Northland water storage: options and opportunities assessment

Jane Frances Paul White
Mike Taves Chris Frost

Aqua Intel Aotearoa Report May 2021

A collaboration between the Provincial Development Unit (PDU – MBIE) and the Institute of Geological & Nuclear Sciences (GNS Science)

CONTENTS

FIGURES

TABLES

APPENDICES

APPENDIX TABLES

APPENDIX FIGURES

EXECUTIVE SUMMARY

Investment in water storage can provide a significant means of increasing prosperity for many regions. The Government has set up a science platform – Aqua Intel Aotearoa – to explore regional water storage needs and opportunities and to consider the potential for water storage to support a lift in sustainable regional production.

PDU – GNS Science platform: Regional Water Needs Assessments

Aqua Intel Aotearoa will identify how water availability can support sustainable land development and identify further investigations that will inform the potential for water storage for the region. The Government is particularly interested in investigating opportunities to support Māori land being brought into production. Aqua Intel Aotearoa are working with four regions within this programme – Northland / Te Tai Tokerau, Gisborne/Tairāwhiti, Otago and Southland.

Northland's Water and Land

Northland is a region that could benefit significantly from investment in water storage. With a few notable exceptions, such as Kerikeri and Maungatapere, there has been little investment in water storage in Northland to enhance land productivity.

The most effective means of overcoming water shortages vary across the region. In the Te Hiku peninsula, groundwater from the Aupouri aquifer is the largest potential source of freshwater. In other parts of the region, water storage infrastructure could be the best means for ensuring a reliable supply of water. While Northland's short-run rivers and streams cannot provide sufficient reliable water throughout the year to support land development, capturing and storing surface water during wet winter months could offer Northland options to support horticulture during the dry summer months.

The main water quality issues in Northland are sediments, faecal bacteria and nutrients. Sediment is a widespread issue for the region. Northland faces frequent droughts in the summer, and these may increase in frequency, duration and intensity as a result of projected changes in climate. Northland also faces flooding in winter, and this may also increase with climate change. Water storage could assist in managing the impact of droughts and floods.

Water availability is managed in accordance with the Northland Regional Plan. Allocation limits and minimum flows and levels have been set for water bodies to protect their associated values. Actual water availability depends on these limits, flows and levels and existing pressures and water use. Groundwater availability also depends on the requirement to avoid saline intrusion and to avoid adverse effects on surrounding surface water bodies.

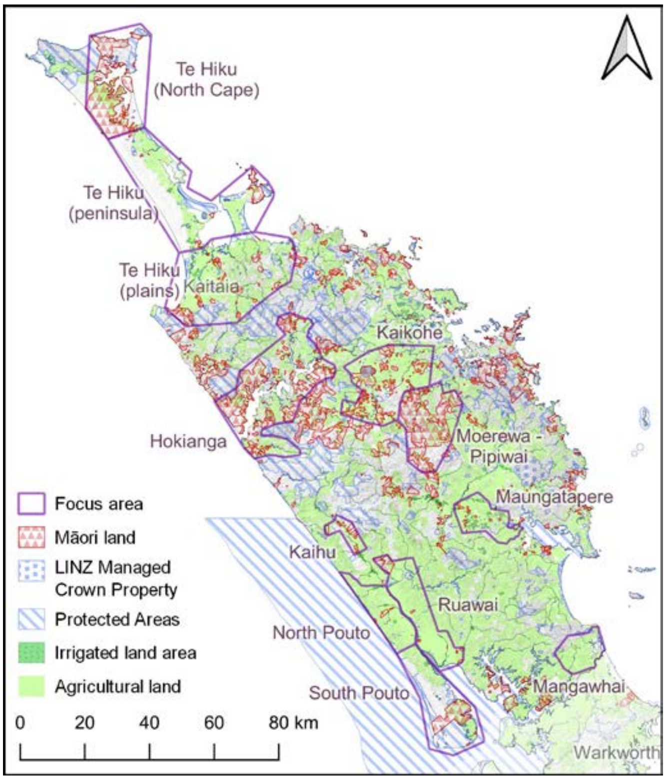
Investing in Water Storage to Enhance Northland's Land Productivity

Primary production is a major sector for the Northland economy. The two largest land uses are pasture (52%) and exotic forest (13%). The region is seeing some shift in land use away from pastoral activities towards horticulture, such as avocados. Reliable supplies of water will be required to support the continuation of this trend. The diversity of crops could increase further with more reliable water. Recent land-use investigations have identified a wide range of potential horticultural crops that could be grown in Northland with a reliable quantity of water supply. These include berries, tree fruit, tropical fruit, flowers and ornamental plants, root and tuber vegetables, legumes, leafy greens, salad vegetables, arable crops and rice.

Investments in water storage are already underway in the mid-North and the Kaipara. The region has identified that the next priority area for investment is the Far North, given the land that could be brought into production, the demand for water and the regional economic development gains that are possible. There are a number of other areas where land productivity could also be enhanced through the introduction of reliable water.

Water Storage Focus Areas and Water Storage Approaches

This work identified a number of focus areas within Northland where there is productive land that could be brought into higher-value sustainable uses, including relatively large areas of Māori land. Within these focus areas, water storage approaches were identified that could enable this land to be brought into horticulture.



Water storage options were identified from a variety of options that take water from surface water or groundwater, including dams for baseflow enhancement, groundwater storage, galleries (where groundwater is taken from shallow gravel-filled pits excavated below the water table), managed aquifer recharge, land subsoil recharge and dams (Appendix 1). A GIS method was used to assess storage options that are relevant to the Northland region. The method included assembly of GIS maps (national and regional) such as land use, soil properties, climate, geology and water flows (rivers and groundwater).

For each of the focus areas, an assessment (using the GIS maps and discussions with local water experts) has identified the top two potential water storage options; each of these options is ranked as high (meaning that this storage option is widespread in the focus area and should produce sufficient water for use needs) or medium (meaning that this storage option is common in the focus area and may produce sufficient water for use needs).

Area	Top-Ranked Water Source	Second-Ranked Water Source
Te Hiku (North Cape)	Groundwater (high)	Galleries (medium in limited areas only)
Te Hiku (Peninsula)	Groundwater (high)	Galleries (medium in limited areas only)
Te Hiku (Plains)	Groundwater (high)	Baseflow enhancement
Hokianga	Groundwater (medium)	Baseflow enhancement
Moerewa-Pipiwai]	Water storage reservoir (medium to high)	Galleries (medium)
Kaihu	Groundwater (medium to high)	Baseflow enhancement
Ruawai	Groundwater (high)	Baseflow enhancement
South Pouto	Groundwater (very high)	Galleries (high)

Investigations into Water Availability

Funding is available for a range of activities that will improve the understanding of the availability of water across Northland and to identify the interest of particular communities in increasing their land productivity. The bulk of the funding will be devoted to investigations of the Aupouri aquifer.

Beyond this, other areas of investment include:

- assessment of groundwater availability in South Pouto
- measurement of surface flows and groundwater recharge across the region as a whole, and
- a study into the viability of harvesting winter flows in Northland.

We will take this work forward in discussion with Northland councils, the Te Tai Tokerau Water Trust and other local parties.

1.0 INTRODUCTION

This report was prepared through Aqua Intel Aotearoa – the collaboration between the Provincial Development Unit (PDU) and GNS Science for addressing regional water storage needs and opportunities. The Government has invested $10 million from the Provincial Growth Fund (PGF) in Aqua Intel Aotearoa to undertake regional needs assessments and investigations of water availability in four regions – Northland, Otago, Southland and Gisborne.

Water storage is one of the most significant investments that can be made to lift regional productivity. For most of the regions, and particularly the PGF surge regions, the primary sector is a major element of the local economy. Land-based production is a comparative advantage of the regions relative to urban areas and has shown itself to be a critical part of the economy through COVID-19.

All PGF water storage investments are guided by a set of investment principles in line with objectives for water storage (Appendix 1), e.g. to:

- strengthen regional economies by shifting to higher-value sustainable land uses,
- address disparities in Māori access to water for land development,
- support micro- and medium-scale water storage projects that strengthen regional partnerships and provide wider public benefits, and
- support land uses that do not increase – and ideally reverse – negative impacts on water quality and that maintain and improve the health of waterways.

In meeting these objectives, PGF investments also consider how investments:

- contribute to a just transition to a low-carbon economy and/or to building climate-change resilience in Northland communities; and
- provide an incentive to change land use that risks degrading the environment to high-value, more sustainable, uses.

Water storage and distribution infrastructure enables regions to bring underutilised land into production. It also enables them to improve the productivity of existing land by moving to higher-value land uses. Providing reliable access to water can be a pre-requisite for most higher-value land uses. Water availability can also be a constraint on Māori land development, particularly in catchments that are largely allocated. Water storage is a means of overcoming this constraint. Water storage also enables regions to diversify their land use and increase horticultural activities to ensure that the primary sector operates sustainably and to mitigate the negative impacts on water quality and maintaining and improving the health of waterways.

The main focus of PGF funding for water storage is to increase land productivity from horticulture. There are a number of limitations on the purposes for which PGF water storage funding can be used. In general, PGF funds cannot be used for municipal water supply or Three Waters infrastructure, used to provide maintenance funding for existing schemes or to support land use that leads to ruminant intensification.

Consideration is underway in other parts of government about the adequacy of water for other purposes, such as drinking water. With climate change, access to water may decline in some regions, leading to greater deprivation for some communities. Water storage can support community incomes in this context. Ultimately, land productivity also requires water availability in neighbouring townships to enable workers and suppliers to live nearby.

While these regional water needs assessments focus on the availability of water for increasing land productivity, the findings will also be relevant to informing work on other potential uses of water, where sources of water are also a matter of importance.

The state of regional economic development heavily influences the water issues faced in the region. For those sub-regions that have had less economic development, the key constraining factor to further development is the availability of reliable water resources. Māori land is most common in regions where there has been limited regional economic development. At the other end of the spectrum, in those sub-regions where there has been economic development over many decades (or into dairy in recent times), the constraining factor is regulatory requirements in relation to water quality. These arise because of the impacts of existing land use. In these regions, it is not feasible to increase water availability for land without utilising some of the additional water to also address water quality issues (e.g. by sustaining stream baseflow).

1.1 Water Storage Development

The delivery of water storage infrastructure is a lengthy process that takes place over a number of years, with numerous phases leading to construction and operation (Figure 1.1 and Table 1.1).

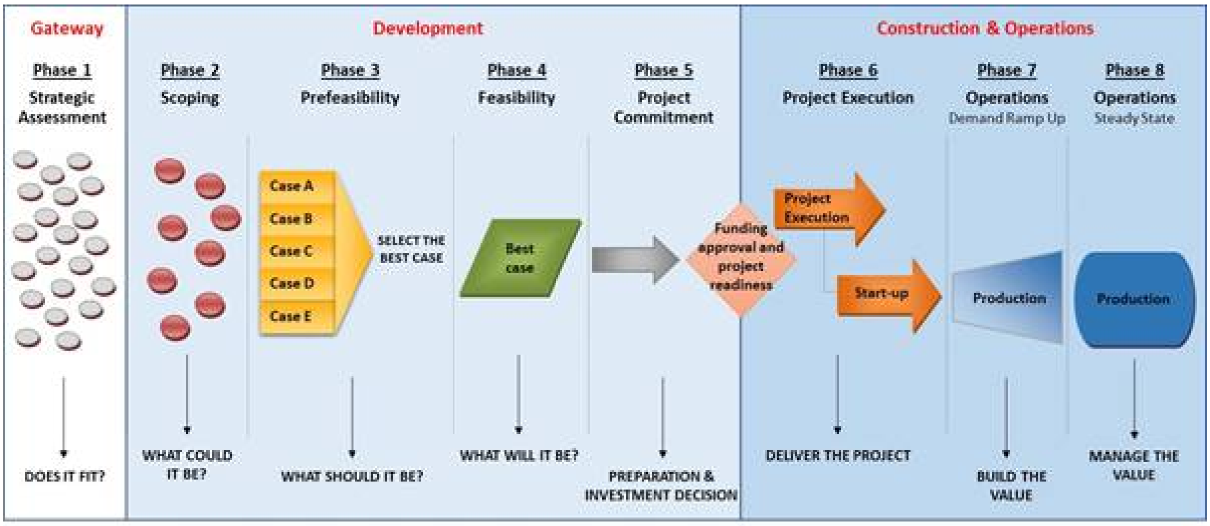


Figure 1.1 The water infrastructure development process.

Information about water availability and potential land use is necessary to bring water storage projects into effect. The information developed through these regional water needs assessments inform Gateway: Phase 1 – the strategic assessment of whether water storage projects could be taken through the development phase.

Table 1.1 Development phases for water infrastructure.

Phases	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Water Availability (Water Supply)	Identify potential sources of water and water storage approaches. Monitor availability of water, e.g. low flows and harvestable flows of water in rivers, streams and groundwater. Determine whether sufficient sustainable water will be available to take water for productive purposes, including meeting regulatory requirements and community expectations.	Assess whether water supply will be sufficient to justify investment.	Identify potential water storage sites based on regional freshwater objectives and regulatory settings, technical feasibility and storage scale. Secure water resource consent(s).		Final site for water storage chosen.	Water storage infrastructure constructed and water becomes available to landowners.		
Land Use (Water Demand)	Identify areas for potential land-use change and what water is needed to support this (including considering land uses that require less water). Undertake preliminary discussions with landowners and potential business partners to assess potential interest in securing water.	Assess whether water demand is likely to be sufficient to meet construction costs.	Build demand from landowners, business partners and other potential owners of the infrastructure (e.g. municipal, industrial).	Secure land-based consents	Owners sign up to project.	Landowners invest funds through purchasing a share of the asset. They utilise water to increase the sustainable productivity of their land.		
Project Development	-	-	Develop a business case for infrastructure investment based on adequate supply and demand. Establish a vehicle to deliver the project.			Manage delivery of project.		

The regional water needs assessments being prepared by Aqua Intel Aotearoa relate to Phase1, i.e.:

- considering the current status of land use and water availability in focus areas within the regions;
- considering potential land use and water storage approaches that could generate an increase in sustainable land development; and
- identifying and funding activities that will progress work on water availability within the focus areas, where assessments show that a viable and sustainable water storage approach is achievable and land productivity can be increased, consistent with the PGF objectives above.

The funds that are available for investment through Aqua Intel Aotearoa will be prioritised toward activities that can progress the region through to later stages of water development (Figure 1.1 and Table 1.1). For example, the project will fund for gauging of surface water in areas that are known to experience water shortage. Decisions about where to undertake gauging will be informed by local expertise from regional councils and water specialists.

This assessment of Northland water needs and opportunities considers potential water use and water availability within focus areas of the region (Figure 1.2). These areas include under-developed land that could be brought into higher levels of productivity. This assessment looks particularly at Māori land with an aim to stimulate development of the Māori economy. The potential for land development by Māori is demonstrated by large areas of agricultural land (see Section 2.2 for the definition of this land use) that is owned by Māori in the focus areas (Table 1.2).

This report summarises the benefits of water storage to Northland and outlines resources relevant to water storage (Section 2). Then, the report identifies twelve focus areas where water storage could be beneficial to the region (Section 3). This includes two areas where water storage projects are currently underway and two areas where the benefits relate to municipal supply and maintenance of existing infrastructure, so these areas are outside the scope of PDU investment.

Water storage options that could provide benefits to the productive sector and the environment are outlined for eight areas, including surface water and groundwater sources (Appendix 2), with maps of preferred options in each area (Section 4). In each of the eight focus areas, the report comments on the potential benefits of water storage, including the benefits to regional economic development, Māori land development and the environmental considerations related to water use limits and allocations. Finally, the report sets out the potential initial investments in each area (Section 5).

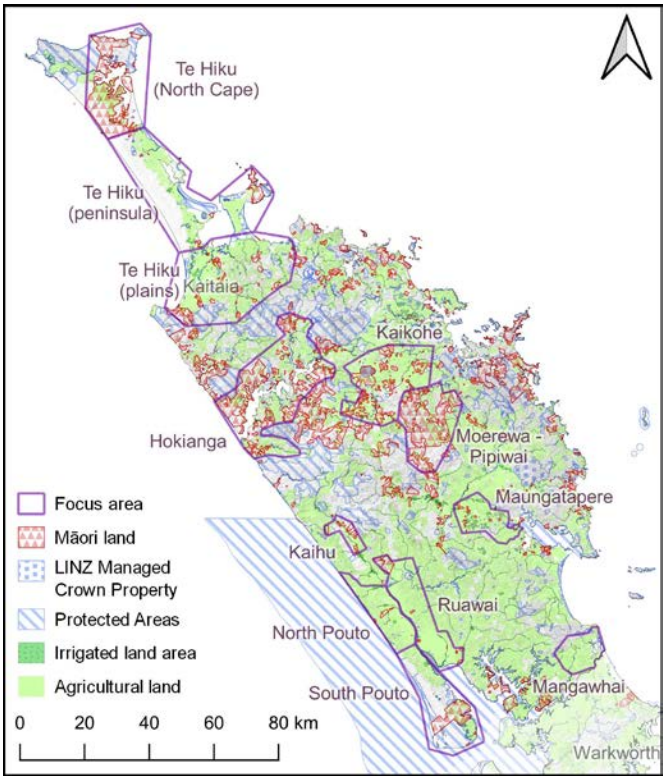


Figure 1.2 Focus areas for Northland water storage assessment.

Table 1.2 Agricultural land and Māori land in the 12 Northland focus areas.

Item	Total (ha)
Agricultural land	223,579
Māori land	87,758
Agricultural land and Māori land	24,893

Since 2017, the National Policy Statement for Freshwater Management requires councils to consider and recognise ‘Te Mana o te Wai’ in policy development related to freshwater. Te Mana o te Wai is the integrated and holistic wellbeing of freshwater bodies, which supports the health and wellbeing of people and the environment. Te Mana o te Wai can also be described as the mauri (energy and flow of life force) of water bodies and taonga species. Water is held in the highest esteem by Māori because the welfare of the life that it contains determines the welfare of the people reliant on those resources.

The National Policy Statement for Freshwater Management 2020 (NPSFM) requires regional councils and tangata whenua to work together to determine how Te Mana o te Wai will be reflected in freshwater management. This covers many aspects of water quality, including provision of clean freshwater for drinking, continuity of flow from mountain to sea, ecosystem health and biodiversity, protection of traditional cultural values, aesthetic qualities and provision of economic values.

As a first step on the journey of implementing Te Mana o te Wai, the Northland Regional Council is developing a change to its Regional Plan to implement the requirements of the NPSFM. This involves working with tangata whenua through forums such as:

- the Tangata Whenua Water Advisory Group (a Taitokerau-based group made up of tangata whenua technical water experts)

- the Te Taitokerau Māori and Council Working Party (a working party of the regional council that includes representation from various hapu and iwi), and
- Te Kahu O Taonui (the Taitokerau iwi collective).

2.0 NORTHLAND REGIONAL SUMMARY

Northland is rich in natural endowments but is one of the most economically challenged regions in New Zealand. Better access to water would enable more productive use of land, which would enable greater economic returns to the region.

The most effective means of overcoming water shortages differ across the region. In the Te Hiku peninsula, groundwater from the Aupouri aquifer is the largest potential source of freshwater. Aquifer investigations will give the region a better understanding of the quantity of water that is available for production.

In other parts of Northland, water storage infrastructure is the best means for ensuring reliable water supplies to Northland. The storage can be supplied from surface water and from groundwater. However, Northland's short-run rivers and streams cannot provide sufficient reliable water throughout the year to support land development. Therefore, capturing and storing surface water and groundwater during wet winter months offers Northland water supply options for horticulture during the dry summer months. This can be observed in those parts of Northland that have had water storage, such as Kerikeri and Maungatapere. These areas have been flourishing horticultural communities since the construction of the water storage infrastructure, approximately four decades ago.

Water storage infrastructure will inform the potential to expand the economic benefits of water storage to other parts of Northland that have not had this available to date.

2.1 Water

Northland's surface hydrology has a complex, dense network of relatively small streams, with approximately 1700 individual 'source to sea' catchments in the region (Osbaldiston 2020a). Northland rivers are generally short and low volume with 'flashy' (highly variable) flows – over 50% of the length of Northland's stream network has estimated 7-day mean annual low flows of less than 5 L/s. The Wairoa River is the only river that can be described as large, in hydrological terms, with mean flows greater than 20 m^3/s.

The main Northland aquifers are the Kaikohe and Whangārei basalts and the Aupouri sands and shellbeds. Sediments along the coastline also host smaller sand and gravel aquifers (Northland Regional Council [2020]b). Basalt aquifers can provide baseflow to springs and streams all year long, depending on the amount of recharge during the winter months. Seawater intrusion can occur in the coastal aquifers in times of increased groundwater abstraction or reduced groundwater recharge.

In the Northland region, consented water takes for horticulture are approximately 56% of the total annual consented allocation (Table 2.1). Most water allocation is from surface water sources, which is partly the result of many properties having relatively easy access to water from the dense network of rivers and streams in the region (Osbaldiston 2020a; Table 2.2). The use of water for drinking water is relatively important in Northland; approximately 58 Million m^3/year is allocated for this purpose, which is approximately 46% of the total consumptive water allocation in the region (Rajanayaka et al. 2010).

Table 2.1 Irrigated land area and allocation in Northland (Rajanayaka et al. 2010).

Irrigated Land Use	Land Area (ha)	Consented Annual Allocation (Million m^3/year)
Arable	30	0.1
Horticulture	4825	28.9
Pasture	9439	22.7
Other	100	-
Total	14,394	51.7

Table 2.2 Summary of consents by type (Osbaldiston 2020b).

Consent Type	Number of Consents	Number of Locations Authorised by Consent
Dam	77	79
Groundwater	310	368
Surface water (including lakes)	177	179

2.1.1 Water Quality

River water quality "is degraded at the majority of the sites in Northland with two thirds of … SoE monitoring sites being moderately to severely degraded"; all river water quality sites "graded as poor are sites where the predominant land cover is pastoral. Conversely almost all sites graded as excellent for water quality have catchments dominated by native or exotic forest." (Nicholson and Perquin 2019).

> *"The main concerns are nutrients, with a high proportion of sites failing to meet the [Northland Regional Council] objective values for dissolved reactive phosphorus, ammoniacal nitrogen and total oxidised nitrogen (65%, 62% and 65% respectively). In contrast, dissolved oxygen, E. coli and turbidity objectives are met at most sites"* (Nicholson and Perquin 2019).

Sediment is a widespread surface water quality issue. The rates of soil erosion and transport of sediment through rivers "has been accelerated by land clearance for agriculture, forestry and urban development" (Nicholson and Perquin 2019).

> *"Summary trend data for water quality / ecological health … shows that there are several improving trends in water quality over the 10 years from January 2007 to December 2016 particularly in ammoniacal nitrogen, nitrogen (TON) and turbidity. There are also many positive improvements in the five years from January 2012 – December 2016. However, a considerable number of sites are showing increasing levels of phosphorus (degrading) (DRP) in the five-year trends"* (Nicholson and Perquin 2019).

Faecal bacteria in waterways may be sourced from farmland. "When it rains, some manure gets washed off land into streams, rivers, and lakes" (Northland Regional Council 2015) and "during times of low rainfall/low flows sources of E. coli are likely to be from direct discharges to water or from stock that have access to unfenced streams" (Nicholson and Perquin 2019).

“Groundwater quality can be influenced by a number of human factors such as land use (for example, effluent disposal and increased use of nutrients for agriculture or horticulture)” (Northland Regional Council 2015). “Groundwater quality at the majority of monitored sites meets the drinking water standards.” “E. coli was detected in 18 bores on three or more occasions during the water sampling over the period 2011–2014.” Most of these detections were in coastal areas associated with small communities and on-site sewage treatment systems (Northland Regional Council 2015).

Northland has a large number of small lakes within sand dunes; these lakes typically lack permanent surface inflows or outflows. Northland Regional Council monitored 26 lakes in 2014, and most of these (54%) are either eutrophic (i.e. poor water quality and high algae concentrations associated with excessive nutrients) or supertrophic (i.e. very poor water quality and high in nutrients with frequent algal blooms). Lakes Ōmāpere and Waiporohita had improving water quality over time with trends from supertrophic to eutrophic state (Northland Regional Council 2015).

While Farm Environment Plans have been a statutory requirement since 2020, Northland Regional Council has worked with landowners since 2012 to develop farm water quality improvement plans. These free, no obligation, plans were part of the Waiora Northland Water programme. They focused on how to improve the quality of surface water on farms and are written by council's land management staff in conjunction with landowners to prioritise recommended actions (Northland Regional Council 2015).

2.2 Land

Primary production occupies most of Northland’s land area. The two largest land uses are pasture and exotic forest, which cover 52% and 13% (i.e. approximately 600,000 ha and 150,000 ha, respectively) of the Northland region (Northland Regional Council 2015). As there is no direct measure of productive land, the assessments use classifications within the Land Cover database v5 (LCDBv5; LRIS Portal 2020) as a proxy – referred to here as ‘agricultural land’. Agricultural land includes the LCDBv5 classifications (with Northland land areas) of:

- short-rotation cropland (3826 ha);
- orchard, vineyard or other perennial crop (5790 ha); and
- high-producing exotic grassland (584,143 ha).

Agriculture (including horticulture) is an important business to Northland. In 2014, agricultural production and production processing earned Northland approximately $880 million, or 15% of Northland’s regional Gross Domestic Product (GDP).

Approximately 4000 ha of avocado orchards are farmed in New Zealand, and Northland is one of the two most important New Zealand regions for this crop (New Zealand Avocado c2020a). This industry is growing in Northland, with 1648 ha of the crop in 2017 (Stats NZ 2018) and reports of the conversion of dairy farms to avocado orchards and orchard development by iwi (New Zealand Avocado c2020b; Ministry of Primary Industries 2019). “Much of the land change shift is coming in Northland where large-scale syndicates and iwi investment is helping change the landscape from what has been largely pastoral, dry stock and dairy properties to expansive orchard operations” (Rennie 2020). Avocado is the largest horticultural crop in Northland by land area, followed by kūmara, kiwifruit and citrus.

Table 2.3 Land areas for horticulture and market gardening in Northland (Stats NZ 2018).

Crop	Land Area in 2017 (ha)			
	Far North	Whangārei	Kaipara	Total
Kiwifruit	408	143	0	551
Avocados	870	744	34	1648
Apples	9	10	1	20
Tamarillos	40	22	1	63
Feijoas	20	7	2	29
Persimmons	3	23	0	26
Blueberries	26	3	0	29
Oranges	43	4	0	47
Lemons	58	5	0	63
Mandarins	182	6	0	188
Olives	86	7	9	102
Other fruit, nuts and edible tree crops	196	9	8	213
Kūmara	194	11	918	1123
Melon water/rock	13	12	8	33
Pumpkin	4	13	31	48
Sweet corn (not maize)	76	14	4	94
Other vegetables (outdoor)	38	15	2	55
Nursery crops, including rootstock (outdoor)	21	11	25	57
Other horticultural (outdoor)	14	12	2	28
Total	2301	1071	1045	4417

Exotic forest area declined by about 20,000 ha between 2012 and 2014 (Northland Regional Council 2015). However, the Government has provided, through the 'billion trees' programme, direct landowner grants in Northland for the planting of trees. These grants were for approximately 420 ha and 359 ha of indigenous and exotic forest, respectively (Te Uru Rākau Forestry New Zealand 2020).

2.3 Climate

Northland's climate is the result of the region's northern location (mostly between latitudes 34°S and 36°S), generally low elevation (mostly below 150 m) and a close proximity to the sea (no place is further than 50 km away from the sea) (Chappell 2014). The summers are warm and humid and the winters mild, with only a few frosts. Mean annual temperatures in Northland range from 14°C to 16.5°C (mean annual temperature calculated for the period between 1981 and 2010) (Chappell 2014).

Across the region, rainfall varies between approximately 800 mm/year in low-lying areas to 2000 mm/year at higher elevations (median annual total rainfall calculated for the period between 1981 and 2010). Seasonal patterns show that 30–40% of the total annual rainfall falls in winter (June to August) and 18–20% of the total annual rainfall falls in summer (December to February) (Chappell 2014).

Northland experiences summer droughts, with at least nine severe droughts since 1900. The 2019/2020 regional drought was a serious climatic event. “Northland has been tipped into one of the most severe droughts on record and there’s no quick fix for the serious situation the region is in ...” (Northland Regional Council 2020e). This last drought has also brought water storage into prominence. Given the emergency conditions in Northland, the Government allocated $2M from the PGF to establish alternative drinking water sources for Kaikohe and Kaitaia, despite municipal water being generally excluded from the scope of PGF water investment. As Northland catchments and streams are typically small, the effects of droughts on stream flow and surface water availability were exacerbated.

2.3.1 Climate Change

Northland temperatures are projected to increase, from the 1986–2005 ‘reference’ climate, by 0.7°C to 1.1°C in 2031–2050 and by 0.7°C to 3.1°C in 2081–2100 (Ministry for the Environment 2018). Frosts will become very rare, and the number of days with temperatures over 25°C will increase. Winter and spring rainfall is generally expected to decrease, while summer and autumn rainfall is projected to increase, although to a lesser extent. The projections show no change or a decrease of the frequency of extreme rainy days and ex-tropical cyclones for Northland. However, the latter are expected to increase in strength, with heavier rain and stronger winds.

As a result of these projected changes in climate for Northland, droughts may increase in frequency, duration and intensity, and there may be an increased flood risk. With higher temperatures, evapotranspiration will increase, and groundwater and river flows rates are expected to decrease (Northland Regional Council [2020]a, Pearce et al. 2016). Lower groundwater levels in combination with higher sea levels will likely result in an increase of salinity in coastal aquifers (Pearce et al. 2016). Agriculture, e.g. kiwifruit, is likely to be affected by the changes in temperatures, lack of frosts and extended droughts (Ministry for the Environment 2018). The projected warmer and drier climate may also increase the risk of fires (Pearce et al. 2016).

Adaption strategies to mitigate the impacts of climate change on freshwater resources include water-saving strategies, such as the utilisation of more efficient irrigation systems and water recycling, as well as adaptions of the water resources infrastructure and changes to water management (Capon 2013). Water storage infrastructure, like dams, may be relocated, upgraded or extended, or new infrastructure may be built if required. Adaption plans, infrastructure and management need regular re-visiting and review following updates of climate change projections to ensure their continued fitness-for-purpose. Without access to water storage, those communities in Northland that have experienced deprivation will face higher levels of deprivation over time. Water storage is key to economic development and other aspects of wellbeing through municipal, and local, supplies.

2.4 Infrastructure

Waingaro Reservoir and Manuwai Reservoir provide water for horticulture, agriculture, lifestyle blocks, commercial users and town supply (Kerikeri Irrigation c2020). This infrastructure “was built by the Ministry of Works and started delivering water in the early 1980s. In 1990, local horticulturists and farmers formed the cooperative Kerikeri Irrigation Co Ltd (KCIL) and purchased the assets off the government." A recent economic analysis of the KICL was undertaken, including identification of the difference between pre-irrigation and post-irrigation for the two main economic measures, i.e. GDP and employment as full-time equivalents (FTEs) (Clarke and De George 2016). The KICL scheme was estimated to contribute $100 million GDP and 1261 FTEs to the Far North economy, i.e. approximately 5.5% and 6.5% of the Far North's GDP and employment, respectively.

An irrigation scheme at Maungatapere uses Maunu Dam as part of its water storage to supply "approximately 760 hectares planted within the district, predominantly avocados and kiwifruit with other crops such as persimmons, tamarillos and citrus" (Maungatapere Water Co. c2020). The scheme, part-built by the Crown in the 1980s, is operated as a co-operative.

Whangārei District Council water supply dams include the Whau Valley Dam (which supplies Whangārei City and surrounds) and Wilson's Dam (which supplies the Bream Bay area) (Whangārei District Council 2020). In the Far North, the Opononi-Ōmāpere water supply comes from the Waiarohia Dam and the Waiotemarama Stream.

Looking beyond the scope of PGF investments to municipal water, Northland's 'Three Waters' infrastructure is struggling, outside Whangārei City, to maintain modern standards because of low population densities, lower-than-average regional wealth and aging pipes and treatment plants. These problems have been exemplified by Mangawhai, where small communities struggled to pay for a wastewater treatment upgrade (Edmunds 2017). Regionally, seven wastewater Northland treatment plants have been identified for upgrading at capital and annual running costs of $45 to $68 million and $1.5 to $2.3 million/yr (GHD Limited and Boffa Miskell Limited 2019).

2.5 PGF Investments in Northland Water Storage

The Government has recognised the importance of water availability for economic development in Northland and has therefore invested in a number of Northland water-storage-related projects through the PGF. These include:

- Te Mana o Te Wai – on-farm water storage in Te Hiku.
- Te Waka Pupuri Putea Trust – transition to horticulture through off-stream water storage.
- Emergency water supplies for Kaikohe and Kaitaia through the 2019/2020 drought.
- Hokianga – small-scale water storage.
- Te Tai Tokerau Water Trust – reservoirs in Kaikohe surrounds and Kaipara.
- Lake Ōmāpere – environmental and economic studies.

The Te Tai Tokerau Water Trust Trust has been established to develop water-storage reservoirs for land surrounding Kaikohe in the mid-North and south of Dargaville (WWLA 2020; WWLA and Riley Consultants 2020a). This planning has included 'conceptual' design and costing with an economic analysis and assessments of benefits and environmental effects (WWLA and Riley Consultants 2020b,c). For example:

- *"The analysis of land use capability revealed that in the Kaipara and Mid-North areas up to 40,000ha of land would be suited to agricultural and horticultural production."* Frost et al. [2017].

- An assessment of four potential water storage schemes (Kaipara, Mid-North A, Mid-North B and Mid-North C) estimated outcomes, including productive land area (11,600 ha), total employment (2700 persons) and a regional GDP increase of $326 million (Frost et al. [2017]).

The Government has also invested in a number of flood management schemes for Pangaru, Kawakawa and Awanui as part of its infrastructure investment programme.

Further investment in water storage is likely to be a key enabler of economic development in Northland, with the potential to bring significant areas of land into production if water can be accessed in reliable quantities in a sustainable manner. This is likely to involve a mix of surface water storage and groundwater. Before investment can be made, a better understanding of the availability of sustainable water sources is required.

2.6 Regional Council Consenting Considerations

Water availability in Northland is managed in accordance with the rules and policies in the Northland Regional Plan. Allocation limits and minimum flows and levels have been set for water bodies to protect their associated values. Actual water availability depends on these limits, flows and levels, and existing pressures and water use. Groundwater availability also depends on the requirement to avoid saline intrusion and avoid adverse effects on surrounding surface water bodies. Groundwater cannot be taken if it reduces water levels to an extent that it risks saline intrusion or if it exceeds a limit in a surrounding water body.

Groundwater is an important water resource for irrigation, human consumption and the environment. For example, the recent Aupouri Aquifer Water Users Group application to Northland Regional Council for 24 new water consents aimed to source groundwater for horticultural irrigation (Northland Regional Council [2020]c).

Water storage reservoirs can provide water for productive purposes while also providing environmental benefits. For example, the Wai-iti Dam (Nelson) was constructed in 2007 as a run-of-river, water augmentation dam, constructed by way of earth-fill embankment. Since then, the dam has been successfully augmenting Wai-iti River flow and the water table in the adjacent aquifer (e.g. including shallow wells) (Thomas 2020; Stephenson 2020, personal communications).

Current allocation and current water allocation limits and minimum flows established to protect Northland’s water bodies determine the water that is available from groundwater and surface water. Northland Regional Council calculates groundwater allocation and groundwater allocation limits in the Northland region by groundwater catchment; groundwater is fully allocated in several aquifers, including small east coast aquifer systems (Figure 2.1). Surface water is fully allocated in some surface water catchments (Figure 2.2). There are 17 fully allocated catchments as a result of consented takes and 11 fully allocated mapped aquifers. Assessment of actual consented water use in three catchments indicates that the median annual water use between 2015 and 2019 is between 12% and 44% of actual consented allocation (Osbaldiston 2020b).

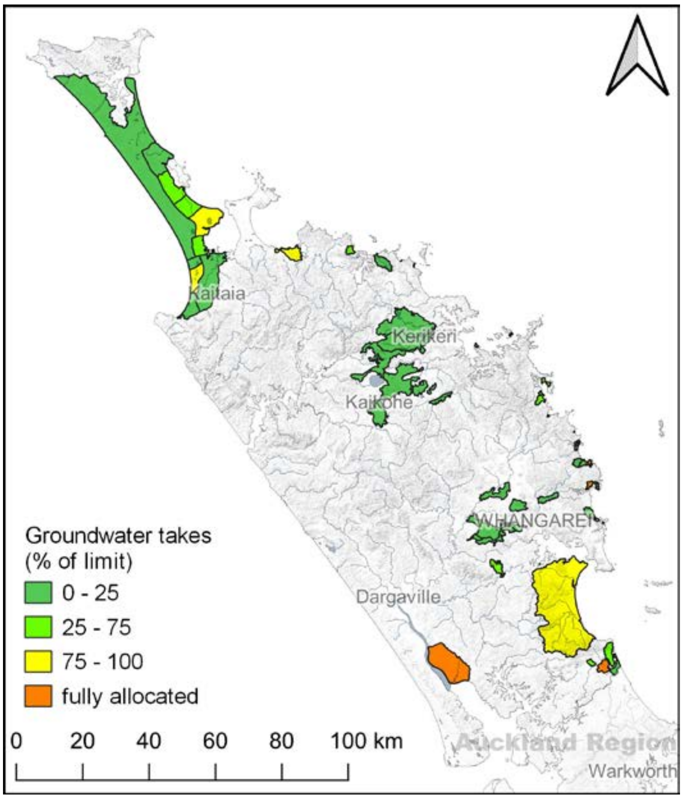


Figure 2.1 Groundwater allocation in Northland (White et al. 2020).

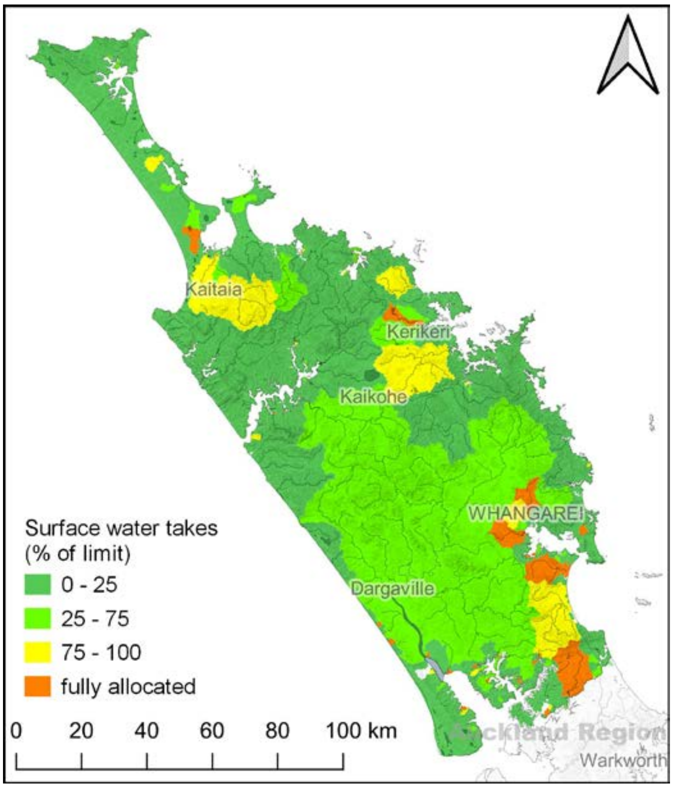


Figure 2.2 Surface water allocation in Northland (White et al. 2020).

3.0 POTENTIAL BENEFITS FROM INVESTMENT IN ACCESSING WATER

This study will provide information to support future developments in the focus areas. Typically, avocado and kiwifruit are the preferred crops in recent large-scale developments, and numerous other crops (e.g. tamarillo, citrus, berries, kūmara and other vegetables) have further development potential in the region (Frost et al. [2017]).

Recent land-use investigations undertaken by several Māori trusts in the Mid and Far North, assisted by Te Puni Kōkiri and the Ministry of Primary Industries, considered the following crops:

- avocadoes
- citrus
- berry fruit
- kiwifruit
- grapes
- tamarillo
- feijoa
- tropical fruit crops
- outdoor flowers and ornamental
- root and tuber vegetables
- leafy greens
- melons and squash
- arable crops
- sweetcorn

Land-use investigations in Kaipara have included the Kaipara Kai Initiative (KKI), which was a multi-disciplinary approach with input from Plant & Food Research, the National Institute of Water & Atmospheric Research (NIWA), Williamson Water & Land Advisory (WWLA) and Coriolis Research. Crops assessed in the KKI, which mostly require a reliable water supply to be grown commercially, included:

- Jerusalem artichoke
- globe artichoke
- avocadoes
- bananas
- beetroot
- blueberries
- capsicums
- carrots
- cucumber
- hemp
- hops
- olives
- peanuts
- pineapples
- potatoes
- rice
- sorghum
- soybeans
- sweetcorn
- tomato

Water quantity and water reliability are required to provide the confidence to invest in horticulture. For example, 2 ha of hydroponic berries would be a better option than 5 ha of avocadoes if only a small amount of water was available and a primary driver of investment was to create employment.

Soil type and climate can play an important part in the selection of crop types, cultivars and growing systems. However, other factors (e.g. values of the landowners, access to capital and market accessibility) are also relevant to land uses. For example, berries are grown hydroponically in the Maungatapere and Te Hiku areas, yet these areas have very different soil types and climates. Similarly, avocadoes grow successfully in both of these areas in very different soils.

4.0 FOCUS AREAS

4.1 Selection of Focus Areas

The selection of Northland focus areas was aligned with PGF water storage objectives, i.e. areas where:

- productive land could be brought into higher-value sustainable uses, and
- relatively large areas of Māori land can also be brought into higher-value uses.

'Agricultural land' (Section 2.2) is not the only land with the potential for irrigation of horticultural crops (Section 5). Following discussions with local experts, it is likely that land with other LCDBv5 classifications could become more productive over time. These land areas have been included in the focus areas where there is an expectation of water demand in the short term.

Within the focus areas, water storage approaches are identified that meet the PGF objectives of:

- supporting micro- to medium-scale water storage projects; and
- supporting land use that does not increase, and ideally reverses, negative impacts on water quality and maintains or improves the health of waterways.

The focus-area assessments do not consider water storage approaches that could undermine the environmental health of waterways.

4.2 Assessment of Focus Areas

4.2.1 Te Hiku (North Cape, Peninsula and Plains)

These areas are a priority for the region and a significant opportunity for Māori land development, given the scale of land for potential development and the significant Māori holdings through the Te Hiku peninsula (Figures 4.1–4.9). Reliable surface water sources are less available in Te Hiku than other parts of the region. Gaining a more nuanced understanding of groundwater will give the community and the council confidence about how much water can be accessed from surface and groundwater while protecting the aquifer from saltwater intrusion and ensuring that there are minimal environmental impacts on dune lakes, wetlands and other water bodies.

Within the community, significant investments have been made to enhance understanding of the groundwater resources as part of consent applications by existing and aspiring horticulturists; in particular, including three of the four Te Hiku iwi. However, there are information gaps associated with groundwater resources (e.g. volume and rates of flow) that, if filled, will enable greater confidence in security of supply for existing and future resources users and inform sustainable economic growth in the area.

4.2.1.1 Te Hiku (North Cape) Storage Options

The preferred storage methods are associated with groundwater resources (Figures 4.2 and 4.3) because surface water flows are low in the area. Groundwater abstraction options could include wells and galleries. The groundwater allocation limit is that of the default National Environmental Standard, i.e. 15% of rainfall recharge (Northland Regional Council 2020d; their Table 27).

The Te Hiku (North Cape) area is included in the ‘Aupouri – other’ groundwater management unit; the allocation limit in this unit is 15% of average annual recharge (Northland Regional Council 2020d; their Table 27). However, this allocation may not be available if groundwater abstraction potentially results in saline intrusion.

Non-irrigated agricultural land within Māori land is the priority for land development. The maximum potential of this land is 5210 ha. However, the potential at the groundwater allocation limit is approximately 773 ha, with a water demand of 35 mm/week during the irrigation season. Horticulture is a possible land-use option in the west coast strip, currently planted in pine trees (Section 5). Consenting issues relevant to the use of water storage in this zone include groundwater limits and conjunctive management of groundwater and surface water through the operation of galleries.

Based on groundwater yields from registered bores, the potential for groundwater storage may be lower than indicated by GIS mapping. However, the location of local drilling within the focus area was not well aligned with the areas that GIS mapping identified as highly productive. Drilling is about to take place in Te Paki, an area that the GIS mapping indicates would be high-yielding. This work, and the aquifer investigations about to be undertaken, will inform the potential for utilising groundwater in the focus area.

Local experts raised a concern that galleries may become connected to surface water and thereby potentially impact on wetlands and dune lakes. As such, they were concerned that galleries may not comply with limits (such as no seasonal change in wetlands). On the considerations about groundwater storage, local experts prioritised an assessment of the potential for small-scale high-flow harvesting for micro-scale on-farm instream storage, noting the very small catchments in the focus area.

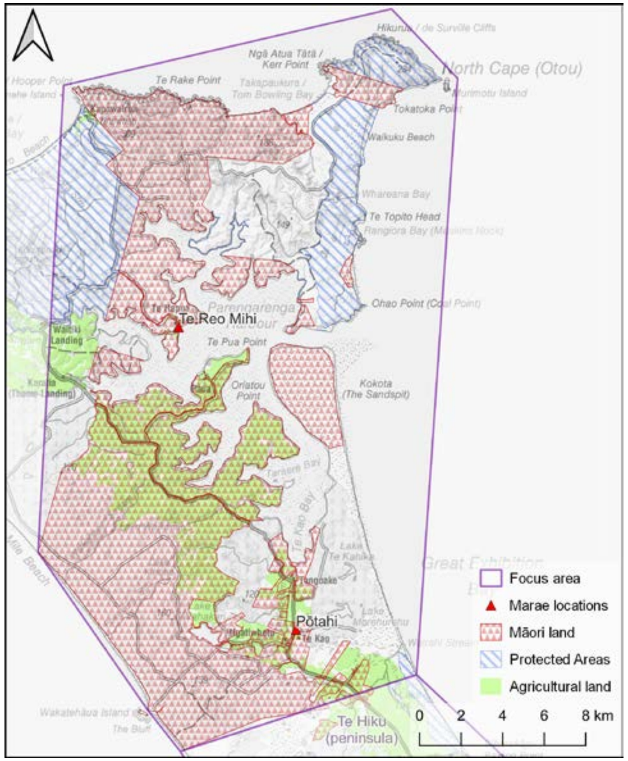


Figure 4.1 Te Hiku (North Cape) focus area summary.

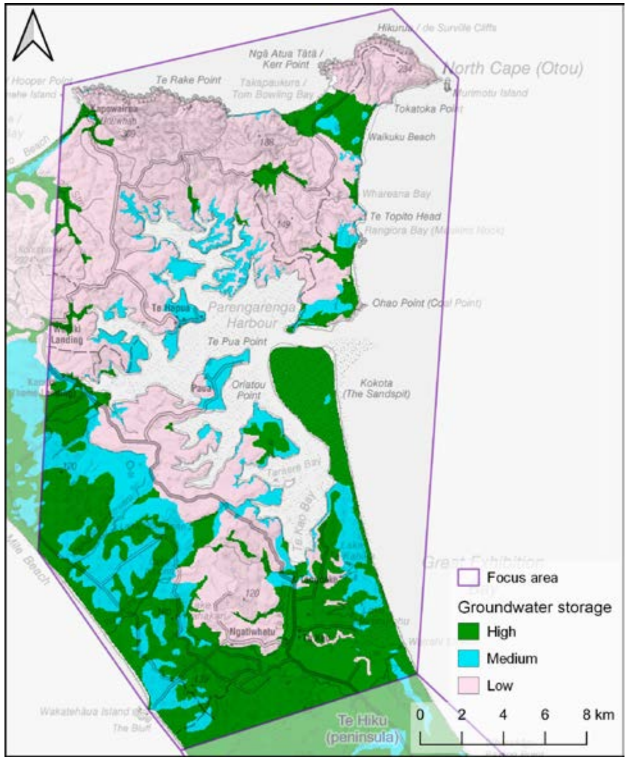


Figure 4.2 Te Hiku (North Cape) options for groundwater storage.

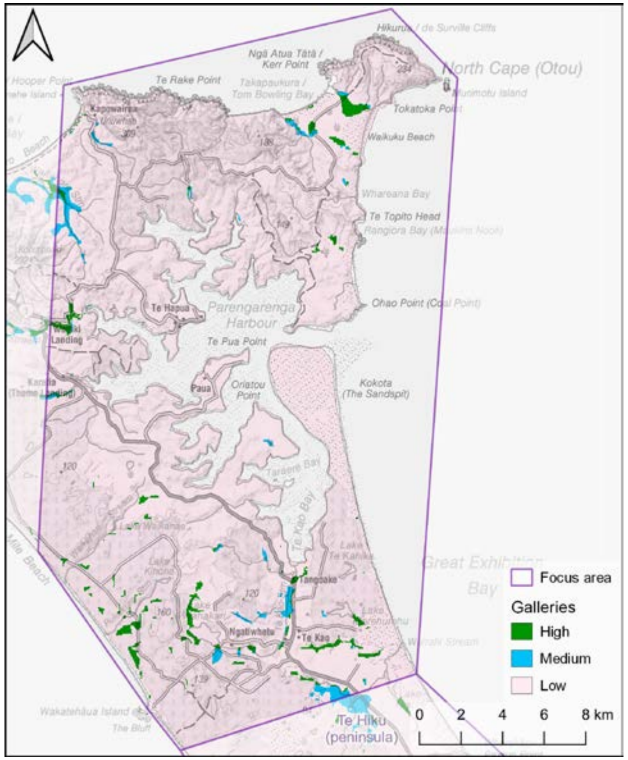


Figure 4.3 Te Hiku (North Cape) options for galleries.

4.2.1.2 Te Hiku (Peninsula) Storage Options

The preferred storage methods are associated with groundwater resources and groundwater galleries (Figures 4.5 and 4.6, respectively) because surface water flows are low in the area. Good prospects for groundwater are mapped in Aupouri and Karikari peninsulas; groundwater galleries may supply limited amounts of water in low-lying areas. Groundwater abstraction options could include wells and galleries. Wetland management for water harvest, Aupouri groundwater allocation, saltwater intrusion and impacts on surface water bodies are consenting issues relevant to the use of water storage in this zone.

Groundwater in this focus area is in demand, with current applications for 24 groundwater consents. These applications seek allocation of 3.4 Mm^3/year in the five groundwater management zones in Karikari peninsula, which is within the Te Hiku (peninsula) focus area (Northland Regional Council 2020e). If approved, these applications will take total allocation in the five zones to approximately 11.3 Mm^3/year.

Therefore, an assessment of groundwater availability is required to assess groundwater availability in this focus area. The Te Hiku aquifer investigation is being undertaken to improve the understanding of the aquifer, including the location of saltwater interface, aquifer properties and connectivity to key surface water features.

Agricultural land (productive land) and Māori land are the priority for water, particularly areas where these two factors are both present. However, there is little of this land in the Te Hiku (peninsula) focus area. However, land that has not traditionally been considered good-quality horticultural land has been found to support avocado cultivation on the peninsula. This is the case with some Māori land.

Agricultural land in this focus area is a total of 20068 ha, of which current irrigation is 633 ha and potential irrigation with the current applications for 24 groundwater consents is 850 ha ("based on an annual pumping volume of 400 mm/yr for the canopy area"; Williamson and Scherberg 2019).

Local experts agreed that groundwater was the top-ranked water storage solution for the focus area. However, they noted that connectivity to surface water bodies and risk of saline intrusion may reduce security of supply from groundwater, depending on the findings of investigations in the region. They also noted that the time implications associated with undertaking groundwater investigations may mean landowners move to surface water storage. It is likely that this would be predominantly filled through the use of baseflow enhancement dams and the harvesting high flows to be released at times of low flow.

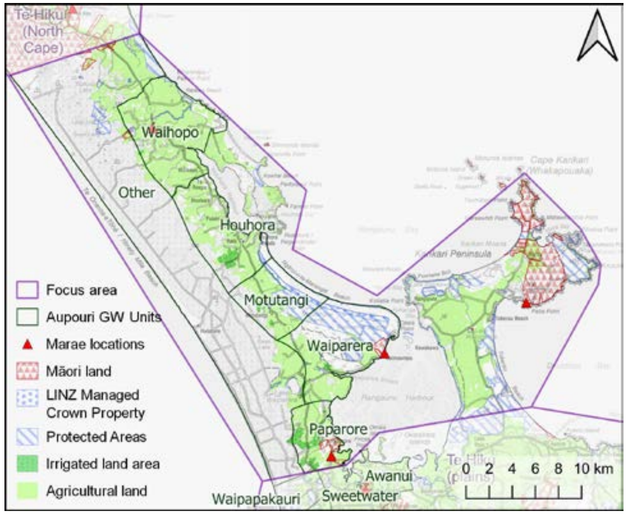


Figure 4.4 Te Hiku (peninsula) focus area summary.

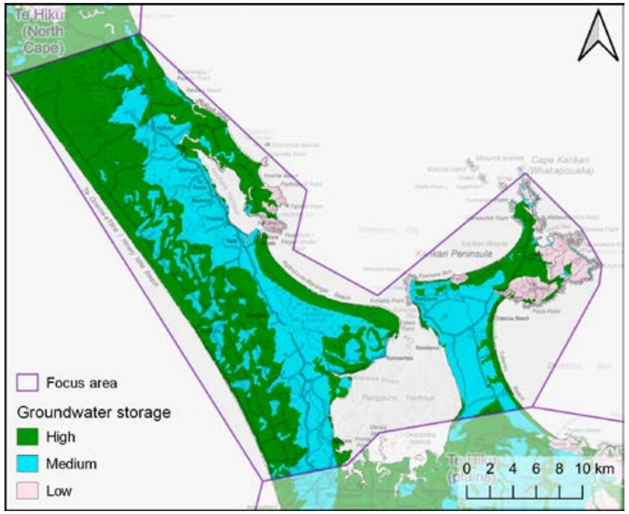


Figure 4.5 Te Hiku (peninsula) options for groundwater storage.

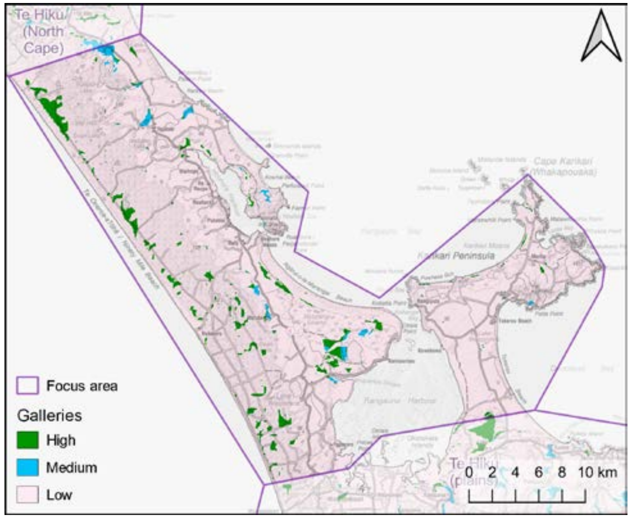


Figure 4.6 Te Hiku (peninsula) options for groundwater galleries.

4.2.1.3 Te Hiku (Plains) Storage Options

The preferred storage methods are associated with groundwater resources and baseflow enhancement dams (Figures 4.8 and 4.9, respectively). Good prospects for groundwater are mapped in Aupouri and Karikari peninsulas. Groundwater abstraction options could include wells and galleries. Groundwater allocation limits are those of Northland Regional Council (2020d; their Table 27) in groundwater allocation zones (Section 2.6).

Agricultural land in the Te Hiku (plains) focus area is a total of 43360 ha, of which current irrigation is an estimated 740 ha and potential irrigation with the current applications for 24 groundwater consents is 850 ha. The latter figure is based on an estimated groundwater use of 0.98 Mm^3/year (from Northland Regional Council 2020e) and “an annual pumping volume of 400 mm/yr for the canopy area” (Williamson and Scherberg 2019). Agricultural land within Māori land is the priority for irrigation. However, there is little of this land in the Te Hiku (plains) focus area.

Policy issues relevant to the use of water storage in this zone include Aupouri groundwater allocation, conjunctive management of groundwater and surface water and the operation of baseflow enhancement dams for productive and environmental benefits.

Based on groundwater yields from registered bores, the potential for groundwater storage may be lower than indicated by GIS mapping, particularly in the southern area of the aquifer and the eastern area of the zone. The aquifer investigations about to be undertaken will inform the potential for utilising groundwater in the focus area. Local experts gave the highest-priority water storage in the Awanui River catchment as use of baseflow enhancement dams and harvesting high flows to be released at times of low flow. Groundwater was the second-ranked priority in the plains and upper catchment. An exception to this approach is to the north of Sweetwater, where groundwater is the highest priority with existing high-yielding wells.

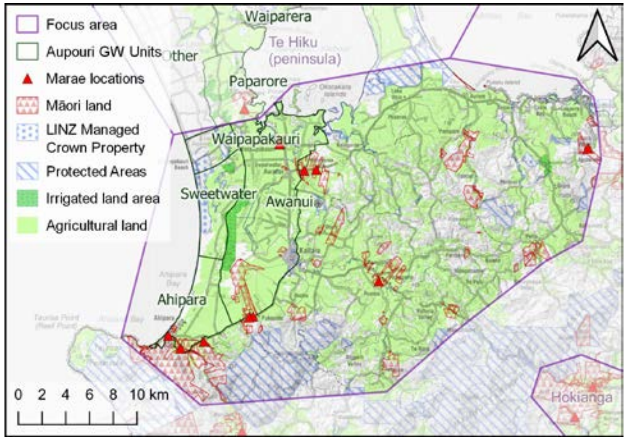


Figure 4.7 Te Hiku (plains) focus area summary.

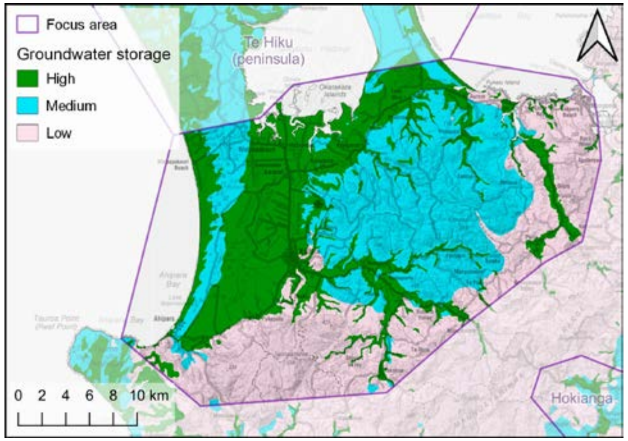


Figure 4.8 Te Hiku (plains) options for groundwater storage.

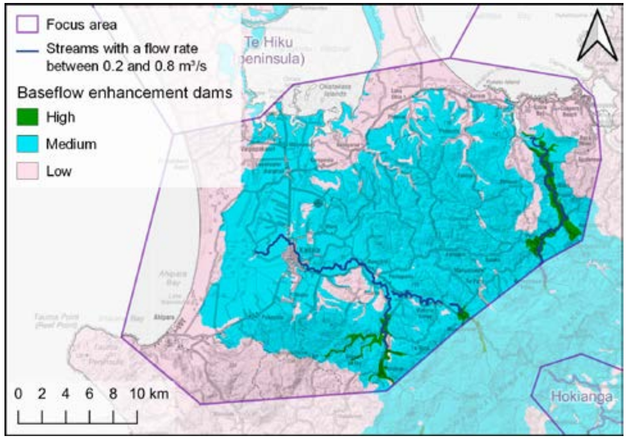


Figure 4.9 Te Hiku (plains) options for dams for baseflow enhancement.

4.2.2 Hokianga

Hokianga is an area with significant Māori land ownership and high levels of economic deprivation, where water storage could enable Māori economic development. Pockets of land around Reena, Tapuwai, Waiotemarama, Whirinake and Mangawhero (Figure 4.10) are examples of high-quality Māori land that could potentially generate significant increases in land productivity through horticulture if sufficient reliable water was available.

4.2.2.1 Hokianga Storage Options

The preferred storage methods are associated with groundwater resources and baseflow enhancement (Figures 4.11 and 4.12, respectively) because surface water flows are low in the area. Groundwater abstraction options could include wells and galleries. The groundwater allocation limit of 15% of annual average rainfall recharge for coastal aquifers is the relevant limit to groundwater allocation; surface water flow limits being relevant to riverine galleries. No groundwater is allocated in this focus area (Figure 2.1).

Non-irrigated agricultural land within Māori land is the priority for water. Approximately 5116 ha of Māori land with agricultural land is mapped in the zone. Horticultural irrigation is a possible option in the area north of North Head, where sand is common (Section 5). Other options for irrigation include the Waimamaku River valley and the Waihou River valley.

Policy issues relevant to the use of water storage in this zone include groundwater allocation limits and conjunctive management of groundwater and surface water through the operation of galleries.

Based on groundwater yields from registered bores, the potential for groundwater storage may be lower than indicated by GIS mapping. With regard to riverine galleries, local experts noted the constraints arising through minimum flows and security of supply considerations. The top priority of local experts is exploration of the potential for micro- to small-scale baseflow enhancement reservoirs and harvesting high flows to be released at times of low flow. The priority areas for exploration within the focus area are Waimamaku and Whirinake.

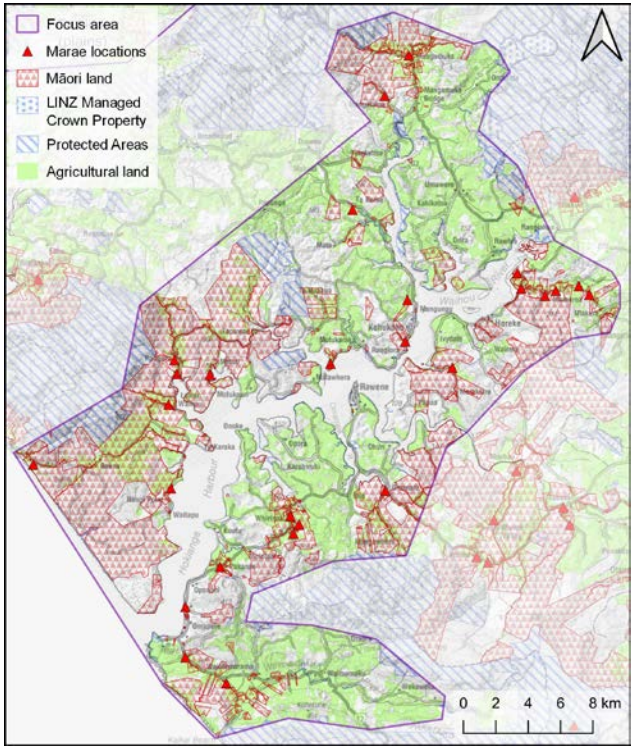


Figure 4.10 Hokianga focus area summary.

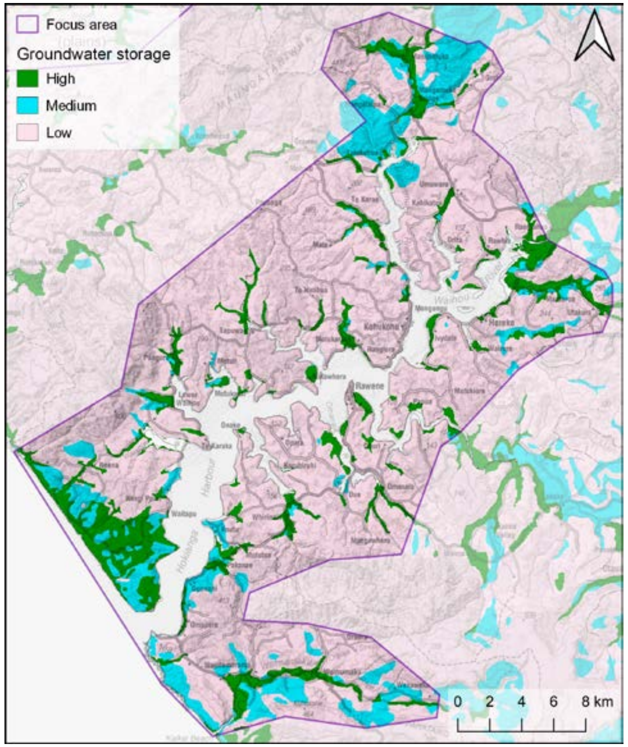


Figure 4.11 Hokianga options for groundwater storage.

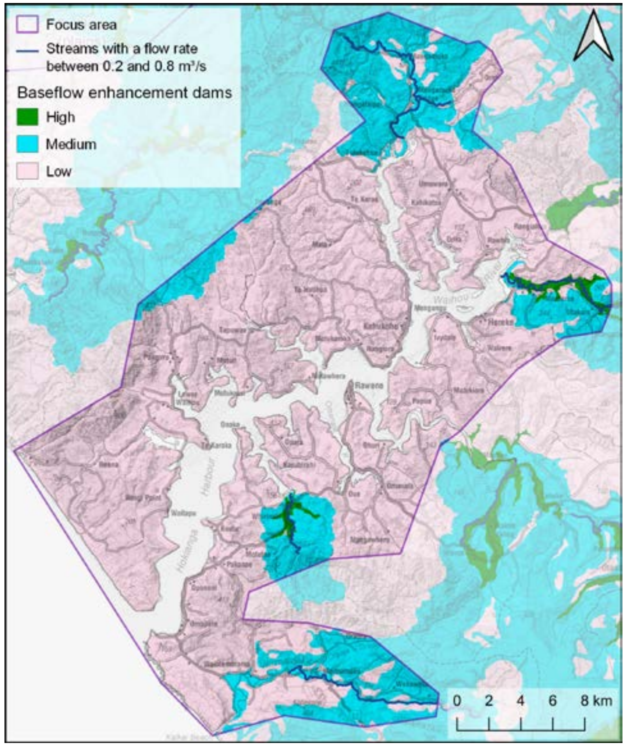


Figure 4.12 Hokianga options for baseflow enhancement.

4.2.3 Moerewa-Pipiwai

A large amount of Māori-owned land in this area is within close proximity to existing industry and transportation links (Figure 4.13). Pockets of this land are suitable for horticulture – much of the land to the south is in forest. Transportation is likely to improve as the PGF investment in the Northland rail line to Otiria is completed, and Ngawha Innovation Park may develop into a horticultural processing hub over time.

4.2.3.1 Moerewa-Pipiwai Storage Options

Preferred storage methods are associated with reservoirs for sustainable productive water and riverine galleries (Figures 4.14 and 4.15, respectively). Surface water flow limits are relevant to galleries. Little surface water is allocated in the Moerewa-Pipiwai focus area (Figure 2.2).

Non-irrigated agricultural land within Māori land is the priority for water. Approximately 5143 ha of Māori agricultural land is mapped in the zone. Policy issues relevant to the use of water storage in this zone include conjunctive management of groundwater and surface water and the operation of baseflow enhancement dams for productive and environmental benefits.

Local experts agree that baseflow enhancement dams are the priority option in the focus area. They note that only small amounts of land, likely disbursed across the focus area, are suitable for horticulture development. Therefore, micro- to small-scale storage is probably most relevant, possibly augmented by individual farmers harvesting winter flows to ensure security of supply.

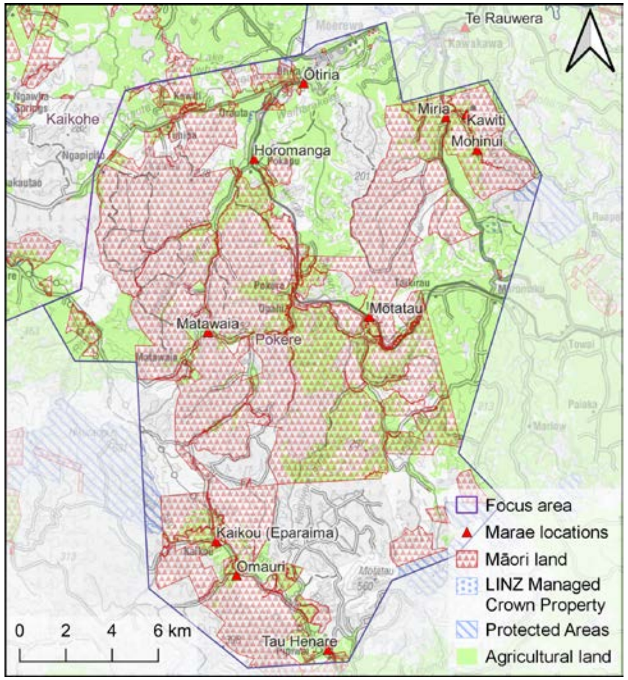


Figure 4.13 Moerewa-Pipiwai focus area summary.

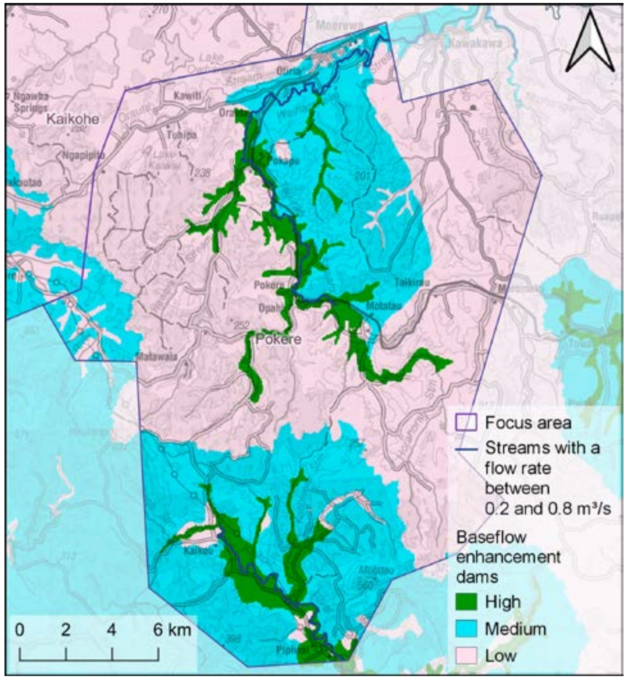


Figure 4.14 Moerewa-Pipiwai options for dams for baseflow enhancement.

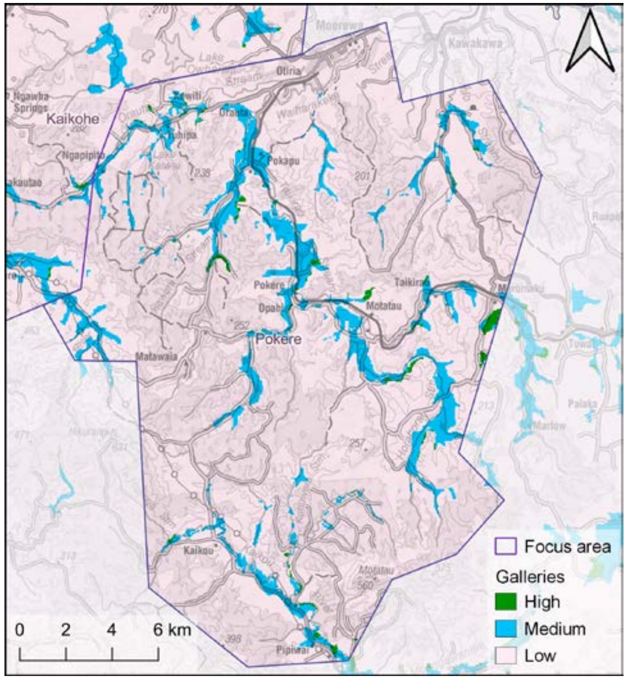


Figure 4.15 Moerewa-Pipiwai options for galleries.

4.2.4 Kaihu

There are some high-quality soils in the Kaihu focus area, currently in dairy, that could be moved into horticultural land. This area includes some high-quality Māori-owned land near Maramanui and land to the west of Ahikiwi (Figure 4.16).

4.2.4.1 Kaihu Storage Options

Preferred storage methods are associated with groundwater and riverine galleries (Figures 4.17 and 4.18, respectively). Surface water flow limits are relevant to galleries. Little surface water is allocated in the Kaihu focus area (Figure 2.2).

Non-irrigated agricultural land within Māori land is the priority for water. Approximately 473 ha of Māori land with agricultural land is mapped in the zone.

Policy issues relevant to the use of water storage in this zone include groundwater allocation limits, conjunctive management of groundwater and surface water and the operation of baseflow enhancement dams for productive and environmental benefits.

Based on groundwater yields from registered bores, local experts note that the potential for groundwater storage may be lower than indicated by GIS mapping. However, the location of local drilling within the focus area is not well aligned with the areas that GIS mapping identified as highly productive. It is worth exploring further the potential for more productive water in areas that have not been drilled. Further investigations will need to take into account the potential impact on minimum flows and security of supply for existing users (including the district council municipal supply).

The priority water storage option for local experts would be baseflow enhancement dams and harvesting peak flows in the Kaihu River catchment to be released at times of low flow, based on flow harvesting in the Kaihu River catchment. This could be on the plains or in the upper catchment.

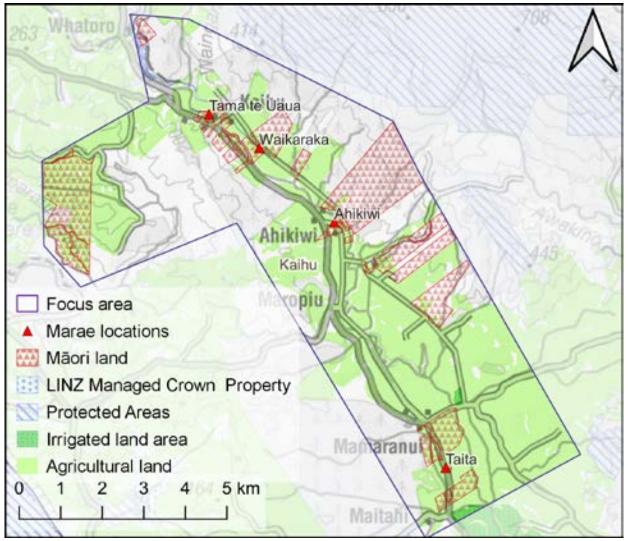


Figure 4.16 Kaihu focus area summary.

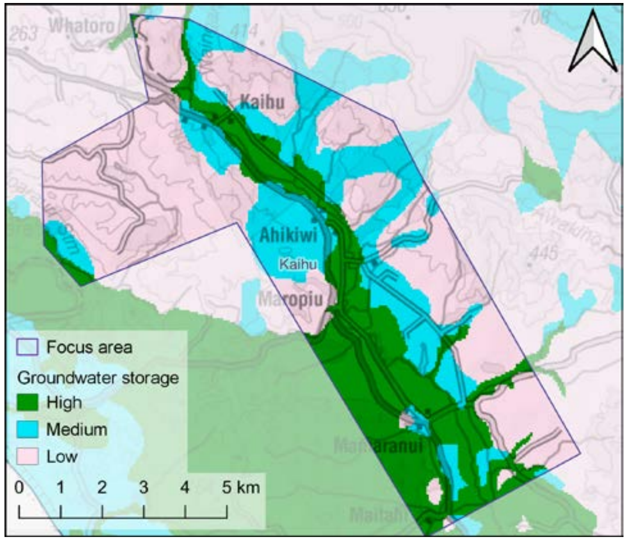


Figure 4.17 Kaihu options for groundwater storage.

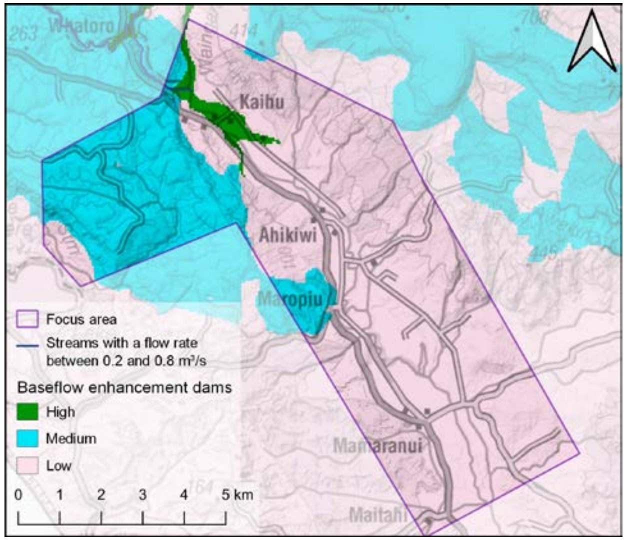


Figure 4.18 Kaihu options for baseflow enhancement.

4.2.5 Ruawai

Ruawai is largely flat, high-value cropping land that is mostly used for dairy and kūmara and has the potential to be used for higher-value horticulture and tree crops. There are small parcels of Māori land within the area, with the largest blocks in the north (Figure 4.19).

4.2.5.1 Ruawai Storage Options

Preferred storage methods are associated with groundwater and storage reservoirs (Figures 4.20 and 4.21, respectively). Surface water flow limits are relevant to galleries. Groundwater is currently fully allocated in the vicinity of Ruawai township, and little surface water is allocated in the Ruawai focus area (Figures 2.1 and 2.2, respectively).

Non-irrigated agricultural land within Māori land in the north of the focus area is the priority for irrigation. Approximately 658 ha of Māori land with agricultural land is mapped in the zone. Baseflow enhancement could take place to the north or east of this Māori land.

Policy issues relevant to the use of water storage in this zone include groundwater allocation limits, conjunctive management of groundwater and surface water and the operation of baseflow enhancement dams for productive and environmental benefits.

Local experts commented that, as groundwater is fully allocated, a better understanding of the groundwater resource is important before allocation limits could be reconsidered. The current understanding is that there is recharge to the aquifer from South Pouto. Investigating the South Pouto aquifer could therefore be beneficial to Ruawai. Given the current allocation settings, local experts would prioritise storage reservoirs (micro to small) on the plains or in the upper catchment. This focus area is below sea level, and climate change may have a significant impact here.

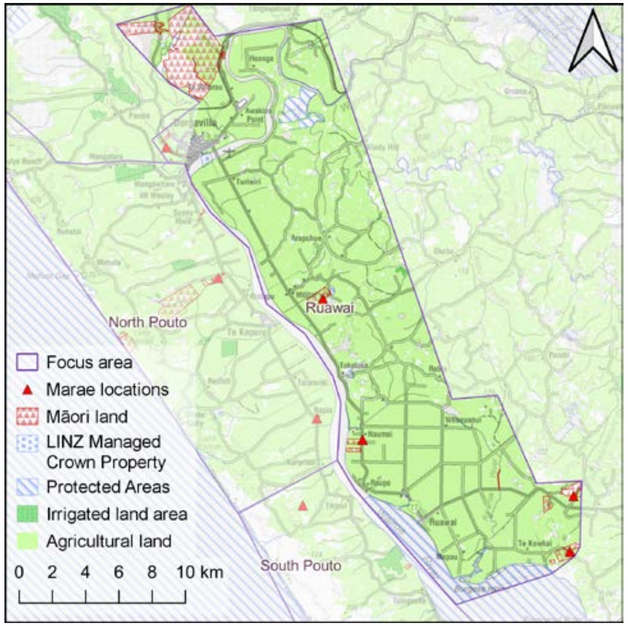


Figure 4.19 Ruawai focus area summary.

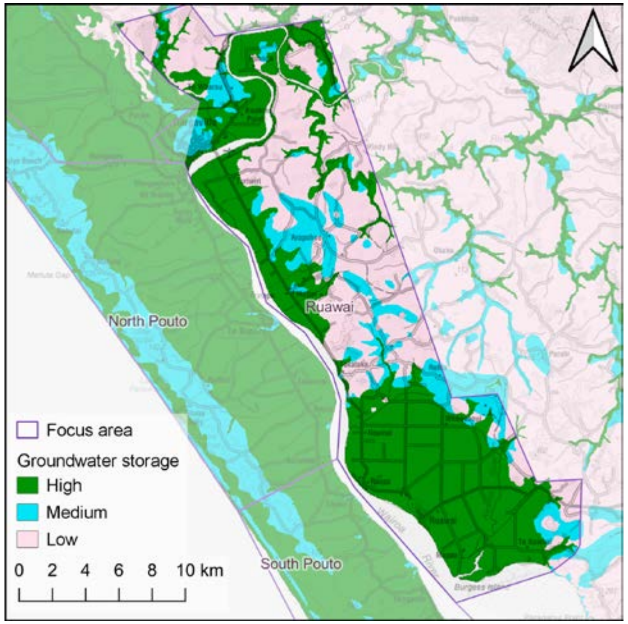


Figure 4.20 Ruawai options for groundwater storage.

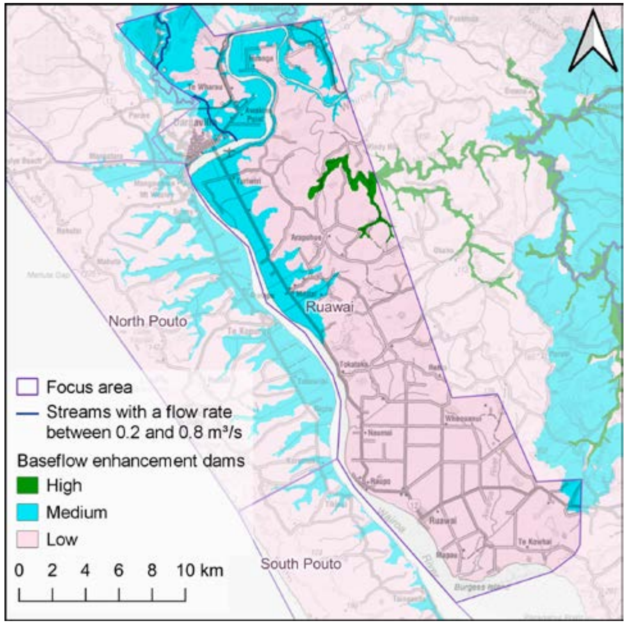


Figure 4.21 Ruawai options for baseflow enhancement dams.

4.2.6 South Pouto

A large block of land to the south of the peninsula is Māori owned (Figure 4.22). The soils in South Pouto are predominantly free-draining sandy soils, and a significant part of the area is covered in forestry. It is anticipated that horticulture such as avocados could be grown if water was available. This area was excluded from the Te Tai Tokerau Water Trust investment in Kaipara, which will take place further up the Pouto peninsula and will involve harvesting of surface water flows. Less information is available on water resources in South Pouto than in the north of the peninsula.

4.2.6.1 South Pouto Storage Options

The preferred storage methods are associated with groundwater resources (Figures 4.23 and 4.24) because surface water flows are low in the area. Groundwater abstraction options could include wells and galleries. The groundwater allocation limit is that of the default NES, i.e. 15% of rainfall recharge and no groundwater is allocated in the area (Figure 2.1).

Non-irrigated agricultural land within Māori land is the priority for water. Approximately 1857 ha of Māori land with agricultural land is mapped in the zone. The estimated groundwater allocation limit is approximately 18.1 Mm^3/year, i.e. 15% of annual rainfall recharge on the zone. This limit is estimated as sufficient to irrigate approximately 350 ha, with a water demand of 35 mm/week during the irrigation season. Horticulture is a possible option in non-agricultural land, i.e. sand country on the west coast (Section 5). Policy issues relevant to the use of water storage in this zone include groundwater limits and the operation of galleries.

Local experts agree that groundwater storage is the priority storage option (incorporating existing basement data). Based on groundwater yields from registered bores, the potential for groundwater storage may be lower than indicated by GIS mapping. However, current wells are shallow, so assessment of the resource would be valuable, particularly in light of the connectivity to Ruawai. Further, the location of local drilling within the focus area is not well aligned with the areas that GIS mapping identified as highly productive. It is worth exploring further the potential for more productive water in areas that have not been drilled.

Local experts see the potential for galleries as limited because of the potential impact on minimum flows and security of supply for existing users (including the District Council municipal supply). Local landowner preference is for micro- to small water storage reservoirs because of the timing of water becoming available and because of concerns about environmental impact.

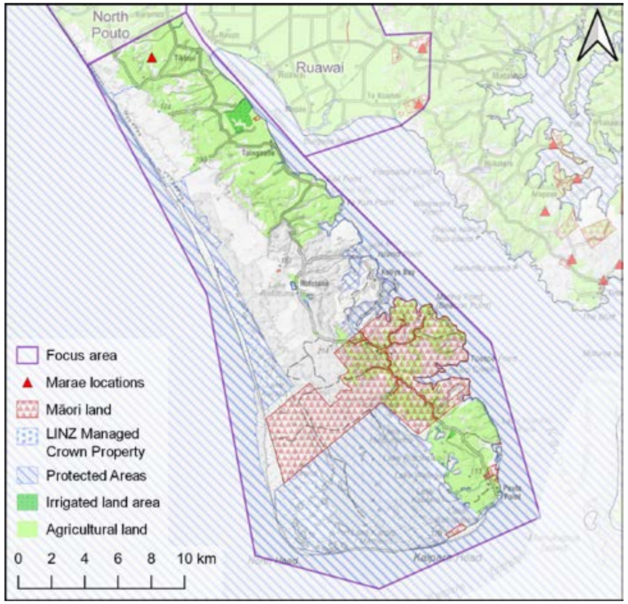


Figure 4.22 South Pouto focus area summary.

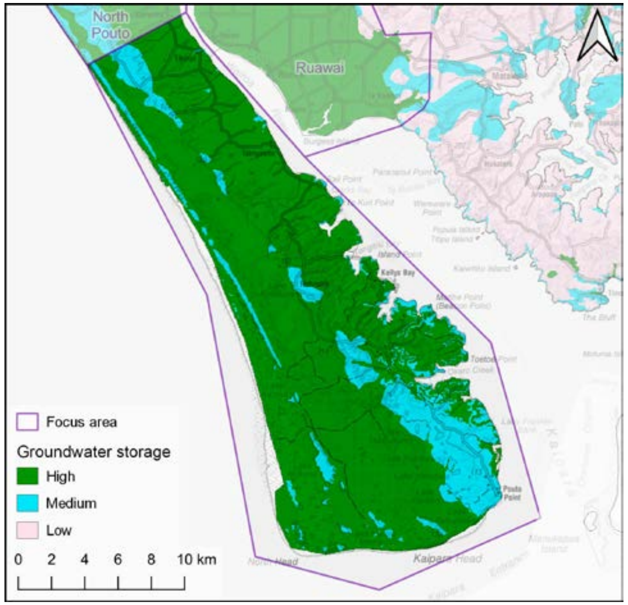


Figure 4.23 South Pouto options for groundwater storage.

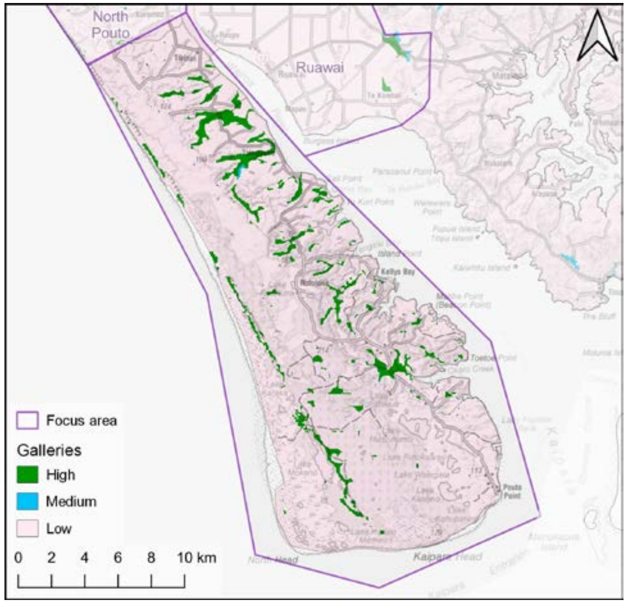


Figure 4.24 South Pouto options for galleries.

4.3 Other Methods

The locations of many dams were identified in Northland, some of which may not currently provide water. These locations may provide Northland with considerable opportunities for surface storage. Infrastructure associated with water storage may remain at these locations; therefore, costs associated with dam refurbishment may be less than costs associated with 'greenfield' dam sites. Enhancement of wetlands may be an option in some areas, with low-scale engineering works that can increase wetland water storage and manage that storage. However, there are significant impediments to this approach, with concerns about sensitive wetlands and national legislation that prevent tampering with wetlands. These concerns are generally based on the historic large-scale drainage of wetlands. However, limited re-watering of wetlands, as would occur with low-scale works, may be acceptable to communities.

4.4 Summary of Focus Areas

The two higher-ranked water storage options are summarised in Table 4.1.

Table 4.1 Summary of preferred storage methods in focus areas.

Area	Top-Ranked Water Source	Second-Ranked Water Source
Te Hiku (North Cape)	Groundwater (high)	Galleries (medium in limited areas only)
Te Hiku (Peninsula)	Groundwater (high)	Galleries (medium in limited areas only)
Te Hiku (Plains)	Groundwater (high)	Baseflow enhancement
Hokianga	Groundwater (medium)	Baseflow enhancement
Moerewa-Pipiwai]	Water storage reservoir (medium to high)	Galleries (medium)
Kaihu	Groundwater (medium to high)	Baseflow enhancement
Ruawai	Groundwater (high)	Baseflow enhancement
South Pouto	Groundwater (very high)	Galleries (high)

5.0 INVESTIGATIONS INTO WATER AVAILABILITY ACROSS NORTHLAND

This report shows that there is scope to increase land productivity in Northland through increased access to water. Investigations into the physical availability of surface water and groundwater will give the region a better sense of the water resources that are available and that could be used for sustainable land development. Investigations will be useful in areas where water resources are already significantly allocated, such as in the Te Hiku peninsula and plains and in Ruawai. Investigations will provide information that will enable Northland Regional Council to re-examine existing water take limits and determine whether it is possible to make more water available. In areas with little or no existing allocations, investigations could inform the potential locations of new land developments.

A number of the focus areas have little or no existing allocations, including Te Hiku (North Cape), Hokianga, Moerewa-Pipiwai, Kaihu and South Pouto. Resource consent applications to access water in these areas may therefore be able to move more quickly through the resource consenting process, subject to community support. Groundwater is a key source of water in each of these areas. Accessing sustainable and reliable groundwater has lower construction costs than surface water storage that harvests surface water flows. Therefore, groundwater may unlock development in these areas in shorter timeframes.

This report shows that there may be groundwater available to support land production in these focus areas. In terms of surface water, further investigations of flows (i.e. high winter flows and low summer flows) and groundwater recharge would provide information on whether sufficient water is harvestable to justify investment in storage infrastructure. Across the focus areas, the combined surface water and groundwater information will inform the council, landowners and potential development partners of the level of water that can be used in the focus area and therefore the potential for land development. Surface water monitoring will be particularly important in the Ruawai focus area, as groundwater is fully allocated in the vicinity of Ruawai township (Figure 2.1).

Investment into Investigations of Water Needs and Opportunities

The PDU has $4M funding available for investment in investigations in Northland (including the regional needs assessment in this report). Funding will be applied to a range of activities that will improve the understanding of water needs and opportunities in the region in relation to bringing land into production in a sustainable manner. The bulk of the funding will be devoted to investigation of the Aupouri aquifer, which is the key focus for improvements in Northland water storage. Significant investments in the mid-North and Kaipara have been funded by the PDU and are being taken forward by the Te Tai Tokerau Water Trust. Consequentially, these focus areas are not discussed further here. However, we note that there are synergies and opportunities to gain efficiencies through collaboration between the regional council and the water trust in undertaking further work on water storage investigations.

The proposed investments fall into the following categories of investigations:

- aquifer mapping
- drilling to explore groundwater
- measuring surface water flows and groundwater recharge, and
- technical/scientific assessment of scope for harvesting winter flows.

These investigations will improve our understanding of water availability on a sustainable basis and will inform the water storage solutions that are most appropriate within each focus area.

Aquifer Mapping: Te Hiku Peninsula and Plains

Given the right geological conditions, aquifer mapping can provide a community with greater certainty about the quantum of water that is present in an aquifer. This, plus added information about groundwater flows, can give the Regional Council and the community confidence about how much water can be used to bring land into sustainable production. Aquifer mapping and groundwater recharge measurement could provide better information about the aquifers in Te Hiku and South Pouto and therefore provide more certainty about the potential for land development in these areas.

The priority for investment in aquifer mapping and groundwater recharge measurement is the Te Hiku area, where groundwater is currently in demand. A recent hearing addressed 24 consent applications for groundwater (see above); and landowners, the council, DOC and other local stakeholders developed an application to the PGF for funding groundwater investigations in the area. There is a desire in the Te Hiku community to bring further land into production if there is sufficient water available in the aquifer to do so.

Investigations of the South Pouto groundwater system will give a good understanding of this resource and are therefore important to the local community. These investigations are beneficial to the region because they will allow assessment of water availability in Poutu and Ruwai.

Mapping of the Aupouri aquifer is the priority for the region as a whole because of:

- the high levels of existing and potential demand for water, current applications for groundwater and residual uncertainty about water availability, particularly groundwater;
- the need for sophisticated information to give the Regional Council and community the confidence that water consents are not environmentally detrimental on the Te Hiku peninsula;
- the need to give investors further certainty about whether water-source reliability, through characterisation of aquifer physical properties and a reassessment of groundwater flows, is suitable for future horticultural investments;
- a significant level of social and economic uplift that is possible from sustainably increasing the productivity of land in this region, particularly for Māori.

Aquifer mapping involves three stages of work:

- pre-mapping investigations
- mapping and data collection, and
- application of data into modelling.

During the first stage of the Te Hiku aquifer mapping, it will be determined whether the geological environment is conducive to aquifer mapping. It may be that the mapping will not be able to sufficiently distinguish the base of the aquifer, depending on the composition of the base surface. If aquifer mapping is not possible, drill testing will be utilised in its place. Some early drilling and field measurements will be undertaken to inform the mapping process.

The Te Hiku project will also include a reassessment of groundwater flows, providing informed input to the regulatory process related to groundwater allocation limits administered by Northland Regional Council. Crucially, groundwater inflow from rainfall will be calculated from field measurements and modelling, including:

- A review of current Northland Regional Council monitoring (rainfall, surface flow and groundwater levels) regarding fitness-for-purpose for characterising Te Hiku groundwater flows. This review will likely include GNS Science, Northland Regional Council and NIWA.
- Design of a monitoring network to measure rainfall, surface flows, groundwater levels and a rainfall recharge site (or sites), e.g. White et al. (2017), relevant to the focus areas, aiming to improve on current monitoring (e.g. the climate stations and surface flow sites noted by Frost et al. [2017]).
- Installation of the network and measurement for five years.
- Modelling after two years of data collection to calculate groundwater inflows and the uncertainty of these inflows.
- Provision of information to inform the regulatory framework for groundwater allocation.

The Te Hiku project will cost approximately $3.6 million, of which the bulk will be funded through this project and the remaining funding to be provided by the project members. This will be the priority investment for Te Hiku peninsula and plains area.

Drill Testing and Galleries to Test Groundwater Availability: South Pouto

Drill testing of groundwater and pilot galleries will provide more localised knowledge of groundwater availability at a lower cost than aquifer mapping. Subject to conversations with local landowners, this would be the priority for South Pouto. Targeted drilling and excavation for galleries would inform the availability of water for productive use in this area, such as avocado orchards. Drilling, excavation and pump testing and data analysis for this focus area is estimated to cost approximately $200,000.

Measurement of Surface Flow and Groundwater Recharge to Calculate Sustainable Water Storage across Northland

Northland has limited data on surface water flows and groundwater recharge in the locations identified in this report. The focus areas would benefit from a better understanding of surface water flows and groundwater recharge. This would enable the region to assess the viability of surface water storage and groundwater storage for these locations.

Gauging and permanent monitoring of surface water flows and measurement of groundwater recharge would provide information about the quantity of water in waterbodies throughout the year, enabling assessment of the need for storage, the impact of harvesting of winter flows and the potential quantity of water available for storage and thereby where and how much land development is possible. It would also be valuable baseline information for informing future resource consent applications, from surface water and groundwater, and updating models that are currently largely based upon synthetic data.

Ideally, a single monitoring network across Northland would be put in place for this purpose to better understand surface water flows, groundwater flows and available water across the region. This would support the region's understanding of environmental impacts of economic activity, as well as identify where water is available for different land use. Continuous surface gauging stations are being established by the Te Tai Tokerau Water Trust at 12 sites in the mid-North and Kaipara. This monitoring could be expanded to include the areas being investigated as part of this project, with the Water Trust also monitoring these sites over time.

A region-wide programme such as this could extend this to a further 30+ surface monitoring sites and numerous groundwater sites across the region, with particular attention given to the focus areas. While all areas would benefit from this investigation, monitoring in these locations would be prioritised if funding is limited.

A first step in monitoring surface and groundwater flows will be to identify the waterbodies to be monitored, which are likely to have sufficient flows to enable environmentally sustainable harvesting while generating enough water to justify investment in water storage and harvesting infrastructure. These waterbodies would need to be within reach of the productive and Māori land to brought into production.

A desktop exercise would be undertaken to develop a prioritised list of catchments for consideration for monitoring. This exercise would use readily available information from Northland Regional Council gauging stations and modelling that is currently funded through other projects. Prioritisation would be based upon key attributes such as size of the water resource, suitability of land for development and proximity to Māori-owned land. Development of a prioritised list of monitoring sites for surface water and groundwater would cost approximately $30,000. The cost of purchasing and installing gauging stations, followed by stream velocity gauging to develop rating curves for each site, is estimated to cost $5000 to $10,000 per site, dependent on localities. Groundwater recharge monitoring site installation costs are an estimated $40,000 per site.

Assessment of Scope for Harvesting Winter Flows across Northland

Harvesting the winter flows of surface water is proposed as one means of generating water for productive purposes while also addressing the impact on rural communities of extreme drought and flooding events. Undertaking a technical and scientific study into the scope for harvesting winter flows in Northland would inform discussions about the feasibility of this approach and its impact on instream values and environmental impacts. This work could also inform similar considerations in other regions where summer droughts are problematic (i.e. east coast North Island, east coast South Island, Waikato, Nelson and inland Southland) and could be undertaken jointly with Gisborne and Southland in a cross-regional project.

Other Regional Water Concerns: Adequacy of Community Water Supplies

The region has concerns about the adequacy of existing schemes such as Maungatapere and Mangawhai. Undertaking assessments of these schemes is a priority for the region; however, such assessments are beyond the PGF’s investment scope. Such assessment would relate to maintenance of existing productivity (rather than growth) or to municipal water (which is being dealt with through other government investments). Assistance to the Mangawhai and Maungatapere communities with their water supplies is important to ensure that primary sector and other activities are maintained. Each community would benefit from investment in water studies (each costing approximately $30,000) to explore the potential for improved community outcomes.

Water demand, particularly municipal supply, is the issue in Mangawhai. The area is growing as increasing numbers of Auckland commuters are now in residence, along with significant new land developments. Without a water study, various ad-hoc and individual projects will continue to be undertaken, with differing requirements, that will not result in the best outcome for the community.

For Maungatapere, the issue is the high cost of the existing water scheme (hindered by historic uptake issues). Potentially, the Maungatapere scheme can be made more efficient to ensure its long-term sustainability. Here, a study that determines scheme efficiencies would be beneficial to bringing more land into production.

Unfortunately, the issues at Mangawhai and Maungatapere do not come within the PGF's scope in relation to water storage. PGF investments relate to lifting productivity and so do not involve maintenance of existing schemes. Many areas in Northland have not had the advantage of water storage in the past, and current PGF funds are directed to addressing such longstanding gaps. However, some areas of Northland are experiencing significant challenges to the adequacy of the existing arrangements. While these assessments cannot be progressed through PGF funding, some external assistance is needed to undertake this work. The Northland region will need to explore how to address these issues through other means, e.g. the Government's 'Three Waters' investment.

Next Steps

The Te Hiku aquifer mapping is the priority project for the region. This will be managed through a governance process involving the PDU – GNS Science collaboration and the Te Hiku project team that developed the aquifer mapping proposal. This will ensure the work addresses the key issues for the community and for Northland Regional Council as the regulator responsible for setting water allocation limits.

Other types of investigations will be considered further by Aqua Intel Aotearoa in discussion with Northland Regional Council, Te Tai Tokerau Water Trust and local experts to determine the most effective use of remaining funds.

Options include:

- Groundwater availability in the South Pouto focus area. Consideration of water availability in this focus area emerged through the scoping of the current Kaipara water storage project and is relevant to current work by the Te Tai Tokerau Water Trust in an area to the north of this focus area. A first step is to engage with the local community to determine their appetite for investigations of water availability and for land development.
- Community engagement with landowners in the other focus areas to determine the potential appetite and the level of investment readiness for bringing land into production.
- Beyond these specific activities in the focus areas, priority investments include extending the programme investment in measurement of surface water flows and groundwater recharge across the region and undertaking a study of the scope of baseflow enhancement supported by the harvesting of winter flows and releasing flow at times of low flow. It is proposed that funding is applied to prioritising locations and installation and monitoring of gauges in the focus areas.

6.0 ACKNOWLEDGMENTS

The authors thank members of the Northland community for their involvement with the project. Particularly, we thank staff at Northland Regional Council for their contributions to the report, including Susie Osbaldiston, Jason Donaghy and Darryl Jones. The contributions from Andrew Macdonald, a consultant for Northland Regional Council, in providing GIS datasets are appreciated. We also thank members of the Te Tai Tokerau Water Trust. We thank PDU staff Richard Westbury and Rose Austen-Falloon for their active participation in guiding the project. GNS Science staff are also acknowledged, including Stew Cameron for his review of the draft; Magali Moreau and Conny Tschritter (for completing some GIS calculations); and Kate Robb for formatting.

7.0 REFERENCES

New Zealand Avocado. c2020a. Tauranga (NZ): New Zealand Avocado; [accessed 2020 Nov 1]. https://industry.nzavocado.co.nz/

New Zealand Avocado. c2020b. Tauranga (NZ): New Zealand Avocado. Avocado orchards take over dairy farms; [accessed 2020 Nov 1]. https://industry.nzavocado.co.nz/avocado-orchards-take-over-dairy-farms/

Booker DJ. 2015. Hydrological indices for national environmental reporting. Christchurch (NZ): National Institute of Water & Atmospheric Research. 39 p. Report CHC2015-015. Prepared for Ministry for the Environment. https://data.mfe.govt.nz/layer/53309-river-flows/

Cameron S, Osbaldiston S, Skuse G, Revfem C. 2001. Northland. In: Rosen MR, White PA. *Groundwaters of New Zealand*. Wellington (NZ): New Zealand Hydrological Society. p. 291–302.

Capon SJ. 2013. Water resources. In: Salinger J, editor. *Living in a warmer world: how a changing climate will affect our lives*. Collingwood (AU): CSIRO Publishing. p. 87–99.

Chappell PR. 2014. The climate and weather of Northland. 3rd ed. Wellington (NZ): National Institute of Water & Atmospheric Research. 38 p. (NIWA science and technology series; 59).

Clarke W, De George B. 2016. KICL: economic, social and environmental impact assessment. Arrowtown (NZ): Rationale Limited. 70 p. Prepared for Kerikeri Irrigation Company Ltd.

Columbus J, Sirguey P, Tenzer R. 2011. A free fully assessed 15 metre digital elevation model for New Zealand. *Survey Quarterly.* 66:16–19.

Donaghy J. 2020 Dec 3. Personal communication. Natural Resources Monitoring Manager, Northland Regional Council, Whangārei, NZ.

Edmunds S. 2017 Sep 10. Rebellion in paradise: the ratepayers who fought the law and won. *Stuff;* [accessed 2020 Nov]. https://www.stuff.co.nz/national/politics/96338350/rebellion-in-paradise-the-ratepayers-who-fought-the-law-and-won

Frost C, Algeo L, Paine S, Adams N, Sanderson K, Stokes F, Morgan D, Gibbs A, Rajanayaka C, Cathcart B. [2017]. Scoping of irrigation scheme options in Northland. Whangārei (NZ): Opus International Consultants Ltd. 90 p. Prepared for Northland Regional Council; [accessed 2021 Apr]. https://www.nrc.govt.nz/your-council/economic-development/water-storage-and-use-project/

GHD Limited, Boffa Miskell Limited. 2019. Three Waters review: cost estimates for upgrading wastewater treatment plants that discharge to the ocean. Auckland (NZ): GHD Limited. 34 p. + appendices. Prepared for the Department of Internal Affairs.

Henderson R. 2019. Personal communication. Principal Scientist, National Institute of Water & Atmospheric Research, Christchurch, NZ.

Kerikeri Irrigation. c2020. Kerikeri (NZ): Kerikeri Irrigation Company Ltd; [accessed 2020 Nov 12]. http://keriirrigation.co.nz/

LINZ Data Service. 2019. Wellington (NZ): Land Information New Zealand. NZ building outlines; [updated 2020 Aug 24; accessed 2020 May 19]; [dataset]. https://data.linz.govt.nz/layer/101290-nz-building-outlines/

LRIS Portal. 2000. Lincoln (NZ): Landcare Research New Zealand. FSL Profile Available Water; [released 2000 Jan 1; accessed 2020 May 19]; [map]. https://lris.scinfo.org.nz/layer/48100-fsl-profile-available-water/

LRIS Portal. 2020. Lincoln (NZ): Landcare Research New Zealand. LCDB v5.0 – Land Cover Database version 5.0, mainland New Zealand. [updated 2020 Jan 29; accessed 2020 May 19]; [map]. https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

Macdonald A. 2020a Jul 10. Personal communication. Biospatial Ltd. Whangārei, NZ.

Macdonald A. 2020b Aug 25. Personal communication. Biospatial Ltd. Whangārei, NZ.

Macdonald A. 2020c Aug 26. Personal communication. Biospatial Ltd. Whangārei, NZ.

Maungatapere Water Co. c2020. Whangārei (NZ): Maungatapere Water Company; [accessed 2020 Nov 13]. http://mpewaterco.co.nz/

Ministry for the Environment. 2018. Wellington (NZ): Ministry for the Environment.Climate change projections for the Northland region; [updated 2018 May 31; accessed 2020 Oct 28]. https://www.mfe.govt.nz/climate-change/likely-impacts-of-climate-change/how-could-climate-change-affect-my-region/northland

Ministry of Primary Industries. 2019 Dec 9. Northland iwi starts planting 20-hectare avocado orchard; [accessed 2020 Nov 1]. https://www.mpi.govt.nz/news-and-resources/media-releases/northland-iwi-starts-planting-20-hectare-avocado-orchard/

Moreau M, White PA, Mourot F, Rawlinson Z, Tschritter C, Cameron SG, Westerhoff RS. 2019. Classification of New Zealand hydrogeological systems. Lower Hutt (NZ): GNS Science. 28 p. (GNS Science report; 2018/35).

Nicholson C, Perquin J-C. 2019. River water quality and ecology in Northland: state and trends 2012–2016. Whangārei (NZ): Northland Regional Council. 57 p.

Northland Regional Council. 2015. State of the environment report 2015. Whangārei (NZ): Northland Regional Council. 130 p.

Northland Regional Council. [2020]a. Whangārei (NZ): Northland Regional Council. Climate change in Northland; [accessed 2020 Oct 28]. https://www.nrc.govt.nz/environment/climate-change/climate-change-in-northland/

Northland Regional Council. [2020]b. Whangārei (NZ): Northland Regional Council. Groundwater; [accessed 2020 Oct 27]. https://www.nrc.govt.nz/environment/water/groundwater1/

Northland Regional Council. [2020]c. Whangārei (NZ): Northland Regional Council. Limited notification – 24 groundwater takes from the Aupouri Aquifer; [accessed 2020 Nov 4]. https://www.nrc.govt.nz/consents/notified-resource-consents/limited-notification-24-groundwater-takes-from-the-aupouri-aquifer/

Northland Regional Council. 2020d. Proposed regional plan for Northland: appeals version – August 2020. Whangārei (NZ): Northland Regional Council. 318 p.

Northland Regional Council. 2020e. Whangārei (NZ): Northland District Council. Drought firmly "locked in" in Northland; [updated 2020 May 1; accessed 2020 Jul 27]. https://www.nrc.govt.nz/news/2020/may/drought-firmly-locked-in-in-northland/

Opus International Consultants Ltd. [2017]. Scoping of irrigation scheme options in Northland. Whangārei (NZ): Opus International Consultants Ltd; [accessed 2020 Nov]. Prepared for Northland Regional Council. https://www.nrc.govt.nz/your-council/economic-development/water-storage-and-use-project/

Osbaldiston S. 2020a Aug 25. Personal communication. Groundwater Management Specialist, Northland Regional Council. Whangārei, NZ.

Osbaldiston S. 2020b. Evidence in chief water resources: in the matter of the Resource Management Act 1991 and of an appeal under clause 14 of Schedule 1 of the Act. 50 p.

Pearce P, Paul V, Mullan B, Zammit C, Sood A, Collins D, Bell R, Law C. 2016. Climate change projections and implications for Northland. Auckland (NZ): National Institute of Water & Atmospheric Research. 105 p. Report 2016072AK. Prepared for Northland Regional Council.

Pene M. 2020. Personal communication. Environmental and Regulatory Services, Northland Regional Council, Whangārei, NZ.

Rajanayaka C, Donaggio J, McEwan H. 2010. Update of water allocation data and estimate of actual water use of consented takes: 2009–10. Christchurch (NZ): Aqualinc Research Ltd. 118 p. Report H10002/3. Prepared for Ministry for the Environment.

Rennie R. 2020 Sep 9. Bright future for avocados. *Gisborne Herald*; [accessed 2020 Nov 1]. http://www.gisborneherald.co.nz/focus-on-the-land/20200909/bright-future-for-avocados/

[Stats NZ] Stats NZ Tatauranga Aotearoa. 2018 May 8. Agricultural production statistics: June 2017; [accessed 2020 Nov 17]. https://www.stats.govt.nz/information-releases/agricultural-production-statistics-june-2017-final

[Stats NZ] Stats NZ Tatauranga Aotearoa. 2020. Regional Council 2020 (generalised). [updated 2020 Jan 30; accessed 2020 May 19]; [dataset]. https://datafinder.stats.govt.nz/layer/104254-regional-council-2020-generalised/

Stephenson D. 2020. Personal communication. Solid Waste and Stormwater Team Leader, Tasman District Council, Nelson NZ.

Tait A, Henderson R, Turner R, Zheng X. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology*. 26(14):2097–2115. doi:10.1002/joc.1350.

Te Uru Rākau Forestry New Zealand. 2020. One Billion Trees Fund 18 month monitoring and evaluation report. Wellington (NZ): Ministry for Primary Industries. 26 p.

Thomas J. 2020. Personal communication. Senior Resource Scientist – Water & Special Projects, Tasman District Council, Nelson NZ.

Thompson S, Grüner I, Gapare N. 2003. New Zealand Land Cover Database Version 2: illustrated guide to target classes. Wellington (NZ): Ministry for the Environment. 126 p.

Todd DK, Mays LW. 2005. Groundwater hydrology. 3rd ed. Hoboken (NJ): Wiley. 636 p.

Westerhoff RS, Tschritter C, Rawlinson ZJ. 2019. New Zealand Groundwater Atlas: depth to hydrogeological basement. Wairakei (NZ): GNS Science. 20 p. Consultancy Report 2019/140. Prepared for the Ministry for the Environment.

Westerhoff R, White P, Miguez-Macho G. 2018. Application of an improved global-scale groundwater model for water table estimation across New Zealand. *Hydrology and Earth System Sciences*. 22(12):6449–6472. doi:10.5194/hess-22-6449-2018.

Whangārei District Council. 2020. Whangārei (NZ): Whangārei District Council. Dam levels and water supply; [updated 2021 Apr 19; accessed 2020 May 19]. https://www.wdc.govt.nz/Services/Water-services/Water-Supply/Water-supply-network.

White PA, Lovett AP, Gordon D. 2017. Quality control and quality assurance of Hawke's Bay rainfall recharge measurements: 2011–2014. Lower Hutt (NZ): GNS Science. 21 p. (GNS Science report; 2016/16).

White PA, Lovett A, Taves MW, Mourot F, Tschritter C, Kelly SD, Clarke LB, Moreau M. 2020. Water storage options: Northland region. Wairakei (NZ): GNS Science. 88 p. Consultancy Report 2020/81. Prepared for the Provincial Development Unit.

White PA, Moreau M, Mourot F, Rawlinson ZJ. 2019. New Zealand Groundwater Atlas: hydrogeological-unit map of New Zealand. Wairakei (NZ): GNS Science. 89 p. Consultancy Report 2019/144. Prepared for Ministry for the Environment.

Williamson J, Scherberg J. 2019. Addendum to assessment of effects reports pertaining to Aupouri Aquifer resource consent applications compiled by WWLA. Whangārei (NZ): Northland Regional Council. 24 p. https://www.nrc.govt.nz/media/3szjkvuw/april-4-2019-addendum-to-aee-reports-for-resource-consent-applications-wwla-4.pdf

[WWLA] Williamson Water & Land Advisory. 2020. Northland Water Storage and Use Project Volume 1: command area analysis and refinement. Auckland (NZ): Williamson Water & Land Advisory. 104 p. Report WWLA0156. Prepared for Northland Regional Council.

[WWLA] Williamson Water & Land Advisory, Riley Consultants. 2020a. Northland Water Storage and Use Project Volume 2: water resources analysis. Auckland (NZ): Williamson Water & Land Advisory, Riley Consultants. 146 p. Report WWLA0156. Prepared for Northland Regional Council.

[WWLA] Williamson Water & Land Advisory, Riley Consultants. 2020b. Northland Water Storage and Use Project Volume 3: conceptual design and costing. Auckland (NZ): Williamson Water & Land Advisory, Riley Consultants. 117 p. Report WWLA0156. Prepared for Northland Regional Council.

[WWLA] Williamson Water & Land Advisory, Riley Consultants. 2020c. Northland Water Storage and Use Project Volume 4: analysis and recommendations. Auckland (NZ): Williamson Water & Land Advisory, Riley Consultants. 106 p. Report WWLA0156. Prepared for Northland Regional Council.

Woods R, Hendrikx J, Henderson R, Tait A. 2006. Estimating mean flow of New Zealand rivers. *Journal of Hydrology (New Zealand)*. 45(2):95–110.

APPENDICES

This page left intentionally blank.

APPENDIX 1 PROVINCIAL GROWTH FUND WATER STORAGE INVESTMENT PRINCIPLES

Economic

- Water storage will strengthen regional economies by shifting land use to higher-value, sustainable uses, while avoiding increases in livestock intensification.
- Water storage will help address disparities in Māori access to water for land development.

Community

- Small-scale community-level projects will be supported rather than mega irrigation schemes.
- There must be public benefit from government funding of a project.
- Projects will involve stronger partnerships at the local level, including with regional councils.
- The Crown Irrigation Investments Limited (CIIL)'s programme of work will not be progressed, although communities that were involved in CIIL initiatives can submit PGF proposals that align with PGF objectives.

Environment

- Water storage proposals should demonstrate that they will support land uses that do not increase – and ideally reverse – the negative impacts on water quality.
- Projects should maintain the health of waterways.
- Water storage will not be used to increase the intensity of ruminant agriculture, or other land uses in a catchment, where this puts greater cumulative pressure on water and risks compromising water quality.
- Water storage proposals should incorporate activities that improve water quality – e.g. activities that improve E. coli levels and ecological health; restoration and protection projects such as improvements in wetlands, fish and wildlife habitats, riverbanks, biodiversity activities, soil health and sediment control.

Climate Change

- Where practical, projects should contribute positively to the target of reducing greenhouse gases. Projects should also demonstrate how they will contribute to mitigating or adapting to climate change effects and to a just transition to a low-emissions economy.
- Proposals should consider the potential to contribute to climate-change resilience in communities. Strengthening municipal water supply is not an objective of PGF funding. However, the PGF will work with councils to include municipal supply as a component of wider water initiatives if it enables councils to contribute more to regional water management.

APPENDIX 2 WATER STORAGE METHODOLOGIES

A Northland Regional Council / GNS Science workshop was held on the 23rd of July 2020 (Appendix 2) following virtual meetings between these organisations and the PDU. The primary aim of the workshop was to enable further discussion between GNS Science and Northland Regional Council technical staff. The workshop was hosted by Northland Regional Council under direction of Darryl Jones (Northland Regional Council).

The morning session was attended by Northland Regional Council technical staff with experience in working with communities, administering the Northland Regional Plan and undertaking environmental monitoring. GNS Science provided an overview of the water storage project and the water storage methods being considered in the Northland region and addressed any questions. The group then considered key issues affecting the freshwater resources, community interests, response to the recent drought and values and interest of tangata whenua, as experienced by Northland Regional Council staff. GNS Science staff explored datasets and GIS layers held by Northland Regional Council to support identification of potential water storage options.

Preliminary GIS analysis of datasets was discussed with Northland Regional Council technical staff to gain feedback on the suitability of the proposed approach. For example, accurate identification of wetlands type and extent can be challenging in the Northland region, and limitations of the Land Cover Database were discussed. Northland Regional Council staff noted the importance of including small wetland systems. The Ministry for the Environment released an RFP titled ‘1065-01-RFP – Wetland Mapping – Freshwater Implementation Project’ to address this knowledge gap on a national scale.

The location of Māori land in the region is of particular interest to the PDU, as they aim to support economic development and wellbeing for Māori communities. Northland Regional Council identified that they have mapped multiple landowner titles in addition to the LINZ Māori-owned (freehold) dataset. There is also a spatial layer indenting marae across the region.

The afternoon session was attended by the Northland Regional Council executive leadership team, including the group managers Colin Dall, Jonathan Gibbard, Ben Lee and Tony Phipps. An introductory presentation was delivered and discussion centred around the key issues pertaining to freshwater management and the impacts and response to the 2019/2020 droughts. The managers spoke of the community perceptions, the Civil Defence response, the nature of small isolated communities and the need to ensure greater resilience to future drought conditions.

Various initiatives currently being explored by Northland Regional Council were discussed, including implementation of off-stream dams, water tanks and groundwater bores (to be utilised by water tankers). The potential to use managed aquifer recharge to enable increased groundwater take during high demand times of year, and other water storage methods, was discussed in both sessions. Northland Regional Council staff were interested in exploring methods and identifying catchments where particular methods would be feasible and found this approach beneficial.

The workshop concluded with the scheduling of several one-on-one sessions the following day in order to elicit specific water allocation information and datasets. In addition, the draft report was discussed with Northland Regional Council via video conference on the 19th of August 2020; Northland Regional Council comments were included in the final report.

During the course of the workshop, a practical policy exercise was undertaken on one wall of the meeting room. The exercise allowed participants to identify values or systems within the region that may present significant policy, or other, limitations to the exploration of water storage options. Land-use change and wetland restoration projects were identified as the more limiting factors for the use of different water storage options. Other limiting factors included minimum flow allocation, baseflow levels, outstanding values of dune lakes (and their catchments), the mixing of different waters and flood hazards.

A2.1 Storage Methods

A2.1.1 Groundwater Storage

The groundwater storage method was developed by combining the hydrogeological system (HS) and hydrogeological-unit map (HUM) stacked datasets (Moreau et al. 2019; White et al. 2019).

Firstly, the HUM units were subdivided using hydrological systems boundaries. The stacked polygons were then collapsed to a 2D dataset to identify confinement status. The confinement status qualifies the way groundwater is stored within a host formation (or a group of formation), which in turn influences the ability for this groundwater to flow and therefore be retrieved. Subsequently, fixed storage coefficient values were assigned (Table A2.2) to sub-HUM units based on the HUM_type (Aquifer/Aquitard/Aquiclude and Basement) and the aquifer confinement status (e.g. unconfined and confined). The assigned values were checked against published values (Cameron et al. 2001). As part of developing the groundwater storage method, layer thicknesses were estimated using the depth to basement and equilibrium water table datasets (Westerhoff et al. 2018; Westerhoff et al. 2019). Finally, the High/Medium/Low assessment was assigned based on groundwater storage coefficient values (Table A2.2).

A2.1.2 Riverine Galleries

This method was developed by combining the HUM outcrop, Equilibrium Water Table, Fundamental Soil Layer (FSL) profile available water, river flow and LCBD datasets (LRIS Portal 2000; Booker 2015; White et al. 2019; LRIS Portal 2020). The High/Medium/Low assessment was assigned based on outcropping lithologies (sand/silt/gravel or else), depth to the water table, proximity to a stream, river flow data, median Profile Available Water (PAW) value and land cover (Table A2.2). In addition, areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice) are classified as ‘Low’.

A2.1.3 Modified Wetlands

This method combines the regional council’s boundaries, the LCDBv5, mean annual precipitation and mean annual evapotranspiration datasets (Tait et al. 2006; Woods et al. 2006; Henderson 2019; Stats NZ 2020; LRIS Portal 2020). The Northland Regional Council wetland dataset combines several sources of information, including from Protected Natural Areas Programme reports. However, the dataset lacks attributes that can rapidly classify, or exclude, known wetlands that could potentially become modified wetlands. For instance, saline wetlands and lakes present in the Northland Regional Council dataset cannot be included in the analysis. LCDBv5 was used in preference, as this dataset can be filtered to identify freshwater wetlands on a national scale. Both of these datasets cover 120 km^2 of common area in the Northland Region.

The wetlands polygons were used as an input layer for further processing to select wetlands that could potentially be modified for water storage purposes. Wetlands are usually complex systems consisting of several land cover classes, e.g. open water classed as lakes and ponds, areas of herbaceous freshwater or saline vegetation, flaxland and scrub classes (Thompson et al. 2003). The saline vegetation classes of wetlands (i.e. herbaceous saline vegetation and mangrove) were excluded, as estuarine and coastal wetlands would not allow freshwater storage due to saline 'contamination'.

The potential supply of water to the selected 'freshwater wetlands' was then calculated based on the difference between the long-term mean annual precipitation (P) and the long-term mean annual actual evapotranspiration on the wetland area. Adjacent wetlands (i.e. located within 50 m) were considered as part of the same wetland for this exercise. The freshwater wetlands allowing a water supply greater or equal to 50 L/s were then characterised as presenting a 'High' potential for water storage, the remaining freshwater wetlands as 'Medium' potential and the other land covers as 'Low' potential (Table A2.2).

A2.1.4 Dams for Baseflow Enhancement

This method was developed using the HS, HUM outcrop and river flow datasets (Booker 2015; Moreau et al. 2019; White et al. 2019). The storage potential was assessed based on proximity and mean flow rates of perennial streams, outcropping lithologies and hydrogeological system type (Table A2.2). In addition, areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice) are classified as 'Low' (Table A2.2).

A2.1.5 Land Subsoil Recharge

This method was developed using the HS, HUM outcrop and FSL datasets (LRIS Portal 2000; Moreau et al. 2019; White et al. 2019), combined with ground slopes calculated from the Digital Elevation Model (Macdonald 2020a).

A2.1.6 Galleries

This method was developed by combining the HUM outcrop, Equilibrium Water Table FSL and LCBDv5 datasets (LRIS Portal 2000; Westerhoff et al. 2018; White et al. 2019; LRIS Portal 2020). The water storage potential was assessed based on outcropping lithologies (sand/silt/gravel or else), depth to the water table, median PAW value and land cover (Table A2.2). In addition, areas with unsuitable land cover (e.g. built-up areas, transportation and infrastructure or permanent snow and ice) are classified as 'Low'.

A2.1.7 Managed Aquifer Recharge

This method was developed using the HS, HUM outcrop and FSL datasets (LRIS Portal 2000; Moreau et al. 2019; White et al. 2019), combined with ground slopes calculated from the Digital Elevation Model (Macdonald 2020a).

Areas of interest for managed aquifer recharge were identified as areas underlain by unconsolidated sediment with a low gradient slope and a low median PAW value (Table A2.2). Any areas that fulfilled all of the previously mentioned conditions and also intersected with catchments or aquifers that had any allocation/take of surface water or groundwater, respectively, were categorised as having a 'High' potential to augment groundwater resources and stream baseflow. Any areas that fulfilled the first three conditions but did not have any allocation/take of surface water or groundwater, respectively, were categorised as having a

‘Medium’ potential. All areas that did not fall into either the ‘High’ or the ‘Medium’ category, or areas with unsuitable land cover (e.g. built-up areas, transportation infrastructure or permanent snow and ice), were categorised as having a ‘Low’ potential for managed aquifer recharge (Table A2.2).

A2.1.8 Dams Identified by Northland Regional Council

This method used the dam register, permit and water takes datasets (Pene 2020). Many dam locations are identified by Northland Regional Council in GIS files (Pene 2020). These files include an inventory of all known dams in Northland (‘DamRegisterJul20’) and dam locations that are allowed, by the current regional plan, to shift to a permitted status once the consent has lapsed (‘DamWPermitJul20’; Donaghy 2020). In addition, Northland Regional Council is currently quality-checking dam locations in these GIS files with a GIS layer that includes around 520 dams larger than 0.5 ha in area, identified from LiDAR (Macdonald 2020b). However, Northland Regional Council records comparatively few active water permits at these locations. Therefore, dams may be located where water permits have expired. These locations are worthy of future investigation, as they may offer storage opportunities.

In addition, Northland Regional Council and the Department of Conservation are currently funding development of a map of Northland water bodies (Macdonald 2020c). This map (the GIS layer ‘Biospatial_Northland_water_bodies’) aims to identify all water bodies that are larger than 100 m^2 by processing the Northland LiDAR map. A map of these features may be relevant to the identification of water storage opportunities.

A2.1.9 Water Tanks

Water tanks provide opportunities for storage throughout Northland. Rooftop rainfall is calculated from GIS datasets that map 155,273 buildings in Northland, with a combined rooftop area of 24.83 km^2; these buildings collect an estimated rainfall of approximately 1500 mm/year.

A2.1.10 Planned Storage Dams

The Te Tai Tokerau Water Trust is currently planning water-storage dams for the purpose of irrigation (WWLA 2020; WWLA and Riley Consultants 2020a). This planning has included ‘conceptual’ design and costing with an economic analysis and assessments of benefits and environmental effects (WWLA and Riley Consultants 2020b,c).

A2.2 GIS Processing

A2.2.1 Datasets

A combination of national- and regional-scale datasets was used to assess water storage (Table A2.1).

Table A2.1 New Zealand datasets and associated references.

Coverage	Dataset	References
National	Depth to basement	Westerhoff RS, Tschritter C, Rawlinson ZJ. 2019. New Zealand Groundwater Atlas: depth to hydrogeological basement. Wairakei (NZ): GNS Science. 20 p. Consultancy Report 2019/140. Prepared for: Ministry for the Environment.
National	Equilibrium water table	Westerhoff R, White P, Miguez-Macho G. 2018. Application of an improved global-scale groundwater model for water table estimation across New Zealand. *Hydrology and Earth System Sciences*. 22(12):6449–6472. doi:10.5194/hess-22-6449-2018.
National	Fundamental Soil Layer Profile Available Water	LRIS Portal. 2000. Lincoln (NZ): Landcare Research New Zealand. FSL Profile Available Water; [released 2000 Jan 1; accessed 2020 May 19]; [map]. https://lris.scinfo.org.nz/layer/48100-fsl-profile-available-water/
National	Hydrogeological Systems	Moreau M, White PA, Mourot F, Rawlinson Z, Tschritter C, Cameron SG, Westerhoff RS. 2019. Classification of New Zealand hydrogeological systems. Lower Hutt (NZ): GNS Science. 28 p. (GNS Science report; 2018/35).
National	Hydrogeological-Unit Map	White PA, Moreau M, Mourot F, Rawlinson ZJ. 2019. New Zealand Groundwater Atlas: hydrogeological-unit map of New Zealand. Wairakei (NZ): GNS Science. 89 p. Consultancy Report 2019/144. Prepared for Ministry for the Environment.
National	Land Cover Database	LRIS Portal. 2020. Lincoln (NZ): Landcare Research New Zealand. LCDB v5.0 – Land Cover Database version 5.0, mainland New Zealand. [updated 2020 Jan 29; accessed 2020 May 19]; [map]. https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/
National	Mean annual actual evapotranspiration	Woods R, Hendrikx J, Henderson R, Tait A. 2006. Estimating mean flow of New Zealand rivers. *Journal of Hydrology (New Zealand)*. 45(2):95–110.
National	Mean annual rainfall	Tait A, Henderson R, Turner R, Zheng X. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology*. 26(14):2097–2115. doi:10.1002/joc.1350.
National	National building outlines	LINZ Data Service. 2019. Wellington (NZ): Land Information New Zealand. NZ building outlines; [updated 2020 Aug 24; accessed 2020 May 19]; [dataset]. https://data.linz.govt.nz/layer/101290-nz-building-outlines/

Coverage	Dataset	References
National	Regional Council boundaries	Stats NZ. 2020. Regional Council 2020 (generalised). [updated 2020 Jan 30; accessed 2020 May 19]; [dataset]. https://datafinder.stats.govt.nz/layer/104254-regional-council-2020-generalised/
National	River flow data	Booker DJ. 2015. Hydrological indices for national environmental reporting. Christchurch (NZ): National Institute of Water & Atmospheric Research. 39 p. Report CHC2015-015. Prepared for: Ministry for the Environment. https://data.mfe.govt.nz/layer/53309-river-flows/
Regional	Available Water Allocation maps (groundwater and surface water)	Pene M. 2020. Personal communication. Environmental and Regulatory Services, Northland Regional Council, Whangārei, NZ.
Regional	Dam permit, Dam register, Dam water takes	Pene M. 2020. Personal communication. Environmental and Regulatory Services, Northland Regional Council, Whangārei, NZ.
Regional	Digital Elevation Model	Macdonald A. 2020a Jul 10. Personal communication. Biospatial Ltd. Whangārei, NZ.
Regional	Water Permit	Pene M. 2020. Personal communication. Environmental and Regulatory Services, Northland Regional Council, Whangārei, NZ.
Regional	Water Tank	Pene M. 2020. Personal communication. Environmental and Regulatory Services, Northland Regional Council, Whangārei, NZ.

A2.2.2 Digital Elevation Model

The New Zealand School of Surveying Digital Elevation Model (NZSoSDEM v1.0) is a free Digital Elevation Model (DEM) covering the country at a spatial resolution of 15 m, created by the School of Surveying by interpolating the LINZ topographic vector data. This DEM was created as a series of 30 maps, whose extents correspond exactly with the LINZ Topo250 topographic map series (Columbus et al. 2011).

A2.2.3 Depth to Basement

This dataset provides an update of New Zealand's depth to hydrogeological basement map. Depth to hydrogeological basement can be loosely defined as the 'base of aquifers', or, more strictly, as "the depth to where primary porosity and permeability of geological material is low enough such that flued volumes and flow rates can be considered negligible" (Westerhoff et al. 2019).

A2.2.4 Equilibrium Water Table

The equilibrium water table dataset consists of a raster file, where the values represent modelled depth to the water tables from the ground surface. The underlying model is a global-scale groundwater flow model that received national input data relevant to terrain, geology and recharge (Westerhoff et al. 2018).

A2.2.5 Fundamental Soil Layer Profile Available Water

The publicly available New Zealand Fundamental Soil Layer (FSL) information combines soil physical, chemical and mineralogical characteristics from the National Soils Database with physical land resource information from the New Zealand Land Resource Inventory. This dataset contains the best available estimate of PAW data, which estimates total available water for the soil profile to a depth of 0.9 m, or to the potential rooting depth (whichever is the lesser). Values are weighted averages over the specified profile section (0–0.9 m) and are expressed in units of mm of water (LRIS Portal 2000).

A2.2.6 Hydrogeological-Unit Map

The publicly available Hydrological-Unit Map (HUM) dataset consists of two GIS files: a stacked map and an outcropping unit map. This is because differently aged HUM units occur within the same area and therefore are 'stacked' vertically within a given land area. The HUM datasets comprise a classification of geological units in terms of their importance for groundwater flow and storage in an ArcGIS seamless digital map. HUM units are classed into four broad types of hydrogeological unit: aquifer, aquiclude, aquitard and basement, defined as follows:

- Aquifer: a hydrogeological unit type defined as:

  "a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs … unconsolidated sands and gravels are a typical example" (Todd and Mays 2005).
- Aquitard: a hydrogeological unit type defined as a saturated but poorly permeable stratum that impedes groundwater movement and does not yield water freely to wells that may transmit appreciable water to or from adjacent aquifers and, where sufficiently thick, may constitute an important groundwater storage zone; sandy clay is an example (Todd and Mays 2005).
- Aquiclude: a hydrogeological unit type defined as a saturated but relatively impermeable material that does not yield appreciable quantities of water to wells; clay is an example (Todd and Mays 2005).
- Basement: a hydrogeological unit type defined as a geologic layer, or group of layers, of Cretaceous age and older; in Northland and East Coast, Tertiary age allochthons were included as Basement.

However, the definition of an aquifer includes an assessment of 'significant quantities of water', which is a regionally variable property. In the nationally consistent HUM dataset, the classification assesses what is considered 'significant quantities of water' at the national level in New Zealand (i.e. what is defined as an aquifer versus an aquitard) (White et al. 2019).

A2.2.7 Hydrogeological Systems

The Hydrological Systems (HS) digital map (1:250,000 scale) consists of two publicly available GIS files: a set of polygons defining hydrogeological systems and relevant attributes and a set of polylines defining the system boundaries and relevant attributes. Hydrogeological systems were defined as geographical areas with broadly consistent hydrogeological properties and similar resource pressures and management issues. Individual systems were mapped using geological, topographical, surface drainage and, where available, groundwater divides data (Moreau et al. 2019).

A2.2.8 Land Cover Database

The New Zealand Land Cover Database (LCDBv5) is a publicly available, multi-temporal, thematic classification of New Zealand's land cover. It identifies 33 mainland land cover classes (35 classes, once the offshore Chatham Islands are included). Land cover features are described by a land cover code and name per polygons at multiple time steps (summer 1996/97, summer 2001/02, summer 2008/09, summer 2012/13 and summer 2018/19). The dataset is designed to complement New Zealand's 1:50,000 topographic database in theme, scale and accuracy and is suitable for infrastructure planning (LRIS Portal 2000).

A2.2.9 Mean Annual Precipitation

Average annual rainfall was based on a NIWA dataset based on the rainfall measurements at individual rainfall stations interpolated throughout New Zealand by NIWA and averaged for the period 1960–2006 (Tait et al. 2006).

A2.2.10 Mean Annual Actual Evapotranspiration

Annual actual evapotranspiration was estimated by GIS as actual evapotranspiration from the land surface, derived from a national-scale map developed by NIWA for the period 1960–2006 without specific consideration of land use, land cover, soil type or groundwater recharge (Woods et al. 2006; Henderson 2019).

A2.2.11 National Building Outlines

The publicly available 'national building outlines' GIS dataset provides building outlines within mainland New Zealand, extracted from multiple years of aerial imagery. It is a 2D representation of the roof outline of a building, which has been classified from LINZ aerial imagery using a combination of automated and manual processes to extract and refine a building roof outline (LINZ Data Service 2019).

A2.2.12 River Flow Data

The publicly available 'River flow' datasets consist of river flow statistics attributed to specific river reaches, which can be used to assess how much water is available for irrigation, drinking water, hydro-electric power generation and recreational activities such as fishing and boating. River flows are also very important for maintaining the health and form of a waterway. This dataset was created to support environmental reporting (Booker 2015).

A2.2.13 Regional Council Datasets

Nationally consistent regional boundaries were obtained from Stats NZ (2020). The following Northland Regional Council GIS datasets were used in this project:

- DamRegisterJul20: register of dam structure permits.
- DamWaterTakJul20: dams with existing water takes.
- DamWPermitJul20: register of water allocation permits for dams.
- Northland10m.tif: LiDAR-based DEM used for elevation, slope and hillshade.
- GroundwaterUnitsPercentAllocation: groundwater allocation units or zones.
- Parcel_TheOwnership.shp: proxy for the Māori land database with land parcels (clipped) that were under multiple ownership.

- SWZonesPercentAllocation_catchments: surface water allocation catchments.
- Wetlands_Known_Wetlands: compilation of known wetlands.

A2.2.14 GIS Engine Implementation

Source spatial datasets were provided either as vector (e.g. shapefile) or raster (e.g. GeoTIFF), with different extents and resolutions. To overlay the spatial information together, each dataset was rasterised or re-gridded to the same projection, extent and grid resolution for the region. This allows each layer to be processed in an array-processing environment. Results were then stored as GeoTIFF rasters, with codes corresponding to low, medium and high assessments. For 1:250,000 map resolution, a common raster resolution of 50 m was used (i.e. 0.2 mm in print). All data were projected in New Zealand Transverse Mercator 2000. For the Northland region, the extent used was 1566000 and 5971000 for minimum Easting and Northing and 1761000 and 6195000 for maximum Easting and Northing. Rasterising and re-gridding were performed with GDAL-based tools from either command prompt or within a Python programming environment with NumPy.

An illustrative example of the spatial overlay method is shown in Figure A2.1 for infiltration galleries:

- (a) shows Quaternary-aged aquifers consisting of gravel, sand and/or silt; other units are excluded using the HUM dataset (White et al. 2019).
- (b) shows median PAW from the FSL dataset (LRIS Portal 2000), with values greater than 80 mm hashed to indicate that they are a poorer soil type for infiltration galleries.
- (c) shows water table depth, estimated using the equilibrium water table dataset (Westerhoff et al. 2018), where depths greater than 2 m are too deep for infiltration galleries.
- (d) shows land cover (LRIS Portal 2020), which excludes infiltration galleries in built-up areas and standing water (among several other conditions that apply outside the figure).

The resulting map (e) was produced by assigning assessment values following a consistent method that combines the datasets (Table A2.2). Assessments are depicted using a three-colour or ‘traffic light’ scheme suitable for a colour-blind audience.

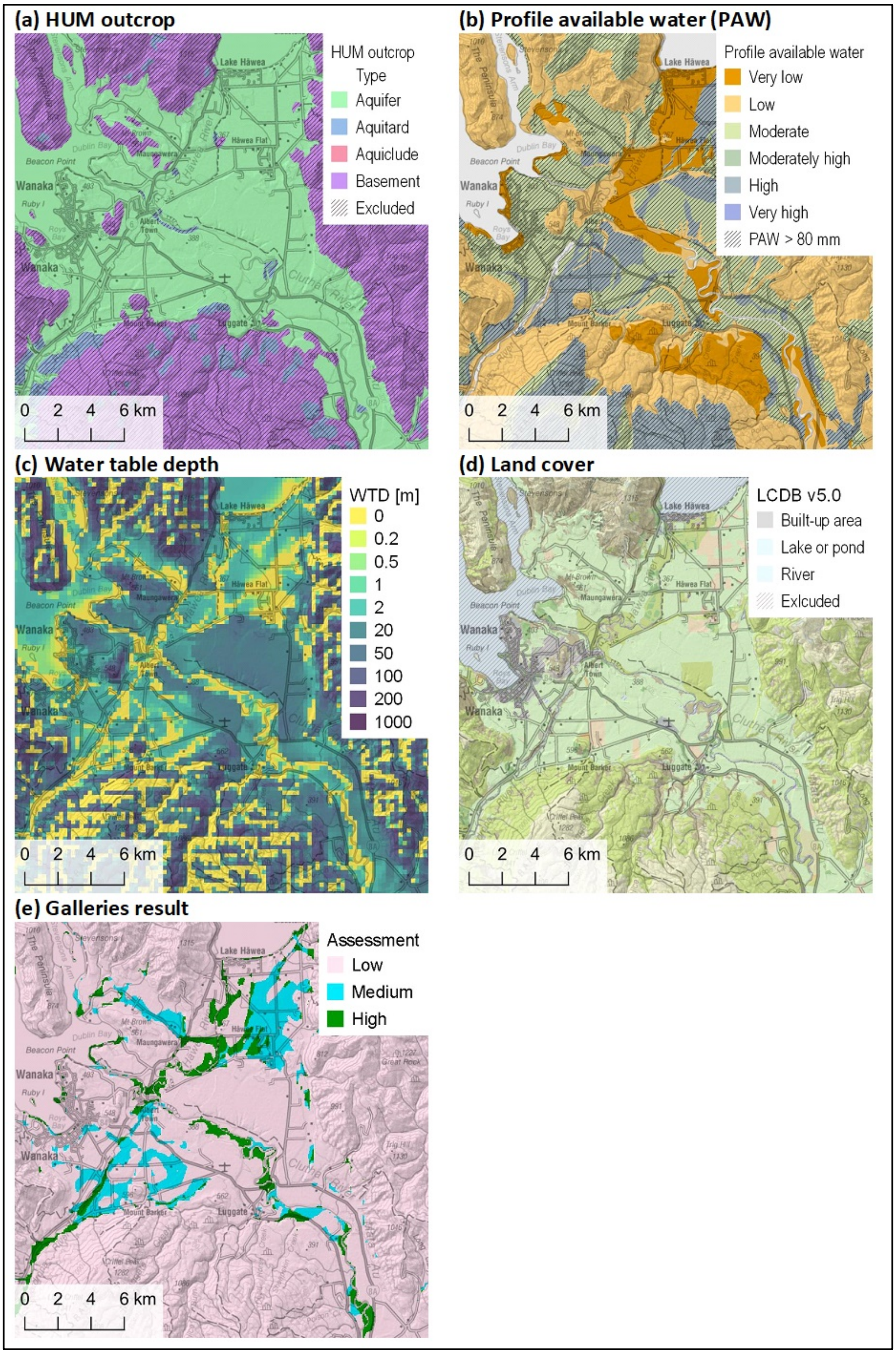


Figure A2.1 Example of a GIS overlay assessment for galleries. Acronyms used in the figure are as follows: Hydrogeological-Unit map (HUM), water table depth (WTD), Land Cover DataBase (LCDB).

Table A2.2 Description of assessment methods and associated datasets.

Method	Assessment			Source Datasets
	High	Medium	Low	
Groundwater storage	Sedimentary aquifers not fully enclosed within the Basement Hydrogeological System.	Volcanic aquifers and sedimentary aquifers fully enclosed within the Basement Hydrogeological System; aquitards.	Aquicludes and Basement.	Hydrogeological-Unit Map Hydrogeological Systems
Riverine galleries	Sediments at surface; water table less than 2 m deep; location within 100 m of stream; low flow greater than 0.1 m^3/s; PAW* less than, or equal to, 80 mm.	Sediments at surface, water table less than 2 m deep, location within 100 m of stream, low flow greater than 0.1 m^3/s, PAW* greater than 80 mm.	No sediments at the ground surface and/or water table deeper than 2 m and/or unsuitable land-cover type (built-up area, etc.).	Hydrogeological-Unit Map Hydrogeological Systems Equilibrium Water Table FSL Profile Available Water River flow data
Modified wetlands*	Wetlands receiving more than 50 L/s supply of water (calculated by subtracting actual evapotranspiration from rainfall over a wetland area*).	Wetland receiving less than 50 L/s supply of water.	Area not covered by any wetlands currently or wetland with saline inputs.	Land Cover Database Mean annual precipitation Mean annual evapotranspiration Regional Council boundaries
Dams for baseflow enhancement	Areas outside of townships with perennial streams that have a low flow in the range 0.2–0.8 m^3/s and Q1 and Q2 sediments in the Hydrogeological system polygon.	Areas outside of townships with perennial streams that have a low flow in the range 0.2–0.8 m^3/s.	All other areas not covered by the ‘High’ and ‘Medium’ category.	Hydrogeological-Unit Map River flow data Land Cover Database
Land subsoil recharge	Areas in the HUM outcrop file in the rock types ‘GravelSandSilt’ and ‘Sand’ categories that are outside town areas and have a slope less than, or equal to, 2% and a median PAW less or equal 80 mm.	Areas in the HUM outcrop file in the rock types ‘GravelSandSilt’ and ‘Sand’ categories that are outside town areas and have a slope less than, or equal to, 2%	All other areas not covered by the ‘High’ and ‘Medium’ category and/or unsuitable land-cover type (built-up area, etc.).	Hydrogeological-Unit Map Land Cover Database Fundamental Soil Layer Profile Available Water Digital Elevation Model

Method	Assessment			Source Datasets
	High	Medium	Low	
Galleries	Sediments at surface; water table less than 2 m deep; PAW less than, or equal to, 80 mm.	Sediments at surface; water table less than 2 m deep; PAW greater than 80 mm.	No sediments at the ground surface and/or unsuitable land-cover type (built-up area, etc.).	Equilibrium Water Table Land Cover Database Hydrogeological-Unit Map Fundamental Soil Layer Profile Available Water
Managed aquifer recharge	Sediments at surface; sediments sand or gravel; slope less than, or equal to, 5%; PAW less than, or equal to, 80 mm; water allocation in the catchment.	Sediments at surface; sediments sand or gravel; slope less than, or equal to, 5%; PAW greater than 80 mm; water allocation in the catchment.	No sediments at the ground surface and/or unsuitable land-cover type (built-up area, etc.).	Hydrogeological-Unit Map Hydrogeological Systems Fundamental Soil Layer Profile Available Water Allocation maps (groundwater and surface water) Digital Elevation Model
Hydro-lake storage	Water from hydro-storage can be moved, mostly under gravity.	Water from hydro-storage can be moved, mostly with pumped systems.	All other areas not covered by the 'High' and 'Medium' category.	-
Dams identified by Northland Regional Council	Not applicable.	Not applicable.	Not applicable.	-
Water tanks	Average annual rooftop rainfall.	Not applicable.	Not applicable.	-

* Wetland polygons within 50 m were clustered together as one continuous wetland body.