NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING
2019 Pacific Conference on Earthquake Engineering
TURNING HAZARD AWARENESS INTO RISK MITIGATION
4 – 6 April | SkyCity, Auckland | New Zealand

Land use planning for Feilding, considering liquefaction hazard

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ABSTRACT

Manawatu District Council was developing a strategy for the growth and development of Feilding and has identified two growth areas on the periphery of the town. Experience from the Canterbury earthquakes highlights the importance of liquefaction hazard vulnerability and risk assessments in land use planning to ensure the resilience of future communities. Manawatu is exposed to a high level of seismicity and an evaluation of the liquefaction hazards in the proposed urban growth areas has been carried out to investigate their susceptibility to liquefaction hazard and their suitability for future urban development.

Geotechnical site investigations were carried out across the study area to provide information to better characterise the ground conditions and assess the hazard posed by liquefaction. A liquefaction assessment was carried out for the 500 years to 2500 years return period events. The liquefaction hazard is generally low in the development areas. Localised pockets of silt may be present which have the potential to liquefy, but this is not considered significant enough to preclude development of these areas. However, we recommended the land prone to the lateral spreading hazard near the Oroua River and Makino Stream should be used for less intensive land use such as rural farming or parks.

This integrated practice in land development will help us to achieve good earthquake resilience of developments. The development of less hazardous areas leads to more sustainable and resilient communities, both of which contribute to sustainable use of resources.

1 INTRODUCTION

Hazards such as earthquakes can cause severe damage and loss of life, as demonstrated recently by the 2008 Wenchuan Earthquake in China, the 2011 earthquake and tsunami in Japan and the 2010-2011 Canterbury and 2016 Kaikōura earthquakes in New Zealand. These events highlight the importance of enhancing the resilience of society to natural hazards. Planning measures provide a valuable mechanism to develop land in

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a sustainable manner and to achieve resilience. These measures range from hazard mapping and dissemination, consideration of hazard effects in zoning land, and district plan rules to guide development to improve resilience (Brabhaharan, 2000).

Manawatu District Council (MDC) in collaboration with Boffa Miskell has been preparing a strategy for accommodating residential and industrial growth areas within Feilding over the foreseeable future. The Council has identified five potential urban growth zones that lie on the periphery of the city. A Lifelines Project that was carried out for Horizons Regional Council identified at a very broad level the liquefaction potential of the elevated terrace land encompassing Precincts 1, 2 and 3 to be very low, whilst Precincts 4 and 5 have moderate susceptibility to liquefaction (MWH 2013). Opus International Consultants Ltd (WSP Opus) was commissioned by the Council in 2013 to carry out a high level liquefaction risk assessment of the proposed Precincts 4 and 5. The objective of this study was to assess earthquake geotechnical hazards of relevance to Feilding, and to define a strategic planning horizon for considering hazard effects in rezoning land for more intensive future use. This paper presents the results of the study.

2 STUDY AREA

The areas under investigation is located on the outskirts of Feilding urban area (Figure 1), to the north east (Precinct-4 Residential Development) and south (Precinct-5 Industrial Development). Both the sites lies on dominantly flat to gently undulating alluvial plains, and the land is predominantly under agricultural use with some rural-residential and industrial developments, see Figure 2.

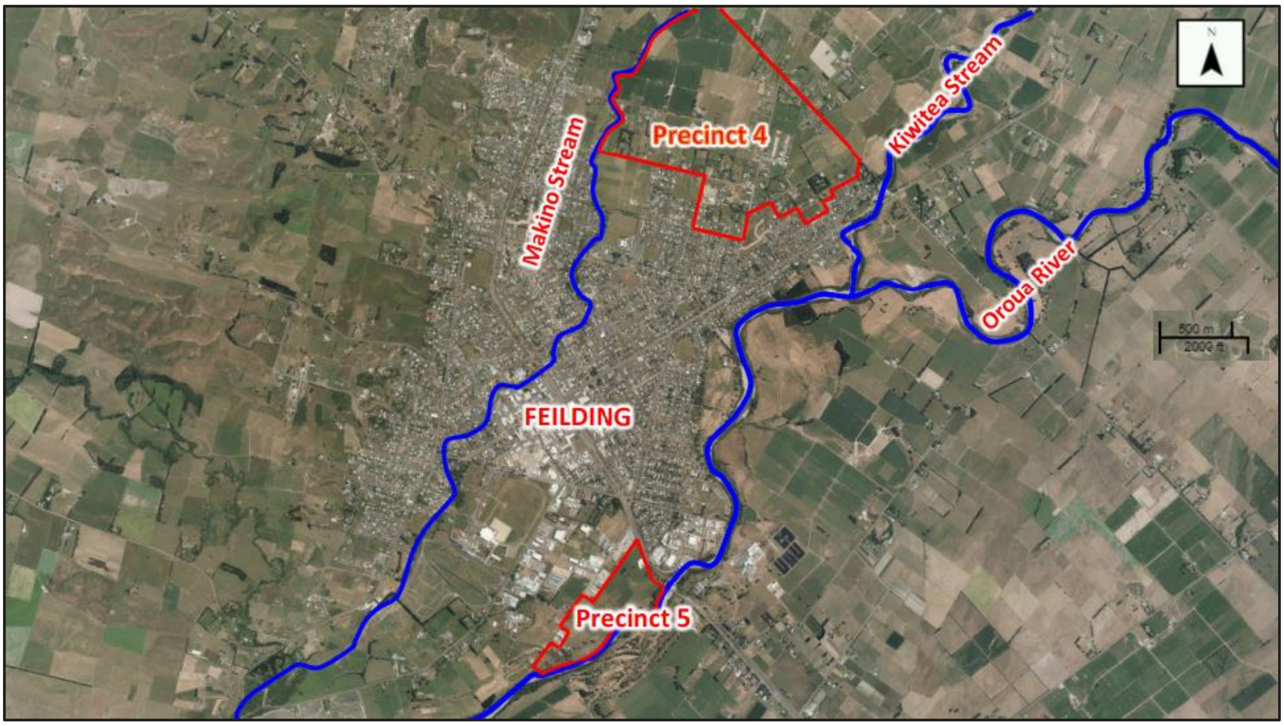

Figure 1: Site location map

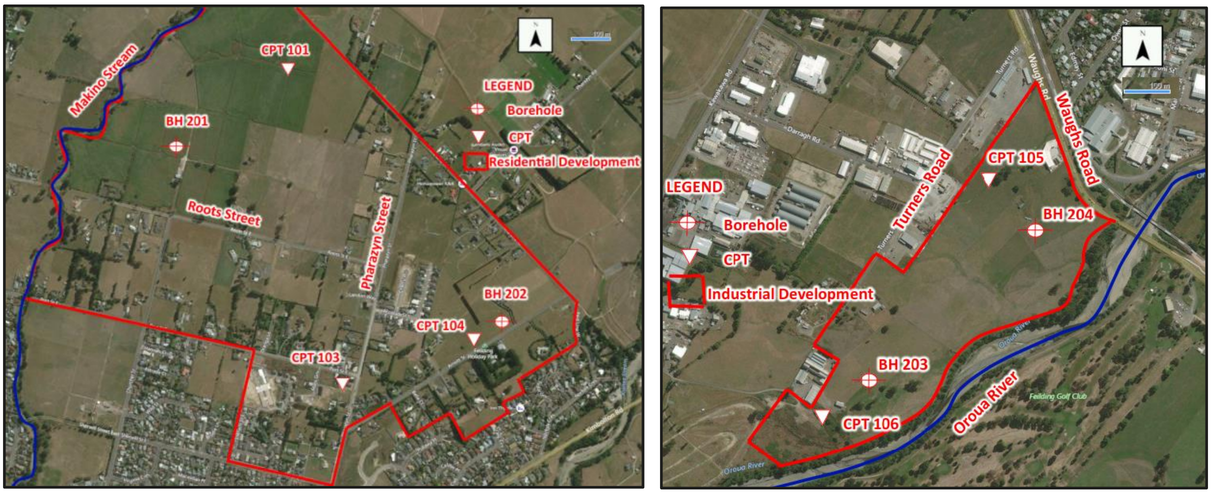

Figure 2: Maps of Precinct 4 (left) and 5 (right)

3 GEOLOGICAL SETTING

3.1 Seismicity

The plate boundary between the Pacific and Australian plates passes through Manawatu region, and consequently this region is an area of high seismicity. The forces involved in plate movement are immense and cause the rock of the Earth's crust to buckle (fold) and fracture (fault) in the general vicinity of the boundary between the plates. There are a number of active faults in the Manawatu region.

The Manawatu Region is an area of high seismicity in New Zealand. The active Wellington Fault lies approximately 25 km southeast of the Feilding Town. It presents the highest seismic hazard to the area, having a recurrence interval of between 500 and 770 years with a magnitude estimate of 7.6 ± 0.3 (Begg et al, 2002).

The Manawatu Region also comprises the Ruahine Fault, Mohaka Fault, Mt Stewart-Halcomb Fault and a number of smaller faults (GNS, 2018). Together, these faults represent earthquake sources that contribute significantly to the seismic hazard in Feilding.

The site class in accordance with NZS1170.5:2004 is assessed to be Class D given the significant thickness of alluvial deposits at the site which exceeds 60 m. Three earthquake events at 500, 1000 and 2500 year return periods were used in the liquefaction analyses. The peak ground accelerations for each event were derived in accordance with New Zealand Earthquake Loading Standard, NZS 1170.5:2004 and given in Table 1.

Table 1: Summary of Peak Ground Acceleration

Return Period	Peak Ground Acceleration
1 in 500 year	0.41g
1 in 1000 year	0.54g
1 in 2500 year	0.75g

3.2 Geology

The Feilding area is underlain by Holocene age and late Pleistocene age river deposits (GNS, 2002). The Precinct-4 (Residential Development Area) is underlain by late Pleistocene age river deposits comprising poorly to moderately sorted gravel with minor sand and silt underlying terraces which includes minor fan deposits and loess.

The Precinct-5 (Industrial Development Area) is underlain by late Holocene age river deposits comprising alluvial gravel, sand, silt, mud and clay with local peat which includes modern river beds. Much of Fielding is located on young terrace alluvium deposited by the Oroua River and the Makino Stream.

3.3 Site Investigations

Geotechnical site investigations have been carried out across the study area to provide information to better characterise the ground conditions and assess the geotechnical issues, particularly relating to the hazard posed by liquefaction. The investigations were carried out in October 2013, and comprised the following:

- Four boreholes, to depths of 20 m, with in-situ Standard Penetration Tests (SPT) carried out at 1.5 m depth intervals.
- Downhole Shear Wave Velocity (SWV) surveys in two boreholes.
- Six Static Cone Penetration Tests (CPTs), to depths of between 1.7 m and 3.8 m, with further penetration retarded by dense gravels.
- Laboratory testing of samples recovered from the boreholes.

The site investigations show the alluvial deposits in both the study area consists of thin surficial layers of soft to firm silts and clayey silts that are underlain by dense to very dense alluvial gravels, with a sandy matrix and some interbedded silt layers. There is likely to be greater thickness of loose alluvium close to the streams and rivers.

Figure 3: Core box photo of Borehole BH201 from 0m to 12.7m

3.4 Groundwater Conditions

The Makino Stream and Oroua River are likely to have a strong influence on regional groundwater conditions. Because of the flat terrain, infiltration could also have an important effect on groundwater.

The groundwater levels recorded during the site investigations generally ranged from 1.1 m to 3.2 m depth below ground level. These results are consistent with longer term static groundwater levels recorded in the wider Feilding area obtained from Horizons Regional Council, which show that the groundwater table lies approximately 1 m to 4 m depth below ground level in Precinct 4, and 1 m to 3 m depth below ground level in Precinct 5.

4 LIQUEFACTION ASSESSMENT

4.1 Liquefaction Susceptibility

The liquefaction potential of soils was assessed with the aid of CLiq, version 1.7.1.6 and LiqIT, version 4.7.7.1 (GeoLogismiki Software, 2006). This software uses cyclic liquefaction and cyclic softening evaluation methods to determine whether liquefaction is likely in a particular earthquake event and estimates the resulting ground subsidence. The Idriss & Boulanger (2008) method was used to assess liquefaction with CPT results and the NCEER (1998) method used to assess liquefaction with SPT and SWV result. The method proposed by Ishihara and Yoshimine (1992) was used to estimate the resulting ground subsidence.

The liquefaction analyses showed the pocket of loose silt in the surficial layer (generally 0.5 m to 2 m thick) to be susceptible to liquefaction in all three return period events. The gravels layers underneath the surficial layer are typically dense to very dense, and do not exhibit liquefaction potential apart from occasional thin layers of soft silt. The gravel layers extend greater than 20 m depth below ground level in the proposed growth areas.

There was no difference in the thicknesses of layers assessed to liquefy between the 1/500, 1/1000 and 1/2500 year return period events. This is because soil layers susceptible to liquefaction have a low density such that they are likely to liquefy in earthquakes with a PGA less than that from a 1/500 year return period level. Larger events with greater ground shaking will only lead to limited additional liquefaction.

The potential for liquefaction induced ground damage will be strongly influenced by the groundwater table depth and thickness of liquefiable soils. The site investigations show the liquefiable soils to be typically 0.5 m to 2 m thick in both the development areas, with groundwater to be between 1.1 m to 3.2 m depth. The areas adjacent to the stream and river can be expected to comprise looser alluvial deposits and hence may be prone to a greater liquefaction susceptibility. The indicative thickness of soil layers likely to experience liquefaction at the localised area during different return periods is tabulated in Table 2.

Table 2: Indicative depth of soil layer likely to experience liquefaction

Location	**Test**	**Reference**	**Return Period**		
			1/500	1/1000	1/2500
Precinct-4	CPT	CPT 101	-	-	-
		CPT 103	-	-	-
		CPT 104	-	-	-
	SPT	BH 201	-	-	-
		BH 202	9.0 m – 9.6 m	9.0 m – 9.6 m	9.0 m – 9.6 m
	SWV	BH 202	2.0 m – 4.0 m	2.0 m – 4.0 m	2.0 m – 4.0 m
Precinct-5	CPT	CPT 105	2.9 m – 3.0 m	2.9 m – 3.0 m	2.9 m – 3.0 m
		CPT 106	2.0 m – 3.0 m	2.0 m – 3.0 m	2.0 m – 3.0 m
	SPT	BH 203	-	-	-
		BH 204	-	-	-
	SWV	BH 204	-	-	-

4.2 Ground Subsidence

Subsidence is the vertical downward displacement of the ground, which happens without any vertical load being applied to the ground. Liquefaction leads to subsidence as a result of the liquefied soil settling to a slightly denser state and ejection of sand with water to the surface. Widespread ground subsidence can cause areas to become more prone to flooding. Localised differential subsidence can lead to cracking and damage to structures, and affect the functionality of services, particularly gravity sewers and storm water systems.

Analysis indicates that the magnitude of expected liquefaction induced localised ground subsidence is in the range of 30 mm to 50 mm. This limited subsidence is also localised in the areas susceptible to liquefaction as discussed above. This estimate does not take into account the subsidence effects of lateral spreading.

4.3 Lateral Spreading

Lateral spreading occurs predominantly in the vicinity of free surfaces such as water courses where the liquefied soil can laterally displace towards the water course but can also occur when there is slope along which the liquefied ground can displace. This can lead to large displacements of the ground from hundreds of millimetres to a few metres.

Lateral spreading can extend to 200 m or more from water courses but is typically more severe nearer the river. In some situations it has extended 300 m to 500 m due to block sliding. This may be mainly in areas where the land can spread in more than one direction due to bends or loops in the water course. Experience from the 2010 Darfield and 2011 Christchurch earthquakes shows the ground damage due to lateral spreading reduces at a distance greater than 130 m from a river or stream (Robinson et al 2014).

Liquefaction induced lateral spreading is likely to be a significant issue, where localised liquefiable deposits are present close to the water courses such as the Makino Stream and Oroua River. Given the alluvial nature of the soils, such localised deposits are possible near these water courses, and hence may lead to liquefaction induced lateral spreading along them.

5 LAND USE PLANNING FOR GEOTECHNICAL HAZARDS

5.1 Strategic Planning Timeframe

One of the objectives of the study was to define a strategic planning timeframe for taking hazard effects into account in determining the suitability of the land for rezoning, for more intensive future use. Areas of urban expansion will have a mix of normal buildings and higher value and importance level infrastructure. Although individual buildings or infrastructure may be renewed from time to time, an area developed could potentially be in use in perpetuity, unless and until there is some major environmental or social change that leads to abandonment of the area.

A life of 50 years is traditionally assumed for normal buildings, and 100 years for infrastructure. For normal buildings of Importance Level 2 (NZS 1170.0), a 500 year return period earthquake hazard is used for ultimate state design. For higher value infrastructure, a 1,000 or 2,500 year return period earthquake is used for ultimate state design, depending on its importance.

In the Feilding area, ground shaking associated with earthquakes with a return period of 500 years is assessed to be sufficient to cause liquefaction (and lateral spreading in vulnerable areas) of the liquefaction-susceptible soft silt present. There is only limited additional liquefaction in larger earthquake events with longer return periods. Therefore, for considering urban growth, the length of the strategic planning period for the liquefaction hazards is not significant.

5.2 Planning Approach to Geotechnical Hazards

Brabhaharan (2013) suggests approaches at three levels that can be considered to avoid hazards such as liquefaction-induced ground damage, depending on the land use and the nature and extent of the hazard.

- Land Use Zoning: Extensive hazardous areas can be avoided by zoning the land prone to those hazards for less intensive land use such as rural farming or parks. This is suitable for zoning and managing the risks for future land use.
- Town or Subdivision Planning: District Plan rules can stipulate that localised effects of severe hazards, such as fault rupture, lateral spreading or landslide hazards, can be mitigated by making use of these areas within a township or sub-division for open areas such as reserves, park lands or car parking, with no buildings. This is useful to manage localised hazards in an otherwise low hazard area.
- Micro-siting: Stipulate and encourage development to avoid areas of high hazard by micro-siting buildings in safer parts of land parcels, with more hazard prone areas used for open space or parking. This is useful to manage risks in existing development areas.

5.3 Poor Foundation Conditions

The thickness of soft and compressible silt and clay deposits present is generally less than 1 m deep, and locally up to 2 m deep. The geotechnical hazards due to poor ground conditions leading to poor foundation conditions and consolidation settlement can be addressed during construction by simple traditional foundation measures. Such measures may include preloading, undercut and replacement or the use of short piles founded below these soft layers.

5.4 Ground Shaking

Buildings are designed to withstand earthquake ground shaking, which is derived for each area of New Zealand. Therefore, existing design standards cover the design of structures in these areas of Feilding, and no special measures are considered to be required to be considered as part of land use planning.

5.5 Fault Rupture

As described above, the known active faults (including Wellington Fault, Ruahine Fault and Mohaka Fault) has been inferred from available geological evidence to lie approximately 24 km to 28 km from the study area at its closest point. The Mt Stewart-Halcomb Fault not recorded on the GNS Active Faults database lies approximately 4 km to the south of Precinct 5.

Experience of the Greendale Fault rupture during the Darfield Earthquake shows ground damage occurred only over a zone up to 300 m wide from the fault. Since there is no obvious fault trace in the proposed development area, fault rupture hazard does not have any implications for land use planning and resilient infrastructure design.

5.6 Liquefaction-Induced Ground Subsidence

Limited liquefaction-induced ground subsidence is expected in the proposed growth areas. Our assessment from the site investigation results shows that the ground subsidence from the limited liquefaction is generally expected to be up to 50 mm. Differential subsidence across a building footprint will be more than 25 mm. This value of subsidence is calculated for the top 20 m of the ground.

The above differential ground subsidence can be compared to the following recommended tolerances:

- Appendix B of Building Code document B1 recommends that foundation design should limit the probable maximum differential settlement over a horizontal distance of 6 m to no more than 25 mm under serviceability limit state load combinations;

- Table 2.2 of the DBH November 2011 guidance document recommend settlement criteria for 'no foundation damage requiring structural repair' of vertical differential settlement <50 mm and floor slab less than 1 in 200 between any two points > 2 m apart.

The amounts of ground subsidence given above are not sufficient to warrant wholesale exclusions on development. It is recommended to allow development in these areas (except areas that are subject to lateral spreading as discussed below) but put in place planning rules to ensure that the development takes into consideration this low consequential subsidence from liquefaction.

Using the principle of resilience, a suitable approach will be to limit damage and / or build in a manner that any damage can be quickly and economically repaired and the building reinstated. For example, building foundations may be designed to protect the building from damage due to such limited subsidence by using short piles up to 3 m depth, or by use of foundations that are tolerant to limited subsidence and can be easily repaired after any event. Services should also be designed with the potential for subsidence in mind, such as using flexible connections along pipelines that tolerate some ground deformation.

5.7 Lateral Spreading

Land susceptible to liquefaction and lateral spreading is prone to significant risks to urban development in earthquake events. Therefore, it would be prudent to not zone for intensive development the areas susceptible to lateral spreading, such as the northwest part of precinct 4 (Makino stream) and the southern part of precinct 5 (Oroua River). Figure 4 shows the study areas and the proximity to nearby rivers and streams.

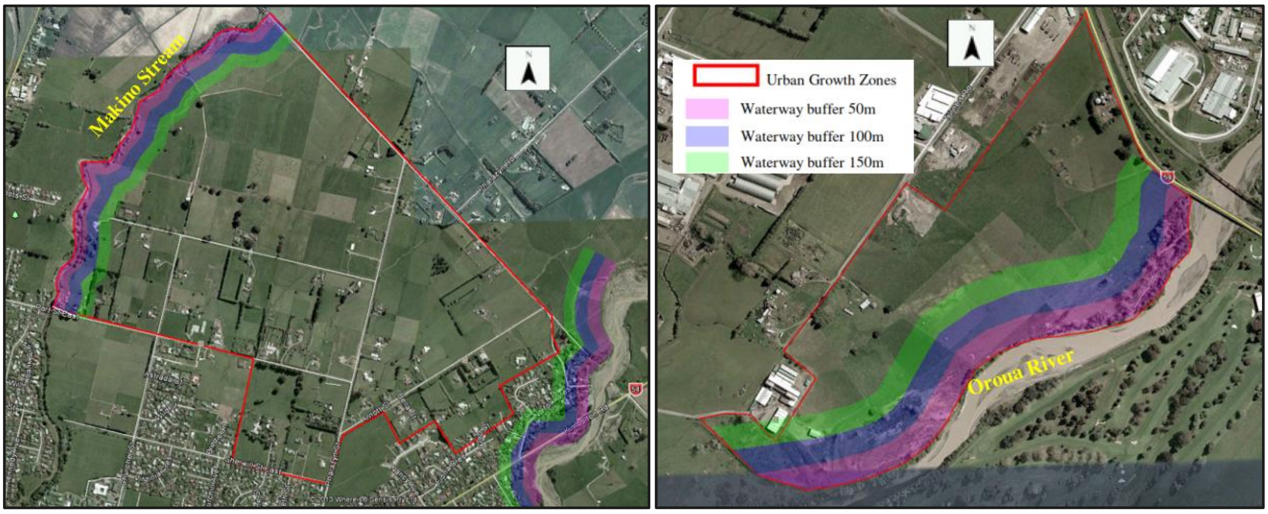

Figure 4: Proximity of waterways

These areas may be subject to liquefaction and lateral spreading and can be used for less intensive land uses such as parks and gardens or agriculture. This could be achieved by appropriate zoning of the land through district planning measures.

6 CONCLUSIONS

Early integrated focus on land use planning by town planners and geotechnical engineers is important to ensure that hazards and their consequences to the built environment are taken into consideration in zoning for urban development. This requires these professionals to work together with focus on resilience from an early stage (Brabhaharan, 2013).

Manawatu District Council's urban growth strategy identified potential growth areas on the north east (Precinct-4) and south (Precinct-5) of the town. The liquefaction hazard is generally low in the proposed development areas. There might be localised pockets of silt which has the potential to liquefy, but this is not considered significant enough to preclude development of these areas. The lands adjacent to the Oroua River and the Makino Stream which are identified as prone to lateral spreading hazards can be used for less intensive land use such as rural farming or parks.

Inappropriate land use planning leading to the development of hazardous land has been a major cause of damage in the Christchurch earthquakes; this project sets a landmark framework for land use planning considering earthquake hazards in developing urban growth strategies. Such an early focus on resilience to hazards helps avoid land subject to significant hazards being developed where alternate land is available. The development of the less hazardous areas leads to less use of resources and the built environment will be more resilient, both of which contribute to the sustainability of the development.

7 ACKNOWLEDGEMENTS

I gratefully acknowledge the permission of Manawatu District Council to publish the paper.

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