Technical Report 35

Assessment of Ground Settlement Effects

NZ TRANSPORT AGENCY

1 MacKays to Peka Peka Expressway

Revision History

Revision N°	Prepared By	Description	Date
A	Lucy Coe	Issued for Internal Review	21-09-11
B	Lucy Coe	Value Engineering changes and review comments incorporated.	14-11-11
1	Lucy Coe	For EPA Completeness Check	02-12-11
2	Lucy Coe	Second issue to the EPA	17-02-12

Document Acceptance

Action	Name	Signed	Date
Prepared by	Lucy Coe		17-02-12
Reviewed by	Gavin Alexander		17-02-12
Approved by	Gavin Alexander		17-02-12
on behalf of	Beca Infrastructure Ltd		

This report has been prepared for the benefit of the NZ Transport Agency (NZTA). No liability is accepted by the company or any employee or sub-consultant of this company with respect to its use by any other person.

This disclaimer shall apply notwithstanding that the report may be made available to other persons for an application for permission or approval or to fulfil a legal requirement.

Table of Contents

Appendices

Appendix 35.A – Sector and Cross-section Location Plan

(Also refer to Drawings GT-SE-050 – 051, Technical Report Appendices, Report 35, Volume 5)

Appendix 35.B – Peat Contour Plans and Typical Peat Treatment Details

(Also refer to Drawings CV-EW-100 – 121, Earthworks, Volume 5)

Appendix 35.C – Existing Building Preliminary Assessment

Appendix 35.D – Predicted Embankment Settlements

Appendix 35.E – Predicted Groundwater Drawdown Settlements

Appendix 35.F – Predicted Combined Settlements

Appendix 35.G – Combined Settlement Contour Plan

(Also refer to Drawings GT-SE-150 – 161, Technical Report Appendices, Report 35, Volume 5)

Appendix 35.H – Effects on Buildings

Appendix 35.I – Effects on Services Settlement Plan

(Also refer to Drawings GT-SE-200 – 232, Technical Report Appendices, Report 35, Volume 5)

1 Executive Summary

The MacKays to Peka Peka Expressway (the ‘Expressway’ or the ‘Project’) is a proposed 16 km long four lane expressway. The proposed Expressway traverses dune sands and peat swamps of the Kāpiti coastal lowlands. Loading (by earthworks) of peat deposits that remain beneath the proposed Expressway embankments, and lowering of groundwater levels in the peat (by excavation or drainage) are the main sources of settlement resulting from the Project. This report presents the assessment of potential ground settlements associated with the construction and operation of the proposed Expressway, and the expected effects of these settlements on existing buildings, services and transport infrastructure. The report proposes a monitoring regime and describes potential mitigation measures for the effects. This report relies in part upon modelling of groundwater effects and so should be read in conjunction with Technical Report 21, Volume 3.

There are four sources of settlements associated with the construction and operation of the proposed Expressway, as follows:

- **Consolidation of the ground due to the construction of the embankments**

  This is time dependent, and represents by far the largest component of predicted ground settlement. These settlements occur beneath and for a small distance beyond the earthworks embankments where they are constructed on peat. As a result, they primarily affect the completed highway pavement and any services buried within the underlying peat. Consolidation settlements are time dependent and are directly related to the embankment height and to the nature, thickness and permeability of the peat. Most of this movement will occur during construction, with on-going secondary compression (creep) settlement continuing at a reducing rate through operation. Up to 1300mm settlement is calculated to occur beneath the higher embankments where they are underlain by several metres of peat. Calculated settlements beyond the earthworks footprint range from 0 mm to 20mm, and extend up to approximately 10m from the embankment toe.

- **Consolidation of the ground due to lowering of the groundwater**

  Lowering of the groundwater level will occur as a result of excavation, which may be either temporary (e.g. short term undercutting to remove peat from beneath the embankment footprint) or long term around excavated stormwater wetlands and storage areas. These settlements are time dependent, and extend beyond the earthworks footprint. They are much smaller in magnitude than the movements resulting from embankment loading, typically reducing to 12.5mm within 70m of the embankment toe.

  Lowering of the groundwater level will potentially result in drying induced volume change settlements. The change in moisture content is expected to be relatively small as a result of infiltration recharge. Complete drying is not expected to occur. Consequently, the drying induced volume change is expected to be relatively small in comparison with the settlements resulting from consolidation due to the groundwater lowering.

- **Mechanical settlement of the ground due to the movement of retaining walls**

  Lateral movement of embedded retaining walls (as the ground is excavated in front of them) results in localised settlement of the ground above. These settlements occur relatively quickly, during and immediately following wall construction.

- **Mechanical settlement of the ground due to vibrations**

  Vibration is used in construction to densify sandy or gravelly soils. This densification results in immediate settlement of the ground surface extremely close to the vibration source. Vibration resulting from general construction operations, and from traffic on the completed Expressway, is not expected to generate sufficiently high shear stresses to cause ground settlement. Consequently, vibration induced settlement is confined to the construction footprint and is essentially “built out” by the construction operation.

The extent of ground settlements resulting from the Project has been determined by superimposing, as applicable, settlement caused by the various sources described above. Plans showing the area of expected effects are provided in Appendix 35.F. The predicted settlements are generally less than 25 mm beyond the edge of the earthworks, and lateral extent of settlement is generally within 50 m to 70 m of the earthworks footprint. At specific stormwater features, the predicted groundwater lowering and resulting consolidation settlements extend a greater distance from the proposed Expressway (refer Table 1).

Potential settlement effects on dwellings and other buildings in the Project area have been assessed using the ‘Limiting Tensile Strain’ concept described by Burland (1997). This approach considers settlement curvature and horizontal strains, and enables classification of the expected severity of damage. It has been used previously in New Zealand and is widely used in the United Kingdom. This level of assessment ignores the (commonly beneficial) interaction between building foundations and the ground, and is consequently considered to be conservative. The actual damage is likely to be less than the assessed damage category. All buildings assessed fell in Damage Category ‘negligible’ (Table 10), described as hairline cracks at worst. As a result the, ground settlement effects on buildings are assessed as being ***low***.

The services and transport infrastructure located outside the proposed earthworks extents are likely to be subject to relatively small changes in grade. Settlement effects on services and on transport infrastructure beyond the Project Footprint are, similarly, assessed as being low. Services that pass beneath the proposed Expressway alignment are being specifically addressed with the respective utility organisations. Discussions are on-going with all of the service providers regarding the existing condition of their assets, their ability to tolerate the predicted settlement values and monitoring and mitigation options. Some will inevitably need to be realigned, and others will be monitored and repaired or protected as agreed with the owner. The effects on the NIMT Railway are assessed as ***low***, and any relevelling required will be agreed with KiwiRail.

Monitoring is proposed to confirm that ground settlement effects are no worse than predicted by this assessment. It will include building condition assessments for structures within a conservatively assessed corridor extending beyond the zone where 12.5 mm settlement and/or 0.2m groundwater drawdown is predicted, together with measurement and reporting of ground settlement and groundwater levels.

2 Introduction

2.1 Project overview

The designation for the Project is proposed to have a general width of 100 m and to span a length of approximately 16km from north of MacKays Crossing (chainage 1900 m) to just north of Peka Peka Road (approx. chainage 18050 m).

The MacKays to Peka Peka Expressway ('the proposed Expressway') will provide for two lanes of traffic in each direction, connections with local roads at four interchanges, construction of new local roads and access roads to maintain local connectivity and an additional crossing of the Waikanae River. The proposed Expressway embankment largely crosses over local roads.

The alignment has been divided into four geographic sectors as outlined in Table 1 and illustrated in Figure 1 below.

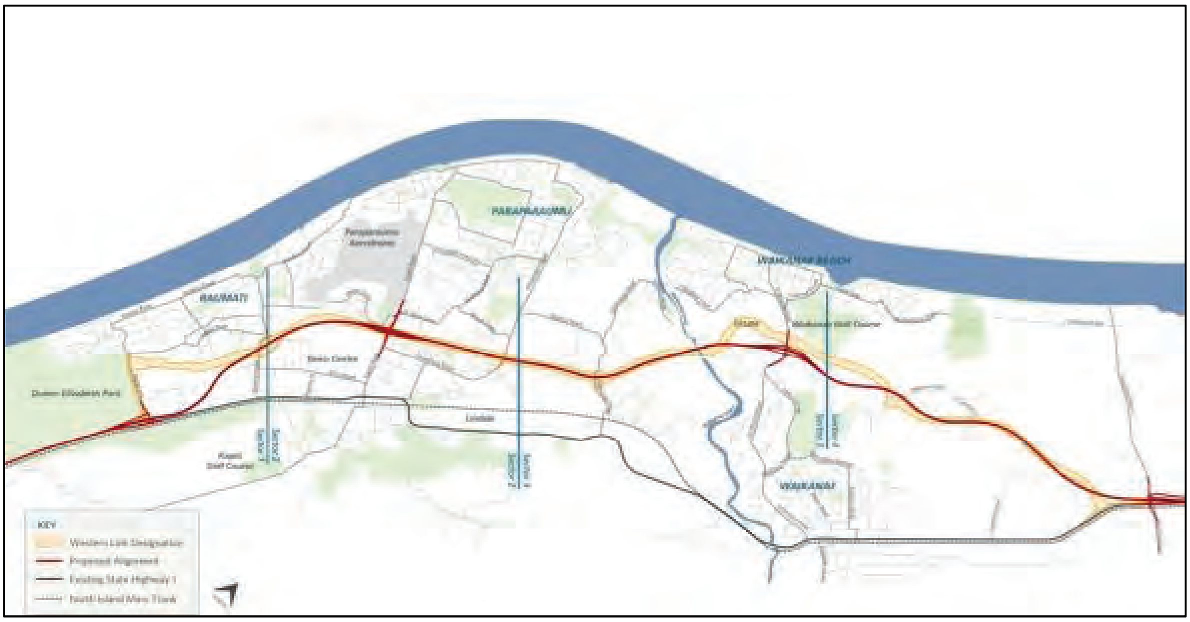
For a full description of the Project refer to the Project Description (Construction and Operation) within Part D, Chapters 7 and 8, Volume 2.

Table 1 – Project Sectors

Sector number	Sector name	Description	Chainage (m)	Length (km)
1	Raumati South	From just south of Poplar Ave to just north of Raumati Road	1900 – 4500	2.6
2	Raumati/Paraparaumu	From north of Raumati Road to north of Mazengarb	4500 – 8300	3.8

Sector number	Sector name	Description	Chainage (m)	Length (km)
		Road		
3	Otaihanga/Waikanae	From north of Mazengarb Road to north of Te Moana Road	8300 – 12400	4.1
4	Waikanae North	From north of Te Moana Road to Peka Peka	12400 – 18050	5.7

Figure 1: Sector Diagram



2.2 Report overview

This report presents the assessment of potential ground settlements ('settlements') associated with the construction and operation of the proposed Expressway, and the effects of these settlements on existing buildings, services and transport infrastructure. The report proposes a monitoring regime and describes potential mitigation measures for these effects.

The proposed Expressway corridor traverses dune sands and swamp deposits of the Kāpiti coastal lowlands. Peat deposits present in the low lying inter-dunal depressions are typically very soft with high organic contents. Groundwater is typically encountered at a shallow depth in the peat deposits.

Ground improvements are required to limit post-construction settlement of the proposed Expressway, where peat deposits are present below the new road embankments. The treatment approaches proposed vary along the proposed Expressway depending on the depth and extent of the peat expected to be encountered and the sensitivity of adjacent areas. Two treatment methods are proposed, as described below:

- **Excavate and replace**

  This treatment option involves removing the peat deposits from below the proposed Expressway footprint. The peat deposits are excavated and replaced with compacted sand.

- **Preload and surcharge**

  This treatment option involves constructing the road embankment over the peat deposits and allowing the majority of settlement to occur prior to pavement construction. Preload and surcharge fill is to be placed above final design level during the settlement period to reduce the long-term settlements. The preload is equivalent to the expected settlement depth and the surcharge is the additional fill placed and removed at the end of the settlement period. Some on-going secondary and creep settlements are expected.

The greatest settlements associated with the proposed Expressway will predominantly result from increased loading of these peat deposits and from groundwater changes within them. Consequently, such settlements largely occur directly beneath the proposed new embankments.

There are several sources of settlement associated with the construction and operation of the proposed Expressway. The potential sources of settlement are as follows:

- **Road embankment loading**

  Consolidation settlements of the underlying peat deposits will occur due to increased loading from the road embankments. These settlements are expected to be of relatively large magnitude within the road embankment footprint, with only limited settlement expected beyond it.

- **Lowering of the groundwater - road embankments**

  The road embankment construction, and consequently the modification of the underlying materials, will result in short-term and long-term changes in the shallow groundwater levels. Lowering of the groundwater associated with the road embankments is expected to result in further consolidation settlements. These further settlements will be smaller in magnitude than those resulting directly from embankment loading, however they are expected to extend up to approximately 50 m to 70 m from the road embankment.

- **Lowering of the groundwater - stormwater features**

  There are a number of proposed stormwater features along the proposed Expressway alignment, including wetlands and storage areas. Some of these features have the potential to result in construction stage and permanent (i.e. operational stage) groundwater lowering, in particular offset storage areas 2 and 3A and wetland 3, south of the Wharemauku Stream. Such groundwater lowering has potential to result in consolidation settlements extending a significant distance from the stormwater features.

- **Retaining walls**

  The proposed Mazengarb Retaining Walls and a number of temporary retaining walls are located adjacent to existing buildings. Construction of these retaining walls will result in ground settlement immediately behind them.

- **Construction vibration**

  Construction vibrations have the potential to cause settlement of loose sands in close proximity to the source.

This report:

- describes the existing environment that may be impacted by the settlements, including existing buildings, services and transport infrastructure have been considered;
- describes these different settlement sources and presents the methods of analysis adopted for predicting the settlement magnitude, extent and timing for each source. In locations where the settlements are additive, the method used to combine the settlement predictions is outlined. The settlement predictions have been used to assess the effects on the existing environment, and these effects are presented;
- proposes a settlement monitoring regime and describes potential mitigation measures. The monitoring regime provides a method for measuring the actual settlements and the resulting effects. Mitigation measures are available that can be implemented should the measured settlements or their effects require it.

The most significant sources of settlement beyond the Project footprint result from groundwater changes. Those changes are described in Technical Report 21, Volume 3. The groundwater regime consists of a series of interbedded aquifers and aquitards creating a leaky, unconfined to semi-confined aquifer system. At depth, moderate to high transmissivity terrestrial gravels form the confined Waimea Aquifer and Parata Aquifer. These are overlain by a series of unconfined aquifers comprised of interbedded regression alluvium, fluvial gravels, and marine sands. These are in turn overlain by alluvium and Holocene dune sand, with areas of peat having developed in the lower lying areas between dunes. The peat ranges from amorphous organic silt to fibrous woody peat of variable permeability and compressibility. The peat is also significant in that it supports a series of recharge and discharge wetlands of high ecological value. The construction of the proposed Expressway has the greatest potential to affect the shallow groundwater system (i.e. the Holocene sand, peat, and alluvium) because works will be largely carried out within these materials. The potential settlement effects are largely derived from the peat deposits.

This report proposes a settlement monitoring regime and describes potential mitigation measures. The monitoring regime provides a method for measuring the actual settlements and the resulting effects. Mitigation measures are available that can be implemented should the measured settlements or their effects require it.

In part this report relies upon, and should be read in conjunction with, Technical Report 21, Volume 3.

2.3 Sources of effects

There are four sources of settlements associated with the construction and operation of the proposed Expressway. These sources of settlement are described below:

2.3.1 Consolidation of the ground due to the construction of embankments

This occurs as a result of the increased load from the fill placed on the underlying saturated and weak peat deposits, and subsequent reduction in excess pore water pressure. The consolidation settlements are time-dependant, and are directly related to the nature, thickness and permeability of the peat. The majority of the settlement will occur during the construction period, with on-going secondary consolidation and creep settlements continuing at a reducing rate through operation.

2.3.2 Consolidation of the ground due to the lowering of the groundwater

Lowering of the existing groundwater level will occur due to the change in material permeability below the proposed Expressway footprint (i.e. compression of the peat or replacement of the peat with sand), and at unlined stormwater features with positive drainage outlets set below the existing groundwater level. In addition, short-term groundwater lowering will occur during construction due to the excavation of foundation materials. These changes in groundwater regime are detailed in Technical Report 21, Volume 3. The lowering of the groundwater level will cause a reduction in pore water pressure and therefore an increase in effective overburden pressure. This will result in compression of the peat deposits over time. The consolidation settlements are time-dependant, and depend upon the amount of groundwater drawdown, and the nature, thickness and permeability of the peat and the existing seasonal variation in groundwater levels. Initial, primary consolidation settlement of peat soils is followed by long term secondary compression or creep.

2.3.3 Mechanical settlement of the ground due to the movement of retaining walls

This settlement results from the lateral movements of the wall as it is loaded. The load is applied as material is either excavated in front of the wall or is backfilled behind it. The lateral displacement translates to a vertical settlement behind the wall, and will occur in close proximity to the rear of the wall. These settlements will occur relatively quickly, during or immediately following wall construction.

2.3.4 Mechanical settlement of the ground due to vibrations

Construction stage vibrations will be generated by earthworks, ground improvement installation (i.e. stone columns) and piling. Mechanical settlements of loose sand deposits may occur as a result of the increased shear stress applied to the sand particles by cyclic loading and the resulting densification of the sand. These potential settlements are expected to occur immediately, in extremely close proximity to the vibration source.

2.4 Expected area of effects

The effects have been assessed over the area of predicted settlements. The study area for this assessment is described below. A plan showing the area of expected effects is provided in Appendix 35.G and in Technical Appendices, Report 35, Volume 5.

The expected area of effects follows the proposed Expressway alignment from south of Poplar Avenue (Chainage 1600) to Te Kowhai Road in the north (Chainage 18050). The lateral extent is generally within 50 m to 70 m of the earthworks footprint.

At specific stormwater features, the predicted lowering of the groundwater and subsequent settlement effects extend a greater distance from the proposed Expressway. These stormwater features and area of effects are detailed in Table 2 below.

Table 2 – Area of Effects – Stormwater Features

Stormwater feature	Type of feature	Location	Chainage	Lateral extent predicted effects[1] (m)
Wetland OA and offset storage area OB	Attenuation/ treatment device and offset flood storage	Raumati South, Sector 1	CH3700 – 4000	Groundwater mounding
Offset flood storage area 2	Offset flood storage area	South of Wharemauku Stream, Sector 2	CH4950 – 5400	500

Stormwater feature	Type of feature	Location	Chainage	Lateral extent predicted effects[1] (m)
Offset flood storage area 3A and wetland 3	Offset flood storage area	South of Wharemauku Stream, Sector 2	CH4950 – 5400	500
Offset flood storage area 6A	Offset flood storage area	Adjacent to the Landfill	CH8800 - 9100	50 to 100
Wetland 8	Attenuation/ treatment device	South of Waikanae River	CH10150 - 10300	50 to 100
Wetland 9	Attenuation/ treatment device	North of Waikanae River, Sector 3	CH11100 – 11350	Groundwater mounding

1. Area of predicted effects is based on extent of groundwater drawdown. Distance tabulated equivalent to the maximum distance from the stormwater feature that the predicted measurable groundwater drawdown in peat extends. Measureable drawdown defined for the purpose of this settlement study is defined as greater than 0.1m calculated drawdown.

The Mazengarb Retaining Walls in Sector 2 are located along both sides of the existing Mazengarb Road, extending approximately 200 m east of the new Mazengarb Road Underbridge. The walls are located adjacent to private properties. Settlements associated with the retaining walls will be in close proximity to the wall, extending less than 10 m from the back face. Other temporary retaining walls are generally located within the extent of earthworks and consequently the settlement.

3 Existing environment

3.1 Overview

This section describes the existing environment in terms of both the ground conditions that may result in settlements, and the structures that may be impacted. The main features of the existing built environments are the buildings, services and transport infrastructure.

The proposed Expressway route traverses the Kāpiti coastal lowlands, where sand dunes rise to around 20 m in elevation and low lying areas and inter-dunal depressions typically contain peat deposits. Key geotechnical considerations for settlement potential are the presence of peat deposits, and the thickness and nature of these deposits. The site topography and shallow ground conditions are described below.

As part of the development of the Kāpiti Coast, the ground conditions have been modified in some areas. Commonly adopted techniques have included excavation of the peat and replacement with dune sand to provide adequate foundations, and excavation of the sand dunes to provide a fill resource. Also, the construction of surface drainage networks has increased the productivity of the land. Consequently, the techniques proposed to construct the proposed Expressway, and the resulting ground settlement effects are widespread in the Project area.

In general, the land adjacent to the proposed Expressway is a mix of urban residential and rural in nature. The urban housing is located close to Paraparaumu and Waikanae town centres. Rural farming and lifestyle properties are located between Otaihanga Road and the Waikanae River, and north of Te Moana Road. The majority of residential buildings have been built over the last 50 years, with a number of newer sub-divisions. There are some commercial and light industrial buildings in Paraparaumu town centre. These are typically two story portal frame structures. The Kāpiti Coast District Council (KCDC) Wastewater Treatment Plant and the Waikanae Christian Holiday Park (El Rancho) are adjacent to the proposed Expressway and have been specifically considered.

There are a number of services crossing or in close proximity to the proposed Expressway alignment. These services are typical of residential areas and include water, wastewater and stormwater networks, electricity and gas distribution, and telecommunications. The Vector Gas Transmission Pipeline Corridor crosses the proposed Expressway alignment at several locations within a 1.6 km stretch north of the Waikanae River. The proposed Expressway passes under the Transpower Bunnythorpe to Haywards A and B 220kV Transmission Lines north of Smithfield Road.

The proposed Expressway crosses the existing local road network at nine locations, including several secondary arterial roads. There are also a number of local roads that are in close proximity to the proposed Expressway that are within the expected area of effects. The existing local roads are generally two lanes (one lane in each direction) and are finished with a chip-sealed surfacing.

The North Island Main Trunk (NIMT) Railway line runs roughly parallel with the existing State Highway (SH1). At the southern and northern extents of the proposed Expressway, the NIMT is located on an embankment to the east of the existing SH1. There are no proposed crossings of the NIMT.

3.2 Ground conditions

The proposed Expressway route traverses the sand dune and swamp deposits of the Kāpiti coastal lowlands. The sand dunes form areas of higher relief, rising to around 20 m in elevation, between the intervening low lying areas. These low lying areas and depressions are located a few metres above sea level and typically contain peat deposits. The dune sands are often inter-fingered with peat deposits, where the dune sands have in places advanced over the swampy ground. Low lying terraces of recent river and fan alluvium are adjacent to the Waikanae River. The surficial geology of area is strongly reflected in the landforms and topography observed.

The potential settlements resulting from the proposed Expressway Project will occur in these recent deposits, in particular the peat. The topography and shallow ground conditions are summarised below to provide a general overview of the sand dune and peat distribution per Sector. Sector descriptions are provided in the Project Description (Construction and Operation) within Part D, Chapters 7 and 8, Volume 2. The regional geological setting and details of the deeper geological units are presented in Technical Report 21, Volume 3 and Technical Report 36, Volume 3.

Plans have been developed illustrating the distribution of peat (and conversely, areas of non-peat) along the route, refer Drawings CV-EW-100 to 111 in Appendix 35.B and in Technical Appendices, Report 35, Volume 5. These plans present contours of the peat thickness over the assessment area. These are based on available geotechnical investigation data, with the lateral extent of the peat mapped from the interpretation of the landforms on aerial photographs and geotechnical site walkover visits.

3.2.1 Sector 1 – Raumati South

From south of Poplar Avenue to just north of Raumati Road, the topography is fairly low lying, comprising peat and/ or organic silts overlying Holocene alluvium and sand, and Pleistocene gravel at depths of 5 to 10m below ground level until chainage 4000, where dunes of around 15m height overly the Pleistocene sand and gravel.

The peat deposits in Sector 1 are typically described as silty peat, with some organic silt, and vary in thickness from 1.0 to 3.5m.

3.2.2 Sector 2 – Raumati/Paraparaumu

From north of Raumati Road to north of Mazengarb Road, the topography is undulating, the route crossing dunes which reach up to 15m in height, with lesser amounts of lower-lying inter-dunal areas in between. It appears that much of this sector of the road corridor preserves a remnant of what was a larger dune field which has undergone extensive earthworks for residential development in Paraparaumu. The geology generally comprises Holocene sand (dune), overlying Pleistocene sand, with peat and organic silt in low lying areas.

The peat deposits in Sector 2 are typically described as silty peat, with some organic silt, and vary in thickness from 1.0 to 3.5m.

It is understood the peat deposits have been excavated from below the newer subdivisions and replaced with sand. Anecdotal evidence suggests that this is the case west of the proposed Expressway between Milne Drive and Mazengarb Road.

3.2.3 Sector 3 – Otaihanga/Waikanae

From north of Mazengarb Road to north of Te Moana Road the topography is undulating, the route passing over dunes (which reach up to 20m height) and lower-lying inter-dunal areas. The geology generally comprises Holocene sand (dune), overlying Pleistocene sand, with peat and organic silt in low lying areas. Toward the centre of this sector the Waikanae River cuts through the route east-west, with associated low-lying alluvial terraces on either side. Geology at depth beneath the Waikanae River area comprises very dense Pleistocene gravel, and some Pleistocene silt.

The peat deposits in Sector 3 are typically described as organic silts and sands, and vary in thickness from 1.0 to 2.5m.

3.2.4 Sector 4 – Waikanae North

From north of Te Moana Road to Peka Peka the topography is undulating, dominated by dunes until Smithfield Road, east of which the route flattens out. The geology comprises Holocene (dune) sand overlying Pleistocene sand and at depth, Pleistocene gravel. Beyond Smithfield Road there are areas of peat and organic silt in low lying areas, particularly north of chainage 15600. At chainage 16200 to 16700 the alignment crosses the Hadfield Fault.

The peat deposits in Sector 3 are typically described as silty peat, with some organic silt, and vary in thickness from 0.5 to 4.5m.

3.3 Buildings

The buildings within the expected area of effects have been visually assessed to determine the structural form and susceptibility to settlement.

The residential buildings in the urban areas are typically low-rise, medium density housing. In rural areas, the buildings are predominantly life style residential in nature and typically low-rise, low density housing.

The residential buildings, in both urban and rural settings, have been characterised based on the assessed sensitivity of the structure to settlement effects. The assessment is based on two types of residential buildings:

- Dwelling type 1 – Masonry Construction or Brittle Clad; and
- Dwelling type 2 – Timber Construction or Flexible Clad.

These categories are outlined below.

The commercial and industrial buildings in the Paraparaumu town centre are low-rise structures. These buildings, along with the KCDC Wastewater Treatment Plant and El Rancho Christian Camp, are potentially susceptible to settlements based on their size and structural form. These buildings have been assessed specifically.

3.4 Residential buildings

3.4.1 Dwelling Type 1 – Masonry Construction/Brittle Clad

Houses defined in this category generally contain one or more brittle elements that may be susceptible to visual cracking in the event of differential ground movement. Visual effects are possible, even when differential ground movement is "slight". Magnitude of effects such as "slight" are defined in Table 10 of the report.

Many of the existing buildings in this category will already exhibit some signs of cracking, as this may be have occurred as a result of historical or seasonal ground movement, drying shrinkage, or thermal stress relief.

The following construction types are included:

- Reinforced or unreinforced concrete block masonry that may be either painted or overlain by a concrete render (often used in basements or over the lower level of a two storey home).
- Unreinforced brick (solid or cavity wall) that may be either exposed or overlain by a concrete render or plaster.
- Single thickness brick or brick/stone veneer over a timber frame or concrete block substrate.
- Stucco or plaster over a timber frame or concrete block substrate.

3.4.2 Dwelling Type 2 – Timber Construction/Flexible Clad

Houses defined in this category are constructed in a more flexible material that is able to accommodate a certain degree of differential ground movement without any visual effects.

The following construction types are included:

- Weatherboard, either painted, stained cedar, or similar.
- Board and batten or similar timber panel type claddings.
- Fibre cement or fibreglass sheet.

3.4.3 Commercial and industrial buildings

The commercial and industrial buildings in Paraparaumu are typically steel portal frame buildings. These buildings have been visually assessed, and characterised in terms of sensitivity to movements. The structural form of these buildings and assessed sensitivity to settlement effects are detailed in Appendix 35.C, and summarised in Table 3. In the summary table, the sensitivity to movement is based on the following two categories:

- Type A - Expected to be susceptible to visual cracking in the event of slight differential ground movement due to cladding type.
- Type B –Not expected to be susceptible to visual cracking in the event of slight differential ground movement.

Table 3 – Existing Commercial and Industrial Buildings Summary

Building ID	Location	Description of structural form	Sensitivity to movement 1
1	20 Manchester Street, Paraparaumu	A series of portal frame buildings, with precast reinforced concrete walls and steel cladding.	B
2	18 Manchester Street, Paraparaumu	A steel portal frame structure with some precast reinforced concrete walls and steel and a board material cladding.	B
3	16 Manchester Street, Paraparaumu	A steel portal frame structure with a concrete block wall on two faces of the building and steel cladding. The concrete block wall is expected to be reinforced.	A
4	12 Manchester Street, Paraparaumu	A steel portal frame structure with some precast reinforced concrete walls and steel cladding.	B
5	11 Sheffield Street, Paraparaumu	A steel portal frame structure with steel cladding and a steel roof. One section of wall approximately 1000mm high was of concrete block construction indicating that there may be more concrete block.	A
6	13 Sheffield Street, Paraparaumu	A steel portal frame structure with precast reinforced concrete walls. The cladding is mainly timber and steel, but there is also a section of brick about 2000m high and 4000mm long.	A
7	15 Sheffield Street, Paraparaumu	A steel portal frame structure with no obvious concrete walls and steel cladding.	B

Building ID	Location	Description of structural form	Sensitivity to movement 1
8	17 Sheffield Street, Paraparaumu	A series of 1-storey frame structures. Buildings are steel clad and likely to be steel framed structures (otherwise timber).	B
9	31 Milne Drive, Paraparaumu	A 2-storey structure. Structural system of the building is unknown. A wall down one side of the building is plastered and could be reinforced concrete or concrete block. The building has stucco cladding.	A
10	27 Milne Drive, Paraparaumu	A steel portal frame structure with stucco cladding. It is connected to the building at 23 Milne Drive.	A
11	23 Milne Drive, Paraparaumu	A steel portal frame structure with stucco cladding. It is connected to the building at 27 Milne Drive.	A
12	11 Kodax Place, Paraparaumu	A portal frame structure with stucco cladding.	A
13	106A Kāpiti Road, Paraparaumu	The main structure is a steel portal frame with a smaller concrete block structure attached to it. The main structure has both steel cladding and concrete blocks. The concrete blocks would be expected to be reinforced.	A
14	106B Kāpiti Road, Paraparaumu	The structures consist of a steel portal frame and concrete block and steel cladding. The concrete blocks would be expected to be reinforced.	A
15	104 Kāpiti Road, Paraparaumu	A steel portal frame structure with steel cladding and a small timber structure on the side.	B

1 – Sensitivity of movement:
Type A – Expected to be susceptible to visual cracking in the event of slight differential ground movement due to cladding type.
Type B –Not expected to be susceptible to visual cracking in the event of slight differential ground movement.

3.4.4 KCDC wastewater treatment plant

The KCDC Wastewater Treatment Plant has a number of buildings and structures. These include office buildings, storage sheds, tank structures and small concrete block structures. These structures have been visually assessed and characterised in terms of sensitivity to movements. The type of structure and assessed sensitivity to settlement effects are detailed in Appendix 35.C, and summarised in Table 4.

The organic filters and concrete block structures are expected to be more sensitive to movement.

Table 4 – KCDC Wastewater Treatment Plant Summary

Building ID	Building Name	Description of structure	Sensitivity to movement 1
a	Office building	1-storey office building of both timber and reinforced concrete wall construction.	B
b	Storage shed	1-storey storage shed of concrete block construction.	A
c	Storage shed	1-storey storage shed of timber and steel construction.	B
d	Tank	Tank is reinforced concrete construction and sits in the ground.	B
e	Fuel storage shed	Two separate structures, one is of steel construction and the other consists of precast concrete panels.	B
f	Organic Filters	Low structure of concrete block and timber construction.	A
g	Mixing tanks	Each of the three mixing tanks is of similar construction. They consist of reinforced concrete and extend approximately 5m below ground level.	B
h	UV treatment shed	1-storey building with precast concrete panel facades.	B
i	Small timber shed	Small 1-storey timber structure.	B

Building ID	Building Name	Description of structure	Sensitivity to movement 1
j	Concrete tanks	These two large tanks are of similar construction and the main structure consists of reinforced concrete.	B
k	Small Concrete Block Structures	Two concrete block structures.	A
1 – Sensitivity of movement: Type A – Expected to be susceptible to visual cracking in the event of slight differential ground movement due to cladding type. Type B –Not expected to be susceptible to visual cracking in the event of slight differential ground movement.			

3.4.5 Waikanae Christian Holiday Camp (El Rancho)

The El Rancho complex has a number of buildings. These buildings are typically timber structures. There are some buildings with plaster or concrete block façade which are expected to be more sensitive to movement. The buildings have been visually assessed and characterised in terms of sensitivity to movements. The type of structure and assessed sensitivity to settlement effects are detailed in Appendix 35.C, and summarised in Table 5.

Table 5 – El Rancho Buildings Summary

Building Name	Description of structural form	Sensitivity to movement [1]
Kauri Hall	A timber or steel portal frame building. Each façade is constructed of a board material that appeared flexible. The entrances consist of columns that have a plaster surface.	B
Poplar Lodge	A 1-storey timber building with timber facades.	B
Oregon Lodge	A 2-storey timber building with timber facades.	B
Willow Lodge and Workshop	Timber buildings.	B
Redwood Hall/Dining Room	A 2-storey structure is constructed from various materials consisting of timber, brick and plaster facades with sections of concrete blocks at the base.	A
Rata Lodge, Rimu Lodge and Toilet Block	Timber buildings on a concrete slab foundation.	B

Building Name	Description of structural form	Sensitivity to movement [1]
Office	A plaster façade with the rest of the building being clad in a board/timber material.	A
Elm Court	A series of timber/board buildings.	B
Apiti Chapel	Timber building.	B
Staff #2	This building is constructed from both timber and plaster facades.	A
Cafe	Timber building.	B
Pinewood Dining and Pinewood Hall	Pinewood Dining and Pinewood Hall both have facades constructed from both brick and concrete block.	A
Villas	2-storey timber building.	B
Caravan Kitchen	Timber building.	B

1 – Sensitivity of movement:
Type A – Expected to be susceptible to visual cracking in the event of slight differential ground movement due to cladding type.
Type B –Not expected to be susceptible to visual cracking in the event of slight differential ground movement.

3.5 Services

3.5.1 General

There are a number of existing services crossing or in close proximity to the proposed Expressway alignment that may be impacted by settlements. These services are typical of residential areas and include the water, wastewater and stormwater networks, electricity and gas distribution, and telecommunications. The Vector Gas Transmission Pipeline Corridor crosses the proposed Expressway alignment at several locations north of the Waikanae River. The proposed Expressway passes under the Transpower Bunnythorpe to Haywards Transmission Line north of Smithfield Road.

Existing Service Plans have been prepared from as-built records provided by the service providers, refer Drawings GT-SE-200 to 232 in Appendix 35.I and in Technical Appendices, Report 35, Volume 5. Collection of further information on the construction of the services and existing condition investigations are on-going.

A number of services will be impacted by the proposed Expressway and will need to be protected or relocated, either temporarily or permanently. The Expressway Alliance has met with all of the service providers to discuss the existing services, and preliminary design solutions where required. Discussions with the service providers and their representatives are on-going.

The majority of services present are typical of an urban setting, and comprise of water, wastewater and stormwater networks, electricity and gas distribution, and telecommunications. In general, these are located between Poplar Avenue and Te Moana Road, and at Peka Peka Road. These services are described below in Table 6, including the likely form of construction.

In addition, the Vector Gas Transmission Pipeline Corridor and the Transpower Bunnythorpe to Haywards A and B Transmission Lines cross the proposed Expressway Alignment. These services have been considered specifically.

Table 6 – Service Networks and Typical Construction

Type of service	Service providers	General locations	Typical construction
Water supply network	KCDC	Leinster Avenue to Ngarara Road	▪ 100mm / 200mm/ 250mm / 300mm diameter asbestos cement water mains ▪ 50mm/ 100mm/ 300mm diameter PVC water mains ▪ Water supply bore ▪ hydrants/ valves
Stormwater network	KCDC	MacKays Crossing to Peka Peka Road	Refer Assessment of Stormwater Effects
Wastewater network	KCDC	Leinster Avenue to Smithfield Road	▪ 100mm/ 150mm/ 450mm/ 525mm diameter asbestos cement gravity mains ▪ 100mm/ 150mm diameter PVC gravity pipes ▪ 525mm diameter RCRRJ gravity main ▪ 100mm / 450mm diameter asbestos cement rising mains ▪ 350mm diameter PE rising main ▪ Pump Station ▪ Manholes

Type of service	Service providers	General locations	Typical construction
Electricity distribution	Electra	MacKays Crossing to Peka Peka Road	▪ 400V / 11kV / 33kV ▪ Buried cables and overhead lines (and poles) ▪ Streetlighting / transformers
Gas distribution	Vector	Raumati Road to Te Moana Road	▪ 32mm/ 50mm/ 100mm PE pipes
Telecommunication, including fibre optic cables	Telecom	Leinster Avenue to Peka Peka Road	▪ Buried cables (telephone and fibre optic) ▪ Telecom cabinets and manholes
	Telstra Clear	MacKays Crossing to Te Moana Road	▪ Buried and overhead cables (telephone and fibre optic)
	FX Network	Kāpiti Road to Mazengarb Road	▪ Buried cables (fibre optic)

3.5.2 Vector Gas transmission pipeline corridor and delivery point station

The Vector Gas transmission pipeline corridor transports gas from Kapuni to Wellington. The corridor crosses the proposed Expressway alignment several times in a 1.6 km stretch immediately north of the Waikanae River. There are two pipelines in the corridor, 200 and 300mm in diameter and they are assumed to be buried 1200mm below the surface.

There is a Delivery Point Station adjacent to the proposed Waikanae River Bridge which comprises filtration, pressure reduction and metering. The station is situated underground in a 20m x 15m compound enclosed by security fencing.

3.5.3 Transpower Bunnythorpe to Haywards A and B Transmission Lines

The Transpower transmission 220kV lines from Bunnythorpe to the Haywards sub-station cross north Waikanae. The proposed Expressway passes under these transmission lines north of Smithfield Road. The Smithfield Road realignment passes under the transmission lines south of the existing Smithfield Road. There are a number of transmission towers that are located in close proximity to the proposed Expressway alignment between Ngarara Road and Peka Peka Road. The transmission tower foundations are typically grillage type.

4 Methodology

4.1 Overview of assessment

The method used for calculating the settlements and assessing the subsequent effects are presented in this section.

The settlements associated with the proposed Expressway will predominantly result from consolidation of the peat deposits. The consolidation of the peat deposits will occur due to direct loading from the new road embankment, as well as lowering of the groundwater as a result of altering the embankment foundation materials, new stormwater features and construction activities. These sources of consolidation settlements are described in Section 1.3 above.

The consolidation settlements from the two sources (new road embankment and groundwater lowering) have been analysed separately, at a number of consistent cross-sections along the length of the proposed Expressway. These settlements have then been combined to assess the total consolidation settlements. The cross-sections have been selected to be representative of the varying peat thicknesses and peat treatment methodologies for the new road embankment. In addition, the cross-sections cover the new stormwater wetlands and offset flood storage areas that may result in lowering of the groundwater level, as identified in Technical Report 21, Volume 3.

The cross-section locations that have been analysed are detailed in Table 7, including a summary of the peat treatment methodology and proximity to stormwater features. An aerial photo showing the locations of the cross-sections is set out in Drawings GT-SE-050 – 051, Appendix 35.A and in Technical Appendices, Report 35, Volume 5.

Table 7 – Settlement Analyses Cross-section Locations

Section	Location	Peat treatment	Settlement source
1	CH2450	Preload and Surcharge	Road Embankment
2	CH3050	Preload and Surcharge	Road Embankment/ Wetland OA and Offset Flood Storage Area OB
3	CH3600	Preload and Surcharge	Road Embankment
4	CH4300	Preload and Surcharge	Road Embankment
5	CH5300	Preload and Surcharge	Road Embankment/ Offset Flood Storage Areas 2 and 3A/ Wetland 3
6	CH6000	Preload and Surcharge	Road Embankment
7	CH6140	Excavate and Replace	Road Embankment

Section	Location	Peat treatment	Settlement source
8	CH6500	Excavate and Replace	Road Embankment
9	CH8900	Preload and Surcharge	Road Embankment and Offset Flood Storage Area 6a
10	CH11200	Excavate and Replace	Road Embankment and Wetland 9
11	CH11700	Excavate and Replace	Road Embankment and Wetland 9
12	CH14400	Excavate and Replace	Road Embankment Wetland 11B/12B and Offset Flood Storage 11[2]
13	CH16000	Preload and Surcharge	Road Embankment and Offset Flood Storage 13/13A

1) A description of the peat treatment methodologies is given in Section 1.2.
2) Wetland 11B/12B and Flood Storage 11 have been assessed as unlikely to affect groundwater

The geotechnical parameters for the peat deposits are presented in Section 3.2. The methods of analyses adopted for the two sources of consolidation settlements are detailed in Sections 3.3 and 3.4, with the method adopted for combining settlements outlined in Section 3.7.

Mechanical settlements will occur as a result of the new retaining walls and construction vibrations, as described in Section 1.3 above. The consolidation settlements are significantly larger, in both magnitude and extent, compared to the mechanical settlements. The mechanical settlements will occur in the dune sands and in close proximity to the source, and as such have been considered independently. The method for assessing the new retaining wall settlements is presented in Section 3.5. The vibration assessment of settlements is discussed in Section 3.6.

The methodology for assessing the effects of the predicted settlements on the buildings and services is detailed in Section 3.8.

4.2 General derivation of parameters for analyses

The geotechnical compression parameters, used to predict the consolidation settlements in the peat deposits, have been derived from available laboratory data, in situ testing and a number of field trials, as well as the historic data. These information sources are detailed in Technical Report 36, Volume 3 and the key sources summarised in Table 8 below.

Table 8 – Information Sources

Type of data	Information source
Geotechnical Field Investigations (In-situ testing and laboratory data)	Existing WLR designation Geotechnical Investigations
	Project team[1] Geotechnical Investigations
Field Trials	Opus Trial Embankment, undertaken for the existing SH1 Raumati Straight widening
	Project team Trial Embankment
	Project team Trial Excavation
Construction Records	SH1 Raumati Straight Widening
	MacKays Crossing Project
Historic Performance	Existing SH1 Raumati Straight

The compression parameters for the peat deposits are presented in Table 9 Non-linear parameters, based on a compression index (Cc) approach, have been used to characterise the peat deposits. The non-linear approach provides a better fit for back analyses of historic data and field trails compared to a linear (Mv) approach, where a variety of embankment heights have been considered.

Table 9 – Peat Compression Parameters

Compression parameter	Symbol	Unit	Value
Unit weight	γ	kN/m^3	10.5
Compression Index Parameter	$C_c/ 1+e_0$	-	0.35
Pre-consolidation Stress	P_0	kPa	15
Recompression Index Parameter	$C_r/ 1+e_0$	-	0.06
Co-efficient of Consolidation (vertical)	C_v	m^2/year	3.0
Recompression Co-efficient of Consolidation (vertical)	C_{vr}	m^2/year	3.0

[1] This Technical Report refers to the Project team as carrying out works on behalf of and as contracted by the NZTA. The NZTA is the requiring authority and the consent holder.

Compression parameter	Symbol	Unit	Value
C_c – Compression Index C_r – Recompression Index e_0 – Initial Void Ratio			

4.3 Embankment settlement methodology

Consolidation settlements of the underlying peat deposits will occur due to increased loading from the new road embankments. Settlement analyses have been carried out at the cross-sections identified in Table 7 based on parameters outlined in Section 3.2. The predicted settlements are summarised in Section 4, and detailed in Appendix 35.D.

Consolidation settlements have been analysed using Settle 3D, version 2.0, a program used for 1-dimensional analysis of vertical consolidation and settlement, developed by Rocscience. The analyses are based on the commonly adopted log-based consolidation method.

The soil profile has been analysed based on an assessed peat thickness for each specific cross-section location. The assessed peat thickness is assumed to be constant across the cross-section. Where no peat deposits are present no settlements are predicted.

The groundwater level has been modelled at 0.5m below the existing ground surface at all locations to represent reasonable long-term average conditions.

The new road embankments have been modelled, including any associated noise bunds or cycleway/walkway embankments. The embankment loads have been modelled using a Boussinesq load distribution approach. The analyses are time-dependant and consider the staged construction, including the preload and surcharge fill during construction and the final embankment form.

Immediate, secondary compression and long term creep settlements were not separately assessed and considered as these settlements are typically at least an order of magnitude less than the consolidation settlements and thus lie within the accuracy of those calculations. Given the conservative nature of the overall assessment, these settlements are considered to be included in the total settlement estimates provided.

Details of the key assumptions and inputs are presented in Appendix 35.D.

4.4 Groundwater drawdown settlement methodology

The lowering of the groundwater level will result in consolidation of the peat deposits over time. This will occur due to the change in material permeability below the proposed Expressway, and at some of the unlined stormwater features. The groundwater drawdowns are presented in Technical Report 21, Volume 3, and form the basis for the calculated groundwater drawdown settlements.

4.4.1 Lowering of the groundwater - road embankment

The road embankment construction, and consequently the modification of the underlying materials, will result in lowering of the groundwater. The predicted groundwater drawdowns are based on 2-dimensional groundwater modelling, with the extent of drawdown predicted from the regional 3-dimensional groundwater model.

A design groundwater drawdown profile is presented in Technical Report 21, Volume 3. This design groundwater profile is applicable for both of the peat treatment methodologies, and for the varying peat thicknesses.

For the preload and surcharge methodology, groundwater drawdown will occur on the downstream or western side of the proposed Expressway. Conservatively, the drawdown curve has been applied to both the upstream and downstream side of the proposed Expressway. This will allow the settlement predictions to include the likely settlements for both peat treatment methodologies.

4.4.2 Lowering of the groundwater – stormwater features

There are a number of proposed stormwater features along the proposed Expressway alignment, including treatment wetlands and offset flood storage areas. Detailed 3-dimensional models have been used to predict the groundwater lowering at the key stormwater features, as detailed below:

- Wetland OA and offset flood storage area OB (existing ecological area);
- Offset flood storage areas 3A and 2, and Wetland 3 (Wharemauku Stream and proposed flood offset area); and
- Offset flood storage area 6a
- Wetland 8
- Wetland 9 (El Rancho ecological and cultural area).

4.4.3 Settlement methodology

Settlement analyses have been carried out at the cross-sections identified in Table 7 based on parameters outlined in Section 3.2 and the drawdowns predicted from the groundwater modelling. The predicted settlements are presented in Section 4.

The consolidation settlement analyses have been based on the change in effective stress resulting from the predicted groundwater drawdowns. The analyses are based on the commonly adopted log-based consolidation method.

The total predicted groundwater drawdowns have been applied to an assessed water table depth of 0.5m.

The soil profile has been analysed based on an assessed peat thickness for each specific cross-section location. The assessed peat thickness is assumed constant across the cross-section. Where no peat deposits are present no settlements are predicted.

A series of drawdown against predicted settlement curves have been developed for varying peat thicknesses, these are presented in Appendix 35.E. These curves have been based on 1-dimensional consolidation theory. These settlement curves, in combination with the peat thickness contour plans, have been used to assess the likely settlement adjacent the proposed Expressway.

The sensitivity of the settlement predictions to a number of variables has been considered, including the unit weight of the peat deposits, existing groundwater levels and initial building surcharge. Details of the key assumptions and inputs are presented in Appendix 35.E.

Drying of peat may result in volume change and therefore settlement. The construction of the proposed Expressway (and modification of the foundations) and construction of the stormwater features is calculated to result in lowering of the groundwater levels, typically less than 0.3m adjacent to the proposed Expressway and reducing with distance away from the proposed Expressway. Although the mean groundwater level is lowered by a small amount, the moisture content of the peat is expected to remain high based on the infiltration recharge. Drying is not therefore expected. The settlements from drying induced volume change are expected to be relatively small and have not been separately quantified. These are considered accounted for within the current estimated settlements.

4.5 Retaining wall settlement methodology

Vertical settlements will occur behind the retaining walls as a result of lateral movements. These lateral movements will arise as the retaining wall is loaded, including during construction, excavation in front of the wall and backfilling behind the wall.

These settlements have been assessed based on guidance provided in CIRIA Report No. C580 ‘Embedded retaining walls – guidance for economic design’.

4.6 Vibration settlement methodology

Construction stage vibrations will be generated by earthworks, the installation of ground improvement (stone columns) and piling. The assessment of vibration effects is detailed in Technical Report 18, Volume 3.

Mechanical settlements of loose sand deposits may occur due to construction stage vibration. The potential settlements are expected to be of relatively small magnitude, and are anticipated to occur in extremely close proximity to the vibration source. They are therefore not expected to occur outside the proposed Expressway footprint. These settlements do not occur concurrently with the settlements from other sources. As such, the vibration settlements are expected to have a negligible effect and have not been considered further.

The vibration settlements and subsequent effects on the built environment are expected to be significantly less than the direct vibration effects. The management of the vibration effects are detailed in CEMP Appendix F, Volume 4.

4.7 Combination of settlement predictions

The settlements will result from a number of sources, as described in Section 1.3.

The total consolidation settlements have been based on a combination of both embankment and groundwater drawdown settlements. The settlements from each source have been superimposed, by adding individual values at the same points across each cross-section.

The extent of vibration and retaining wall settlement is considerably more localised in extent than for the embankment and groundwater drawdown consolidation settlements. The predicted settlements are shown on total settlement plans.

4.8 Methodology for assessment of effects

4.8.1 Buildings

The method described by Burland (Burland, 1997) was used to assess the effects of settlement on buildings. The approach upon which this paper is based remains the most commonly used and recommended method in international references.

The concept of Limiting Tensile Strain (presented in the above paper) has been used, which enables a classification of the expected severity of damage, of an "idealised" building, at each location where vertical and horizontal ground movement data is available.

The settlement profile extending 10m beyond the proposed Expressway is dominated by the predicted groundwater drawdown settlement resulting from the road embankments. These settlements have been assessed based on a series of drawdown against predicted settlement curves developed for varying peat thicknesses, as described in Section 3.4. For each of these settlement curves, an arbitrary building is assumed to "bend" to follow the predicted ground shape, whether it is a hogging or sagging[2] profile. The maximum tensile strain arising in the building as a

---

[2] A hogging profile is where the building curves upwards in the middle, and the maximum tensile strain occurs at the top. A sagging profile is where the building curves downwards in the middle, and the maximum tensile strain occurs at the bottom.

result of this profile is calculated and combined with the predicted horizontal strain at the same location, using the method described by Burland 1997.

The building parameters adopted in the analysis are analogous to a continuous masonry wall façade, rectangular in elevation, and this can be varied in scale and aspect ratio to be broadly representative of the typical buildings in the Study Area.

The resulting maximum tensile strain is then compared to the limiting strains that correspond to thresholds or categories of damage. Table 10 below shows the limiting strains adopted and overviews an objective system for the classification of damage. This system assigns a description of typical damage, severity and ease of repair to each of the categories described.

It is important to note this method of assessment and classification is specifically relevant to buildings of brick or block masonry construction (i.e. analogous to Dwelling Type 1 as described in Section 2.4.2). Buildings comprising more flexible construction types, such as timber clad dwellings, are considered less likely to exhibit visible effects (particularly at the low damage categories predicted for the majority of buildings) given the same categorisation.

The above assessment method ignores the interaction between the building foundations and the ground. All buildings will exhibit a degree of restraint against a bending action imposed by the ground and this restraint will be a function of the building stiffness and continuity. For this reason, the effects predicted in Table 10 can generally be taken as conservative.

This method of assessment has been used previously in New Zealand and is widely used in the UK. It has been used to enable a broad analysis of the possible degrees of damage to the buildings in the Study Area. This level of assessment is considered conservative and the actual damage is likely to be less than the assessed damage category.

Appendix 35.H provides the graphs that have been prepared to determine the damage categories for each settlement curve. These graphs have been formulated, based on the procedure outlined above and assuming a 10m wide by 3m high building, analogous to a single storey residence (note: a sensitivity analysis undertaken has found there is little change in the outcome if the building length is doubled to 20m). The graphs plot horizontal strain versus surface deflection ratio for each data point at 5m intervals perpendicular to the alignment. From these graphs, and with reference to Table 10 below, those areas where adverse effects on buildings may occur can be established. No buildings have been identified that lie within an area where the settlement modelling estimates greater than “negligible” effects (i.e. damage category 0).

The building damage category has been specifically assessed based on the predicted settlement contours for the following buildings and structures:

- Commercial and industrial buildings, as outlined in Table 3.

- KCDC Wastewater Treatment Plant buildings and structures, (refer Table 4).
- Waikanae Christian Holiday Camp, (refer Table 5).
- All buildings within 10m of the proposed Expressway.

Table 10 – Building/Structure Damage Category (after Burland, 1997)

Damage category	Category of damage	Description of typical damage	Approximate crack width (mm)	Limiting tensile strain (%)
0	Negligible	Hairline cracks	< 0.1	< 0.05
1	Very Slight	Fine cracks that can be easily treated during normal decoration. Perhaps isolated slight fracture in buildings. Cracks in external brickwork visible on inspection.	< 1	0.05 – 0.075
2	Slight	Cracks are easily filled. Redecorating probably required. Several slight fractures showing inside of building. Cracks are visible externally and some repointing may be required externally to ensure weather tightness. Doors and windows may stick slightly.	< 5	0.075 – 0.15
3	Moderate	The cracks require some opening up and can be patched by a mason. Recurrent cracks can be masked by suitable lining. Repointing of external brickwork and possible a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired.	5-15 or a number of cracks > 3	0.15 – 0.3
4	Severe	Extensive repair work involving breaking out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning and bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15-25 but also depends on number of cracks	> 0.3

Damage category	Category of damage	Description of typical damage	Approximate crack width (mm)	Limiting tensile strain (%)
5	Very Severe	This requires a major repair job involving partial or complete rebuilding. Beams lose bearing, walls lean badly and require shoring. Windows broken due to distortion. Danger of instability.	Usually > 25 but depends on number of cracks	

1) In assessing the degree of damage, account must be taken of its location in the building or structure.
2) Crack width is only one aspect of damage and should not be used on its own as a direct measure.
3) The table is based on buildings of brick/blockwork masonry construction.

4.8.2 Services

The effects of the predicted settlements on existing underground services have been assessed.

The total settlement contours, described in Section 4.4, have been overlain on the services plans. The Services Settlement Plans are presented in Drawings GT-SE-200 – 232, Appendix 35.I and in Technical Appendices, Report 35, Volume 5. These plans have been used to calculate the settlement profile and gradient significant services.

The settlement effects have been assessed considering the sensitivity of the service to movement. The sensitivity depends on the construction type, age and condition of the service. The main services of concern are expected to be older piped services constructed of asbestos cement.

The potential settlement effects and sensitivity of the services are being discussed with the service providers.

4.8.3 Transport infrastructure

The settlement effects on the road network have been assessed. The settlement gradients have been calculated based on the Total Settlement Plans set out in Drawings GT-SE-150 – 161, Appendix 35.G and in Technical Appendices, Report 35, Volume 5. The effect of these settlements on the assets has then been determined.

The settlement effects on the NIMT Railway adjacent to Peka Peka Interchange have been assessed based on the groundwater drawdown predictions from the coarse regional groundwater model. The effect of these settlements on the NIMT Railway has been determined.

5 Settlement estimates

The settlements estimated for the separate settlement sources are presented in Sections 5.1 to 5.3. The total settlements from the combined sources are presented in Section 4.4.

The consolidation settlements from construction of the new road embankment govern the settlements below the proposed Expressway footprint. The settlements away from the proposed Expressway are predominately from groundwater drawdown settlements due to modification of the foundation materials below the proposed Expressway. Over the 10m immediately adjacent to the proposed Expressway footprint, settlements result from a combination of these two sources.

The majority of settlement results from consolidation of the peat deposits. The nature and thickness of these deposits is highly variable and is expected to result in variation of the peat settlements. Typically, the differential settlements are estimated to be in the order of half the calculated settlement magnitude. These potential differential settlements are an important consideration in assessing the settlement effects.

5.1 Road embankment settlements

Consolidation settlements resulting from the construction of the new road embankment are presented in Appendix 35.D. These settlements are estimates at the completion of the construction phase, and have been calculated for representative sections as outlined in Table 7. Settlement plots for each section are also included in Appendix 35.D.

In calculating the settlements, sensitivity to a number of factors has been considered. The analyses indicate the predicted settlements are sensitive to the initial water table depth, with settlements increasing as the initial water table depth is reduced. The calculated settlements were relatively insensitive to the unit weight of the peat.

The calculated settlement profiles indicate relatively large magnitude settlements directly below the embankment footprint, reducing toward the edge of the embankment. The settlements increase with peat thickness, final embankment height and temporary surcharge height.

The settlements beyond the embankment footprint range from 0 to 20mm, and extend for approximately 10m distance. The magnitude and extent of the settlement beyond the embankment footprint is dependent on the embankment height. The highest differential movements occur at the edge of the embankment loading.

5.2 Groundwater drawdown settlements

The calculated consolidation settlements resulting from groundwater lowering are presented in Appendix 35.E. A series of curves for drawdown versus predicted settlement have been used to assess the settlements resulting from groundwater lowering, due to both the modification of the new embankment foundation materials and the construction of new stormwater features. The predicted groundwater drawdown settlements resulting from the new stormwater features are relatively small compared to those resulting from the new road embankment.

Sensitivity to a number of factors has been considered, including the unit weight of the peat deposits, existing groundwater levels and initial building surcharges. The settlement magnitude is sensitive to changes in the initial building surcharge.

5.2.1 Lowering of the groundwater - road embankments

Consolidation settlements resulting from groundwater drawdown due to the construction of the new road embankment have been calculated based on the design groundwater drawdown profile presented in the Assessment of Groundwater Effects. Settlement curves corresponding to the predicted design curve for various peat thicknesses are presented in Appendix 35.E.

These curves indicate that the extent of settlements depends on the thickness of the peat deposits. The variation in the settlement extent for varying thicknesses of peat deposits is summarised in Table 11. For 2.0m thick peat deposits, settlements greater than 12.5mm extend up to 10m from the edge of the earthworks footprint. For 3.0m thick peat deposits, settlements greater than 12.5mm extend up to 70m from the edge of the earthworks.

Table 11 – Predicted Groundwater Drawdown Settlement Extents

Settlement (mm)	Extent of settlement1 (m)			
	1.0m Peat Deposits	2.0m Peat Deposits	3.0m Peat Deposits	4.0m Peat Deposits
> 25mm	0m	0m	0m	20m
12.5mm	0m	10m	70m	100m
< 5mm	0m	130m	190m	230m
1) Extent of settlement from the edge of the earthworks footprint (m).				

These predicted groundwater drawdown settlements dominate the combined settlements away from the proposed Expressway. The settlement curves based on the predicted design drawdown curve have been used to determine the settlement effects on buildings located at least 10m away from the edge of the proposed Expressway.

5.2.2 Lowering of the groundwater – stormwater features

The consolidation settlements resulting from the new stormwater features have been assessed using the series of drawdown versus predicted settlement plots described above in Section 4.2.

These settlements are presented on the relevant representative cross-sections in Appendix 35.F, and summarised below for key stormwater features.

The predicted settlements resulting from the new stormwater wetlands and offset flood storage areas are relatively small due either the thickness of peat deposits at the feature locations or the engineering measures incorporated to reduce groundwater drawdown. In areas where the peat deposits are shallow, the groundwater drawdown results in settlements of approximately 5mm. Pond liners have been proposed at a number of stormwater features to reduce the groundwater effects, and subsequently reduce the potential settlements.

5.2.3 Wetland OA and Offset flood storage area OB (CH3700 – 4000)

Wetland OA is proposed to be lined, and therefore the predicted groundwater drawdowns adjacent to the pond are less than 0.1m. Settlements of less than 5mm are predicted adjacent to this feature.

5.2.4 Offset flood storage areas 2 and 3A, Wetland 3 (CH4950 – 5400)

The offset flood storage areas 2 and 3A and wetland 3 are predicted to result in 0.6m of groundwater drawdown close to the features, reducing to 0.1m of groundwater drawdown at a distance of 500m from the offset flood storage area. The predicted settlements due to this feature are less than 12.5mm based on relatively thin peat deposits of 1.2m thickness.

5.2.5 Offset Flood Storage Area 6a

Offset flood storage area 6A is predicted to result in 0.5m of groundwater drawdown close to the features, reducing to 0.1m of groundwater drawdown at a distance of 50 to 100m from the offset flood storage area. The predicted settlements due to this feature are less than 12.5mm based on relatively thin peat deposits of less than 1.0m thickness.

5.2.6 Wetland 8

Wetland 8 is predicted to result in 0.5m of groundwater drawdown close to the features, reducing to 0.1m of groundwater drawdown at a distance of 50 to 100m from the wetland. The predicted settlements due to this feature are less than 12.5mm based on relatively thin peat deposits of less than 1.0m thickness.

5.2.7 Wetland 9 (CH11100 – 11350)

The stormwater pond located at Wetland 9 is proposed to be lined, and no groundwater drawdown or settlement is predicted.

5.3 Retaining wall settlements

There are several retaining walls required to retain near vertical cuts in the sand dunes. These walls will generally be constructed using a top down methodology, where the wall is installed first, followed by excavation of the in situ material in front of the wall.

The permanent walls are typically cantilever post and panel walls, with concrete bored piles. The temporary walls are typically cantilever sheet pile walls. Tied back piled walls or soil nail walls are proposed for the temporary walls with higher retained heights. The final retaining wall forms will be determined during detailed design.

Lateral displacements will occur at various stages during wall construction; there will be a degree of soil relaxation as the soil is excavated for pile construction prior to placement of reinforcing cages and concreting. The excavated pile holes will be supported by bentonite slurry or temporary casings. The magnitude of these movements is difficult to calculate, however they are expected to be negligible as the piles will be discrete excavations, filled as the wall construction progresses. Subsequent excavation of the ground in front of the walls will result in lateral displacement of the walls. For cantilever walls, the maximum lateral displacement will generally be at the ground surface behind the top of the wall.

Vertical ground movement (settlement) behind the walls results from the lateral soil displacement described above. The settlements resulting from lateral movements during excavation in front of the walls are expected to be greatest immediately adjacent to the rear of the walls, reducing to negligible within a distance equivalent to the wall height from the back of the walls. These settlements will occur relatively quickly, during or immediately following wall construction.

The excavations in front of the walls are typically above the existing groundwater level and within material characterised as medium dense sands. As such groundwater drawdown settlements due to excavation in front of the retaining walls are expected to be negligible.

5.3.1 Mazengarb Road retaining walls (permanent)

Mazengarb Wall 1 runs adjacent to the south side of the existing Mazengarb Road along the residential boundary. The retained height varies from 5.5m at Chainage 190 to 1.5m at Chainage 280, and is approximately 90m long.

The estimated lateral deflections at the top of the wall are in the order of 25 to 75 mm. The vertical displacements are expected to be of a similar order, reducing to less than 5mm at approximately 5m from the back of the wall.

Mazengarb Wall 2 runs adjacent to the north side of the existing Mazengarb Road along the residential boundary. The retained height varies from 4.0m at Chainage 205 to l.5m at Chainage 330, and is approximately 125m long.

The estimated lateral deflections at the top of the wall are in the order of 25 to 50mm. The vertical displacements are expected to be of a similar order, reducing to less than 5mm at approximately 5m from the back of the wall.

5.3.2 Raumati Road retaining wall (temporary)

The Raumati Road Wall is a temporary retaining wall and is required to support an excavation adjacent to 90 Raumati Road as part of the construction of the Raumati Bridge southern abutment. The wall has an approximate retained height of 10m, and is approximately 55m long. Anchors are likely to be required due to the retained height.

For this tied back wall, lateral deflections are expected to be greatest near the base of the excavation. The estimated lateral deflections at the base of the excavation are in the order of 20 to 40mm. The vertical displacements are expected to be approximately 20mm at 10m from the back of the wall, reducing to less 5mm at around 30m from the face.

5.4 Combined settlements

The settlements estimated from the above sources have been combined to estimate the total settlements from the proposed Expressway. The separate settlement components and total settlements are plotted at the representative cross-section locations, refer Appendix 35.F.

The total settlements calculated at the representative sections have been used in combination with the settlement versus groundwater drawdown curves to interpolate the total settlements along the proposed Expressway. These are presented on the Total Settlement Contour Plans, refer Drawings GT-SE-150 to 161 in Appendix 35.G and in Technical Appendices, Report 35, Volume 5. The total settlements include the mechanical settlements from retaining walls.

The total settlements have been estimated following completion of construction, where primary settlements are expected to be generally complete. The settlements are relatively large magnitude (in the order of 200mm or greater) within the road embankment footprint where peat deposits are present. The groundwater drawdown settlements, from either excavating and replacing or preloading and surcharging the peat deposits, govern the settlements 5 to 10m beyond the road embankment footprint.

For a 3m thick peat deposit, settlements of 12.5mm extend 70m from the edge of the embankment footprint. Relatively small settlements of between 5mm and 12.5mm extend up to 200m from the edge of the embankment footprint.

The total settlement contours indicate the sensitivity of the total settlements to the thickness of the peat deposits present. The predicted settlement extent and magnitude increases as the peat thickness increases.

6 Effects assessment

6.1 Effects overview

This section presents the assessment of effects based on the estimated settlements detailed in Section 4. The impacts on the main features of the existing built environment have been assessed, including buildings, services and transport infrastructure.

The predicted settlements are generally less than 25mm beyond the edge of the earthworks. In areas of deeper peat deposits (3.5m thick and above), the predicted settlements are in the order of 25 to 50mm up to 20m from the earthworks footprint, reducing to less than 25mm beyond this. Based on these relatively small estimated settlements, the assessed effects on the existing buildings, services and transport infrastructure adjacent to the proposed Expressway are expected to be low. The actual settlements and associated effects will be monitored, as detailed in CEMP Appendix J, Volume 4 to confirm this assessment.

6.2 Effects on buildings

The building effects have been assessed for residential, commercial and industrial buildings, as described below. The Public Works Act 1981 covers these buildings where they are affected by settlements as a result of the proposed Expressway.

6.2.1 Residential buildings

The building effects have been assessed using the methodology outlined in Section 3.8. The predicted settlement profiles have been compared against the Building Damage Criteria. For buildings located less than 10m from the earthworks extent, each dwelling has been assessed based on the settlement profile shown on the Total Settlement Contour Plans. Plots of the resulting Building Damage Categories are presented in Appendix 35.H. All of the residential buildings are assessed to have a 'negligible' building damage category as defined in Table 10.

The existing residential dwellings are located where estimated settlements are less than 25mm and typically less than 12.5mm. As such, the estimated differential settlements resulting from the variable nature of the peat deposits are relatively small. These total and differential settlements are consistent with the assessed 'negligible' effects.

There are a number of inherent uncertainties within the settlement predictions. There is a risk that the actual settlements will exceed the predicted values. If the predicted values are exceeded, the dwellings with the greatest potential to be affected by settlements are summarised below:

- Dwellings within 20m of the proposed peat treatment extents,
- Dwellings adjacent to new stormwater features with predicted groundwater drawdown of greater than 0.2m,

- Dwellings in areas where the predicted settlements are greater than 12.5mm, including (as a precautionary measure) 10m beyond the predicted 12.5mm settlement contour.

It is recommended that these dwellings be inspected prior to construction commencing to identify any pre-existing defects or sensitive features. These buildings are proposed to be inspected periodically during critical phases of construction. The proposed monitoring regime is detailed in Section 6.

6.2.2 Commercial and industrial buildings

For the commercial and industrial buildings identified in Section 2.4.2, a preliminary structural assessment has been undertaken to determine the potential building damage. This has been based on the method outlined in Section 3.8, and does not consider the foundation form. The building effects assessment is summarised in Table 12.

Table 12 – Commercial and Industrial Buildings Effects Assessment

Building ID	Location	Building Damage Category1
1	20 Manchester Street, Paraparaumu	Negligible
2	18 Manchester Street, Paraparaumu	Negligible
3	16 Manchester Street, Paraparaumu	Negligible
4	12 Manchester Street, Paraparaumu	Negligible
5	11 Sheffield Street, Paraparaumu	Negligible
6	13 Sheffield Street, Paraparaumu	Negligible
7	15 Sheffield Street, Paraparaumu	Negligible
8	17 Sheffield Street, Paraparaumu	Negligible
9	31 Milne Drive, Paraparaumu	Negligible
10	27 Milne Drive, Paraparaumu	Negligible
11	23 Milne Drive, Paraparaumu	Negligible
12	11 Kodax Place, Paraparaumu	Negligible
13	106A Kāpiti Road, Paraparaumu	Negligible
14	106B Kāpiti Road, Paraparaumu	Negligible
15	104 Kāpiti Road, Paraparaumu	Negligible
1) Building Damage Category is defined in Table 10 and based on Burland 1997.		

The buildings outlined in Table 12 are assessed to have a ‘negligible’ building damage category, however further assessment is required due to the proximity of these buildings to the proposed Expressway and the sensitivity of these buildings. It is proposed these buildings are individually assessed during detailed design, considering the specific structural foundations and soil conditions.

6.2.3 KCDC wastewater treatment plant

The settlements at the KCDC Wastewater Treatment Plant are estimated to be less than 12.5mm. These assessed settlements are based on limited geotechnical investigation data at this site, and there is the potential that the actual settlements are greater than the predicted. There are a number of sensitive buildings and structures, including concrete tanks and pipe network, which have the potential to be affected by settlements. Therefore, a detailed assessment of these structures is proposed, including confirmation of the structural forms and soil conditions across the site.

Discussions are on-going between the Expressway Alliance and KCDC over the potential settlements and potential mitigation measures required. The detailed assessment and development of appropriate monitoring and mitigation measures will be undertaken as part of the proposed Expressway detailed design.

6.2.4 Waikanae Christian Holiday Camp (El Rancho)

The Waikanae Christian Holiday Camp is not within the area of predicted settlements.

For the buildings identified in Table 5 as Type A and considered sensitive to differential movements, it is recommended that these be inspected prior to construction commencing to identify any pre-existing defects or sensitive features and again following completion of construction.

6.2.5 Properties within the designation

There are a number of existing residential buildings within the proposed construction designation. Some of these buildings are not within the proposed final designation and are likely to remain intact following construction. Where these buildings are outside the earthworks extent, the settlement effects have been assessed following the methodology adopted for residential buildings (refer Section 5.2.1).

The settlement effects on these buildings have been assessed as 'negligible'.

6.3 Effects on services

6.3.1 General services

Services may be impacted by settlements due to potential changes in grade and horizontal strain (i.e. elongation). The sensitivity of a service to these changes is dependent on the type of service, construction material, joint type and the age and condition of the service.

The predicted total settlement contours have been combined with the as-built service drawings to show the potential settlement effects on the services, refer Drawings GT-SE-200 to 232 in Appendix 35.I and in Technical Appendices, Report 35, Volume 5.

The services that are located below the footprint and founded above the base of the peat deposits will require relocation or active protection due to either the settlements effects or physical construction works. Where preload and surcharge is adopted as the peat treatment methodology, the predicted settlement magnitude and rate of change within the earthworks extent is significant. In areas where the peat is to be excavated and replaced, the excavation works will impact the services. The services located below the peat deposits or in areas where peat deposits are not present will not be affected by settlements.

The services located outside the proposed earthworks extents are likely to be subject to relatively small changes in grade and horizontal strain, as indicated on the settlement effects plans.

Discussions are on-going with all of the service providers regarding the existing condition of their assets, their ability to tolerate the predicted settlement values and monitoring and mitigation options. Many of the services require relocation and or active protection measures regardless of the estimated settlement effects.

6.3.2 Vector Gas transmission pipeline corridor and delivery point station

The Vector Gas pipes are to be relocated as part of the Project. The Project team and Vector Gas are currently assessing the relocation options and likely timing of these works. Any potential settlement effects will be addressed as part of the relocation design.

6.3.3 Transpower Bunnythorpe to Haywards A and B Transmission Lines

There are a number of Transpower transmission towers located in close proximity to the edge of the proposed Expressway. The tower foundations are typically grillages and expected to be founded on sand deposits based on historical construction methods. Therefore, the settlement effects are expected be negligible.

It is recommended that a detailed assessment of the existing tower foundations be undertaken in areas where settlements are predicted. As part of this assessment, site investigations will be required to determine the as-built foundations and soil conditions.

The Expressway Alliance is in on-going discussions with Transpower, and some of the towers may require either foundation strengthening or relocation as a result of the proposed physical works. Any foundation investigations and potential mitigations will also be addressed.

6.4 Effects on transport infrastructure

6.4.1 Local road network

The effects of the predicted settlements and subsequent changes in road gradients have been assessed for the road network.

The effects on the local roads outside the proposed construction designation are assessed as negligible, with all changes in grade less than 1 in 2000.

The proposed Expressway crosses over several existing local roads, in these locations the bridge approach embankments typically rise 7.0m above the local road. Construction of the bridge crossings will require works to be undertaken adjacent to the abutments and the local roads will be re-surfaced following construction, where required. This re-surfacing will remediate any settlements that have occurred.

6.4.2 North Island Main Trunk (NIMT) railway

The NIMT Railway is located close to the alignment at each end.

At the southern end, the NIMT Railway is not within the area of predicted settlements. Therefore, the settlement effect on the railway line is considered to be negligible. The proposed settlement monitoring will be used to confirm no detectable settlements extend to the railway.

At the northern end, localised groundwater drawdown is evident on the 3-dimensional regional model. The drawdown is calculated to result in settlement of less than 10mm at the railway line. This is based on limited geotechnical investigation data and the coarse regional scale groundwater modelling. A detailed assessment of potential effects on the NIMT at the northern end of the project is proposed. The Expressway Alliance will work with KiwiRail to develop appropriate mitigation strategies if required. Settlement monitoring will be undertaken to confirm the effects are within the agreed range.

7 Monitoring and mitigation

Monitoring of the actual ground settlements and the resulting effects will be undertaken to confirm the estimated settlements and the predicted effects of these settlements. Groundwater monitoring will be carried out to confirm the predicted groundwater drawdown, which has been used to estimate the settlement.

The monitoring will be used to refine the settlement predictions. The results will serve as a trigger to require more comprehensive monitoring and/ or implementation of mitigation measures if required.

This section describes the proposed settlement monitoring regime philosophy and the potential mitigation options available.

The Settlement Effects Management Plan (CEMP Appendix J, Volume 4) describes the proposed settlement monitoring and mitigation measures in detail. The Settlement Effects Management Plan (CEMP Appendix J, Volume 4), along with the Groundwater (Level) Management Plan (CEMP Appendix I, Volume 4), form part of the Construction Environmental Management Plan (CEMP, Volume 4) for the proposed Expressway.

7.1 Monitoring

This section details the proposed settlement monitoring regime. This monitoring regime provides a method for measuring the actual settlements and the resulting effects. Monitoring is required prior to construction, during construction and following construction to provide a comprehensive assessment of effects. The measured settlements and resulting effects will be compared with the predicted values. The settlement predictions will be calibrated as the monitoring results become available, and the assessment of potential effects updated.

The settlement monitoring outlined in this section is proposed to extend beyond the earthworks extent and the expected area of resulting effects. It does not cover settlement monitoring required for the embankment construction control (i.e. to determine the surcharge duration and/ or to predict the long-term pavement performance).

7.1.1 Survey of general monitoring points

A series of survey marks will be installed and regularly monitored using conventional vertical level survey equipment to provide information to compare to the settlement estimates.

The framework marks will extend out from the proposed Expressway and be placed, as far as practical, to match with the cross sections that have been used for the settlement estimates. The number of marks at each cross section will depend on the location of buildings or other features relative to the section (i.e. where there are more buildings there will be more frequent marks and where there is open land the spacing of marks may be increased) and access to those locations for surveying. Marks will be placed at specific stormwater features where groundwater drawdown is predicted (refer Assessment of Groundwater Effects). The marks will be placed to coincide with the groundwater level monitoring where possible.

In addition to the above, survey monitoring marks will be placed on or around building or features that are considered to be particularly sensitive. The number and layout of these marks will be specific to each building or feature.

The framework marks will serve as the main monitoring points. The framework marks will be placed as detailed below:

- Along the cross-sections used for settlement predictions as far as practical. The marks will extend out from the proposed Expressway, where settlements are expected to be greater than 12.5mm. Typically 2 – 4 marks will be installed per cross-section.
- Adjacent to stormwater features where groundwater drawdown of greater than 100mm is predicted.
- KCDC Wastewater Treatment Plant.
- At buildings identified in the course of detailed design.
- Additional marks will be placed in areas where buildings are located close to the proposed Expressway and in areas where the settlement predictions extend beyond the proposed Expressway footprint.

The proposed framework marks are identified on the Settlement Monitoring Plans (refer CEMP Appendix J, Volume 4).

Intermediate marks may be installed between and around the framework marks to provide additional detail as required and to allow level traverses to be undertaken.

If required, a series of datum points will be established for the later surveys. These will be located well outside the area expected to be affected by the settlements and will be protected.

The framework marks will be installed initially and monitored for vertical movement with 13 sets of baseline values taken during the year prior to the proposed Expressway construction commencing. The 13 sets comprise the initial installation survey and the subsequent survey rounds on a monthly basis.

The ongoing frequency of monitoring will then vary depending on the stage of construction. At the start of the Project construction, each framework mark will be monitored for vertical movement on a quarterly basis.

As the active construction stage starts to affect the relevant section, all marks will be monitored monthly for vertical movement. For this Project, 'active construction' can be defined as:

- Starting when earthworks commence within 500m of a particular location and ending when pavement construction is complete at that location, and
- Starting when excavation in front of a retaining wall comes within 50m of a section and ending when the permanent wall supports are in place beyond a distance of 50m.

Once the active construction for each section is complete, the monitoring can then reduce to the pre-active construction frequency (i.e. quarterly monitoring for all marks) if the results indicate that the settlements and effects are within an acceptable range. Following a six month period of this quarterly monitoring and if results indicate that the settlements and effects are still within an acceptable range, then the framework marks will be monitored on a six month basis for an additional period of at least 2 years.

The survey monitoring is summarised in Table 13.

Table 13 – Survey Monitoring Regime

Project Phase	Vertical Survey Monitoring Frequency of Framework Marks
Preconstruction	Monthly for 12 months
During Construction	Quarterly
During Active Construction	Monthly
Post Active Construction (1)	Quarterly for 6 months, reducing to half yearly

1. 'active construction' can be defined as:
   - Starting when earthworks commence within 500m of a particular location and ending when pavement construction is complete at that location, and
   - Starting when excavation in front of a retaining wall comes within 50m of a section and ending when the permanent wall supports are in place beyond a distance of 50m.

If the monitoring results indicate the movements are outside the expected range, or if there are other reasons for concern, then the monitoring frequency and/ or extent can be increased to cover those areas of concern. For example, the quarterly monitoring of framework marks pre and post active construction could be increased to monthly and/ or intermediate marks installed for monitoring. The number of marks and frequency of monitoring can be modified to address any specific concerns identified.

7.1.2 Building condition assessments

Individual structural condition assessments of buildings will be carried out as follows:

- Dwellings within 20m of the proposed peat treatment extents.
- Dwellings adjacent to new stormwater features where predicted groundwater drawdown is greater than 0.2m (as identified in Assessment of Groundwater Effects).
- Dwellings in areas where the predicted settlements are greater than 12.5mm, including (as a precautionary measure) 10m beyond the predicted 12.5mm settlement contour shown on the drawings in Appendix 35.F.
- KCDC Wastewater Treatment Plant.
- El Rancho (buildings identified in Table 4 as Type B).
- Specific buildings identified in the course of detailed design.

The initial assessment will comprise an inspection of each building and significant structure on the property to establish and record its condition. Each assessment will produce a written description including photographs of any existing damage and a copy of this report will be provided to the owner. These assessments will be carried out prior to the commencement of the earthworks, excavation and retaining wall construction. These assessments will provide a baseline of the condition of each building.

In addition, monthly visual assessments of the following buildings will be carried out during the 'active construction' phase of the Project ('active construction' is defined above):

- Dwellings where the total settlements are estimated to be greater than 25mm.
- Dwellings where the predicted Building Damage Category is greater than 'negligible' (noting that there are none in this category at this stage).
- KCDC Wastewater Treatment Plant.
- All other specifically identified buildings.

The purpose of the assessment will be to look for any evidence of effects, with reference to the initial condition (baseline) survey. If mitigation is required, options available are outlined in Section 6.2 below.

Assessments of other buildings, or on a more frequent basis, will also be carried out if the monitoring indicates that there may be significant settlement effects. All inspections would be subject to the approval of the owner to enter their property.

It is also proposed that the following dwelling types and specific buildings be the subject of level surveys on a monthly basis during the 'active construction' phase of the Project.

- KCDC Wastewater Treatment Plant.
- Specific buildings identified in the course of detailed design.
- The NIMT Railway at the northern end of the project, if detailed analysis indicates it is warranted.

The purpose of the level survey will be to provide a basis for evaluating the rate of any movement and to enable a correlation with the visual survey. If mitigation is required, possible options for action are discussed above.

7.1.3 Retaining wall monitoring

Embedded retaining walls will be specifically monitored for movement using survey monitoring. These values will be compared to the estimated values and if the results indicate movements greater than those anticipated the mitigation measures outlined in Section 6.2 may be implemented. The locations for the instrumentation and trigger levels for action will be determined during detailed design.

7.1.4 Services monitoring

In addition to the survey marks monitoring described above, CCTV inspections of some stormwater and wastewater services will be carried out to assess the effects of the settlements. For stormwater and wastewater services identified as being susceptible to damage or particularly critical, an initial preconstruction CCTV inspection will be carried out to provide a baseline for assessing any future damage. As the construction progresses, additional CCTV inspections may be carried out depending on the results of the survey monitoring and feedback from service providers.

For other services identified as being susceptible to damage or particularly critical, visual inspections may be undertaken by excavating to expose the service if required.

7.2 Mitigation of effects

Mitigation measures are not expected to be required based on the Settlement Effects Assessment presented in this report. There are mitigation measures available that can be implemented should the measured settlements or their effects require it. This section outlines a variety of mitigation measures that could be used. The Project team will determine the most appropriate measures for each specific case. The measures will be implemented in accordance with the Conditions and in agreement with the Greater Wellington Regional Council.

7.2.1 Road embankment settlement contingency measures

Consolidation settlements of the underlying peat deposits will occur due to increased loading from the road embankments. The road embankment construction, and consequently the modification of the underlying materials, will result in short-term and long-term changes to the shallow groundwater levels. Lowering of groundwater levels beneath the road embankments is expected to result in further consolidation settlements. These settlements are expected to be of relatively large magnitude within the road embankment footprint, with only limited settlement expected beyond it.

If the actual settlements beyond the earthworks footprint are of greater magnitude and/ or extend further beyond the footprint, the following actions may be taken:

- Change the ground improvement approach where the proposed Expressway is constructed over peat deposits. The two proposed treatment methods are 1) Excavate and Replace and 2) Preload and Surcharge. These methods are interchangeable.
- Modify the ground improvement approaches, for example:
  - For the Preload and Surcharge method, a more permeable material may be used for the starter/ drainage layer, to reduce the “damming” effect of compressed peat on the groundwater flows across the alignment.
  - For the Excavate and Replace method, the length and drained duration of the temporary excavation may be limited, to reduce the magnitude and extent of groundwater changes.

- Use alternative ground improvement approach for localised areas i.e. a load transfer platform combined with foundations, to avoid excavating or loading the underlying peat.
- Reduce the embankment footprint over localised areas. This may be achieved by using geogrid reinforcement to allow steepening of embankment slopes, to increase the distance between the construction activity and the sensitive items.

7.2.2 Groundwater drawdown settlement contingency measures

Consolidation settlements of the underlying peat deposits will result from groundwater lowering. Lowering of the groundwater level will occur due to construction of the road embankment (as described above) and at unlined stormwater features. In addition, short-term groundwater lowering will occur due to temporary excavations. The groundwater drawdown contingency measures are detailed in Section 4.1 of the GWMP, and summarised below:

- Change to construction methodology i.e.
  - Alternative peat treatment (as described above)
  - Lining (temporary and/ or permanent) of cuts below the groundwater level; or
  - Limit the length and drained duration of temporary excavations.
- Local cut off (clay bund or slurry wall).
- Recharge trenches/ walls.

7.2.3 Retaining wall settlement contingency measures

Lateral movement of embedded retaining walls (as the ground is excavated in front of them) will result in localised settlement of the ground above. These settlements occur relatively quickly, during and immediately following wall construction. If the retaining wall deflections exceed the anticipated limits, a review of the design will be undertaken to assess the increased load in the piles. If required, the following actions may be taken:

- Remove surcharge close to the wall.
- Place a berm in front of the wall.
- Reduce the extent of temporary over excavation in front of the wall.
- Install additional or stiffer piles.
- Install props or ground anchors.

7.2.4 Building damage repair measures

Non-structural effects

If the proposed Expressway works result in building damage, then general repairs may be required. These repairs may include repointing of brickwork, repainting and redecorating. In severe cases, repairs may require some partial re-building work, although this is considered highly unlikely. The timing of such repairs would depend on the stage of construction, the building owner's preference and the degree of damage.

7.2.5 Structural effects

The settlement effects assessment has not identified any buildings with a Building Damage Criteria of greater than 'negligible'. As such, structural building damage is highly unlikely and not envisaged on this Project. However, if any effects of a structural nature are identified during the course of the monitoring programme then a detailed evaluation will be required by a Structural Engineer. Any recommendations for repair and an increased level of monitoring arising from this evaluation will then be implemented. In extreme cases where local repair or re-construction is not sufficient, then additional measures such as underpinning or strengthening may be required.

In the event of a "substantial injurious affection" to a person's land resulting from the construction of the MacKays to Peka Peka Expressway, section 63 of the Public Works Act would entitle that person to compensation.

7.2.6 Services repair measures

The services that are located below the footprint and founded above the base of the peat deposits will require relocation or active protection due to either the settlements effects or physical construction works. These works will be agreed with the service providers prior to Project works commencing.

The services located outside the proposed earthworks extents are likely to be subject to relatively small changes in grade and horizontal strain, as indicated on the settlement effects plans. The services outside the earthworks extents will be monitored. If this monitoring indicates damage may have occurred, a detailed investigation of the area and affected services will be promptly carried out. This assessment will include a detailed examination of the site, coordination with the relevant service providers to ascertain what effects their network is experiencing, and an assessment of what remedial action is required. Any remedial works will be carried out as soon as possible. If the investigation reveals no immediate damage, the services will continue to be monitored closely until all parties are satisfied no damage has occurred.

There are a number of measures available to mitigate damage to services. The specific measures selected would depend on the type of service, location and severity of the damage and agreement with the service provider. If required, the following actions may be taken:

- Permanently divert the service through another nearby service and abandon the original service line (the capacity of the nearby service would need to be checked).
- Temporarily divert the service and repair the original service.

- Expose the service and undertake a repair.
- Replace the service. In cases of severe damage, a length of the service may be replaced.

7.2.7 Transport infrastructure repair measures

The effects on the local roads outside the proposed construction designation are assessed as negligible, with the predicted changes in grade being relatively small. Settlements may result in grade changes and differential movements. If the measured effects are greater than anticipated, the following actions may be taken:

- Overlay the road surface to raise to the previous level and re-shape any differential movements.
- Reconstruct the kerb and channels, and footpaths to mitigate changes in grade and/ or differential settlements.
- Install additional drainage if new areas of ponding are identified.

The effects on the NIMT Railway at the northern end are expected to be able to be remediated by regular maintenance track relevelling. This will be agreed with KiwiRail if necessary once more detailed assessments have been undertaken.

7.3 Reporting

The settlement monitoring and resulting effects will be reported to Greater Wellington Regional Council.

Preconstruction monitoring will be carried out as described above in Section 6.1 and reported following the final set of data, prior to the start of construction. This data will be factual in nature, with assessment only required for anomalous results. The report will form part of the input for the construction phase assessments.

The monitoring data will be processed and compared to the design analyses. Once construction starts, the data will be used to reassess the building damage categories and these categories will then be compared to the results in the settlement assessment report. The effects on services will also be assessed from the settlement gradients. If this reassessment indicates that the damage category has increased by a significant amount then additional analyses or more frequent monitoring may be required and the affected buildings identified for potential mitigation work. Similarly, an increase in estimated effects on the services will require additional review and potentially amended monitoring and mitigation. Consideration may also need to be given modifying the construction approach to reduce ground settlements, if groundwater drawdown is greater than expected due to ground excavation.

Reporting will be determined by the stage of construction and actual results. During the active construction stage it is anticipated that initial internal review of monitoring results will take place shortly after receipt of the processed data. As long as the results show no significant anomalies or assessed significant increased risk to buildings, these monitoring results would be presented on a quarterly basis. If there are any significant anomalies or significantly increased risk to buildings, then following a more detailed review of the data, those parties would be notified and mitigation measures agreed. The results of this more detailed work and the outcomes, along with the agreed way forward will then be reported.

The post active construction stage results (quarterly and six monthly) will be reviewed and reported shortly after receipt of the processed data. Where any significant anomalies or assessed significantly increased risk to buildings occurs, then the reporting will follow the process as described above for active construction.

8 Summary and conclusions

The potential ground settlements associated with construction and operation of the proposed Expressway have been estimated. The sources of settlement considered include: direct loading from the road embankments, groundwater drawdown associated with the modification of the foundation materials below the road embankments, groundwater drawdown associated with new stormwater features, retaining walls and vibrations.

The majority of the settlement results from consolidation settlements from construction of the new road embankment and this governs the settlement below the proposed Expressway footprint. The settlements away from the proposed Expressway result predominately from groundwater drawdown settlements due to modification of the foundation materials below the proposed Expressway. Over the 10m immediately adjacent to the proposed Expressway footprint, settlements result from a combination of the two sources.

The predicted settlements are generally less than 25mm beyond the edge of the earthworks. In areas of deeper peat deposits, the predicted settlements are in the order of 25 to 50mm up to 20m from the earthworks footprint, reducing to less than 25mm beyond this.

The effects of these estimated settlements on existing buildings, services and transport infrastructure have been assessed. The assessed effects are summarised below:

- The existing residential buildings are located where estimated settlements are less than 25mm, and typically less than 12.5mm. The settlement effects on residential buildings are assessed to be ***low***.
- The settlement effects on the commercial and industrial buildings identified in 2.4.2 are low. For the buildings that have been identified, based on the proximity to the alignment and the potential sensitivity of these structures to settlement effects, individual assessments will be undertaken during detailed design to confirm the assessed 'negligible' Building Damage Category.

- The services that are located below the footprint and founded above the base of the peat deposits will require relocation or active protection due to either the settlements effects or physical construction works. The services located outside the proposed earthworks extents are likely to be subject to relatively small changes in grade and horizontal strain, as indicated on the settlement effects plans. Settlement effects on services beyond the Project footprint are assessed as being ***low***. Discussions are on-going with all of the service providers regarding the existing condition of their assets, their ability to tolerate the predicted settlement values and monitoring and mitigation options. Some will inevitably need to be realigned, and others will be monitored and repaired or protected as agreed with the owner.
- The effects on local roads have been assessed as ***low***.
- Effects on the NIMT are assessed as low. Any relevelling required will be agreed with KiwiRail.

The proposed settlement monitoring regime provides a method for measuring the actual settlements and resulting effects. The monitoring will include building condition assessments for structures within a conservatively assessed corridor extending beyond the zone where 12.5 mm settlement and/or 0.2m groundwater drawdown is predicted, together with measurement and reporting of ground settlement and groundwater levels. Mitigation measures are available that can be implemented should the measured settlements or their effects require it.

9 References

Bradshaw, J. Geotechnical Factual Report: Technical Report 37, Volume 3 of the MacKays to Peka Peka Expressway Project AEE.

Burland, J.B. (1997), “Assessment of risk of damage to buildings due to tunnelling and excavation”, Earthquake Geotechnical Engineering, Ishihara (ed.), Balkema, Rotterdam, 1997.

Coe, L. Geotechnical Interpretive Report: Technical Report 36, Volume 3 of the MacKays to Peka Peka Expressway Project AEE.

Coe, L. Settlement Effects Management Plan: CEMP Appendix J, Volume 4 of the MacKays to Peka Peka Expressway Project AEE.

Construction environment management plan, Volume 4 of the MacKays to Peka Peka Expressway Project AEE.

France, S. & Michaelsen, J. Assessment of Groundwater Effects: Technical Report 21, Volume 3 of the MacKays to Peka Peka Expressway Project AEE.

France, S., Goff, P. and Utting, M. Groundwater (Level) Management Plan: CEMP Appendix I, Volume 4 of the MacKays to Peka Peka Expressway Project AEE.

Opus, 1997: State Highway 1 Poplar Avenue to MacKays Crossing Scheme Opus, 2007: Stage 1 Boreholes and Trial Pits, complete copy of bore logs and variable head tests.

Opus, 1997: State Highway 1 Poplar Avenue to MacKays Crossing Scheme Assessment: Geotechnical Report. Prepared for Transit New Zealand.

Opus, 1998: Kāpiti Urban Roading Project, Geotechnical Investigations for Estimation of Peat Thickness, Factual Report, prepared for KCDC.

Opus, 1999: SH1 Poplar Avenue to MacKays Crossing: Safety Improvements, Geotechnical Assessment of Trial Embankment.

Opus, 2007: Stage 1, Raumati Rd to Te Moana Rd Site Investigation Report.

Opus, 2009: Stage 3 Geotechnical Investigations Site Investigations Report.

Whitlock, J. Assessment of Vibration Effects: Technical Report 18, Volume 3 of the MacKays to Peka Peka Expressway Project AEE.

Wilkening, S. and Whitlock, J. Construction Noise and Vibration Management Plan: CEMP Appendix F, Volume 4 of the MacKays to Peka Peka Expressway Project AEE.

Appendix A

Sector and Cross-section Location Plan

Drawing Plotted: 08 Mar 2012 03:54 p.m.

NOTES:

Original Scale (A3)

Revision.	Amendment.	Approved.	Date.
1	AEE LODGEMENT	LC	15.03.12

NZ TRANSPORT AGENCY
WAKA KOTAHI

Project:
MACKAYS TO PEKA PEKA EXPRESSWAY

Title:
SETTLEMENT CROSS-SECTIONS AND KEY SITE LOCATIONS

Document ID: M2PP-AEE-DWG

Drawing No: GT-SE-050

Rev: 1

Document No. M2PP-AEE-DWG-GT-SE-050.DWG

Drawing Plotted: 08 Mar 2012 04:07 p.m.

NOTES:

Original Scale (A3)

Revision.	Amendment.	Approved.	Date.
1	AEE LODGEMENT	LC	15.03.12

NZ TRANSPORT AGENCY
WAKA KOTAHI

Project: MACKAYS TO PEKA PEKA EXPRESSWAY

Title: SETTLEMENT CROSS-SECTIONS AND KEY SITE LOCATIONS

Status: FOR CONSENTING

Document ID: M2PP-AEE-DWG

Drawing No: GT-SE-051

Rev: 1

Document No. M2PP-AEE-DWG-GT-SE-051.DWG