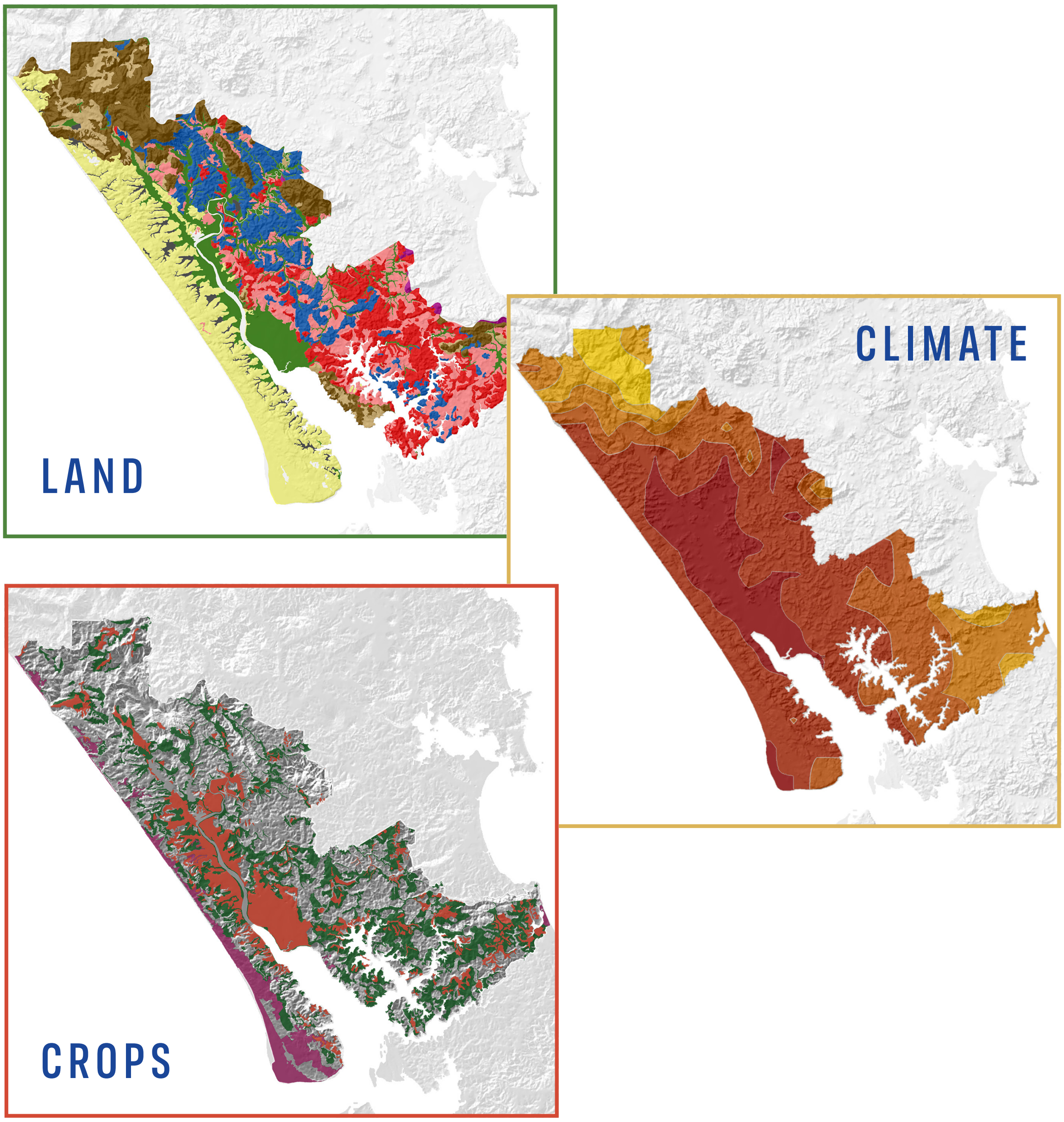
CURRENT & FUTURE CROP SUITABILITY IN THE KAIPARA DISTRICT

Prepared for Kaipara District Council May 2020



NIWA Taihoro Nukurangi
Manaaki Whenua Landcare Research
Plant & Food RESEARCH RANGAHAU AHUMĀRA KAI

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Kaipara District Council commissioned NIWA, Manaaki Whenua Landcare Research and Plant & Food Research to prepare a Topo-Climate Study for six key crops (avocado, sorghum, olives, peanuts, soybeans and hops/hemp/CBD (Cannabidiol) cannabis) in the Kaipara District. This project is one of three work streams in the wider Kaipara Kai programme.

By combining soil data from Manaaki Whenua Landcare Research and climate data from NIWA, a non-crop specific assessment of general horticulture found that of the 310,000 ha of land within the boundaries of the Kaipara District Council, approximately 44,200ha (14%) is generically suitable for horticulture. An additional 17,000 ha (5%) of land could also be suitable, although this area is susceptible to wind erosion and would most likely require appropriate management, shelter mitigation, and irrigation. In addition to these areas, a further 69,000 ha (22%) is considered suitable for arable cropping. Overall, there is good potential for horticulture in the district.

A more detailed look into the suitability of the chosen six crops showed that they present an opportunity to be grown and incorporated into cropping rotations with existing agricultural systems in the Kaipara District. Some limitations such as soils with poor drainage and shallow potential rooting depth could be mitigated with options such as artificial drainage and/or mounding along the row of horticultural crops.

Summary of soil resources:

Soil Terrains: Nine soil terrains are depicted in the Atlas of Soil Information, and each terrain represents a broad division of the landscape according to the general type of soil parent material and slope:

1. Sand country (22%): Sand country soils occur all the way up the west coast of the study area. Sand country soils become older and more weathered inland from the coast. Many soils within this terrain show high variability over short distances with some soils having a pan, so detailed site investigation is recommended.
2. Flood plains (12%): Soils on flood plains may be well suited to some high value land uses. The poorly drained clays of the Ruawai flats are already well understood and widely used with highly specialised management. The narrower flood plains of the hill country are generally not used for cropping and may be subject to flooding. Careful site assessments are required when considering soil water sensitive crops.
3. Peatland (2%): While peatland soils are generally very poorly drained, with shallow rooting depth, they may provide growing environments for a limited range of specialised crops.
4. Downland from sedimentary rock (15%): Although the easy slopes in this terrain make it a potential area for land-use intensification or diversification, the terrain is scattered throughout the study area and most soils in this terrain are imperfectly drained, suggesting some impediment to soil water sensitive plants.
5. Downland from volcanic rocks (4%): Rolling slopes on andesitic and basaltic volcanics, together with terraces from redeposited volcanic material, offer good opportunities for crop production. Soils in this terrain are naturally well supplied with plant nutrients

and generally have good physical properties. Some of the soils contain a localised iron pan, while others are imperfectly drained, so detailed site investigation is recommended.

6. Hill country from weathered sedimentary rocks (14%): On rolling slopes in this terrain, the soils likely have drainage restrictions for moisture sensitive crops but on hilly slopes the drainage may improve. They have few root restrictions above about 60 cm depth but may need checking for subsoil pH. Slope generally precludes arable land uses.

7. Hill country from mixed crushed & sheared rocks (14%): This terrain is underlain by tectonically disturbed rocks. The rock masses which are mixed and change over short distances with the land often subject to earthflow and gully erosion. Soils likewise form complex patterns.

8. Hill country and occasional steepland from volcanic rocks (16%): Where the land is steep and rocky it is often scrub-covered, with limited productive potential beyond environmental protection and biodiversity preservation.

9. Hill country and steepland from greywacke and argillite (1%): Slope steepness constrains land-use options and while pockets of land are versatile, some soils show evidence of short periods of waterlogging in the upper part of the subsoil.

Where climatic data suggests land use could be suitable for the selected crops, more detailed soil assessment including field site assessment by a qualified soil surveyor is required to ascertain soil variability within the soil map unit and the suitability of the soil for the proposed land use. Without field verification it is not possible to assess the quality of the current regional-scale soil information, although experience from remapping of other regions has shown considerable differences can occur.

Summary of climate:

The climate of Kaipara District can be characterised as mild, humid and rather windy; owing to its northern location, low elevation and proximity to the sea. Summers are warm and tend to be humid, while winters are mild, with much of the district only observing a few light frosts per year. Rainfall is typically plentiful year-round, with occasional very heavy falls. However, dry spells and drought can occur, especially during summer and autumn. Some of the key features of Kaipara District's present climate include:

- Annual average temperature of 14.8°C to 15.4°C. Summer average maximum temperatures in Dargaville average 22-24°C, with winter average minimum temperatures averaging 7-8°C.
- Average annual rainfall of 1,100 mm to 1,400 mm, with summer being the driest season. On average, Dargaville observes 140 wet days per year.
- Average annual sunshine of 1,850 hours to 1,950 hours.

Summary of crop assessment:

The regional-scale land-use capability (LUC) maps indicate that horticultural crops would be suitable for some 59,200 ha of land within the Kaipara District, and that arable cropping could potentially be carried out across some 130,000 ha of the Kaipara District. The data from six NIWA Virtual Climate Station Network (VCSN) stations was analysed to assess suitability for specific crops or crop groups, together with additional data on soils. The findings are:

Olives: Olives are already grown around Northland, including the Kaipara District near Mangawhai, and the climate and soils assessment indicates that this crop could be considered for cultivation in other areas of the Kaipara District.

Hops, hemp and CBD cannabis: In terms of day length and summer warmth, the Kaipara District is considered suitable for hops, hemp and CBD cannabis. Due to the warm, humid climate of Northland, pest and disease control will likely be required. There may also be mitigation requirements for poor draining soils such as those near Dargaville and mounding of soils or breaking the pan would be a possibility. In the case of hops, excessive wind is likely to be a limitation.

Avocados: Avocados are already grown in Northland, and the climate and soils assessment indicates that there are likely to be more areas in the Kaipara District where the growing avocados could be considered. The need for deep and free-draining soils could exclude Dargaville and Ruawai without soil mitigation. However, Mangawhai and the west coast are also potentially suitable areas.

Peanuts: It is likely that peanuts would be best suited to the sandy soils in the west of Kaipara District, especially on the Pouto Peninsula.

Soybeans and Sorghum: Soybeans and sorghum would be better suited to the heavier textured soils surrounding the Kaipara Harbour and Ruawai, plus those in the east towards Mangawhai. Choice of soybean and sorghum cultivar will be critical to ensure that the crops can reach grain maturity. It will be important to select cultivars that have not been genetically modified (GM) as they are currently not legal in New Zealand without ERMA approval, and virtually all US varieties are GM. Sorghum could also be used as a green-feed crop with multiple cuts or grazings, or it could be grown for conserved feed in the form of silage.

Summary of climate change impacts:

Climate change is projected to impact New Zealand's climate considerably (MfE, 2018). Some of the key features of Kaipara District's projected future climate include[1]:

- Annual average temperature increases of 2.0-3.5°C (by 2090 under RCP8.5).
- Annual hot days and heatwave days increasing by 60-80 days (by 2090 under RCP8.5).
- Growing degree day (the total number of degrees Celsius each day is above a threshold of 10 degrees Celsius) increases of 250-300 GDD per year by 2040 under RCP4.5, and increases of 900-1,000 GDD per year by 2090 under RCP8.5.

[1] See Section 4 for a description of the climate models and downscaling method used and for definitions of RCPs (representative concentration pathways).

- Average annual rainfall decreases of 2-6% for northern inland areas (by 2090 under RCP8.5), but little change (±2%) for the District overall under remaining future scenarios. Increases to autumn rainfall of 2-15% projected under all future scenarios. Winter and spring rainfall projected to decrease by 6-15% by 2090 under RCP8.5.
- Annual wet days decreasing by 16-22 days (by 2090 under RCP8.5).
- Extreme, rare rainfall events are projected to become more severe in the future. The depth of a current 1:100-year 1-hour duration rainfall event is projected to increase by approximately 35% by 2090 under RCP8.5.
- Increase in amount of accumulated potential evapotranspiration deficit (PED), resulting in a projected increase in drought potential. An increase in PED of 120-160 mm per year is projected by 2090 under RCP8.5.
- Mean annual river discharge generally decreases by mid-century across the Kaipara District. By late century, mean discharge decrease is accentuated in the north-eastern area of the district with increasing greenhouse gas concentrations.
- Floods (characterised by the Mean Annual Flood (annual peak flood)) are expected to become larger for many parts of the district under high radiative forcing scenarios.
- Coastal flooding from extreme sea levels will increase in frequency and magnitude as global climate change forces sea-level rise.
- Projected climate changes will bring challenges (e.g. higher PED resulting in increased demand for water resources) and opportunities (e.g. warmer temperatures more suitable to warm climate crops) to the horticulture industry of Kaipara District.

Summary of how climate change may affect future crop suitability:

In general, it is expected there will be significantly more GDD_{10} over the growing season and a corresponding decrease in winter chilling and frost by 2050.

It is projected that crops with significant summer warmth requirements and no specific winter chilling requirements would be better suited for Kaipara in the 2050s, including avocados, sorghum, soybeans and peanuts.

No major change in the suitability of olives for Kaipara in general is expected, however appropriate selection of cultivar would be important depending on the area and how the winter chill hours are projected to change for that area. Fungal control is an important consideration for olives currently, and we would not expect that to change in the 2050s as the autumnal rainfall is projected to increase.

While the projected temperatures in the 2050s would appear to be suitable for hemp and CBD cannabis, as Kaipara is expected to remain about as windy as it currently is, hops would be difficult to grow with conventional tall trellises.

1 Introduction

Kaipara District Council commissioned the National Institute of Water and Atmospheric Research (NIWA), in collaboration with Manaaki Whenua Landcare Research and Plant & Food Research, to undertake a topo-climate study on the suitability of existing and future crops for the Kaipara District (Figure 1-1). This is one of three work streams in the *Growing Kai in Kaipara* programme. The other two work streams attend to Kai feasibility and activation plans as well as water storage options (see Coriolis (2020) and Williamson Water and Land Advisory (2019).

This report presents key topo-climate information for the purposes of better informing decision-making with regard to horticultural investment and transformation in the Kaipara District. The contents are divided according to key themes: the soils of Kaipara District; the current climate of the Kaipara District; the suitability of six horticultural crops; and the projected climate changes for Kaipara District. The structure of this report is presented as such. The report concludes with a discussion of the findings, the limitations of data, and proposes a set of recommendations.

Figure 1-1: Map of Kaipara District.

The reports that make up this summary document are an update to information provided in a 2003 report titled *'Use of Climate, Soil, and Crop Information for Identifying Potential Land-Use Change in the Hokianga and Western Kaipara Region'* (Griffiths et al., 2003). The original report covered the western Kaipara and Hokianga region whereas the updated information used the Kaipara District Council boundaries as the extent of the study. The updated report also has a larger future focus to allow for longer term planning. The key differences and additions in the updated report are:

Soils: The soil, land, and Land Use Capability (LUC) class attributes were extracted from the same dataset used in the 2003 report but differ because of the different study region between the two reports. Whereas some soil series used in the Griffiths *et al.* (2003) report do not occur in the current report, there are soil series in the current report which do not occur in the Griffiths *et al.* (2003) report (this is due the different extent of the study areas). Accordingly, these new soil series have been classified for subsoil acidity, potential rooting depth, drainage class and soil profile available water. Because of different underlying soil forming parent rock, further LUC units have been incorporated into the current report. However, the underlying premise that LUC Classes 1 to 4 are suitable for arable cropping, horticultural pastoral grazing, tree crop or production uses with LUC Classes 5 to 7 being not suitable for arable cropping, still remains.

Climate: There were considerable updates to the climate information provided between the two reports. The maps of average climate and supporting information in the Griffiths *et al.* (2003) report were based on the 1971-2000 30-year average period while the update report uses the most recent 1981-2010 information. One of the biggest improvements in the most recent report is the breadth and region specific detail provided on the potential future climate of the Kaipara District. The Griffiths *et al.* (2003) report only had four pages of information on climate change, the maps were at a national scale and were only made for temperature and rainfall. This is reflective of our understanding and modelling capabilities at the time. Since then, significant advances in modelling have allowed us to provide a much more detailed view of the future climate in the Kaipara District. The full NIWA 2020 report includes regional level maps and information for a number of climate variables (as well as non-climatic variables such as river flows and sea level rise) now and into the future. This information was used to consider not only current, but future crop suitability, and will hopefully provide a variety of decision-makers with new and useful information.

Crops: Six crops were selected for detailed consideration through consultative discussions with the Kaipara District Council and Coriolis Research and these were the three horticultural crops of olives, avocados, plus hops, hemp and CBD cannabis, along with the arable crops of peanuts, sorghum and soybeans. Market opportunities, compatibility with other land-uses, and profitability were part of the selection criteria, and not part of the suitability assessments. This approach differed to the 2003 study where ten crops of interest were selected based on two public meetings and consultation and guidance from horticultural scientists. The 2003 study did not have the market opportunity and profitability considerations included this time round. In this study, six virtual climate station network (VCSN) stations were selected to provide daily records of weather over 46 years at six representative locations across the District. The crop phenological characteristics were the use to assess climatic suitability through consideration of warmth for sowing dates, flowering dates, maturation and harvest dates, plus assessment of risks associated with lack of winter chill, frosts, wind, drought, and rain prior to harvest. This level of detail was not carried out in the 2003 study. In a concluding assessment, the risks and opportunities as a result of climate change were analysed. The impact of future climate on crop suitability was not considered in the initial report.

Soils of the Kaipara District

The Kaipara District has over 120 soil types (for further detail see Appendix A). Soils are grouped into series of similar soil profiles, similar temperature, moisture regime and parent material. The series is frequently given the name of a locality where it is well developed. Soil types within a series are defined by topsoil texture, and so textural terms are placed after the series name. Soil phases are an informal subdivision of soil types to reflect a soil property of potential importance to land use and management.

The soil series, type and phase provide a link to soil attributes that require consideration when investigating land-use opportunities and management requirements. Relevant soil and land data were extracted from Manaaki Whenua – Landcare Research's Fundamental Soils Layer (FSL) and NZ Land Resource Inventory (NZLRI) databases to identify soils in the Kaipara District. See McLeod (2019) for the full soils of the Kaipara District Reference report commissioned by NIWA. As an additional resource, Cox et al. (1983) provide an extensive survey of the Northland area. The following sections provide a summary of McLeod's report.

Soil Terrains of the Kaipara District

Nine soil terrains are present in the Kaipara District. The terrain represents a broad division of the landscape according to the general type of soil parent material and slope. The nine terrains recorded are: Sand Country (22%); Flood Plains (12%); Peatland (2%); Downland from sedimentary rocks – most slopes <16° (15%); Downland from volcanic rocks – most slopes <16° (4%); Hill country from weathered sedimentary rocks (14%); Hill country from mixed crushed & sheared rocks (14%); Hill country and occasional steepland from volcanic rocks (16%); and, Hill country and steepland from greywacke and argillite (1%). A little over half of the Kaipara District area has the soil type being sand country, flood plains or downland terrains (volcanic and sedimentary rocks). See **Figure 1-2** or Appendix A for a detailed map.

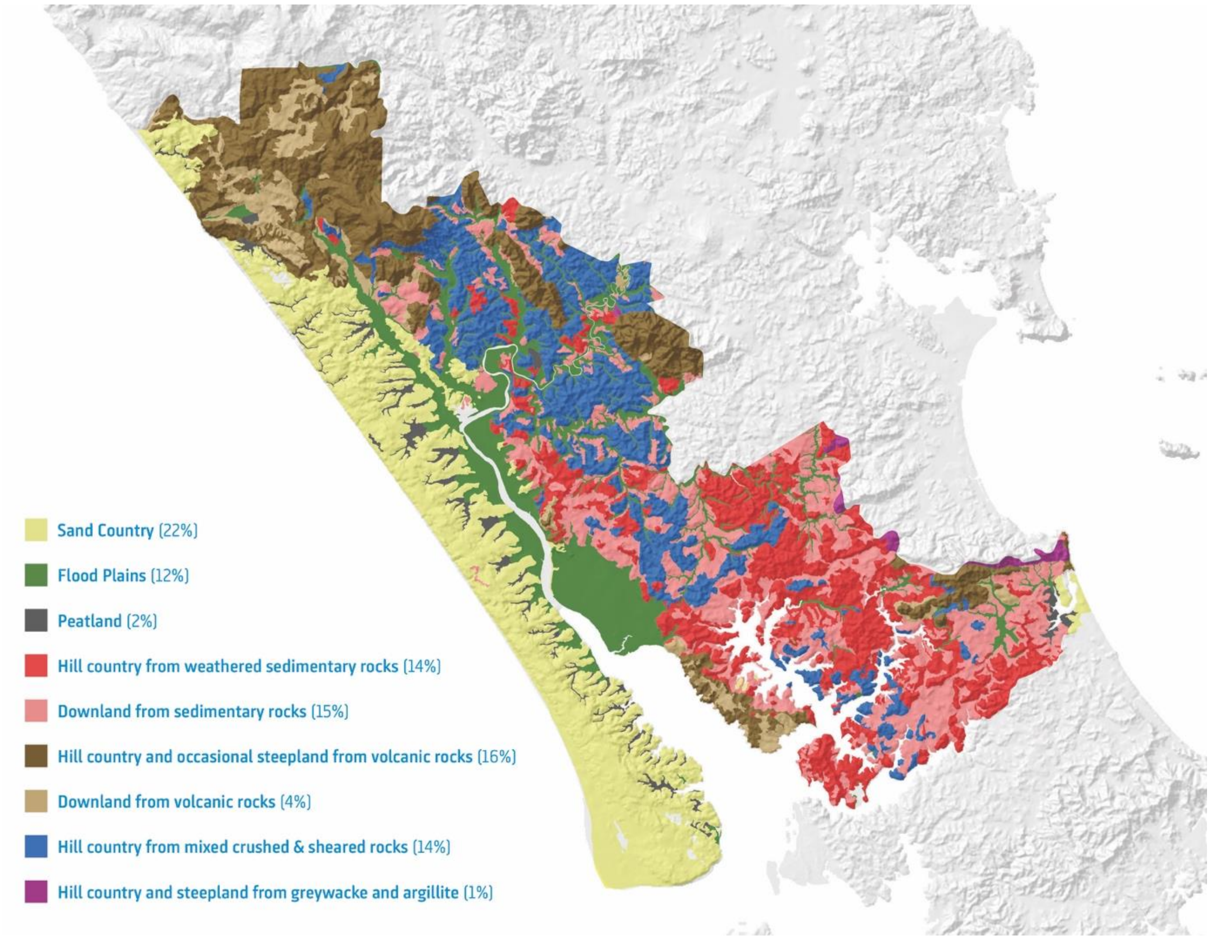

Figure 1-2: Soil Terrains of the Kaipara District

The following paragraphs detail the predominate soils according to soil terrains in the Kaipara District. See Appendix A for the full size maps described on this section.

Sand country soils often include those mapped as Bare Rock (soils with little vegetation) in the NZLRI and occur all the way up the west coast of Kaipara. Sand country soils become older and more weathered away from the coast. The sequence begins seaward with areas of sand dunes which show minimal soil development being delineated as Bare Rock followed by soils with very weak soil development–Pinaki soils (86 km^2, 3%). Red Hill soils (93 km^2, 3%) generally occur inland from Pinaki soils. Red Hill soils have enough soil development to provide one of the better opportunities for land-use intensification, although subsoil acidity would need checking that it is not too low. Tangitiki soils (225 km^2, 7%) are slightly older and show high variability over short distances, and some sites with white sandy layers below the topsoil and a coffee-coloured pan below ('egg cup podzols' where large kauri trees once grew). This variability would make general crop predictions unreliable at a broad scale. Podzols named Te Kopuru soils (128km^2, 4%) occur furthest inland on the oldest dunes. These soils are uniformly poor having low natural fertility and an iron pan which affects the growth of deeper rooting and soil water sensitive crops as water can perch on the pan.

Flood plain soils account for about 12% of soils in the Kaipara District and these may be well suited to some high value land uses. The poorly drained clays and peaty clays of the Kaipara soil suite (207 km^2, 7%) are already well understood and widely used for kumara growing – with highly specialised management. The narrower flood plains of the hill country are generally not used for cropping. Whakapara soils from alluvium derived from sedimentary rocks occur in valleys throughout the study area (81 km^2, 3%), whereas Mangakahia soils from alluvium derived from volcanic terrains are generally mapped in valleys north of Dargaville (63 km^2, 2%). Although both soils are well supplied with plant nutrients, they can be imperfectly drained and may also be subject to flooding. Careful site assessments are required when considering soil water sensitive crops.

Peatland soils account for a small portion of Kaipara land. About 50 km^2 of Parore peaty sandy loam occurs in small valleys in the sand country of the west coast and smaller areas of Otonga peaty loam in backswamp positions. While these soils are generally very poorly drained, with shallow rooting depth, they may provide growing environments for a limited range of crops.

Soils downland from sedimentary rocks (most slopes <16°) are scattered across Kaipara. The easy slopes in this soil terrain make it a potential area for land-use intensification or diversification. The terrain is dominated by Aponga and Waikare soils developed in claystone, mudstone or shale. Potential plant rooting depth is generally about 90–120 cm for Aponga soils (71 km^2, 2%) and slightly less (60–90 cm) in Waikare soils (78 km^2, 2%). Arapohue and Rockvale soils from argillaceous limestone have heavy clayey subsoils. The potential plant rooting depth is about 60–90 cm in Rockvale soils (35 km^2, 1%), but is shallow (25–45 cm) in Arapohue soils (46km^2, 1%). Most soils in this terrain are imperfectly drained, suggesting some impediment to soil water sensitive plants.

Soils downland from volcanic rocks (most slopes <16°) generally occurs near Tutamoe and north of Lake Taharoa. Rolling slopes on andesitic and basaltic volcanics, together with terraces from redeposited volcanic material, offer good opportunities for crop production. Soils are naturally well supplied with plant nutrients and have good structure. While upper subsoils can be firm and plant rooting slightly restricted, the soils do not become firmer with increasing depth (unlike soils of the sedimentary downlands). Tutamoe, Whatoro, Aranga, Katui, Waimatenui, Rangiuru, and Kohumaru soils at least appear to provide an opportunity for land-use intensification, (together, covering 106 km^2, 3%). Some of the soils, especially those in higher rainfall areas or receiving drainage water, contain a localised iron pan, while others are imperfectly drained, so detailed site investigation is recommended.

Soils from hill country from weathered sedimentary rocks (most slopes 16 – 25°) generally occur south west of Dargaville. This soil terrain is underlain by stable rocks (not crushed or sheared), and they are mostly sandstones. The main soil series is Waiotira. On rolling slopes, the soils are imperfectly drained but on hilly slopes the drainage may improve, and the soils are moderately well drained. They have few root restrictions above about 60 cm depth but may need checking for subsoil pH. Slope generally precludes arable land uses.

Soils attributed to hill country from mixed crushed and sheared rocks (most slopes 16 – 25°) occur throughout the study area, although larger contiguous areas occur south west and north east of Dargaville. This soil terrain is underlain by tectonically disturbed and finer grained sedimentary rocks. The rock masses are mixed and unpredictable, and often subject to earthflow and gully erosion. Soils likewise form complex patterns. While this land has limited cropping potential (too hilly, erodible, infertile, etc.) small, low slope-angle areas of Waiotira should not be discounted where soil water sensitive plants are not considered.

Soils attributed to hill country and steepland from volcanic rocks (most slopes16 – 35°) include very large contiguous areas of Tangihua Volcanics and Waipoua Basalts in the north of the Kaipara.

Where the land is steep and rocky it is often scrub-covered, with limited productive potential beyond environmental protection and biodiversity preservation.

Soils attributed to hill country and steepland from greywacke/argillite (most slopes16 – 35°) generally lie along the foothills north of Mangawhai Heads (greywacke covers just 18 km^2, <1%). Soils are predominantly Te Ranga steepland soils (10 km^2) where slope steepness constrains land-use options, and the hilly Marua soils (4 km^2). Marua soils are versatile but some show evidence of short periods of waterlogging in the upper part of the subsoil - plant rooting depth is very deep (to about 90–120cm). Rangiora soils (3 km^2) are less versatile, being more strongly weathered on the easier slopes, imperfectly drained, and have more restricted plant rooting (although still moderately deep at 60–90 cm). See Appendix A for a detailed map.

Slope Classes of the Kaipara District

Consideration of slope underpins almost every land-use and management decision. The NZLRI slope delineations are recorded as one or two slope classes : A (0–3°), B (4–7°), C (8–15°), D (16–20°), E (21–25°), F (26–35°), G (>35°). Each class is important for particular aspects of land management, for example, the use of wheeled vehicles is appropriate up to and including slope C; hill country that can be cultivated using tracked or four wheel drive tractors lies in class D; hill country that cannot be cultivated using tracked or four wheel drive tractors is in class E. Cultivation for cropping is not feasible for E slopes and steeper. Slopes are generally subdued (<20°), in the study area. The only significantly steep and very steep country is where Tangihua Volcanics form craggy mountain slopes to the west of Pukehuia. Other areas of steepland slopes are scattered throughout the study area but cover only 5% of the area. Over seventy percent of the area has slopes of less than 20°, and these can be cultivated, although with a significant risk of erosion and soil loss on slopes greater than about 12°. See Appendix A for a detailed map.

Subsoil Acidity in the Kaipara District

Soil acidity is a measure of whether the soil solution is acid, neutral or alkaline, and is expressed in pH units from 1 to 14. A pH of <4.5 is extremely acid and a pH of >9 is extremely alkaline. The pH affects plant growth largely through its influence on nutrient availability, the presence of toxic ions, and soil biological composition, including the amount and type of bacteria present. For example, many of the exchangeable nutrients used by plants for growth are less available in strongly acid soils. Subsoil pH over much (70%) of the Kaipara District is rated as moderately low to very low (pH 4.5 to 5.7). Amelioration of low subsoil pH is usually impractical because lime does not move very far through the soil, so taking account of existing subsoil pH becomes important when crop/soil matching. Soils with a high ability to exchange nutrients such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+) such as those rich in clay (as are many soils in Northland) or organic matter, have greater reserves of acidity or alkalinity than do soils with lower ability to exchange nutrients, such as sandy soils. Consequently, the pH values of clayey soils are less easily changed and are said to be 'well buffered'. Such soils would therefore require significant additions of lime to raise pH levels. Although most plants tolerate a wide range of pH, each plant has a narrower range for optimum growth. Remember, pH varies between soil types and sometimes within a soil type. See Appendix A for a detailed map.

Potential Rooting Depth in the Kaipara District

Potential rooting depth (PRD) is the depth to a layer that may physically or chemically impede root extension. It is the depth of soil that can be potentially exploited by the rooting systems of most common crops, providing a medium for root development, water and nutrient uptake. Plant root penetration is seriously restricted in Kaipara and Otonga soils (because of poor drainage), Te Kopuru soils (because of subsoil pans), some Arapohue soils and Konoti soils (rock at shallow depth) with root extension being limited to the soil volume above 45 cm. These soils account for most of the shallow to very shallow rooting soils. Soils in class 4 (17% of the land area) may restrict root extension in some tree crops, but a large area (classes 1, 2, and 3—61%) is not limited by this soil attribute.

Soil Drainage Classes in the Kaipara District

Soil drainage classes provide a qualitative indication of the likely wetness status of the soil and its seasonal aeration constraints. The classes may also be used to understand water availability, drainage requirements and trafficability constraints. Generally, poorly drained soils "lie wetter" for longer compared to better drained soils making it more difficult to work the soil in a timely fashion without damaging soil structure. However, poorly drained soils may "hang on longer" during dry periods.

Nearly half the Kaipara District has imperfectly drained soils, which mirrors conditions across the Northland region and is often due to the clayey subsoil conditions. Imperfect or poor drainage of soils is a normal condition for almost all flood plain soils in the Kaipara District. Poorly drained Kaipara soils occur on the wide Wairoa River flood plain whereas imperfectly drained Mangahakia and Whakapara mottled clay loams occur in narrow river valleys of the Kaipara District. In the older inland dunelands, imperfectly drained Tangitiki and very poorly drained Te Kopuru soils are recorded.

Better drainage status (well- and moderately well-drained soils) occurs with Pinaki and Red Hill soils in the younger coastal dunelands, and soils developed in volcanic material. Well- and moderately well-drained soils provide favourable environments for plant roots. Imperfectly drained soils present some problems for soil water sensitive crops. Poorly drained and very poorly drained soils present serious problems to most crop plants but can be useful with high management inputs and specialised crops. See Appendix A for a detailed map.

Profile Total Water Available in the Kaipara District

Profile total available water (PAW) is the total amount of water available to plant roots within the potential rooting depth, or to a depth of 0.9m, expressed as mm of water. It is water that occurs between the field capacity (amount of water in the soil 24 hours after heavy rain) and permanent wilting point (the amount of water in the soil when plants die from lack of water). Only a portion of the PAW closer to field capacity is considered readily available to plants and this is when plants grow best. Different soil types release water in a different pattern depending to some extent on their texture. For most clayey soils in the Kaipara District soil water which is readily available to plants is approximately 25% of PAW. Approximately 90% of the Kaipara District has soils with moderate to high levels of PAW. See Appendix A for a detailed map.

2 The climate of the Kaipara District

Kaipara District's latitude means that the track of anticyclones (high pressure systems) crossing New Zealand are often centred to the south. As a result, winds tend to be south-easterly following the passage of a trough (low pressure system) as the next anticyclone advances. These winds shift to the northeast once the anticyclone moves off to the east. Northeast winds typically have an extended passage over warm sea surface waters north of New Zealand, and the associated airmass is usually relatively moist, resulting in high humidity over Kaipara District. Tropical cyclones, or storms of tropical origin, affect Northland (and Kaipara District) from time to time. These weather systems usually bring heavy rain and strong easterly winds to the area. Characteristic weather sequences in Northland include fine weather spells, showery weather and prolonged rainfall. See, The Climate and Weather of Northland (Chappell, 2013) for further details.

The climate of Kaipara District can be characterised as mild, humid and rather windy; owing to its northern location, low elevation and proximity to the sea. Summers are warm and tend to be humid, while winters are mild, with much of the district only observing a few light frosts per year. Rainfall is typically plentiful year-round, with occasional very heavy falls. However, dry spells and drought can occur, especially during summer and autumn. The following sections provide a summary of the NIWA (2020) climate report for the Kaipara District.

Temperature in the Kaipara District

The Kaipara District's annual average temperature is between 14.8°C - 15.4°C. Summer averages are between 18.5°C - 19.5°C and winter averages are between 11°C - 12°C. The annual average temperature for the Kaipara District is shown in Figure 2-1. For seasonal average temperatures, see NIWA (2020).

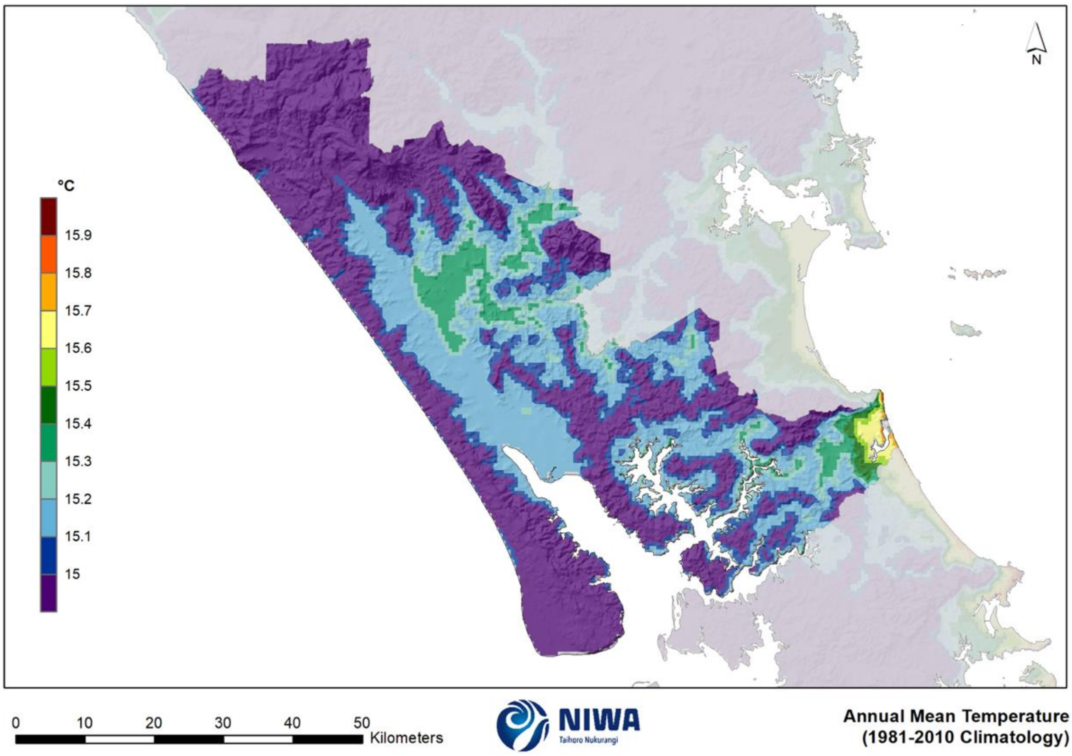

Figure 2-1: Annual average temperature for the Kaipara District.

Maximum temperature

Most of the Kaipara District observes an average of 25-40 hot days (days >25°C) as shown in Figure 2-2.

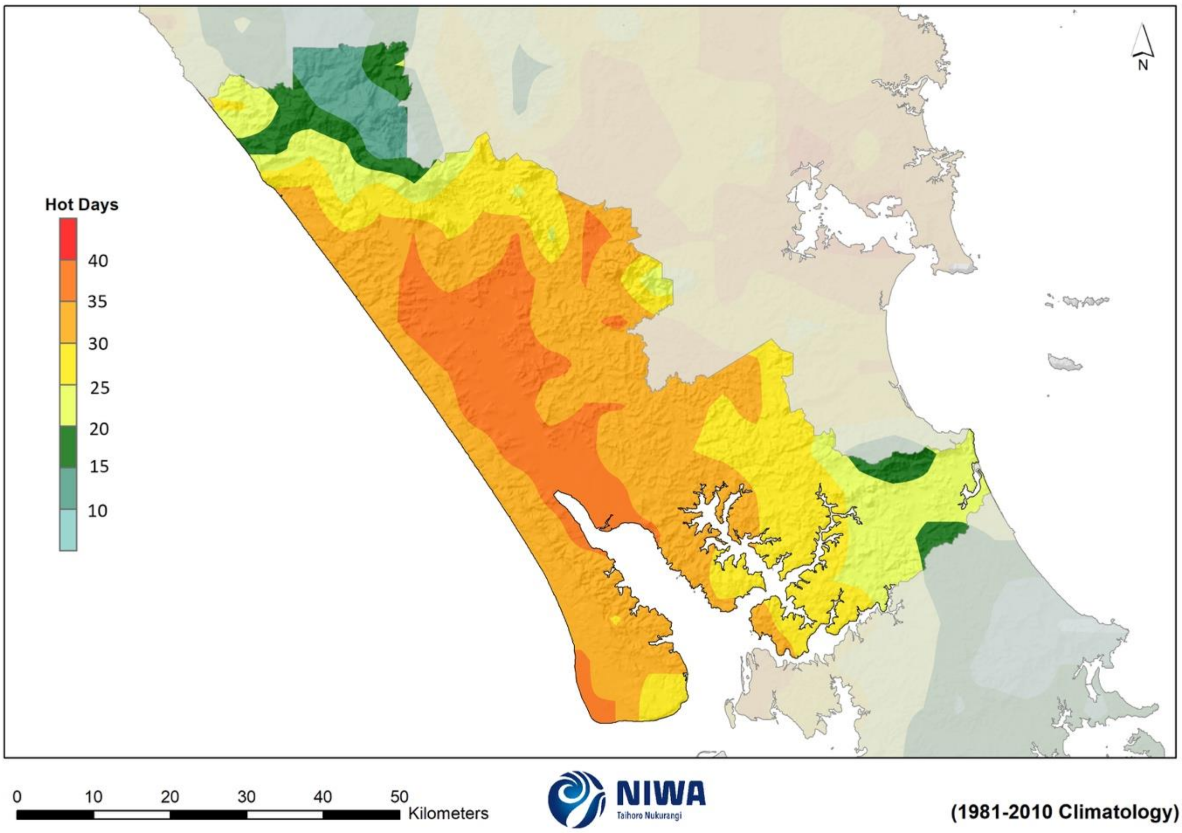

Figure 2-2: Annual number of hot days for the Kaipara District.

Dargaville has an annual average maximum temperature of 19.6°C, reaching 24.4°C during February. Dargaville averages 32 hot days/year (daily maximum temperature >25°C). The highest temperature on record for Dargaville is 32.4°C.

Table 2-1: Monthly and annual maximum temperature statistics for Dargaville

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANN
Avg. max. temp	24.1	24.4	22.9	20.8	18.2	16.1	15.3	15.6	17.0	18.1	19.9	22.2	19.6
Extreme max temp (year)	31.8 (1954)	32.4 (1998)	32.1 (1946)	28.9 (1998)	24.9 (1995)	24.4 (1998)	21.7 (1999)	23.2 (2001)	24.5 (1995)	25.6 (1949)	27.3 (1949)	29.9 (1998)	32.4
Mean no. of hot days	10	11	5	1	0	0	0	0	0	0	0	5	32

Minimum temperature

A frost day is defined as when the daily minimum temperature falls below 0°C. This is purely a temperature-derived metric for assessing the potential for frosts. Frost conditions are influenced at the local scale by temperature, topography, wind, and humidity, so the results presented in this section can be considered as the large-scale temperature conditions conducive to frosts. Frosts typically do not occur in the Kaipara District after 8 August (Julien day 220) in a given year (Figure 2-3).

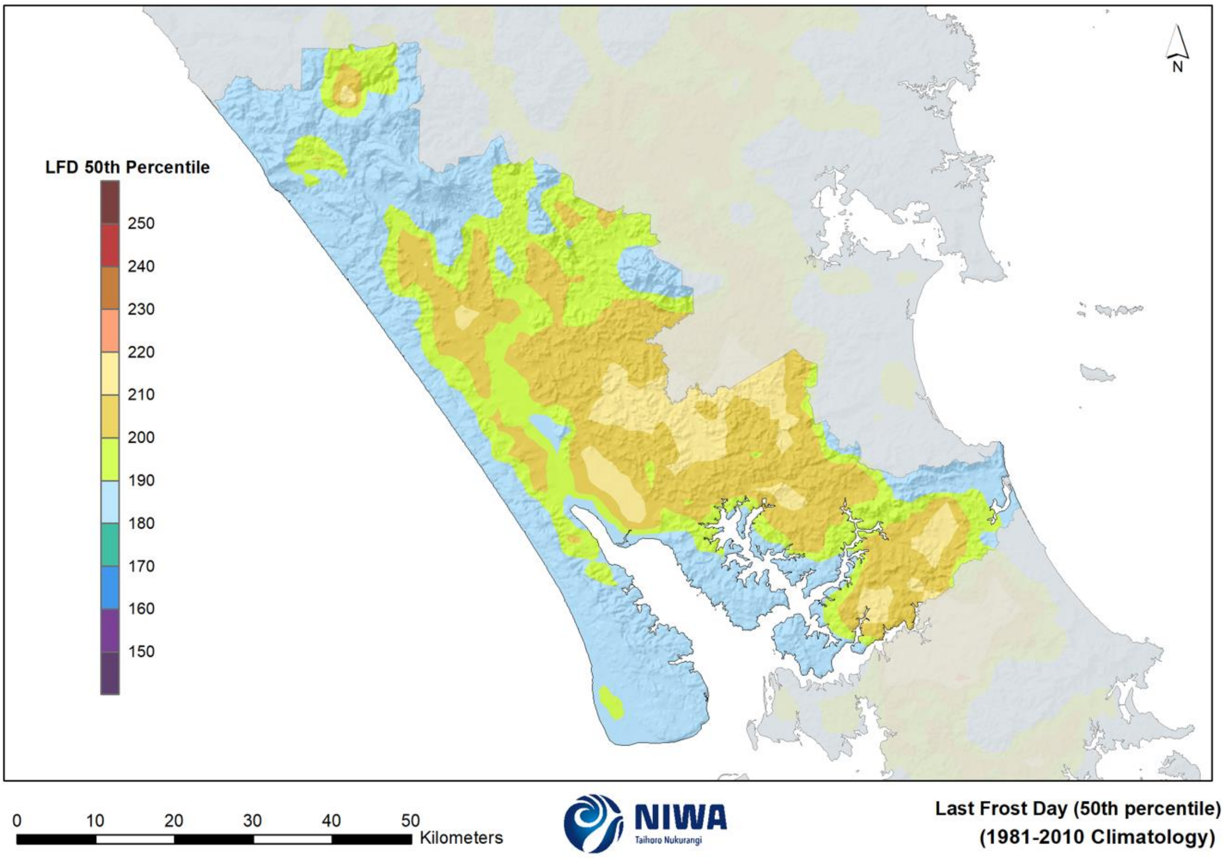

Figure 2-3: Median (or 50th percentile) last frost date (LFD) in Kaipara District**.** Presented as Julien days e.g. 1 June is Julien day 152 and 1 August is Julien day 213. Based on the 30-year average from 1981 - 2010.

Monthly and annual minimum temperature statistics for Dargaville are presented in Table 2-2 Dargaville has an annual average daily minimum temperature of 11°C, reaching a low of 7.2°C during July. Dargaville averages 3 frost days/year and the lowest temperature on record is -5.0°C (August 1949). Average daily minimum temperature and average number of frost days are based on the climate normal period 1981-2010. Lowest recorded temperatures are based on all available data for Dargaville, which spans the period 1943-2019.

Table 2-2: Monthly and annual minimum temperatures statistics for Dargaville.

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANN
Avg. min. temp	14.4	15.0	13.5	11.7	10.0	7.8	7.2	7.8	8.9	10.4	11.7	13.4	11.0
Extreme in temp (year)	4.0 (1987)	1.7 (1950)	0.0 (1947)	-1.3 (1992)	-3.3 (1964)	-3.3 (1959)	-5.0 (1949)	-3.3 (1965)	-1.9 (1957)	0.6 (1973)	2.2 (1947)	1.2 (1961)	-5.0
Mean no. of frost days	0	0	0	0.1	0	1.0	1.3	0.3	0	0	0	0	2.7

Growing degree days

Growing degree-days (GDD) express the sum of daily temperatures above a selected base temperature (e.g. 10˚C) that represent a threshold for plant growth. The average amount of GDD in a location may influence the choice of crops to grow, as different species have different temperature thresholds for survival. The daily GDD total is the amount the daily average temperature exceeds the threshold value (e.g. 10°C) per day. For example, a daily average temperature of 18°C would have a GDD base 10°C value of 8. Here, GDD are accumulated from July to June, and presented for the historic 1981-2010 average. Annual mean GGD (base 10°C) ranges between 1,700-2,000 GDD for most of Kaipara District. In higher elevation terrain to the north of Kaipara District, GDD (base 10°C) ranges between 1,200-1,400 GDD. For seasonal mean growing days, see NIWA (2020).

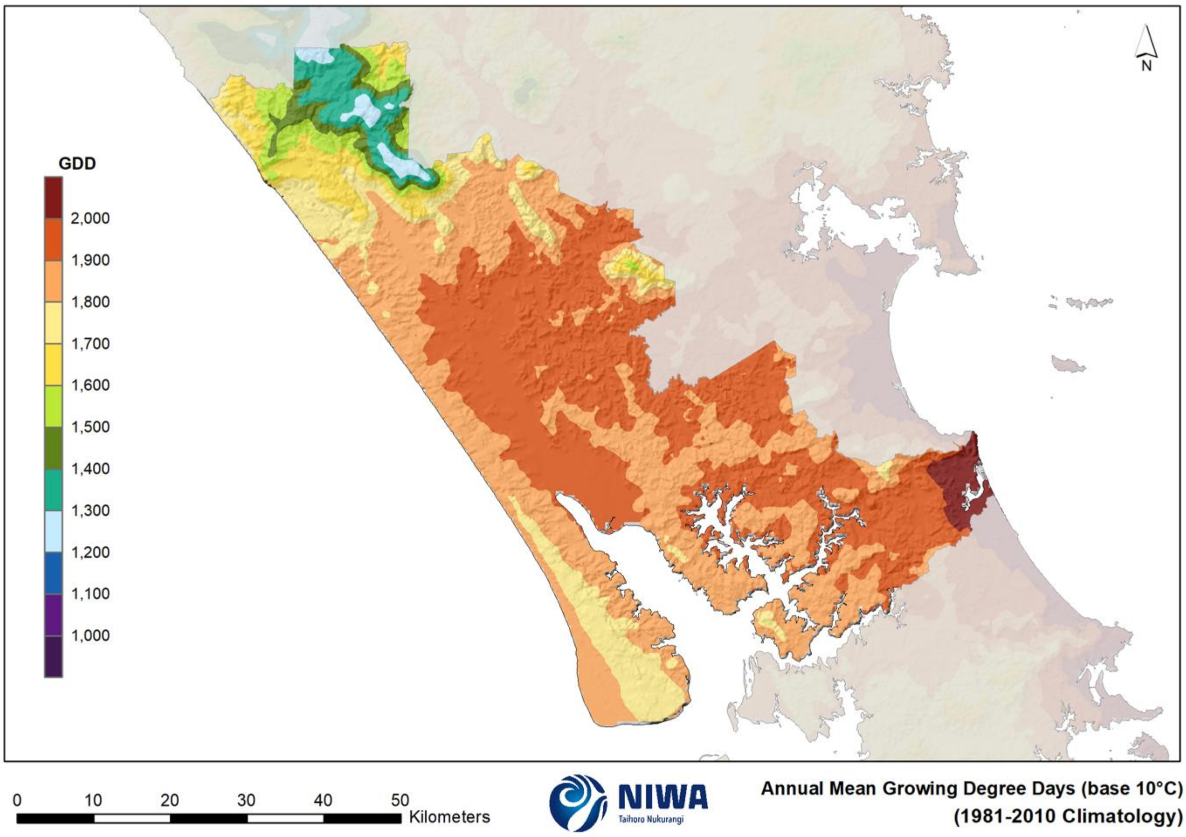

Figure 2-4: Annual mean growing degree-days for the Kaipara District (base 10°C)

Rainfall in the Kaipara District

The annual average rainfall is between 1,100mm and 1,400mm for most of Kaipara District; western areas are typically drier than eastern areas. Summer is typically the driest season, with summer total rainfall ranging from 225-300mm for much of Kaipara. Winter is typically the wettest season, with rainfall ranging from 350-500mm for much of Kaipara. For seasonal average rainfall, see NIWA (2020).

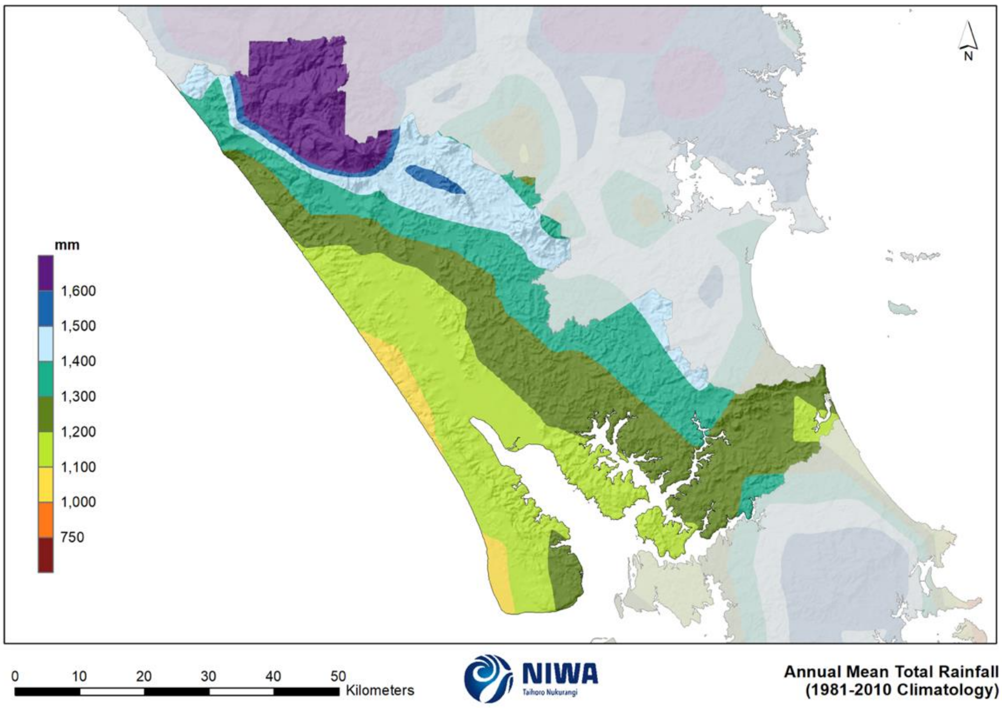

Figure 2-5: Annual mean total rainfall (mm)

Wet days

'Wet days' are days when greater than 1mm of rainfall is recorded. Monthly and annual wet days statistics for Dargaville are presented in

Table 2-3. Dargaville averages 140 wet days/year (i.e. days with at least 1mm total rainfall, with an average of 7 wet days in January and February, and 17 wet days in August. Average number of wet days are based on the climate normal period 1981-2010. Minimum and maximum number of wet days are based on all available data for Dargaville, which spans the period 1905-2019.

Table 2-3: Monthly and annual wet day statistics for Dargaville.

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANN
Avg no. wet days	7	7	9	10	14	16	16	17	13	12	9	9	140
Fewest wet days	0	1	1	4	4	7	3	8	5	3	2	1	108
Most wet days	15	14	18	24	26	24	28	25	22	21	20	18	178

Dry spells and drought

Periods of fifteen days or longer with less than 1 mm of rain on any day are referred to as "dry spells". Dry spells in Kaipara are not uncommon and occur most frequently during summer and early autumn. There is usually at least one, and frequently two dry spells each year between December and March.

NIWA recently developed a standardised climate index called the New Zealand Drought Index (NZDI), in order to keep track of drought conditions across New Zealand. Note that this index is a measure of meteorological drought and is not to be confused with Government declarations of adverse events due to drought. Figure 2-6 shows the NZDI for Kaipara District from January 2007 to April 2020 According to this index, Kaipara District has regularly observed periods of drought, with three severe droughts occurring since 2007. The most severe drought since 2007 occurred in early 2013, when the NZDI value peaked at 2.49 on 25 March 2013. An adverse event due to drought was declared in Northland by the Government on 27 February 2013. Subsequent analyses determined that the potential evapotranspiration deficit (PED) accumulation for the period July 2012 to May 2013 exceeded 450 millimetres in southern Northland, making it the highest PED accumulation for the area since 1949-50 (Porteous and Mullan, 2013). More recently, on 12 March 2020 the Government declared an adverse event due to drought in Northland (and the entire North Island), a medium-scale drought declaration had previously been announced for Northland. The NZDI value for this event peaked at 2.23 on 1 March 2020.

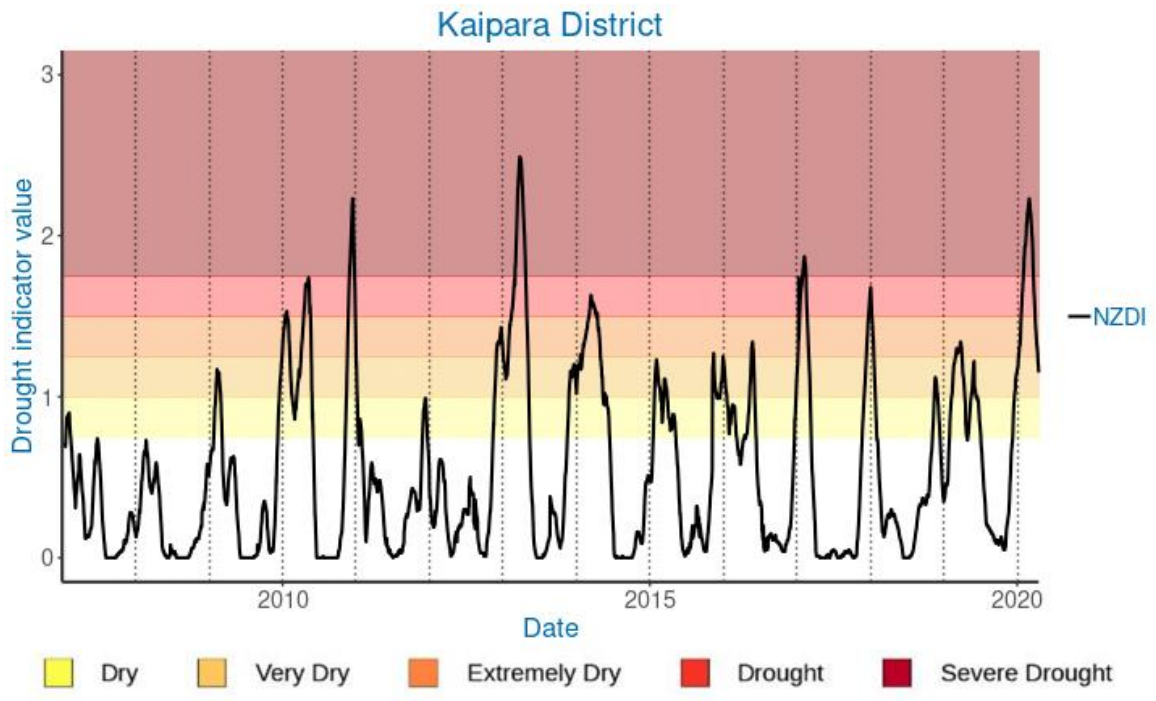

Figure 2-6: New Zealand Drought Index values averaged over the Kaipara District, January 2007-April 2020. For more information about this index see https://niwa.co.nz/climate/information-and-resources/drought-monitor.

Sunshine

Median annual sunshine hours for Northland are shown in Figure 2-7. For Kaipara District, annual sunshine hours typically range between 1,850-1,950 hours. In Dargaville, highest monthly sunshine hours are typically observed in January (approximately 210 hours), with fewest sunshine hours observed in June (approximately 100 hours) (Chappell, 2013).

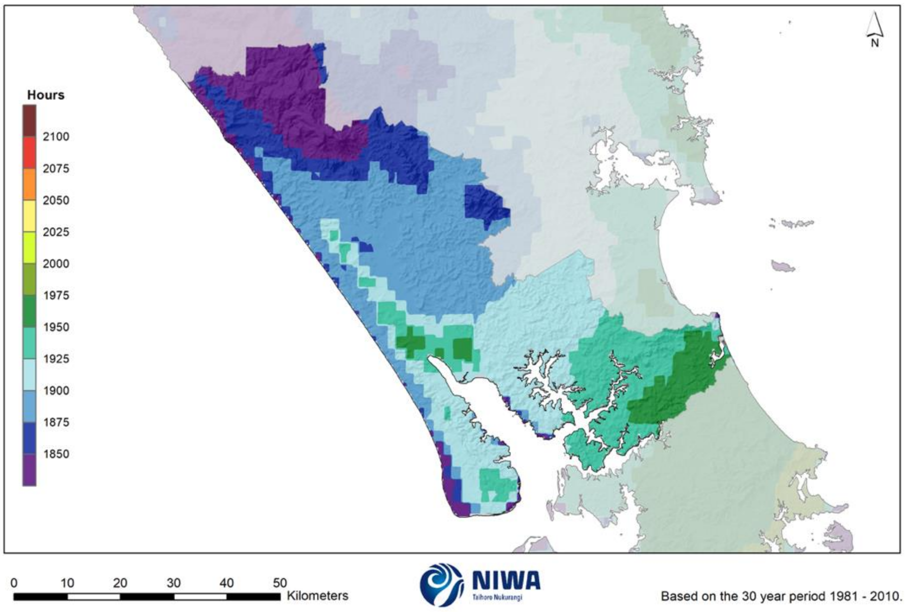

Figure 2-7: Median annual sunshine hours (based on the 30yr average, 1981-2010)

Wind

Median annual average wind speed for Kaipara District is shown in Figure 2-8. Median annual average wind speed for the Kaipara District is 3-5 m/s (approximately 11-18 km/hr). The strongest winds in Dargaville are typically between the directions of west and southwest.

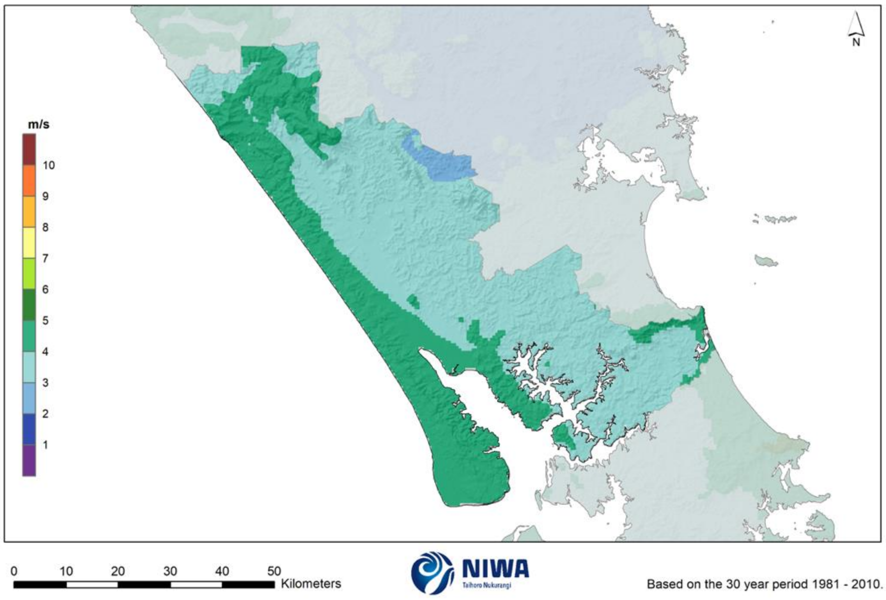

Figure 2-8: Median annual average wind speed (m/s) (based on the 30yr average, 1981-2010)

3 Suitability of 6 key crops

This section is a summary of key crop information in the research conducted by Plant and Food Research under contract for NIWA (see Ward & Clothier, 2019; Ward, Funnell & Clothier, 2019; and Ward & Clothier, 2020). A generic suitability of horticultural in the Kaipara District is introduced and then followed by detailed suitability analysis of the six key crops chosen by Kaipara Kai: Avocados; Olives; Hops, Hemp and CBD Cannabis; Peanuts; Sorghum; and Soybeans. The first three crops were selected after a workshop held at the KDC in 2019. The rationale for the selection of the latter three crops can be found in Ward & Clothier (2020).

An Overview of Generic Suitability of Horticulture for the Kaipara District

Plant and Food Research undertook an initial study of the potential suitability for horticulture in the Kaipara District. This was a broad-based study using general criteria for land and climate requirements to understand the potential for generic horticulture. Figure 3-1 illustrates the potentially land suitable for horticulture and being land with a slope value of less than 15˚ (to ensure trafficability of operations).

Key information

- Approximately 44,200 ha (14%) of land within the Kaipara District is suitable for generic horticulture.
- An additional 17,000 ha of land (5%) could be suitable for horticulture, although this area is susceptible to wind erosion and most likely requires management, shelter mitigation, and irrigation.
- A further 69,000 ha (22%) is considered suitable for arable cropping.
- 'Suitable' land is that which meets the following criteria:
  - The Land Use Capability (LUC) classes are 1, 2, 3, and 4s - 7s. The latter classes are specifically for viticulture. These criteria cover 'good' land without severe limitations.
  - The number of Growing Degree Days base 10°C (GDD_{10}) is greater than 800 degree-days. This is to ensure fruit maturation.
  - The frost-free period is greater than 200 days. This is to ensure no frost occur after fruit flowering or before fruit maturation and harvest (i.e. October to April).
  - A slope value of less than 15˚ (to ensure trafficability of operations).
- Some soils in the Kaipara District have poor drainage and shallow potential rooting depths. Mitigation options, such as mounding or breaking the pan, should be investigated.

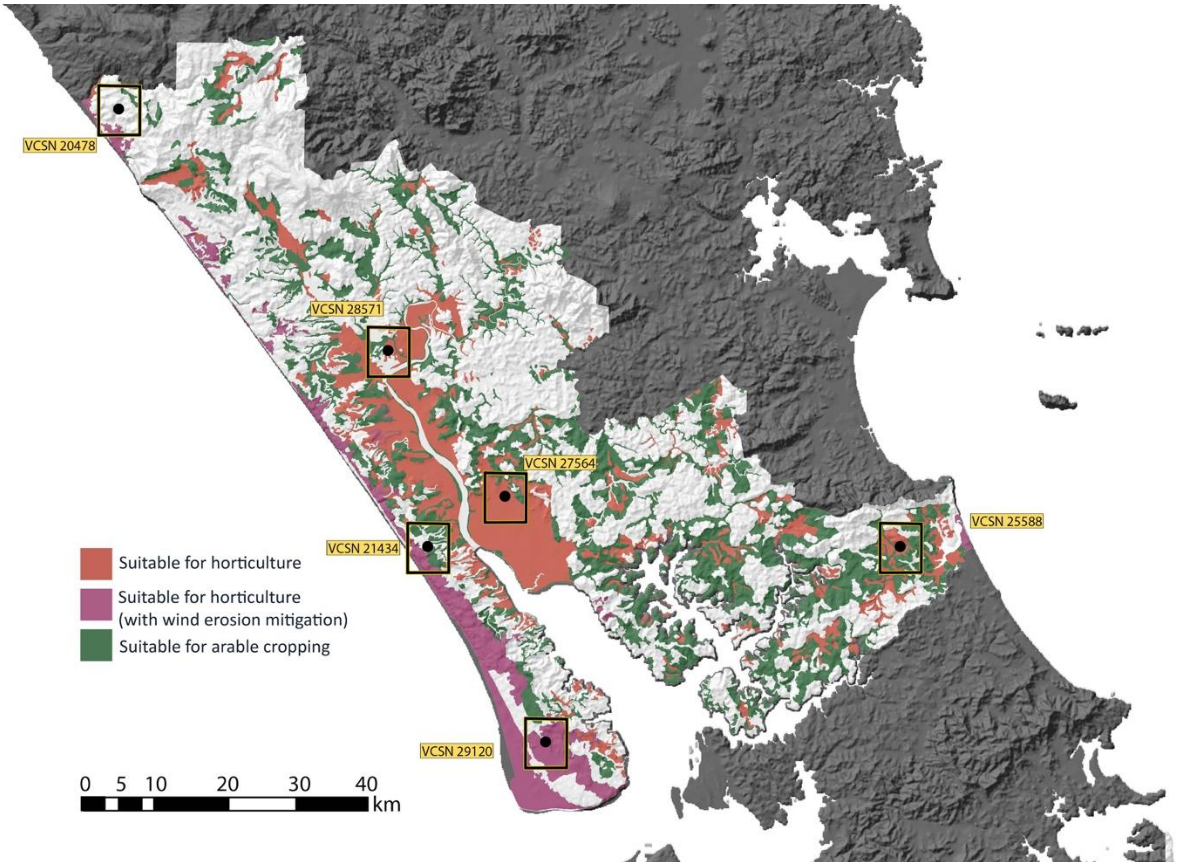

Figure 3-1: Areas of the Kaipara District considered suitable (red) for horticulture and further areas (sand country) susceptible to wind erosion that may be suitable (pink). Additional areas that may be suitable for arable cropping is coloured green. VCSN refers to Virtual Climate Station Network.

Detailed Evaluation of Selected Horticultural Crops

Based on the identified potential horticultural areas (Figure 3-1) Plant and Food research selected six NIWA Virtual Climate Station Network (VCSN[2]) grid points for further analysis of the suitability for cultivation of six specific crops/groups of crop: Avocados; Olives; Hops, Hemp and CBD Cannabis; Peanuts; Sorghum; and, Soybeans. The suitability of the three selected horticultural crops for the Kaipara District Council was calculated by using climate data from the VCSN, and the report on soils by Manaaki Whenua Landcare Research (MWLR) (McLeod, 2019).

Avocados

Most New Zealand's avocado orchards are in the Bay of Plenty and Northland. The focus in Northland is around Whangarei, due to the favourable climate there. Avocados require fairly warm climates and are relatively intolerant of cold temperatures. They also require adequate soil moisture, wind shelter and, as seedlings, protection from sunburn. Pest, disease and weed control are generally required for avocados. Weeds will compete with the trees' nutrients, while pests and diseases can cause low-

[2] The VCSN is a network of grid points covering all New Zealand at a spacing of approximately 5km (0.05 degrees latitude by 0.05 degrees longitude). Daily climate data recorded at climate stations around the country are spatially interpolated onto this network, thus providing estimated daily time series of multiple climate variables such as rainfall, air temperature, wind speed etc. at every VCSN grid point. See: https://niwa.co.nz/climate/our-services/virtual-climate-stations for more details.

quality fruit and are a biosecurity risk for export. These may be managed through a range of management practices.

Temperature

The main requirement for avocados is that there are generally warm temperatures all year. There needs to be sufficiently high temperatures in the spring for flowering. Avocados are relatively intolerant of frosts, so winter temperatures that never get too cold are a requirement. Unlike many other crops which, with appropriate mitigation, can be grown in areas that may not have ideal conditions, avocados are sensitive to cold weather, so these conditions are more limiting.

The average minimum temperatures in the spring should be at least 8°C, 9°C and 10°C for September, October and November respectively. Average minimum temperatures of 7°C, 8°C and 10°C for September, October and November, respectively, are acceptable, but less than ideal. The average maximum temperatures in the spring should be at least 15°C, 16°C and 17°C for September, October and November respectively. Acceptable, although marginal, maximum temperatures for those months should be 14°C, 15°C and 17°C respectively.

The final temperature requirement is that, on average, the temperature should never drop below 0°C at any point during the year. It is also acceptable, but less than ideal, for this annual extreme temperature to drop below 0°C, as long as it never drops below -2°C.

Rainfall

The dry summers in Northland present a challenge. Irrigation is generally considered necessary in summer for the avocados to be grown here, so this would likely be necessary in the Kaipara District as well.

Soil

Avocados are relatively deep-rooting trees and they require a potential rooting depth of at least 60 cm, and ideally about 90 cm. They also require free-draining soils to avoid waterlogging and anaerobic conditions developing in the rootzone. As shown in Appendix A, the PRD and drainage classes in most of the areas considered suitable for horticulture is relatively poor, particularly the imperfect drainage class of soils on the plains around Dargaville and Ruawai. Avocados planted here would likely require soil mitigations such as mounding and pan ripping, which is common in other areas where avocados are grown such Kerikeri (Figure 3-2). However, Mangawhai and long stretches of the west coast of the Kaipara District appear to have suitable soils. Wind protection would be required in the west.

Recommendations

Avocados require similar conditions to olives. Since both olives and avocados are already grown in Northland, there are likely to be many areas in the Kaipara District where the growing of avocados would be possible. The need for deep and free-draining soils could exclude Dargaville and Ruawai without soil mitigation. In terms of soil suitability however, Mangawhai and the west coast are potentially suitable areas.

Olives

There are over 50,000 olive trees in Northland and approximately 118 ha of olive groves. The most common cultivar across New Zealand is Frantoio. Olives New Zealand (https://www.olivesnz.org.nz/) reports some 200 members, and of these 56% are full members with more than 250 trees. Only 20%

of members are full-time professional growers. There are about 400,000 olive trees in New Zealand, and Olives New Zealand reports that over 25% of its members are in the Wairarapa, with 12% in both Northland and Kāpiti. Olives New Zealand lists six olive groves from Northland (https://www.olivesnz.org.nz/ourgrowers/northland/). These cover groves from near Mangonui, Kaikohe, and around Mangawhai.

Soils

Olives prefer well-drained soils that are slightly alkaline and with low to medium fertility. This would favour sandy soils, and land of Land Use Capability (LUC) classes LUC 1-3. Many of the soils in the Kaipara District have low subsoil acidities. Olives favour near neutral, or better still, slightly alkaline conditions. Acid subsoils should be avoided or managed by strategies such as liming.

Furthermore, olives prefer free-draining soils, so if there were a wetness (‘w’) limitation in the LUC classification, or a shallow potential rooting depth, then mitigation would be required. Sandy loam, silty loams, sandy clays and silty clays are preferred, rather than heavier textured soils (IOO, 2007). The drainage class information presented in Section 2 (Soils of the Kaipara District) provides insight into which soils could be considered for olives, and those with poor internal drainage classifications that should be avoided.

The root system of olives is concentrated in the top 50-70 cm. Where there are limitations to rootzone depth, either by pans or imperfect drainage, mounding of the interrow soil along the row can create a rootzone of sufficient depth. Ripping of the pan can help too. Mounding of soil along the row is a common practice in Northland orchards, as imperfect drainage can result from sub-surface pans at around 40-50 cm (Figure 3-2).

Figure 3-2: Avocados growing successfully near Kerikeri on a soil with a shallow impermeable pan. The soil of the interrow has been mounded along the row to provide a rootzone with good drainage characteristics.

Climate

Olives are of Mediterranean origin, and so they favour cool winters and warm summers. Yet they are adaptable to a wide range of conditions. Waimea Nurseries in Nelson have provided a guide to olive varieties for professional growers (see reference link).

Olives require winter chilling to trigger floral initiation, rather than to continue vegetative growth. The cultivars vary in their chilling requirements, depending on their provenance. Italian winters are quite long, so Italian cultivars such as 'Frantoio' and 'Leccino' have a winter-chilling requirement of about 600 hours under 7°C. Tunisian, Greek (Crete), and Spanish cultivars like 'Chemlali', 'Koroneiki' and 'Arbequina', where winters are shorter, have lower chilling requirements of between 150 and 300 hours (https://www.nature-andgarden.com/gardening/olive-tree-cold.html).

Despite the greater chilling requirements for 'Frantoio', many are grown in groves in the Mangawhai region, where winter chilling hours are typically less than 600. Future climates might pose a problem with the future loss of winter chilling hours. Torres et al. (2017) reported that in north-western Argentina normal flowering of the variety 'Arbequina' was observed at almost all sites and in all years, while normal flowering events in 'Frantoio' and 'Leccino' were uncommon. These results confirmed that these two latter cultivars require a very high number of chilling units in accordance with values from the World Olive Germplasm Bank of Córdoba (Spain), and that the winter temperatures in north-western Argentina do not meet their chilling requirements for normal flowering in most years. In kiwifruit, and other crops, hydrogen cyanamide (Hicane®), or the cytokinin called benzyladenine can be used to break dormancy and induce flowering, but Torres et al. (2019) reported that this was not successful with 'Frantoio' olives in north-western Argentina.

One of the major problems threatening the young New Zealand olive industry is olive leaf spot, also called 'peacock spot', which is caused by the fungus Spilocaea oleagina. Obanor (2005) showed that lower temperatures (10-20°C), free moisture on leaves, and high humidity (100%) favoured the development of 'peacock spot' (http://www.olivesnz.org.nz/wpcontent/uploads/2012/03/Olive-Leaf-Spot-Disease.pdf). Autumnal rains would increase the risk of 'peacock spot', and the VCSN stations record that there is on average between 160 mm and 200 mm of rain in March and April across the district. A good fungal-control programme will be needed.

Recommendation

Since olives are already grown around Northland, including the Kaipara District near Mangawhai, it is likely that there are other areas of the Kaipara District where olives would be able to be grown. Based on the need for deep, free-draining soils, the west coast around Dargaville and the Pouto Peninsula could potentially be sites worthy of further investigation. Mounding of the soil, or deep ripping might be needed where the soils have imperfect drainage.

Hops, Hemp and CBD cannabis

Taxonomically, hops (*Humulus*) and both hemp and cannabis (*Cannabis*) are closely related, and both genera belong to the *Cannabaceae* family. Given their close nature of these crops , within this report hops, hemp, and CBD cannabis, are treated as one crop, recognising of course that their cultivation will involve different management and cultural practices. Furthermore, because there is much more information publicly available on hops, after presenting a brief overview of the situation analysis for these three crops, subsequent sections will primarily refer to hops only. However, the interpretations will, in general, apply to hemp and CBD cannabis. The exception is in relation to risks due to wind, as the cultivation system used for hops is quite different from that for hemp and CBD cannabis

CDB Cannabis (overview)

Cannabidiol (CBD) is a phytocannabinoid discovered in 1940. It is one of 113 identified cannabinoids in cannabis plants. Clinical research on cannabidiol includes preliminary studies of anxiety, cognition, movement disorders, and pain. In 2017 the New Zealand government made changes to the regulations so that restrictions would be removed, which meant a doctor was able to prescribe cannabidiol to patients. Next, the passing of the Misuse of Drugs (Medicinal Cannabis) Amendment Act in December 2018 meant that cannabidiol is no longer a controlled drug in New Zealand, but is a prescription medicine under the Medicines Act, with the restriction that the amount of tetrahydrocannabinols (THC) and psychoactive related substances must not exceed 2 percent of the total CBD tetrahydrocannabinol and psychoactive substances content. In anticipation of further changes in the social and political environment, some NZ-based companies have gained research licenses to growing CBD cannabis crops. There are regulatory restrictions.

Hemp (overview)

Hemp, or industrial hemp, is a strain of the *Cannabis sativa* species that can be grown for industrial uses of its derived products. It is a fast-growing plant and was first spun into usable fibre over 10,000 years ago. Hemp has lower concentrations of THC and higher concentrations of CBD, which decreases, or eliminates its psychoactive effects. The New Zealand Hemp Industries Association (https://nzhia.com/about-nzhia/) is a resource for information and advice on the growing of hemp. To grow hemp a licence is required from the Ministry of Health, and there must be a secure site, more than 5 km from a school, and the growing area should not be visible from the street. Hemp seed is used for hemp seed oil, protein powders and hemp milk. The stalks provide a source of versatile fibre.

Hops (overview)

Hops (*Humulus lupulus*) is a niche, though important, crop grown around the world. New Zealand produces less than 1% of the global total, but almost all of it is sold before harvest for export, as New Zealand cultivars are highly regarded around the world by the craft-beer industry. Many of these cultivars were developed by Plant & Food Research in Motueka. In 2019, twenty-one cultivars were produced commercially along with various trial varieties. New Zealand's hops industry is centred on Motueka, and almost all hops grown on a commercial scale are produced here. This dominance is largely because Motueka is where hops have historically been grown in New Zealand, not because there's anything special about the region with regards to hops. Apart from Motueka, Plant & Food Research currently runs hops trials in Clyde and at Kerikeri.

Cultivation (Hops)

Hops are a type of plant called a 'bine', which is like a vine, but instead of using tendrils and suckers to climb, the main stem itself entwines the support strings. They are typically grown on trellised systems not unlike wine grapes, albeit significantly taller. In New Zealand, the trellis is usually five metres high. In some other countries, the hops trellises may be six or eight metres high, while in China relatively short trellises of just three metres are used. The reason for such high trellises is that the main driver of growth in hops is sunlight, and these trellises are the optimal configuration for maximising sunlight exposure for the natural photoperiod, given that photoperiod dictates the timing of when plants change from vegetative to floral each season. Because of the need for trellises, hops are a crop that requires significant infrastructure, and they are relatively expensive and labour-intensive to establish.

Harvesting involves cutting the entire bine down and feeding it through a mechanical device that strips and separates the flowers from the bines and leaves. Often the hop flowers are then dried, powdered and pelleted for distribution to breweries. Fresh, 'green' hops are sometimes used in brewing, however fresh hops must be used within a day or two of harvest, so this method of brewing is relatively niche. Cover crops can be used over the winter for various reasons such as aiding in nitrogen fixing, however this is not typical in New Zealand. The usual practice here is to graze sheep in hopyards over the winter.

Mites are frequently noted as being problematic but downy mildew is considered most limiting in crops internationally. The problems of fungal infections coinciding with the harvest period in regions where autumn rains occur are also noted, so a vigilant pest and disease programme is likely to be required.

Soil (Hops)

There are reports that hops can grow well in soils that are also used to grow potatoes, with good drainage and soil pH between 6.2 and 6.5 being recommended. A large proportion of the Kaipara District has near neutral soils with pH levels between 5.8 and 6.4, denoted by the teal areas of the Subsoil Acidity map in Appendix A, and these would be suitable soils for hops. There is also a large proportion of the district with moderately low pH soils of between 5.5 and 5.7, shown by the light green areas of the same map, which would likely be acceptable for hops as well. Where there are areas with imperfect soil drainage, mounding of soil along the row would be recommended.

Climate (Hops)

Relatively little research has been done on the growth and developmental response of hops to various weather and climate factors. One of the main reasons for this is that hops have been grown in the same areas for decades, if not centuries, and there has been little demand to significantly expand where hops are grown. The other main reason is that hops behave like 'weeds' in some ways, and they will grow in many different climates and conditions. This, however, does not necessarily mean that hops are commercially viable in all places where it is possible to grow them.

- *Day length (Hops)*

The most important climatic factor for successful cultivation of hops is day length, also referred to as photoperiod. Hops will grow vegetatively with increasing day length, then flowering will begin when the days become shorter. However, a critical day length must be met before flowering is triggered, and this varies between cultivars. The critical day length is considered to be 15 hours, including an allowance for twilight

- *Growing Degree Days (Hops)*

Each of the climate stations in Kaipara suggest the district exceeds the growing degrees days required for hops.

- *Wind*

Since hops are typically grown on tall trellises, they are susceptible to wind damage. Hence wind is an important consideration for establishing a commercial hops operation. Corroborating this, Plant & Food Research has trialled hops in the Marlborough region, but the crops there failed, in part, due to excessive wind. Hemp and CBD cannabis are cultivated differently to hops and so wind is likely to be less of a concern for these crops.

Since it appears that the entire Kaipara District is relatively windy, it is likely that additional wind mitigation will be needed for hops, regardless of where they are grown. It is also possible that some areas of the Kaipara District would be unsuitable for hops due to excessive wind, even with additional mitigation.

Recommendation

In terms of day length and growing degree days (GDD), the Kaipara District is considered suitable for hops, hemp and CBD cannabis. Due to the warm, humid climate of Northland, pest and disease control will likely be required. There may also be mitigation requirements for poor draining soils such as those near Dargaville and mounding of soils, or deep ripping, would be a possibility.

In the case of hops, excessive wind is likely to be a limitation. Since the wind in Kaipara is generally comparable to, or greater than, the windrun in Blenheim, wind mitigation is very likely to be needed. This could potentially be in the form of shelterbelts, or alternative methods of growing hops, such as the short, three-metre trellises common in China. However, in the windiest parts of the Kaipara District, such as the Pouto Peninsula, it could be possible that the wind is so strong to make the growing of hops not possible, even with mitigation measures

Peanuts

Peanuts (*Arachis hypogaea* L.), also known as groundnuts, are a leguminous crop growing mainly for their edible seeds. Although not botanically a true nut, peanuts are commonly referred to as nuts. The botanist Carl Linnaeus named the species *hypogaea*, which means 'under the earth' as the peanut pods develop underground. The seed has a high oil content of between 44 and 52%. Peanuts grow best in light sandy loam soils and being a legume, they require little nitrogenous fertiliser. Peanuts therefore work well in a rotation sequence with other crops. Peanuts are consumed as whole peanuts, or pressed for oil, as well as being used to make peanut butter and peanut flour. A by-product of oil pressing is the residue, which is pressed into a protein cake that is used as an animal feed, or even fertiliser

Peanuts had been grown in New Zealand in the 1980s as small-scale crops across the country in areas with warm climates. This has included Northland, the Hawke's Bay and Marlborough. These crops were typically less than one hectare in size. Yields of up to four tonnes per hectare have been achieved, although yields of between 2 and 2.5 t/ha are more typical, depending on variety. Some crops produced very low yields, but the most common factor for that had been poor crop management such as poor weed control. The most successful cultivars were various Spanish and Valencia type peanuts.

The most important requirement for peanuts to grow is sufficiently warm temperatures and warm soil temperatures, especially in spring. Seeds are typically sown when the ground temperature reaches 15°C, and they require sustained periods of at least 18°C for sufficient growth. On average, the soil temperature across the Kaipara district will reach 15°C in early-mid October and stay above there until April. The soil temperature will be at or above 18°C, on average, from late November to March. Most years will have at least 1 or 2 months with sufficient soil temperatures for peanut growing, and it is rare for the soil temperature not to reach 18°C at all in a given year. This contrasts with most of the rest of New Zealand. Hence peanuts represent a good opportunity for the Kaipara District.

Peanuts require warm and free-draining soils, and relatively deep potential rooting depths, they are likely to be an agronomically feasible crop to grow in Kaipara. The Pouto Peninsula is a likely candidate for peanut cultivation since the free-draining, sandy soils are common there, and they would likely be suitable for peanuts. However, since the Pouto Peninsula is susceptible to erosion, measures to mitigate or protect from wind erosion would likely be needed.

Peanut agronomic potential in Kaipara

Table 3-1 provides agronomic insights into the potential for the arable cropping of peanuts. The average earliest planting date in terms of soil temperature would be around 1 October. Table provides the prediction of the mean season length and mean harvest date for both long- and short-season cultivars of peanut. Also shown is the percentage of years where there would be sufficient warmth for harvest to be achieved.

Table 3-1: Date of the first day when soil temperature at 10cm exceeds 15˚C.

Seed germination	Waipoua VCSN20478	Te Kopuru VCSN21434	Ruawai VCSN27564	Dargaville VCSN28571	Pouto VCSN29120	Mangawhai VCSN25588
First day T_{soil} >15°C	6 October	7 October	30 September	2 October	6 October	2 October

Table 4-2: Predictions of the mean season length (d) and mean harvest date of a short-season peanut cultivar (top) and a long-season cultivar (bottom) growing in the Kaipara District near six virtual climate station network sites (VCSN). The planting date was assumed to be 1 October. Also given are the percentage of the years, in the VCSN record of 46 years, in which the respective GDD10 criteria would be realised.

Peanuts	Waipoua VCSN20478	Te Kopuru VCSN21434	Ruawai VCSN27564	Dargaville VCSN28571	Pouto VCSN29120	Mangawhai VCSN25588
Short-season cultivar GDD_{10} = 1450						
Mean season length (d)	204	203	191	194	198	192
Mean harvest date	26 April	26 April	9 April	14 April	21 April	12 April
Years with GDD_{10}	87%	83%	95%	95%	87%	95%
Long-season cultivar GDD_{10} = 1600						
Mean season length (d)	225	224	215	213	223	213
Mean harvest date	13 May	13 May	2 May	30 April	13 May	2 May
Years with GDD_{10}	60%	56%	87%	77%	70%	85%

Soybeans

Soybean, sometimes called soya bean, (*Glycine max* L. Merr.), is a legume that is a native of East Asia. Being a legume, soybeans fix atmospheric nitrogen, and this makes it a useful crop to have in a rotation with other crops. Soybeans are used in a wide variety of ways. Soybean seed contains about 20% oil, and solvent extraction is used to remove the oil, and it is then refined and ends up in many processed foods or is used for cooking.

Soybean growth and development is sensitive to both photoperiod and temperature. A decline in photoperiod speeds up development, whilst temperature enhances the rate of development. Cultivars of soybean are adapted to a narrow range of latitudes due to their photoperiod requirement for floral initiation. There is a cultivar classification into ten maturity groups, from 00 to 8, according to their adaptation to latitude.

The feasibility of soybean production in the Kaipara and Northland region has been previously trialled. Piggot et al. (1980) carried out soybean trials on three cultivars at four sites in Northland: Dairy Flat, Helensville, Otakanini (on the south shore of Kaipara Harbour), and Ruatangata (northwest of Whangarei). The cultivar 'Amsoy' produced the best yields. In 1976–77, 'Amsoy' produced 2.5 and 2.6 t ha-1 at Otakanini and Helensville. Over the years 1978/79 and 1979/80 it yielded 6.2 and 5.0 t ha-1 at Otakanini. The yields from planting earlier than 10 November were the same as those planted 1 to 2 weeks later. A paper entitled "Soybean – A new crop for the Kaipara District" (Turnball 1976) described trials near Helensville with 20 soybean cultivars. The average soybean yield was 2.23 t ha-1, with the four 'Amsoy' hybrids yielding 2.73 t ha-1. The study was undertaken in unseasonal wet weather during October and planting was delayed until early November. Turnbull (1976) concluded that to provide financial returns that would be competitive with local maize crops yielding 6–8,000 kg ha-1 of grain, soybeans would need to yield between 2000 and 2750 t ha-1. The study suggested that 12 cultivars had the yielding ability to give equal or better returns than the average maize crop grown in Kaipara this season.

Recommendations

Soybeans could provide a useful rotation crop in Kaipara District to be used in conjunction with pasture, sorghum, kumara, and possibly even peanuts. Additionally, when soybeans are rotated with grain sorghum, the yields of soybean have been shown to increase (~50%), and when soybeans are grown after 3 years of fescue pasture yields also increase (~70%). The positive rotation effects on soybean yield were attributed to the reduction in soybean cyst nematode populations.

Given the high proportion of modern soybean seed-lines that are genetically modified (GM) to resist Roundup or increase oil quality. Indeed over 80% of the world's soybean crops are GM. So judicious choice of cultivar would be needed, and care would be needed to select locations with the best climate, as we discuss later (Section 6). An early to mid-October planting date in Kaipara is possible, heavy rainfalls notwithstanding.

Soybean agronomic potential in Kaipara

Table provides agronomic insights into the potential for the arable cropping of soybean. The average earliest planting date in terms of soil temperature would be around 1 October. Table provides the prediction of the mean season length and mean harvest date for both long- and short-season cultivars of soybean. Also shown is the percentage of years where there would be sufficient warmth for harvest to be achieved.

Table 4-3: Date of the first day when soil temperature at 10cm exceeds 15˚C.

Seed germination	Waipoua VCSN20478	Te Kopuru VCSN21434	Ruawai VCSN27564	Dargaville VCSN28571	Pouto VCSN29120	Mangawhai VCSN25588
First day T_{soil} >15°C	6 October	7 October	30 September	2 October	6 October	2 October

Table 4-4: Predictions of the mean season length (d) and mean harvest date of a short-season soybean cultivar (top) and a long-season cultivar (bottom) growing in the Kaipara District near six virtual climate station network sites (VCSN). The planting date was assumed to be 1 October. Also given are the percentage of the years, in the VCSN record of 46 years, in which the respective GDD_{10} criteria would be realised.

Soybean	Waipoua VCSN20478	Te Kopuru VCSN21434	Ruawai VCSN27564	Dargaville CSN28571	Pouto VCSN29120	Mangawhai VCSN25588
Short-season cultivar GDD_{10} = 1283						
Mean season length (d)	179	179	168	170	174	169
Mean harvest date	3 April	4 April	18 March	21 March	30 March	21 March
Years with GDD_{10}	97%	97%	97%	97%	97%	97%
Long-season cultivar GDD_{10} = 1629						
Mean season length (d)	231	228	215	219	225	218
Mean harvest date	19 May	15 May	1 May	4 May	13 May	6 May
Years with GDD_{10}	56%	50%	79%	75%	60%	83%

Sorghum

Sorghum is a genus of flowering plants in the grass family and is an indigenous crop to Africa. Traditionally sorghum was used in drought prone areas to provide better food security than could be provided by maize. The common grain sorghum is *Sorghum bicolor* (Lynn.) Moench. This sorghum variety is used as a food crop, animal fodder, plus for alcoholic beverages and for biofuels.

During the 1970s there was emerging interest in Sorghum, and much of this work focussed on new cropping options for Northland, where droughts then (and now) compromise pasture production. Deeper rooting crops were seen as a better option for drought avoidance. The research in New Zealand focussed on the use of sorghum and sorghum-Sudan grass hybrids for:

- **Grain production Ryan (1975)**

Ryan (1975) assessed both maize and sorghum grains as being high-energy grain crops and potentially suited as stockfeeds for layer hens and broilers, as well as for pigs and stock. He noted that nutritionally maize and sorghum are similar, and he concluded that these were ideally suited for stockfeed, especially in the warmer parts of the North Island. Taylor et al. (1974) carried out trials with sorghum at three sites in Northland, and they presented results for grain production at two contrasting sites for five cultivars of sorghum with different maturity times. Yields on peaty soil (~7 t ha^{-1}) exceeded those on sandy soil (~6 t ha^{-1}). Late season droughts also reduced the yields of late-season cultivars.

- **Greenfeed fodder (Jurlina 1978)**

From field trials carried out in 1970–80s it was shown that sorghum can be grown successfully for greenfeed in Northland, and that it could provide more feed than that which can be expected from pasture during dry summers.

- **Conserved silage (Taylor et al. 1974)**

Taylor et al. (1974) considered that "… the main use envisaged for sorghums in Northland is production of stored feed as silage rather than for grain." They added that the total dry matter yields were "… most encouraging considering the very dry 1973–74 summer."

- **Energy farming for ethanol (Piggot and Farrell 1980)**

With the feed-food dilemma today, and the rise in electric vehicles, interest in farming energy crops is waning. However, Sudax and in particular Sweet sorghum cv. 'Sugar Drip', or 'Saccaline', were seen as good options for energy crops, especially in Northland. Piggot and Farrell (1980) described a trail at six sites in the north with 'Saccaline', and they compared these results with a trial at Pukekohe on two sugar beet cultivars and two fodder beet cultivars. The 'Saccaline' was planted during the last fortnight of November 1979. The sorghum reached the hard dough stage in early May. The 'Saccaline' averaged 20.3 t DM ha-1, and the Sudax 15 t DM ha-1. The beets averaged a sugar yield of 14 t ha-1, whereas the 'Saccaline' produced only about 4 t ha-1 of sugar. Nonetheless, the DM results from Piggot and Farrell (1980) highlight the high yields possible with Sudax and 'Saccaline'.

Despite earlier research ventures, there is no reported commercial production of sorghum in New Zealand; although the crop has been available for over a decade. Nonetheless, the production of sorghum can itself be affected by droughts, and soils with greater water holding capacities will provide better yields. Growing sorghum for grain is possible, especially for early maturity cultivars, although the yields tend to be less than that likely to be achieved with maize. Sorghum can also be used in rotation with sweet potatoes, as well as with soybeans. Thus sorghum, and soybeans, could well be used across the Kaipara District in rotation with themselves, as well as with pasture and kumara.

Sorghum agronomic potential in Kaipara

Table provides agronomic insights into the potential for the arable cropping of sorghum. The average earliest planting date in terms of soil temperature would be around 1 October. Table shows the prediction of the mean season length and mean harvest date for both long- and short-season cultivars of sorghum. Also shown is the percentage of years where there would be sufficient warmth for harvest to be achieved.

Table 4-5: Date of the first day when soil temperature at 10cm exceeds 15˚C.

Seed germination	Waipoua VCSN20478	Te Kopuru VCSN21434	Ruawai VCSN27564	Dargaville VCSN28571	Pouto VCSN29120	Mangawhai VCSN25588
First day T_{soil} >15°C	6 October	7 October	30 September	2 October	6 October	2 October

Table 4-6: Predictions of the mean season length (d) and mean harvest date of a short-season sorghum cultivar (top) and a long-season cultivar (bottom) growing in the Kaipara District near six virtual climate station network sites (VCSN). The planting date was assumed to be 1 October. Also given are the percentage of the years, in the VCSN record of 46 years, in which the respective GDD_{10} criteria would be realised.

Sorghum	Waipoua VCSN20478	Te Kopuru VCSN21434	Ruawai VCSN27564	Dargaville VCSN28571	Pouto VCSN29120	Mangawhai VCSN25588
Short-season cultivar						
Mean season length (d)	209	205	197	200	204	198
Mean harvest date	1 May	27 April	16 April	19 April	26 April	18 April
Years with GDD_{10}	83%	75%	95%	95%	85%	95%
Long-season cultivar						
Mean season length (d)	247	247	250	253	246	250
Mean harvest date	22 May	23 May	29 May	31 May	24 May	1 June
Years with GDD10	10%	10%	37%	31%	12%	35%

Summary of selected crops and their potential for Kaipara

Olives are already grown around Northland including the Kaipara District near Mangawhai, it is likely that there are other areas of the Kaipara District where olives would be a suitable croc. Due to the warm, humid climate of Northland, pest and disease control will likely be required. Based on the need for deep, free-draining soils, the west coast around Dargaville and the Pouto Peninsula would potentially be suitable sites. Mounding of the soil, or deep ripping, might be needed where the soils have imperfect drainage.

In terms of day length and summer warmth, the Kaipara District is considered suitable for **hops, hemp and CBD cannabis**. Due to the warm, humid climate of Northland, pest and disease control will likely be required. There may also be mitigation requirements for poor draining soils such as those near Dargaville, and mounding of soils and deep ripping would be a possibility. In the case of hops, excessive wind is likely to be a limitation, because hops are grown on 5 m high trellises, so wind mitigation is very likely to be needed. This could potentially be in the form of shelterbelts, or alternative methods of growing hops, such as the short, three-metre trellises common in China. However, in the windiest parts of the Kaipara District, such as the Pouto Peninsula, it could be possible that the wind is so strong to make the growing of hops not possible, even with mitigation measures.

Avocados require similar conditions to olives. Since both olives and avocados are already grown in Northland, it is considered worthy of further investigation for cultivation in the Kaipara District. The need for deep and free-draining soils could exclude Dargaville and Ruawai without soil mitigation. Mangawhai and the west coast are potentially suitable areas.

Sorghum, soybeans and peanuts, present an opportunity to be incorporated into cropping rotations with existing agricultural systems in the Kaipara District. For all crops, matching cultivar selection to location will be important to ensure the local weather and soil conditions are appropriate. It is likely that peanuts would be best suited to the sandy soils in the west of Kaipara District, especially on the Pouto Peninsula, whereas soybeans and sorghum would be better suited to the heavier textured soils surrounding the Kaipara Harbour and Ruawai, plus those in the east towards Mangawhai. Choice of soybean and sorghum cultivar, in relation to season-length, will be critical to ensure that the crop can reach grain maturity. Sorghum could also be used as a green-feed crop, or grown for conserved feed in the form of silage. These crops can be used in rotation with each other, as well as with existing crops in the Kaipara such as kumara.

4 Future climate and crop suitability

Climate change is projected to impact the climate of New Zealand considerably. Making informed decisions on any existing and/or future horticultural investment/transformation and land-use change should consider the role of climate change as well as natural variations in the climate. The information presented in this section is informed by assessments of the Intergovernmental Panel on Climate Change (IPCC, 2013, IPCC, 2014c, IPCC, 2014a, IPCC, 2014b) and related New Zealand studies. Details specific to the Kaipara District were based on NIWA's modelling for New Zealand that involved downscaling of global climate model simulations. This effort utilised several IPCC representative concentration pathways (RCPs) for the future and this was achieved through NIWA's Strategic Science Investment Fund (SSIF) programme on Regional Climate Modelling. The climate change information presented in this report is consistent with recently updated national-scale climate change guidance produced for the Ministry for the Environment (2018).

The following sections provide a summary of the NIWA (2020) report and the report by Plant and Food (2020). The projected future changes presented consider differences between the historical period (based on the 1986-2005 average) and two future time-slices, 2031-2050 (depicted by the mid-point year 2040) and 2081-2100 (mid-point year 2090). Representative concentration pathways (RCPs) depict a range of global atmospheric greenhouse gas concentrations from 2005 to 2100, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. This summary report references two of the scenarios: RCP4.5 – a mid-range scenario and RCP8.5 – a business-as-usual scenario.

Climate projections for the Kaipara District

Average temperature

Annual average air temperature is projected to increase by 0.5-1.0°C for all seasons (and annual) by 2040 under RCP4.5. The same is projected for 2040 under RCP8.5, except autumn is projected to warm by 1.0-1.5°C. By 2090, most of the region is projected to warm by 1.0-1.5°C under RCP4.5 for all seasons and at the annual scale. Under RCP8.5 warming is projected to be around 2.0-3.5°C by 2090 for most of the region at the annual and seasonal scale.

Hot days and extreme hot days

The number of hot days per year (days with temperature >25°C) shows similar patterns under both RCP4.5 and RCP8.5 by 2040 (Figure 4-1), with increases of around 5-20 days. By 2090, the projected magnitude of changes in hot days are quite different between the two scenarios, although the spatial pattern is similar. Under RCP4.5, 15-40 more hot days per year are projected for most of Kaipara District. In contrast, under RCP8.5 60-80 more hot days per year are projected for the District.

For extreme hot days (days with temperature >30°C), minor increases of between 0-1 days are projected by 2040 under RCP4.5 and RCP8.5. In contrast, by 2090 under RCP8.5, western parts of Kaipara District are projected to see a 10-12 day increase in extreme hot days.

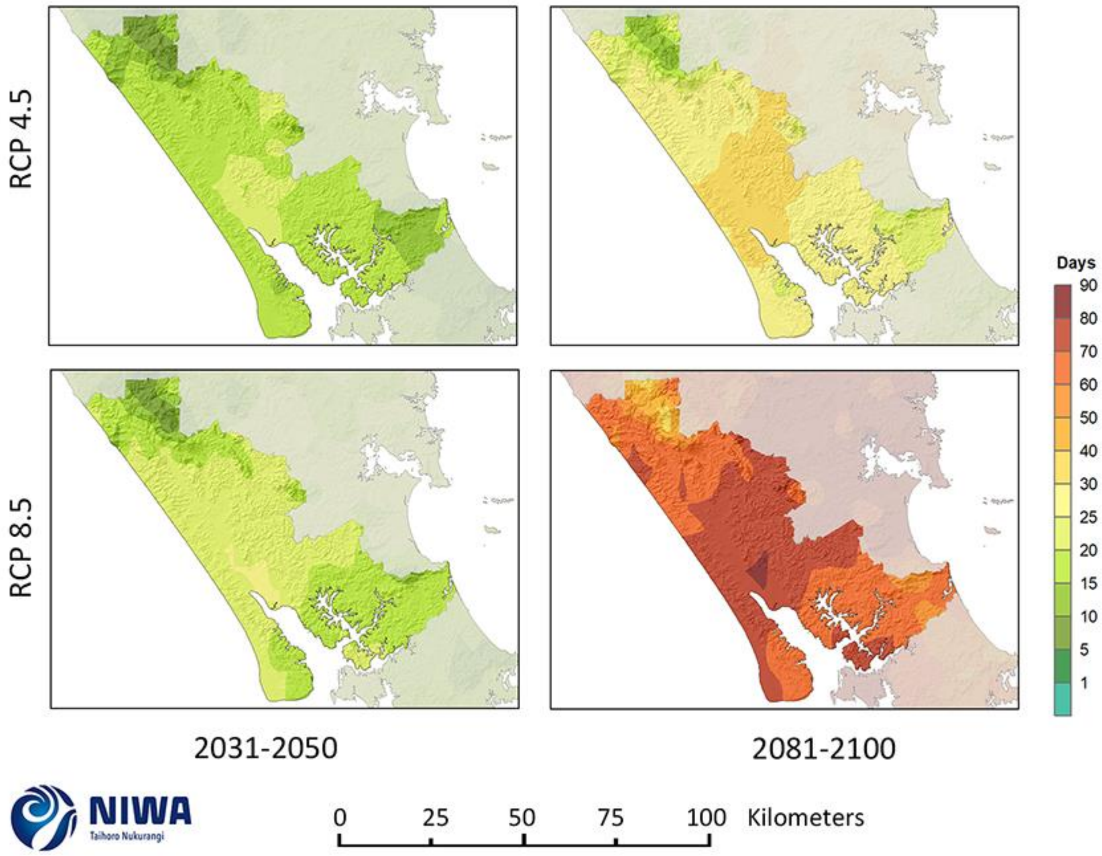

Figure 4-1: Projected annual hot day (max. temp. >25˚C) changes for RCP4.5 and RCP8.5 by 2040 and 2090.

Heatwave days

The definition of a heatwave as considered here is a period of three or more consecutive days where the maximum daily temperature exceeds 25°C. The number of heatwave days per year shows similar patterns of change under both RCP4.5 and RCP8.5 by 2040, with projected increases of 10-20 days for much of Kaipara District (Figure 4-2). By 2090, the projected magnitude of changes in heatwave days are quite different between the two scenarios. Under RCP4.5, 20-30 more heatwave days are projected for most of Kaipara District. Under RCP8.5, 60-80 more heatwave days per year are projected for most of the area.

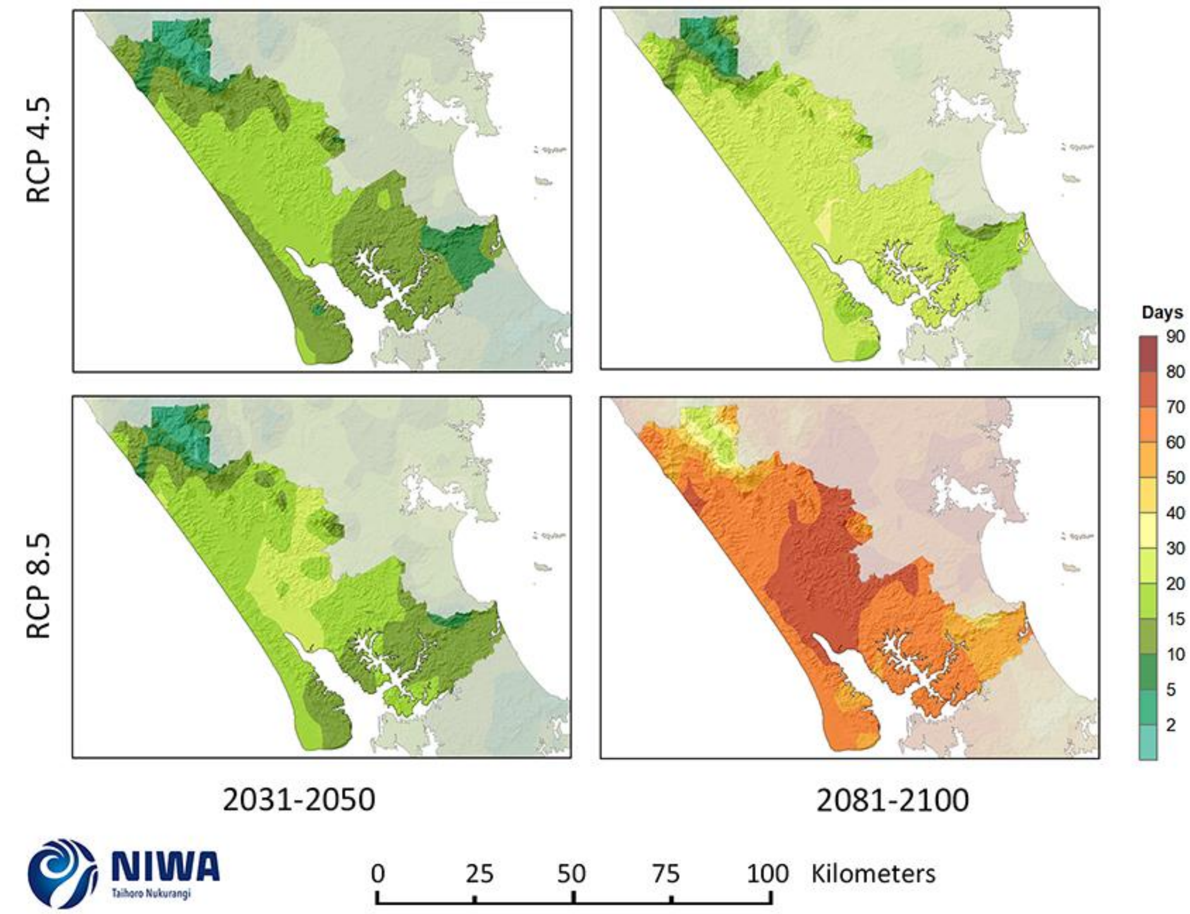

Figure 4-2: Projected annual heatwave day (≥ 3 consecutive days with max. temp. >25˚C) changes for RCP4.5 and RCP8.5 by 2040 and 2090.

Growing degree days

The number of growing degree days (GDD) is projected to increase under all scenarios (see Figure 4-3). By 2040 under RCP4.5, most of the Kaipara District observes a projected increase of 250-300 GDD per year. By 2040 under RCP8.5, most of the District observes a projected increase of 300-350 GDD per year. By 2090 under RCP4.5, increases of 400-450 GDD per year are projected. By 2090 under RCP8.5, increases of 900-1,000 GDD per year are projected for the majority of the Kaipara District.

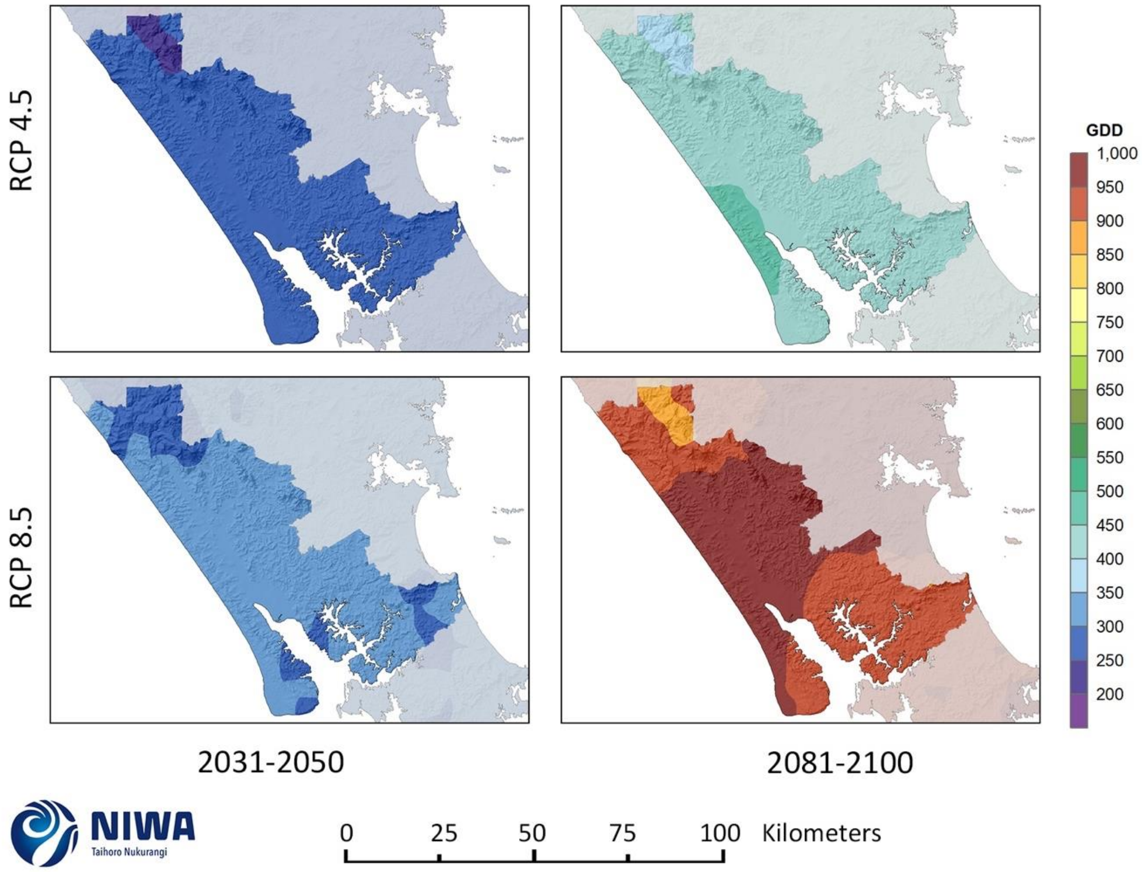

Figure 4-3: Projected annual growing degree day (base 10˚C) changes for RCP4.5 and RCP8.5 by 2040 and 2090.

Projected rainfall and drought for the Kaipara District

Kaipara District is generally projected to have only small changes to future annual rainfall. By 2040 under RCP4.5, projected changes to annual rainfall are typically ±2%, with 2-4% more annual rainfall projected for northern coastal areas. By 2040 under RCP8.5 (Figure 4-4), annual rainfall is projected to change by ±2% throughout Kaipara District. At the seasonal scale, increases in autumn rainfall of between 6-15% are projected for much of Kaipara District by 2040 under RCP4.5, with a decrease in summer rainfall of 4-8% projected under this scenario. By 2040 under RCP8.5 (Figure 4-4), increases in autumn rainfall of between 2-8% are projected for much of Kaipara District, with a decrease in spring rainfall of 2-10% projected in most parts.

By 2090 under RCP4.5, annual rainfall changes of ±2% are projected for Kaipara District. By 2090 under RCP8.5 (Figure 4-4), a decrease in annual rainfall of 2-6% is projected for northern and inland parts of Kaipara District. At the seasonal scale, increases in autumn rainfall of between 4-10% are projected for much of Kaipara District by 2090 under RCP4.5, with a decrease in spring rainfall of 4-10% projected under this scenario. By 2090 under RCP8.5 (Figure 4-4), increases in autumn rainfall of between 6-15% are projected for southern parts of Kaipara District, with a decrease in winter and spring rainfall of 6-15% projected in most parts.

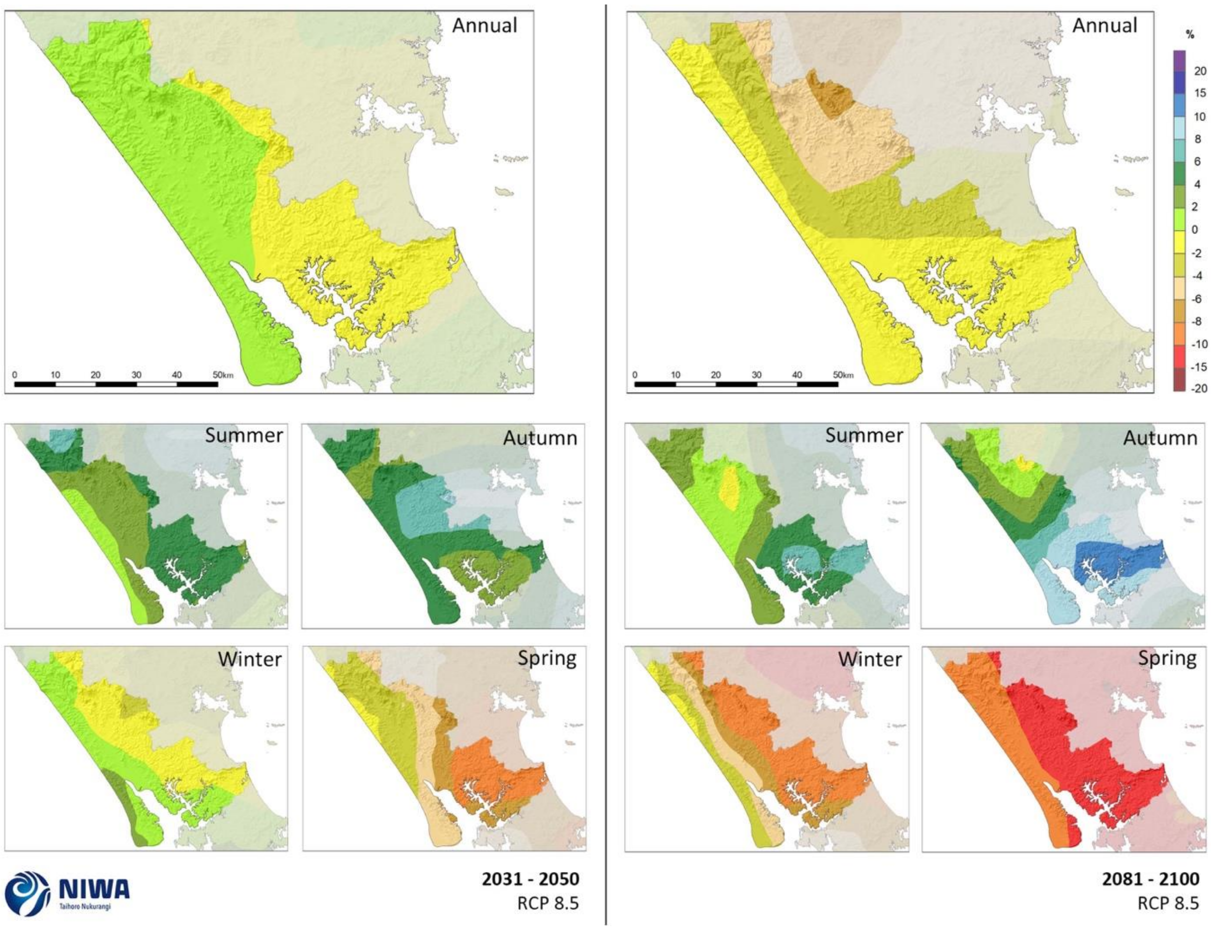

Figure 4-4: Projected mean annual and mean seasonal rainfall changes by 2040 (left) and 2090 (right) for RCP8.5.

Wet days

Most of Kaipara District is projected to observe a decrease in wet days of 16-22 days per year (by 2090 under RCP8.5). A decrease of 4-8 wet days is projected for most of Kaipara District by 2040 under RCP4.5 and RCP8.5. By 2090 under RCP8.5, a decrease of 6-10 wet days in spring is projected for most of the district.

Extreme, rare rainfall events

Extreme, rare rainfall events are likely to increase in intensity in Kaipara District because a warmer atmosphere can hold more moisture. Rainfall depth increases are projected at both future periods (2040 and 2090) under all four RCPs; greatest increases are projected by 2090 under RCP8.5 (up to 35% higher for a 1:100 year 1-hour duration rainfall event). Short duration rainfall events have the largest relative increases. Extreme rainfall projections for any New Zealand location can be viewed at https://hirds.niwa.co.nz/. Increases in extreme rainfall events may cause more flooding, but this is yet to be thoroughly researched in New Zealand. Table 4-1 – Table 4-3 show modelled historic and projected rainfall depths for a 1-hour rain event, 6-hour rain event, and 24-hour rain event, based upon a 50-year Average Recurrence Interval (ARI) and a 100-year ARI.

Table 4-1: Modelled historic and projected rainfall depths (mm) for a 1-hour event with a 50-year ARI (top) and a 100-year ARI (bottom).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Dargaville	40.3	43.5	44.3	44.0	44.9	43.5	46.9	49.2	54.4
Mangawhai	56.4	60.9	62.0	61.5	62.8	60.9	65.6	68.8	76.0

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Dargaville	44.9	48.5	49.4	49.0	50.1	48.5	52.3	54.8	60.6
Mangawhai	63.0	68.1	69.4	68.8	70.3	68.1	73.4	77.0	85.1

Table 4-2: Modelled historic and projected rainfall depths (mm) for a 6-hour event with a 50-year ARI (top) and a 100-year ARI (bottom).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Dargaville	90.5	96.5	98.0	97.4	99.2	96.5	103	107	117
Mangawhai	114	122	124	123	125	122	130	135	147

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Dargaville	101	108	109	109	111	108	115	120	131
Mangawhai	128	136	138	137	140	136	145	151	165

Table 4-3: Modelled historic and projected rainfall depths (mm) for a 24-hour event with a 50-year ARI (top) and a 100-year ARI (bottom).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Dargaville	153	161	163	162	164	161	169	174	187
Mangawhai	178	187	189	188	191	187	196	203	217

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Dargaville	171	180	182	181	184	180	189	195	209
Mangawhai	199	209	212	210	213	209	220	227	243

Dry days

A dry day considered here is when < 1 mm of rainfall is recorded. By 2040 under RCP4.5, the annual number of dry days is projected to increase by 4-8 days for most of Kaipara District. The greatest increase in seasonal dry days is projected in summer, with 2-4 more dry days for most of the District.

By 2090 the pattern of increase in dry days is amplified. Under RCP8.5, a considerable increase in annual dry days is projected, with 16-22 more dry days for most of the District. The greatest seasonal change is projected for spring, with 6-10 more dry days for most of the area.

Potential evapotranspiration deficit and soil moisture deficit

In the future, the amount of accumulated potential evapotranspiration deficit (PED[3]) is projected to increase across Kaipara District (Figure 4-5), therefore drought potential is projected to increase. By 2040 under both RCPs, most of the District is projected to experience an increase in annual PED of 80-100 mm. By 2090 under RCP4.5, much of the District is projected to experience an additional 80-100 mm of annual PED, with areas along the northeastern fringes of the District projected to experience an additional 60-80 mm of annual PED. By 2090 under RCP8.5, annual PED is projected to increase by 120-160 mm for most of the Kaipara District. For north-eastern parts of the District, annual PED is projected to increase by 100-120 mm.

Kaipara District is projected to observe an increase in days of soil moisture deficit (SMD) of 20-35 days per year (by 2090 under RCP8.5). An increase of 2-10 days of SMD is projected for most of Kaipara District by 2040 under RCP4.5. By 2090 under RCP8.5, an increase of 15-20 days of SMD in spring is projected for most of the District.

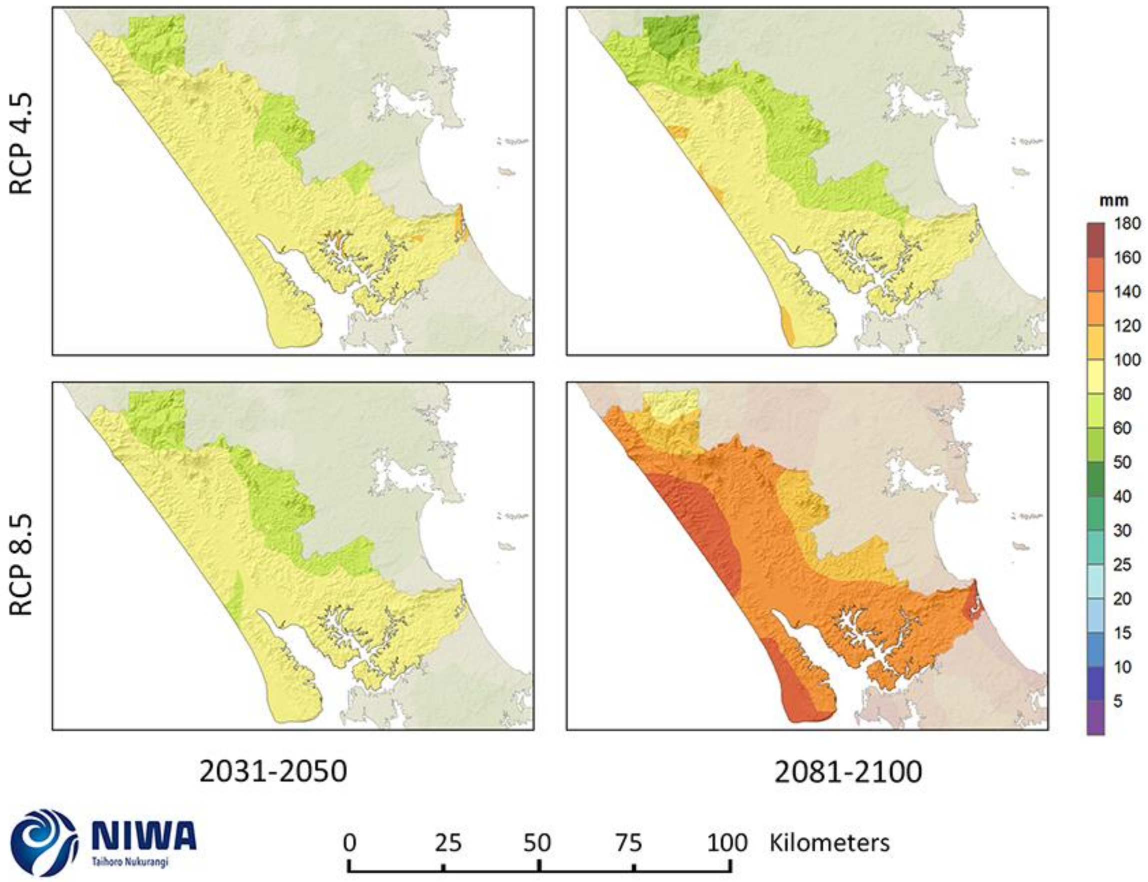

Figure 4-5: Projected annual potential evapotranspiration deficit (PED) accumulation changes for RCP4.5 and RCP8.5 by 2040 and 2090.

Impacts of sea-level rise

Local sea level trends show a national average rise of 1.8 mm/year from the early 1900s to 2015 (MfE, 2017). Adaptation to sea-level rise (SLR) requires knowledge on why and how local SLR around New Zealand is affected by ongoing vertical land movement. Of most concern is the presence of any

[3] PED may be considered to represent the additional water that would need to be added (e.g. via rainfall or irrigation) to maintain pasture growth.

significant ongoing subsidence of the landmass, which will exacerbate the absolute ocean SLR. Coastal flooding from extreme sea levels will increase in frequency and magnitude as global climate change forces sea-level rise. Extreme sea level events, rare in the recent past (i.e., once per century), are projected to occur at least once per year by 2050 along many of the world's coastlines.

A large portion of land exposed to 100-year annual recurrence interval extreme sea levels in the Kaipara District is productive land. The total amount of land exposed in the future will depend on the extent of sea-level rise.

To assist with adaptive approaches to planning, the bracketed time window (approximate earliest to latest) when various SLR increments may be reached is shown in for all scenarios in Table 4-4 (except for NZ RCP6.0 which is similar to NZ RCP4.5). For example, 0.5 m of SLR for New Zealand is projected to occur by 2060 at the earliest (assuming a RCP8.5 83rd percentile scenario) and 2110 at the latest (under the low-emission RCP2.6 scenario). Even earlier exceedance of the specific SLR increment cannot be entirely ruled out (depending on the future emission controls and possible runaway polar ice sheet responses). Exceedance of a 1 m SLR is projected by 2100 for a possible earliest (based on the RCP8.5 83rd percentile scenario) and after 2200 at the latest.

Table 4-4: Approximate years, from possible earliest to latest, when specific SLR increments (metres above 1986-2005 baseline) could be reached for various projection scenarios of SLR for the wider New Zealand region. From Stephens et al. (2017)

SLR (metres)	Year achieved for RCP8.5 (83%ile)	Year achieved for RCP8.5 (median)	Year achieved for RCP4.5 (median)	Year achieved for RCP2.6 (median)
0.3	2045	2050	2060	2070
0.4	2055	2065	2075	2090
0.5	2060	2075	2090	2110
0.6	2070	2085	2110	2130
0.7	2075	2090	2125	2155
0.8	2085	2100	2140	2175
0.9	2090	2110	2155	2200
1.0	2100	2115	2170	>2200
1.2	2110	2130	2200	>2200
1.5	2130	2160	>2200	>2200
1.8	2145	2180	>2200	>2200
1.9	2150	2195	>2200	>2200

Hydrological impacts of climate change for Kaipara District

Hydrological modelling shows that the future mean annual discharge of rivers is set to generally decrease by mid-century across the Kaipara District (NIWA, 2020). By late century, the mean discharge decrease is accentuated in the north-eastern area of the district with increasing greenhouse gas concentrations. The mean annual low flow of rivers is also expected to generally decrease by late century, with decreases exceeding 20% in many areas of the district.

Despite decreases in mean flows, floods are expected to become larger for many parts of the district under high greenhouse gas concentrations. This is due to the projected increase in magnitude of extreme rainfall events.

A separate water options report by Williamson Water and Land Advisory (2019) provides an analysis of potential water supplies capable of supporting small scale horticulture developments in the Kaipara District, that could be accessed readily in the short term.

Impact of climate change on crop suitability

Plant & Food assessed the future suitability of crops in Kaipara by using data provided by NIWA for the projected climate under the RCP 8.5 climate change scenario in the 2050's and comparing with suitability calculations for 1986 to 2005. A full breakdown of projected changes for each of the crops selected for this project is available in Ward (2020).

In general, it is expected there will be significantly more GDD_{10} over the growing season and a corresponding decrease in winter chilling and frost.

It is projected that crops with significant summer warmth requirements and no specific winter chilling requirements would be better suited for Kaipara in the 2050s, including avocados, sorghum, soybeans and peanuts.

No major change in the suitability of olives for Kaipara in general is expected, however appropriate selection of cultivar would be important depending on the area and how the winter chill hours are projected to change for that area. Fungal control is an important consideration for olives currently, and we would not expect that to change in the 2050s as the autumnal rainfall is projected to increase.

While the projected temperatures in the 2050s would appear to be suitable for hemp and CBD cannabis, as Kaipara is expected to remain about as windy as it currently is, hops would be difficult to grow with conventional tall trellises.

5 Discussion

There are 310,000 ha of land within the boundaries of the Kaipara District Council. By combining soil data from Manaaki Whenua Landcare Research and climate data from NIWA, a non-crop specific assessment of general horticulture found that approximately 44,200ha (14%) of this land is generically suitable for horticulture (Figure 3-1). An additional 17,000 ha (5%) of land could also be suitable, although this area is susceptible to wind erosion and would most likely require appropriate management, shelter mitigation, and irrigation. In addition to these areas, a further 69,000 ha is considered suitable for arable cropping. Overall, there is good potential for horticulture in the district.

A more detailed look into the suitability of the chosen six crops (avocado, sorghum, olives, peanuts, soybeans and hops/hemp/CBD cannabis) showed that they present an opportunity to be grown and incorporated into cropping rotations with existing agricultural systems in the Kaipara District. Some limitations such as soils with poor drainage and shallow potential rooting depth could be mitigated with options, such as artificial drainage, and/or mounding along the row of horticultural crops.

Climate change will likely impact the horticulture industry in Kaipara District, particularly through changes to temperature and rainfall. Projected climate changes will bring challenges (e.g. higher PED resulting in increased demand for water resources) and opportunities (e.g. warmer temperatures more suitable to warm climate crops) to the horticulture industry of Kaipara District.

Increasing temperatures will impact all types of crops, as plant phenological development may occur at a faster rate. Different stages of plant growth (e.g. bud burst, flowering, and fruit development) may happen at different times, which may affect the harvested crop. For example, the hottest summer on record for New Zealand in 2017/18 saw wine grapes in multiple New Zealand regions ripen faster than usual (Salinger et al., 2019). In Central Otago, this resulted in the earliest start to harvest of Pinot Noir grapes on record (almost a month earlier than usual). In Wairarapa, the period from flowering to harvest for wine grapes was about 10 days shorter than usual[4].

Extreme heat affects the rate of evapotranspiration, or the uptake of water by plants. Therefore, increases to extreme heat may affect water availability, as under hot conditions plants use more water than usual. Extreme heat may also result in current varieties of crops and pasture becoming unsustainable if they are not suited to growing in hot conditions.

Reductions in cold conditions may have positive impacts for diversification of new crop varieties that are not able to currently be grown in Kaipara District. However, future warmer temperatures may create issues for horticulture in the District. Increasing risk from pests (plants and animals) and diseases is a concern. Currently, many pests are limited by New Zealand's relatively cool conditions, so that they cannot survive low winter temperatures, and therefore their spread is limited (Kean et al., 2015). Under a warmer climate, these pests may not be limited by cold conditions and therefore cause a larger problem for farmers and growers in Kaipara District.

Increases in extreme rainfall event magnitudes may impact horticulture in several different ways. Slips on hill country land may become more prevalent during these events, and soil erosion may also be exacerbated by increasing drought conditions. This has impacts on the quality of soil for horticulture, the area of land available for production, and other impacts such as sedimentation of waterways (which can impact flooding and water quality). Slips may also impact transport infrastructure (e.g. roads, farm tracks) which may in turn affect connectivity of farms and orchards to markets.

Increased prevalence of drought and longer dry spells in Kaipara District will likely have impacts on water availability for irrigation and other horticultural uses. Low river flows are likely to decline in the District, with reduced flow reliability (the time period where river water abstraction is unconstrained). In addition, soils are generally projected to be drier in Kaipara District, which may further impact plant growth and increase the need for irrigation.

6 Limitations

- Where climatic data suggests land use could be suitable for the selected crops, more detailed soil assessment including field site assessment by a qualified soil surveyor is required to ascertain soil variability within the soil map unit and the suitability of the soil for the proposed land use. Without field verification it is not possible to assess the quality of the current regional-scale soil information, although experience from remapping of other regions has shown considerable differences can occur.

- Fieldwork to generate the soil maps used in this study was undertaken in the mid-1950s with soils developed in similar rocks aggregated into 'soil suites'. It is unlikely we would use the same methods today as soils within the soil suites can show considerable variation in

[4] https://michaelcooper.co.nz/2018-regional-vintage-overview-report/

properties such as drainage class. The Kaipara District is not covered by Manaaki Whenua – Landcare Research's most recent S-map product and associated soil information.

7 Recommendations

This report has assessed crop suitability for selected crops based on available climate and soil data. There remain a number of knowledge gaps in this information, as well as opportunities for further application to inform decision making in the Kaipara District. We make the following recommendations for council's consideration:

- This study focused on land suitable for crops. Unfavourable cropping soils may still provide development opportunities for carbon sequestration (and associated carbon markets) as well as contribute to biodiversity resilience. Further work could be done to investigate this potential.
- As stated in the limitations, the fieldwork to generate the soil maps used in this study was undertaken in the mid-1950s. To assess the quality of the soil information, it is recommended that fieldwork is carried out to check both the spatial variation in soil types as well as characterisation of key soil attributes such as drainage class, soil water holding capacity, and crop root limitations such as subsoil pans.
- Selected crops and other potential horticulture income streams require information on their impact on regional biodiversity and impact under different climate change scenarios. The impact of fertiliser use, especially for soybeans and sorghum, on receiving water quality would need to be considered. Likewise, the risk of sediment losses through expansion of arable cropping also needs to be considered.
- Any large-scale horticulture land-use change should consider biosecurity threats under different climate change scenarios. Ongoing biosecurity in the region is a challenge and climate change may result in the incursion of new pests and diseases in New Zealand, particularly the Northland-Auckland region.
- The effects of climate change on water quality, water availability and implications for water storage options should be assessed.
- The modelling predictions of meteorological drought risk indicates that more detailed crop and soil specific soil water deficit assessment would be valuable for planning of future land-use change options.

8 Kaipara Kai reports

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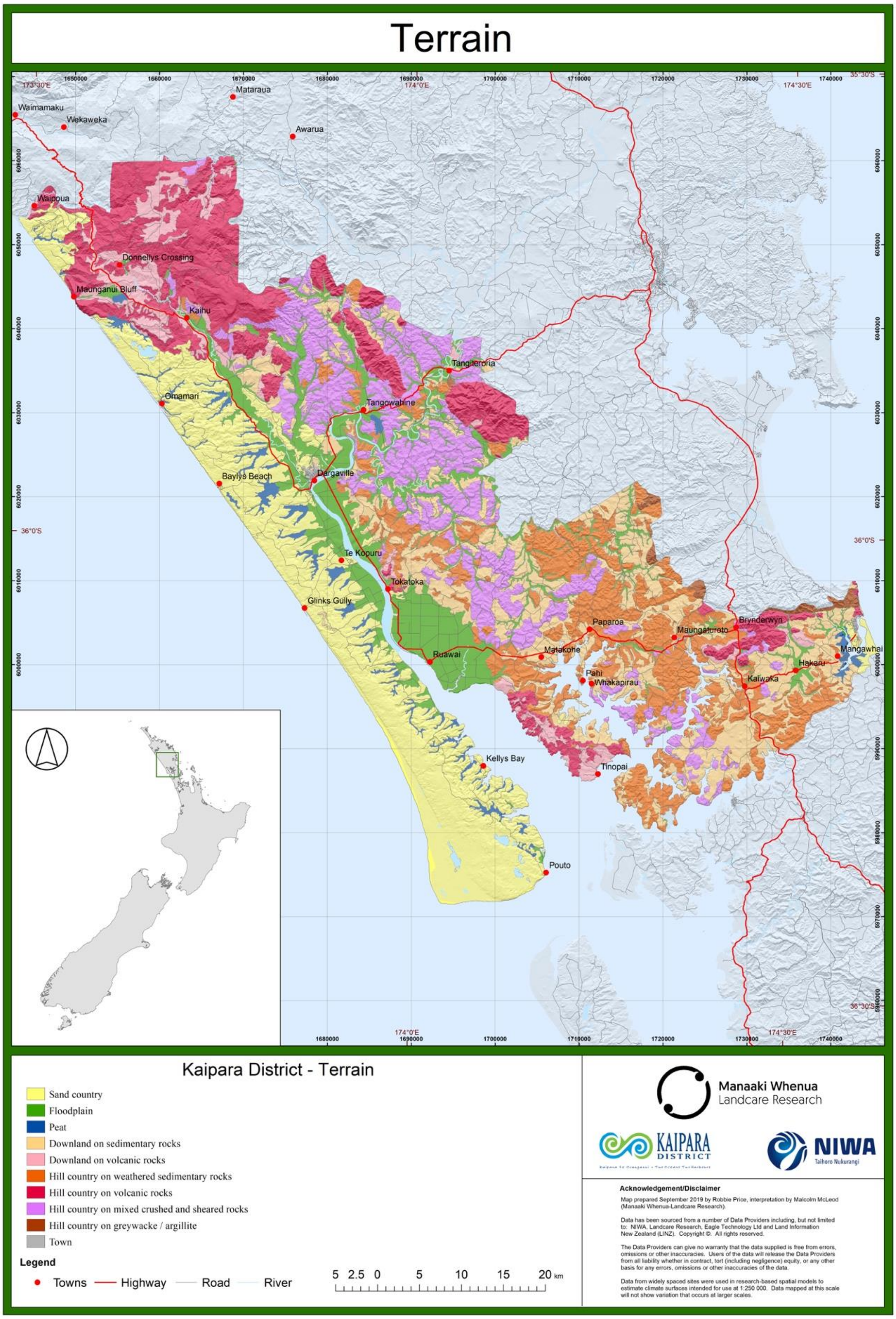
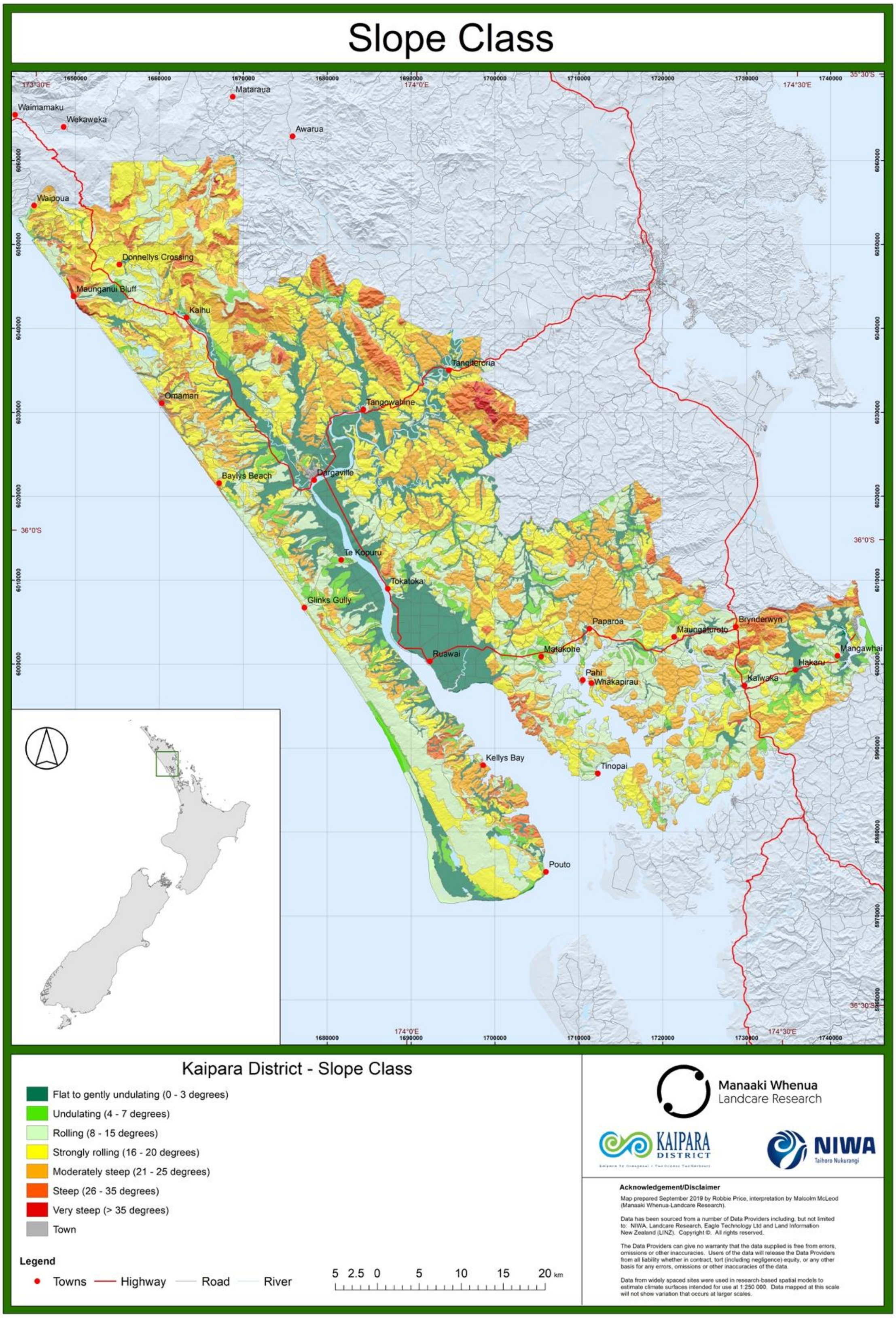
10 Appendix A





Slope Class
Waimamaku
Wekaweka
Mataraua
Awarua
Waipoua
Donnellys Crossing
Maunganui Bluff
Kaihu
Tangiteroria
Omamari
Tangowahine
Baylys Beach
Dargaville
Te Kopuru
Tokatoka
Glinks Gully
Paparoa
Maungaturoto
Brynderwyn
Ruawai
Matakohe
Pahi
Whakapirau
Kaiwaka
Hakaru
Mangawhai
Kellys Bay
Tinopai
Pouto
174°0'E
174°30'E
36°0'S
Kaipara District - Slope Class
Flat to gently undulating (0 - 3 degrees)
Undulating (4 - 7 degrees)
Rolling (8 - 15 degrees)
Strongly rolling (16 - 20 degrees)
Moderately steep (21 - 25 degrees)
Steep (26 - 35 degrees)
Very steep (> 35 degrees)
Town
Legend
Towns
Highway
Road
River
5 2.5 0 5 10 15 20 km
Manaaki Whenua
Landcare Research
KAIPARA DISTRICT
NIWA
Taihoro Nukurangi
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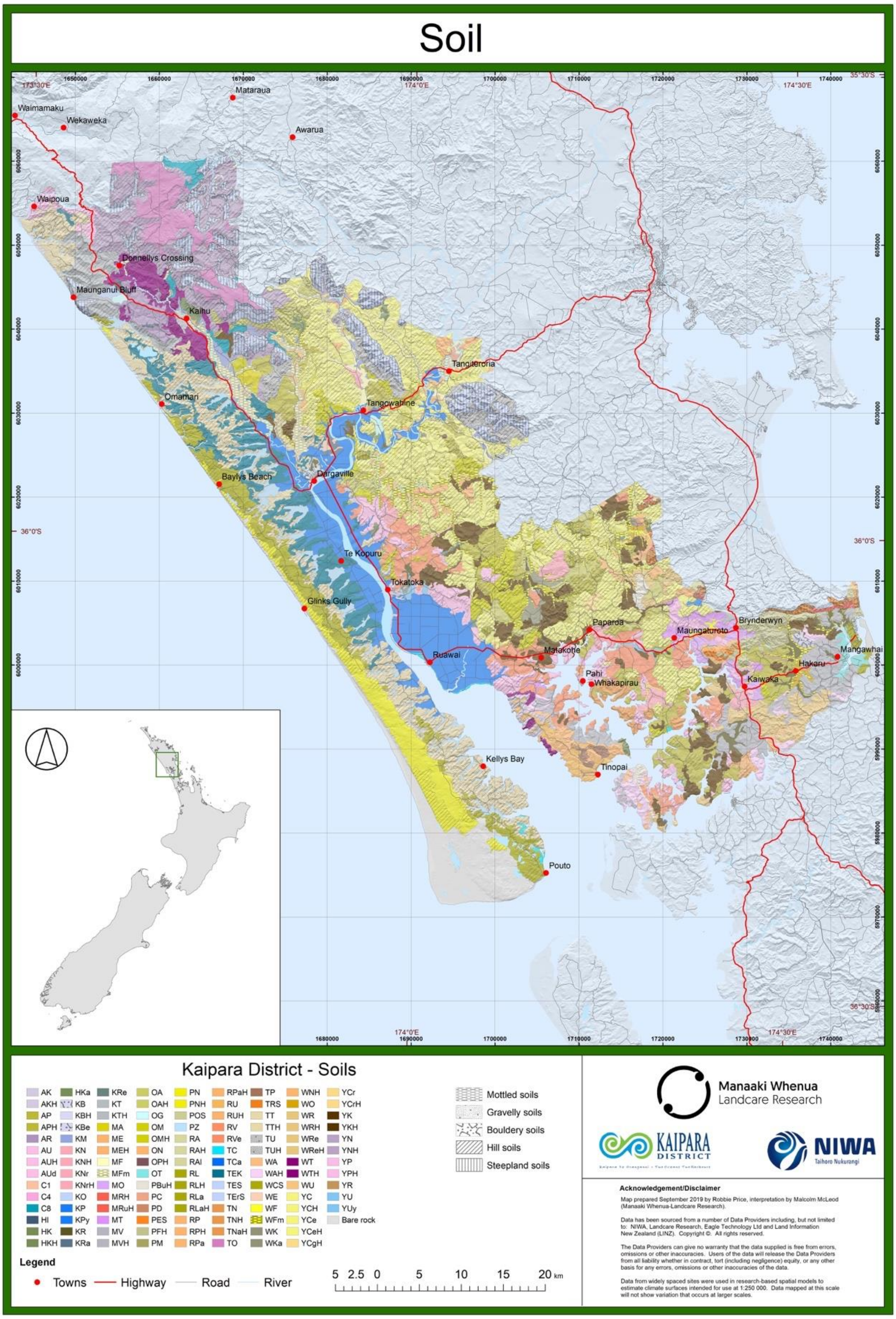
Soil
Waimamaku
Wekaweka
Mataraua
Awarua
Waipoua
Donnellys Crossing
Maunganui Bluff
Kaihu
Tangiteroria
Omamari
Tangowahine
Baylys Beach
Dargaville
Te Kopuru
Tokatoka
Glinks Gully
Paparoa
Maungaturoto
Brynderwyn
Mangawhai
Ruawai
Matakohe
Pahi
Whakapirau
Kaiwaka
Hakaru
Kellys Bay
Tinopai
Pouto
173°30'E
174°0'E
174°30'E
35°30'S
36°0'S
36°30'S
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Kaipara District - Soils
AK AKH AP APH AR AU AUH AUd C1 C4 C8 HI HK HKH
HKa KB KBH KBe KM KN KNH KNr KNrH KO KP KPy KR KRa
KRe KT KTH MA ME MEH MF MFm MO MRH MRuH MT MV MVH
OA OAH OG OM OMH ON OPH OT PBuH PC PD PES PFH PM
PN PNH POS PZ RA RAH RAI RL RLH RLa RLaH RP RPH RPa
RPaH RU RUH RV RVe TC TCa TEK TES TErS TN TNH TNaH TO
TP TRS TT TTH TU TUH WA WAH WCS WE WF WFm WK WKa
WNH WO WR WRH WRe WReH WT WTH WU YC YCH YCe YCeH YCgH
YCr YCrH YK YKH YN YNH YP YPH YR YU YUy Bare rock
Mottled soils
Gravelly soils
Bouldery soils
Hill soils
Steepland soils
Legend
Towns
Highway
Road
River
5 2.5 0 5 10 15 20 km
Manaaki Whenua
Landcare Research
KAIPARA DISTRICT
NIWA
Taihoro Nukurangi
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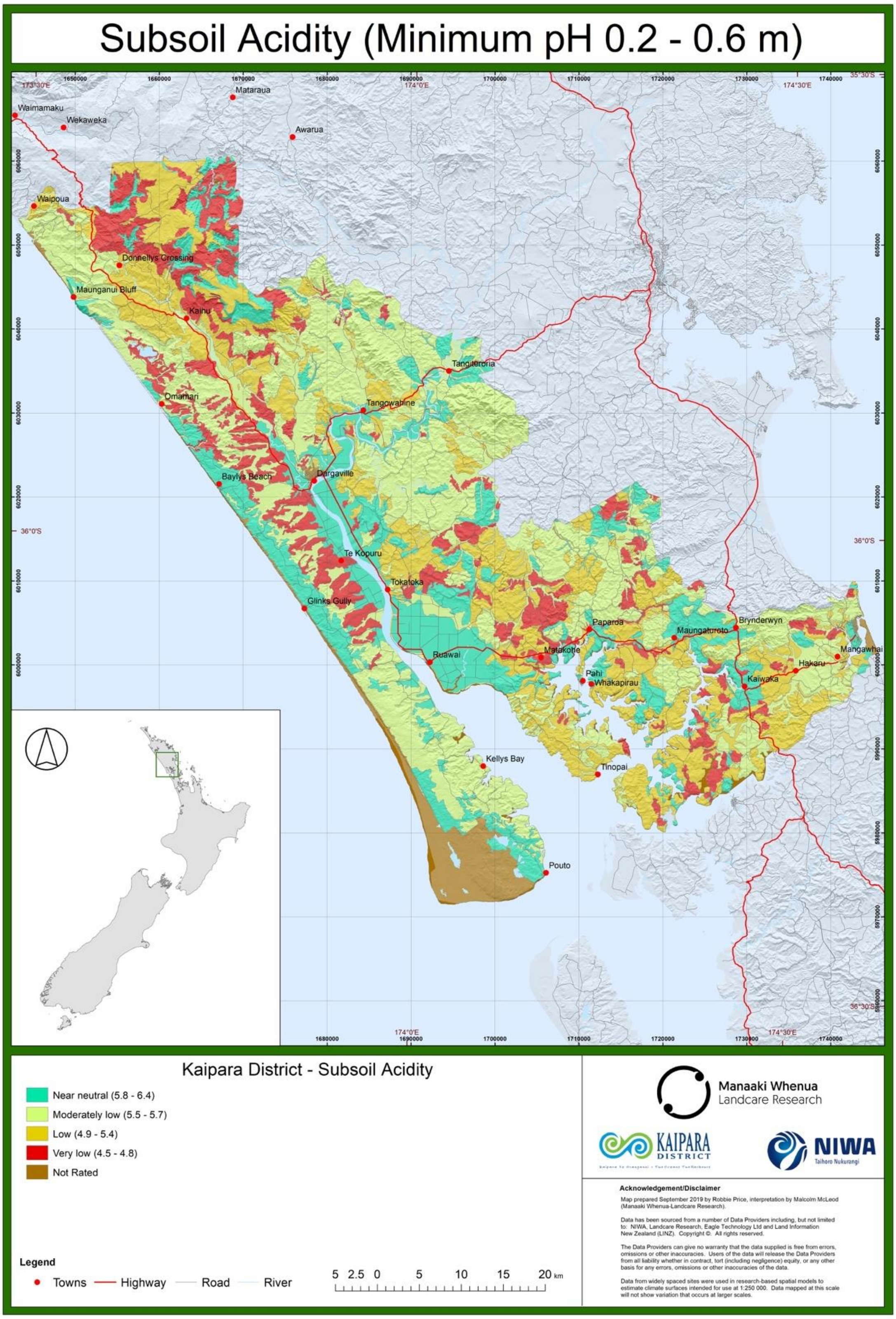
Subsoil Acidity (Minimum pH 0.2 - 0.6 m)
Waimamaku
Wekaweka
Mataraua
Awarua
Waipoua
Donnellys Crossing
Maunganui Bluff
Kaihu
Tangiteroria
Omamari
Tangowahine
Baylys Beach
Dargaville
Te Kopuru
Tokatoka
Glinks Gully
Paparoa
Maungaturoto
Brynderwyn
Mangawhai
Ruawai
Matakohe
Pahi
Whakapirau
Kaiwaka
Hakaru
Kellys Bay
Tinopai
Pouto
Kaipara District - Subsoil Acidity
Near neutral (5.8 - 6.4)
Moderately low (5.5 - 5.7)
Low (4.9 - 5.4)
Very low (4.5 - 4.8)
Not Rated
Legend
Towns
Highway
Road
River
5 2.5 0 5 10 15 20 km
Manaaki Whenua
Landcare Research
KAIPARA DISTRICT
NIWA
Taihoro Nukurangi
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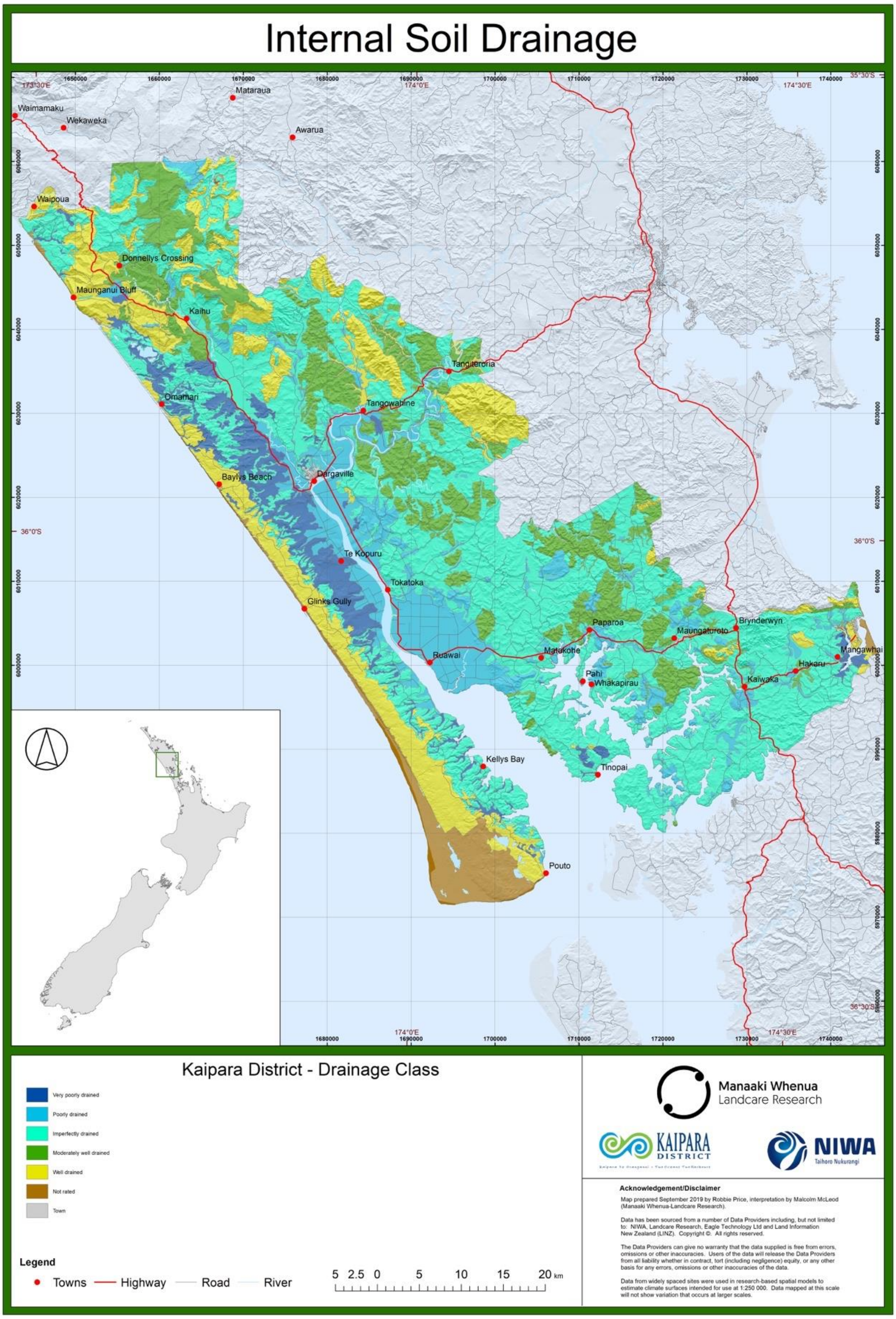
Internal Soil Drainage
Mataraua
Waimamaku
Wekaweka
Awarua
Waipoua
Donnellys Crossing
Maunganui Bluff
Kaihu
Tangiteroria
Omamari
Tangowahine
Baylys Beach
Dargaville
Te Kopuru
Tokatoka
Glinks Gully
Paparoa
Maungaturoto
Brynderwyn
Mangawhai
Ruawai
Matakohe
Pahi
Whakapirau
Kaiwaka
Hakaru
Kellys Bay
Tinopai
Pouto
36°0'S
174°0'E
174°30'E
Kaipara District - Drainage Class
Very poorly drained
Poorly drained
Imperfectly drained
Moderately well drained
Well drained
Not rated
Town
Legend
Towns
Highway
Road
River
5 2.5 0 5 10 15 20 km
Manaaki Whenua
Landcare Research
KAIPARA DISTRICT
NIWA
Taihoro Nukurangi
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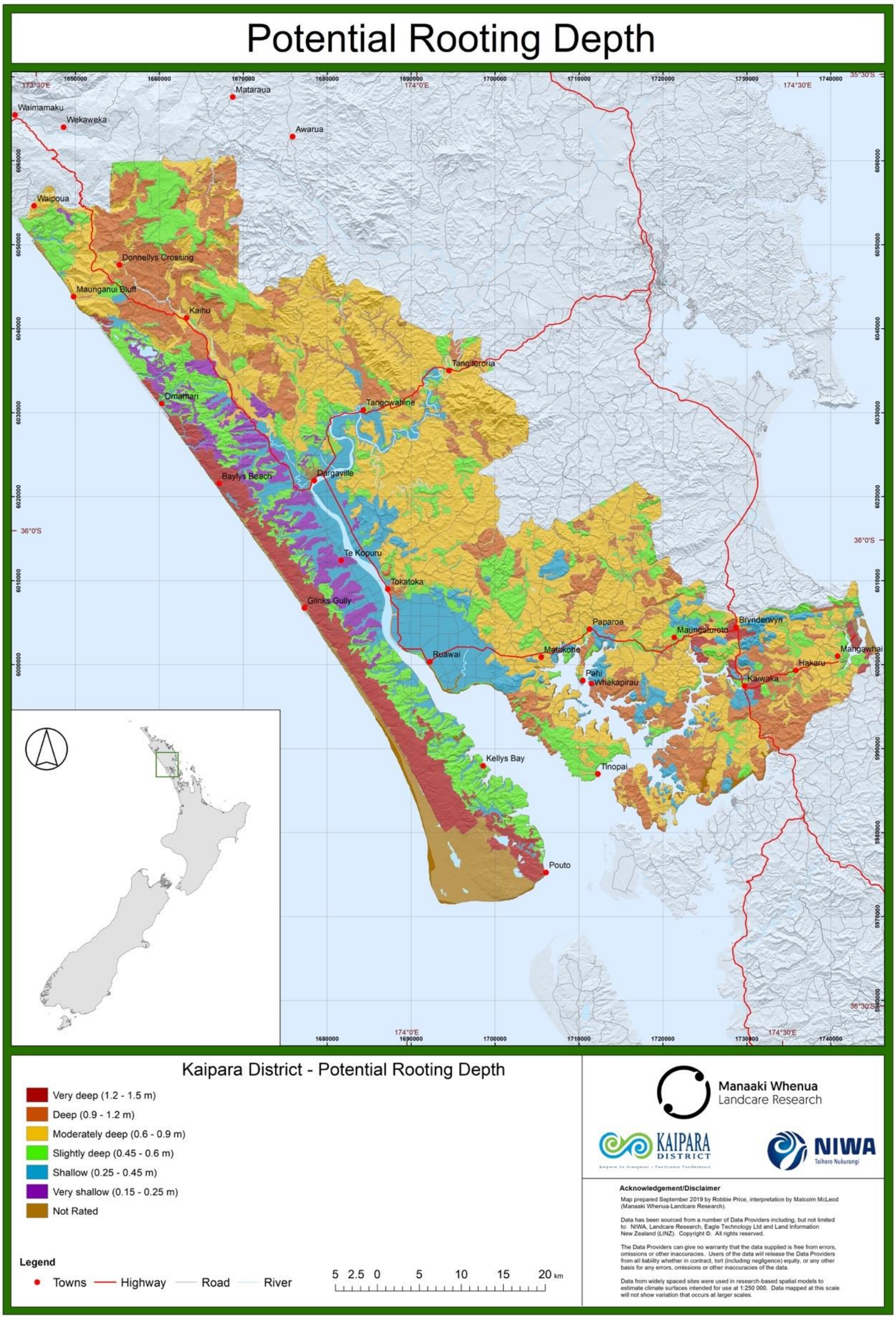
Potential Rooting Depth
Waimamaku
Wekaweka
Mataraua
Awarua
Waipoua
Donnellys Crossing
Maunganui Bluff
Kaihu
Tangiteroria
Omamari
Tangowahine
Baylys Beach
Dargaville
Te Kopuru
Tokatoka
Glinks Gully
Ruawai
Matakohe
Paparoa
Pahi
Whakapirau
Maungaturoto
Brynderwyn
Kaiwaka
Hakaru
Mangawhai
Kellys Bay
Tinopai
Pouto
Kaipara District - Potential Rooting Depth
Very deep (1.2 - 1.5 m)
Deep (0.9 - 1.2 m)
Moderately deep (0.6 - 0.9 m)
Slightly deep (0.45 - 0.6 m)
Shallow (0.25 - 0.45 m)
Very shallow (0.15 - 0.25 m)
Not Rated
Legend
Towns
Highway
Road
River
5 2.5 0 5 10 15 20 km
Manaaki Whenua Landcare Research
KAIPARA DISTRICT
NIWA Taihoro Nukurangi
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Data from widely spaced sites were used in research-based spatial models to estimate climate surfaces intended for use at 1:250 000. Data mapped at this scale will not show variation that occurs at larger scales.

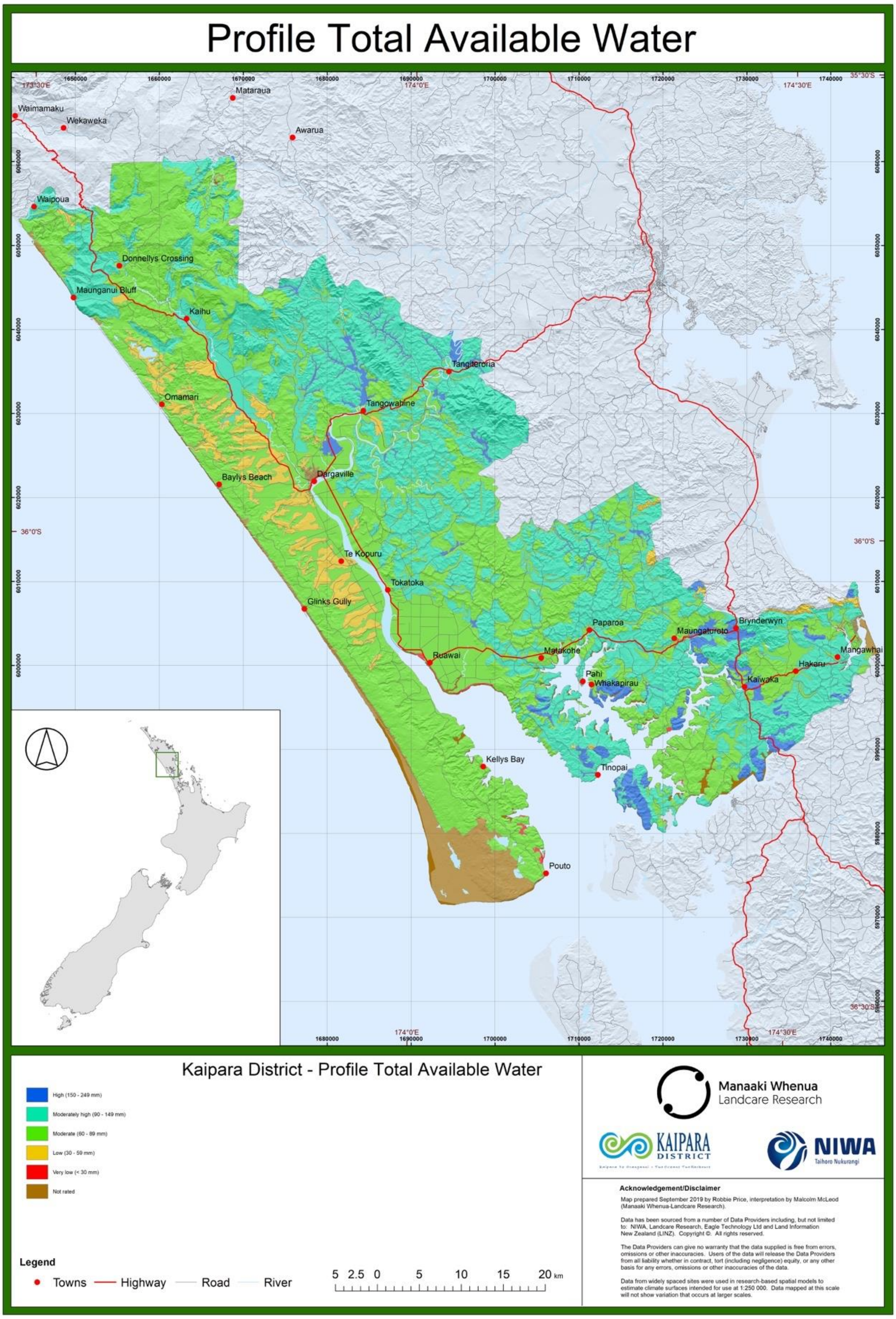
Profile Total Available Water
Waimamaku
Wekaweka
Mataraua
Awarua
Waipoua
Donnellys Crossing
Maunganui Bluff
Kaihu
Tangiteroria
Omamari
Tangowahine
Baylys Beach
Dargaville
Te Kopuru
Tokatoka
Glinks Gully
Paparoa
Maungaturoto
Brynderwyn
Mangawhai
Ruawai
Matakohe
Pahi
Whakapirau
Kaiwaka
Hakaru
Kellys Bay
Tinopai
Pouto
Kaipara District - Profile Total Available Water
High (150 - 249 mm)
Moderately high (90 - 149 mm)
Moderate (60 - 89 mm)
Low (30 - 59 mm)
Very low (< 30 mm)
Not rated
Legend
Towns
Highway
Road
River
5 2.5 0 5 10 15 20 km
Manaaki Whenua
Landcare Research
KAIPARA DISTRICT
NIWA
Taihoro Nukurangi
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Table A1: List of soil names and their area in the Kaipara District.

Soil code	Soil series	Soil type	Soil phase	Area (km2) of series	Soil code	Soil series	Soil type	Soil phase	Area (km2) of series
Water bodies				32	Town				5
Bare rock (sand dune)				120	AK	Awapuku	clay loam		2
AKH	Awapuku	clay loam	hill	11	AP	Aponga	clay		100
APH	Aponga	clay	hill	39	AR	Aranga	clay		21
AU	Arapohue	clay		36	AUd	Arapohue	clay	deep	16
AUH	Arapohue	clay	hill	36	C1	C1 complex			3
C4	C4 complex			<1	C8	C8 complex			15
HI	Hihi	clay		2	HK	Hukerenui	silt loam		6
HKa	Hukerenui	sandy loam		1	HKH	Hukerenui	silt loam	hill	3
KB	Kiripaka	silt loam	bouldery	3	KBe	Kiripaka	boulder silt loam	bouldery	1
KBH	Kiripaka	silt loam	hill	<1	KM	Kohumaru	clay		12
KN	Konoti	clay		15	KNH	Konoti	clay loam	hill	2
KNr	Konoti	clay		11	KNrH	Konoti	clay	hill	2
KO	Kamo	clay loam		3	KP	Kaipara	clay loam		188
KPy	Kaipara	peaty clay loam		20	KR	Kara	silt loam		20
KRa	Kara	sandy loam		2	KRe	Kara	clay		2
KT	Katui	clay loam		16	KTH	Katui	clay loam		31
MA	Mata	clay loam		5	ME	Maungarei	clay		3
MEH	Maungarei	clay	hill	1	MF	Mangakahia	clay		19
MFm	Mangakahia	clay loam		44	MO	Maungatoroto	clay		16
MRH	Marua	clay loam	hill	4	MRuH	Marua	clay loam	hill	<1
MT	Motatau	clay		14	MV	Mahurangi	fine sandy loam		63
MVH	Mahurangi	fine sandy loam	hill	14	OA	Okaka	clay		24
OAH	Okaka	hill		28	OG	Otonga	peaty clay loam		4
OM	Omu	clay loam		15	OMH	Omu	clay loam	hill	50
ON	Omanaia	clay loam		4	OPH	Otaika	silt loam	hill	<1
OT	One tree point	peaty sand		7	PBuH	Puhoi	light brown clay loam	hill	8
PC	Pakotai	clay		2	PD	Puketitoi	sandy loam		1
PES	Parakiore	stony clay loam	steep	4	PFH	Piroa	clay	hill	12
PM	Pukenamu	silt loam		1	PN	Pinaki	sand		46
PNH	Pinaki	sand	hill	39	POS	Pukekaoro	clay loam	steep	15
PZ	Parore	peaty sandy loam		50	RA	Rangiora	clay		2

Soil code	Soil series	Soil type	Soil phase	Area (km2) of series	Soil code	Soil series	Soil type	Soil phase	Area (km2) of series
RAH	Rangiora	hill		<1	RAl	Rangiora	silty clay loam		<1
RL	Red Hill	sandy loam		19	RLa	Red Hill	sandy clay loam		48
RLaH	Red Hill	sandy clay loam	hill	6	RLH	Red Hill	sandy loam	hill	20
RP	Riponui	clay		20	RPa	Riponui	silty clay loam		6
RPaH	Riponui	silty clay loam	hill	5	RPH	Riponui	clay	hill	4
RU	Rangiuru	clay		18	RUH	Rangiuru	clay	hill	10
RV	Rockvale	clay		98	RVe	Rockvale	clay	coarse subsoil	10
TC	Takahiwai	clay		4	TCa	Takahiwai	sand		<1
TEK	Te Kopuru	sand		128	TErS	Te Kie	reddish clay loam		61
TES	Te Kie	clay loam		75	TN	Tanoa	sandy clay loam		2
TNaH	Tanoa	sandy loam		6	TNH	Tanoa	sandy clay loam	hill	9
TO	Tutamoe	clay		70	TP	Tinopai	sandy loam		5
TRS	Te Ranga	clay loam	steep	11	TT	Tangitiki	sandy loam		56
TTH	Tangitiki	hill		170	TU	Takitu	clay loam	gravelly	5
TUH	Takitu	gravelly clay loam	hill	39	WA	Warkworth	clay, sandy clay loam		8
WAH	Warkworth	clay, sandy clay loam	hill	24	WCS	White cone	sandy clay loam	steep	6
WE	Waitemata	silt loam		2	WF	Whakapara	sand		11
WFm	Whakapara	clay	mottled	70	WK	Wharekohe	silt loam		8
WKa	Wharekohe	sandy loam		1	WNH	Whirinaki	clay loam	hill	2
WO	Whaeora	clay loam		4	WR	Whangaripo	clay loam		4
WRe	Whangaripo	clay		3	WReH	Whangaripo	clay	hill	26
WRH	Whangaripo	clay loam	hill	15	WT	Whatoro	clay		27
WTH	Whatoro	clay	hill	23	WU	Waipuna	clay		8
YC	Waiotira	clay loam		77	YCe	Waiotira	clay		38
YCeH	Waiotira	clay	hill	35	YCgH	Waiotira	gravelly sandy loam	hill	3
YCH	Waiotira	clay loam		253	YCr	Waiotira	brownish clay loam		<1
YCrH	Waiotira	brownish clay loam	hill	<1	YK	Waikare	silt loam		103
YKH	Waikare	silt loam	hill	20	YN	Waimatenui	clay		24
YNH	Waimatenui	clay	hill	107	YP	Waipoua	clay		2
YPH	Waipoua	clay	hill	13	YR	Wairiki	clay loam		1
YU	Waipu	clay		3	YUy	Waipu	peaty silt and clay		2