9.0 Geotechnical Assessment

A preliminary geotechnical assessment has been produced, based on existing geological information and previous investigations in the area. The full report is included in Appendix H.

The two locations of geotechnical interest are in the Paterson/Dufferin Streets area, and the Buckle/Sussex Streets area. These are the two areas where bridges and cuts are proposed. All other areas of the Basin are proposed to be at grade.

9.1 Geotechnical conditions around the Basin

9.1.1 Dufferin/Patterson Street Area

This area is underlain by up to 3 m of fill. The fill is underlain by medium dense alluvium comprising gravely, sandy clay. Basement rock is at 9.5 m depth on Paterson Street and appears to be sloping steeply to the west, deepening to 30 m depth beneath Dufferin Street.

Standard Penetration Tests in this area show N values of 1 and less for the top 3 m. This layer is identified as a potentially liquefiable layer. Below 3 m, SPT N values increase rapidly from 7 at 3 m to greater than 50 at 8 m depth.

A water level has been measured at this site approximately 0.5 m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground.

9.1.2 Sussex/Buckle Street Area

From previous investigations it appears that this area is underlain by approximately 25 m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. Basement rock is located at 27 m depth and appears to be sloping gradually to the east deepening to greater than 30 m depth on the other side of the Basin below Dufferin Street.

SPT show N values to be variable between 11 and 96 for the upper 11 m. Below this depth N values vary between 24 and 75, and are greater than 100 within 2 m of the basement contact.

A water level has been measured as approximately 2 m below ground surface and most likely represents a piezometric pressure at depth.

Appendix H
Preliminary Geotechnical Assessment

Basin Reserve Long Term Improvements

Geotechnical Assessment of 5 Options

1.0 INTRODUCTION

Long term improvements for traffic flow around the Basin Reserve in Wellington are proposed.

A Preliminary Geotechnical Assessment of the site comprising a desk study of existing geological maps of the area and an examination of existing records of previous investigations located around the Basin Reserve was carried out in February 2000. The geology of the area and current knowledge of ground conditions at the site are provided in that report.

This report presents our geotechnical assessment of specific site conditions for five proposed options for the Basin Reserve Improvements. The assessment is based on existing available geotechnical information only.

2.0 SUMMARY OF IMPROVEMENT OPTIONS

The five options proposed can be divided into two categories. The first category includes an at grade intersection with few geotechnical issues, and the second including bridges and cuts requiring significant geotechnical input..

The first category includes options E and F which comprise at grade intersections and require shallow cuts to a maximum height of 2m. The second category includes options H, I and J which comprise a combination of bridge structures with cuts to 4m and embankment fills to 5m.

Improvement options and geotechnical issues are summarised below. The option layouts are shown on the scheme plans. Geotechnical assessment of pavement subgrade is common to all options.

a) Option E comprises a realignment and an at-grade intersection at Buckle/Sussex Streets, and a realignment of Paterson/Dufferin Streets. The geotechnical issues for this option are minor and relate to two low cuts that will require retaining to 2m height, and a pedestrian underpass beneath Paterson Street.

b) Option F is very similar to Option E. It comprises a realignment and an at grade intersection at Buckle/Sussex Streets, and a realignment of Paterson/Dufferin Streets. The geotechnical issues for this option are minor and relate to two low cuts that will require retaining to 2m height, and a pedestrian underpass beneath Paterson Street.

c) Option H comprises a 2 lane bridge passing Buckle Street over Sussex Street, and a 4 lane bridge passing Paterson Street over Dufferin Street. The bridge approach at Buckle Street will include a 2m high fill above a 4.6m deep cut (total 7m retained height) forming its western abutment. The geotechnical issues associated with this option relate to bridge foundations, cut batter slopes and retaining structures, embankment fills and groundwater conditions. Seismic issues include foundation liquefaction potential.

Option H is the preferred option.

d) Option I comprises a 2 lane bridge passing Buckle Street over Sussex Street, a realignment of Paterson Street and a pedestrian underpass beneath Paterson Street. The bridge at Buckle Street will include a cut to 5m beneath it. The geotechnical issues associated with this option relate to bridge foundations, cut slopes, retaining structures to 5m, embankment fills and

groundwater conditions. Seismic issues include foundation liquefaction potential.

e) Option J comprises a 4 lane bridge passing Sussex Street over Buckle Street, a realignment of Patterson Street, and a pedestrian underpass beneath Paterson Street. The bridge at Buckle Street will include a cut to 3.5m beneath it. The geotechnical issues associated with this option relate to bridge foundations, cut slopes, retaining structures to 5m, embankment fills and groundwater conditions. Seismic issues include foundation liquefaction potential.

Details of the five options are described in the following section.

3.0 DETAILED DESCRIPTIONS OF OPTIONS

The following sections describe the geotechnical issues relating to each of the 5 options described above. These sections are somewhat repetitious, however for completeness it is considered necessary to include details of each feature in each section so that each section can stand alone.

3.1 Option E

Option E comprises a realignment and an at grade intersection at Buckle/Sussex streets, a realignment of Paterson/Dufferin Streets and a pedestrian underpass beneath Paterson Street.

Geotechnical issues relate to low (2m maximum height) retaining structures to accommodate the realignments of Paterson/Dufferin and Sussex Streets, and the construction of the pedestrian underpass beneath Paterson Street.

3.1.1 Likely Ground Conditions

3.1.1.1 Paterson/Dufferin Streets Realignment and Pedestrian Underpass

The Paterson/Dufferin Streets realignment will require a shallow (2m maximum) cut across the gentle slope from the flat at the Basin Reserve to the steep slopes of Mt Victoria, and a 6m deep cut and cover pedestrian underpass.

From previous investigations (machine drillhole D11) it appears that the area is underlain by up to 3m of fill. The fill is underlain by medium dense alluvium comprising gravelly, sandy clay. The basement rock was intersected in D11 at 9.5m depth and appears to be sloping steeply to the west deepening to greater than 30m depth beneath Dufferin Street.

Standard Penetration Tests in D11 show N values of 1 and less for the top 3m (fill). This layer is identified as a potentially liquefiable layer. Below 3m SPT N values increase rapidly from 7 at 3m to greater than 50 at 8m depth.

Groundwater levels were measured in D11 from a standpipe piezometer with a tip sealed beneath 7.5m. A water level has been measured in this piezometer approximately 0.5m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground.

3.1.1.2 Sussex/Buckle Streets Realignment

The Sussex/Buckle Streets realignment will require a shallow (2m max) cut across the gentle slope from Te Aro area down to the valley invert at Cambridge Terrace.

From previous investigations (machine drillhole D4) it appears that the area is underlain by approximately 25m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. The basement rock was intersected in D4 at 27m depth and appears to be sloping gradually to the east deepening to greater than 30m depth beneath Dufferin Street.

Standard Penetration Tests in D4 show N values to be variable between 11and 96 for the upper 11m, below this depth N values vary between 24 and 75, and are greater than 100 within 2m of the basement contact.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. A water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a piezometric pressure at depth.

3.1.2 Recommended Geotechnical Investigations

Recommended geotechnical investigations for this option are summarised on the following table.

Feature	Inspection Pitting	Machine Drilling
Patterson Street Realignment Retaining Structure	4 x 4m	2 x 10m
Buckle Street Realignment Retaining Structure	4 x 4m	2 x 10m
Paterson Street Pedestrian Underpass		2 x 12m

Machine drilling depths are selected to allow consideration of a number of cut retention options including piled walls.

Existing pavement and subgrade condition will be assessed from pavement pitting and where proposed subgrade is deep inspection pitting. Sampling for laboratory testing (CBR MDD/OMC) will be carried out. DCP will be used to provide insitu strength data.

3.2 *Option F*

Option F comprises a realignment and an at grade intersection at Buckle/Sussex streets, a realignment of Paterson/Dufferin Streets and a pedestrian underpass beneath Paterson Street.

Geotechnical issues relate to low (2m maximum height) retaining structures to accommodate the realignments of Paterson/Dufferin and Sussex Streets, and the construction of the pedestrian underpass beneath Paterson Street.

3.2.1 *Likely Ground Conditions*

3.2.1.1 *Paterson/Dufferin Streets Realignment and Pedestrian Underpass*

The Paterson/Dufferin Streets realignment will require a shallow (2m maximum) cut across the gentle slope from the flat at the Basin Reserve to the steep slopes of Mt Victoria, and a 6m deep cut and cover pedestrian underpass.

From previous investigations (machine drillhole D11) it appears that the area is underlain by up to 3m of fill. The fill is underlain by medium dense alluvium comprising gravelly, sandy clay. The basement rock was intersected in D11 at 9.5m depth and appears to be sloping steeply to the west deepening to greater than 30m depth beneath Dufferin Street.

Standard Penetration Tests in D11 show N values of 1 and less for the top 3m (fill). This layer is identified as a potentially liquefiable layer. Below 3m SPT N values increase rapidly from 7 at 3m to greater than 50 at 8m depth.

Groundwater levels were measured in D11 from a standpipe piezometer with a tip sealed beneath 7.5m. A water level has been measured in this piezometer approximately 0.5m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground.

3.2.1.2 *Sussex/Buckle Streets Realignment*

The Sussex/Buckle Streets realignment will require a shallow (2m max) cut across the gentle slope from Te Aro area down to the valley invert at Cambridge Terrace.

From previous investigations (machine drillhole D4) it appears that the area is underlain by approximately 25m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. The basement rock was intersected in D4 at 27m depth and appears to be sloping gradually to the east deepening to greater than 30m depth beneath Dufferin Street.

Standard Penetration Tests in D4 show N values to be variable between 11and 96 for the upper 11m, below this depth N values vary between 24 and 75, and are greater than 100 within 2m of the basement contact.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. A water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a piezometric pressure at depth.

3.2.2 *Recommended Geotechnical Investigations*

Recommended geotechnical investigations for this option are summarised on the following table.

Feature	Inspection Pitting	Machine Drilling
Patterson Street Realignment Retaining Structure	4 x 4m	2 x 10m
Buckle Street Realignment Retaining Structure	4 x 4m	2 x 10m
Paterson Street Pedestrian Underpass		2 x 12m

Machine drilling depths are selected to allow consideration of a number of cut retention options including piled walls.

Existing pavement and subgrade condition will be assessed from pavement pitting and where proposed subgrade is deep inspection pitting. Sampling for laboratory testing (CBR MDD/OMC) will be carried out. DCP will be used to provide insitu strength data.

3.3 Option H

Option H comprises a 2 lane bridge passing Buckle Street across Sussex Street and a 4 lane bridge passing Patterson street across Dufferin Street. The bridge at Buckle Street will include a 2m high fill above a 4.6m cut. The fill and cut form the bridge's western approach, and allows two traffic lanes on Sussex Street to pass beneath the bridge.

The geotechnical issues associated with this option relate to bridge foundations at 2 locations, cut batter stability, retaining structures to 6m, embankment fill foundations and batter/retaining structure design, and groundwater conditions. Seismic issues include foundation liquefaction potential.

3.3.1 General Ground Conditions

Ground and groundwater conditions have been interpreted from the results of previous investigations carried out by others. A preliminary geotechnical assessment of the site was prepared by Worley and reported in February 2000. The documents reviewed for this study are listed in that report and in the references in section 4.0. The locations of the previous investigations are illustrated on Figure 2 of that report.

Previous investigations were related to at-grade and below-grade construction. Machine drill holes in the basin area were to a depth of 30m and revealed a profile along the proposed alignment comprising alluvial materials overlying greywacke basement rock. The contact between greywacke and alluvium slopes down from west to east, at its deepest beneath Dufferin Street, then sloping up steeply toward Mt Victoria. The drill holes encountered the contact along most of the alignment (D11, D3, D4, D102 and B5) but were stopped short of it where it is deepest (D1 and D2).

3.3.2 Patterson Street Bridge Foundation Conditions

Foundations for the Patterson Street bridge structure are likely to be driven or bored piles. Piles may either be socketed into the greywacke basement beneath the alluvium or driven as an end bearing/friction piles terminating at some shallower depth, depending on the magnitude of applied loads. The principal geotechnical issues are:

a) The geotechnical properties and thickness of the alluvium and underlying greywacke with respect to piling.
b) Groundwater conditions.
c) Seismic response of foundation materials

From previous investigations (machine drillhole D1, D2 and D11) it appears that the eastern part of the area is underlain by up to 3m of fill. The fill is underlain by medium dense alluvium comprising gravelly, sandy clay. The basement rock was intersected in D11 at 9.5m depth and appears to be sloping steeply to the west deepening to greater than 30m depth (D1 and D2) beneath Dufferin Street. Previous drillholes did not reach the base of the alluvial materials where the basement contact is deepest (D1 and D2) and provide only a minimum thickness of alluvium (30m).

Standard Penetration Tests in D11 show N values of 1 and less for the top 3m (fill). This layer is identified as a potentially liquefiable layer. Below 3m SPT N values increase rapidly from 7 at 3m to greater than 50 at 8m depth. SPT N values in D1 are 13 to 19 in the upper 6m and between 30 and 60 for the remainder of the hole. In D2 SPT N values are 9 to 12 in

the upper 5m and between 20 and 40 for the remainder of the hole. Near basement all holes have SPT N values greater than 50.

Groundwater levels were measured in D11 from a standpipe piezometer with a tip sealed beneath 7.5m. A water level has been measured in this piezometer approximately 0.5m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground. In D1 groundwater levels were not measured. In D2 groundwater levels were measured in two standpipe piezometers. The shallow piezometer with its tip sealed below 4m showed a water level 0.6m above ground level, the deeper piezometer with its tip sealed below 15m showed a water level of 3m above ground surface. These water levels most likely represent a pressure head increasing with depth, which is not unexpected for this area.

Potentially liquefiable layers have been identified in the upper 3m of DH11 and in the upper 2m of DH2.

3.3.2.1 Recommended Investigations for Paterson Street Bridge Foundations

Investigations for bridge foundation are recommended to confirm the thickness and geotechnical properties of alluvium beneath Dufferin Street and asses pile embedment depth in the underlying greywacke. Machine drill holes, and where possible Dutch Cone Penetrometer Testing (CPT), will be required to provide ground condition data at specific pier locations. This will require approximately 3 drill holes to 40m depth and 5 CPTs to 30m depth. Standard Penetration Test (SPT) data from drill holes and CPT data will be used together with laboratory test results (Particle Size Distribution (PSD), Atterberg Limits) to determine potential liquefaction characteristics, and provide data for seismic hazard assessment and subsequent site response analyses. The extent of subsurface investigations and laboratory testing recommended are summarised in the following table and scheduled in more detail in the tables in Section 3.3.9 and their locations shown on Figure 1.

Feature	Machine Drilling	CPT	Laboratory Testing
Patterson Street Bridge	3x 40m with SPT and piezometer clusters	5x30m	PSD, Limits, MC%, DTX

3.3.3 Buckle Street Bridge Foundations

Foundations for the Buckle Street bridge structure are likely to be driven or bored piles. Piles may either be socketed into the greywacke basement beneath the alluvium or driven as an end bearing/friction piles terminating at some shallower depth, depending on the magnitude of applied loads. The principal geotechnical issues are:

d) The geotechnical properties and thickness of the alluvium and underlying greywacke with respect to piling.
e) Groundwater conditions.
f) Seismic response of foundation materials

From previous investigations (machine drillholes D4 and DH3) it appears that the area is underlain by approximately between 20m and 30m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. The basement rock was intersected in D4 at 27m depth and appears to be sloping steeply gradually to the east and intersected at 25m depth (DH3) at Cambridge terrace. The elevation of the ground surface falls 8m from DH4 to DH3.

Standard Penetration Tests in D4 show N values vary between 11and 96 for the upper 11m, below this N values vary between 24 and 75, and greater than 100 within 2m of the basement contact. SPT N values in DH3 are between 3 and 9 in the upper 6m then generally increase to greater than 50 below 11m depth.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. A water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground. Groundwater levels were not measured in DH3.

Potentially liquefiable layers have been identified in the upper 4m of DH4 and in the upper 10m of DH3.

3.3.3.1 Recommended Investigations for Buckle Street Bridge Foundations

Investigations for bridge foundation are recommended to determine geotechnical properties and thickness of the alluvium between existing investigation locations to confirm piling conditions, groundwater conditions and asses pile embedment depth in the underlying greywacke. Machine drill holes and where possible CPTs will be required to provide ground condition data for specific pier locations. This will require a minimum of 2 machine drill holes to approximately 30m depth and 4 CPTs to 30m depth. Standard Penetration Test (SPT) data from drill holes and CPT data will be used together with laboratory test results (PSD and Atterberg Limits) to determine potential liquefaction characteristics, and provide data for seismic hazard assessment and subsequent site response analyses. The extent of subsurface investigations and laboratory testing recommended are summarised in the following table and scheduled in more detail in the tables in Section 3.3.9 and their locations shown on Figure 1.

Feature	Machine Drilling	CPT	Laboratory Testing
Buckle Street Bridge	2x 30m with SPT and piezometer clusters	4x30m	PSD, Limits, MC%, DTX

3.3.4 Bridge Approach Embankment Structures

Low Embankments to maximum height of 3m are proposed at either end of both bridge structures. These embankments will most likely have retained sides although in some cases fill batters may be more appropriate, particularly where space permits and landscaping is required. Geotechnical issues relating to approach embankments are foundation conditions, embankment fill material, fill slope and retaining structure foundations.

Foundation conditions at the proposed embankment locations are indicated from previous investigations and described in the following sections.

3.3.4.1 Buckle Street Bridge Western Approach

At the western end of the project area, foundation conditions for the eastern approach to the Buckle Street bridge are likely to be favorable; groundwater levels are well below the founding level and materials appear to be dense. Pervious investigations (D4) show a thin layer of fill underlain by fine grained materials with SPT N values greater than 10 and generally greater than 20. Fill foundation settlement is expected to be within tolerable limits.

3.3.4.2 Paterson Street Bridge Eastern Approach

Foundation conditions for the eastern approach to the proposed Paterson street bridge will be variable. Previous investigations indicate that in some areas the site is underlain by up to 3m of fill (D11). In this hole SPT N values for the fill were very low (0 to 1). It will be necessary to remove this fill and replace with compacted hardfill. Foundation conditions beneath the proposed compacted hardfill are favorable with SPT N values in drill holes greater than 10. Groundwater levels may be close to foundation levels, in which case drainage will be required. Gravity drainage is available toward Dufferin Street.

3.3.4.3 Buckle Street Bridge Eastern and Paterson Street Western Approach

These approach embankments are to 2m high and will be founded within 5m of mean sea level. Foundation conditions will be variable. In this area recent swamp deposits up to 2m thick with low SPT N values (<10) underlie the fill.

Groundwater levels are expected to be close to ground surface. In D2 groundwater levels were measured in two standpipe piezometers. The shallow piezometer with its tip sealed below 4m showed a water level 0.6m above ground level, the deeper piezometer with its tip sealed below 15m showed a water level of 3m above ground surface. These water levels

most likely represent a piezometric head increasing with depth, which is not unexpected for this area.

It is likely that settlement of embankment foundations may be an issue for these bridge approaches, however foundation treatment such as undercutting and replacement with compacted hard fill will limit embankment foundation settlement within tolerable limits.

3.3.4.4 Recommended Investigations for Bridge Approach Embankments

Investigations will be required to confirm foundation ground and groundwater conditions for approach embankments. It is proposed that 2 inspection pits to 4m depth at each embankment locations are excavated and logged. Hand shear vane tests in pit walls together with DCP tests carried out as pit excavation proceeds will provide foundation strength parameters and identify any requirement for foundation treatment. It is also recommended that machine drill hole (15m) is drilled at each of the two embankment locations near Kent and Cambridge Terraces to confirm groundwater conditions and provide samples for consolidation testing. No consolidation data for the site is available from the previous investigations. It is proposed that samples are collected from embankment foundation locations for consolidation testing during the stage 1 investigations. If required, these samples will be tested during stage 2.

The extent of subsurface investigations recommended are summarised in the following table and scheduled in more detail in the tables in Section 3.3.9 and their locations shown on Figure 1.

Feature	Machine Drilling	Inspection Pit	Laboratory Testing
Patterson Street Bridge Eastern Approach		2 x 4m	CBR
Patterson Street Bridge Western Approach	1x 15m with piezometer cluster	2 x 4m	CBR, Consolidation
Buckle Street Bridge Eastern Approach		2 x 4m	CBR
Buckle Street Bridge Western Approach	1x 15m with piezometer cluster	2 x 4m	CBR, Consolidation

3.3.5 Sussex Street Cut

An underpass comprising a cut to 4.6m is to be located at the western end of the alignment to allow two lanes of traffic on Sussex Street to pass underneath Buckle Street. This cut will be retained to vertical in medium dense to dense alluvial materials near groundwater level. It is proposed that the western approach embankment to the Buckle Street Bridge will be located at the top of this cut resulting in an effective height requiring retaining of 6.6m.

The principal geotechnical issues are the geotechnical properties of the alluvium, groundwater conditions within the cut, the seismic performance of these materials.

From previous investigations (machine drillhole D4) it appears that the area is underlain by approximately between 28m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. Standard Penetration Tests in D4 show N values to be variable between 11and 96 for the upper 11m, below this N values are variable between 24 and 75, and greater than 100 within 2m of the basement contact.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. Water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a pressure head on groundwater at depth and not a static water level in the surrounding ground. However it is likely that groundwater will be encountered in the proposed 4.6m cut.

Potentially liquefiable layers have been identified in the upper 4m of DH4 and in the upper 10m of DH3.

3.3.5.1 Recommended Investigations for Cuts

Investigations are proposed at proposed cut locations to provide subsurface ground and groundwater information for excavation and retaining structure design. Sub-surface investigations will comprise machine drill holes (15m) with installed piezometers and inspection pitting up to 4m in depth. Insitu strength data will be provided by SPTing in machine drill holes and hand shear vane tests carried out in inspection pits.

Material will be sampled from pits and drill holes for laboratory testing. Testing will provide strength parameters for design of retaining structures (triaxial testing), classification of materials for liquefaction analysis (PSD and limits), and compaction characteristics and strength parameters (CBR, MDD/OWC and insitu density testing) of cut material to determine suitability for use in approach embankment construction.

The extent of subsurface investigations recommended are summarised in the following table and detailed in the schedule in in the tables in Section 3.3.9 and their locations shown on Figure 1.

Feature	Machine Drilling	Inspection Pit	Laboratory Testing
Sussex Street Cut	2 x 20m with piezometer clusters	5 x 4m	CBR, MDD, WC, Density, PSD, Limits, Triaxial

3.3.6 Pavement Subgrade

Pavement subgrade condition is expected to be variable across the site. Results from previous investigations indicate that most of the site is underlain by a variable thickness of fill, at the eastern end of the site up to 3m thick. The condition of this fill is not clear from the reports reviewed, however it is likely that this material will provide a less than satisfactory subgrade and will require treatment. Likely treatment will comprise undercutting the fill to a depth of 0.5m to 1.0m below finished grade and replacement with a subgrade improvement layer.

Previous investigations indicate that subgrade conditions in the base of the Sussex Street cut can be expected to be reasonably good. SPT N values in drill holes are typically greater than 10 indicating equivalent CBR% of greater than 7.

The recommended investigations provide for a more detailed assessment of insitu subgrade conditions.

3.3.6.1 Recommended Investigations for Pavement Foundations

Existing pavement and subgrade condition will be assessed from pavement pitting and where proposed subgrade is deep inspection pitting.

Subgrade conditions in the Sussex Street cut will be investigated using inspection pits and machine drill holes that are otherwise scheduled for the investigation of that cut.

Sampling for laboratory testing (CBR MDD/OMC) will be carried out. DCP and SPT will be used to provide insitu strength data.

Recommended pavement subgrade investigations are summarised on the following table and detailed in the schedule in the tables in Section 3.3.9 and their locations shown on Figure 1.

Feature	Machine Drilling	Pavement Pit	Inspection Pit	Laboratory Testing
At Grade Sections		10		CBR
Sussex Street Cut Subgrade	SPT testing in Drillholes for Sussex Street Cut	2	DCP Testing in Inspection pits for Sussex Street Cut	CBR, MDD, MC, Density

3.3.7 Seismic Hazard General

It is assumed at this stage that the Wellington fault, located approximately 2.5km from the project area, will influence project design. This fault has a return period of 600 years. It is proposed that the seismic hazard will be based on a deterministic assessment of the Wellington fault as the controlling seismic source rather than a probabilistic analysis that considers all possible sources.

The presence of alluvium of variable depth over the length of the bridge structure will effect ground motions and will require assessment for final design.

3.3.7.1 Recommendations for Seismic Hazard Evaluation and Seismic Design Parameter Determination

It is recommended that a staged approach to assessing the seismic hazard is made. The first stage will result in the quantification of seismic hazard in terms of acceleration response spectra for the range of site-soil conditions that exist on site.

The second stage will be required for final design and will depend on the design methodology and the type of structure adopted. In this stage site response analyses and selection of time histories may be necessary. Quantification of likely out of phase ground motions over the extent of the structure may also be necessary.

Dynamic analysis of founding material (dynamic triaxial testing) may be required to provide parameters for dynamic modelling for bridge design. An allowance for two tests has been made for stage 2 investigation. Sampling for these tests will be carried out during stage 1.

3.3.8 Preliminary Design Recommendations

Buckle Street Abutments

Bored Piles		Driven Piles			Retaining Walls						Slopes	
					Foundation			Backfill				
Ultimate Bearing Capacity (MPa)	Length * (m)	Ultimate Bearing Capacity (MPa)	Ultimate Skin Friction (kPa/m^2)	Length ** (m)	γ_b (kN/m^3)	c' (kPa)	ϕ' (°)	γ_b (kN/m^3)	c' (kPa)	ϕ' (°)	Cut***	Fill
16	Varies , up to 30m	5	30	Varies , up to 25m	18	0	25	18	0	30	1V : 2H	1V : 2H

Notes:
* From existing ground level to 2m embedment into greywacke
** For 6m embedment in 'peri-glacial' deposits
*** Cut slopes less than 3m high
**** Assume groundwater level is at the surface for scheme design
***** Geotechnical strength reduction factor = 0.5

Patterson Street Abutments

Bored Piles		Driven Piles			Retaining Walls						Slopes	
					Foundation			Backfill				
Ultimate Bearing Capacity (MPa)	Length * (m)	Ultimate Bearing Capacity (MPa)	Ultimate Skin Friction (kPa/m^2)	Length ** (m)	γ_b (kN/m^3)	c' (kPa)	ϕ' (°)	γ_b (kN/m^3)	c' (kPa)	ϕ' (°)	Cut***	Fill
16	Varies , up to 40m	8	50	Varies , up to 15m	18	0	30	18	0	30	1V : 2H	1V : 2H

Notes:
* From existing ground level to 2m embedment into greywacke
** For 6m embedment in 'peri-glacial' deposits
*** Cut slopes less than 3m high
**** Assume groundwater level is at the surface for scheme design
***** Geotechnical strength reduction factor = 0.5

3.3.9 Recommendations for Further Investigations

Previous investigations at the project location were carried out for the proposed "Tunnel Link" between the Terrace and Mt Victoria Tunnels in the early 1990s. The majority of that proposed route was below grade. Consequently the investigations concentrated on geotechnical issues relating to at-grade and below-grade construction.

Investigations are proposed for option 3 to provide geological, geotechnical, groundwater and seismic data sufficient for design of the project. The proposed investigations have been separated into two stages. Stage 1 investigations are intended to be sufficient for design of the project provided that ground conditions are similar to those interpreted from the results of previous investigations and illustrated on Figure 2. If ground conditions are significantly different from those indicated, or structure element locations are changed after stage 1 investigations are complete further investigations will be required. These are detailed in the table below as stage 2 investigations and are intended as a contingency.

Description	Stage 1 Investigations															
	Field							Lab								
	FP/HA	HA/DCP	IP	CPT		DH		CBR	PSD	MCC/OWC	Lim's	MC	Con sol	TX	UCS	DTX
	#	#	#	#	Each m	#	Each m	#	#	#	#	#	#	#	#	#
Sussex Street Cut to 4.5m	2		5			2	20	7	4	4	4	10		3		
Buckle Street Bridge				4	30	2	30		15		15	20				
Paterson Street Bridge				5	30	3	40		15		15	20				
Dufferin Street Realignment			3													
At Grade Pavement	10							10								
Approach Embankments to 3m			8			2	15		2	2	2	4	6			
Alternative Borrow Materials								5		5						
Total	**12**	**0**	**16**	**9**	**270**	**9**	**250**	**22**	**36**	**11**	**36**	**54**	**6**	**3**	**0**	**0**
	Stage 2 Investigations															
Sussex Street Cut to 4.5m			2			1	15	2		2	1			1		
Buckle Street Bridge				2	30	1	30		8		8	16		1		1
Paterson Street Bridge				2	30	1	40		10		10	20		1		1
Dufferin Street Realignment																
At Grade Pavement	4							4								
Approach Embankments to 3m			4										2	1		
Alternative Borrow Materials								2		2						
Total	**4**	**0**	**6**	**4**	**120**	**3**	**85**	**8**	**18**	**4**	**19**	**36**	**2**	**4**	**0**	**2**

3.4 Option I

Option I comprises a 2 lane bridge passing Buckle Street over Sussex Street, and a realignment of Paterson/Dufferin Streets and a pedestrian underpass beneath Paterson Street. The bridge at Buckle Street will include a combined cut to 5m with fill above it to 2m (total 7m retained height) forming its western abutment and allowing 4 traffic lanes on Sussex Street to pass beneath it.

The geotechnical issues associated with this option relate to bridge foundations at 1 location, cut batter stability, retaining structures to 6m, embankment fill foundations and batter/retaining structure design, and groundwater conditions. Seismic issues include foundation liquefaction potential.

3.4.1 General Ground Conditions

Previous investigations were related to at-grade and below-grade construction. Machine drill holes in the basin area were to a depth of 30m and revealed a profile along the proposed alignment comprising alluvial materials overlying greywacke basement rock. The contact between greywacke and alluvium slopes down from west to east, at its deepest beneath Dufferin Street, then sloping up steeply toward Mt Victoria. The drill holes encountered the contact along most of the alignment (D11, D3, D4, D102 and B5) but were stopped short of it where it is deepest (D1 and D2)

3.4.2 Paterson/Dufferin Streets Realignment and Pedestrian Underpass

The Paterson/Dufferin Streets realignment will require a shallow (2m max) cut across the gentle slope from the flat at the Basin Reserve to the steep slopes of Mt Victoria, and a 6m deep cut and cover constructed pedestrian underpass.

From previous investigations (machine drillhole D11) it appears that the area is underlain by up to 3m of fill. The fill is underlain by medium dense alluvium comprising gravelly, sandy clay. The basement rock was intersected in D11 at 9.5m depth and appears to be sloping steeply to the west deepening to greater than 30m depth beneath Dufferin Street.

Standard Penetration Tests in D11 show N values of 1 and less for the top 3m (fill), this layer flagged as a potentially liquefiable layer. Below 3m SPT N values increase rapidly from 7 at 3m to greater than 50 at 8m.

Groundwater levels were measured in D11 from a standpipe piezometer with a tip sealed beneath 7.5m. Water level has been measured in this piezometer approximately 0.5m below ground surface and most likely represents a pressure head on groundwater at depth and not a static water level in the surrounding ground.

3.4.3 Buckle Street Bridge Foundations

Foundations for the Buckle Street bridge structure are likely to be driven or bored piles. Piles may either be socketed into the greywacke basement beneath the alluvium or driven as an end bearing/friction piles terminating at some shallower depth, depending on the magnitude of applied loads. The principal geotechnical issues are:

g) The geotechnical properties and thickness of the alluvium and underlying greywacke with respect to piling.
h) Groundwater conditions.
i) Seismic response of foundation materials

From previous investigations (machine drillholes D4 and DH3) it appears that the area is underlain by approximately between 20m and 30m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. The basement rock was intersected in D4 at 27m depth and appears to be sloping steeply gradually to the east and intersected at 25m depth (DH3) at Cambridge terrace. The elevation of the ground surface falls 8m from DH4 to DH3.

Standard Penetration Tests in D4 show N values vary between 11and 96 for the upper 11m, below this N values vary between 24 and 75, and greater than 100 within 2m of the basement contact. SPT N values in DH3 are between 3 and 9 in the upper 6m then generally increase to greater than 50 below 11m depth.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. A water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground. Groundwater levels were not measured in DH3.

Potentially liquefiable layers have been identified in the upper 4m of DH4 and in the upper 10m of DH3.

3.4.4 Bridge Approach Embankment Structures

Low Embankments to maximum height of 3m are proposed at either end of the bridge structure. These embankments will most likely have retained sides although in some cases fill batters may be more appropriate, particularly where space permits and landscaping is required. Geotechnical issues relating to approach embankments are foundation conditions, fill batter design, retaining structure design and embankment fill material properties.

Foundation conditions for the eastern approach to the Buckle Street Bridge are likely to be favorable, groundwater levels are well below the founding level and materials appear to be dense. Pervious investigations (D4) show a thin layer of fill underlain by fine grained materials with SPT N values greater than 10 and generally greater than 20. Groundwater levels will be well below the foundation level. Fill foundation settlement is expected to be within tolerable limits.

The western approach embankment will be founded within 5m of mean sea level. Foundation conditions will be variable. In this area recent swamp deposits up to 2m thick with low SPT N values (<10) underlie the fill. Groundwater levels are expected to be close to the surface. In D2 groundwater levels were measured in two standpipe piezometers. The shallow piezometer with its tip sealed below 4m showed a water level 0.6m above ground level, the deeper piezometer with its tip sealed below 15m showed a water level of 3m above ground surface. These water levels most likely represent a pressure head increasing with depth, which is not unexpected for this area.

It is likely that settlement of embankment foundations may be an issue for these bridge approaches, however foundation treatment such as undercutting and replacement with compacted hard fill will limit embankment foundation settlement within tolerable limits.

3.4.5 Sussex Street Cut

An underpass comprising a cut to 4.6m is to be located at the western end of the alignment to allow two lanes of traffic on Sussex Street to pass underneath Buckle Street. This cut will be retained to vertical in medium dense to dense alluvial materials near groundwater level. It is proposed that the western approach embankment to the Buckle Street Bridge will be located at the top of this cut resulting in an effective height requiring retaining of 6.6m.

The principal geotechnical issues are the geotechnical properties of the alluvium, groundwater conditions within the cut, the seismic performance of these materials.

From previous investigations (machine drillhole D4) it appears that the area is underlain by approximately between 28m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. Standard Penetration Tests in D4 show N values to be variable between 11and 96 for the upper 11m, below this N values are variable between 24 and 75, and greater than 100 within 2m of the basement contact.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. Water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a pressure head on groundwater at depth and not

a static water level in the surrounding ground. However it is likely that groundwater will be encountered in the proposed 4.6m cut.

Potentially liquefiable layers have been identified in the upper 4m of DH4 and in the upper 10m of DH3.

3.4.6 Pavement Subgrade

Pavement subgrade condition is expected to be variable across the site. Results from previous investigations indicate that most of the site is underlain by a variable thickness of fill, at the eastern end of the site up to 3m thick. The condition of this fill is not clear from the reports reviewed, however it is likely that this material will provide a less than satisfactory subgrade and will require treatment. Likely treatment will comprise undercutting the fill to a depth of 0.5m to 1.0m below finished grade and replacement with a subgrade improvement layer.

Previous investigations indicate that subgrade conditions in the base of the Sussex Street cut can be expected to be reasonably good. SPT N values in drill holes are typically greater than 10 indicating equivalent CBR% of greater than 7.

3.4.7 Seismic Hazard

It is assumed at this stage that the Wellington fault, located approximately 2.5km from the project area, will influence project design. This fault has a return period of 600 years. It is proposed that the seismic hazard will be based on a deterministic assessment of the Wellington fault as the controlling seismic source rather than a probabilistic analysis that considers all possible sources.

The presence of alluvium of variable depth over the length of the bridge structure will effect ground motions and will require assessment for final design.

3.4.8 Recommended Geotechnical Investigations

Recommended geotechnical investigations for this option are summarised on the following table.

Feature	Machine Drilling	CPT	Inspection Pit	Pavement Pit
Patterson Street Realignment Retaining Structure	2 x 10m		4 x 4m	
Paterson Street Pedestrian Underpass	2 x 12m			
Sussex Street Cut	2 x 20m		5 x 4m	
Buckle Street Bridge Approachs	1 x 10m		4 x 4m	
Buckle Street Bridge	3 x 30m	4 x 30m		
Subgrade for at Grade Sections				10
Sussex Street Cut Subgrade	SPT testing in DHs for Cut		DCP in IPs for Cut	

3.4.8.1 *Recommendations for Seismic Hazard Evaluation and Seismic Design Parameter Determination*

It is recommended that a staged approach to assessing the seismic hazard is made. The first stage will result in the quantification of seismic hazard in terms of acceleration response spectra for the range of site-soil conditions that exist on site.

The second stage will be required for final design and will depend on the design methodology and the type of structure adopted. In this stage site response analyses and selection of time histories may be necessary. Quantification of likely out of phase ground motions over the extent of the structure may also be necessary.

Dynamic analysis of founding material (dynamic triaxial testing) may be required to provide parameters for dynamic modelling for bridge design. An allowance for two tests has been made for stage 2 investigation. Sampling for these tests will be carried out during stage 1.

3.5 *Option J*

Option J comprises a 4 lane bridge passing Sussex Street over Buckle Street, and a realignment of Paterson/Dufferin Streets and a pedestrian underpass beneath Paterson Street. The bridge at Sussex will include a cut to 3.6m to allow 2 traffic lanes on Buckle street to pass beneath it.

The geotechnical issues associated with this option relate to bridge foundations at 1 location, cut batter stability, retaining structures to 4m, embankment fill foundations and batter/retaining structure design, and groundwater conditions. Seismic issues include foundation liquefaction potential.

3.5.1 *General Ground Conditions*

Previous investigations were related to at-grade and below-grade construction. Machine drill holes in the basin area were to a depth of 30m and revealed a profile along the proposed alignment comprising alluvial materials overlying greywacke basement rock. The contact between greywacke and alluvium slopes down from west to east, at its deepest beneath Dufferin Street, then sloping up steeply toward Mt Victoria. The drill holes encountered the contact along most of the alignment (D11, D3, D4, D102 and B5) but were stopped short of it where it is deepest (D1 and D2)

3.5.2 *Paterson/Dufferin Streets Realignment and Pedestrian Underpass*

The Paterson/Dufferin Streets realignment will require a shallow (2m maximum) cut across the gentle slope from the flat at the Basin Reserve to the steep slopes of Mt Victoria, and a 6m deep cut and cover pedestrian underpass.

From previous investigations (machine drillhole D11) it appears that the area is underlain by up to 3m of fill. The fill is underlain by medium dense alluvium comprising gravelly, sandy clay. The basement rock was intersected in D11 at 9.5m depth and appears to be sloping steeply to the west deepening to greater than 30m depth beneath Dufferin Street.

Standard Penetration Tests in D11 show N values of 1 and less for the top 3m (fill). This layer is identified as a potentially liquefiable layer. Below 3m SPT N values increase rapidly from 7 at 3m to greater than 50 at 8m depth.

Groundwater levels were measured in D11 from a standpipe piezometer with a tip sealed beneath 7.5m. A water level has been measured in this piezometer approximately 0.5m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground.

3.5.3 *Sussex Street Bridge Foundations*

Foundations for the Sussex Street bridge structure are likely to be driven or bored piles. Piles may either be socketed into the greywacke basement beneath the alluvium or driven as an end bearing/friction piles terminating at some shallower depth, depending on the magnitude of applied loads. The principal geotechnical issues are:

j) The geotechnical properties and thickness of the alluvium and underlying greywacke with respect to piling.
k) Groundwater conditions.
l) Seismic response of foundation materials

From previous investigations (machine drillholes D4 and DH3) it appears that the area is underlain by approximately between 20m and 30m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. The basement rock was intersected in D4 at 27m depth and appears to be sloping steeply gradually to the east and intersected at 25m depth (DH3) at Cambridge terrace. The elevation of the ground surface falls 8m from DH4 to DH3.

Standard Penetration Tests in D4 show N values vary between 11and 96 for the upper 11m, below this N values vary between 24 and 75, and greater than 100 within 2m of the basement contact. SPT N values in DH3 are between 3 and 9 in the upper 6m then generally increase to greater than 50 below 11m depth.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. A water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a piezometric pressure at depth and not a static water level in the surrounding ground. Groundwater levels were not measured in DH3.

Potentially liquefiable layers have been identified in the upper 4m of DH4 and in the upper 10m of DH3.

3.5.4 Bridge Approach Embankment Structures

Low Embankments to maximum height of 3m are proposed at either end of the bridge structure. These embankments will most likely have retained sides although in some cases fill batters may be more appropriate, particularly where space permits and landscaping is required. Geotechnical issues relating to approach embankments are foundation conditions, fill slope design, retaining structure design and embankment fill material properties.

Foundation conditions for the southern approach to the Sussex Street Bridge are likely to be favorable, groundwater levels are well below the founding level and materials appear to be dense. Pervious investigations (D4) show a thin layer of fill underlain by fine grained materials with SPT N values greater than 10 and generally greater than 20. Groundwater levels will be well below the foundation level. Settlement of the foundation is likely to be within tolerable limits.

The northern approach embankment will be founded within 5m of mean sea level. Foundation conditions will be variable. In this area recent swamp deposits up to 2m thick with low SPT N values (<10) underlie 1m – 2m of fill. Groundwater levels are expected to be close to the surface. In D2 groundwater levels were measured in two standpipe piezometers. The shallow piezometer with its tip sealed below 4m showed a water level 0.6m above ground level, the deeper piezometer with its tip sealed below 15m showed a water level of 3m above ground surface. These water levels most likely represent a pressure head increasing with depth, which is not unexpected for this area.

It is likely that settlement of embankment foundations may be an issue for the northern bridge approach.

3.5.5 Buckle Street Cut

An underpass comprising a cut to 3.6m is to be located at the western end of the alignment to allow 2 lanes of traffic on Buckle Street to pass underneath Sussex Street. This cut will be retained to vertical in medium dense to dense alluvial materials near groundwater level

The principal geotechnical issues are the geotechnical properties of the alluvium, groundwater conditions within the cut, and the effects of seismic events on these materials.

From previous investigations (machine drillhole D4) it appears that the area is underlain by approximately between 28m of alluvium comprising medium dense to very dense gravel, silt, sand and clay. Standard Penetration Tests in D4 show N values to be variable between 11and 96 for the upper 11m, below this N values are variable between 24 and 75, and greater than 100 within 2m of the basement contact.

Groundwater levels were measured in D4 from a standpipe piezometer with a tip sealed beneath 19m. Water level has been measured in this piezometer approximately 2m below ground surface and most likely represents a pressure head on groundwater at depth and not a static water level in the surrounding ground. However it is likely that groundwater will be encountered in the proposed 4.6m cut.

Potentially liquefiable layers have been identified in the upper 4m of DH4 and in the upper 10m of DH3.

3.5.6 Pavement Subgrade

Pavement subgrade condition is expected to be variable across the site. Results from previous investigations indicate that most of the site is underlain by a variable thickness of fill, at the eastern end of the site up to 3m thick. The condition of this fill is not clear from the reports reviewed, however it is likely that this material will provide a less than satisfactory subgrade and will require treatment. Likely treatment will comprise undercutting the fill to a depth of 0.5m to 1.0m below finished grade and replacement with a subgrade improvement layer.

Previous investigations indicate that subgrade conditions in the base of the Buckle Street cut can be expected to be reasonably good. SPT N values in drill holes are typically greater than 10 indicating equivalent CBR% of greater than 7.

3.5.7 Seismic Hazard

It is assumed at this stage that the Wellington fault, located approximately 2.5km from the project area, will influence project design. This fault has a return period of 600 years. It is proposed that the seismic hazard will be based on a deterministic assessment of the Wellington fault as the controlling seismic source rather than a probabilistic analysis that considers all possible sources.

The presence of alluvium of variable depth over the length of the bridge structure will effect ground motions and will require assessment for final design.

3.5.8 Recommended Geotechnical Investigations

Recommended geotechnical investigations for this option are summarised on the following table.

Feature	Machine Drilling	CPT	Inspection Pit	Pavement Pit
Patterson Street Realignment Retaining Structure	2 x 6m		4 x 4m	
Paterson Street Pedestrian Underpass	2 x 8m			
Buckle Street Cut	2 x 15m		4 x 4m	
Sussex Street Bridge Approaches	1 x 8m		4 x 4m	
Sussex Street Bridge	4 x 30m	4 x 30m		
Subgrade for at Grade Sections				10
Buckle Street Cut	SPT testing in		DCP in IPs	

3.5.8.1 *Recommendations for Seismic Hazard Evaluation and Seismic Design Parameter Determination*

It is recommended that a staged approach to assessing the seismic hazard is made. The first stage will result in the quantification of seismic hazard in terms of acceleration response spectra for the range of site-soil conditions that exist on site.

The second stage will be required for final design and will depend on the design methodology and the type of structure adopted. In this stage site response analyses and selection of time histories may be necessary. Quantification of likely out of phase ground motions over the extent of the structure may also be necessary.

Dynamic analysis of founding material (dynamic triaxial testing) may be required to provide parameters for dynamic modelling for bridge design. An allowance for two tests has been made for stage 2 investigation. Sampling for these tests will be carried out during stage 1.

4.0 LIMITATION

This report is an assessment of geological conditions in the project area and is based on a review of existing available published and unpublished data form investigations and studies carried out by others only. Inferences about the nature and continuity of ground conditions are made but cannot be guaranteed.

The report has been prepared for the particular project described in the brief to Worley Consultants Limited and no responsibility is accepted for the use of any part of this report in any other or for any other purpose. .

5.0 REFERENCES

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