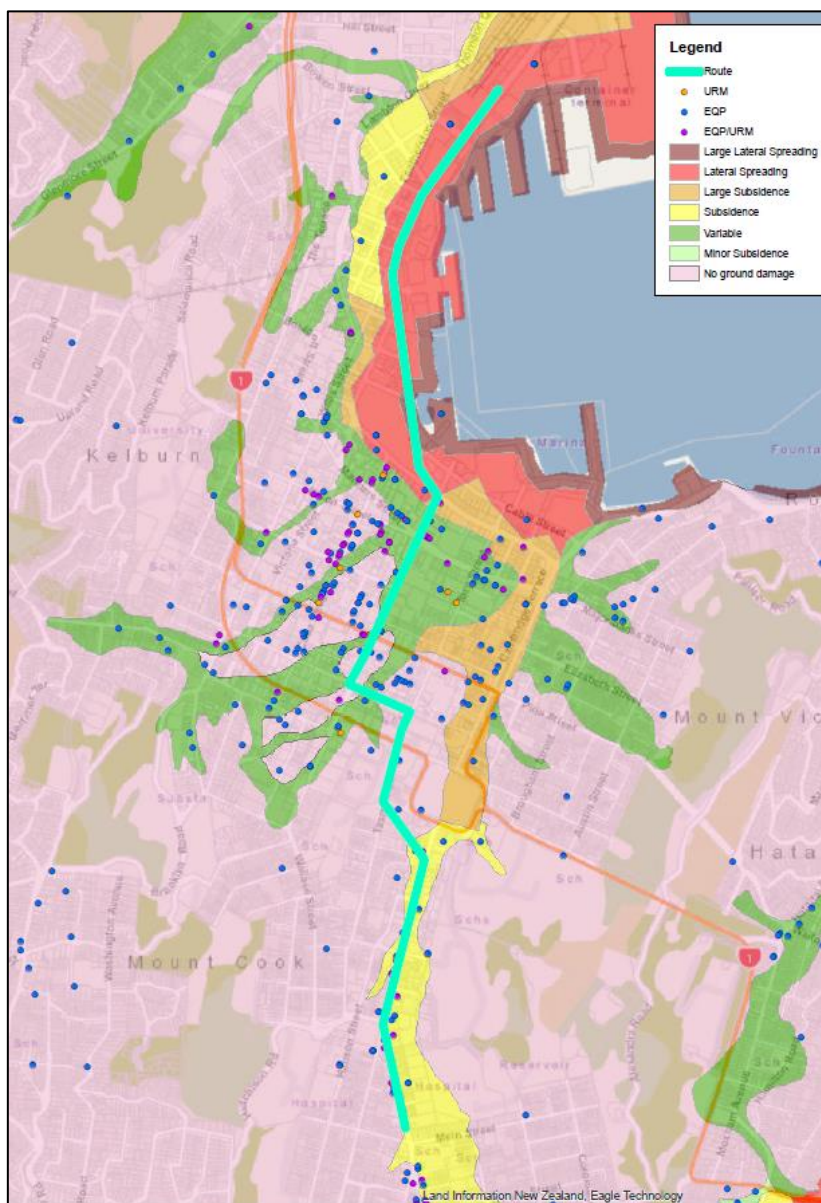


Figure 3: Liquefaction Ground Damage Hazards along the LRT Route  
(Liquefaction hazards after WRC, 1993)

The section of the route along the waterfront is on land reclaimed from the sea over the last century or so. This land has been identified as being susceptible to liquefaction and associated lateral spreading (Wellington Regional Council, 1993).

The reclamation fills are generally less susceptible to liquefaction because of the weathered rock derived fill used, although some of these end-tipped fill materials did liquefy and cause damage to the port area in the 2016 Kaikōura earthquake. Underlying the reclamation fills in this area are natural marine beach deposits which are more liquefiable. Liquefaction could lead to subsidence of hundreds of millimetres and lateral spreading towards the harbour. Past earthquakes have indicated that there is potential for ground damage from lateral spreading to extend to distances of the order of 200 m from a free surface, in this case the harbour seawall. Observations from the Canterbury Earthquakes indicate that the most severe lateral spreading has generally been over distances up to 50 m or so, and a lesser level of lateral displacement of the ground between 50 m and 130 m.

The proposed LRT route is closer than 50 m adjacent to Whitmore Street along Waterloo Quay and the lagoon adjacent to the Star Boating Club near the City to Sea Bridge along Jervois Quay (see the brown zone in Figure 3). Along these sections there is expected to be large displacements, the magnitude of which will depend on the performance of the sea walls along these sections, see Section 2.5. Much of the remaining sections of the LRT route along the waterfront will be in the red zone in Figure 3 where limited lateral spreading, and subsidence can be expected.

Along a potential alternate route via the Golden Mile, Featherston Street and Victoria Street (partly in the yellow zone and partly in the red zone), subsidence and smaller lateral spreading displacements of the ground could occur. Given that the marine beach sands are at shallower depth, particularly along the old shore line along the Golden Mile, liquefaction may cause more near surface ground damage to shallow foundations.

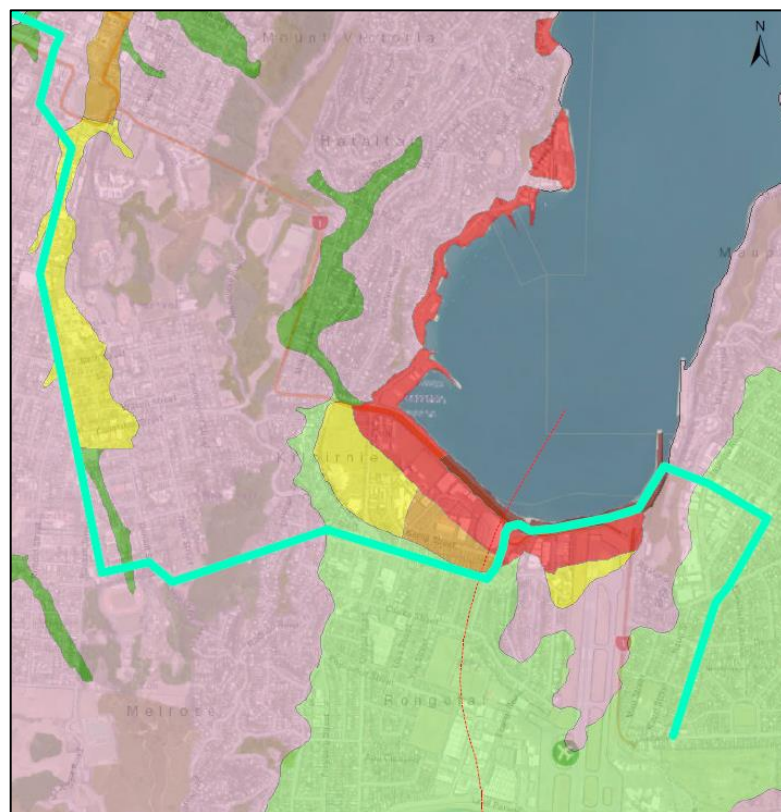


Figure 4: Liquefaction Ground Damage Hazards along the LRT Route in the Eastern Suburbs

(Liquefaction hazards after WRC, 1993; see legend in Figure 3)



Along the route through Newtown (western yellow zone in Figure 4), subsidence of the ground will be expected, but not lateral spreading.

An extract of the liquefaction ground damage map for the eastern suburbs of Wellington is presented in Figure 4. Through the eastern suburbs of Kilbirnie and Miramar, the LRT route runs along the eastern section of Cobham Drive which is potentially vulnerable to severe liquefaction and lateral spreading.

### 2.2.2 Flooding

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 5, reproduced from Wellington Water (2018). The map shows the potential for flooding along some corridors considered for the mass transit route from the railway station to the airport.

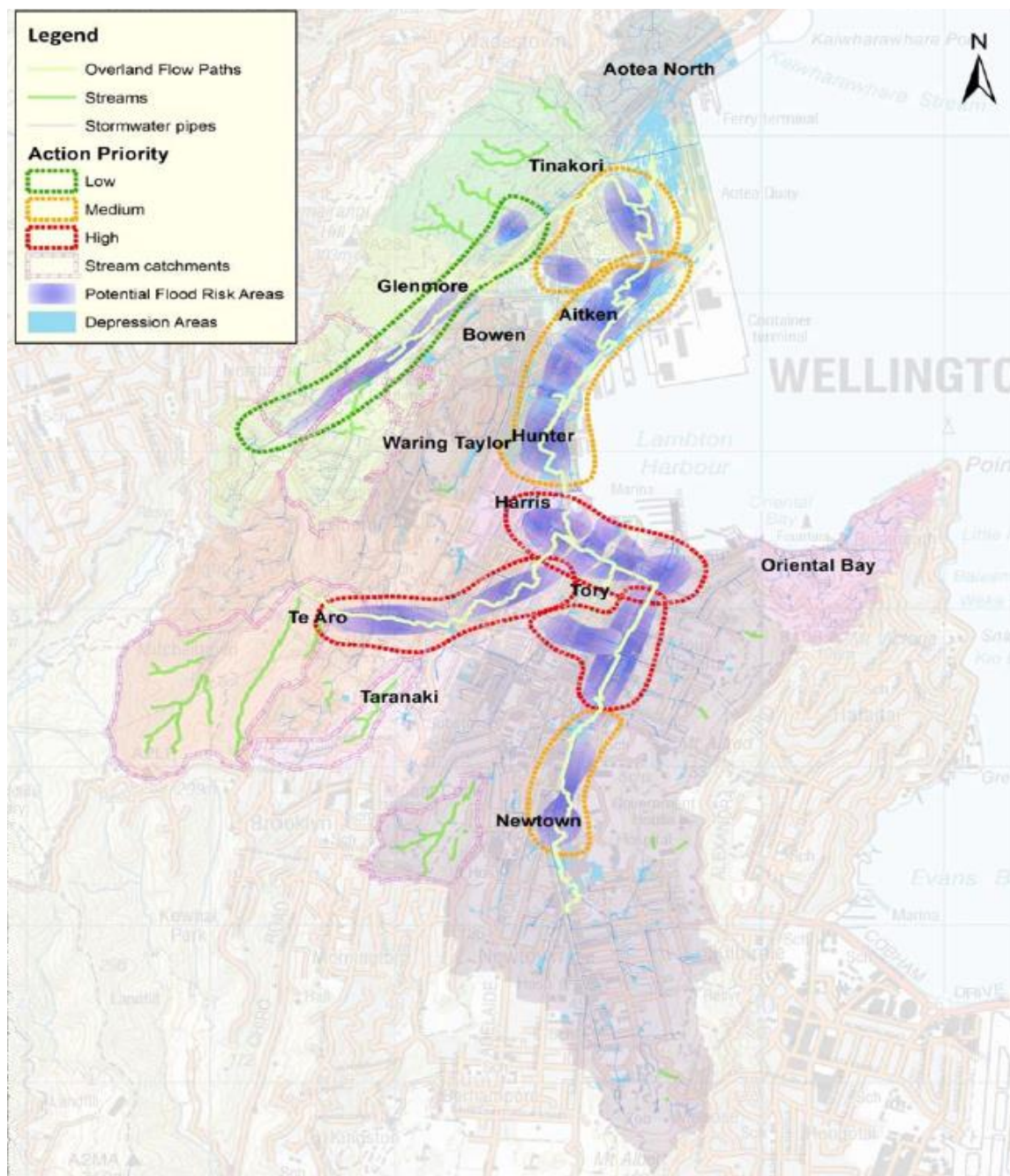


Figure 5: Flood hazards and action priorities in Wellington City

(Wellington Water, 2018)

A more detailed flood map for a 100-year return period rainfall events is shown on Figure 6.

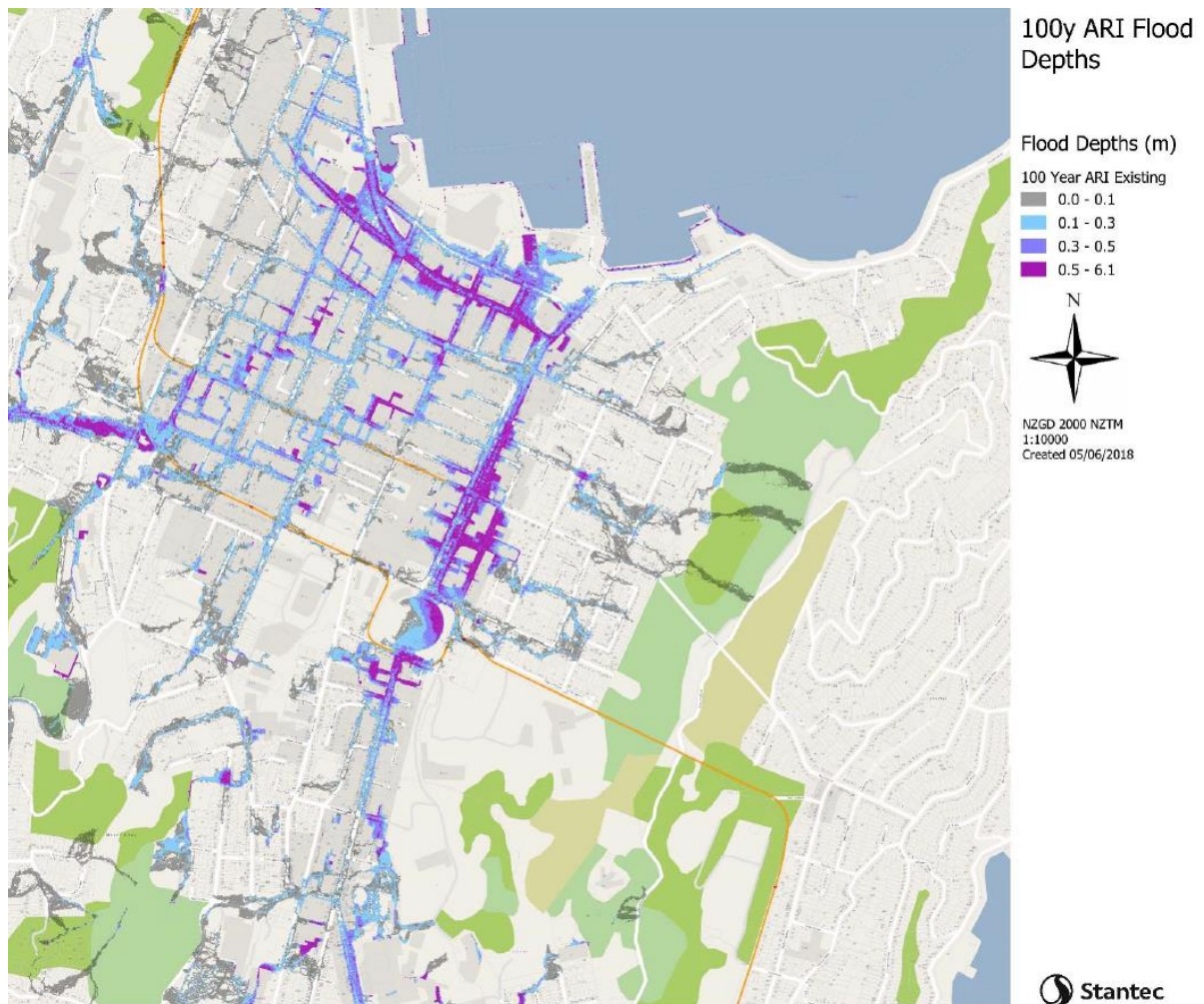


Figure 6: 100-year ARI Flood depths in Wellington City  
(after Wellington Water, 2018)

### 2.2.1 Sea-Level Rise

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 the thermal expansion of sea water.

The potential for sea level rise has been assessed and recommendations made for local authorities by the Ministry of the Environment (MfE, 2017). 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 in this case would be about 1.4 m. This should be considered further at the next stage, together with the consequent effects of sea level rise on groundwater levels and storm water/drainage.

The potential 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 7.





Figure 7: Sea-Level Rise Impact on Wellington CBD

(Sea level maps after Wellington City Council, 2014)

### 2.2.1 Structures

The City to Sea pedestrian overbridge and the adjacent pedestrian overbridge may be vulnerable to damage in an earthquake and need to be assessed. Damage or failure of these bridges could pose a safety risk to the transport corridor below.

The seawalls along Kings Wharf and near the lagoon, adjacent to the city to sea bridge along Jervois Quay, are potentially vulnerable to damage or failure in a large earthquake. Failure of these seawalls could lead to a larger failure of the ground.

These structures have identified as being vulnerable in the Wellington Land Transport Resilience PBC (WSP Opus, 2018), and would need to be assessed and strengthened, as part of any LRT development along the waterfront route.

### 2.2.2 Building Damage Hazards

The waterfront transport corridor is wide, and there are fewer buildings of significant height that can be damaged in an earthquake and pose a hazard to the transport corridor. Compared to the waterfront route, the Golden Mile or Featherston Street corridors have many high-rise buildings on both sides of these roads that may suffer from damage in earthquakes or have their façade or glazing pose a risk to the use of these roads for access.

An assessment of the hazards as part of the Wellington Land Transport Resilience Study indicated that the Golden Mile along Lambton Quay / Willis Street and Featherston Street are likely to be closed for access after a major earthquake, see Figure 8. The closure of the roads within the Christchurch CBD after the Canterbury Earthquakes, due to hazards from building/ damage in 2010-2011 and the closure of some streets in Wellington CBD after the distant Kaikōura earthquake on November 2016, support this assessment.

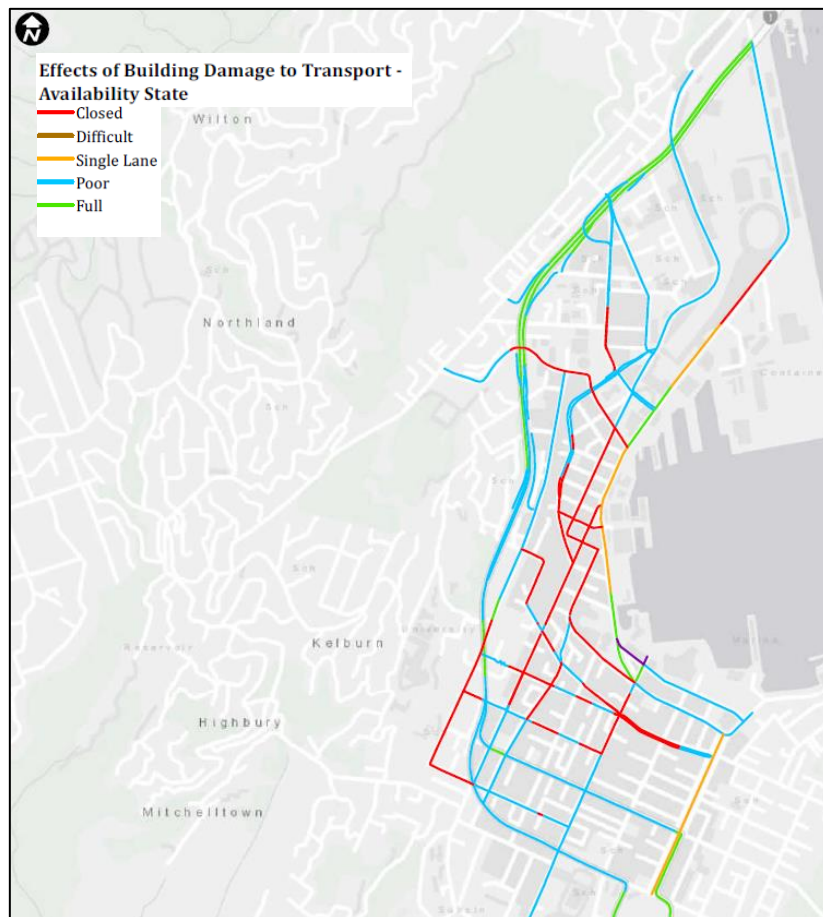


Figure 8: Resilience of City Streets to Building Damage and Safety Hazards

(Wellington Land Transport Resilience, 2017)

For the currently proposed LRT route along the waterfront corridor, the eastern fringe of the corridor would be more likely to remain secure from building damage and safety risk in the aftermath of a large earthquake. The western fringe of the waterfront route will be vulnerable to building damage hazards. Any future planning and redevelopment of this space would need to consider this issue, as a change in the landscape could potentially increase the risks beyond those which exist today.

## 2.3 Resilience of LRT v Rubber tyre-based Systems

### 2.3.1 Hazard environment

As discussed above, the LRT route is prone to earthquake hazards associated with liquefaction and particularly lateral spreading towards the harbour. Therefore, subsidence of the ground and lateral spreading leading to cracking of the ground can be expected. Seawall and pedestrian overbridge structures may also be vulnerable to damage or failure in an earthquake. These hazards are higher along the waterfront route than the Golden Mile / Featherston Street routes.

There is also the hazard from building damage and collapse, and associated safety to pedestrians and users of the LRT or rubber tyre-based systems. Along the waterfront route the hazard from adjacent buildings is currently lower, particularly if the LRT line is located away from the buildings that are along the western fringe of the transport corridor.

### 2.3.2 Resilience of LRT Systems

A comparison of the resilience of LRT and rubber tyre-based systems is presented in Table 1. It has been assumed that a rubber tyre-based system will be similar to buses that are not constrained to run along a defined path. An LRT system is assumed to be on a fixed guideway (tracks) and in this instance, is assumed to be a surface running system rather than underground. It is also assumed at this stage that the LRT will be on a rigid concrete track form to facilitate pedestrian, cycle and vehicular movements in a shared use urban environment.

Table 1: Comparison of Resilience

Hazard	Resilience		Comments
	Rubber tyre-based system	LRT	
<b>Flooding</b>	Both rubber tyre-based and LRT systems will be affected by any flooding. Tyre-based systems could be temporarily reassigned to the motorway / Karo Dr.	LRT system would be equally prone to flooding, but cannot be reassigned to another route.	The hazard associated with flooding will increase as a result of climate change and would affect both systems.
<b>Sea Level Rise</b>	Both rubber tyre-based and LRT systems will be affected by any flooding. However, tyre-based systems could be reassigned to the motorway / Karo Drive	LRT system would be equally prone to flooding, but cannot be reassigned to another route.	Sea level rise would have an impact much beyond the mass transit system, and would need to be considered holistically. A rubber tyre system would be able to adjust to changes much more readily than a fixed track LRT system.
<b>Tsunami</b>	Rubber tyre-based systems would be able to run after the tsunami waves cease and debris on the road is cleared. Some erosion of the road may need to be repaired.	LRT will be similarly able to run after tsunami waves cease and allowing for clearance of debris from the track and also repair any damage to the base of the tracks and communications / electrical systems.	Tsunami poses a similar resilience risk to rubber tyre-based and LRT systems. It is assumed that the LRT is along the surface and not in a tunnel which may be inundated by tsunami waves.
<b>Building Damage Hazards</b>	Rubber tyre-based systems will be vulnerable to road closures due to building damage collapses of their frontages. Generally, there are less buildings along the wide waterfront route and particularly if the western fringe with buildings is avoided in the choice of alignment. Tyre-based systems may be able to be reassigned to run along the motorway – Karo Drive, if that is open.	LRT systems will be similarly vulnerable, but cannot be reassigned if the LRT corridor is affected. Generally, the more heavily built-up alternative Golden Mile – Featherston Street – Victoria Street corridors will be closed after moderate to large earthquakes due to safety hazards associated with buildings, or their facades and glazing.	The waterfront route is wider and has fewer buildings particularly if the LRT is away from the western side of the waterfront transport corridor. Since buildings could potentially be affected by more moderate earthquakes as well (e.g. Kaikōura earthquake), this will be an important consideration, as the economy is likely to be largely functional and with an associated demand for public transport.



Hazard	Resilience		Comments
	Rubber tyre-based system	LRT	
<b>Structures</b>	Rubber tyre-based systems will be constrained by potential damage to the seawalls or damage / collapse of the city to sea and pedestrian overbridges. But there may be a possibility that tyre-based systems may be able to be reassigned to run along the motorway.	The functioning of the LRT will also be constrained by potential damage or failures of the seawalls or damage / collapse of the city to sea and pedestrian overbridges.	The sea walls and bridges would need to be assessed and strengthened, as identified in the Wellington Land Transport Resilience study. LRT would require a detailed assessment of the track form and supporting structures (power poles, stops) which are not a consideration for rubber tyre-based systems.
<b>Liquefaction and lateral spreading</b>	Rubber tyre-based vehicles would be able to run after some sealing of cracks and levelling. These vehicles can be re-routed along different roads or across different lanes if some lanes are affected by more cracking of the road surface following a large earthquake.	LRT cannot be shifted if the tracks are damaged. The ability of the LRT to be relevelled following liquefaction subsidence will depend on the type of track used. Given the urban environment it is assumed that the tracks will be on a concrete or similar hard surface. These cannot be repaired or relevelled easily.  An LRT system along an alternate Golden Mile or Featherston Street corridors will be subject to much lower lateral spreading, and some subsidence from liquefaction. Shallow liquefaction along the Golden Mile could still cause damage to LRT tracks on shallow foundations.	Resilience to earthquakes would favour a rubber tyre-based system due to their flexibility in routing. The use of ballast for rail is not likely to be acceptable in an urban environment. There is an opportunity to explore alternate non-traditional foundations that are flexible and can be repaired more readily.  From a practical perspective the demand for LRT after a major earthquake will be very low, given that damage to the built environment will mean that economy will not be functional within the CBD for some time. However, there may still be a demand for public transport given the number of people living in the CBD.

In summary, both tyre-based systems and the LRT will be significantly affected by earthquakes and the associated effects of liquefaction, damage to seawall and overbridge structures and building damage safety hazards. Tyre-based mass transit systems can run after some quick repairs from liquefaction, whereas LRT tracks will take much longer to repair. The repair times can be reduced by using ballasted tracks, but this will cause issues with achieving an acceptable surface in an urban city environment with shared users. There is an opportunity to explore alternate non-traditional foundations that are flexible and can be repaired more readily.

Both rubber tyre-based and LRT systems will be equally affected by failure of structures and safety hazards associated with damaged buildings.

The adoption of mixed systems will provide diversity and facilitate alternate response to be provided such as using rubber tyre-based systems during periods of recovery after events such as a major earthquake.

## 2.4 Resilience of Golden Mile v Waterfront Route

### 2.4.1 *Effect of various hazards*

The resilience of the mass transit route as proposed along the waterfront and an alternate route along the Golden Mile / Featherston Street / Victoria Street corridors have been considered. The impact of various hazards on LRT routes along these corridors are presented in Table 1. It is assumed that the risk associated with sea wall and overbridge structures will be addressed as part of the construction of an LRT route along the waterfront.

### 2.4.2 *Effect of liquefaction and lateral spreading*

In summary, an LRT route along the waterfront route would be more vulnerable to liquefaction and associated lateral spreading, as it is on deeper reclaimed land and is closer to the waterfront sea walls, see Figure 3. Lateral spreading will cause more deformation and damage to the LRT tracks. However, extensive liquefaction and lateral spreading would require a major earthquake, which would also lead to extensive damage to the built environment resulting in much-reduced activity in the CBD and will take time to recover. This would allow time for repair and restoration of the LRT route, during which more limited temporary public transport such as using buses could be adequate to cater for people living in the CBD and reduced government and business activity. An LRT route on ballast could more quickly be repaired and restored, but would be more difficult and require thought on how this would be integrated within an urban environment.

An LRT route on the Featherston Street route will also be damaged by liquefaction and subsidence to a lesser degree, but may still take a considerable time to restore. A Golden Mile route near the former shoreline may be more damaged due to shallow liquefaction below the tracks than a Featherston Street route with deeper reclamation fill.

### 2.4.3 *Effect of flood hazards*

The effect of the flood hazard on both the Golden Mile / Featherston Street routes as well as the waterfront route are broadly similar.

Initiatives to reduce the flood hazards could be considered in conjunction with the proposed mass transit development projects, similar to how the storm water system was upgraded while developing the inner city bypass route in 2005-2007, regardless of which route is adopted. The cumulative effects of climate change and sea level rise on flood hazards, groundwater levels and storm water drainage should be considered as part of any development,

### 2.4.4 *Effect of building damage safety hazard related closures*

An LRT route along the Golden Mile / Featherston Street / Victoria Street corridor would be located in a much denser built up environment, and these corridors would be more likely to be closed due to safety hazards associated with damage or failure of buildings in the aftermath of earthquakes. Therefore, this route has been assessed to be much more vulnerable to closure from building damage, see Figure 8. Building damage caused by the Kaikōura earthquake of 2016, and the associated road closures, show that such building related closures can happen in moderate earthquakes and not just major events. In such moderate earthquakes, the CBD will be largely functional, and the demand for the LRT will remain but its availability will be affected by closures along its route. The whole inner city in Christchurch was closed to building damage safety issues following the 2010-2011 Canterbury earthquakes.

The CBD in Wellington may not be closed in a similar manner due to its location and presence of a significant inner-city resident population but will pose complex issues due to damage to buildings, presence of a larger number of residents and the lack of transport. The waterfront route has buildings mainly along the western fringe, and an LRT route located eastwards of these will more likely remain open.

#### 2.4.5 Overall resilience comparison

Assuming a depot would be located on a property somewhere along the waterfront, it would be vulnerable regardless of the route alignment. The depot and stabling will need to be in safe working order prior to any resumption of services, and therefore careful consideration of the location and design is important to ensure that parked vehicles and facilities are secure in hazard events.

It is recognised that the liquefaction risk is greater along the waterfront route and the building damage safety risk is greater along the Golden Mile / Featherston Street routes.

The liquefaction and associated lateral spreading is likely to cause severe damage only in large earthquakes with a long recurrence interval, and in such earthquakes, the demand for LRT systems would be less because of the widespread damage to the CBD. Damage to the tracks from liquefaction and lateral spreading can be limited by design measures (ground improvement, and more resilient track foundations).

Building damage-related road corridor closures can occur in relatively moderate earthquakes, as illustrated by building damage in the distant Kaikōura earthquake, and hence can occur in more frequent moderate return period earthquakes. Even localised building damage related closures can close the LRT operation, and this risk is uncontrollable by the agencies designing or operating the LRT system.

Therefore, an LRT system along the Golden Mile or Featherston Street – Victoria Street corridors has a lower overall level of resilience of being able to operate, because of the uncontrollable building damage related closures in moderate or large earthquakes, than a well-designed LRT system on the waterfront, designed to minimise damage from liquefaction and lateral spreading. In larger earthquakes causing widespread damage in the CBD and lack of socio-economic activity, there is likely to be a low demand for a mass transit system, and passenger transport needs may be able to be provided using temporary bus services.

## 2.5 Resilience of Te Aro to Airport Route

### 2.5.1 The Route

The Te Aro to Airport LRT route under consideration is shown on Figure 9.

### 2.5.2 Te Aro to Newtown

The proposed LRT route runs along Taranaki Street, which is likely to only experience localised liquefaction hazards which might cause some subsidence. The route then turns east and then runs south along Tory – Tasman Streets to join Adelaide Road where it crosses the low activity Lambton Fault.

Adelaide Road to lower Riddiford Street are along the base of the valley where liquefaction hazard could lead to subsidence of the ground in earthquakes, but lateral spreading is unlikely given the generally flat ground, see Figure 3. The subsidence will cause limited damage to the LRT tracks in an earthquake.

A corridor to the west along Hanson Street and south Adelaide Road would have lesser liquefaction risks and hence would be more resilient. It is recognised that this may be further from the commuter users, and therefore may not be suitable.

There are some low level of flooding hazards along Taranaki and Adelaide Road and a greater hazard along Riddiford Street. These flood hazards generally affect the route for short periods. There is an opportunity to implement any flood hazard improvements in conjunction with the proposed mass transit route development.

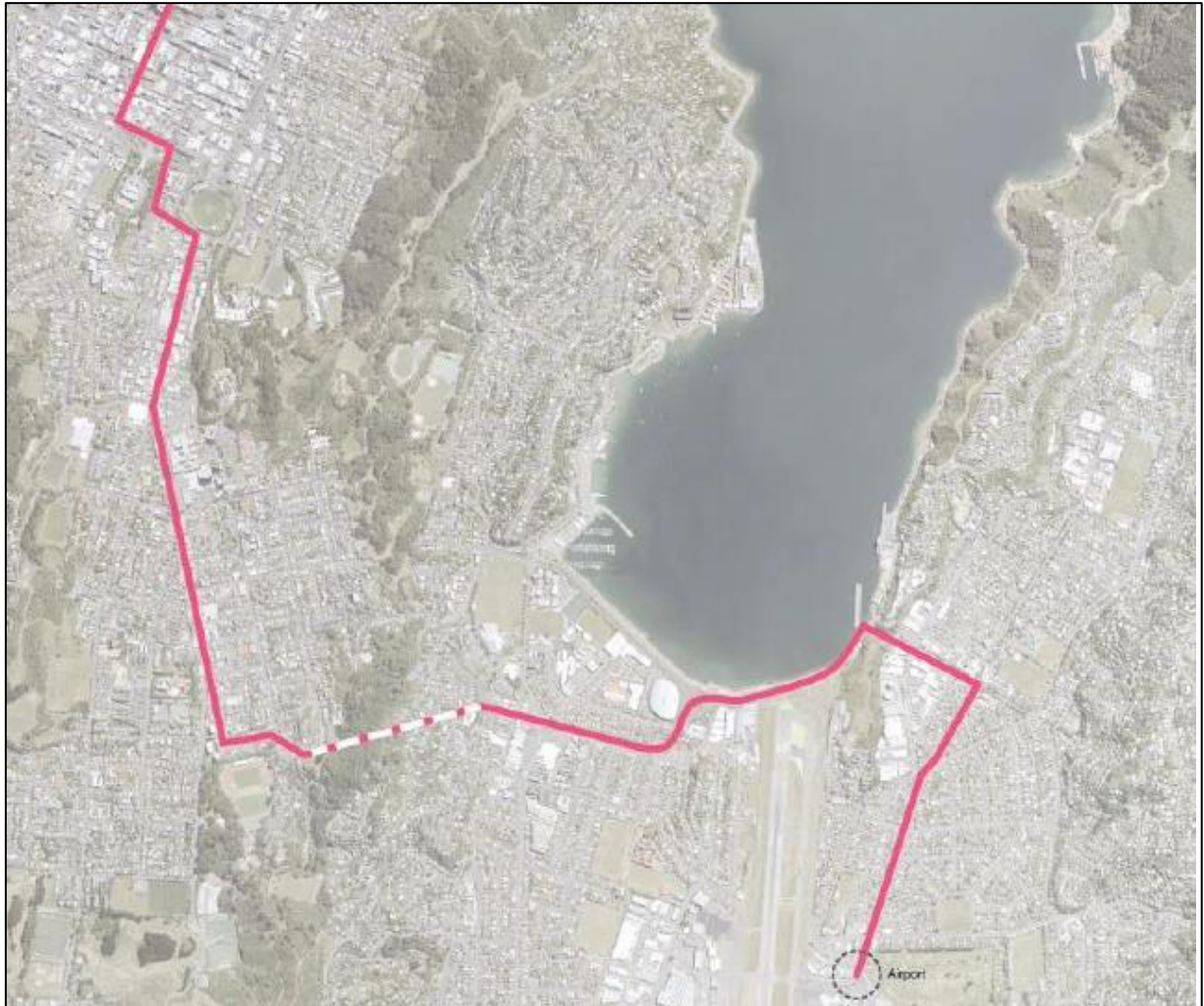


Figure 9: LRT Route under consideration: Te Aro to Airport

(after NZ Transport Agency – Greater Wellington – Wellington City Council, 2018)

### 2.5.3 Newtown to Kilbirnie – Mt Albert Tunnel

The route then turns east and runs through a tunnel under Mt Albert, which should pose low resilience risks, provided the tunnel portals and approaches are constructed to ensure resilience by adopting flatter slopes and stabilisation measures.

### 2.5.4 Kilbirnie to Miramar Peninsula and Airport

Kilbirnie was a tidal flat before being uplifted by the 1855 Wairarapa Earthquake, and has a high liquefaction hazard (see Figure 4) and vulnerability to tsunami hazards (see Figure 2). The liquefaction and consequent lateral spreading will be more severe along Cobham Drive, where the reclaimed land could laterally spread towards Evan's Bay. This section of the route along Evan's Bay would be particularly vulnerable. The central valley through Miramar peninsula also has deep, soft deposits and would be vulnerable to liquefaction and enhanced ground shaking in earthquakes.

It is also noted that tsunami hazards are greater in the suburbs of Kilbirnie and Lyall Bay closer to Evans Bay and Lyall Bay, and particularly severe along Cobham Drive, see Figure 2. Sea level rise hazards are greater in Kilbirnie between Cobham Drive and Rongotai Road.

An opportunity for enhanced resilience would be to consider an alternate route through Rongotai and below the airport runway, as this alternative will have a lower level of natural hazards exposure and hence provide better resilience as discussed in Section 2.6.

## 2.6 Alternate corridors

### 2.6.1 CBD Section

An alternate route for a LRT can be considered along the Wellington Urban Motorway, through a second Terrace Tunnel and along Karo Drive. This route will potentially be much more resilient to earthquakes and sea level rise issues. However, it is recognised that this will be away from users of the mass-transit system, and thus may not be suitable for other reasons.

### 2.6.2 Newtown to Miramar and Airport

An opportunity to provide a more resilient LRT link between Newtown and Miramar peninsula would be to consider as route through Rongotai, in the middle of the Kilbirnie-Lyall Bay isthmus. This route will have moderate liquefaction, tsunami and low sea level rise hazards, and will therefore provide greater resilience for a route through this vulnerable section, than a route through Kilbirnie and Cobham Drive. The route could then cross the airport runway through an underpass similar to the existing pedestrian underpass, to the airport and Miramar.

It is appreciated that this has been considered as part of the development of the RPI. Information available to the study may have suggested that a large portion of the airport runway and adjacent safety areas are on reclaimed land and hence may require a much deeper bored tunnel and may be vulnerable in earthquakes. On this basis a tunnel under the runway may have been considered to be cost prohibitive or not feasible.

A more detailed consideration of the geology shows that the middle north section of the airport runway has been excavated into bedrock, see Figure 10. The light blue areas indicate the presence of bedrock near the surface. This shows the presence of bedrock in the middle north section of the runway, with reclaimed land (light pink) at the northern end and southern part of the runway only. The existing pedestrian subway is also shown on the map, which is in the area of bedrock. The map also shows the extensive reclamation along Cobham Drive.

A 1950s photograph showing the cut to fill operations for the construction of the airport is presented in Figure 11. The photograph shows the hills with steep temporary cuttings to excavate into them to form the runway, further indicating the presence of bedrock. The presence of bedrock rather than reclaimed land may enable a much shallower tunnel underneath the runway.

The additional information on the geology and the construction of the airport runway, and hence the presence of bedrock may provide an opportunity to review the feasibility of an underpass or tunnel under the runway and associated much more resilient route for the Newtown to Miramar section of the mass transit or LRT route. If this was feasible, then a greater resilience of access for the community in Miramar peninsula and for the airport could be achieved.

A route through Rongotai to the airport, via Coutts Street and through an underpass below the runway, would therefore provide better resilience than the currently proposed route through Kilbirnie and Cobham Drive.



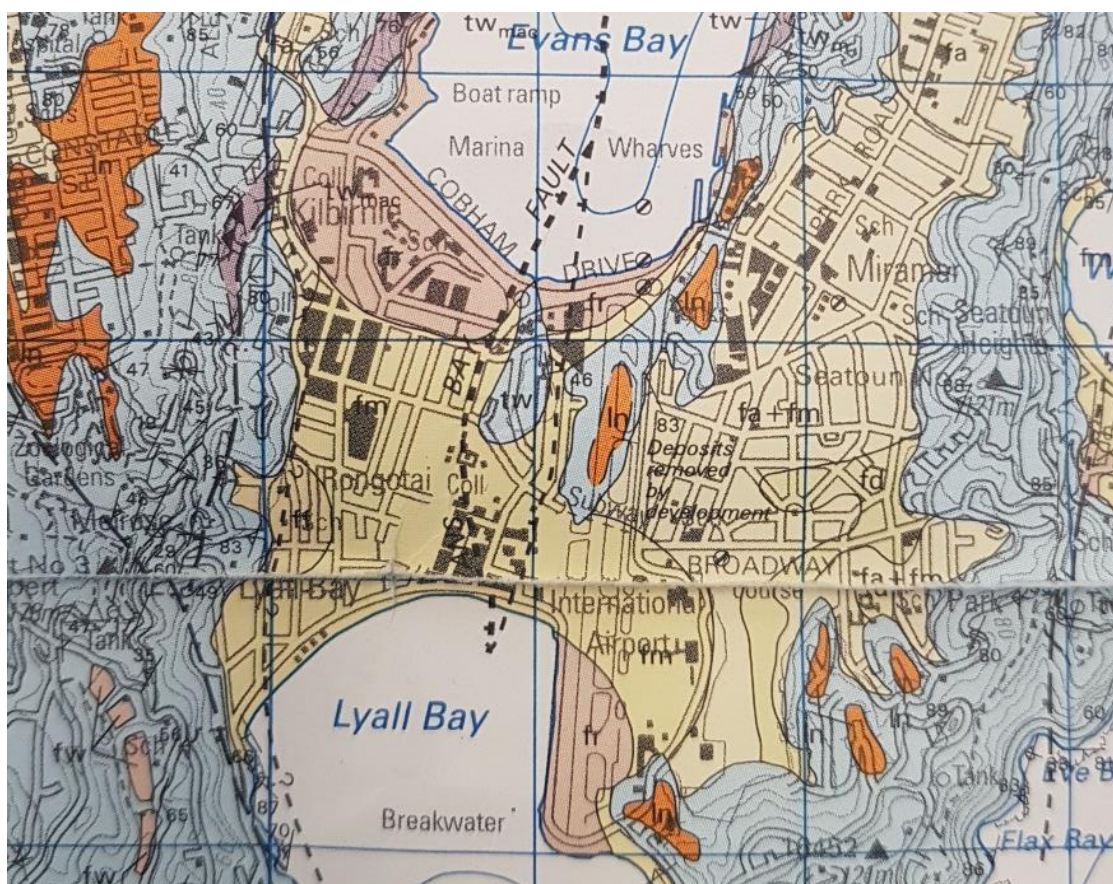


Figure 10: Geology of the Wellington Airport area  
(Geological and Nuclear Sciences, 1996)



Figure 11: Photograph during Construction of Wellington Airport runway (c.1950)

## 3 Resilience of Proposed Strategies and RPI

### 3.1 Introduction

The summary report prepared by the NZ Transport Agency, Greater Wellington and Wellington City Council provides a number of strategies and a Recommended Programme of Investment (RPI) for Wellington City's transport system.

These strategies and associated RPI have been considered and comments on the associated resilience issues are presented in this section.

### 3.2 Land use and urban form

The strategy envisages limiting transport demand by encouraging and allowing growth in the population living in the Wellington CBD, south suburbs and east Suburbs.

The resilience of Wellington has reduced over the past 25 years as more and more people live in the CBD, where buildings are at risk because of the higher levels of ground shaking from basin edge effects, reclaimed land and associated liquefaction, together with the earthquake performance of existing buildings. Access issues into the city from outside also poses a risk to the population in the event of a major disaster such as an earthquake. In addition, it is recognised that water supply to the city, and in particular the eastern suburbs, will be an issue after major earthquakes.

While there is benefit in reduced transport demand, this should be considered holistically with associated strategies and investments in the resilience of the building stock, access and water and other lifelines. Otherwise, this increased population could lead to a much-reduced resilience for society. An option would be to consider the type of growth in areas that are vulnerable to earthquakes, for example the CBD and the Kilbirnie Isthmus, and ensure that the type of development and growth is consistent with the hazard environment, and society is able to be serviced in the aftermath of disasters.

### 3.3 A Walkable City and Connected Cycleways

Increased opportunities for walking and cycling will enhance resilience in the event of a disaster by enabling modes of transport that are not reliant on vehicular access, fuel and power. However, if all these routes are through the densely built up urban centre, the access after an earthquake may be compromised by potential building damage, collapse or facade / outer glazing safety hazard, as noted in Section 2.2.2 and shown on Figure 8.

### 3.4 Step Change in Public Transport Connections to the North

A step change in public transport will bring resilience benefits as it will bring diversity to travel options available to the community, particularly in frequent low impact hazard events.

The following are noted, which can compromise the resilience of public transport routes:

- (a) Hutt Road is vulnerable to closure from failure of structures (road and rail overbridges, retaining walls and slopes), and a parallel enhancement of their resilience is important; and
- (b) The rail network that serves Wellington from the surrounding areas and districts is vulnerable to earthquake, landslide and coastal hazards, and therefore the resilience of access into Wellington will remain fragile, because:

- i. The Johnsonville line is vulnerable to landslides along the steep slopes and steep tunnel approaches in storm and earthquake events, as well as potential vulnerability of the bridges along the route during large earthquakes;
- ii. The NIMT is vulnerable due to potential vulnerability of the bridges (e.g. overbridge across Ngauranga Gorge). It is also vulnerable at tunnel approaches, particularly along the Pukerua Bay to Paekakariki section of the railway, in earthquakes, landslides and storm events;
- iii. The Hutt Valley line is vulnerable to the expected poor performance of the Southern Rail overbridge along the SH1 motorway between Ngauranga and Kaiwharawhara, and the vulnerability of the Ngauranga to Petone section of the railway line to earthquakes, landslides, and storms; and
- iv. The overall resilience of the rail network is poorly understood because a systematic assessment of the resilience of the rail network has not been carried out similar to the road network.

Understanding and improving the resilience of the rail connections is critical to enhance public transportation enhancements for Wellington city, which relies on these links.

### 3.5 Step Change in Public Transport through the Central City

Implementing a dual public transport spine through the central city by using the Golden Mile as well as the waterfront route / Taranaki Street will help enhance resilience by:

- (a) Adding redundancy to the public transport network, which enhances resilience in routine to frequent events;
- (b) The Golden Mile is vulnerable to safety hazards due to damaged buildings and facades after moderate to large earthquakes, and the waterfront route to liquefaction induced lateral spreading, as discussed in Section 2.4. Having redundancy of routes will provide for functionality in the event that either of these routes are affected.

Alternate public transport routes along the Thorndon to Basin Reserve section of the SH1 motorway will further enhance resilience.

### 3.6 Step Change in Public Transport through Mass-Transit

The resilience of the mass transit routes and LRT is discussed in Section 2.

### 3.7 Improving the Bypass route from the North

#### 3.7.1 Key Features

Key features of this strategy are to include the following presented in the RPI:

- i. Southbound widening of SH 1 between Ngauranga and Aotea Quay
- ii. Duplication of the Terrace Tunnel

The resilience issues associated with these investments are discussed below.

#### 3.7.2 Southbound Widening of SH1 between Ngauranga and Aotea Quay

Widening of the southbound SH 1 through the addition of a 4<sup>th</sup> lane is proposed and planned to be allocated for high-occupancy vehicles or buses to move more people with fewer vehicles.



This section of motorway is vulnerable to coastal and sea level rise hazards as well as liquefaction and lateral spreading towards the harbour in earthquakes. The liquefaction hazard is particularly pronounced south of Kaiwharawhara near the Aotea Quay off-ramp in the vicinity of the Inter-islander ferry terminal. The Wellington Fault also crosses this area, see Figure 12.

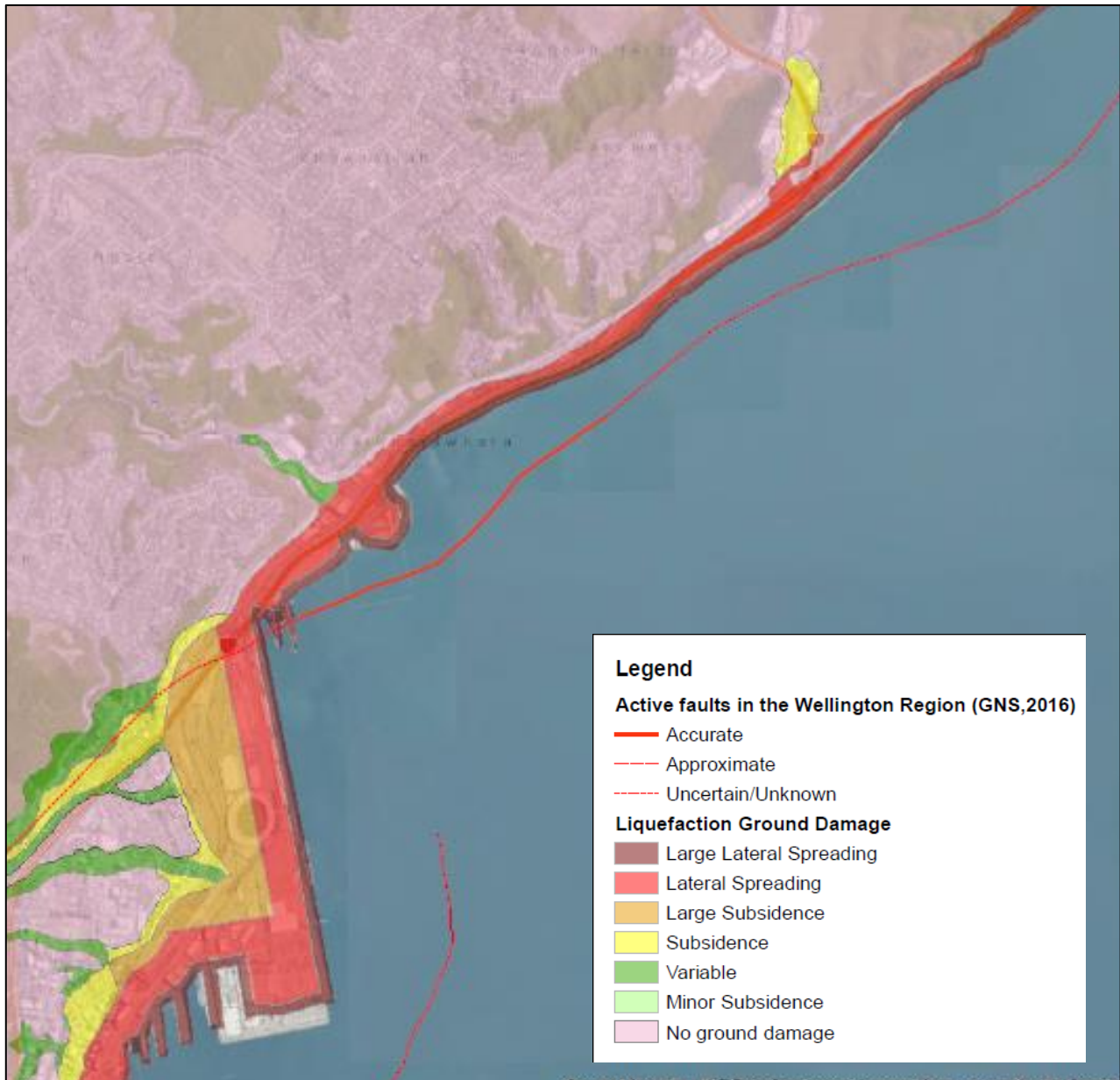


Figure 12: Liquefaction Ground Damage Hazards along Ngauranga to Thorndon

(Liquefaction hazards after WRC, 1993)

An additional lane on the eastern southbound side would be particularly vulnerable being adjacent to the coast, and be exposed to both coastal hazards, liquefaction-induced lateral spreading and sea wall failure. The addition of a lane could provide an opportunity to enhance the sea defences to sea level rise and coastal hazards, but it is unlikely to be practical to mitigate against liquefaction and lateral spreading for such a long section. One option would be to ensure that the additional southbound lane is constructed with a simple embankment or at grade form that can be quickly reinstated when damage occurs.

Alternatively, widening on the landward side (where space is available) may provide enhanced resilience, but would involve additional costs of moving the lanes across.

South of Kaiwharawhara, there is the opportunity to use the additional lane to enhance resilience of access along this critical northern access into the city. The addition of the 4<sup>th</sup> lane would need to be considered together with the proposed review of the ferry terminal and port operations, as well as the upgrade of the rail access into Wellington Station. For example, consideration could be given to the 4<sup>th</sup> lane separating from the main motorway and crossing the Wellington Fault at grade rather than on a bridge across the fault. An at-grade crossing would enable quicker restoration of access, compared to the current crossing of the fault on the Thorndon Overbridge, and would mean that at least this additional lane would be available in a large earthquake, particularly involving a rupture of the Wellington Fault. This would require careful co-ordination and integration with the port and rail yard operations and changes.

### 3.7.3 Second Terrace Tunnel

A second Terrace Tunnel would add redundancy of access in the event of closure of one tunnel, due to accidents, fire etc, and would help enhance resilience of access in the city.

It should be noted that both tunnels cross the Terrace Fault, but this is not considered to be a Class 1 active fault, and has not moved for a long time.

The previously constructed access bridge piers on the north end would need to be checked and strengthened as necessary, to allow for present day seismic design standards.

## 3.8 Improving Bypass Route through Te Aro

The main component of the RPI along the section from the Terrace Tunnel to the Basin Reserve is to reconstruct the state highway along Karo Drive underground.

The proposed 'undergrounding' of the state highway, in both directions, along the Karo Drive corridor will enhance resilience of access by providing:

- (a) An alternate route to the city streets along Vivian Street and Karo Drive; and
- (b) A route that is not affected by damage to buildings and facades (see Figure 8), in the event of a moderate to large earthquake.

The additional redundancy and protection from building hazards provides enhanced network resilience.

Alternative options for an arterial route along this corridor, between the Terrace Tunnel and the Basin Reserve, considering the route in a trench as well as an alternate 'cut and cover' tunnel scheme, was developed in 1989-1992. A study of geotechnical issues and hazards along this route identified only localised liquefaction and high groundwater levels (Brabhaharan, 1992). The groundwater studies carried out along this route, and the experience in constructing the trenched Inner-City Bypass section, between the Terrace Tunnel and Willis Street – Abel Smith Street intersection (Brabhaharan, 2007), provide the confidence that these groundwater issues can be effectively dealt with as part of design and construction, and that a resilient route can be achieved.

Tunnels are generally resilient to earthquakes, provided they are designed with attention to seismic performance of structural and mechanical components.

This tunnel will significantly enhance resilience by providing a route around the Wellington CBD which is not vulnerable to building damage safety hazards in the built-up CBD and Te Aro area and the liquefaction and lateral spread issues along the waterfront route.



### 3.9 Improving the Bypass Route - Grade Separation at the Basin Reserve

A short bridge, to provide grade separation, is proposed at the Basin Reserve. The Basin area is underlain by potentially liquefiable ground and a high artesian groundwater regime. Any development of this area should consider the effects of these conditions to ensure that the resultant transport system is resilient in both normal conditions as well as in a large earthquake.

An indicative scheme that has been developed for the Basin Reserve area is presented in Figure 13. The scheme indicates at-grade roads around the Basin Reserve, with the exception of a bridge carrying an extension of Sussex Street over SH 1 (including the east-bound carriageways relocated from its current position along Vivian Street) to the western side of the Basin.

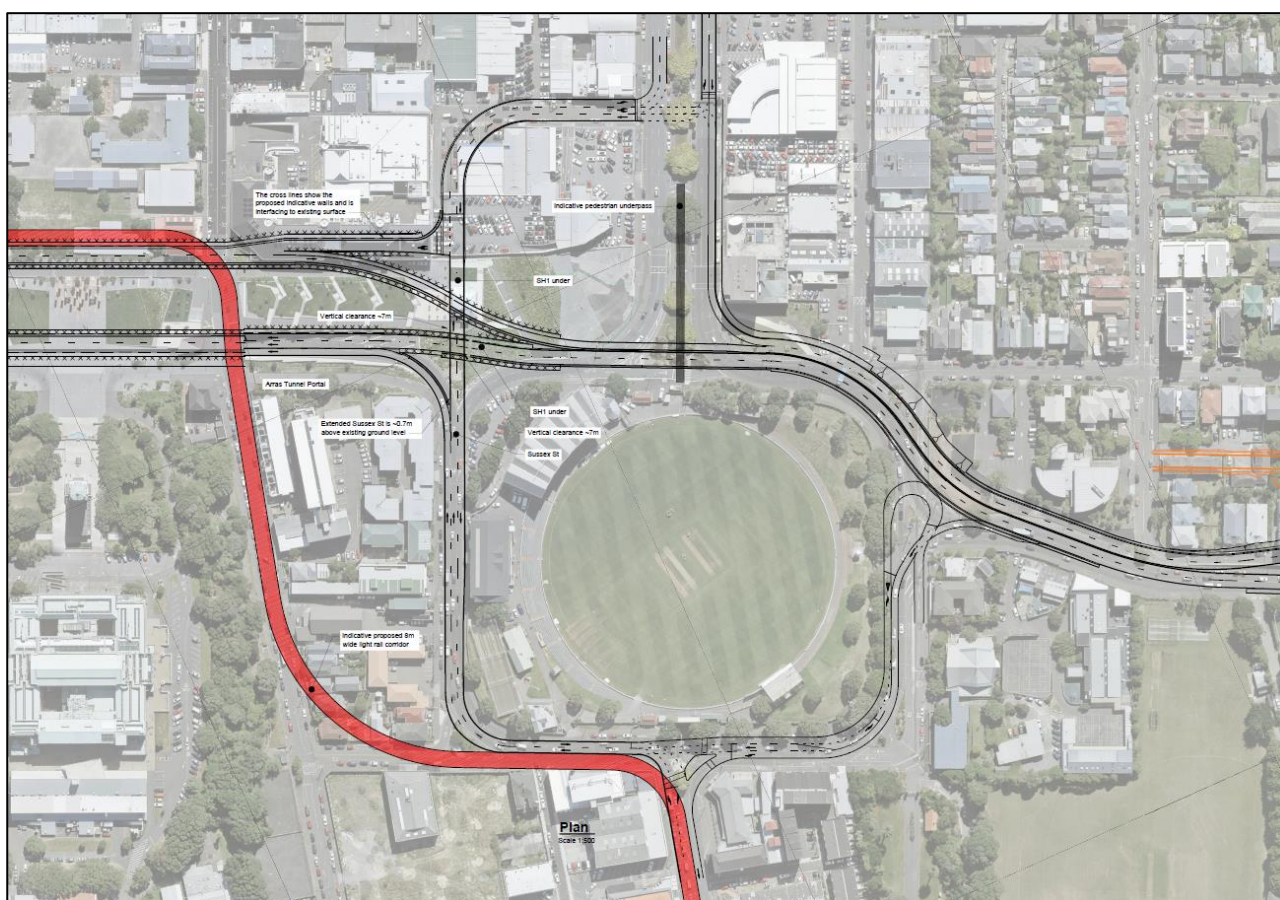


Figure 13: Proposed Scheme around the Basin Reserve Area

(NZ Transport Agency – Greater Wellington – Wellington City Council, 2018).

The proposed bridge is located where the natural ground falls from the terrace opposite the Carillion, to the low-lying ground where the Basin Reserve is located. Geotechnical investigations for the Memorial Park tunnel uncovered veins of sand through the overlying soil deposits. These sand-filled veins suggested cracks filled with ejected sand formed by liquefaction of the underlying sand deposits and lateral spreading in historic earthquakes. This indicates that there is a significant risk of liquefaction and lateral spreading in this area, and given the change in ground level and slope, the ground is likely to laterally spread towards the Basin in future earthquakes, which could severely damage the proposed bridge which will straddle this slope, and potentially cut off the state highway in this area.

To ensure the resilience of SH1 and the local road overbridge, extensive ground improvement at significant additional cost would be necessary.

The at-grade section of SH1 north of the Basin Reserve will continue to be located on ground with a potential for significant liquefaction and related subsidence. It is noted that the Basin Reserve and the Cambridge Terrace / Kent Terrace corridor were low lying swamps, and the then government had proposed an inland port at the Basin Reserve (hence the name). The land was uplifted in the 1855 Wairarapa Earthquake, and subsequently the basin area was drained. The groundwater levels are still high, near the surface, with artesian ground water pressures (a head several metres above ground level) in the semi-confined aquifer below ground.

Liquefaction is expected to cause severe cracking and deformation of the ground and hence SH1, and potentially flooding given the high groundwater pressures and ejection of sand and water. However, the local road around the western and southern side may be able to be used to gain access through Newtown until the road can be reinstated after an earthquake.

It is noted that a north-south pedestrian underpass is being proposed along the low-lying reserve land between Cambridge and Kent Terraces and under the at-grade SH1. To provide an attractive area for access to the Basin Reserve, the underpass will need to be at least a few metres deep. With the ground water levels at almost ground surface, and artesian water pressures below, the design and construction of such an underpass would be a challenge and almost impractical, given large uplift pressures even under static conditions. These issues will be exacerbated in an earthquake, where liquefaction is likely to lead to floatation of the underpass due to higher groundwater pressures. This will then cut off the SH1 access across the basin area for a much longer period of time, reducing the resilience of the route.

An alternative would be to avoid the pedestrian underpass and gain access to the Basin Reserve either from Sussex Street or Rugby Street on the eastern side.

### 3.10 Improving the Bypass Route – Better Access to the East

Key features of the RPI along this section is to provide:

- (a) A second Mt Victoria Tunnel; and
- (b) Widening of Ruahine Street to improve access for bus and high occupancy vehicles.

#### 3.10.1 Second Mt Victoria Tunnel

A second Mt Victoria tunnel will provide enhanced access between the CBD and the airport and Miramar Peninsula.

The existing tunnel has resilience vulnerabilities at the approaches, particularly at the eastern approach near Hataitai, where high steep slopes are expected to fail and close access to the tunnel in a large earthquake. This has been identified in the Wellington Land Transport Resilience Studies as a key vulnerability in the access between the airport and the Wellington CBD. Tunnels themselves are generally resilient to earthquakes and other events, provided the design provides attention to details of associated structural and mechanical components.

The second tunnel provides the opportunity for constructing a tunnel with approaches that are more resilient than the current tunnel, and hence to enhance the resilience of access between the airport and the CBD.

#### 3.10.2 Widening Ruahine Street

While widening Ruahine Street will enhance traffic capacity, this in itself will not significantly change the resilience of access in Wellington, as the current road is not particularly vulnerable to hazards.

## 4 Other Interventions to Address Resilience Risks

The Recommended Programme of Investment proposes a number of strategies and projects to enhance transport in Wellington, and their resilience contributions are presented above.

A programme business case for Wellington Land Transport Resilience (WSP Opus, 2018) has been developed and is being finalised. This has systematically assessed and identified resilience gaps for land transport in the Wellington Region.

There are a number of additional interventions that are appropriate to enhance the resilience of the transport in Wellington City.

The resilience risks and potential interventions that fall within the Let's Get Wellington Moving study area are summarised in Table 2. The table summarises the link, the resilience issues, and suggest potential interventions that could be considered as part of the overall transport strategy.

Table 2: Additional Resilience Interventions

Link	Resilience		Comments
	Issue	Intervention	
<b>Communications</b>	In the event of an incident or natural disaster, information on transportation and access is critical for society to react and respond accordingly. The Cook Strait earthquakes in 2013 highlighted the lack of co-ordinated communication.	A well-established communication strategy and implementation is critical for the Wellington community's response and survival after incidents and disasters.	
<b>Ngauranga Interchange</b>	Resilience risks are: <ul style="list-style-type: none"> <li>SH1- SH 2 interchange vulnerable to earthquakes - liquefaction lateral spreading</li> <li>SH1 NIMT rail overbridge potentially vulnerable to earthquakes</li> <li>Southern rail overbridge vulnerable to earthquake shaking and liquefaction.</li> </ul>	<ul style="list-style-type: none"> <li>Strengthen reinforced earth walls at interchange and ground improvement.</li> <li>Assess and strengthen Ngauranga rail overbridge.</li> <li>Replace southern rail overbridge.</li> </ul>	Could be carried out with southbound access widening along Ngauranga to Aotea.
<b>Ngauranga to Thorndon seawall</b>	Resilience risk associated with the seawall that is vulnerable to coastal erosion, sea level rise and earthquake induced liquefaction and lateral spreading.	Strengthen and raise seawall.	Could be carried out with southbound access widening along Ngauranga to Aotea.
<b>Wadestown to Johnsonville route</b>	Key alternative response route for SH1 motorway, vulnerable to some old retaining walls, slopes and potentially rail crossings.	Strengthen retaining walls, slopes and rail crossings.	Could be carried out together with Hutt Road improvements.
<b>Hutt Road – Thorndon to Ngauranga</b>	Resilience risk associated with steep slopes, retaining walls and rail / road overbridges.	Strengthen slope, retaining walls. Assess and strengthen rail / road overbridges.	Could be carried out together with Hutt Road improvements.

Link	Resilience		Comments
	Issue	Intervention	
<b>Ngaio Gorge alternative route to SH1</b>	Resilience risk associated with steep slopes, retaining walls.	Strengthen slope, retaining walls.	Being actioned by Wellington City Council.
<b>CBD to Airport access</b>	Resilience risks are: <ul style="list-style-type: none"> <li>• Crawford Road retaining wall failure</li> <li>• Cobham Drive liquefaction and lateral spreading in earthquakes.</li> </ul>	<ul style="list-style-type: none"> <li>• Assess and strengthen old retaining walls.</li> <li>• Assess and strengthen road.</li> </ul>	
<b>Waterfront route</b>	Resilience risks associated with: <ul style="list-style-type: none"> <li>• Waterloo-Jervois Quay seawalls</li> <li>• City to sea and pedestrian overbridges</li> </ul>	<ul style="list-style-type: none"> <li>• Assess and strengthen seawalls</li> <li>• Assess and strengthen overbridges</li> </ul>	This work could be carried out with potential mass transit along the waterfront route.
<b>Port access from North</b>	Lack of resilient access to port from the north.	Develop port access route that is sympathetic to changes to Centre Port.	Could be carried out with southbound access widening along Ngauranga to Aotea.
<b>SH1 Thorndon Overbridge</b>	Vulnerability to lateral spreading in earthquakes and Wellington Fault rupture.	Strengthening ground, access from north not crossing Wellington Fault on bridge structure.	Could be carried out with southbound access widening along Ngauranga to Aotea.
<b>Urban Motorway – Thorndon to Terrace Tunnel</b>	Performance of retaining walls and bridges	Assess and strengthen retaining walls and bridges.	
<b>Wellington to Petone</b>	Resilience of land transport access between Wellington and Hutt Valley	Enhanced ferry services between Wellington and Petone.	This sea transport would provide the basis for response in the event of closure of the motorway into the city from the north.



## 5 References

- Brabhaharan, P (1994). Assessment and mapping of earthquake induced liquefaction hazards in the Wellington Region, New Zealand. The first ANZ Young Geotechnical Professionals Conference, February 9-12, 1994, Sydney, Australia.
- Brabhaharan, P (2007). Performance-based Earthquake Design and Construction of the Wellington Inner City Bypass, Wellington. NZ Society for Earthquake Engineering Annual Conference. 30 March - 1 April 2007. Palmerston North.
- Geological and Nuclear Sciences (1996). Geological Map of the Wellington area. 1:50,000. Wellington. New Zealand.
- NZ Transport Agency – Greater Wellington – Wellington City Council (2018). DRAFT Recommended Programme of Investment. Summary Report. September 2018.
- NZ Transport Agency – Greater Wellington – Wellington City Council (2018a). Preferred mass transit route – response to further queries.
- Opus (2017). Wellington Land Transport Resilience. Prioritisation of Resilience Risks. Prepared by P Brabhaharan for the NZ Transport Agency and Greater Wellington. June 2017.
- T&T (2014). Sea Level rise options analysis. Prepared for Wellington City Council. June 2013.
- Wellington Region Emergency Management Office. Tsunami Evacuation Maps, published on the web.
- Wellington Regional Council (1993). Liquefaction Hazards Maps for Wellington. Published as maps and booklets.
- Wellington Water (2018). WCC CBD Flood Management Workshop. 18 June 2018.
- WSP Opus (2018). DRAFT Programme business case for Wellington Land Transport Resilience. Prepared for the NZ Transport Agency. August 2018



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