AQUA INTEL AOTEAROA
Insights and actions for sustainable water use

Gisborne water storage: options and opportunities assessment

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

GNS SCIENCE TE PŪ AO

PROVINCIAL DEVELOPMENT UNIT

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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 (AIA), which includes the Provincial Development Unit (PDU) and GNS Science (GNS) – to explore regional water storage needs and opportunities and consider the potential for water storage to support a lift in sustainable regional production.

PDU-GNS Platform: Regional Water Needs Assessments

AIA 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. AIA are working with four regions within this programme – Northland / Te Tai Tokerau, Gisborne/Tairāwhiti, Otago and Southland.

Gisborne's Water and Land

The Gisborne region is predominantly hill country that is subject to significant land erosion. Hill country pastoral farming and exotic forestry dominate land use throughout the district. However, river flats throughout the region provide areas of productive flat land of differing sizes. Poverty Bay Flats is the most sizable area in the region and has had a long history of seasonal and permanent horticulture. Gisborne could benefit significantly from investment in water storage as a means of increasing land productivity and economic returns in these areas of flat land.

The flat southern areas of the Gisborne region, such as Poverty Bay Flats and Tolaga Bay Flats, host the region's known groundwater resources. Surface water in these areas is also heavily allocated. Further land development would require storage solutions and better information for council limit-setting processes.

The groundwater resources in the north of the region are less known, with little bore data available in the area. A low level of consents has been granted outside Poverty Bay Flats, so water may be available for landowners that want to bring their land into production. However, better information on water availability is required in these other parts of the region before the council can allocate significant quantities of water.

The main water quality issues in Gisborne are sediment, *E. coli* and nutrients. Sediment is a widespread issue for the region due to Gisborne's geology and erosion-prone landscape. The Gisborne climate is warm and relatively dry. Climate change may increase the warmth and dryness of the region throughout the year but increase rain in the summer.

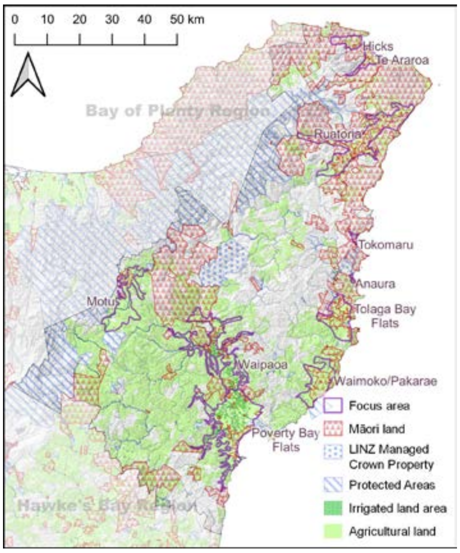
Investing in Water Storage to Enhance Gisborne's Land Productivity

Poverty Bay Flats is the main area for horticulture in the region, with twice as much land in horticulture here than in the remainder of the region. Outside of the Poverty Bay Flats, little intensive agriculture is occurring. Tolaga Bay, Te Karaka and Ruatoria have a history of permanent horticulture at a less intensive level. Across the region, half of the horticulture is maize/corn, with the other major crops including squash, citrus and grapes. The diversity of crops would potentially be increased with more reliable water.

While there is further land that could be brought into production in the Poverty Bay Flats, groundwater in the areas is either considered to be fully or over-allocated. Better understanding of the aquifer would inform this and support the community and the council to manage the groundwater that is available for productive purposes. With continual pressure on water and land resources in the Poverty Bay Flats, it is expected that further development will organically occur up the East Coast.

Water Storage Focus Areas and Water Storage Approaches

This work identified a number of focus areas within Gisborne 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 without undermining the environmental health of waterways.



The two preferred water storage sites across the region are groundwater and baseflow enhancement reservoirs. While the full range of water storage methods were considered for the region, these two approaches are most appropriate across the region due to the geological and hydrogeologic setting. In the Waimoko/Pakarae focus area, baseflow enhancement through off-stream storage is the most preferred of these two approaches. In all other focus areas, use of existing groundwater resources is the most preferred option.

Investigations into Water Availability

Funding will likely be applied to a range of activities that will improve the understanding of availability of water across the Gisborne region and to identify the interest of particular communities in increasing their land productivity. Much of the funding will likely be devoted to investigations of the Poverty Bay Flats aquifer system. Beyond this, other areas of investment include measurement and modelling of groundwater and surface water flows in the wider region. Potential investigations may be established to assess options for harvesting peak flows in winter for storage and baseflow enhancement in the drier months.

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1.0 INTRODUCTION

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

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.

The key objectives for PGF wider investment in water storage are 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, or 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 communities; and
- provide an incentive to change land use that risks degrading the environment to higher-value, more sustainable, uses.

All PGF water storage investments are guided by a set of investment principles in line with these objectives (Appendix 1). The PDU-GNS regional needs assessments are consistent with these objectives and investment principles.

Water storage and distribution infrastructure enables regions to bring under-utilised 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 is a pre-requisite for most higher-value land uses. Water availability is a known 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, for provision of 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 and incomes in this context.

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).

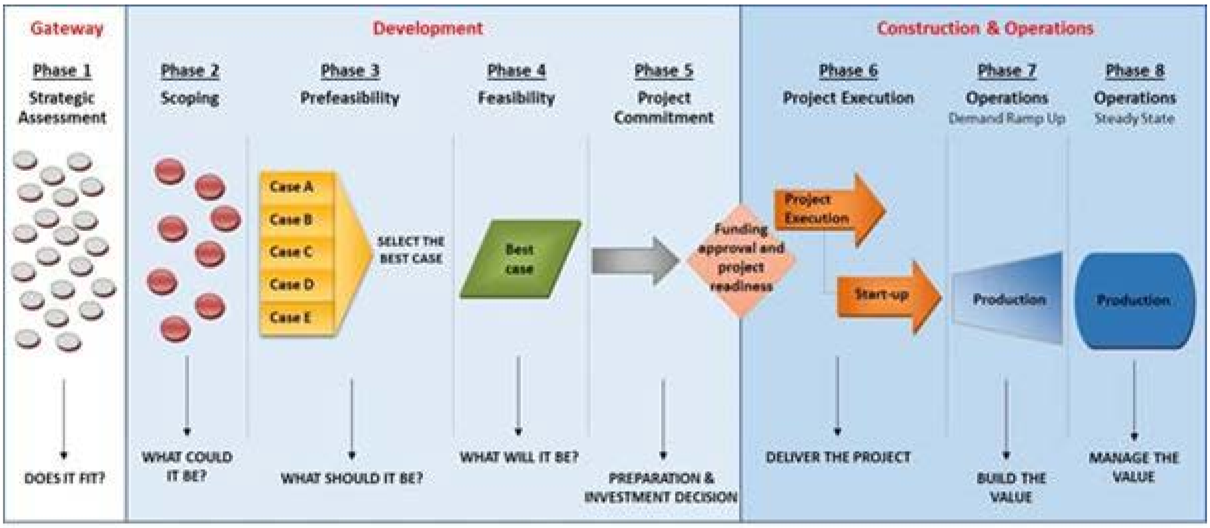

Figure 1.1 The water infrastructure development process.

Information about water availability and potential land use is necessary to effect water storage projects. The information developed through these regional water needs assessments inform Gateway: Phase 1 – the strategic assessment of whether water storage projects could be taken to 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 AIA relate to Phase 1, 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 PDU objectives above.

The funds that are available for investment through AIA will be prioritised toward activities that can progress the region through to later stages of water development (as above in the diagram/ table). For example, the project will fund 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.

1.2 Gisborne Water Needs Assessment

This assessment of water needs and opportunities in Gisborne considers potential water use and water availability within focus areas of the region (Figure 1.2). These areas include underdeveloped 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 Māori land development 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 Gisborne and outlines resources relevant to water storage (Section 2). Then, the report identifies 10 focus areas where water storage could be beneficial to the region (Section 3). This includes the Poverty Bay Flats, where a water storage project is currently underway. Water storage options that could provide benefits to the productive sector and to the environment are outlined for ten focus areas, including surface water and groundwater sources (Appendix 2) with maps of preferred options in each area (Section 4). In each of the focus areas, comment is made regarding the potential benefits of water storage, including the benefits to regional economic development, Māori land development and the environment. Finally, the potential initial investments in each area are presented (Section 5).

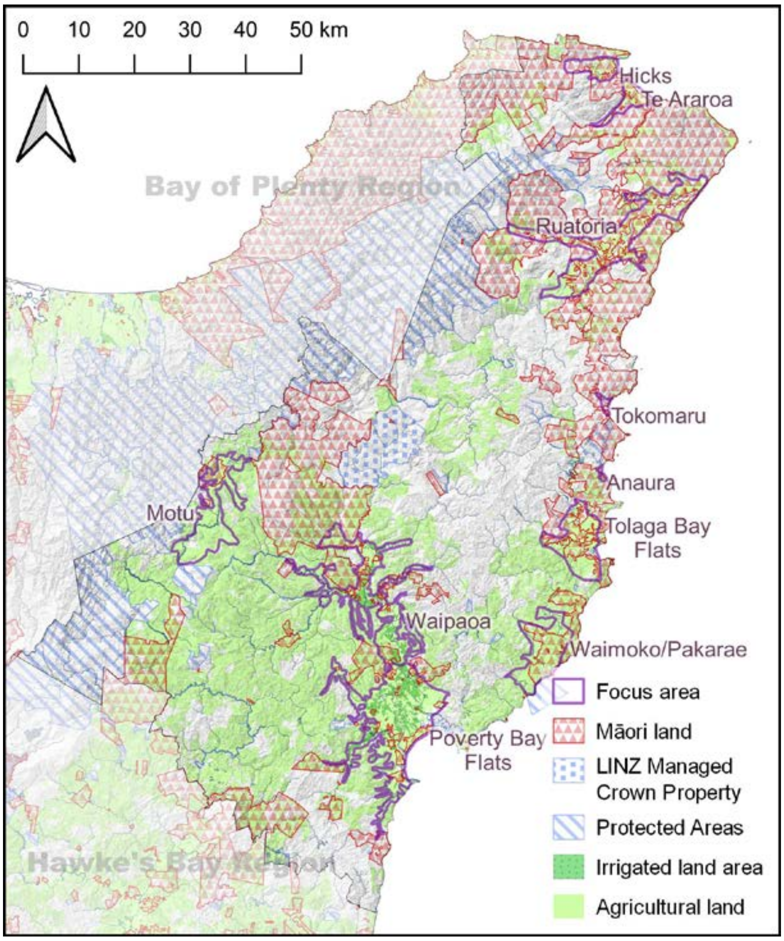

Figure 1.2 Focus areas for Gisborne water storage assessment.

Table 1.2 Agricultural land and Māori land in the Gisborne focus areas.

Item	Total (ha)
Agricultural land	47,006
Māori land	9381
Agricultural land and Māori land	21,883

1.3 Te Mana o te Wai

Since 2017, the National Policy Statement for Freshwater Management (NPSFM; 2020) 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 these resources.

Regional councils and local communities work together to determine how Te Mana o te Wai will be reflected in regional planning and consenting arrangements. This covers many aspects of water, including continuity of flow from mountain to sea, water quality, provision of clean freshwater for drinking, ecosystem health and biodiversity, protection of traditional Māori cultural values, aesthetic qualities and provision of economic values.

Since 2015, the Gisborne District Council and Ngāti Porou have entered a joint management agreement (JMA) for the Waiapu River catchment to enable decision-making and to co-develop a Waiapu Catchment Management Plan that would manage all land and water use in the catchment (Te Runanganui o Ngāti Porou 2019). AIA will discuss with Ngāti Porou what they would value in terms of further investigations.

2.0 GISBORNE REGIONAL SUMMARY

The Gisborne district, also known as Tairāwhiti, with its equitable climate and long coastline, has many economic opportunities. However, GDP/capita in the district is amongst the lowest in the country (Stats NZ 2020a). Better access to water would enable more productive use of land, which would enable greater economic returns to the region.

Agriculture is an opportunity for economic growth, with increasing popularity of horticulture and cropping (Gisborne District Council 2020). The Poverty Bay Flats are the main area for agriculture and horticulture; these activities take approximately 80% of water usage in the district (Rajanayaka 2013). However, little intensive agriculture is occurring outside of the Poverty Bay Flats. This is partly due to the nature of land in the district, e.g. much land is hilly and erosion-prone (Gisborne District Council 2020) and not suitable for agricultural intensification.

Water storage infrastructure will allow the economic benefits from agriculture to spread beyond the Poverty Bay Flats and to include Māori-owned land. Water storage infrastructure is the best means for ensuring reliable water supplies to the district. The storage can be supplied from surface water and from groundwater. Capturing and storing surface water and groundwater during wet winter months offers Gisborne water supply options for horticulture during the dry summer months. This can be observed in other regions that have had some water storage schemes, such as Northland, where flourishing horticultural communities have developed since the construction of water-storage infrastructure approximately four decades ago.

2.1 Water

The Gisborne district contains six major rivers: the Waipaoa, Waioku, Maraeteha, Te Arai, Taruheru and Waiapu rivers. The Waipaoa River and its tributary, the Te Arai River, drain the Poverty Bay Flats. The district also contains the headwaters of four major rivers that flow into other regions. The Hangaroa River flows into the Hawke's Bay region. Rivers that flow into the Bay of Plenty region (i.e. the Motu, Waioeka and Waikura rivers) are clear and fast-flowing and highly regarded for their recreational value of fishing, canoeing and white-water rafting (Gisborne District Council c2020a). The Motu River has been under a Water Conservation Order since 1984 (Ministry for the Environment 2018).

The Gisborne district's flats host the region's known groundwater resources, which, for management purposes, are split between the Poverty Bay Flats and the East Coast Alluvial areas (Tschritter et al. 2016; White et al. 2012). The Poverty Bay Flats is a large (185 km^2) sedimentary basin formed within the Quaternary floodplain of the Waipaoa River (White et al. 2012). The East Coast Alluvial areas are filled with Holocene sediments (Tschritter et al. 2016).

Until recently, groundwater development in the district has been focused on the Poverty Bay Flats aquifer system. The Poverty Bay Flats aquifer system is a multi-layer complex consisting of (in order of increasing depth): the shallow Te Hapara Sands within 5 km of the coast, the Shallow Fluvial Gravels, associated with the Waipaoa River; the Waipaoa Gravels, strongly connected hydraulically with the Waipaoa River; the extensive Makauri Gravels; and the deep Matokitoki Gravels, which directly overlie the greywacke basement. The connection to the sea for both the Makauri Gravels and Matokitoki Gravels is uncertain (Moreau and White 2020). The East Coast Alluvial aquifers are generally uncharacterised, although Gisborne District Council is in the process of establishing a monitoring network in them (Tschritter et al.

2016; Moreau and White 2020). The East Coast Alluvial areas include the Wharekahika, Karakatuwhero, Orutua, Tunanui, Waiapu, Mangahauini, Waipare, Uawa, Pakarae, Waiomoko, Wainui and Muriwai areas.

In the Gisborne district, consented water takes for irrigation were reported as used exclusively for arable land (Table 2.1). Approximately 68% of the total annual consented allocation is from surface water (surface water and storage) (Table 2.2). Drinking water is an important use of water in Gisborne; approximately 0.28 Million m^3/week is allocated for this purpose, which is approximately 46% of total water allocation (Rajanayaka et al. 2010).

Table 2.1 Irrigated land area in Gisborne (Rajanayaka et al. 2010).

Irrigated Land Use	Land Area (ha)	Consented Annual Sum (Mm^3/year)
Arable	3925	17.1
Total	3925	17.1

Table 2.2 Sources of irrigation water in Gisborne (Rajanayaka et al. 2010).

Source	Consented Annual Sum (Mm^3/year)
Groundwater	5.4
Storage	0
Surface water	11.6
Total	17.1

2.1.1 Water Quality

High sediment loads are common in surface water, owing to the predominance of the soft-sediment geology of the district. These high loads can lead to increased phosphorous levels and reduce ecosystem health if combined with higher-conductivity water (Roil and Death 2018; Gisborne District Council 2020). A large proportion of the district is classed as highly erodible land at risk of erosion (16%, 1377 km^2), and a significant area is classed with severe earthflow risk (235 km^2) and gully risk (162 km^2); these areas are the largest relative areas for New Zealand regions (Stats NZ 2020a). A study of the erosion issues in the Waiapu River catchment confirmed that afforestation, where it has been applied, was an effective method of controlling erosion (Gisborne District Council c2020a).

Generally, nutrient levels in Gisborne rivers are lower than elsewhere in the country, although hotspots caused by human activities remain, typically with higher nutrient concentrations in winter than summer. Most sites in the district meet Gisborne District Council objective values for ammoniacal nitrogen, with the notable exceptions of sites located in the Gisborne city urban area (Roil and Death 2018; Gisborne District Council 2020).

Most streams that are monitored indicate fair or good water quality related to macro invertebrate and periphyton (69%) (Roil and Death 2018). A portion of sites (17%) were classed as below the national bottom-lines for ecosystem health and associated with low elevation and intensified land use (e.g. pasture, urban and cropping). All sites (12%) with excellent health were located within high-elevation catchment covered with forest (Roil and Death 2018).

Groundwater quality varies between aquifers, with generally diluted, faster-flowing shallow systems and slower, more evolved groundwaters at depth (Moreau and White 2020). Median nitrate-nitrogen concentrations over the 1994–2015 period were well below the drinking-water standard in all aquifers; however, this may be due to reducing conditions occurring in the Shallow Fluvial Gravels and the deeper aquifers triggering the conversion of nitrate into ammonia (high concentrations of ammonia are recorded at some wells). Median iron and manganese concentrations in the Poverty Bay aquifer systems were higher than the guideline values at most sites (Moreau et al. 2017; Moreau and White 2020). Over the 1994–2015 period, most groundwater quality parameters exhibited an absence of statistically significant trend (Moreau and White 2020).

In the Te Hapara Sands and Waipaoa Gravels aquifers, *E. Coli* was detected in 11 of the 21 (52%) monitoring bores of the Poverty Bay Flats, meaning that water was unsafe for drinking over the period 2014–2020. Some shallow bores within the flats also exhibited elevated nitrate concentrations. Pesticides have also been detected within the shallow groundwater at high concentrations since the 1990s, which have decreased significantly over time (Gisborne District Council 2020). A 10-year horizon (2018–2028) Gisborne District Council project (DrainWise, with a budget of $20.8 million) is currently underway to reduce wastewater discharge into rivers and groundwater. These discharges are particularly strong during heavy rainfall events, where stormwater can result in wastewater flows that are above network capacity. This project plan includes wastewater network upgrades, stormwater extensions, gully-trap repairs, education and enforcement (Gisborne District Council 2020).

2.2 Land Use

Primary production occupies most of Gisborne district's land area. The two largest land uses are pasture and exotic forest, which cover 70% and 17% (i.e. approximately 588,000 ha and 142,000 ha, respectively), of the Gisborne district (NZTE 2016; Gisborne District Council 2020).

Gisborne district's population of approximately 48,000 is concentrated in the main municipal centre of Gisborne (population 37,200). In contrast, the next largest municipal centre is Ruatoria, with 860. The local economy is reliant on the primary industry, with agriculture, horticulture and forestry being the largest employment sectors. Agriculture makes up 10% of the district's GDP. In comparison, forestry, fishing and mining, with a land area of 150,500 ha, make up 14% of the district's GDP (MBIE 2020).

Gisborne's climate enables the district to excel at growing crops, trees and pasture. High sunshine hours and moderate rainfall attributes contribute to these suitable growing conditions. Hill country pastoral farming and exotic forestry dominate land use throughout the district, providing much of the employment in smaller centres such as Ruatoria and Tolaga Bay.

The Gisborne district land cover is predominantly hill country; however, coastal river flats throughout the district provide areas of productive flat land. The Poverty Bay Flats has a long history of seasonal and permanent horticulture and is currently highly sought after for further development (Gisborne Chamber of Commerce 2019).

Horticulture in the Gisborne district is dominated, in terms of land area, by seasonal crops such as maize, sweetcorn and squash (Table 2.3). Permanent horticulture is focused in the areas surrounding Gisborne; small pockets of permanent horticulture are found in other areas throughout the Gisborne district.

Table 2.3 Gisborne region horticulture areas.

Localities	Area (ha)
Gisborne (*Lower Waipaoa)*	10,226
Tolaga Bay and Tokomaru Bay	2095
Te Karaka / Whatatutu (*Upper Waipaoa*)	1916
Ruatoria	1014
Motu/Matawai	182.2

The maize and sweetcorn grown in the district are utilised for processing and fresh consumption. Cedenco, Corsons and Leaderbrand are all major producers of processed maize and sweetcorn in Gisborne. Squash, grown predominantly for the international market, is a crop grown over summer, with land often reverting back to pasture for winter lamb fattening. Squash is the only produce, apart from Pinus Radiata, to be exported directly from the Gisborne Port.

Permanent horticulture, such as kiwifruit, grapes and apples, have a long history in the district (Table 2.4). In 2021, permanent horticulture represents 131% of the irrigated land area reported in 2010. The importance of permanent horticulture to the local economy is immense. Known as an early-producing district, Gisborne growers often receive financial benefit for producing early crops. For example, Gisborne is known as an early producer of Gold Kiwifruit, with growers receiving early production incentive bonuses. Early production also benefits crops grown for the domestic market, with early-season fruit prices often being far higher than mid-season prices.

Table 2.4 Gisborne crop types and their land area, from the annual crop survey 2020/21 (Gisborne District Council 2021).

Crop Type	Area (ha)
Maize/Sweetcorn	6486
Squash	1595
Citrus	1534
Grapes	1383
Chicory	888
Kiwifruit	689
Apples	393

Unlike many areas of New Zealand, dairy has little presence in Gisborne. This is a result of isolation, with the distance to the nearest dairy production facility meaning that production is uneconomic. District livestock farming is focused on sheep and beef production in low-intensity farming systems. Exotic forestry has been prevalent in Gisborne for the past 40 years. Plantings increased as a means of stabilising land after Cyclone Bola. Now, plantings are occurring not only for harvestable timber but also for carbon sequencing. The future economic effects of carbon forestry on the district are currently unknown; however, effects on district employment and economic income are of concern.

The Poverty Bay Flats has a high range of crops under permanent horticulture. Citrus, grapes, kiwifruit, apples, feijoas, persimmons and avocados are all grown commercially in the area. Individual horticulture businesses often grow a variety of crops, which helps to spread labour requirements across seasonal labour availabilities. The range of different horticultural crops grown across the Gisborne district is unlike many other regions, where production is dominated by one or two land uses.

Gisborne has approximately 185,000 ha of Māori freehold land, which equates to 16% of the total national Māori-title land area and 22% of the district land area. Tairāwhiti iwi include Ngāti Porou, Ngāi Tāmanuhiri, Rongowhakaata and Te Aitanga-a-Māhaki. Over 50% of the district's population identify as being Māori. Though there are many large Māori land titles, Māori own many small pockets of land. These are often not economically feasible to operate as livestock farms or to harvest seasonal crops. Commonly, these land blocks are leased out, creating a perpetual cycle of insufficient development capital and low revenues for the owners.

Permanent horticulture in the Gisborne district is increasing. This intensification, predominantly in apples, kiwifruit and citrus, is displacing seasonal crops from the Poverty Bay Flats. The current area for horticulture (i.e. citrus, grapes, kiwifruit and apples) in the district is 3999 ha (Table 2.4). Kiwifruit's canopy area in the district has more than doubled in the past eight years. This development is focused on the G3 variety, which is providing good returns for growers. Apples, commonly club varieties, are increasing in planted area. These apples, often grown under contract to the marketer who owns the plant-variety patent, also provide good returns to growers. The rate of growth in permanent horticulture, though positive for district employment, is placing strain on supporting infrastructure.

In comparison, grapes have been reducing in planted area across the district as land use changes to higher-value permanent crops. Grapes, a commonly non-irrigated permanent horticulture, have reduced from 2350 ha in 2007 to 1380 ha in 2020. This trend is in reverse to grape numbers across New Zealand.

2.3 Climate

Gisborne's weather conditions differ from most of the country, owing to its easternmost location. The district is warmer than most parts of New Zealand, with high sunshine hours, low temperatures over winter and moderate levels of rain occurring relatively evenly throughout the year. It is bounded in the north and east by the coast; in the west by the Raukumara Range, whose highest point is Mount Hikurangi (1753 m); and in the south by the Waipaoa River catchment boundary. The Raukumara Range shelters the district from westerly rain, allowing for relatively high temperatures. Under easterlies, the district receives more rain and temperatures are lower (Chappell 2016). The summers are warm and breezy, and the winters are mild with infrequent frosts in flat areas. Mean annual temperatures in the district range from 9°C in the Raukumara Range to 16.5°C in low-lying coastal areas (mean annual temperature calculated for the period between 1981 and 2010) (Chappell 2016).

The rainfall pattern is markedly influenced by its orography. Across the district, rainfall varies between around 1300 mm to 1800 mm/year in coastal areas to in excess of 2200 mm/year in the highest part of the range elevations (median annual total rainfall calculated for the period between 1981 and 2010). Seasonal patterns show that 30% of the total annual rainfall falls in winter (June to August) and 20% of the total annual rainfall falls in summer (December to February). Moisture-laden easterlies can lead to heavy rainfall, occasionally accompanied by thunderstorms (Chappell 2016).

Gisborne has regularly experienced severe extreme weather events associated with significant damage and disruption since records began in 1900 (NZ Historic Weather Events Catalogue 2018). Recently (i.e. 1982 to 2015), at least six severe extreme weather events were associated with significant damage and disruption; two of these were declared as Civil Defence emergencies (8–10 April 1982; 26–27 July 1985).

2.3.1 Climate Change

Future climate change projections are relevant to water resources in Gisborne because projected temperatures and rainfall may impact on growing seasons, crop types and water availability. For example, higher soil moisture deficits are projected "in mid-spring to early autumn in the 2090s" with increasing chances of drought and a "higher risk of 'back-to-back' droughts" for the Te Arai River catchment (Sood and Mullan 2020).

Mullan et al. (2018) calculate temperature and rainfall changes in the long term with four Representative Concentration Pathways (RCPs). For example, they calculate mean annual temperature increases in the Gisborne district between 1986 and 2005 and 2081 and 2100 of: 0.7–3.8°C. They also calculate that Gisborne's annual rainfall decreases 1% to 4% between 1986 and 2005 and 2081 and 2100. In addition, Gisborne District Council (2020) state that "recent climate change projections for the Gisborne District have a 2.1°C increase in annual average temperature and a 5% reduction in annual average rainfall by 2090."

The seasonal variability of future Gisborne climate under climate change is predicted to see an increase in mean summer rainfall, with Gisborne likely to receive increases in precipitation in the summer by 2090, so the likelihood of summer droughts may reduce over time. In contrast, a decrease in mean winter rainfall is predicted. A consistent pattern of Te Arai River (near Gisborne) flow decline was modelled by Kamish et al. (2020): "By 2080, median flows (50% exceedance) are projected to decrease by approximately 3–14%." However, these calculations do not seem to factor uncertainty in model inputs such as temperature and rainfall.

Uncertainties in climate change predictions probably mean that these predictions could be treated as speculative. Firstly, the calculation of atmospheric CO_2 concentrations to 2100 is uncertain because the global track of future CO_2 generation is unknown and the global policy response to future CO_2 generation is unknown. Secondly, a range in future climate change is calculated with each RCP. For example, annual average rainfall with RCP 8.5 in 2081–2100 is in the range -13% to 15% (5th percentile to 95th percentile, respectively) of annual average rainfall in 1986–2005.

2.4 Infrastructure

The Poverty Bay Flats is the major agricultural area in Gisborne and has the greatest use for irrigation. Irrigation investigations of the Waipaoa River catchment in the 1980s identified that "communal irrigation development on the Waipaoa Flats [i.e. the flats immediately north of Ormond, the high terrace adjacent to State Highway 36 and flats in the Te Arai Valley] must rely largely or totally on supply from storage" and that "the Waipaoa River, with its extremely high sediment loading, is unattractive for an on-stream reservoir ..." (Reid and Anaru 1986). Reid and Anaru (1986) noted that "preliminary investigations … indicate that alternative groundwater resources are of doubtful quantity and/or quality and, while offering opportunities for small scale private supply, are not considered to have potential for communal development."

Today, groundwater from the Makauri Gravel Aquifer and Matokitoki Gravel Aquifer, supplied to irrigators from individuals' wells, is the main source of irrigation water on the Poverty Bay Flats. Surface water from the Waipaoa River is also supplied to irrigators through multiple small private irrigation schemes (Murphy 2/3/2021). These schemes do not incorporate storage, i.e. they take water directly from the river to the demand point. Outside of the Poverty Bay Flats, there is very little irrigation infrastructure; any irrigation is small in volume and irrigates small areas. Gisborne City water supply is supplied by pipeline "from the Mangapoike dams and the Te Arai bush catchment" (Gisborne District Council c2020c).

2.5 Resource Management Challenges

The Tairāwhiti Resource Management Plan is a vision for the region for the next 30 years (Gisborne District Council c2020b). This 'spatial plan' developed in 2020 identifies the regions key challenges and aspirations for future wellbeing, sets strategic direction and identifies where critical infrastructure will be required to support this. Key challenges in the Tairāwhiti Resource Management Plan are identified as community resilience, sustainability and prosperity; meeting the needs and aspirations of Māori; protecting heritage; and creating connected and safe communities.

Gisborne District Council is considering how to lift the productivity of the region's land resources in a sustainable manner. A number of the challenges in the Tairāwhiti Resource Management Plan could be addressed by generating higher incomes from the region's resources. The council is considering how to support a move toward higher-value industries, for example, through diversification to crops such as kiwifruit and apples and to higher-value products from natural farming systems. It is looking at working with Māori to support the development of under-utilised Māori-owned land and considering how to encourage the growth of horticulture north of Gisborne. Water storage could be an enabler for a number of these economic activities.

Concurrently, Gisborne District Council is considering how to address challenges in relation to water availability for other uses, such as drinking water and water quality. The key challenges for the district include freshwater contamination; over-allocation in groundwater aquifers; and freshwater supply not being able to meet increasing demands, including under-utilised Māori land blocks. The council wants to see no 'at risk' catchments in the region, restoration of existing wetlands and swimmable waterways. It is exploring alternative uses, or retirement, of vulnerable land and the potential for transitioning to more dry cropping and surface water storage opportunities to support horticulture. (Gisborne District Council c2020b; their Section C5–8, pages 9–28).

The Tairāwhiti Resource Management Plan incorporates the district plan, regional policy statement, regional coastal plan, regional plans and freshwater plan (in part). The regional policy statement identifies ecosystem health, water quality and quantity, social and cultural importance of water bodies, recognition of cultural values and a need for integrated management. Catchment planning for the region will determine flows and limits by catchment area. These metrics will need to respond to the NPSFM 2020 and will be informed by monitoring data identified in the State of the Environment reporting for 2020.

2.5.1 Water Challenges and Current Initiatives for Water

State of the Environment reporting and specific investigations inform an understanding of the challenges and underpin the development of limits and measures (both scientific and cultural/ social) that implement Te Mana o Te Wai through the Tairāwhiti Resource Management Plan (Gisborne District Council c2020b). The recent State of the Environment report highlights that:

- there has been an increase in the area consented for irrigation (predominantly on the Poverty Bay Flats), primarily resulting from expansion and intensification of horticultural activities, particularly kiwifruit and apples;
- *E. coli* in shallow groundwater used for drinking water requires treatment in the Poverty Bay Flats;
- groundwater salinity is increasing at Eade Road Bore and in the Makauri Gravel Aquifer; and
- pesticides are emerging contaminants in groundwater.

There are several initiatives underway within the region that relate to management of water resources and address some of the trends identified in the 2020 State of the Environment report (Gisborne District Council 2020), including:

- **Managed Aquifer Recharge (MAR)**: This project, with funding from PDU, aims to inject water from the Waipaoa River into the Makauri Gravel Aquifer for use on 3000 ha of irrigated horticultural farmland; a trial began in 2017.
- **Water storage:** A water storage project in collaboration with Turanga Waimaori Ltd, and funding from PDU, plans to provide water to the Poverty Bay Flats.
- **Wastewater management and DrainWise (2018 to 2028):** A project that aims to fix problems with stormwater and wastewater systems that affect water quality.
- **Salinisation of groundwater:** Seawater intrusion due to increased groundwater abstraction or reduced groundwater recharge has been identified as a potential risk (Tschritter et al. 2016; Moreau and White 2020).
- **Declining groundwater levels:** A long-term decline in groundwater elevations has been reported in the Makauri Gravel Aquifer and the Matokitoki Gravel Aquifer (White et al. 2012; Moreau et al. 2017; Moreau and White 2020). This observation triggered, in 2012, the calculation of Groundwater Available for Allocation for Poverty Bay Flats aquifers (White et al. 2012). The two key policy considerations for allocation include minimum groundwater levels (Gisborne District Council c2020b; their Section B6, page 53) and the acceptability of long-term groundwater level decrease in the Makauri Gravel Aquifer and Matokitoki Gravel Aquifer.
- **Erosion:** Rates of natural erosion and sedimentation are high in the Waiapu River catchment. Afforestation, where it has been applied, is an effective method of controlling erosion. (Gisborne District Council c2020a). Erosion in this catchment is of spiritual, cultural and economic significance to Ngāti Porou (Ministry for Primary Industries 2012).

2.5.2 Current Water Allocation

Current allocation and current water allocation limits and minimum flows established to protect Gisborne's water bodies determine the water that is available from groundwater and surface water. Groundwater is fully allocated in several aquifers in the Poverty Bay Flats (Figure 2.1). Current surface water allocation is less than surface water (Figure 2.2).

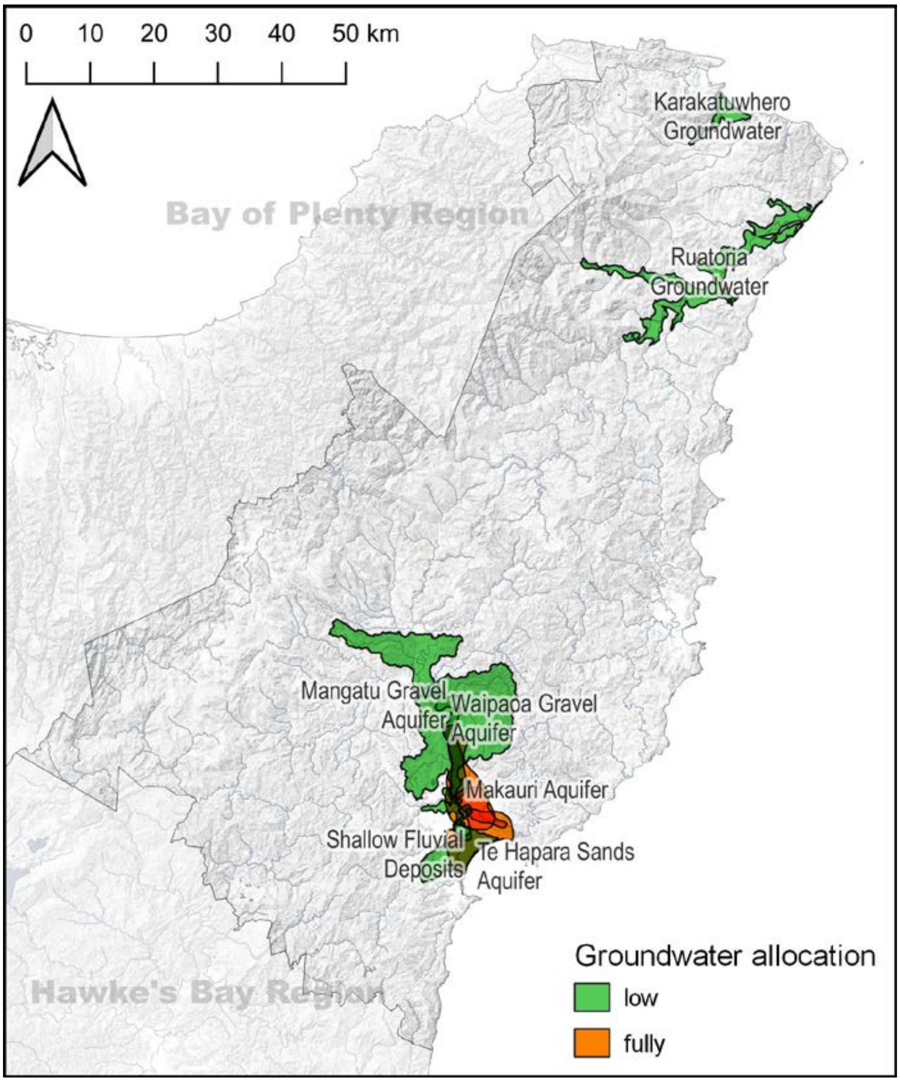

Figure 2.1 Groundwater allocation in the Gisborne district.

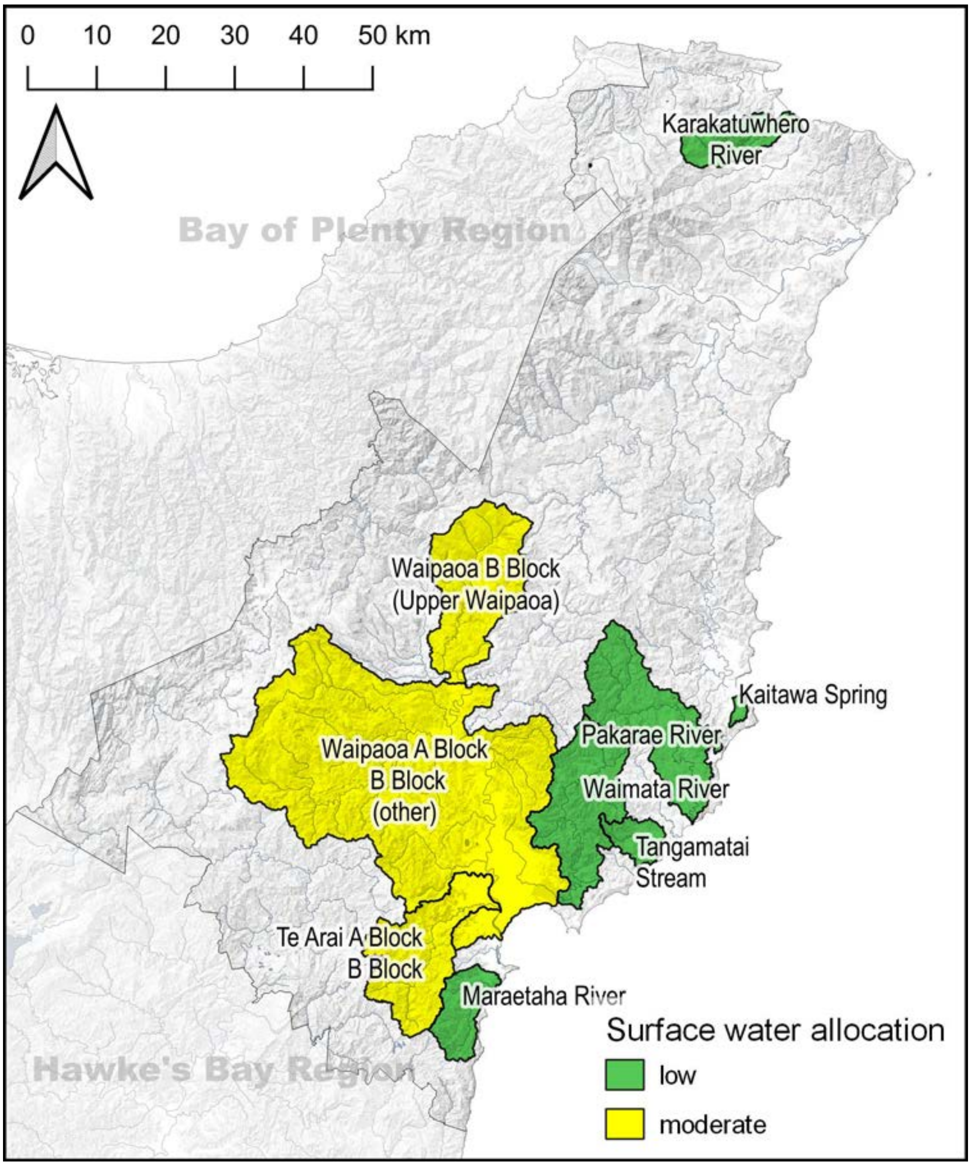

Figure 2.2 Surface water allocation in the Gisborne district.

3.0 POTENTIAL BENEFITS FROM INVESTMENT IN WATER STORAGE

The Poverty Bay Flats has moderate rainfall with a mean annual rainfall of approximately 990 mm/year. This rainfall, paired with high sunshine hours, provides a suitable climate for growing a large range of crops (Figure 3.1). Unlike other regions in the north of New Zealand, the Poverty Bay Flats provide natural chilling conditions over winter for many crops, which is a necessary component of production. In contrast, other regions may be dependent on chemicals to replace natural chilling, resulting in long-term production that is less sustainable.

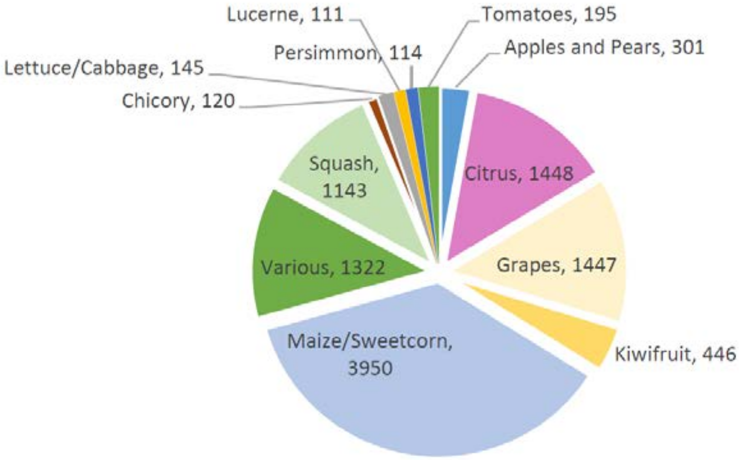

Figure 3.1 Crop types in the Poverty Bay Flats (ha) (Lockwood and Brown 2019).

The Poverty Bay Flats soils are heavily influenced by the Waipaoa River. Large silt deposits predominantly close to the river become heavier further from the river. The majority of the Poverty Bay Flats is well-suited to permanent and seasonal horticulture. The Waipaoa River, along with multiple aquifer systems, is the main water source for the district. Groundwater resources on the Poverty Bay Flats are mostly all fully allocated (Section 2.6). Therefore, water storage is required to provide for future development of water-dependent horticulture.

Water storage would provide an opportunity to continue the development of permanent horticulture in the region, lifting the average return per hectare of cropped land and therefore improving the economic return that horticulture provides to the local economy. Some of New Zealand's most important high-value crops, such as apples and kiwifruit, require irrigation on the Poverty Bay Flats; water storage will allow these crops to produce economic benefits for the district.

The storage of water for use on the Poverty Bay Flats during the irrigation season would provide a large benefit to the local Gisborne economy. Work completed for the managed aquifer recharge trail currently underway in Gisborne has a 30% increase in the available water from the Makauri Gravel Aquifer, resulting in an increased orchard gate return of approximately $8.5 million/year (Ayers and McDonald 2017). The Tairāwhiti Economic Action Plan (TEAP) places focus on sustainable value-added horticultural production (Trust Tairāwhiti 2019). This report values the GDP associated with horticultural land on the Poverty Bay Flats as $160 million/year and notes that this figure would double with an additional 3000 ha of irrigated horticulture (Trust Tairāwhiti 2019). These examples of the positive economic impact of water storage could be replicated across the district.

The development of horticulture industry in Gisborne will be negatively impacted without additional water storage. With gold kiwifruit and club apple varieties producing strong revenues, with orchard gate returns exceeding $100,000/ha, the opportunity cost of not implementing water storage for the region is immense to the region's GDP growth. The growth of the kiwifruit industry on the region of Northland has been estimated to contribute to an additional $41.4 million/year of regional GDP by 2029 (Scrimgeour et al. 2017). Gisborne has the opportunity to grow their kiwifruit crop at this rate or greater if water is available.

The scarcity of water resource is restricting the total area of irrigated horticulture on the Poverty Bay Flats. This is creating a trend toward monocultures, i.e. the use of irrigated land for a few high-returning crops. This trend focuses the available resources on the highest-returning crop(s). However, the trend also reduces the diversity of local horticultural production and increases the risks of crop-specific biological threats to the local economy. With additional water resources, a larger, more diverse, horticulture industry will be able to flourish on the Poverty Bay Flats.

Areas identified for potential irrigation development all exhibit the physical properties necessary to support high-value horticulture, both permanent and seasonal. With continued pressure on water and land resources in the Poverty Bay Flats, it is expected that further development will organically occur up the East Coast within the focus areas (Section 4). This development can be aided by pre-emptive water resource allocation and management and ensure that a repeat of what has occurred on the Poverty Bay Flats, where resources have been allocated and then deemed to be over-allocated, does not occur.

The northern focus areas have suitable climate and soils for horticulture. However, they face significant issues with isolation and access to support services that restrict the ease of development and the operation of horticulture.

Tolaga Bay has a history of permanent horticulture. Currently, there are multiple operations growing a range of crops such as blueberries, kiwifruit and feijoas (Figure 3.2). Historically, a large number of kiwifruit orchards were present in the district; however, these were removed during the late 1980s / early 1990s. This was due to financial instability in the industry and flooding damage caused by cyclone Bola. Water is sourced from both groundwater and surface water. Water consumption is low and therefore the area does not have a catchment plan in place. The low population of Tolaga Bay makes it difficult to source employees for full-time and seasonal work.

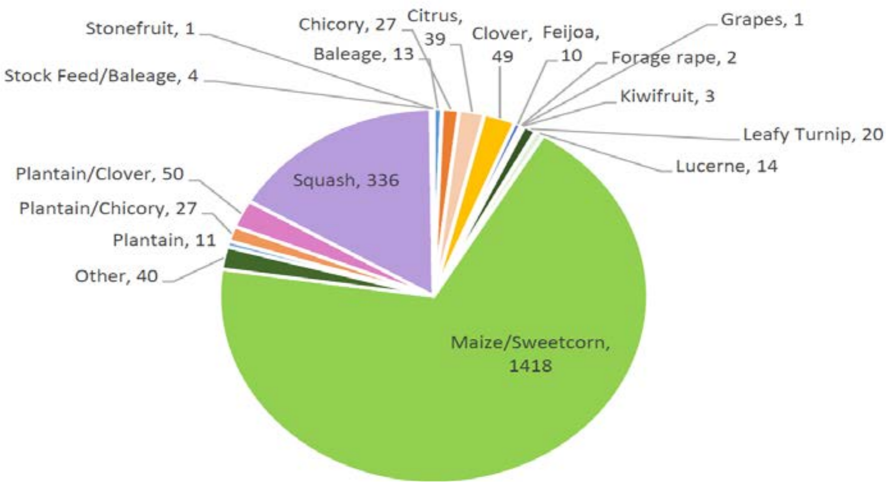

Figure 3.2 Crop types in the East/Tolaga/Tokomaru area (ha) (Lockwood and Brown 2019).

Ruatoria, with a population of 860, is the second-largest centre in the Gisborne district. Most flat land is part of the Waiapu River catchment. The area is well-suited for horticulture; however, land is under-utilised because of isolation from Gisborne and a lack of support infrastructure. The majority of seasonal crops are grown for animal grazing, with modest maize production (Figure 3.3). The Waiapu River currently has little demand for consented water takes and therefore little need for water storage to enable development in the short term. This may change in the future as demand of flat, horticultural-suitable land increases.

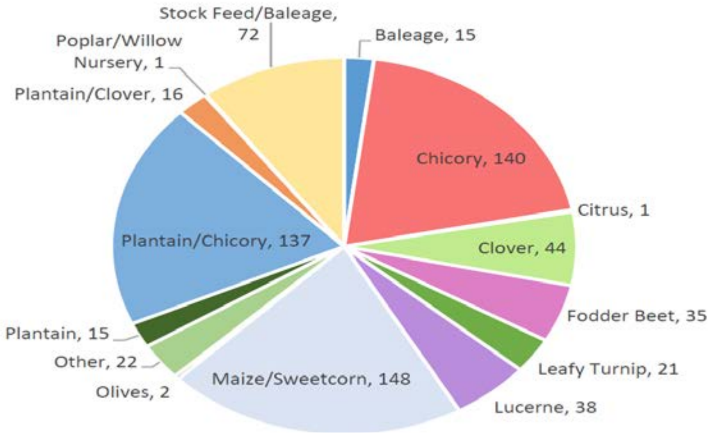

Figure 3.3 Crop types in the Ruatoria area (ha) (Lockwood and Brown 2019).

Te Araroa and Hicks Bay are small coastal bays. Little seasonal cropping or permanent horticulture occur in these areas. Employment in the district is focused on pastoral farming and forestry. The area is well-known for mānuka production for honey and for mānuka oil. In recent years, mānuka has been planted on flat land in uniform rows, allowing mechanical harvesting for oil production. Unproductive land, with reverted native forest, is common in these areas.

Motu and Matawai are the only non-coastal focus areas in this report. Matawai's elevation of 580 m means that it has a relatively different climate to that of coastal areas. The main productive land use is pastoral hill country farming with a handful of dairy units. These diary operations are situated in Matawai, with its proximity to Fonterra's Edgecumbe processing plant. Horticulture in the district is focused on crops grown for livestock feed (Figure 3.4). These are used to help offset seasonal feed requirements of animals.

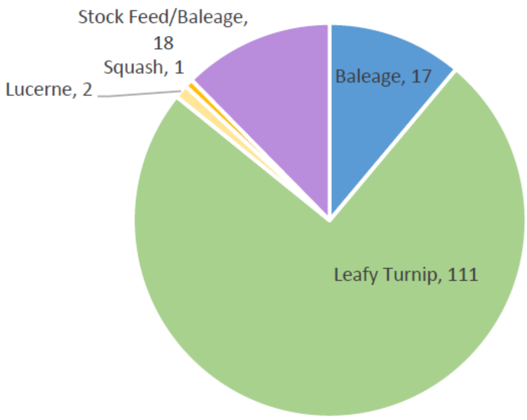

Figure 3.4 Crop types in the Motu and Matawai areas (ha) (Lockwood and Brown 2019).

4.0 FOCUS AREAS

4.1 Selection of Focus Areas

Focus areas in Gisborne were selected based on alignment with PGF water storage objectives and consideration of the following factors (Figure 4.1):

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

The assessment considers 'agricultural land' in the focus areas (see Section 1.2). However, 'agricultural land' is not the only land with the potential for irrigation of horticultural crops (Section 5). It is possible that land with other Land Cover Database classifications could become more productive over time. These land areas have been included in the focus areas where there is a potential for 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. Eight of the focus areas in the Gisborne District are located along the east coast (from north to south), including: Hicks, Te Araroa, Ruatoria, Tokomaru, Anarua, Tolaga Bay Flats, Waimoko/Pakarae and Poverty Bay Flats (Figure 4.1). The remaining focus areas are located further inland, including Waipaoa and Motu.

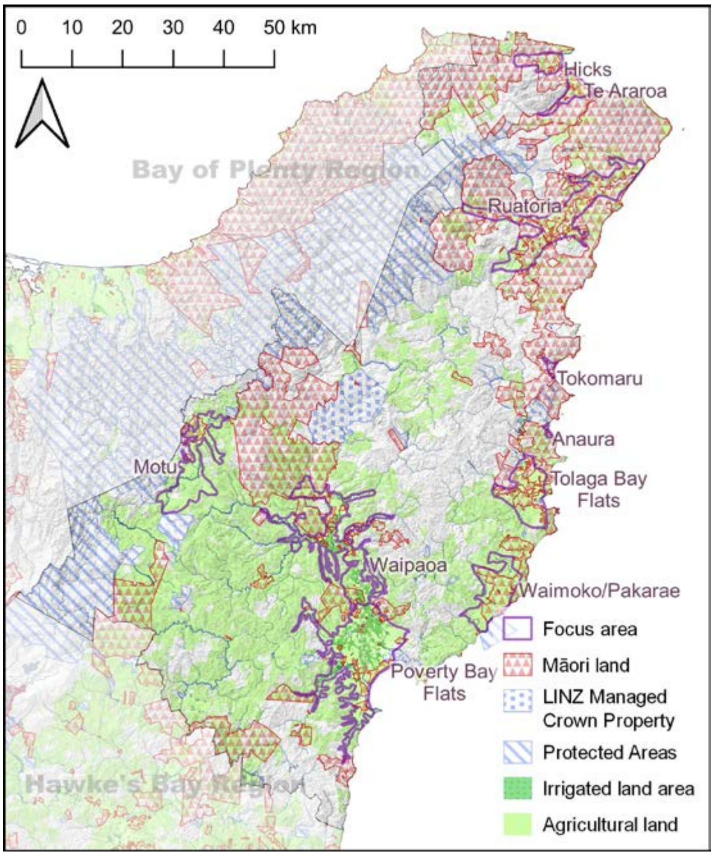

Figure 4.1 Focus areas in the Gisborne District.

4.2 Summary of Focus Areas

4.2.1 Hicks

Agricultural land area is an estimated 941 ha (Figure 4.2). The majority of this land (793 ha) is Māori-owned land.

4.2.1.1 Hicks Focus Area

The two preferred options for water storage are baseflow enhancement and groundwater (Figures 4.2 and 4.3, respectively). The catchment of the Wharekahika River can be separated into two areas: inland valleys, where baseflow enhancement may be appropriate; and the coastal strip, where a groundwater source may be the better option. The groundwater allocation limit is 30% of rainfall recharge (Murphy 2021b), and the potential for saltwater intrusion could be estimated. Water is available for allocation, subject to consideration of environmental effects, because current allocation is zero (Figure 2.1).

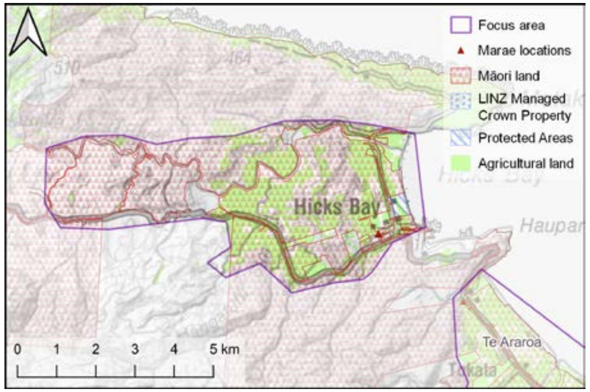

Figure 4.2 Hicks focus area summary.

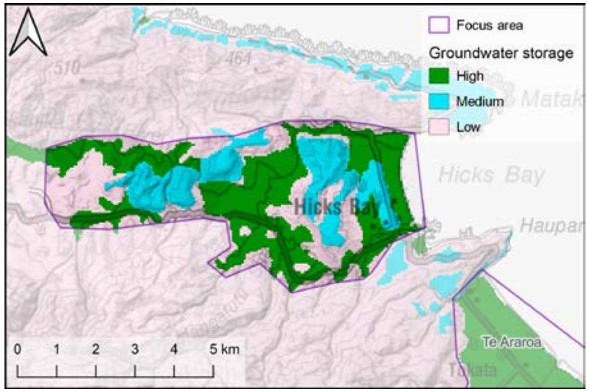

Figure 4.3 Hicks options for groundwater storage.

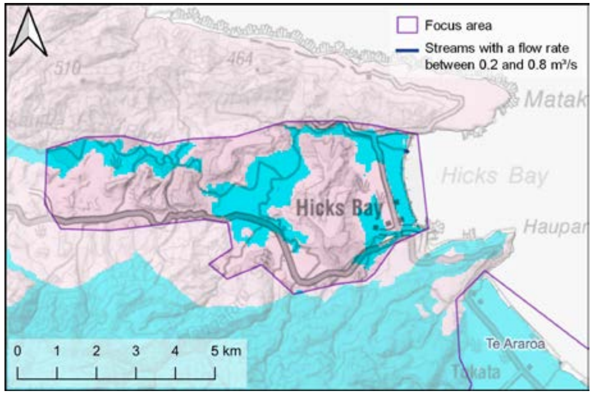

Figure 4.4 Hicks options for baseflow enhancement.

4.2.2 Te Araroa

Agricultural land area is an estimated 1174 ha (Figure 4.5). The majority of this land (979 ha) is Māori-owned land.

4.2.2.1 Te Araroa Focus Area

The two preferred options for water storage in the Te Araroa focus area are groundwater and baseflow enhancement (Figures 4.5 and 4.6, respectively). The alluvial plain west of Te Araroa provides opportunities for groundwater extraction, and the catchment of the Karakatuwhero River seems to provide opportunities for baseflow enhancement dams. The groundwater allocation limit is 30% of rainfall recharge (Murphy 2021b), and the potential for saltwater intrusion could be estimated. Water is available for allocation, subject to consideration of environmental effects, because current water allocation is low (Figure 2.1).

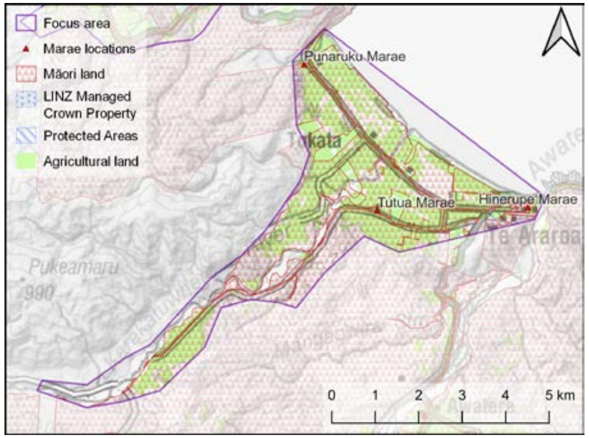

Figure 4.5 Te Araroa focus area summary.

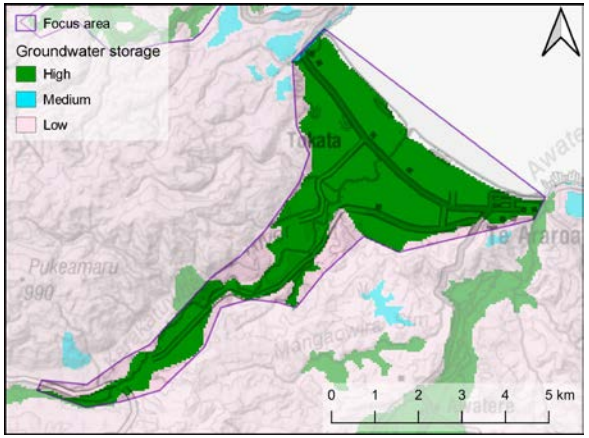

Figure 4.6 Te Araroa options for groundwater storage.

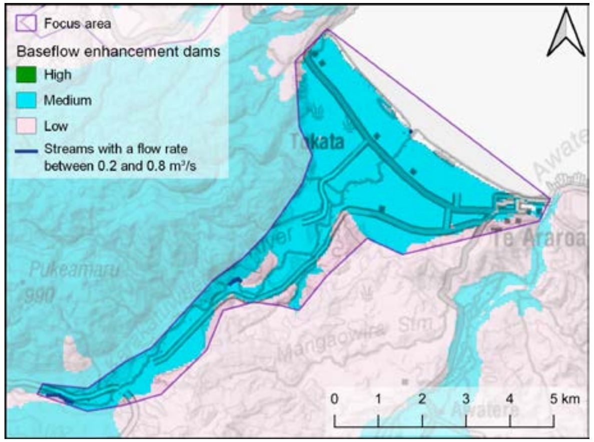

Figure 4.7 Te Araroa options for baseflow enhancement.

4.2.3 Ruatoria

Agricultural land area is an estimated 10,208 ha (Figure 4.8). The majority of this land (7365 ha) is Māori-owned land.

4.2.3.1 Ruatoria Focus Area

The two preferred options for water storage in the Ruatoria focus area are groundwater and baseflow enhancement (Figures 4.8 and 4.9, respectively). Riverine galleries are a third opportunity for water supply. The alluvial valley of the Waiapu River provides opportunities for groundwater extraction, with potential sites for baseflow enhancement dams in the upper reaches of the catchment. The risk of saltwater intrusion to this catchment is low because the river valley is narrow at the coast relative to the valley length. Water is available for allocation, subject to consideration of environmental effects, because current groundwater allocation is low and surface water allocation is zero (Figure 2.1).

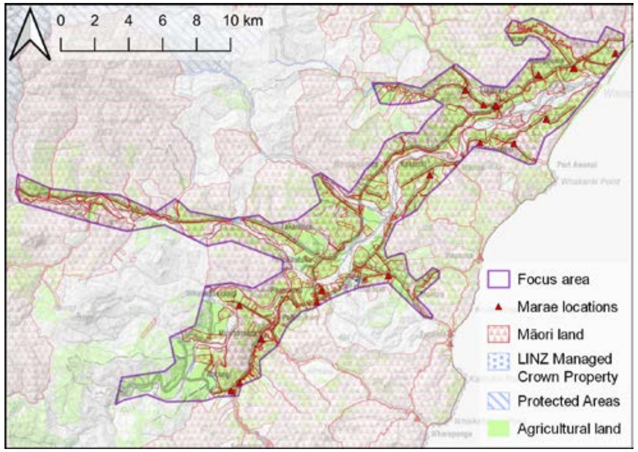

Figure 4.8 Ruatoria focus area summary.

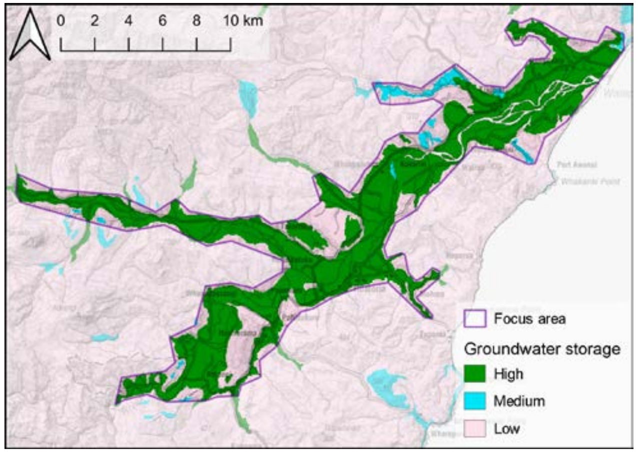

Figure 4.9 Ruatoria options for groundwater storage.

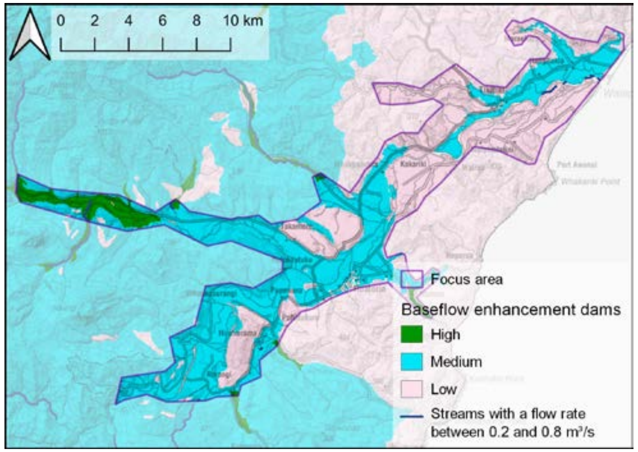

Figure 4.10 Ruatoria options for baseflow enhancement.

4.2.4 Tokomaru

Agricultural land area is an estimated 55 ha (Figure 4.11). The majority of this land (39 ha) is Māori-owned land.

4.2.4.1 Tokomaru Focus Area

Groundwater is the preferred option for water storage in the Tokomaru focus area. Riverine galleries may provide some water in the Mangahauini River valley (Figures 4.11 and 4.12, respectively). The use of groundwater near the town may result in the risk of saltwater intrusion, and an allocation limit is that of the default NES (i.e. 30% of rainfall recharge; Murphy 2021b). Water is available for allocation, subject to consideration of environmental effects, at the very low rates required to provide for the small areas of agricultural land for allocation because current groundwater allocation and surface water allocation are zero (Figure 2.1).

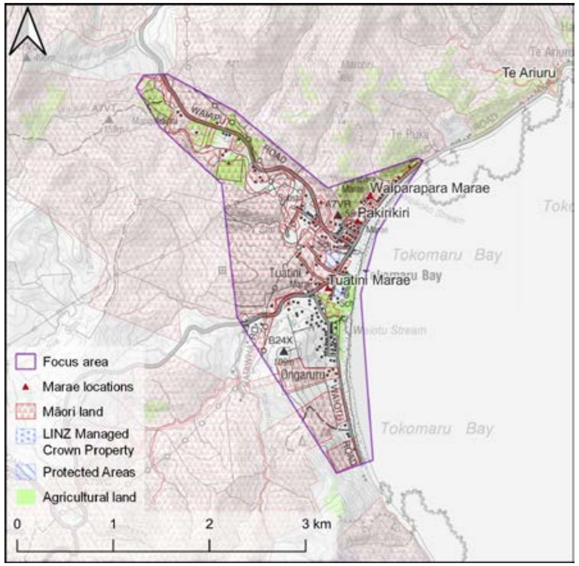

Figure 4.11 Tokomaru focus area summary.

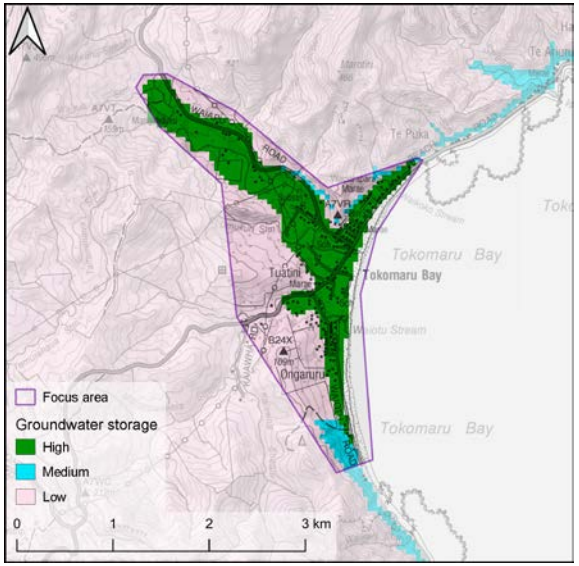

Figure 4.12 Tokomaru options for groundwater storage.

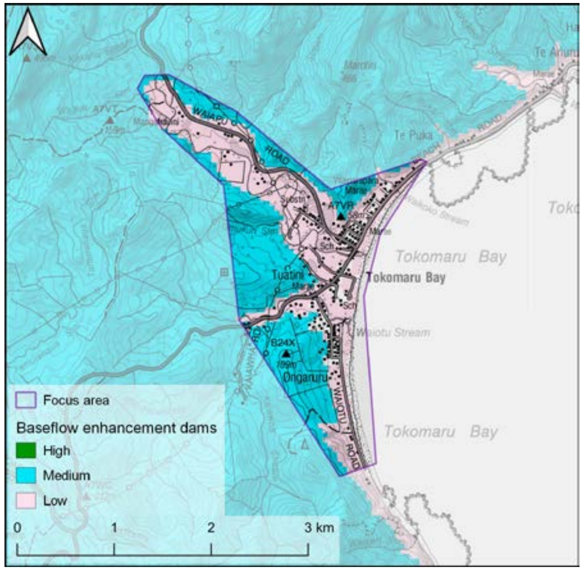

Figure 4.13 Tokomaru options for baseflow enhancement.

4.2.5 Anaura

Agricultural land area is an estimated 136 ha (Figure 4.14). The majority of this land (99 ha) is Māori-owned land.

4.2.5.1 Anaura Focus Area

Groundwater is the preferred option for water storage in the Anaura focus area; baseflow enhancement in the areas surrounding Anaura Bay may provide some water in the coastal strip (Figures 4.14 and 4.15, respectively). The use of groundwater may result in the risk of saltwater intrusion, and an allocation limit is that of the default NES (i.e. 30% of rainfall recharge; Murphy 2021b). Water is available for allocation, subject to consideration of environmental effects, at the very low rates required to provide for the small areas of land for allocation because current groundwater allocation and surface water allocation are zero (Figure 2.1).

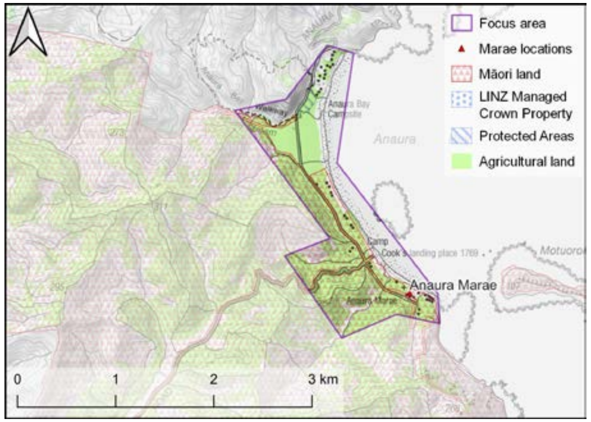

Figure 4.14 Anaura focus area summary.

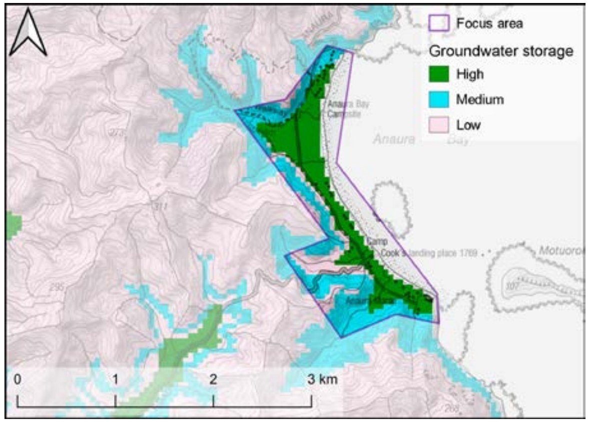

Figure 4.15 Anaura options for groundwater storage.

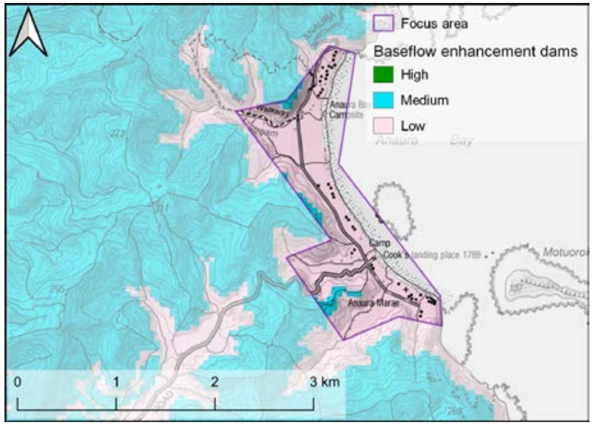

Figure 4.16 Anaura options for baseflow enhancement.

4.2.6 Tolaga Bay Flats

Agricultural land area is an estimated 6723 ha (Figure 4.17). Over a third (36%) of this land (2429 ha) is Māori-owned land.

4.2.6.1 Tolaga Bay Flats Focus Area

The preferred options for water storage in the Tolaga Bay Flats focus area are groundwater and baseflow enhancement (Figures 4.17 and 4.18, respectively). The use of groundwater in the vicinity of the Tolaga Bay township may result in the risk of saltwater intrusion in this area. Therefore, an allocation limit in the area could be that of the default NES (i.e. 30% of rainfall recharge; Murphy 2021b). Water is available for allocation in the catchment of the Uawa River, subject to consideration of environmental effects, to provide for allocation because current groundwater allocation and surface water allocation are zero (Figure 2.1).

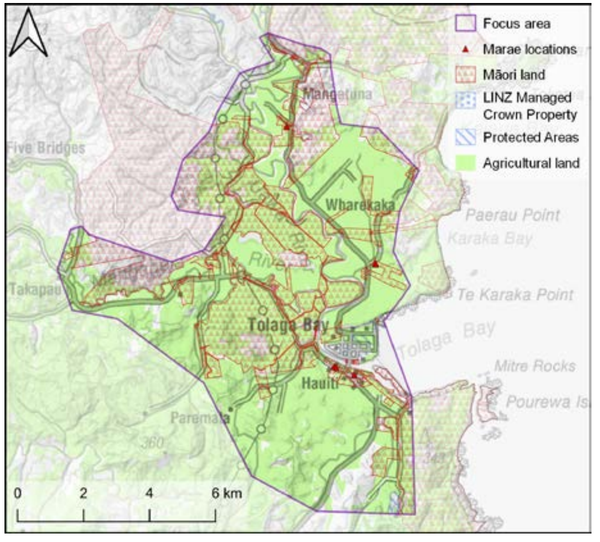

Figure 4.17 Tolaga Bay Flats focus area summary.

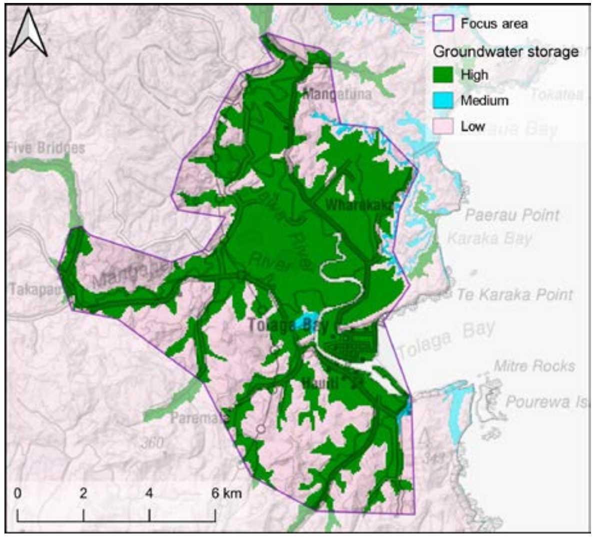

Figure 4.18 Tolaga Bay Flats options for groundwater storage.

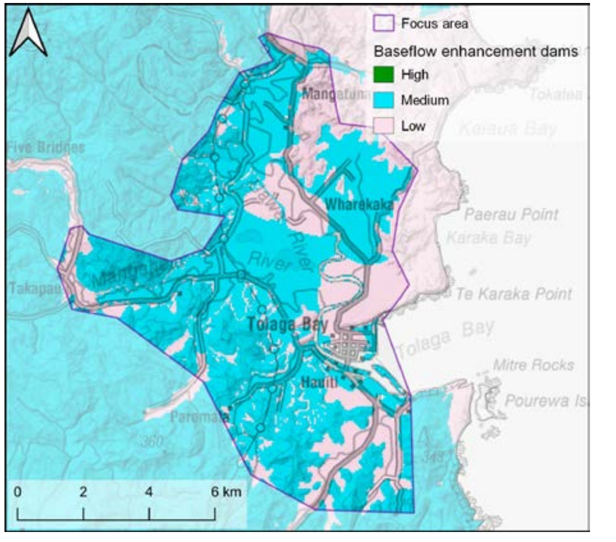

Figure 4.19 Tolaga Bay Flats options for baseflow enhancement.

4.2.7 Waimoko/Pakarae

Agricultural land area is an estimated 7595 ha (Figure 4.19), with very little (5.7 ha) of this land under irrigation. Māori-owned land covers 3773 ha (approximately 50%) of the agricultural land.

4.2.7.1 Waimoko/Pakarae Focus Area

The preferred options for water storage in the Waimoko/Pakarae focus area are baseflow enhancement and groundwater storage (Figures 4.20 and 4.21, respectively). The use of baseflow enhancement in the areas surrounding the Waimoko/Pakarae focus area may provide some water to the agricultural land in the area. Groundwater yields are likely to be low because fine sediments are likely to be common in these aquifers. Water is available for allocation in the focus area, subject to consideration of environmental effects, because the portion of current surface water allocation is low and groundwater allocation is zero (Figure 2.1).

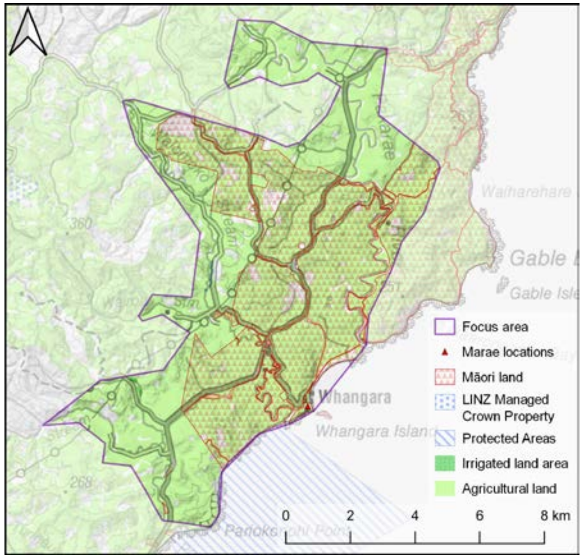

Figure 4.20 Waimoko/Pakarae focus area summary.

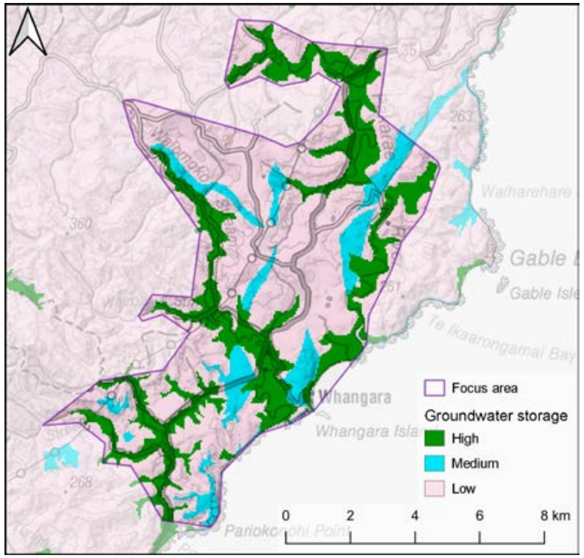

Figure 4.21 Waimoko/Pakarae options for groundwater storage.

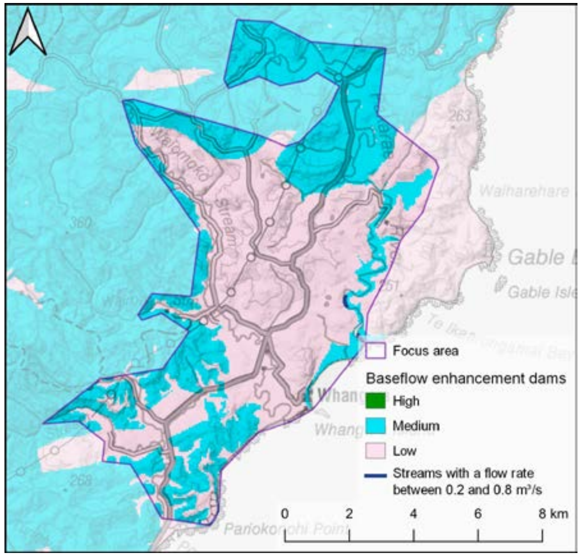

Figure 4.22 Waimoko/Pakarae options for baseflow enhancement.

4.2.8 Waipaoa

Agricultural land area is an estimated 13,750 ha (Figure 4.22) with 2259 ha (approximately 16%) is irrigated. Māori-owned land covers 3327 ha of the agricultural land.

4.2.8.1 Waipaoa Focus Area

The preferred options for water storage in the Waipaoa focus area are groundwater and baseflow enhancement (Figures 4.23 and 4.24, respectively). Galleries may also provide a water supply. Groundwater yields are likely to be reasonable because gravels are commonly associated with the Waipaoa River. Water is available for allocation in the focus area, subject to consideration of environmental effects, because current surface water allocation is moderate and groundwater allocation is low (Figure 2.1).

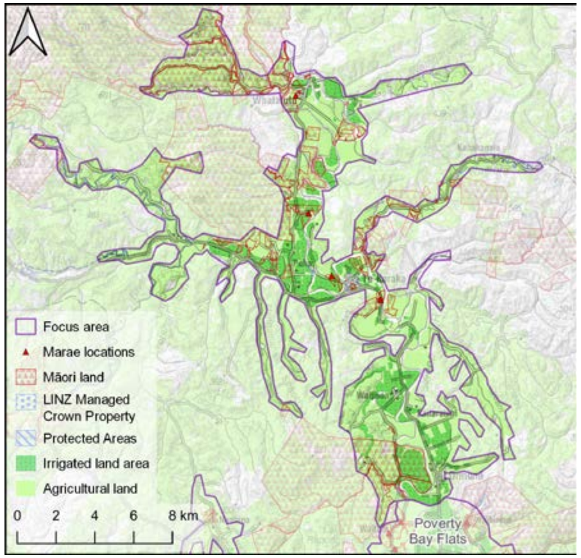

Figure 4.23 Waipaoa focus area summary.

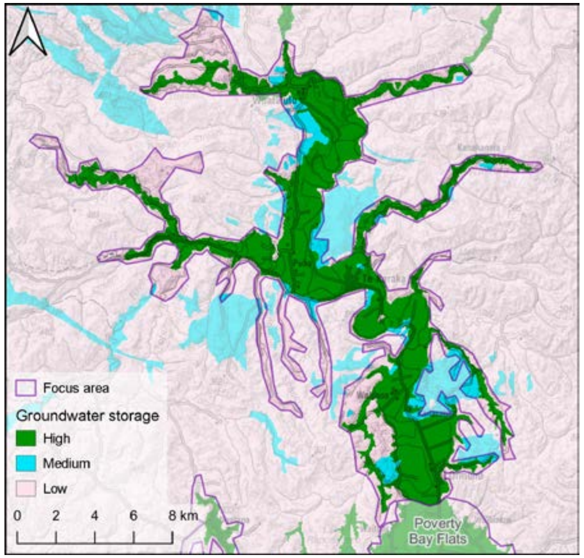

Figure 4.24 Waipaoa options for groundwater storage.

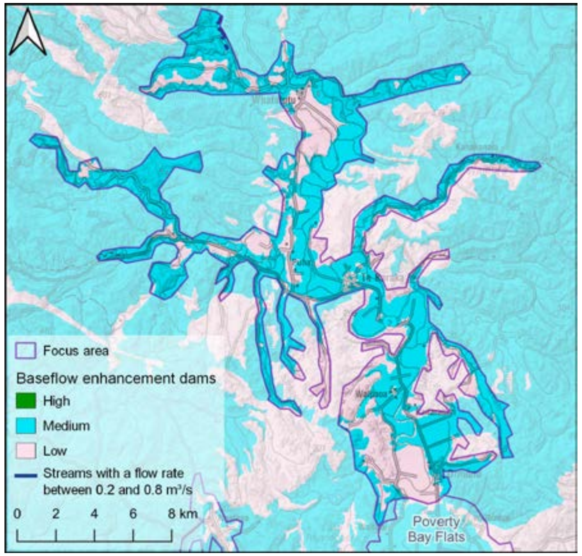

Figure 4.25 Waipaoa options for baseflow enhancement.

4.2.9 Poverty Bay Flats

Agricultural land area is an estimated 19,583 ha (Figure 4.25), with 4198 ha (21%) under irrigation. Māori-owned land covers 2150 ha of the agricultural land.

4.2.9.1 Poverty Bay Flats Focus Area

The preferred options for water storage in the Poverty Bay Flats focus area are groundwater and baseflow enhancement (Figures 4.26 and 4.27, respectively). A third option of managed aquifer recharge may also provide a water supply in the upper reaches, including the Te Arai River flats. However, water is generally not available for allocation in the focus area because groundwater is typically fully allocated (e.g. for the Makauri and Matokitoki aquifers) and only 'B' Block surface water allocation is available (Figure 2.1). This has led Gisborne District Council and groundwater users to develop a managed aquifer recharge trial (Section 2.5). Baseflow enhancement structures located to the west and north of the Poverty Bay Flats may provide a water supply option for the area.

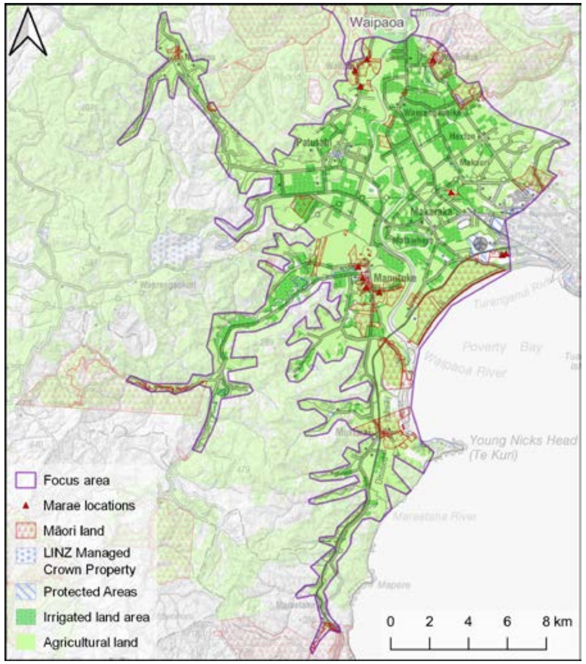

Figure 4.26 Poverty Bay Flats focus area summary.

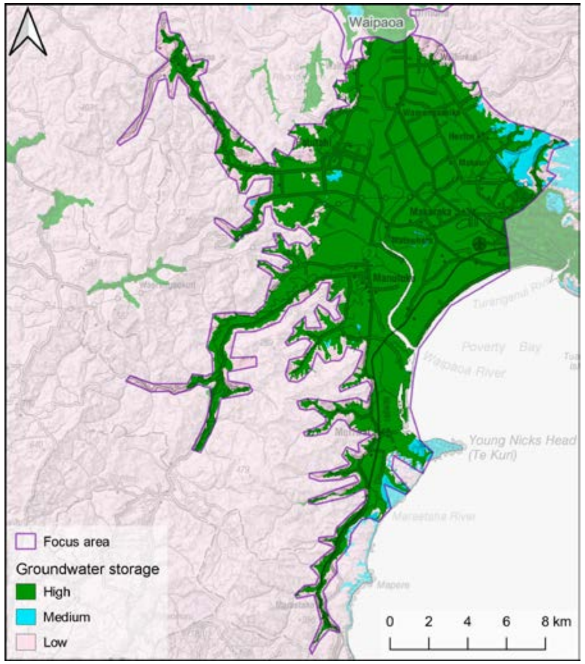

Figure 4.27 Poverty Bay Flats options for groundwater storage.

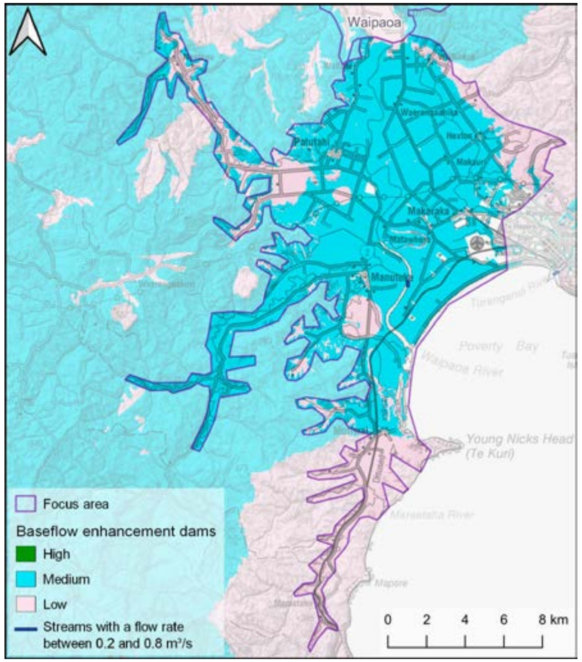

Figure 4.28 Poverty Bay Flats options for baseflow enhancement.

4.2.10 Motu

Agricultural land area is an estimated 8723 ha (Figure 4.28), and none of this land is currently irrigated. Māori-owned land occupies 2150 ha (25%) of the agricultural land.

4.2.10.1 Motu Focus Area

The preferred options for water storage in the Motu focus area are baseflow enhancement and groundwater storage (Figures 4.29 and 4.30, respectively). Water is available for allocation in the focus area, subject to consideration of environmental effects, because current surface water allocation is zero and groundwater allocation is zero (Figure 2.1). The Motu River Water Conservation Order must be considered in the context of water storage and may place constraints on water availability (Ministry for the Environment 2018).

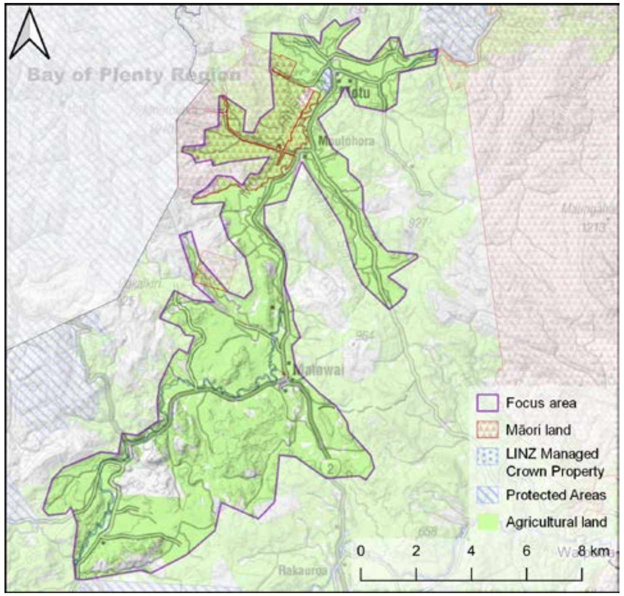

Figure 4.29 Motu focus area summary.

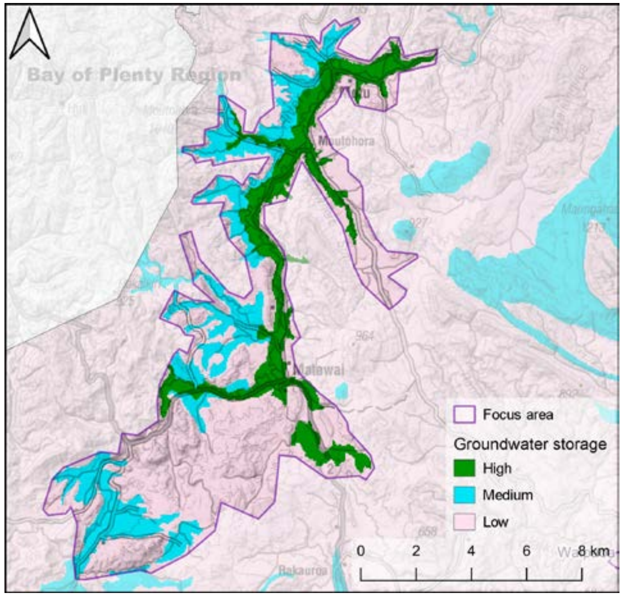

Figure 4.30 Motu options for groundwater storage.

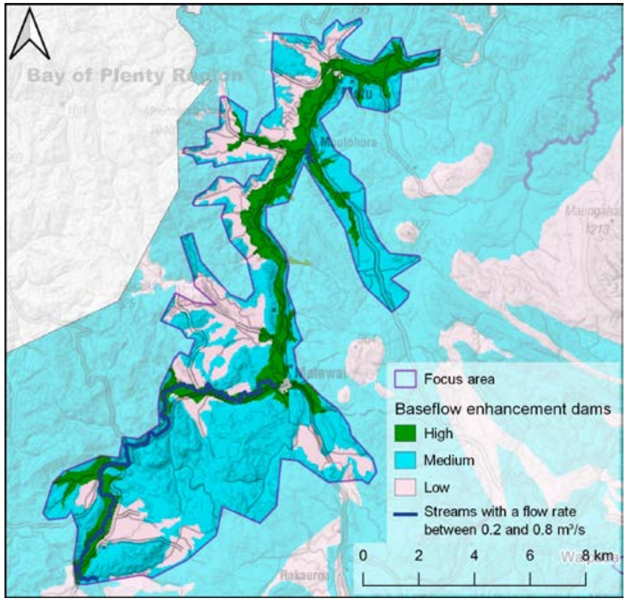

Figure 4.31 Motu options for baseflow enhancement.

4.3 Summary of Storage Options in Gisborne

Potential water storage methods for each of the 10 focus areas in Gisborne are summarised (Table 4.1). The GIS processing datasets and methods identification of water storage methods are provided in Appendix 1. For example, the term 'groundwater storage' in this report refers to water naturally stored within an aquifer and is distinguished from alternative groundwater such as managed aquifer recharge. For all focus areas, the top two preferred water storage methods are groundwater and baseflow enhancement reservoirs. Other methods may provide storage (e.g. riverine galleries); these have been assessed, but the opportunities for these methods are limited. These limitations are generally due to the abundance of low-permeability rocks at the ground surface (i.e. mudstones and basement greywacke) and the hydrology of the Gisborne district (i.e. typically dry summer conditions that are typical of the east coast of the North Island). Notably, the assessment did not show that managed aquifer recharge was an option for the Poverty Bay Flats. This was because the managed aquifer recharge assessment method used in this report assumed surface water application, in common with other PDU reports. In contrast, the Poverty Bay Flats managed aquifer recharge trial has water injection through wells.

Table 4.1 Preferred water storage methods in Gisborne focus areas.

Focus Area	Preferred Water Storage Methods
Hicks	Groundwater storage Baseflow enhancement
Te Araroa	Groundwater storage Baseflow enhancement
Ruatoria	Groundwater storage Baseflow enhancement
Tokomaru	Groundwater storage Baseflow enhancement
Anarua	Groundwater storage Baseflow enhancement
Tolaga Bay Flats	Groundwater storage Baseflow enhancement
Waimoko/Pakarae	Baseflow enhancement Groundwater storage
Waipaoa	Groundwater storage Baseflow enhancement
Poverty Bay Flats	Groundwater storage Baseflow enhancement
Motu	Baseflow enhancement Groundwater storage

5.0 INVESTIGATIONS INTO WATER AVAILABILITY ACROSS GISBORNE

This report shows that there is scope to increase land productivity in Gisborne through increased access to water. Investigations into the physical availability of groundwater and surface water will give the district a better sense of the water resource that is available and that can be used for sustainable land development. Investigations will be useful in areas where water resources are already significantly allocated, such as in the Poverty Bay Flats. Investigations will provide information that will enable Gisborne District Council to determine water take limits in other parts of the region. In areas with little or no existing allocations, investigations will inform the potential locations where water is available for economic development.

A number of the focus areas have little or no existing water allocations, including Hicks, Te Araroa, Ruatoria, Tokomaru, Anaura, Tologa Bay Flats, Waikou/Pakarae, Waipaoa and Motu. Resource consent applications to access water in these areas may progress more slowly through the resource consenting process because of the lack of data.

This report shows that there is potentially sufficient groundwater available to support land production in these focus areas. 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.

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 and therefore the potential for land development. Surface water monitoring will be particularly important in the Poverty Bay Flats focus area because groundwater is heavily allocated.

The PDU has funding available for investment in further scientific investigations in Gisborne. This funding will be applied to a range of activities that will improve the understanding of water needs and opportunities in the district in relation to bringing land into production in a sustainable manner. In this report, the locations of interest, potential benefits of water storage and most beneficial forms of water storage infrastructure for these locations have been identified.

The proposed investments fall into the following categories of investigations:

- airborne electromagnetic surveying
- 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.

5.1 Airborne Electromagnetic Surveying: Poverty Bay Flats

Given the right geological conditions, airborne electromagnetic surveying 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, could give Gisborne District Council and the community confidence about how much water can be used to bring land into sustainable production. Airborne electromagnetic surveying and groundwater recharge measurement could provide better information about the aquifers in Poverty Bay Flats and therefore provide more certainty about the potential for further land development.

The priority for investment in aquifer mapping and groundwater recharge measurement is the Poverty Bay Flats, where groundwater is in demand. In this focus area, the challenge is how to make water available to others while addressing environmental issues. Better information on groundwater may inform and support changes to regulatory limit setting to support sustainable use of the water.

Mapping of the Poverty Bay Flats aquifers 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; and
- the need for sophisticated information to give Gisborne District Council and the community confidence that existing and future further water consents will not be environmentally detrimental.

Once the area of interest has been defined, airborne electromagnetic surveying involves three primary stages of work:

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

During the first stage of aquifer mapping, it will be determined whether the geological environment is conducive to this method. It may be that the aerial mapping would not be able to sufficiently distinguish the base of the aquifer, and aquifer properties, depending on the basement rock type. If mapping is not feasible, drill testing will be utilised. Some early drilling and field measurements will be undertaken to inform the mapping process.

The project will also include a reassessment of groundwater flows, leading to a reconsideration of groundwater allocation limits in the area by Gisborne District Council. For example, groundwater inflow from rainfall may be calculated from field measurements and modelling, including:

- design of a monitoring network to measure rainfall, surface flows, groundwater levels and installation of a rainfall recharge site/s;
- 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; and
- identification of the pathway to Gisborne District Council's consideration of groundwater allocation limits.

5.2 Test Drilling and Galleries for Groundwater Availability

Test drilling of groundwater, and pilot galleries, will provide more localised knowledge of groundwater availability at a lower cost than aquifer mapping. Gisborne District Council monitors water quality and quantity at approximately 100 bores across the Poverty Bay Flats, so bore drilling would be a priority for other parts of the region where there are not monitoring bores, such as the Hicks Bay, Te Araroa, Ruatoria and Waipaoa focus areas. Targeted drilling, excavation and pump testing and data analysis would inform the availability of water for productive use in these areas. This could also be useful for some parts of Poverty Bay Flats where data is lacking.

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

There is currently limited data available for surface water flows and groundwater recharge in the locations identified in this report. The focus areas identified in the report would benefit from a better understanding of surface water flows and groundwater recharge. This would enable the viability of surface water storage and groundwater storage for these locations to be assessed.

The gauging of surface water flows and measurement of groundwater recharge would provide information about the quantity of water in waterbodies throughout the year. In turn, this would enable assessment of the need for storage, the impact of harvesting of winter flows and the potential quantity of water available for storage. From this information, the locations and areas of land available for development can be determined. This information will also be valuable 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 Gisborne would be put in place to better understand surface water flows, groundwater flows and available water across the region. This could be administered by Gisborne District Council. It would support the region's understanding of environmental impacts of economic activity, as well as identifying where water is available for different land use.

A region-wide programme could define an appropriate number of surface water and groundwater monitoring 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. Surface waters will likely have sufficient flows to enable environmentally sustainable harvesting while generating enough water to justify investment in water storage and harvesting infrastructure. These waterbodies will need to be within reach of the productive and Māori land to be 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 Gisborne District 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.

5.4 Assessment of Scope for Harvesting Winter Flows across Gisborne

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 Gisborne would inform discussions about the feasibility of this approach, its impact on instream values and environmental impacts. This work could be undertaken as part of a cross-regional programme including Northland and Gisborne, as both areas are considering this approach. This would inform similar considerations in other regions where summer droughts are problematic (i.e. east coast South Island, Waikato, Nelson and inland Southland).

5.5 Other Regional Water Issues: Adequacy of Community Water Supplies

Investments could be made into assessments of the adequacy of existing rural water supply schemes. Such assessments are priorities for the region but do not fit within the PGF's investment scope, as they relate to maintenance of existing productivity (rather than growth) or to municipal water (which is being dealt with through other government investments). While these cannot be progressed through PGF funding, some assistance is needed to undertake this work.

5.6 Next Steps

Priority investigations for the region include aerial electromagnetic surveying of the Poverty Bay Flats groundwater system, extending the measurement of surface water flows and groundwater recharge across the region and undertaking a study of the scope of harvesting winter flows with baseflow enhancement dams. Allied investigations could include assessments of the effects of water takes from groundwater and surface water. AIA will continue to work with the region to identify the priority locations for undertaking investigations and the most effective investigations for these locations. This will involve further discussions with Gisborne District Council and engagement with Ngāti Porou.

6.0 ACKNOWLEDGMENTS

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APPENDICES

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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

Two face-to-face consultation workshops were held in Gisborne between Gisborne District Council, the Provincial Development Unit, GNS Science and AgFirst in the development of this report. Discussion in the 4th February workshop began with a general consideration of issues, including background and status of the water storage project, Gisborne District Council's current catchment plans, vulnerable catchments, erosion, the shortfall of rain in the area, community drinking-water supplies, catchment water-quantity limits and catchment water-quality limits. Then, the water storage project methodology was introduced, followed by a general discussion about water storage in the Gisborne region. The meeting also discussed the proposed timeline for the project and the importance of iwi interaction.

A discussion of the draft water storage report was the focus of the workshop on the 22nd March. Water storage approaches were discussed in the focus areas, from north to south, finishing with the Poverty Bay Flats. The workshop also included an outline, for local PDU staff, of the approach taken in the report; current progress with the managed aquifer recharge trial in the Poverty Bay Flats; and a summary of complementary Gisborne District Council projects. The meeting concluded with a discussion of next steps, e.g. report completion, engaging with iwi and other actions.

A2.1 Storage Methods

A2.1.1 Groundwater Storage

The groundwater storage method was developed by combining the Hydrogeological System 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. Then, the stacked polygons were 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, 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 Layers (FSL) profile available water, river flow and Land Cover Database (LCDB) 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 LCDB, mean annual precipitation and mean annual evapotranspiration datasets (Tait et al. 2006; Woods et al. 2006; Henderson 2019; Stats NZ 2020b; LRIS Portal 2020).

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 Hydrogeological Systems, 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 Hydrogeological Systems, 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 2020).

A2.1.6 Galleries

This method was developed by combining the HUM outcrop, Equilibrium Water Table FSL and LCDB 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 2020).

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).

A2.2 GIS Processing

A2.2.1 Datasets

A combination of national- and regional-scale datasets were 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.

Coverage	Dataset	References
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/
National	Regional Council boundaries	Stats NZ. 2020b. 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)	Murphy (2021a).
Regional	Water Permit	Murphy (2021a).

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 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 millimetres 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 different-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 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 LCDB 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 National Institute of Water & Atmospheric Research (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 (2020b). The following GNS GIS datasets were used in this project:

- Large Dams Gisborne District Register (A505884), MS Excel file (Murphy 2020)
- GDCAquifers, shapefile (Murphy 2021a)
- GDCGroundwaterRegions, shapefile (Murphy 2021a)
- GDCRiverCatchmentsPart1, shapefile (Murphy 2021a).

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 Gisborne region, the extent used was 1959000 and 5674000 for minimum Easting and Northing and 2092000 and 5834000 for maximum Easting and Northing. Rasterising and re-gridding were performed with GDAL-based tools from either command prompts 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.

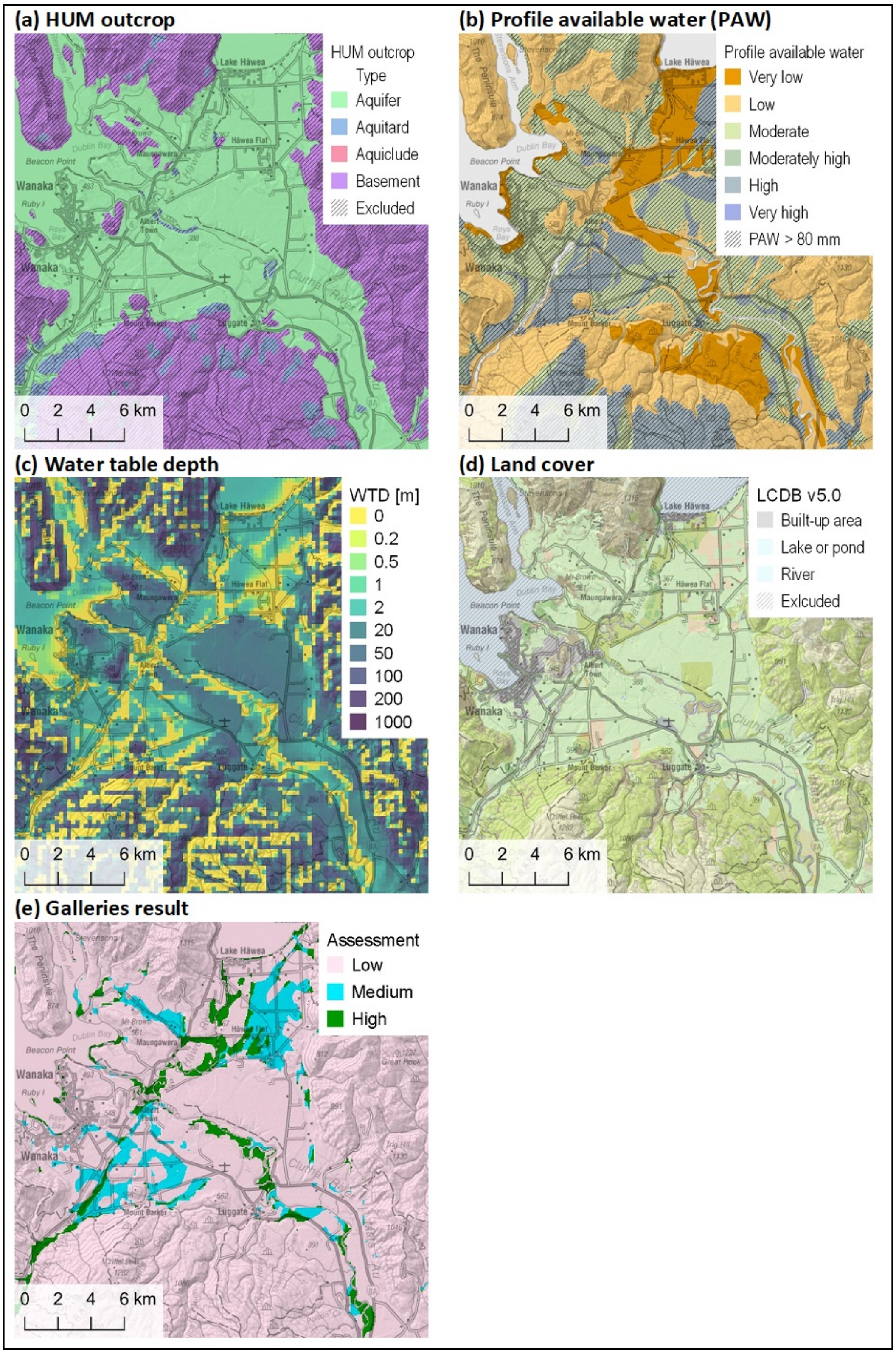

Figure A2.1 Example of a GIS overlay assessment for galleries. Acronyms used in the figure are as follows: Hydrogeological-Unit map (HUM), water table depth (WTD), Land Cover DataBase (LCDB).

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
Dams identified by Gisborne District 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.