Gisborne District Council

Poverty Bay Flats Groundwater Modelling Programme Summary Report

TECHNICAL REPORT

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EXECUTIVE SUMMARY

Introduction

A numerical groundwater model of the Poverty Bay Flats/Tūranganui-a-Kiwa has been developed based on a geological model using Gisborne District Council (GDC) bore lithological data. A number of exploratory scenarios were run in the model to provide guidance on potential groundwater management measures. This report summarises the findings of the scenario modelling.[1]

Conceptual Groundwater Model

A conceptual model of the groundwater system of the Poverty Bay Flats was built that incorporates five primary aquifers. The shallow and predominantly unconfined Te Hapara Sands and Shallow Fluviatile Gravel Aquifers are highly connected to each other and to surface water bodies within the catchment, including the ocean. The deeper Waipaoa, Makauri and Matokitoki Aquifers are predominantly confined. The Makauri Aquifer, which is the water source most utilised for horticultural purposes, is considered to extend offshore but the southern and western extents of this aquifer are uncertain.

The primary sources of natural recharge to the groundwater system are rainfall and flow losses from the Waipaoa River to underlying aquifers at the northern end of the Poverty Bay Flats. There is evidence to indicate some recharge to the confined aquifers is occurring in localised areas along the eastern and southeastern edges of the flats. However, as the mechanisms, seepage paths and rates of these recharges are poorly understood, they have not been incorporated in the numerical model. Groundwater discharges are distributed between the ocean, the Waipaoa River, streams, wetlands drains and bores.

Exploratory Model Scenario Results

Exploratory Scenarios were designed to enable a better understanding of existing and future groundwater issues and to provide guidance on potential management measures. The Exploratory Scenarios, together with model scenarios to be developed in the future by GDC, can be used to investigate combinations of management and mitigations measures to address the community concerns. Responses to specific questions raised by the community in consultation workshops are summarised below, based on Exploratory Scenario model results (Table A).

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[1] GDC commissioned Wallbridge Gilbert Aztec (WGA) and AQUASOIL Ingenieure & Geologen GmbH (AQUASOIL) to develop a groundwater model including; a 3D geological model, a conceptual groundwater model and a numerical FeFlow groundwater model. The model incorporates a wide range of climatic, hydrological, hydrogeological, groundwater abstraction and water quality data. Detailed descriptions of the numerical geological and groundwater models are documented in separate technical reports that should be considered in conjunction with this report. These separate reports include model input parameters and input derivations, technical assumptions and limitations.

Is there a decline in the aquifers?

A review of the groundwater levels in the Makauri Aquifer, which is by far the largest source of water for horticultural purposes, indicates that both summer pumped groundwater levels and recovered winter peak levels are declining. These declines are due to increasing groundwater pumping over time. In addition, analysis showed that the time required for groundwater level to recover following droughts is increasing. As the frequency and severity of droughts are predicted to worsen, it will take longer for the Makauri Aquifer to recover in the future. The cumulative modelling results indicate that additional abstraction during droughts could potentially be accommodated by increased downward flows from overlying aquifers and increased inflows to the northern end of the aquifer. However, additional abstraction resulted in increased surface water depletion and groundwater level recovery after drought periods may take years.

What is the current status of the aquifers?

As detailed above, the review of historical monitored groundwater levels indicated a decline in the Makauri and Matokitoki aquifers. Shallower aquifers showed stable groundwater level trends. However, coastal groundwater levels temporarily dropped below sea level in the Te Hapara Aquifer.

The model was used to assess the ongoing groundwater level trends under various scenarios. The baseline Model Scenario 1.1 was used to determine if levels would stabilise if groundwater abstraction was held at the current rates. Model Scenario 1.1 represents a continuation of the current climate conditions, with no allowances made for climate change, droughts or increases in groundwater demand above the current metered rate. Modelling results indicated that with abstraction held at the current rates groundwater levels are dynamically stable. Therefore, observed declines are considered to be due to increasing abstraction rates over time. However, the model outcomes also indicate local trends of increasing groundwater salinity are likely to continue. This implies, management measures may need to be implemented to address increases in groundwater salinity even if the projected climate change impacts do not eventuate. In reality, the modelled Baseline Scenario 1.1 will not occur as demand for groundwater abstraction will increase. This is covered in the modelling under Scenario 2.1.

What effects would climate change have?

Model Scenario 2.1 incorporates a continuation of existing groundwater allocation and abstraction (1,188,000 m^3/year), in addition to climate change effects. These effects include reduced natural recharge, progressive sea level rise, increased groundwater pumping to offset decreasing summer rainfall and extreme drought events. Scenario 2.1 is considered to be a **baseline** reference, against which the other model scenarios are compared. The model results indicate that aquifer conditions will progressively worsen for all values considered under this project: aquifer status (groundwater pressures and levels), cultural values, surface ecosystems, and groundwater salinity (Table A).

What effects would occur when Te Mana O Te Wai is placed above commercial use?

Model Scenario 3.1 represents a ‘no-pumping’ or ‘natural state’ projection. Groundwater abstraction is reduced from 1,188,000 m^3/year to zero across all five aquifers, but the other aspects of climate change projections are incorporated as represented in Scenario 2.1. If groundwater abstraction were to cease completely, the model indicates groundwater levels and baseflows in the surface water ecosystems would increase (Table A). However, even under this extreme scenario groundwater salinity trends are unlikely to be reversed compared to the baseline scenario (and therefore are considered to stay the same). The impacts of climate change on the agreed cultural indicators are still likely to worsen, mainly due to projected sea level rise. Turning off all groundwater pumping would have substantial economic and social impacts on the region.

What effects arise if existing allocations are used to full entitlement?

Model Scenario 4.1 explores the consequences of increasing pumping up to the full 2021 groundwater allocation limit of 3,980,908 m^3/year distributed across all five aquifers. This abstraction is increased to allow for the need for further progressive increases in abstraction in response to climate change stresses. The overall model results indicate increased pumping up to the currently consented allocation limit draws down the groundwater levels, but the system subsequently stabilises in a dynamic equilibrium at a lower level. However, the lower groundwater levels within each aquifer could cause issues such as reduced groundwater availability in bores and increased salinity. Increased groundwater usage acts to worsen the outcomes for all values against which the model has been evaluated (Table A). Model results indicate that there would be increased pressures on surface water baseflows and progressive degradation of groundwater quality in the form of increasing salinity, particularly along western side of the Makauri Aquifer. However, the maximum volumes allocated under individual groundwater abstraction consents are designed to provide irrigators with water security through drought periods. In reality, the regular year-to-year use of all allocated water is not considered a likely scenario.

What effects would replenishment have on groundwater levels?

Model Scenario 5.1 explores the benefits of incorporating a focused managed groundwater replenishment programme to actively recharge groundwater supplies. Under this scenario replenishment was initiated at 600,000 m^3/year, increasing over time to 780,000 m^3/year as an offset to increasing water demand driven by climate change. Model results indicated that clear benefits could be achieved in the form of increased groundwater pressures within the targeted Makauri Aquifer. The enhanced recharge helped offset the effects of climate change and helped maintain current surface water conditions (Table A). In addition, the model outcomes indicate the application of managed aquifer recharge could provide a first line of defence in reducing and reversing the spread of saline water within the Makauri Aquifer. This modelled scenario did not result in improved outcomes for cultural values because these values were measured for coastal sites with links to shallow groundwater whereas the simulated replenishment targeted the Makauri Aquifer at an inland site.

Table A: Groundwater Model Results for Selected Community Outcomes.

Summary Community Questions	Investigation Exploratory Scenarios [(1)]		Human Usage	Aquifer Status	Cultural	Surface Water Ecosystems	Salinity
	Baseline	1.1	Current	Stay the Same	Stay the Same	Stay the Same	Worsen
	Baseline + Climate Change	2.1	Current	Worsen	Worsen	Worsen	Worsen
What effects would occur if Te Mana O Te Wai was placed above commercial use?	Natural State	3.1	Zero	Improve	Worsen	Improve	Stay the Same
What happens if allocations are used to full entitlement?	Entitled Allocation	4.1	Full 2021 Allocation	Worsen	Worsen	Worsen	Worsen
What effect would replenishment have on groundwater levels?	Groundwater Replenishment	5.1	Current	Improve	Worsen	Stay the Same	Improve
What is a sustainable allocation rate?	Sustainable Allocation	7.1	*Variable*	Stay the Same	Worsen	Improve	Worsen

What is a sustainable allocation rate?

Defining a 'sustainable' pumping rate from a groundwater system requires a thorough definition of what is to be protected and what changes are considered sustainable, derived through community/stakeholder consultation. Model Scenario 7.1 explores one concept for a potential 'sustainable groundwater allocation' in response to projected climate change effects. Under this scenario the model objective was to maintain groundwater levels within the currently observed ranges through to 2050. This was achieved through a 15% reduction in pumping from the 2021 actual groundwater use. Then through time the modelled abstraction was increased to account for increasing demand with climate change to meet crop requirements, under the same irrigated area. The modelled increased abstraction steps in response to potential evapotranspiration deficit requirements were; no increase until 2029, 5% increase from 2030 and 15% increase from 2045.

The results indicate that the modelled pumping during both normal and drought years increases progressively in response to increasing water demand driven by climate change. In addition to groundwater levels being maintained in the Makauri Aquifer within the currently observed ranges through to 2050, improvements were modelled in surface water flows. However, outcomes for both cultural values and increasing groundwater salinity both worsened (Table A).

The concept of 'sustainability' used as a measure for Scenario 7.1 is limited to groundwater levels and pressures. To achieve improvements in all community set outcomes for 'sustainability' a combination of setting an allocation limit combined with groundwater replenishment would be needed.

Overall Model Results

None of the modelled scenarios led directly to improved outcomes for the agreed cultural indicators developed through the project (Table A). The main reason for the consistently worsening outcomes are the overriding impacts of climate change rather than the impacts of groundwater abstraction. There is limited groundwater abstraction close to the coast, which means shutting down this pumping did not effectively offset the projected negative impacts of sea level rise. Also, possible changes to surface water drainage systems were not included in any of the simulated scenarios, further limiting any potential benefits of groundwater management.

The modelled scenarios provide guidance on measures that may be considered for future investigation and modelling to achieve improved outcomes for culturally valued features. These include, for example, using targeted enhanced recharge to prevent or reverse saline water intrusion to aquifers along the coast.

Summary and Recommendations

The model results indicate that the combined application of both groundwater replenishment and abstraction allocation management can provide options to enable improved quality and quantity outcomes, even in the context of climate change.

WGA recommends that GDC model a set of Solution Scenarios that investigate the options for how these two levers (**groundwater replenishment** and **allocation limits**) may be used in tandem to achieve as many of the desired outcomes as possible.

The calibrated groundwater model provided to GDC is a tool that can be used to test groundwater management options and thereby support the development of a progressive set of policies and management goals to inform climate change adaptation planning and further community engagement.

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Revision History

Rev	Date	Issue	Originator	Checker	Approver
A	12/09/2022	Draft for review	BAS/RJB	CHO	RJB
B	10/11/2022	Final draft	BAS/RJB	CHO	RJB
C	19/05/2023	Final	BAS/RJB	CHO	RJB
D	20/07/2023	Final revised Exec Sum	BAS/RJB	CHO	CHO
E	27/09/2023	Final revised Exec Sum	BAS/RJB	CHO	CHO
F	21/11/2023	Final revised Exec Sum	BAS/RJB	GDC	CHO

1 INTRODUCTION

1.1 OVERVIEW OF THE MODELLING PROGRAMME

Starting in 2021, Gisborne District Council (GDC) commissioned Wallbridge Gilbert Aztec New Zealand (WGA) and its project partner AQUASOIL Ingenieure & Geologen GmbH (AQUASOIL) to provide technical support for the development of a definitive and defensible groundwater model for Poverty Bay Flats/Tūranganui-a-Kiwa (Poverty Bay Flats). The model would be designed to simulate the behaviour of groundwater flows and water quality changes within the aquifers underlying the Poverty Bay Flats. The modelling programme that GDC established was more comprehensive than is typically developed for numerical groundwater model building processes (Figure 1).

Firstly, a comprehensive understanding of the geology beneath the Poverty Bay Flats was established. This process clarified the spatial distribution and extent of the five primary aquifers based on the available geologic information. This process helped to clarify areas where data was sparse or even unavailable, which in turn will help GDC decide where to prioritise future data collection efforts. The information generated in this assessment was then used to construct a geologic framework inside a specialised 3D modelling software package named **GeoModeller.** A completed geological model for the Poverty Bay Flats groundwater system formed the structural foundation on which the numerical groundwater model was constructed (Figure 1).

The second important step in this process, was the development of a **FEFLOW** numerical groundwater model for the area. This model incorporates a wide range of hydrologic, climatic, abstraction, hydrogeology and geochemical data that has been collected by GDC over several decades. The model was also developed to help evaluate the effects of climate change model through model scenario comparisons. Outcomes from national climate change modelling completed by the National Institute of Water and Atmosphere (NIWA) were also incorporated to help simulate the climate effects in our scenario modelling process.

When the model was calibrated, validated and ready for use, a series of model scenarios were generated to evaluate a range of groundwater management questions about the Poverty Bay Flats. For the Poverty Bay Flats model scenarios, the model was set up to estimate current groundwater conditions as well as the predicted effects of climate change. The combination of current conditions with the influence of climate change were used as the basis to which all modelled management scenarios were compared.

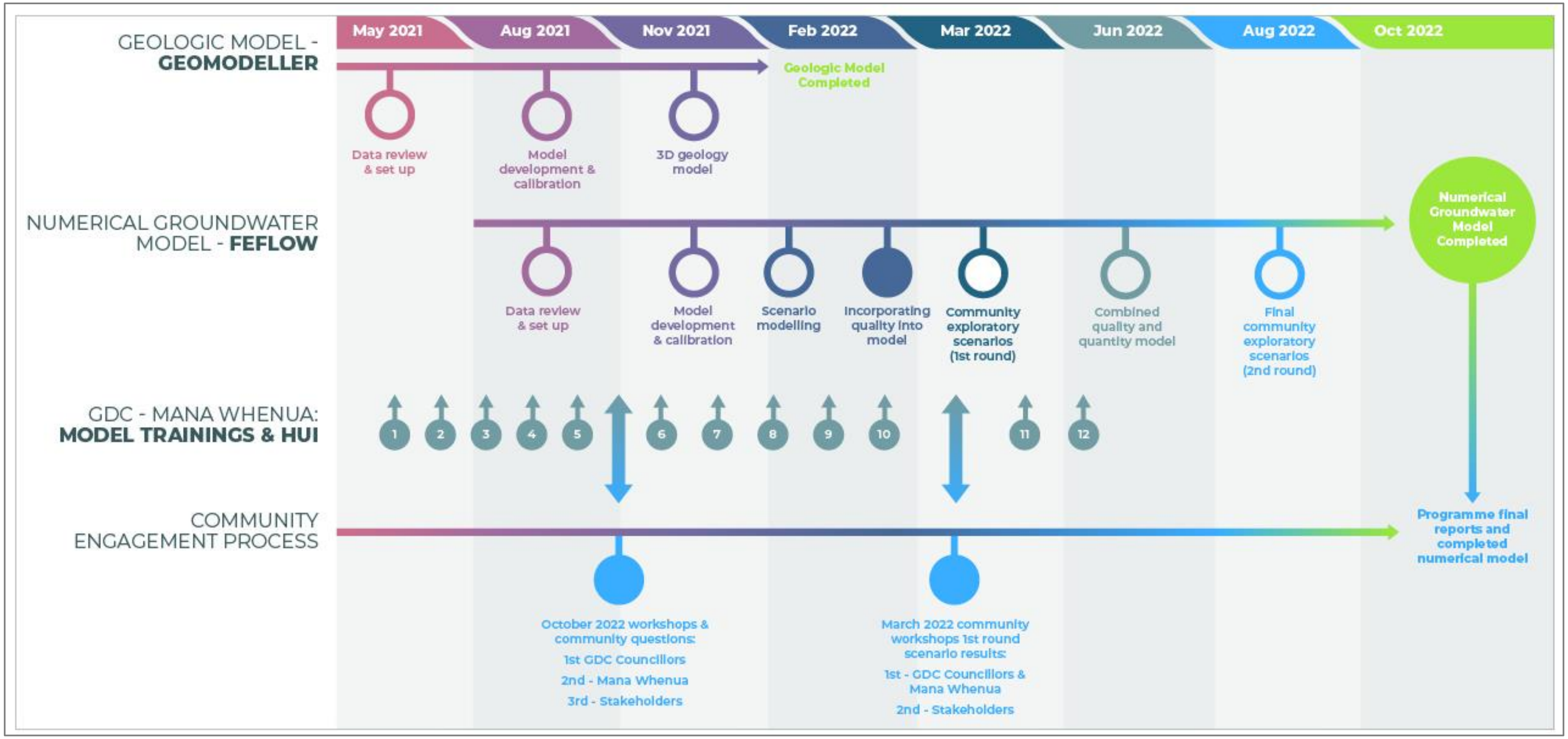


Figure 1: Poverty Bay Flats Numerical Groundwater Model and Community Engagement Process (May 2021 to October 2022)

In addition to the numerical model development process, GDC established a parallel community engagement strategy to help incorporate the wider community's input and answer questions about the model development process. As part of the engagement with GDC treaty partners, key representatives from **Mana Whenua**[2] were invited to and participated in the twelve online FEFLOW technical trainings (Figure 1). During these trainings, technical aspects of the modelling process were shared and discussed.

During these hui, the technical team was fortunate to have Mana Whenua also share learnings about surface and groundwater in the project area from a cultural history perspective. As a means to help ingrain a cultural perspective in the modelling process, the technical team worked with Mana Whenua to identify a series of culturally important locations. The effects at these sites were assessed qualitatively through each of the groundwater management scenarios being evaluated using the numerical model (e.g., likely to improve, likely to stay the same, likely to worsen). These indicators provided the project team a means by which to start to connect identified cultural values with possible future management decision making alongside the anticipated effects of climate change including sea level rise and the increased frequencies of extreme weather events. Similarly, measurements of other environmental indicators such as changes in groundwater salinity and the effects of groundwater management on environmental surface flows were linked using some key qualitative statements.

In addition to the Mana Whenua hui, GDC technical staff worked with the GDC councillors and wider community stakeholders in a series of **workshops** (Figure 1). These workshops were designed to inform the participants as well as incorporate various perspectives into the model development process. The first set of these workshops in October 2021, helped inform the participants on the overall hydrogeology of the area as well as the construction and capabilities of the numerical groundwater model. During the workshops, GDC lead an interactive process by which the various stakeholder groups were asked to pose specific 'big picture' questions relative to the current and future management of the Poverty Bay Flats groundwater system. These questions were related to resource sustainability, climate change, groundwater replenishment, and various levels of allocated groundwater usage. From a compiled list of these community questions, a series of 'first cut' exploratory scenarios were quantified numerically and incorporated as tests of the newly calibrated and validated groundwater model. The scenarios sought to provide projections of groundwater flow and levels under a range of management options over a period from present (2022) through to the end of the climate forecast modelling period (2090). After completion of the first round of exploratory scenario modelling the results were presented and discussed in a series of community workshops in April 2022 (Figure 1).

During the engagement process, the quality of groundwater in the Poverty Bay Flats was raised as an issue of particular concern to the Mana Whenua and the wider community. These concerns covered a number of parameters, but in particular the issue of salinity intrusion along the coast and in the western portion of the Makauri Aquifer, where the poor quality of available groundwater restricts its use. GDC instructed the modelling team to review and compile all groundwater quality data and then work to incorporate salinity modelling into the community scenario development process. For the purposes of the groundwater quality modelling and this report, the term salinity is taken to specifically mean chloride concentration. As the modelling and community workshops progressed, GDC, Mana Whenua and community stakeholders developed a series of questions on the current and future management of the Poverty Bay Flats groundwater system. The modelling team transcribed the technical essence of the questions into the context of numerical modelling scenarios.

[2] Gisborne District Council is developing a treaty partnership with representatives from the local iwi groups as part of a co-governance model approach to resource management.

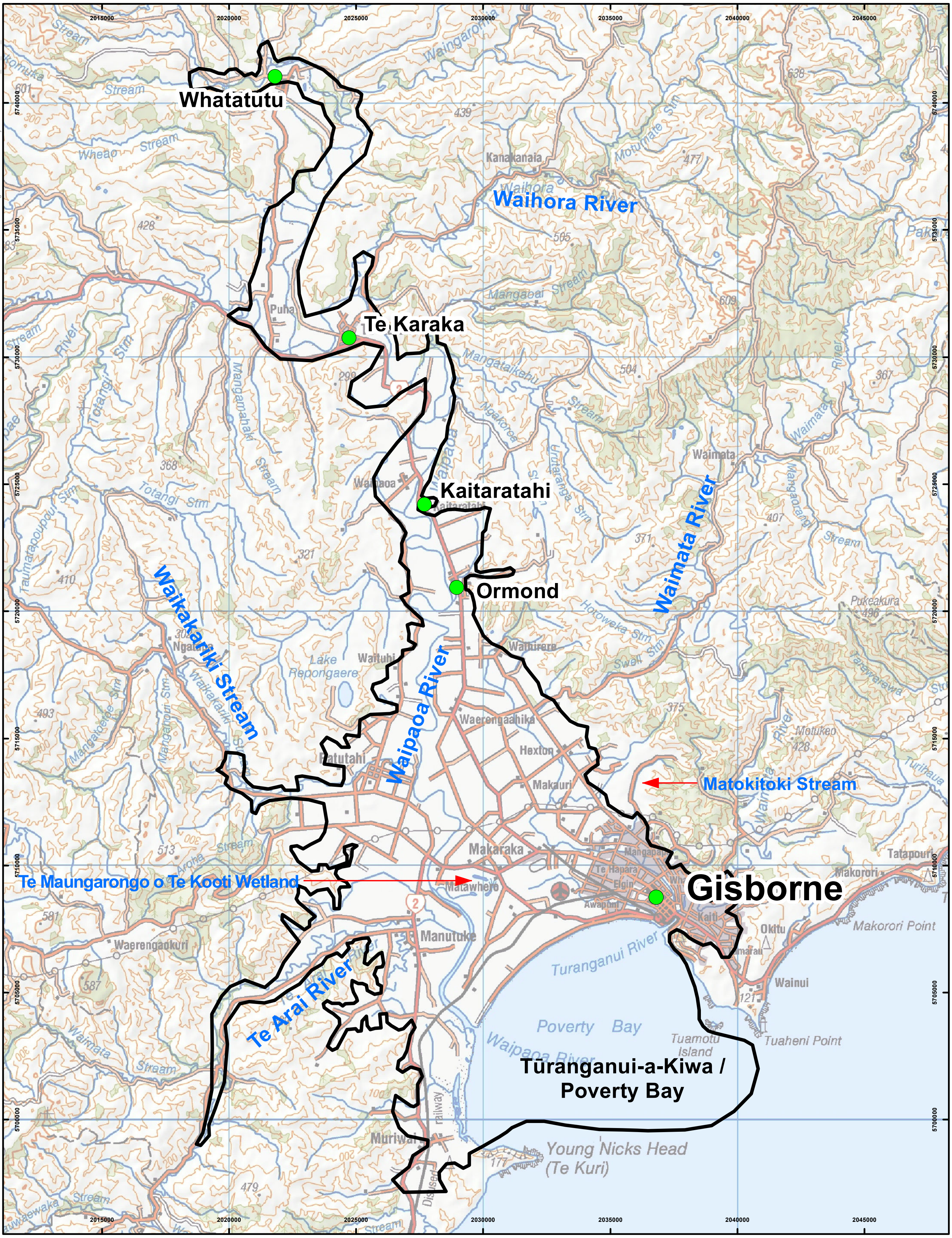
Informed by the community workshop process and after further consideration of the technical results from the first round of **exploratory scenarios**, a second and final round of scenarios was commissioned by GDC. The major changes in the second round of scenarios were to refine and better represent the likely effects of climate change. This included combining three separately modelled issues (anticipated sea level rise, increased severity of droughts, and increasing irrigation water demands resulting in increased groundwater pumping) into a combined comprehensive baseline with the influence of climate-change modelling scenario. With the incorporation of the water quality function into the FEFLOW model, this second round of modelling scenarios also incorporated the expected changes in chloride concentrations into the various scenarios results. This second round of community exploratory scenarios is considered the final outputs from the project and is presented in this final Poverty Bay Flats groundwater modelling programme report.

1.2 POVERTY BAY FLATS GROUNDWATER SYSTEM

The Poverty Bay Flats covers an area of about 200 km^2 comprising the coastal alluvial floodplains in the Gisborne Region/Te Tai Rāwhiti, on the Northeast Coast of the North Island of New Zealand. The Poverty Bay Flats extend inland for approximately 20 km to Ormond, which lies at an elevation of about 20 m above mean sea level (Figure 2).

The Waipaoa River, which is the primary surface waterbody, flows southward for over 80 kilometres from its headwaters in the Raukumara Range capturing flow from a total catchment area of approximately 2,165 km^2. Smaller rivers and streams flowing into the Poverty Bay Flats modelling area include the Te Arai, Waimata and Wahiora Rivers as well as Matokitoki and Waikakariki Streams. Other water features include the Te Maungarongo o Te Kooti Rikirangi wetland (also known as the Matawhero wetland), which formed in a former oxbow of the Waipaoa River and is one of the largest remaining wetlands on the Poverty Bay Flats. This wetland holds culture significance to local iwi as well as terrestrial and aquatic environmental values.

The Gisborne district has approximately 1,000 mm annual precipitation at the coast to 1,400 mm in the upper parts of the Waipaoa River catchment (Chappell, 2016). Monthly rainfall (Gisborne AWS) ranges a low of 57 mm (December) through a high of 131 mm in July (Table 1). Average monthly potential evapotranspiration substantially exceeds monthly rainfall from October through to February (Figure 3) which drives the need for groundwater pumping to help support agriculture on the Poverty Bay Flats. Spatially distributed rainfall recharge to the Poverty Bay Flats aquifers is considered to predominantly occur through the period March to August annually. Although irrigated areas have increased over time as the horticultural industry in the region has expanded, most of the irrigation is designed to maintain soil moisture levels through the main summer crop production period. Irrigation practices on the horticultural areas of the Poverty Bay Flats are relatively efficient and do not appear to lead to widespread and frequent exceedance of the soil water holding capacity.



N

0 2.5 5 km

Scale 1:200,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user.

LEGEND

City

Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure 2
Gisborne MAR Model
Poverty Bay Flats Project Area and Topography

Table 1: Monthly Average Rainfall and Potential Evapotranspiration

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Waipaoa Rainfall (1)	98	116	130	130	127	156	186	123	98	93	66	73	1,395
Gisborne AWS rainfall (2)	59	68	93	97	96	105	131	78	72	70	63	57	987
Gisborne EWS ET (3)	161	119	97	59	40	29	31	47	73	110	132	147	1,045

Notes: 1) 1981 – 2010 (Chappell 2012)

2) Metservice dataset from NIWA CLIFLOW database, Gisborne monitoring stations 2809 and 2810, Period 1982 – 2021

3) Metservice dataset from NIWA CLIFLOW database, Gisborne monitoring station 2810, Period 1992 – 2021

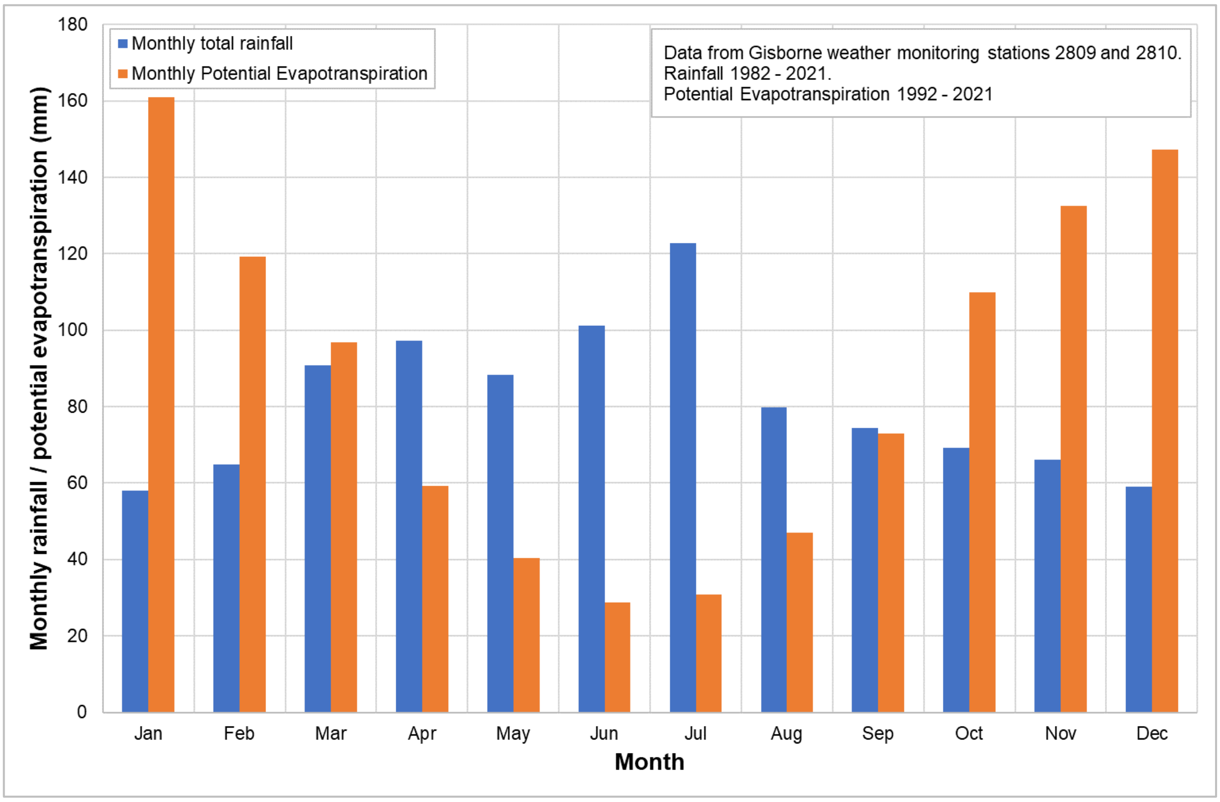


Figure 3: Average Monthly Rainfall and Potential Evapotranspiration at Gisborne

For the purposes of the groundwater modelling, it is assumed that distributed groundwater recharge to the unconfined aquifers is predominantly limited to the period March to August annually. Monthly recharge is calculated for the numerical model by subtracting potential evapotranspiration from rainfall on a monthly basis.

Average high air temperatures for the area range from over 20˚C during the summer months (December to March) down to below 0˚C during the winter months (June to August). The Gisborne district is one of New Zealand's sunniest regions with western areas receiving between 1,800 and 2,100 hours of bright sunshine per year. The prevailing winds for the Poverty Bay Flats are from the west, where various mountain ranges provide some protection against more severe wind and weather events.

Gisborne is the major municipal centre of the region with a population of approximately 47,517 in 2018. The Poverty Bay Flats is a nationally recognised horticultural area covering approximately 18,500 hectares (ha) of highly productive soils suitable for arable farming, market gardening, horticulture, and viticulture. Irrigation for horticultural purposes is one of the main uses of water across the Poverty Bay Flats with a substantial proportion of the water used for irrigation being derived from groundwater. Within the entire Tairawhiti region resource consents have been granted authorising surface and groundwater takes enabling the irrigation of 7,120 ha, 96% of which is on the Poverty Bay Flats.

Water use in the Poverty Bay Flats is sourced from both from both surface and groundwater sources with a reported 85% of all groundwater takes for the Gisborne District located in this area. Relative to groundwater use, currently there is nearly 4 million m^3/year of consented allocation between the five aquifers which are the Makauri (48%), the Te Hapara Sands (23%), the Shallow Fluviatile (16%), the Waipaoa Gravels (11%) and the Matokitoki (2%) aquifers. GDC's operative 2018 Resource Management Plan[3] outlined a "paper-based" reduction in the allocation to horticulturists from the Makauri Aquifer has been implemented by GDC. The first stage was to reduce the groundwater allocation from approximately 8,000,000 m^3/year to approximately 1,800,000 m^3/year which is currently consented. A further reduction is planned to occur in 2023, with the allocation limit being set at 1,700,000 m^3/year.

A Managed Aquifer Recharge (MAR) trial targeting the Makauri Aquifer has been operating at Kaiaponi since 2017 and represents New Zealand's first Aquifer Storage Transfer Recovery (ASTR) bore. Outcomes from the trial to date indicate MAR can be a viable tool to help slow and reverse the declining groundwater level trends in the Makauri Aquifer. Further discussions with the community on the application of groundwater replenishment techniques are ongoing. Use of these techniques is being considered as one of the groundwater management options in this modelling programme.

Hydrogeologically, from the ground surface through to the basement bedrock, there are 10 unique units of aquifers and aquitards which form the Poverty Bay Flats groundwater system. The aquifers tend to be composed of riverine deposited alluvium while the aquitards tend to be formed from geologic sources of silts and mudstones or from marine sediments or swamp deposits. There are five main aquifers which underlie the Poverty Bay Flats (from shallower to deeper): Te Hapara Sand, Shallow Fluviatile, Waipaoa, Makauri and Matokitoki Aquifers. None of the aquifers are continuous across the full extent of the Poverty Bay Flats. The aquifers range in confinement from shallow unconfined aquifers to the deeper semi to fully confined aquifers. The spatial distribution of the three deeper and more productive aquifers are shown in Figure 4. The extent to which the Makauri Aquifer extends offshore is somewhat speculative, although it is supported by an understanding of sea levels at the time of deposition and the current gradient of the aquifer beneath the Poverty Bay Flats (WGA 2022a).

The largest groundwater abstraction by volume is from the Makauri Aquifer, with approximately 900,000 m^3 being abstracted during a typical irrigation season. Previous studies and reviews of groundwater levels in the Poverty Bay Flats aquifers have identified declining groundwater pressure trends (e.g., Moreau et al 2020). These trends are linked to increasing groundwater abstraction for irrigation purposes. Continuation or exacerbation of these trends has been identified by the GDC as presenting environmental, economic, cultural, and social risks linked to water flow and supply reliability issues. GDC considers most of the aquifers to be either fully allocated or over-allocated and no new resource consents for groundwater abstraction currently being issued.

[3] https://www.gdc.govt.nz/council/tairawhiti-plan/tairawhiti-plan#heading-1

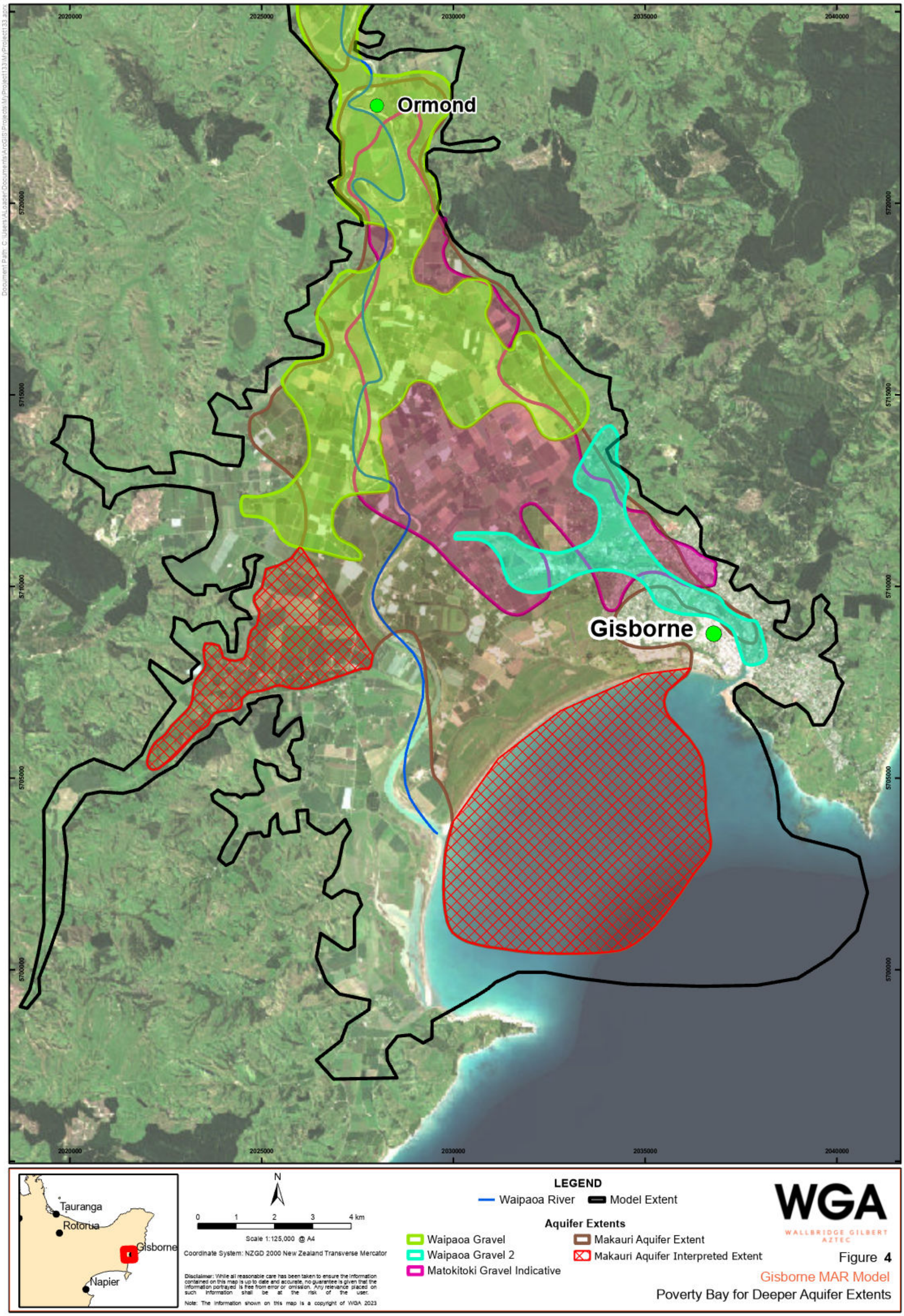


Figure 4

Gisborne MAR Model

Poverty Bay for Deeper Aquifer Extents

Groundwater quality for the Poverty Bay Flats is highly variable between the various aquifers and in relation to their proximity to the ocean. The shallow, unconfined aquifer is susceptible to land use activities and contamination sources in the form of nutrients for agriculture fertilisers and faecal bacteria from livestock. The interaction with the rivers also means that these shallow systems are higher in oxygen levels and nearer the coast, increased levels of salts from windblown ocean spray as well as the tidal fluctuations.

The deeper, confined aquifers are more disconnected from these surface activities. The confinement means that natural recharge from the surface water bodies takes longer, and the qroundwater quality changes with increased residence time. Oxygen depletion results in higher levels of dissolved metals such as iron and manganese in the deeper aquifers, which makes the water less potable for drinking water and has resulted in some ongoing issues for irrigation systems.

The interpreted western section of the Makauri Aquifer is characterised by elevated groundwater salinity, with few bores having been drilled there over the past few decades. The reasons for this inland saline condition are yet to be determined. However, it is hypothesised that paleo marine sediments deposited in this area when the ocean levels were higher may be a continued source of salts. Concerns raised during the groundwater modelling process include the threats of saline water intrusion to the shallow aquifer from climate change (e.g., rising sea levels) and saline intrusion issues caused by continued declines in groundwater pressures from over pumping.

1.3 TECHNICAL SUPPORTING INFORMATION

The Poverty Bay Flats Groundwater Modelling programme has resourced information from a wide range of GDC databases, reports, and journal articles. A comprehensive list of these formal references can be found in the References Section 7. In addition to this document, the following reports directly support the modelling programme:

- Poverty Bay Flats Geological and Conceptual Hydrogeological Models (WGA, 2022a)
- Poverty Bay Flats Conceptual Groundwater Quality Model – Salinity (WGA, 2022b)
- Groundwater Modelling of the Poverty Bay Flats – Turanganui a Kiwa (Gisborne): 3D FEFLOW Groundwater Model (AQUASOIL, 2022)

This report is intended to provide a high-level overview of the technical information and biophysical settings in which this modelling programme was developed. It also provides an overview of the community engagement process and the exploratory scenario modelling results. At the conclusion of this programme, GDC has a fully developed FEFLOW numerical groundwater model for the Poverty Bay Flats which is intended for use in future science and regional planning processes.

2 MODELLING PROCESS

2.1 INTRODUCTION

The primary objective of the Poverty Bay Flats modelling programme was to develop a fit-for-purpose numerical model to improve GDC's scientific understanding of the groundwater system as well as inform the regional management planning processes. The programme has delivered a calibrated numerical model which has been used to evaluate a series of exploratory groundwater management scenarios. These scenarios were used to test the capabilities of the model as well as provide indicative information on some of the major water management issues facing the system.

Two numerical models were developed during this process: a 3-D geological model (Geomodeller) which formed the structural foundation for the FEFLOW groundwater model. The FEFLOW model provides computational assessment of both groundwater quantity and quality parameters. A series of comprehensive reports documented specifics of the construction of these models, with references to these documents provided in Section 7. This section of the report summarises the key features and design criteria for these models as an introduction to the use of the model in the Exploratory Scenario results and discussion found in Section 4.

2.2 MODELLING OBJECTIVES

The objectives of this programme were primarily to develop a functioning set of geologic and numerical groundwater models to service GDC's future needs. Specific to this modelling and community engagement programme, the key objectives that the team worked toward were:

- Develop a robust numerical model as a tool to better understand the Poverty Bay Flats aquifer system's groundwater quantity and quality characteristics.
- Enable the model to be fit-for-purpose for future Tūranganui-a-Kiwa regional planning to support regulatory decision making.
- Develop an engagement process where the model and understanding of the Poverty Bay Flats is developed through a co-design philosophy partnership, with Mana Whenua (treaty partners) providing insights from their local knowledge as well as learnings into the technical model build process.
- Develop a wider community consultation process to help inform and educate area stakeholders on the hydrogeology of the Poverty Bay Flats groundwater system and the computational capabilities of this newly developed numerical tool.
- Develop the model structure to enable the modelling of a series of Exploratory Scenarios designed to ask specific questions from Mana Whenua and the wider Gisborne community about this groundwater system.

- Develop the capability to provide 3D visualisation of this complex Poverty Bay Aquifer system for both a better science understanding as well as sharing with the community.

The following sections provide an overview of conceptual and numerical models relative to their development steps. It also provides a summary of the completed models that have been used to investigate the Exploratory Scenarios discussed in this report.

2.3 CONCEPTUAL GEOLOGICAL MODEL DEVELOPMENT

The initial step in the development of any numerical groundwater model is to develop a conceptualisation of how the overall hydrogeologic system is laid out and how it functions. Draft concept models of the geology and hydrogeology were set up based on a review of the available physical data and various geology reports about this area. As the numerical modelling process progressed, these conceptual models were revised and adapted based on our improved understanding of the system. The final hydrogeological conceptual model was different from the one with which the process started.

The Poverty Bay Flats geology can be conceptually represented as a triangular 3-dimensional sedimentary prism, expanding from north (narrow top) to south (wide bottom), of thick silt and clay deposits alternating with substantially thinner gravel and sand deposits (WGA, 2022A). This prism is underlain by Tertiary (> 2.6 million years) aged bedrock (Figure 5). This depositional prism is bounded laterally to the east and west by Tertiary and Quaternary (< 2.6 million years old) siltstones and sandstones. The sedimentary prism has its greatest thickness at the coastline marking the southern end of the flats.

The internal area of the prism consists of Quaternary aged sediments deposited through geologic time by the rivers and streams that flow into Poverty Bay Flats. The youngest deposits, representing the coastal Te Hapara Sands and the Waipaoa River’s Shallow Fluviatile Gravels, are shallow and close to the surface. At the north end of the prism, where the Waipaoa River system enters the Flats, these gravel beds merge. As we move deeper in this prism, older buried river deposits of gravels and sandy gravels make up the Waipaoa, Makauri and Matokitoki gravel beds. The gravel beds generally increase in depth from north to south across this prism and as they deepen, they become increasing separated by thickening silt deposits. The silt deposits act as barriers (aquitards) which were thought to have formed as overbank riverine, swamp, and estuary deposits. Nearest the coast, the shallower Te Hapara Sand and the deeper Makauri gravel deposits both appear to extend offshore.

A branch of the Matokitoki Gravel deposit, which appears to represent an ancient, buried river channel, extends underneath Gisborne. This branch becomes shallower toward the southeast and is likely to consist of sediments derived from the Waimata River catchment. An interpreted branch of the Makauri Gravel, which extends westward under the Te Arai River terrace, is similarly thought to consists of sediments derived from the Te Arai River catchment (Figure 5).

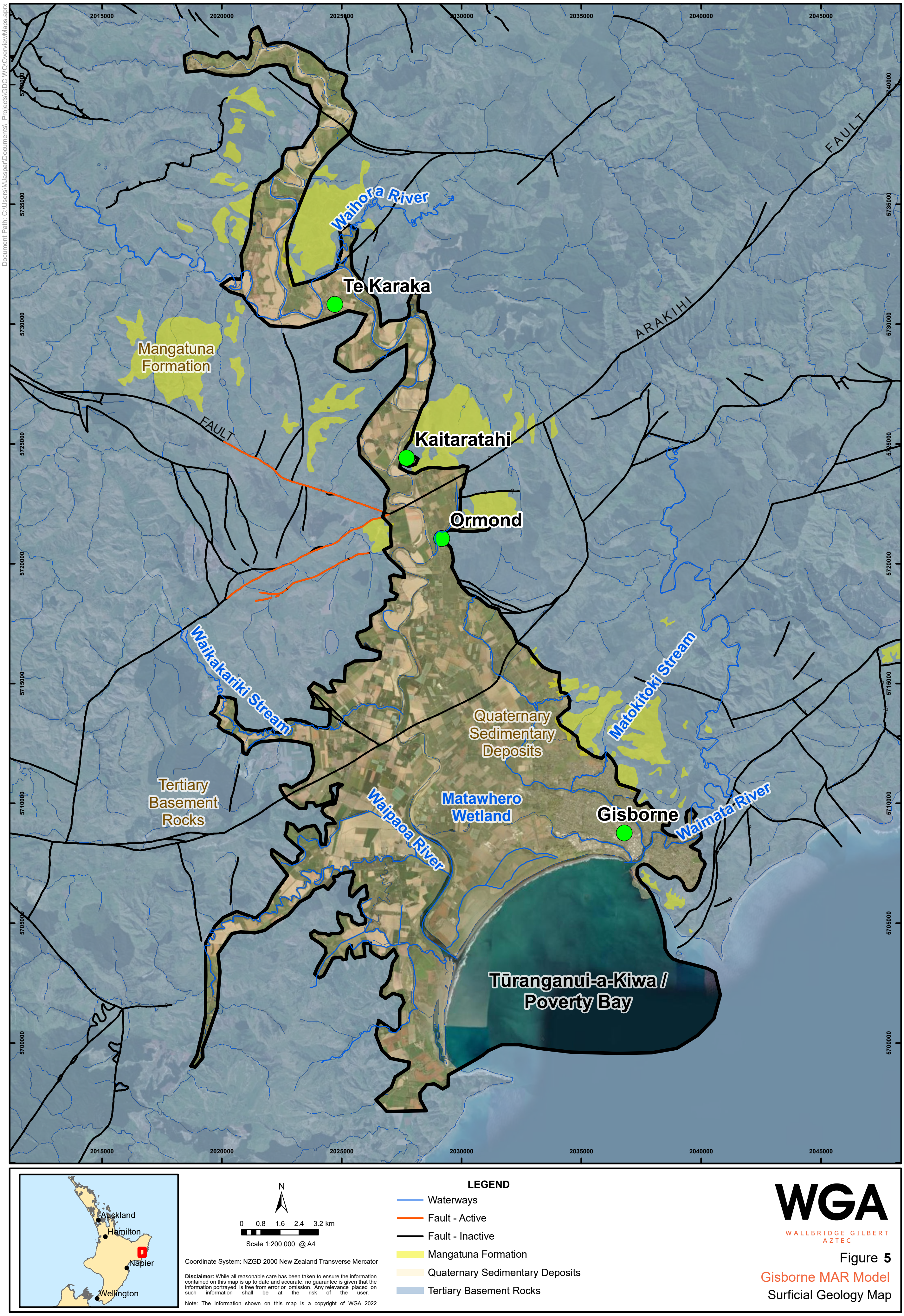


Figure 5
Gisborne MAR Model
Surficial Geology Map

2.4 NUMERICAL GEOLOGICAL MODEL

Based on the geologic data available and this geologic conceptualisation, a geologic model of the Poverty Bay Flats was built using the GeoModeller software package. A detailed technical summary of this process is presented in the conceptual hydrogeology report by WGA (2022a).

Generally, the geological model was developed through creating a grid of cross sections between a series of exiting well's drillholes. The available lithological information was correlated between drillholes, and sedimentary layers defined. Once the cross sections were completed, the layers were connected between the cross sections to create the 3D geologic model. This was an iterative process, with numerous reinterpretations of the sedimentary layers. The completed numerical geologic model was provided to GDC in February 2022. The geological modelling report (WGA 2022A) provides maps and visualisations of geological model layers, which can be used by GDC in future scientific projects. Figure 6 provides an example of the 3-D visualisation capability of the model as presented to Mana Whenua during one the model training sessions in September 2021. Figure 7 provides an example of a north-south cross-section across the Poverty Bay Flats showing the interpreted geological deposits (WGA 2022A).

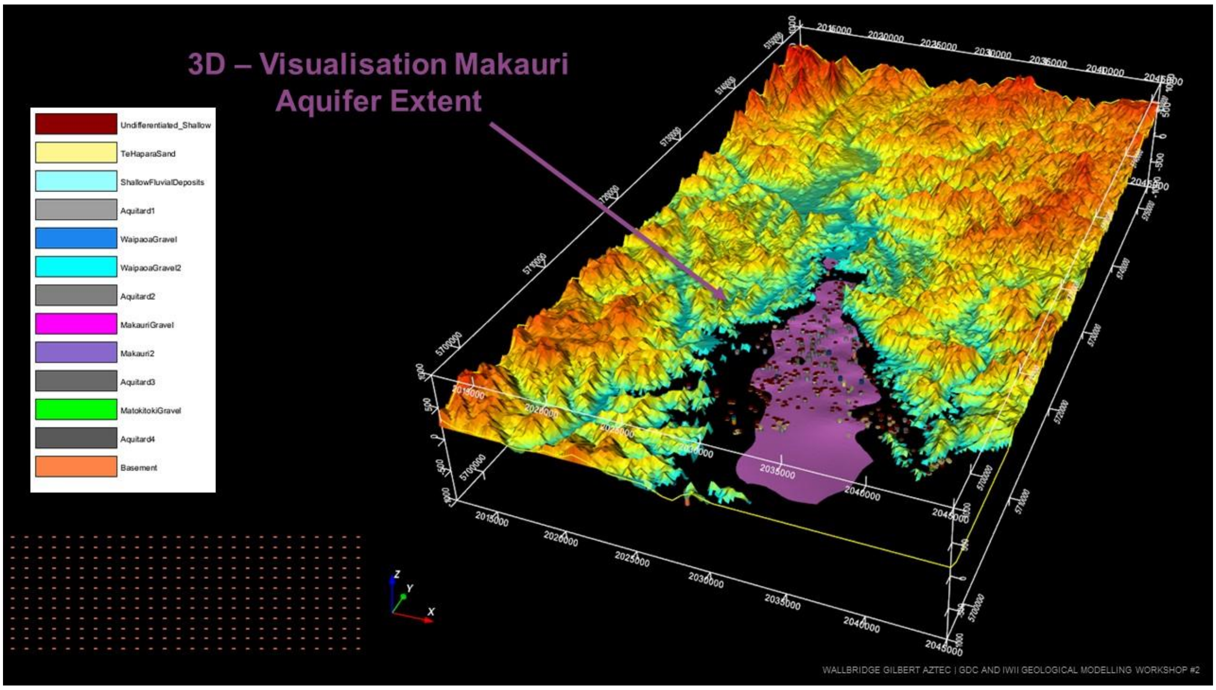


Figure 6: Example of 3D Visualisation using Poverty Bay Flats Geological Model – GDC – Mana Whenua Training Workshop (7/0/2021)

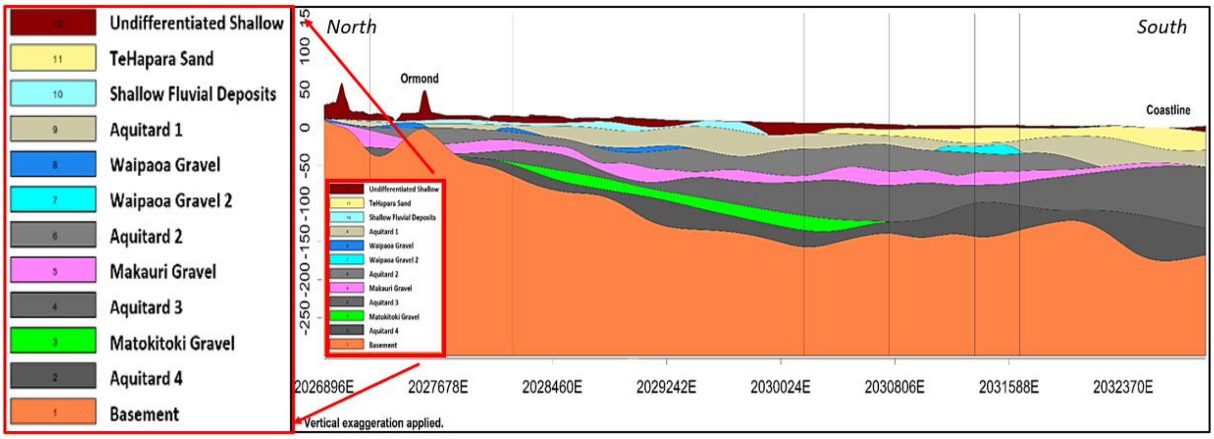


Figure 7: Example of North – South Geologic Cross Section of Poverty Bay Flats (WGA 2022a)

2.5 CONCEPTUAL HYDROGEOLOGIC QUANTITY AND QUALITY MODEL

With the completion of the geologic model framework, the next step in the process was the development of the hydrogeologic numerical model in the FEFLOW modelling software package. A detailed summary of that model development process can be found in the WGA (2022A, 2022B) and in AquaSoil (2022) reports.

The hydrogeological conceptualisation of the groundwater system underlying the Poverty Bay Flats utilised the geologic framework and essentially ‘added water’ to the conceptualisation process. Large amounts of GDC groundwater monitoring data and hydraulic tests performed Poverty Bay Flats bores helped build a picture of how water behaves in this system.

Natural recharge is driven by rainfall and river loss recharge, groundwater flows through this system are primarily through the shallower fluviatile gravel and sand aquifers. The shallowest aquifers extend northward from the Poverty Bay Flats as components of the valley fill alluvium within the Waipaoa River valley. As groundwater moves southward into the deeper parts of the system, spatially extensive thick silt beds act to hydraulically separate the aquifers, acting as efficient aquitards limiting the vertical leakage and natural recharge processes.

The shallowest of the aquifers are the Shallow Fluviatile Gravel and the Te Hapara Sands, which are generally unconfined[4] but can be locally confined[5] by surficial silt deposits. Both shallow aquifers are generally highly connected with the rivers, streams, and wetlands of the Poverty Bay Flats. Based on our conceptualisation, toward the coast, these same aquifers tend to discharge baseflows to the Waipaoa River and other surface water bodies such as wetlands and artificial drains. Along the coastline the Te Hapara Sand Aquifer also discharges freshwater directly to the ocean and receives saline water inflows from the ocean.

The deeper river gravel deposits constitute the Waipaoa, Makauri and Matokitoki Aquifers. These aquifers are predominantly confined and hydraulically separated from each other, although they merge at the northern end of the Poverty Bay Flats. There is also evidence that southeastern branches of these aquifers are hydraulically connected under Gisborne City. These aquifers are not known to directly interact with surface waterbodies except at their northern end where the Waipaoa River enters the Flats. Recharge to these aquifers occurs at this northern end from incipient rainfall and losses from the Waipaoa River. There is evidence to indicate some focused recharge to the confined aquifers may be occurring along the eastern edge of the Poverty Bay Flats and to the southeast of Gisborne. However, the exact mechanism, locations, pathways and potential rates for this recharge are unknown. Consequently, focused recharge in these areas has not been incorporated in the numerical FEFLOW model.

Groundwater flows through each of these confined aquifers tend to follow elevation gradients from north to the south. The notable exceptions to this are the southeastern branches of the Matokitoki, Makauri and Waipaoa Aquifers, which appear to contain groundwater flowing toward the northwest away from the eastern hills near Gisborne. Flow rates through the aquifers vary depending on the aquifer’s degree of confinement and depth. Groundwater in the shallower confined aquifers tends to move faster than the deeper aquifers, which is reflected in the groundwater quality and age information used to support the model conceptualisation. However, ‘fast’ is a relative term in groundwater movement and should be noted as being much slower than flows visually apparent in surface water bodies such as rivers and streams.

[4] Water table open to the infiltration of water from the surface including rainfall and river losses.

[5] Surficial silt beds may locally partially isolate the shallow aquifers from direct rainfall recharge and hydraulically separate the aquifer from overlying shallow drains.

Groundwater quality conditions in the various aquifers of this system are highly dependent on their location, confinement, and depth. The shallow unconfined aquifers have a stronger connection with surface land use activities, tend to have higher levels of nutrients from farming and enteric bacteria from animal sources are more often detected in groundwater samples. The deeper confined aquifers tend to demonstrate reducing redox or low oxygen conditions. Groundwater in these deeper aquifers tends to contain higher concentrations of dissolved metals such as iron.

Salinity was selected as a focus point for this numerical modelling process based mainly on the prevalence in the Poverty Bay Flats as well as concerns over increasing coastal saline intrusion related to the effects of changing climate. Salinity measured as chloride is another feature of this coastal groundwater system and can be found distributed throughout all the aquifers. Additionally, the reducing conditions and the presence of organic material in the silt aquitards has led to high dissolved gas loads including methane in the deeper groundwater.

Salinity in the Poverty Bay Flats groundwater system is conceptualised to be from several potential sources and processes. In the deeper parts of the system, fine-grained sediments deposited under marine conditions likely contain elevated salt levels representing relic sea water from the deposition process. These marine sediments constitute the various aquitards that separate the deeper aquifers (Waipaoa, Makauri and Matokitoki). The limited seepage flows through the thicker aquitards means salts may be retained in the geologic matrix for very long periods of time.

The western section of the Makauri Aquifer is characterised by high chloride concentrations. This has resulted in few water bores being installed in this area. The geological, hydraulic and groundwater quality information from this area is limited. Although the salt in the groundwater of this area may be a relic of the depositional period, insufficient information is available to be confident in this interpretation.

The shallower parts of the groundwater system, which are highly connected to the freshwater recharge from rivers and rainfall, have low concentrations of chloride. In the Te Hapara Sand and Shallow Fluviatile aquifers, groundwater salt concentrations are likely influenced by other processes. Rainfall recharge closer to the coast is interpreted to be influenced by onshore winds carrying chloride in ocean spray. Shallow groundwater chloride conditions along the coast indicate that this effect decreases with increasing distance from the coast.

The coastline presents as a sharp saline water intrusion interface within the Te Hapara Sand Aquifer. Sea water is seeping through the coastal sands toward the drained low-lying Awapuni Moana area, which was historically an estuary. Relic salts may still be present in the fine-grained estuary deposits. The lack of coastal monitoring wells limits understanding of potential saline intrusion effects to the deeper Makauri aquifer, which is thought to extend some distance offshore. However, any future drawdown of groundwater pressures in the coastal Makauri Aquifer below sea level would clearly represent a risk of saline water intrusion to this aquifer.

2.6 NUMERICAL GROUNDWATER MODEL

The numerical groundwater flow model was developed through a comprehensive process outlined in detail in the AQUASOIL (2022) report. This process started with the construction of FEFLOW model mesh both horizontally and vertically forming the foundation of the computational structure. Several iterations of the mesh were tested and revised as a combination of model results, new information and new requirements placed on the model helped to guide improvements as the project progressed. A total of 10 primary hydrogeological layers were constructed into the model based on the numerical geological model, with 6 aquifer units and 4 aquitards. Figure 8 shows the Makauri Aquifer as it is represented in the FEFLOW numerical model. Figure 9 provides a 2D cross section of how all the hydrogeologic units are situated inside the FEFLOW model.

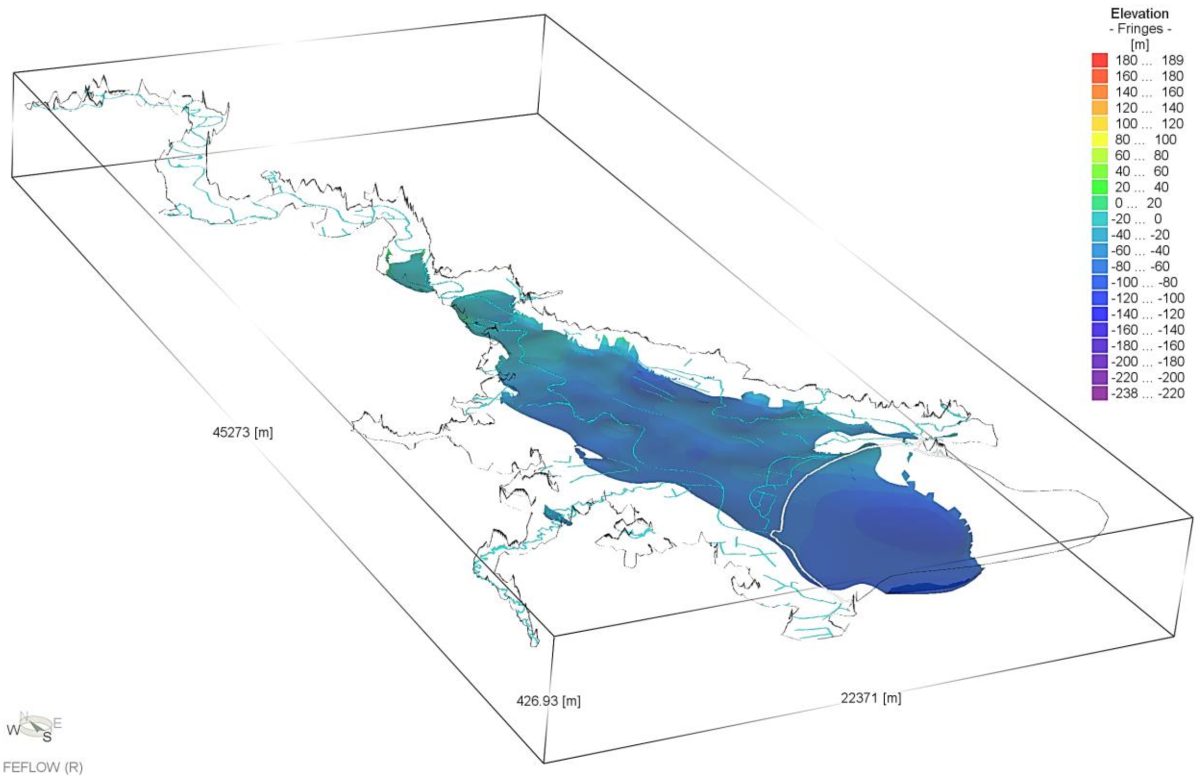


Figure 8: 3D View of Makauri Aquifer in FEFLOW Model (AQUASOIL, 2022)

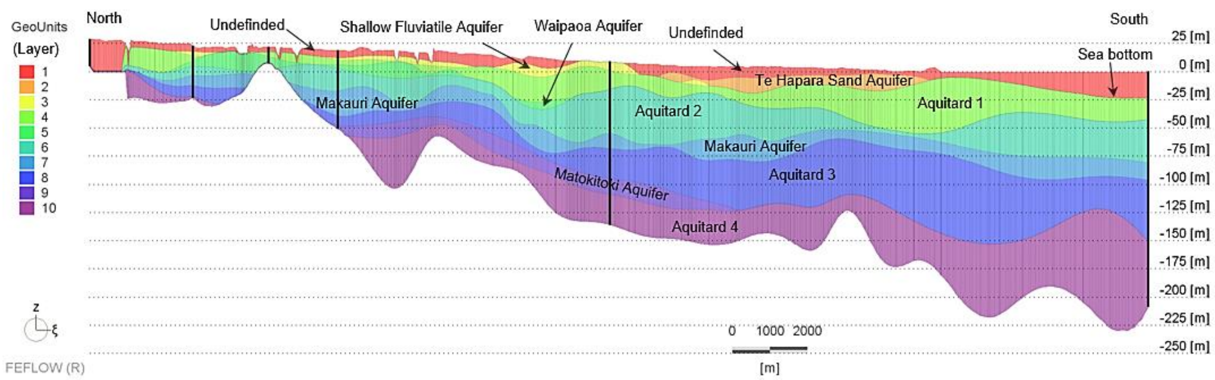


Figure 9: Vertical 2D Cross Section of Poverty Bay Flats FEFLOW Model showing various Hydrogeologic layers: North – South (AQUASOIL, 2022)

Following the construction of the model mesh, the hydraulic properties and boundary conditions of all the model were defined based on a combination of available data as well as according to the conceptual hydrogeological model (WGA 2022a). Key elements to this process included incorporating spatially distributed rainfall-recharge into the model based in land use types and measured seasonal climate information. All known monitoring bores were also incorporated into the model in order to be able to extract and compare results during the calibration/validate as well as the scenario generation process.

The next phase of the model was to calibrate, validate and verify the 3D model. This started with a steady calibration with used simulations and sensitivity analysis to establish the calibration. A transient calibration of the model followed that included simulations and comparison with time-series surface and groundwater data, groundwater age (residence times) and electrical conductivity simulations through mass-transport verification. The calibration and validation process for both the steady state and the transient state models was successful.

At this time, the community workshop establishing the Exploratory Scenarios was completed, and the modelling team developed the first Round of scenarios for FEFLOW simulation testing. During this community process, it was determined that groundwater quality (salinity) would be incorporated into the FEFLOW model. The main purpose of the salinity scenario to discern the possible transport processes or/and behaviour of salinity characterised by chloride concentrations in the Poverty Bay Flats groundwater system based on the assumptions of the conceptual groundwater quality model (WGA 2022B). Similar to the quantity model, the salinity transport simulation needed to be parameterised and tested through simulations until it was ready for scenario modelling. It required two rounds of conceptualisation and model changes in order to get this function in the model working to represent the likely salinity changes in our Exploratory Scenarios. The groundwater quality conceptualisation and numerical quality modelling is described in detail in both the WGA (2022B) and the in AQUASOIL (2022) reports.

At the conclusion of the numerical groundwater quantity and quality model build process, the WGA, GDC and AQUASOIL team deemed the model to be fit-for-purpose for incorporation into the predictive Exploratory Scenario simulations to evaluate potential future groundwater quantity and quality trends. The remaining sections of this report present a summary of the Exploratory Scenario results from the FEFLOW numerical model and a discussion of their results relative to potential use for future groundwater management planning efforts.

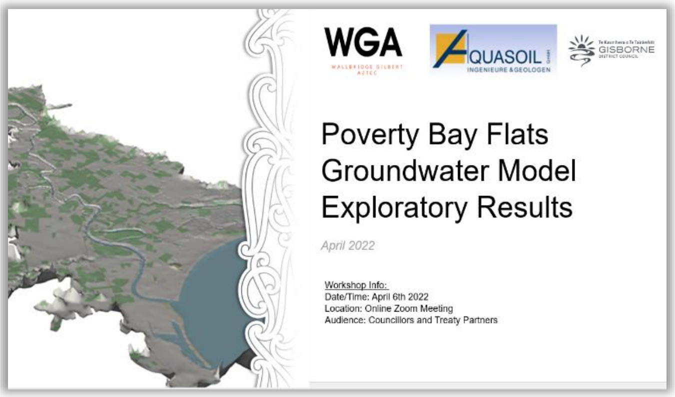
3 COMMUNITY ENGAGEMENT AND EXPLORATORY SCENARIOS

3.1 OVERVIEW

GDC developed an interactive engagement process in order to proactively involve the GDC Councillors, Mana Whenua, and the wider community in the groundwater modelling process. This was conducted in two forums, the first being twelve **GDC staff - Mana Whenua Model Trainings** (hui) which were hosted online over the course of the model development process (Figure 1). During each training session details of the environmental data being used and the way in which this information was being incorporated into the groundwater model were shared and discussed with GDC staff and Mana Whenua. During this process, Mana Whenua shared culturally and environmentally relevant insights on various waterbodies and landmarks of the Poverty Bay Flats. This information had a direct influence on the model's development, as well as the establishment of a series of qualitative cultural and environmental indicators for modelling scenario process. These GDC – Mana Whenua Trainings are discussed in detail in **Section 3.2**.

The other primary engagement process that GDC established for this project, was a series of **modelling workshops** to educate and inform the wider community on the Poverty Bay Flats groundwater system, the development of numerical model, and its capabilities. The first set of separate workshops was held in October 2021 with GDC Councilors, Mana Whenua – Treaty Partner representatives, and the wider Gisborne stakeholder community. During these workshops, a set of community questions were developed about the Poverty Bay Flats groundwater system. The questions were centered around the current and potential future management of this groundwater system as it related to climate change and human usage. These questions were used to form the basis for the numerical modelling predictive scenarios. These Exploratory Scenarios were used to compare the various single management change future states of this aquifers system. The results from these workshops are discussed further in **Section 3.3**.

After the Exploratory Scenarios were processed through the Poverty Bay Flats numerical model, a second set of workshops were held in April 2022 (see inset cover slide) to share the results of these Exploratory Scenarios. The two separate workshops were firstly a combined workshop for GDC councilors and Mana Whenua, and a second workshop for the wider Gisborne community. The results from these workshops are discussed further in **Section 3.4.**



3.2 GDC – MANA WHENUA TRAINING (HUI)

GDC commissioned WGA and AQUASOIL to build a numerical model but requested that GDC staff be upskilled on the modelling as the model was built. As the programme progressed, GDC also invited Mana Whenua to the training sessions. This was both to help inform the Treaty Partners Representatives on the groundwater model's inner workings as well as share the learnings that the model provides about how the Poverty Bay Flats groundwater system behaves scientifically. In turn, the technical modelling staff were able to learn from Mana Whenua about natural and cultural history of the area and incorporate some of this knowledge into a refined modelling process. In total there were twelve trainings that took place from May 2021 to June 2022 as summarised in Table 2.

As a means to attempt to try and capture the concept of 'cultural indicators' in the modelling process, a series of qualitative indicators were also developed for key water features. Whilst the cultural values of the Poverty Bay Flats are understood to be much more than simply groundwater levels and quality measures, the training – hui format provided a unique opportunity to combine scientific and cultural knowledge sources into a more representative modelling process. It is understood that this represents only a start of the partnership between GDC and Mana Whenua which is the focus on the co-governance and management model being pursued in the region.

3.3 COMMUNITY WORKSHOPS – INTRODUCTORY AND COMMUNITY QUESTIONS

3.3.1 Introduction

Three separate workshops were held in the GDC offices in late October 2021. The workshop focused on introducing the conceptual understandings of the Poverty Bay Flats groundwater system as well as how the numerical model was being constructed and used for water management decision making. The workshops also worked on gathering specific questions from the stakeholders that could then be addressed either with existing information or through running scenarios in the numerical groundwater model.

3.3.2 Predictive Scenario Development

During the workshops, the modelling team provided an overview of the process by which the model was being developed and the use of firstly Exploratory Scenarios and then subsequently Solutions Scenarios to help inform water management decision making (Figure 10). Whilst the Exploratory Scenarios are designed to ask specific standalone questions such as '*what happens if all the wells get turned off?*', the Solutions Scenarios would be used to combine various management options into a final suite of solutions which work to better manage the resource. This is an approach that is used in various regions throughout New Zealand when working to develop water management plans that include community consultation as part of the process. Environment Canterbury used a similar approach to numerical modelling and scenario development in its sub-regional Canterbury Water Management Strategy process (Bower, 2014).

Table 2: Community Engagement, Internal Workshops and Trainings

INTERNAL/ COMMUNITY WORKSHOPS AND TRAININGS (hui)	DATE(s)
Internal Workshop #1: Project start-up. Geologic modelling update, and data compilation summary. Attend scoping, trainings, workshops. Provide overview of GeoModeller (geological) / FEFLOW (groundwater) models.	26/05/2021
Training #1. Geological model draft structure, data input, cross sections and interpretation discussion.	15/6/2021
Training #2. Geological unit interpolation and interpretation process. Interpretation discussion.	7/7/2021
Training #3. Additional training for discussion on the geologic model as requested by GDC staff.	20/7/2021
Internal Workshop #2: Draft geological model handover with documentation, GDC peer review and discussions	13/08/2021 Workshop
Training #4. FEFLOW model mesh generation of Poverty Bay Flats area.	15/09/2021
Training #5.1. FEFLOW Models build and hydrogeological conceptualisation. Also work through review on the draft geological model in Geomodeller.	22/09/2021
Training #5.2. FEFLOW model parameterisation and set up.	06/10/2021
Training #6. FEFLOW Model Run training – using FEFLOW to run various management scenarios.	13/10/2021
Training #7. FEFLOW model calibration and validation results and discussion	10/11/2021
Community Workshop #1: Introduction of Geomodeller and FEFLOW Models, introduction on modelling scenarios, generation of community groundwater questions.	26 & 27 October 2021 at GDC
Internal Workshop #3: on initial FEFLOW numerical model calibration and validation outcomes. Changes required to facilitate climate change and community questions into scenarios.	24/11/2021
Training #8. FEFLOW - Allocation rate and effects and revised model update on calibration.	8/12/2021
Training #9. FEFLOW Results - Community exploratory scenarios generation in FEFLOW	2/3/2022
Training #10. FEFLOW - Incorporating water quality into model based on 1st conceptualisation of salinity and scenarios.	23/3/2022
Community Workshop #2: summary on FEFLOW model exploratory water quantity/quality scenario outcomes (1st Round Scenarios), draft report, and appendices for external review.	5, 6 and 7/4/2022 at GDC
Training #11. FEFLOW Scenarios: 2nd Round of Water Quantity and Quality Modelling Results from FEFLOW. Final combined training with Mana Whenua, and modelling training completion.	29/6/2022

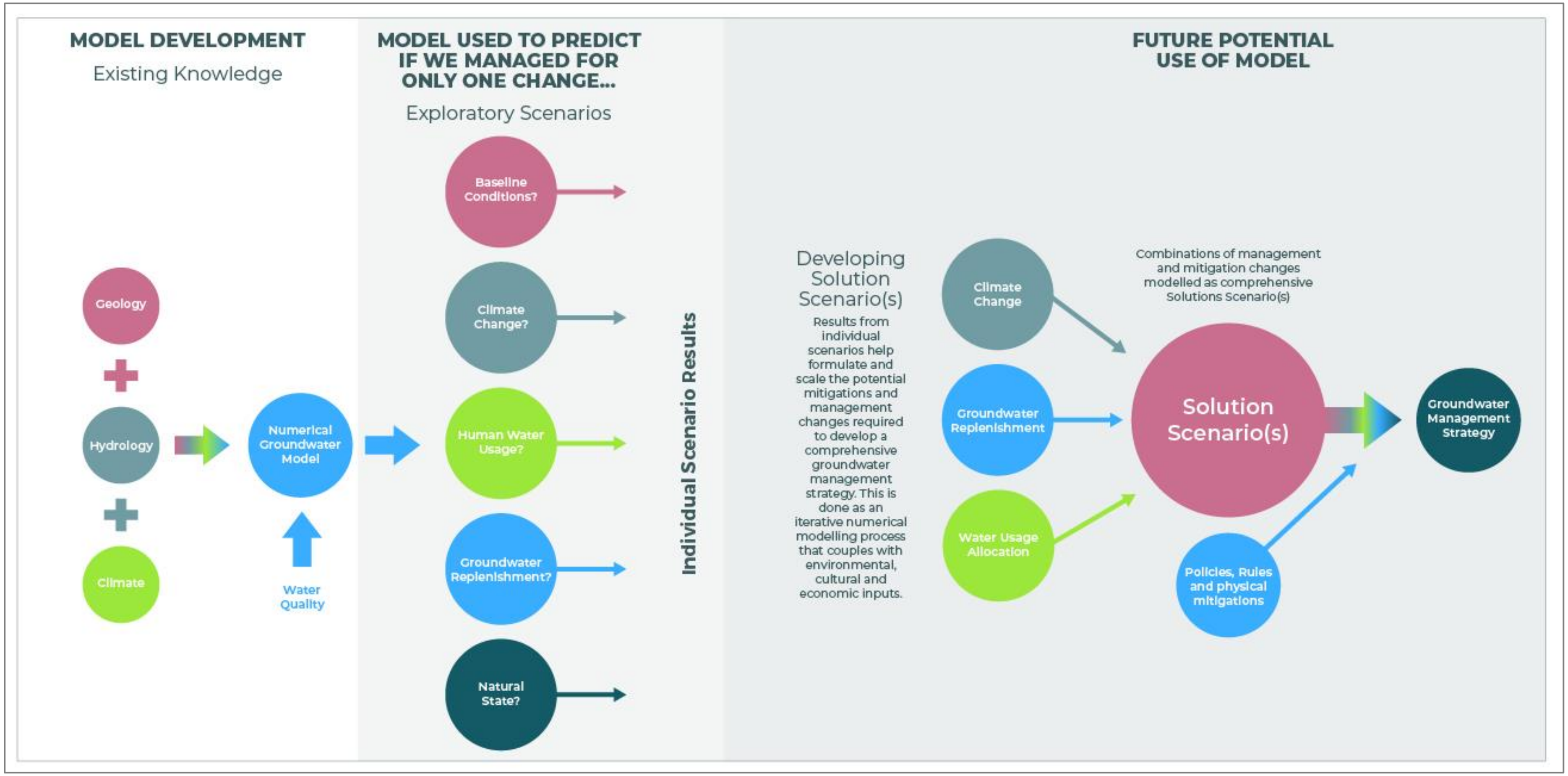


Figure 10: Poverty Bay Modelling Programme – Model and Scenario Development Steps

The general approach to using a model to develop water management plan is outlined in the following steps.

- From the basis of a fully functional numerical model with scenario capability, a set of Exploratory Scenarios based on community input are developed. The community engagement process helps to socialise the model, its capabilities and what it tells us about the behaviour of groundwater flow and quality. The community questions about the current state of the groundwater system and the various management options are compiled into numerical changes to the model inputs to best reflect changes to the physical environment and water management.

- The results from the round of Exploratory Scenarios helps to frame the overall groundwater management context and often used as ‘bookend’ type scenarios to define the boundaries of possibility for water management decisions. The results also inform the measurable changes to the groundwater system which are then used as part of an iterative process to refine and improve the scenarios as they are formulated for use in the model.

- Based on the learnings from the Exploratory Scenario process the development of potential changes in water management policies and the enabling of various physical mitigations, a combined suite of changes are developed into a round of Solution Scenario modelling. Consistent with the community engagement during the Exploratory Scenario process, an iterative process to fine tune the scaling and timing of the various mitigations are combined with other key factors like environmental, cultural, and economic values to work toward a final Solutions Scenario package. This final Solution Scenario forms the basis of a groundwater resource management plan leading into the regional planning process.

It is important to note that the Poverty Bay Flats groundwater modelling programme has completed the Exploratory Scenario stage of this process. Upon completion of this project, GDC will determine how best to proceed with the use of the numerical groundwater model platform and scenario results to develop regional water management goals.

3.3.3 Community Questions

GDC led the workshops to facilitate discussions predicated on having stakeholders scope their specific big picture questions about the Poverty Bay Flats groundwater system from a current, historical, or future state perspective. The questions were then consolidated into key themes from all three workshop groups and compiled in the questions presented in Table 3. It is important to note that there were great number of questions raised at the workshops that were not directly relevant to kinds of scenarios that could be generated using a regional groundwater model. Examples of these questions included changes in specific reach of rivers or specific spring flows, and questions on specific bores which were of interest to participants. Whilst these are all valid resource management questions, the ability to model some of these localised effects is beyond the design of the regional scale groundwater numerical model. The description of the modelling methodology used to represent the key questions shown in Table 3 is discussed in Section 3.5.

It is also important to note that there was a total of two rounds of Exploratory Scenarios generated for this final report (Table 3). The first round included a number of climate change scenarios (modelled separately) which were then combined and incorporated into the final climate modelling used. Water Quality in the form of salinity was also incorporated into the modelling capability along with the ability to provide qualitative results for the cultural indicators identified in the discussions with Mana Whenua. The 2nd round of Exploratory Scenarios represent the final outcomes of the scenario modelling process and what are presented in this report. Only one scenario scoped in the first round was not continued in the 2nd round (scenario 6.0) which had higher replenishment recharge volume.

The compiled final list of questions was transformed into specific changes to the numerical groundwater model and used to generate scenario results. As noted in Figure 10, each of the scenarios were "single issue" or 'book end' scenarios which provided a general sense of the boundaries of possibly for future management options. These Exploratory Scenarios were not considered in context to cultural, environmental, social and/or economic values but rather as numerical model possibilities.

Table 3: Community Groundwater Questions Leading to Exploratory Scenarios (1st and 2nd Rounds)

COMMUNITY QUESTIONS	1st Round SCENARIOS: NAME AND NUMBER	2nd Round SCENARIOS: NAME AND NUMBER	MODELLING ASSUMPTIONS -REPORT SECTION
What is the current status of the different aquifers? **Is there a decline in the aquifers?**	Baseline only (1.0)	Baseline only (1.1)	Section 3.6.1
What effect would extreme dry weather have?	Baseline + Climate Change (2.0)	Baseline + Climate Change (2.1)	Section 3.6.2
What effects would occur if Te Mana O Te Wai was placed above commercial groundwater use?	Natural State (3.0)	Natural State (3.1)	Section 3.6.3
Would there be a change in wetland and spring persistence?			
Would there be a change in groundwater salinity?			
What happens if current paper allocations are used to full entitlement?	2021 Current Paper Allocation (4.0)	2021 Current Paper Allocation (4.1)	Section 3.6.4
What effect would replenishment have on groundwater levels?	Groundwater Replenishment (MAR) – +600,000 m^3 recharge (5.0)	Groundwater Replenishment (MAR) - +600,000 m^3 up to +780,000 m^3 (5.1)	Section 3.6.5
	Groundwater Replenishment (MAR) – +1.2 Million m^3 recharge (6.0)	*Not modelled in 2nd round*	
What is a 'sustainable allocation rate'?	Sustainable Allocation (7.0)	Sustainable Allocation (7.1)	Section 3.6.6
Can we understand aquifer recovery rates?			

3.4 COMMUNITY WORKSHOPS – EXPLORATORY SCENARIO RESULTS AND DISCUSSIONS

Following the calibration and validation of the Poverty Bay Flats Groundwater Model, the community question based Exploratory Scenarios were run and the first round of results compiled into a summary workshop format. In April 2022, two workshops were hosted with GDC Councillors – Mana Whenua first and the wider community stakeholders in the second. The format of the workshop was to cover the results of these exploratory scenarios and discuss the general implications and next steps for the overall groundwater management strategy process. GDC and WGA staff co-presented the outputs and addressed a range of questions about the modelling.

Whilst some of the model-scenario outputs were easily quantifiable based on measured model outputs, a number of specific cultural and environmental indicators were more difficult to quantify. These indicators were determined to be best captured as **qualitative indicators** and measured as resulting in one of the following terms: '*generally improve*', '*stay the same*', or 'likely to *worsen*' relative to the baseline + climate change scenario (Scenario 2.1). The specific quantitative and qualitative model indicators are detailed fully in Section 4.

At the time of this workshop, only the water quantity aspect (e.g., levels and flows) was ready for use in scenario modelling. The conceptualisation and incorporation of the water quality (i.e., salinity) into the model required additional data and a variety of modelling changes in order to be ready to evaluate scenarios for changes in salinity. The first round of Exploratory Scenarios also tested three different 'climate change' scenarios based on NIWA climate modelling for the Gisborne area. A comparison of these climate scenarios helped refine and finalise the climate change settings for the FEFLOW model. Based on the quality modelling changes and final climate change scenario settings were then incorporated into a second round of Exploratory Scenario results which are presented in this report.

Following the April workshop, the numerical outcomes from the results led to the numerical modelling team refining and improving both the numerical model as well as the scenarios. In addition to changes to the model structure (e.g., coastal mesh refinement) and scenario input data, the water quality modelling component was added to the FEFLOW model. The results particularly brought into focus that a combination of the climate change drivers (e.g., rainfall recharge, extreme events, sea level rise and increased water demands) should all be encompassed into the scenario modelling process. The specific question around the degree of salinity effect in coastal areas with the anticipated sea level rise was identified as both culturally and environmentally valuable to better understand.

Section 4 provides a detailed summary of the community based Exploratory Scenarios as part of the completion of this stage of the groundwater modelling programme. These results have not yet been presented in a community workshop format.

3.5 EXPLORATORY SCENARIO MODELLING ASSUMPTIONS

The development of the Exploratory Scenarios based on the community questions required a combination of changing the input parameters to the model as well as understanding what climate change related issues may influence future groundwater management decisions. As outlined in the previous sections as well as is highlighted in Table 2, the Exploratory Scenarios were founded on community workshop questions. WGA and AQUASOIL worked collaboratively with GDC guidance on determining how the scenarios would be set up and run through the model period.

There are few key guidance notes on the scenario designs:

- Incorporating climate change predictions in the model was completed based on climate modelling done by NIWA for the Gisborne Regional area. The numerical groundwater model provides projections out to 2090 as it models long term changes in climate and sea levels. All scenario runs were modelled out to the end of this period and were presented in the first workshop.

- The Exploratory Scenarios focus on results for the shorter-term timeframes as set out by GDC for the following dates: 2025, 2035, and 2045. This is based on GDC district council's 10-year regional planning cycle and are required to be completed under the Resource Management Act. The current regional plan covers up to 2024, with a new regional plan being developed in 2023 and 2024 that will cover the period from 2025 to 2035.

- The Poverty Bay Flats Groundwater model provides results for all the aquifers in this groundwater system, but for the purpose of sharing the most relevant, WGA has generally focused on the Makauri Aquifer, Shallow Fluviatile and Te Hapara Sand aquifers. The Makauri Aquifer has the vast majority of the groundwater abstraction whilst the two shallower aquifers have a direct link to surface waterbodies including the coast, rivers, streams, and wetlands of Poverty Bay Flats.

The following sections cover the methodology and rationale behind each of the scenarios. A more technical summary of the specific inputs to the scenario modelling can be found in Appendix B.

3.5.1 Baseline Conditions

The two primary community questions relative to the baseline and/or current conditions of the groundwater system were:

- **What is the current status of the different aquifers?**

- **Is there a water level decline in the aquifers?**

The answers to these questions can be generated both from an analytical summary of the existing historical data, as well as through running a simulated baseline groundwater scenario into the future (2090).

As part of the groundwater modelling programme, WGA conducted analytical review of the available data for the various aquifers in order to help answer this question for the workshop. A review of the groundwater levels in the Makauri Aquifer, which has the vast majority of groundwater usage, indicates that both summer pumped groundwater levels as well recovered winter peak levels are declining (Figure 11). Current allocation used in this scenario was modelled at 1,188,000 m^3/year combined from all five aquifers. The data also shows that droughts are becoming more difficult for the groundwater levels to recover from (Figure 11– Points A, B, C). As the frequency and severity of droughts are predicated to worsen, it will take longer for the Makauri Aquifer to recover.

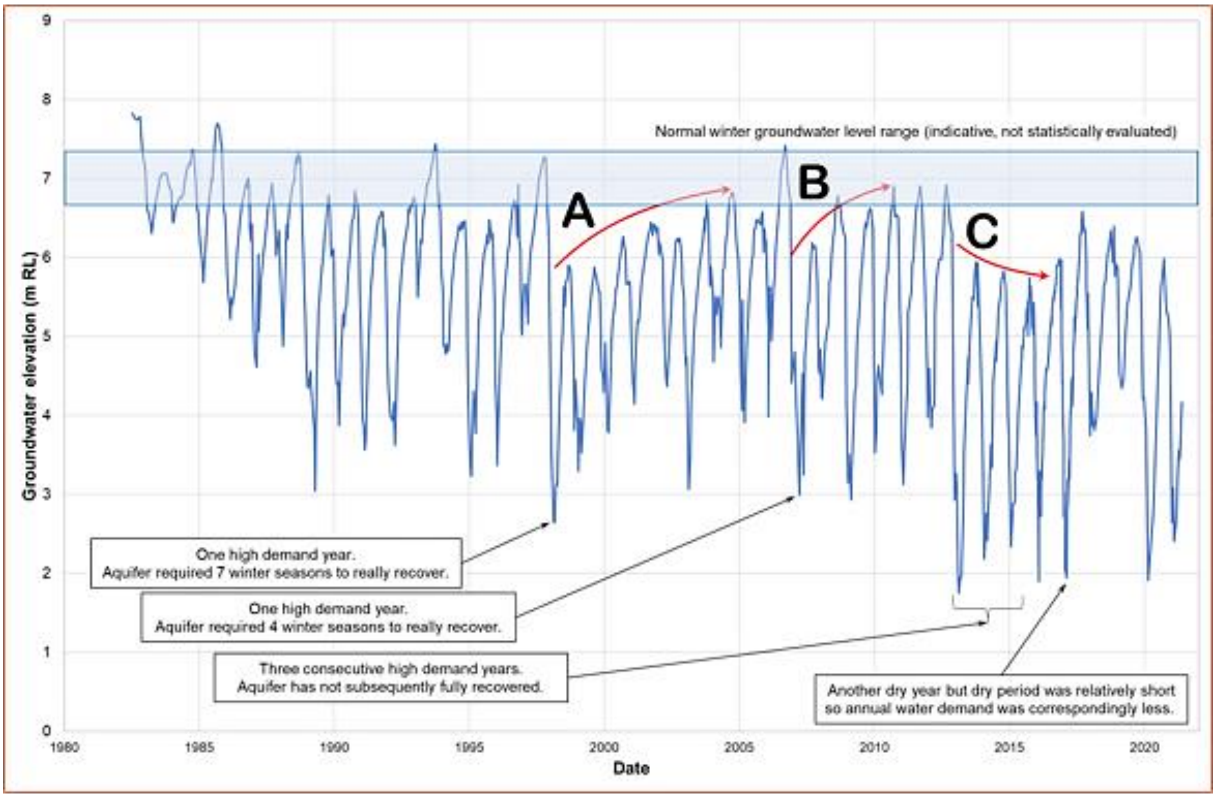


Figure 11: Historical Trends in Makauri Aquifer Indicating Declining Levels and Drought Recovery Issues (Bore GPJ040)

The Te Hapara Sand Aquifer is a coastal aquifer (bounded by the coastline) and is directly interactive with surface waterbodies including some key cultural and environmental wetland areas. Groundwater level data from a GDC monitoring bore in the Te Hapara Sand Aquifer shows similar responses to droughts periods with groundwater levels falling below mean sea level at times (Figure 13). Similarly, WGA's review of groundwater level trends in the Matokitoki Aquifer indicates potential declines in water level as shown in (Figure 13). The downward trends are consistent with GDC groundwater reports and regional planning changes which have been designed to help to resolve the groundwater abstraction pressure. The ASTR MAR pilot site has been in operation since 2017, and therefore MAR is a mitigation option being explored further during the groundwater numerical modelling process.

As the Poverty Bay Flats FEFLOW model was calibrated, validated, and set up to mimic the current aquifer conditions, it provides a baseline scenario.

Table 4 provides an overview of the FEFLOW modelling settings for the baseline condition including current metered usage, and current or actual levels of rainfall recharge rate and groundwater demand. These parameters are changed for each of the scenarios in order to evaluate the community questions through the Exploratory Scenario modelling process. Current seasonal usage based on metered takes were used in combination current climate conditions. The technical results from this scenario are presented and discussed in Section 5.

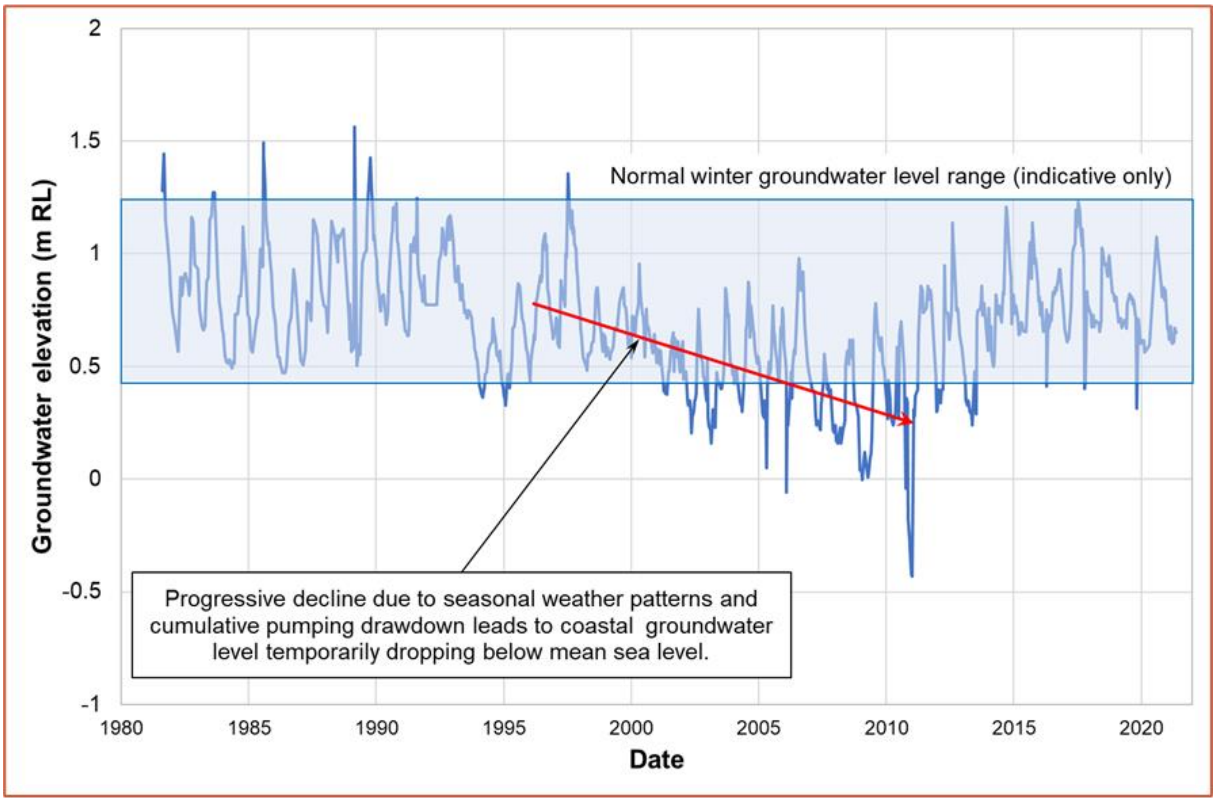


Figure 12: Te Hapara Sand Aquifer Analysis of Longer-Term Historical Data Trends (GPA003)

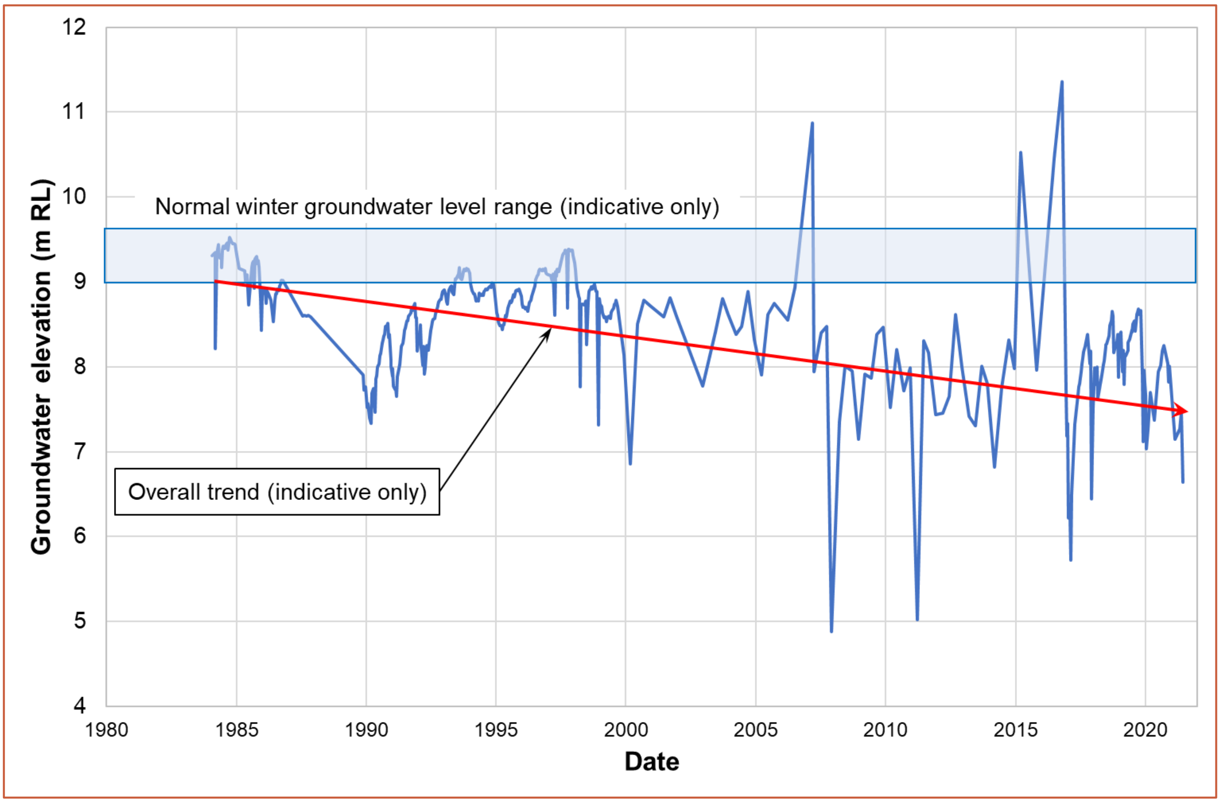


Figure 13: Analytical Assessment of Historical Trends in Matokitoki Aquifer (GPB102)

Table 4: Baseline Scenario Model Settings (Scenario 1.0)

SCENARIO NAME (#)	DESCRIPTION	CLIMATE CHANGE	METERED CURRENT USAGE	2021 PAPER ALLOCATION	MANAGED GROUNDWATER REPLENISHMENT
Baseline (1)	Current seasonal metered usage, no MAR, no climate change	Yes	Yes [(1)]	No	No

Note: 1) - **Metered Usage (- m^3/year)** - Usage by aquifer Makauri @ 847,000 m^3, Matokitoki @ 62,000 m^3, Te Hapara Sands @ 103,000 m^3, Waipaoa Gravel @ 69,000 m^3, and Shallow Fluviatile @ 107,000 m^3. Data sourced from GDC metered usage data.

3.5.2 Baseline + Climate Change Scenario

As climate change influences projections of the future baseline (current management) scenario, the community workshop question around climate change were amalgamated into two general questions:

- **How is climate change including extreme dry weather (droughts) expected to impact groundwater?**

For New Zealand's coastal communities, climate change impacts are important to consider for developing sustainable management strategies for groundwater resources. The primary drivers of hydrologic change under climate change include decreasing amounts of natural groundwater recharge directly related to changing rainfall patterns as well as flow in surface waterbodies (Figure 14). Increasing soil temperatures directly relate to increased soil moisture deficits resulting in additional water being required to irrigate the same crop yields. This in turn drives up the water demands resulting in increased groundwater pumping. These are compounded further when droughts are longer and drier as the frequency and duration of extreme weather events increase. For coastal aquifer systems increasing sea level rise coupled with storm surges will work to put additional pressures on freshwater aquifer supplies both in the shallow and deeper aquifers. Saline intrusion related to increased and prolonged groundwater pumping has been shown globally to be a challenging issue for coastal communities.

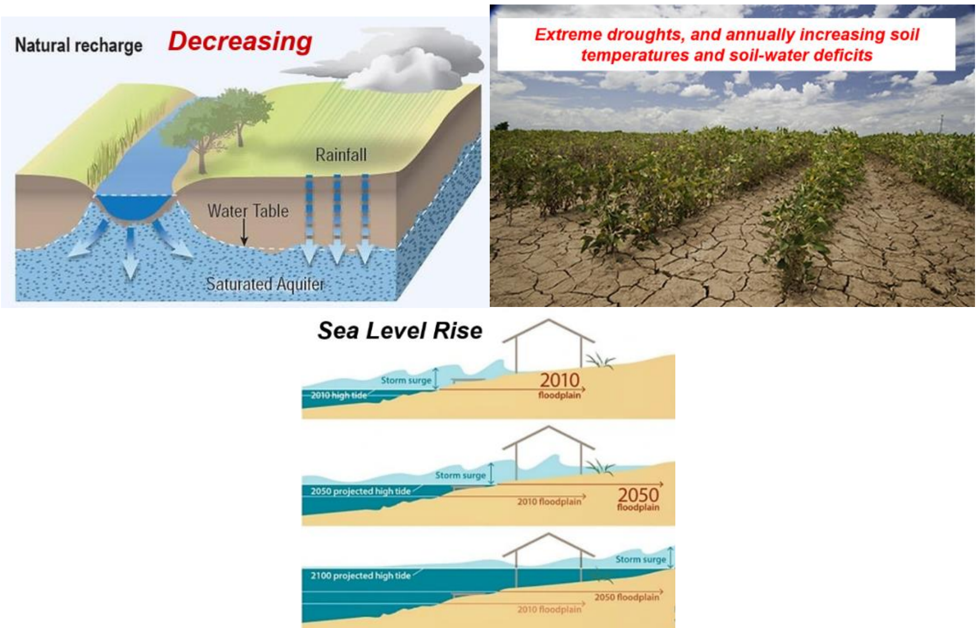


Figure 14: Examples of Climate Change Drivers Influencing Coastal Groundwater Systems

For the Poverty Bay Flats an important factor is that climate change will have implications that mean that the 'current' conditions will change even while maintaining the current irrigation area. WGA notes that that when planning for the future sustainable management, climate change should be factored in so as to develop the polices, rules and mitigations that work to adjust to these issues. For the purposes of adding the effects of climate change to our current or baseline scenario for this modelling programme, WGA worked with GDC staff to develop a set of climate change drivers that were incorporated into the modelling process. This was done through the two rounds of scenario modelling in order to arrive on the baseline + climate change scenario presented in this report in Section 3.5.

3.5.2.1 Technical Foundations for Climate Change Model Drivers

During the first round of Exploratory Scenarios, three different climate change scenarios were modelled to provide a sense of how the aquifer conditions changed. Information used for these scenarios was based on a combination of GDC database information as well as several NIWA technical reports. The assessments of historical drought events in the Gisborne area (NIWA 2013) were coupled with NIWA national report on coastal hazards as they relate to climate change to provide the reference information required. The primary climate related information was drawn from NIWA (2020) which provided water resource specific impacts for the Gisborne/Tairawhiti area. The NIWA climate change modelling report refers to a number of possible modelled climate change predictions relative to certain input parameters with the nomenclature of RCP 4.5 and RCP 8.5 (NIWA, 2020). RCP 4.5 represents a more conservative prediction (less change) than does the RCP 8.5 predictions (highest level of change).

WGA notes that GDC prepared a technical memorandum on the climate change decision making process which is included in Appendix B of this document.

During the first round of scenarios, three climate scenarios were developed to test the influence of three ranges of climate effects. These trial testing climate scenarios were as follows:

a) **Baseline + Climate Change (RCP 4.5):** Only rainfall was reduced due to climate change (NIWA 2020, RCP4.5). This influenced the natural groundwater recharge and was incorporated into every first-round scenario.
b) **Baseline + Climate Change (RCP 8.5):** A second round of baseline + climate change was modelled based on the more intensive predictions for rainfall and changes in natural recharge.
c) **Baseline + Extreme Events (RCP 8.5 + Droughts):** This scenario incorporated extreme drought events based on direct examples from GDC historical database into the model. These events were combined with baseline usage and added the more severe of the climate change predictions (NIWA 2020, RCP 8.5) for changes in rainfall, and increased irrigation demands from soil temperatures and moisture deficits.

Sea level rise was also incorporated into the overall FEFLOW modelling process, but not on a scenario comparison basis. Sea level rise was included by changing ocean boundary conditions as the model ran from 2022 to 2090. The amount of rise incorporated is documented in Section 3.5.2.5.

All of these first-round models were evaluated to the full extent of the NIWA predictive modelling timeline (current to 2090). The following sections provide an overview of the settings for the various climate related groundwater model inputs.

3.5.2.2 Changes in Rainfall (NIWA, 2020)

Changes in rainfall related to climate change were evaluated in all three of the first-round climate scenarios. The rainfall changes are sourced from the NIWA (2020) climate change report for Tairawhiti. The percentage decreases in rainfall were chosen by GDC for both RCP 4.5 and RCP 8.5. The projected rainfall changes from NIWA (2020) are as follows:

RCP 4.5

- Decrease of <5 % of actual until 2040 (RCP4.5)
- Decrease Summer 5-15% of actual until 2040 (RCP4.5)
- Decrease Spring and Summer 5-15% of actual 2040-2090 (RCP4.5)

RCP 8.5

- Decrease <10 % of actual until 2040 (RCP8.5)
- Decrease Spring and Summer 5-15% of actual until 2040 (RCP8.5)
- Decrease 5-15 % of actual 2040-2090 (RCP8.5)

For the purpose of setting a specific step change value for the FEFLOW scenario modelling, AQUASOIL assumed the upper limits for each of these RCP ranges of:

- **RCP 4.5** = -5% in 2040, -15% in Sept in 2090
- **RCP 8.5** = -10% in 2040, -15% in Sept 2040 and -15% in 2040-2090.

3.5.2.3 Extreme Weather - Droughts

Climate change is expected to increase the severity and frequency of severe weather events including flooding events and extended droughts. It was decided as part of modelling process, that increased severity of droughts would not be implicitly modelled as it would mostly likely mean changes in rainfall and/or river recharge which is difficult to simulate in a regional context. However, the predicted increased severity and frequency of droughts were incorporated into the Baseline + Extreme Events scenario.

The Baseline + Extreme Events scenario is based on GDC historical drought information as well as a drought report done by NIWA (2013) for the Gisborne area. A review of the GDC historical drought information indicates that two droughts were of recent mention, the El Nino period of 1997 -1998 was one of the highest on records, whilst the more recent 2012 – 2013 drought was ranked 5th most severe since 1940. A review of the data indicates that the frequency of droughts appears on average about every 7 years, however for the purposes of numerical testing the effects of these droughts in the scenario process, it was determined that three individual drought periods would be simulated. This was done by using a ratio of the measured increased abstractions (GDC metered flow data) from the recorded drought event in 2012-2015 and applying it as a three-year drought period occurring from 2035-2038, 2050-2053 and 2070-2073. For more information on these extreme droughts and the scenario modelling see Section 4 in the AQUASOIL (2022) report. The inclusion of droughts based on the NIWA reports and historical records is discussed in more detail in Appendix B.

3.5.2.4 Increased Water Demands (PED)

Determining how to model climate related increases in water demand required the use of the readily available estimates of changes in Potential Evaporative Demand (PED) predictions from the NIWA climate modelling report (2020). The use of PED as a surrogate for water demands for irrigation was determined in part due to the FEFLOW model’s inability to capture PED from a surface water exchange. The relationship between PED and usage was determined by applying the relative percentage difference in climate change increases in PED (mm/year) against the total annual metered groundwater usage, resulting in a proportionate increase in groundwater usage related to climate change (Figure 15).

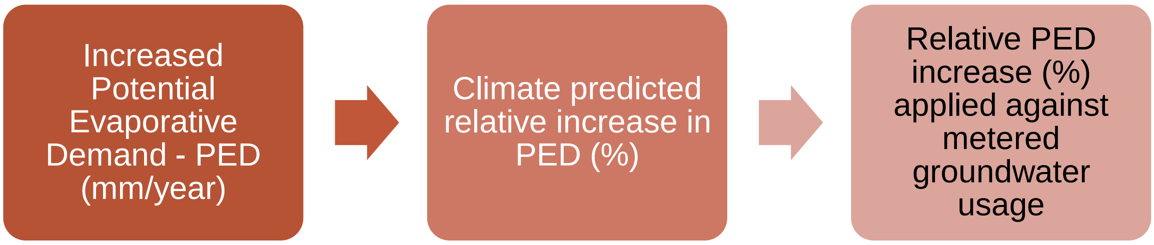


Figure 15: Relationship Applied to Utilise Climate Predictions for Changes in PED to Changes in Irrigation Demands

Changes in groundwater usage (as PED) were chosen by GDC staff for both RCP 4.5 and RCP 8.5 as follows:

For **RCP 4.5** scenarios GDC worked back in 15-year increments from 2090 for the 42% increase and used a linear relationship to fill in the previous years.

- Average (2008-2021) Takes to increase:
- 5% in 2030
- 15% at 2045
- 24% at 2060
- 33% at 2090

For **RCP 8.5** scenarios NIWA provided two sets of incremental changes which for the purpose of these scenarios GDC assumed a median value be applied.

- Average (2008- 2021) Takes to increase:
- 21% in 2030
- 42% at 2040
- 53% at 2065 to 2090

For more information on these extreme droughts and the scenario modelling see Section 4 in AQUASOIL (2022) report.

3.5.2.5 Sea Level Rise

Coastal New Zealand is expected to experience changes in sea level rise, increasing severity of storm surges, and a range of other factors. For the purposes of a numerical groundwater model, only sea level rise could be incorporated into the scenario development process.

Sea level rise was also included in the climate scenario changes based on information from two sources. The progressive scenario information for all of New Zealand from NIWA (2017, Table 10) and more specifically from the for RCP 4.5 and RCP 8.5 model predictions provided in NIWA (2020) which are only considered marginally different. For the purposes of the FEFLOW scenario modelling the sea level rises were as follows:

For **RCP 4.5,** a total incremental sea level rises of 0.41 m from 2020 to 2090, with step increases every decade (2030, 2040, 2050, etc).

For **RCP 8.5** a total incremental sea level rise of 0.58 m from current to 2090, with step increases every decade (2030, 2040, 2050, etc).

For more information on these extreme droughts and the scenario modelling see Section 4 in the AQUASOIL (2022) report.

3.5.2.6 Second Round Exploratory Climate Model Settings

The Exploratory Scenario testing of several climate change settings allowed the modelling team the opportunity to evaluate how the model responded to a range of climate predictions. As climate change was to be embedded in all final Exploratory Scenarios, it was important to select a combination that was suited to the goals of testing the model capabilities as well as provide a preliminary answer to the questions posed by the community. Appendix B provides an overview of GDC's decision-making process around selecting the most appropriate climate change scenario inputs, as well as the logic behind the final decisions made to progress to the final climate change settings used in this reports scenario's results.

Generally, the decision was made to use the more conservative NIWA predicted model settings (RCP 4.5) for changes in rainfall, increases in water usage and changes in sea level rise. Extreme weather events droughts based on historic GDC data was also added to the final Baseline + Climate Change scenario. After the results from the three first round climate scenarios were completed, the modelling team finalise the climate scenario settings as follows:

Rainfall Recharge Rates[6] - Decrease <5 % of actual until 2040 (RCP4.5), Decrease Summer 5-15% of actual until 2040 (RCP4.5), and Decrease Spring and Summer 5-15% of actual 2040-2090 (RCP4.5).

Potential Evaporation Demand (PED)[7] - PED to increase +125 mm. Utilised mid-range of NIWA prediction, +100-150 mm until 2090. RCP 4.5). The modelling team utilised PED as a surrogate to represent increases in groundwater usage. Increasing soil temperatures and soil moisture deficits are assumed to result in increasing water demands. Relative PED changes converted to increased groundwater takes to increase: 5% at 2030, 15% at 2045, 24% at 2060, 33% at 2075, 42% at 2090.

Droughts – Actual observed 3 Year drought periods from historical Poverty Bay Flats records from 2013, 2014, 2015 replicated generally in their severity and longevity. Applied to model years 2036, 2051, and 2071. Data sourced from GDC groundwater and climate data.

Sea Level Rise[8] **-** Applied projected sea level rise from NIWA scenario RCP4.5 (mid-range). Table 10 of NIWA (2020) indicating; +0.13m by 2030, +0.19m by 2040, +0.24m by 2050, +0.30m by 2060, +0.36m by 2070, +042m by 2080, and +0.49m by 2090.

Table 5: Baseline + Climate Change Scenario Model Settings (Scenario 2.1)

SCENARIO NAME (#)	DESCRIPTION	CLIMATE CHANGE	METERED CURRENT USAGE	2021 PAPER ALLOCATION	MANAGED GROUNDWATER REPLENISHMENT
Baseline + Climate Change (2.1)	Current seasonal metered usage, baseline conditions with Climate Change	**Yes**	**Yes 1,188,000 m^3/year**	No	No

[6] Section 5.1 NIWA 2020
[7] Section 6.1 NIWA 2020
[8] Table 10 of NIWA 2020

3.5.3 Natural State

As part of the community workshops there was specific interest in understanding how the Poverty Bay Flats groundwater system may respond if the influence of groundwater abstraction (usage) was removed. The specific questions that led to the Natural State scenario from the community were as follows:

- **What effects would occur if Te Mana O Te Wai was placed above commercial groundwater use?**
- **Would there be a change in wetland and spring persistence?**
- **Would there be a change in groundwater salinity?**

This Natural State scenario was reasonably easy to simulate in the model, which simply required that all simulated groundwater abstraction was ceased from 2020 to 2090. Of course, the scenario still has the imbedded human-caused influence of climate change which will continue to influence and change all of New Zealand's freshwater systems. In the context of climate change, perhaps 'natural state' is better described as 'no abstraction' which has other social and economic implications which will be covered in the results section (Section 4.5.4). For more information on the modelling settings for Natural State scenario modelling see Section 4 in the AQUASOIL (2022) report.

Table 6: Natural State Scenario Model Parameters (Scenario 3.1)

SCENARIO NAME (#)	DESCRIPTION	CLIMATE CHANGE	METERED CURRENT USAGE	2021 PAPER ALLOCATION	MANAGED GROUNDWATER REPLENISHMENT
Natural State (3.1)	All irrigation pumps cease to operate	Yes	**No** (1)	No	No

Note: 1) 2021 Consented Paper Allocation (- m^3/year) - Usage turned off to 0 meters/year for all aquifers. Permitted activity wells (unmetered) for drinking and stock not included in this scenario, all assumed to still be pumping.

3.5.4 2021 Paper Allocation Usage

The primary community questions relative to the effects of currently consented groundwater allocation are:

- **What happens if current paper allocations are used to full entitlement?**
- **Can we understand aquifer recovery rates?**

This scenario provides a view of the potentially extreme situation where the maximum amount of groundwater abstraction is withdrawn every year between 2020 and 2090. GDC reported paper allocation for all five aquifers is 3,980,908 m^3/year. The additional pressures placed on the aquifer from climate change are also imbedded in this scenario. This would mean an increase of metered abstraction of between 100% and 555% when compared to the baseline current usage.

The modelling team understood that this is not a realistic scenario in the sense of actual water demands in a year-to-year basis. However, the scenario provides a test of the bookend or extreme boundary value from which to evaluate how the aquifer system would respond to heavy pumping pressures. Table 7 provides a summary of the modelling settings for this scenario.

Table 7: 2021 Paper Allocation Scenario Modelling Settings (Scenario 4.1)

SCENARIO NAME (#)	DESCRIPTION	CLIMATE CHANGE	METERED CURRENT USAGE	2021 PAPER ALLOCATION	MANAGED GROUNDWATER REPLENISHMENT
2021 Paper Allocation Limit (4.1)	All groundwater consents are utilised representing total consent allocation	**Yes**	No	**Yes** (1) **3,980,908 m³/year**	No

Note: 1) 2021 Consented Paper Allocation (- m³/year) - Usage increased to full paper allocation for each aquifer. Usage by aquifer Makauri @ 1,906,362 m³, Matokitoki @ 343,900 m³, Te Hapara Sands @ 613,346 m³, Waipaoa Gravel @ 535,440 m³*, Shallow Fluviatile @ 581,860 m³*. Data sourced from GDC Consents. * *Based on annual paper allocation of individual bores*.

3.5.5 Groundwater Replenishment (MAR)

From the community workshops there was a general interest in understanding role groundwater replenishment could play as a mitigation in increase recharge to groundwater system. Given that GDC initiated the first ASTR bore in New Zealand and has successfully conducted a MAR trial since 2017, the information required for this scenario was readily available for the modelling process.

This general interest area was formulated into the question:

- **What effect would replenishment have on groundwater levels?**

Similar to other scenarios, the first round of groundwater replenishment scenarios helped to better define application of recharge through a combination of recharge scenarios. The simulation of six aquifer recharge bores was provided by GDC based an assessment of potential locations that were assessed during the GDC-Kaiaponi ASTR MAR trial.

The two first round scenarios were set up as follows:

- **Replenishment Scenario 1** – six bore locations targeting the Makauri Aquifer, recharge occurring during summer season, a total of 600,000 m³ recharged annually (Scenario 5.0 and 5.1).

- **Replenishment Scenario 2** – six bore locations targeting the Makauri Aquifer, recharge occurring during summer season, a total of 1,200,000 m³ recharged annually (Scenario 6.0).

All of the recharge scenarios are designed to directly relate to the quantity of water being abstracted from the Makauri Aquifer. The use of recharge sites to help manage the **salinity issues** in the aquifer had not been a topic of discussions with Mana Whenua and the October 2021 community meetings. Whilst not being part of the community processes, the concern around the effects and management of salinity was clear from the community.

The final scenario modelled used the results from those initial MAR model scenarios as follows:

Final Replenishment (2nd Round) Scenario – six bore locations targeting the Makauri Aquifer, recharge occurring during summer season, a starting recharge rate of 600,000 m³ recharged annually is increased in a stepwise process (to response to groundwater usage driven by climate change) up to an annual recharge rate of 798,000 m³ annually by 2090.

Table 8 provides the FEFLOW numerical modelling changes used to generate this scenario. Specific technical information on the results from this scenario is detailed in the results section (Section 4.5.6). For more information on the modelling settings for Sustainable Allocation scenario modelling see Section 4 in the AQUASOIL (2022) report.

WGA notes here that these two scenarios represented numerical scenario 5.0 and 6.0 in the first round of modelling. Replenishment Scenario 2 was evaluated during the first round of scenarios but not included in the second round leading to the removal of scenario 6 from the scenario numbering process.

Table 8: Groundwater Replenishment (MAR) Scenario Modelling Parameters (Scenario 5.1)

SCENARIO NAME (#)	DESCRIPTION	CLIMATE CHANGE	METERED CURRENT USAGE	2021 PAPER ALLOCATION	MANAGED GROUNDWATER REPLENISHMENT
MAR (5.1)	Managed Aquifer Recharge applied, increased in response to climate change pressures on demand	**Yes**	**Yes** **1,188,000 m^3/year**	No	**Yes** (1) **600,000 m^3/year increasing to 780,000 m^3/year**

Note: 1) Managed Aquifer Recharge (MAR) targeting only Makauri Aquifer starting at 600,000 m^3/year increasing up to 847,000 m^3/year to offset the increasing pumping demands from climate change. Increase recharge relative to climate change water use demands (PED, RCP 4.5): 5% at 2030, 15% at 2045, 24% at 2060, 33% at 2075, 42% at 2090. Recharge values based on MAR trial results.

3.5.6 Sustainable Allocation

From the community workshops there was a general interest in understanding what long term abstraction rates might result in a *sustainable* groundwater system. This general interest area was formulated into the question:

- **What is a 'sustainable' allocation rate of usage for the Poverty Bay Flats aquifers?**

At first glance, using the term 'sustainable' appears to be a reasonable approach to describe managing a resource to some abstraction limit that does not cause any long-term degradation of the resource. However, the term 'sustainable' in the context of the wide range of issues that could be encompassed within the concept of sustainability is problematic. Even more difficult is to determine what indicators could be used to measure 'sustainability'. For example, what is a sustainable allocation rate with background implications of the numerous pressures applied from ongoing climate change? The technical team decided that it was important to clearly define the use of 'sustainable' in the context of this this Exploratory Scenario modelling process which is as follows:

*'**Sustainable Allocation** is used in the context of this modelling as description text for a particular Exploratory Scenario. This scenario is intended on starting the process to establish a sustainable annual allocation abstraction volume which will decrease current human usage until measured declines in the aquifer potentials are stabilised. As with all the scenarios, this includes the modelled effects of climate change. However, we recognise that the concept of sustainability is measured well beyond just the issue of groundwater potentials and a range of other factors including economics, water quality, cultural values, and groundwater dependent ecosystems all would need to be considered in a full assessment of sustainable groundwater usage.'*

WGA also notes that as all of the Exploratory Scenarios are single resource management changes that are typically only used to provide a reference to evaluate the range of potential groundwater management options relative to changes seen in the modelling. Given that climate change will make ‘sustainability’ a challenge for all natural freshwater systems, future combinations of policies, rules and mitigations are likely how a well-defined sustainable groundwater allocation level can be achieved.

For the purposes of this modelling project, a simplified numerical definition of sustainability has been used as a guide for the iterative evaluation of a sustainable allocation. The amount of annual groundwater abstraction is reduced to the point whereby groundwater levels do not drop below the current levels (Scenario 2.1) in late summer through to 2050. This Scenario does not specifically seek to maintain current groundwater levels in late winter, following seasonal groundwater level recoveries. Additionally, different aquifers respond to changes in abstraction in different ways. As the percentage changes in abstraction rates are applied equally to all production bores simulated in the model, the results vary on an aquifer-by-aquifer basis when compared to the Scenario objectives. Therefore, the main focus for Scenario 7.1 was to manage groundwater pressures in the Makauri Aquifer, which is the target for the largest groundwater abstractions.

Table 9 provides the FEFLOW numerical modelling changes used to generate this scenario. Specific technical information on the results is provided in Section 4.5.7. For more information on the modelling settings for Sustainable Allocation scenario modelling see Section 4 in the AQUASOIL (2022) report.

Table 9: Sustainable Allocation Scenario Model Parameters (Scenario 7.1)

SCENARIO NAME (#)	DESCRIPTION	CLIMATE CHANGE	METERED CURRENT USAGE	2021 PAPER ALLOCATION	MANAGED GROUNDWATER REPLENISHMENT
Sustainable Allocation (7.1)	Iterative modelling to determine rate of water usage (abstraction) where groundwater levels stablise.	**Yes**	**Variable Rates** (1)	No	No

Note: 1) See Section 4.5.7.

3.6 WATER QUALITY SCENARIOS - SALINITY

As water quality was built into the model after the community scenarios on groundwater quantity were established, salinity modelling was discussed generally during the community Exploratory Scenario process, but the modelling capability was not established after those workshops. The modelling of salinity, specifically chloride, required two rounds of conceptualisation and model simulation testing before it was ready for use in the final round of Exploratory Scenarios, the second-round results are shared in this report. Fundamentally information provided to conduct this modelling was limited and GDC is working toward gathering more field information to help understand this quality issues. This has resulted in the quality modelling focusing mainly on a qualitative comparison of results between scenarios. WGA (2022b) provides a technical summary of the various model inputs and conceptual understandings that were used for the scenario modelling. These qualitative results and discussion of the salinity modelling is included in Section 4. A further discussion of risks and recommendations around salinity and water quality more generally are discussed in Section 5.

4 EXPLORATORY SCENARIOS - RESULTS AND DISCUSSION

4.1 OVERVIEW

This Section provides an overview of the Exploratory Scenario outcomes including a summary of the quantitative and qualitative outputs as well as the individual scenario results with discussion. The results in this section with the exception of the Climate Change Scenarios represent the second (refined) Round of FEFLOW model simulation outputs. The results from the first round presented at the April 2022 community workshops are provided in the Appendices of the AQUASOIL (2022) modelling report.

4.2 INDICATORS OF MODELLED EFFECTS

The numerical model generates wide range of simulation results. These results include text files documenting:

- Water flow budgets for the Poverty Bay Aquifers
- Water budgets for the consented production bores within the modelled area.
- Water budgets for the Waipaoa River and each of the simulated drains within the modelled area.
- Groundwater level hydrographs at all GDC monitoring wells, not only for the aquifer monitored by the well but also for any underlying and overlying aquifers.
- Chloride concentrations over time for all GDC groundwater quality monitoring wells.
- Chloride concentrations over time for a series virtual groundwater quality monitoring wells aligned in transects close to the coastline.
- Chloride mass loads for the Waipaoa River and each of the simulated drains within the modelled area.

The model results also include maps documenting:

- Groundwater levels for each aquifer at a series of times through the model run.
- Changes in groundwater level for each aquifer compared to the baseline scenario at a series of times through the model run.
- Changes in chloride concentration for each aquifer compared to the baseline scenario at a series of times through the model run.

The volume and complexity of the model outputs is very large. Therefore, it has been necessary to define a set of indicators to enable a clear and defensible comparative evaluation of model results from the various scenarios simulated. These indicators are in two forms:

- Quantitative indicators that are supported by graphs or maps showing projected outcomes (Section 4.3).
- Qualitative indicators that represent broader quality, environmental, cultural, and social outcomes (Section 4.4).

The quantitative and qualitative indicators should be considered together when assessing the simulated effects arising from the various modelled scenarios.

4.3 QUANTITATIVE INDICATORS

4.3.1 Hydraulic Head Changes

Through discussions between GDC and WGA, a set of existing groundwater level monitoring wells has been chosen as providing appropriate monitoring points to evaluate the simulated behaviour of the Poverty Bay Flats aquifers. For the Te Hapara Sand Aquifer, five monitoring wells have been chosen reflecting the range of concerns and areas sensitive to the effects of climate change and future groundwater abstraction (Table 10). In contrast, the simulated effects on the confined Waipaoa, Makauri and Matokitoki aquifers are each considered to be adequately represented by the simulated hydrographs from single monitoring wells (Table 10).

Table 10. Groundwater Model Quantitative Monitored Bores

AQUIFER	MONITORED WELL	LINKED SURFACE FEATURE
Te Hapara Sand	GPA003	Te Waiohiharore
	GPB099	Taruheru Stream
	GPC029	Te Maungarongo o Te Kooti Rikirangi Wetland
	GPC080	Awapuni Moana Drains, Waipaoa River
	GPC094	Awapuni Moana Drains
	GPI007	Waipaoa River
Shallow Fluviatile Gravel	GPF068	Waipaoa River
Waipaoa	GPE040	Indirect to Waipaoa River
Makauri	GPJ040	N/A
Matokitoki	GPB102	N/A

The representative monitoring wells have been chosen because they each have a long monitoring history and none of these wells are located close to major water production bores. The hydrographs for these representative wells should not be overly influenced by nearby simulated pumping operations. Consequently, the simulated hydrographs are considered to reasonably represent the effects of climate change and changes to groundwater management regimes for the aquifers as a whole. The simulated effects vary laterally within each aquifer and these representative wells do not reflect the impacts of climate change and changes in water demand or water supply security at specific production bores.

Groundwater levels in the Shallow Fluviatile Gravel Aquifer are not represented by any monitoring well for the purposes of this assessment. This exclusion is because the groundwater levels in this aquifer are strongly tied to water fluctuations in the Waipaoa River. The river has not been modelled in this project, except as a boundary condition for the groundwater model (i.e., reflecting inflow and outflow from the groundwater system to the river during baseflow conditions). Therefore, simulated groundwater level fluctuations in the Shallow Fluviatile Gravel Aquifer are not considered to fully respond to projected climate change effects on the integrated groundwater and surface water system.

For clarity, simulated groundwater level hydrographs are presented on two-time scales: the full model run period from 2021 to 2090 and a five-year extract from 2040 to 2045 (Figure 16). The extracted period was chosen to be relevant to upcoming regional plan development processes and also be within a timeframe where climate change projections are associated with a high degree of confidence.

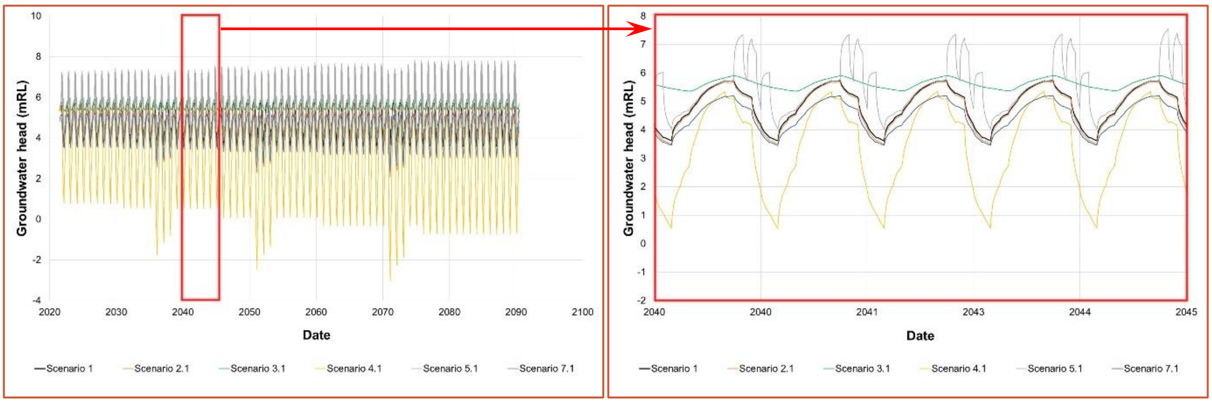


Figure 16: Model Output Full Record Compared to a Five-Year Extract

Comparisons between groundwater hydrographs from different modelled scenarios are presented in two forms:

- Hydrographs presented as absolute groundwater level (mRL) fluctuations over time, with multiple scenarios being presented in a single graph.
- Difference hydrographs which represent the difference between the simulated hydrograph for a specific scenario and the baseline + climate change simulated hydrograph (Figure 17). i.e., Are groundwater levels going to rise or fall compared to the continuing with the status quo abstraction in the face of projected climate change?.

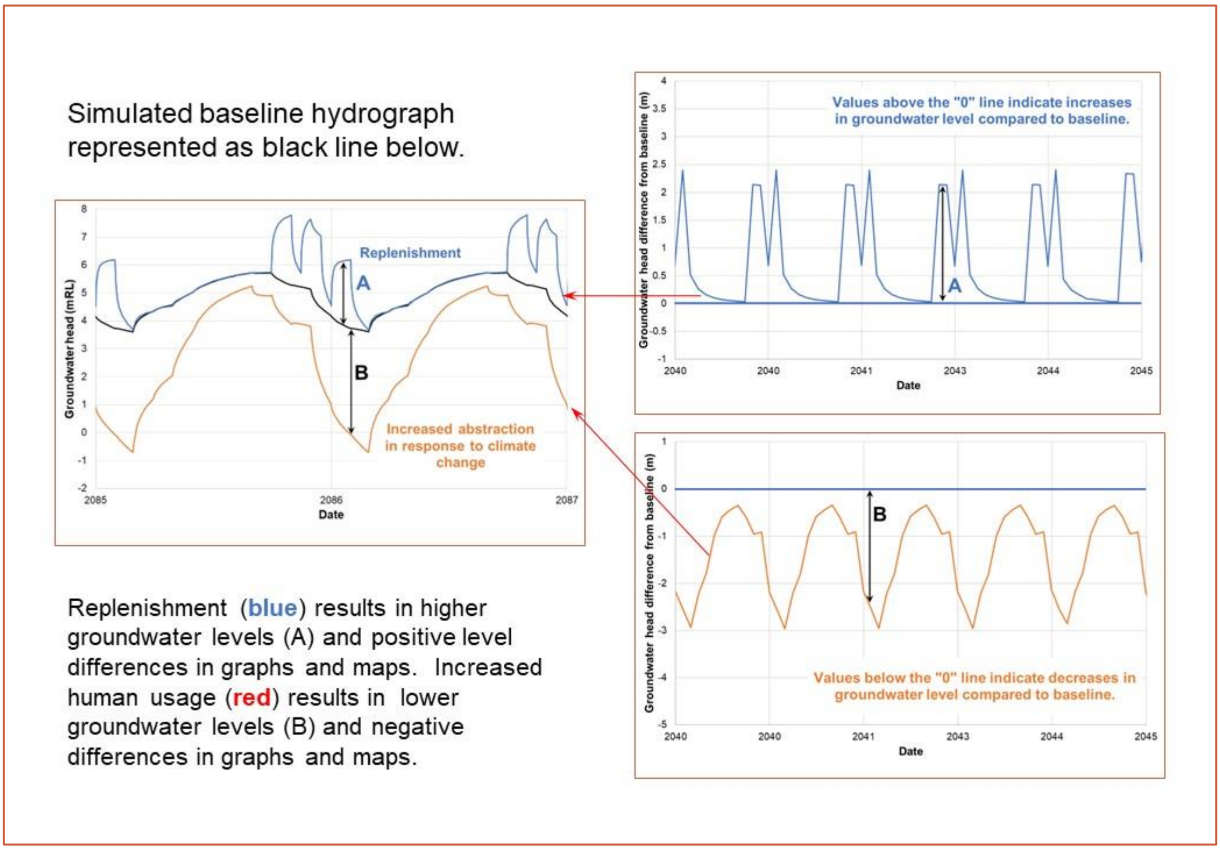


Figure 17: Derivation of Groundwater Difference Graphs

The effects on groundwater levels arising from the different simulated scenarios when compared to the baseline scenario are also presented in map form (Figure 18). In each of these maps the groundwater level at a particular point in time is compared to the groundwater level from the baseline + climate change scenario (Scenario 2.1) at the same point in time. Negative values indicate a drawdown of groundwater level compared to Scenario 2.1. Conversely, positive values indicate groundwater level rises compared to the Scenario 2.1.

4.3.2 Vertical Hydraulic Gradients

An important differentiator between scenario outcomes is the vertical hydraulic gradient between aquifers. Under natural conditions without the influence of pumping vertical groundwater gradients between aquifers have tended to be downward across the northern third of the Poverty Bay Flats. These gradients generally changed to be upward gradients across the southern half of the Poverty Bay Flats. The upward hydraulic gradients have helped to protect the confined aquifers from saline water intrusion close to the coast. Furthermore, these upward gradients also help to reduce the risk of other shallow groundwater contaminants impacting groundwood quality in the confined aquifers.

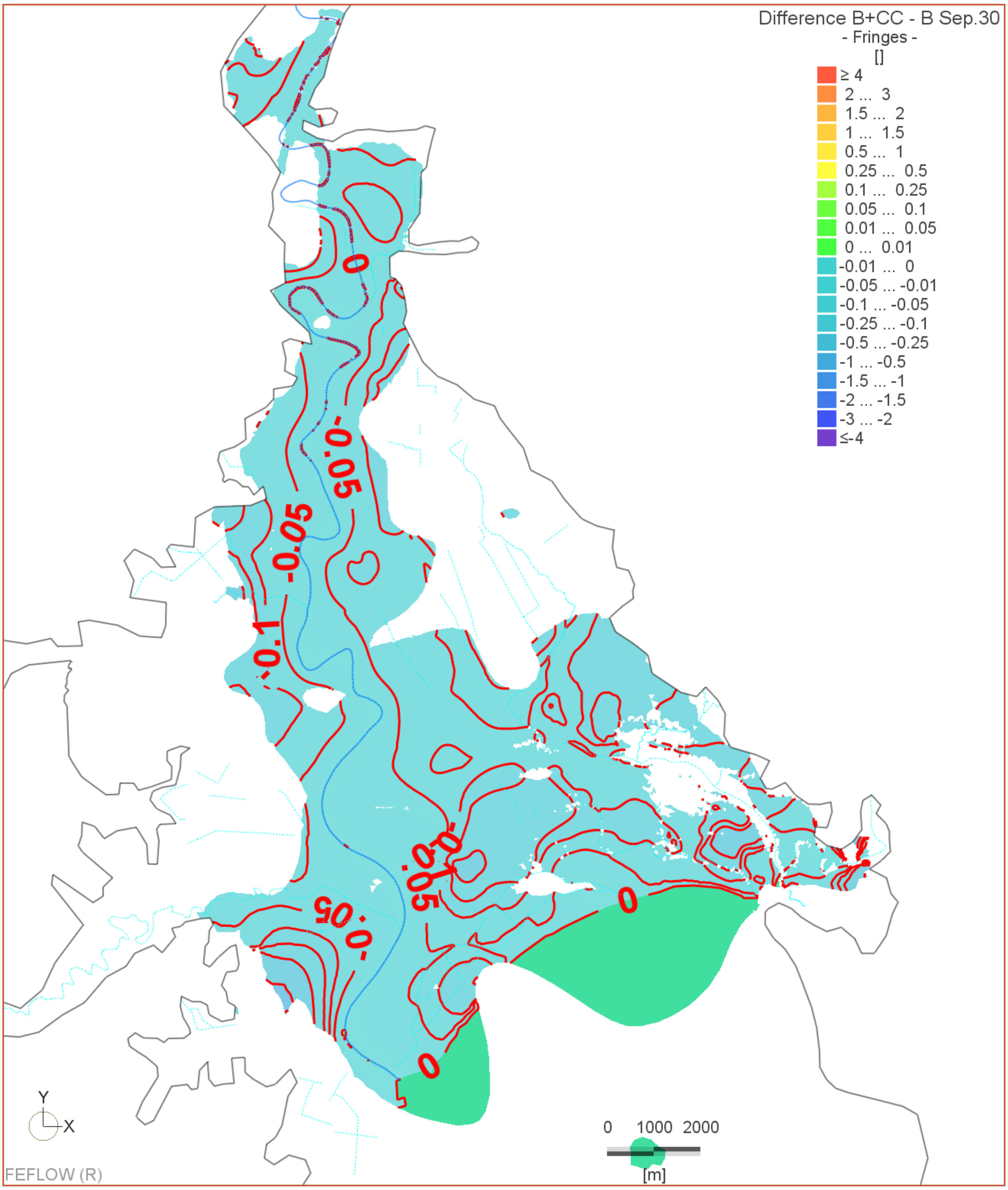


Figure 18: Example of Head Difference Map[9]

[9] Note that head difference maps for all results are available in the AQUASOIL 2022 report. For the remainder of the maps shared in this document, WGA has provided a qualitative range to help the reader understand relative changes (increasing, decreasing, etc).

Over the past three decades, groundwater abstraction from the confined aquifers has resulted in seasonally increased downward hydraulic gradients from the shallow aquifers. These seasonal changes in vertical hydraulic gradients cannot be prevented without reducing groundwater abstraction from the confined aquifers to a negligible amount. However, the effects from the various modelled scenarios can be evaluated in terms of winter vertical hydraulic gradients. Retaining or re-establishing upward hydraulic gradients through the winter periods will help to protect the quality of groundwater in the confined aquifers over the long term. Therefore, graphs summarising winter vertical hydraulic gradients between aquifers are presented in this report.

4.3.3 Salinity Trends

Monitoring of chloride concentrations and electrical conductivity in the ground water across the Poverty Bay Flats has identified a number of trends over time. In many areas, groundwater salinity has remained stable over the past 30 years. In some areas groundwater salinity is increasing over time. GDC has held concerns over the past few years regarding the potential for groundwater abstraction and future sea level rise to lead to increased groundwater salinity.

The groundwater quality modelling to date has successfully simulated these trends in key aquifer areas. However, there are several key input parameters for the groundwater quality modelling that require further clarification through field investigations and testing. Therefore, model outputs documented in this report have focused on expected changes in water quality into the future at key monitoring locations. Graphs showing projected differences in chloride concentrations compared to the baseline are presented in this report. However, the effects arising from the various scenarios on groundwater salinity are summarised as qualitative outcomes from the model (refer Section 4.4).

The effects of projected sea level rise on groundwater salinity within the Te Hapara Sand Aquifer is of concern for cultural, ecological, and social reasons. Increases in salinity have been observed in shallow groundwater monitoring wells and in drains crossing the Awapuni Moana area. However, past work on water quality in this area has shown that changes result from a highly complex combination of factors and are not simply related to groundwater behaviour alone. For this reason, it has proven difficult to replicate salinity trends observed in individual monitoring wells and to generate location-specific projections into the future.

The potential effects of sea level rise on groundwater quality in coastal areas of the Te Hapara Sand Aquifer have been investigated using virtual groundwater monitoring points. Two lines of simulated monitoring points have been added to the model, with these lines running inland from the coast (Figure 19). Simulated changes in chloride concentrations have been recorded along these lines of monitoring points and the relative changes concentration are summarised in this report for each of the modelled scenarios.

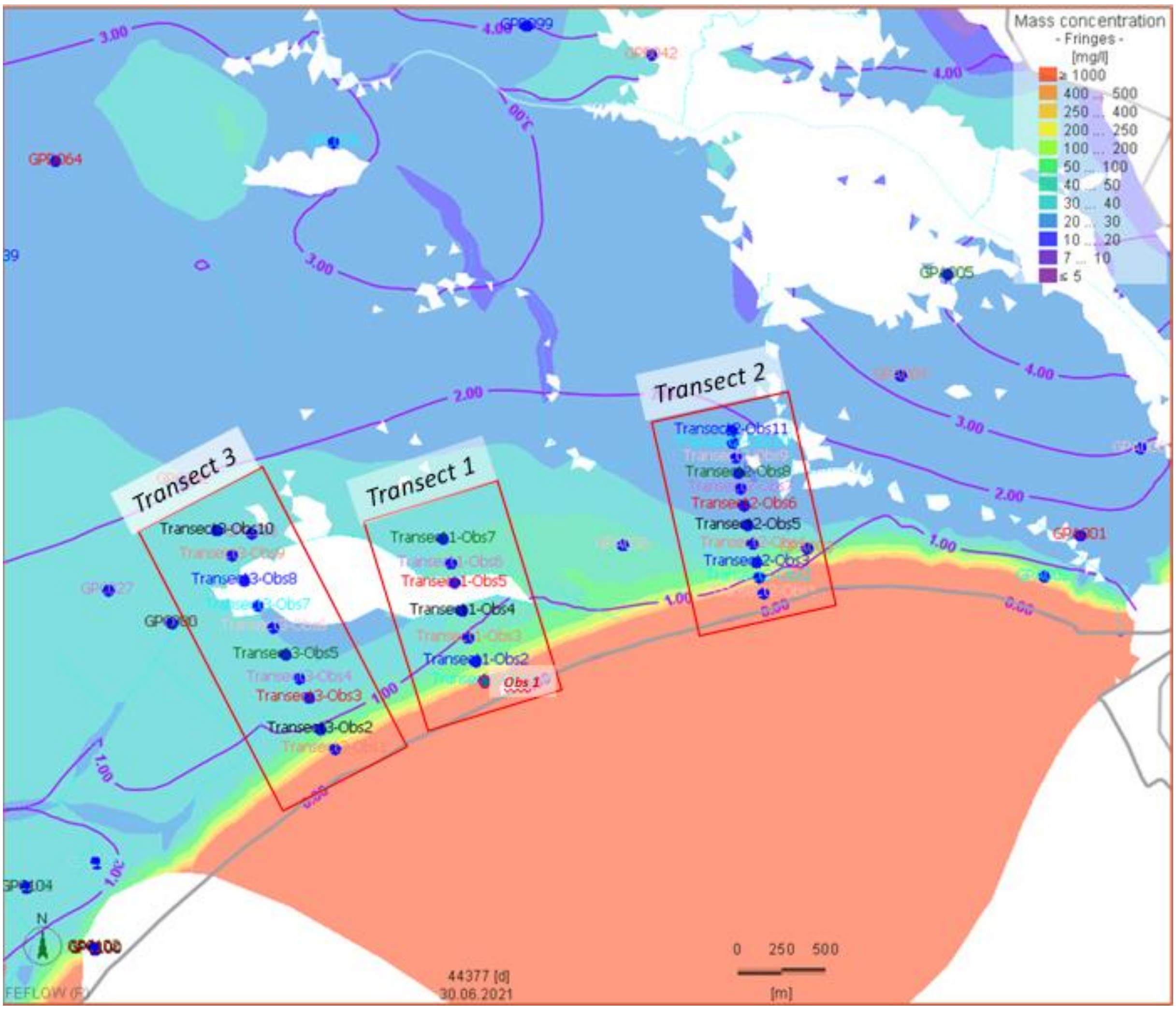


Figure 19: Simulated Chloride Monitoring Points in the Coastal Te Hapara Sand Aquifer from AQUASOIL (2022)

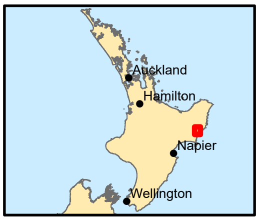
4.4 QUALITATIVE INDICATORS

4.4.1 Introduction

Qualitative indicators referenced to the model outcomes are listed in Table 11. The locations of monitoring stations referred to in Table 11 are presented in Figure 20. The groundwater model does generate quantitative outcomes linked to some of these monitoring sites, such as groundwater flow budgets for the Waipaoa River and the Awapuni Moana drains. However, no corresponding surface water flow model is available at this stage and a detailed assessment of the consequences of changes in groundwater flows or levels on surface water ecology or cultural values is outside the scope of this assessment. The effects of changes in the groundwater system are summarised qualitatively rather than quantitatively. In this sense, the effects arising from each of the modelled Exploratory Scenarios are summarised qualitatively as indicated in the final column in Table 11.

Table 11: Groundwater Model Qualitative Categories, Monitored Features and Outputs

CATEGORIES	SURFACE WATER CONNECTION	AQUIFER CONNECTION	MODEL OUTPUT PARAMETER	OPTIONS FOR STATUS OUTPUT
Cultural	Te Waiohiharore	Te Hapara Sand Aquifer	Has there been a relative change in groundwater levels at GPA003?	Likely to **improve** Likely to **stay the same** Likely to **worsen**
	Awapuni Moana Drains	Te Hapara Sand Aquifer	Has there been a relative change in groundwater levels at GPC080 and GPC094? Has there been a relative change in outflows to the drain?	
Surface water ecosystems	Te Maungarongo o Te Kooti Rikirangi Wetland	Te Hapara Sand Aquifer	Has there been a relative change in groundwater levels at GPC029?	
	Waipaoa River baseflow	Shallow Fluviatile Gravel Aquifer	Has there been a relative change in groundwater levels at GPC080 and GPF068? Has there been a relative change in net outflows to the river?	
	Taruheru baseflow	Te Hapara Sand Aquifer	Has there been a relative change in groundwater levels at GPB099? Has there been a relative change in net outflows to the river?	
Groundwater salinity	No direct connection	Makauri Aquifer	Has there been a relative change in trend for salinity at GPD115 and GPJ040?	
	Ocean Awapuni Moana Drains	Te Hapara Sand Aquifer	Has there been a relative change in trend for salinity at GPC026? What is the relative change in trend for salinity along the monitoring transects?	



N

0 0.5 1 1.5 2 km

Scale 1:125,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user.

Note: The information shown on this map is a copyright of WGA 2022

LEGEND

Shallow Fluviatile Gravel
- Surface water ecosystem

Te Hapara Monitoring Wells
- Cultural
- Cultural / Surface water ecosystem
- Surface water ecosystem

Makauri Fluviatile Gravel
- Salinity

Matokitoki Monitoring Wells

Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **20**

Gisborne MAR Model

Qualitative assessment locations of interest

4.4.2 Cultural

A number of surface water features that are at least partially dependent on groundwater discharges have been highlighted by the Mana Whenua as being of great cultural importance (Table 11). These features include:

- The Waipaoa River, especially with respect to protecting flows during summer periods
- The Awapuni Moana area, which was historically a tidal estuary and important kai moana source
- Te Maungarongo o Te Kooti Rikirangi Wetland, which is an oxbow of the Waipaoa River
- Te Waiohiharore spring

The projected effects of the modelled scenarios on these features have been evaluated based on review of a range of model outputs, including flow rates, water levels and salinity trends. The relative importance of these factors has been summarised qualitatively as described above rather than trying to reach value judgements from numerical changes.

4.4.3 Surface Water Ecosystems

In this assessment it has been assumed that increased flows from the groundwater system to surface wetlands, drains and rivers during summer will lead to increased and more stable flows through these surface water features. It has also been assumed that any increases in summer surface water flows will enable a corresponding improvement in the associated surface water ecology. Therefore, increased groundwater flows during summer to simulated surface water bodies has been qualitatively described as a potential improvement in surface water ecosystem outcomes.

4.4.4 Salinity

Groundwater quality model outputs for salinity have focused on the projected change in chloride concentrations into the future at key monitoring points. Additionally, simulated salinity trends in the Te Hapara Sand Aquifer have been monitored along three coastal transects (Figure 19). For reasons presented above (Section 4.3.3) the model indicates general expectations for increasing or decreasing chloride concentrations at these monitoring points. The effects on groundwater salinity arising from the various scenarios are summarised as qualitative outcomes from the model. i.e., The outcomes are presented as potentially improving, stable or potentially getting worse.

4.5 FINAL SCENARIO RESULTS

As discussed in the previous sections, this project incorporated groundwater modelling for two rounds of Exploratory Scenarios. The second round of scenarios was informed by the results from the first round and GDC's feedback and aspirations for the model capability. Changes between the first and second rounds of models focused on:

- Improving the coastal model structure to incorporate sea level rise projections into the model, and
- Applying a consolidated set of 'climate change' settings to produce a final baseline plus climate change scenario (Scenario 2.1) against which the effects of the other scenarios (Scenarios 3.1 through to 7.1) are considered.

The following sections provide a short description of the model stages that led to the development of the Scenario 2.1 model. The rest of Section 4.5 summarises the outcomes of the remaining Round 2 scenarios, which are considered the final exploratory scenarios under this project.

4.5.1 Scenario 1.1 – Round 1 Baseline

The Baseline Scenario (or continuation of the status quo) is the same for model Rounds 1 and 2 because climate change is not considered in this scenario. Examples of hydrographs from bores used to monitor the Te Hapara Sand and Makauri Aquifers (Figure 21) show that seasonal climate variation is considered but no further variability in annual weather patterns or allowance for sea level rise is incorporated. The initial rise in groundwater level shown in both hydrographs covers a model stabilisation period rather than an actual projected change in groundwater level.

4.5.2 Scenario 2.0 – Round 1 Baseline Plus Climate Change

The initial exploratory round of modelling incorporated a climate change scenario (Scenario 2.0) that was little different from the baseline scenario described in Section 4.5.1. As a consequence, the simulated hydrographs for monitored wells showed little change from the baseline scenario (Scenario 1; Figure 22). On review, it was determined that the Round 1 scenario incorporating climate change did not appropriately account for likely additional water demand, drought events or sea level rise. For this reason, an updated scenario for baseline plus climate change was developed for Round 2.1, as described in Section 3.5.

4.5.3 Scenario 2.1 – Round 2 Baseline Plus Climate Change

A Round 2 version of the baseline + climate change scenario (Scenario 2.1) was developed, against which all of the long-term predictive scenarios were to be considered. Scenario 2.1 incorporates a progressive increase in sea level (see GPA003 hydrograph in Figure 23), a progressive increase in groundwater abstraction in response to increasingly dry summer conditions and three drought periods (see GPJ040 hydrograph in Figure 23). Sea level rise also is incorporated into the modelling (See Baseline + Climate Change Scenario 3.5.2 for reference information). Scenario 2.1 has been used for comparison purposes going forward because it is considered to represent a more realistic projection of climate change effects together with a reasonably foreseeable irrigation response to these changes based on existing land use, compared to Scenario 2.

The results documented below are comparing the outcomes from Scenario 2.1 to those from Scenario 2, as described in Section 4.5.1.

Te Hapara / Shallow Fluviatile Aquifers. When compared to Scenario 2, adding climate change to the model results in a small increase in groundwater levels close to the coast over time. This rise results in a minor (<0.2 m) increase in late winter groundwater levels at GPA003 by 2045, linked to projected sea level rise. The Te Hapara Sand Aquifer does not react significantly to additional pumping during major drought events.

Waipaoa Aquifer. When compared to Scenario 2, Scenario 2.1 results in a slight progressive decrease in both late winter and late summer groundwater levels in the main body of the Waipaoa Aquifer. By 2045 this additional late summer drawdown of approximately 0.3 m is relatively minor, as measured at GPE040. However, additional pumping in response to extended droughts results in approximately one metre additional drawdown by 2045.

Makauri Aquifer. When compared to Scenario 2, Scenario 2.1 results in a progressive decrease in late summer groundwater levels. By 2045 this additional drawdown is relatively minor (Figure 23). However, over the longer term the additional drawdown is approximately 0.5 m. Additional pumping in response to droughts results in approximately one metre additional drawdown by 2045.

Matokitoki Aquifer. When compared to Scenario 2, incorporating climate change into the model results in a progressive decrease in late summer groundwater levels over time. The late winter groundwater levels remain similar to Scenario 2 levels. The additional pumping in response to three-year droughts results in an additional metre drawdown at GPB102.

Salinity

Water quality projections for Transects 1 and 3 (Figure 19) between the coast and Awapuni Moana indicate the movement of saline water inland through the Te Hapara Aquifer toward the Awapuni drains will be similar under both Scenario 2 and Scenario 2.1. The chloride projections for these points taking into account climate change show no substantial difference to the baseline projections (Figure 24, Figure 25).

The eastward movement of saline groundwater from the western saline area of the Makauri Aquifer is projected to continue under both Scenario 2 and Scenario 2.1.

Cultural Indicators

Groundwater levels are projected to increase at Te Waiohiharore (GPA003) by 2045, mainly linked to the projected sea level rise incorporated in Scenario 2.1. The model indicates no substantial increase in saline water movement from the ocean toward Te Waiohiharore (Figure 26).

In Scenario 2.1, groundwater levels are projected to increase at Awapuni Moana (GPC080 and GPC094), resulting in increased flows to Awapuni Moana drains. Although these changes appear mainly linked to projected sea level rise, the Scenario 2.1 model indicates no substantial increase in saline water movement from the ocean toward the drains at Awapuni Moana.

Surface Water Ecosystems

Under Scenario 2.1, summer water levels in Te Maungarongo o Te Kooti Rikirangi Wetland (GPC029) are projected to decrease by 20 mm by 2045, with winter water levels being unaffected. It is also shown that the Waipaoa River summer base flow increased due to reduced losses from river to adjacent shallow aquifers. It is also predicted to result in small increases in groundwater levels in Shallow Fluviatile Aquifer.

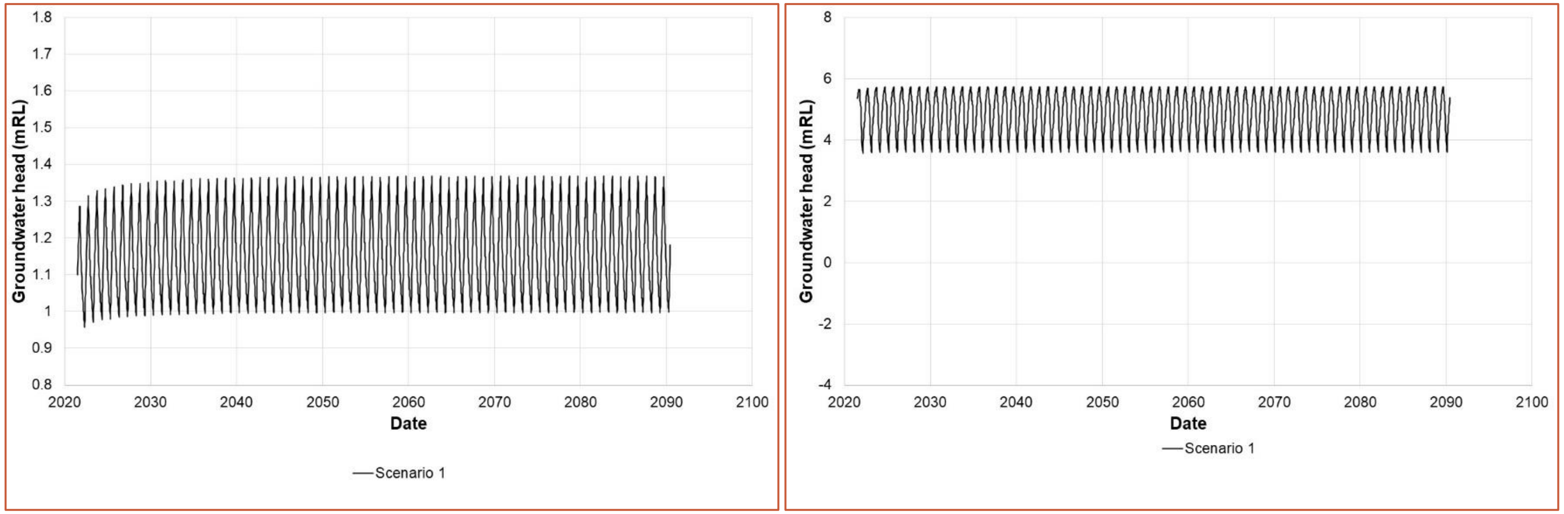


Figure 21: Scenario 1 Hydrographs for Te Hapara Sand (GPA003 left) and Makauri (GPJ040 right) Aquifers

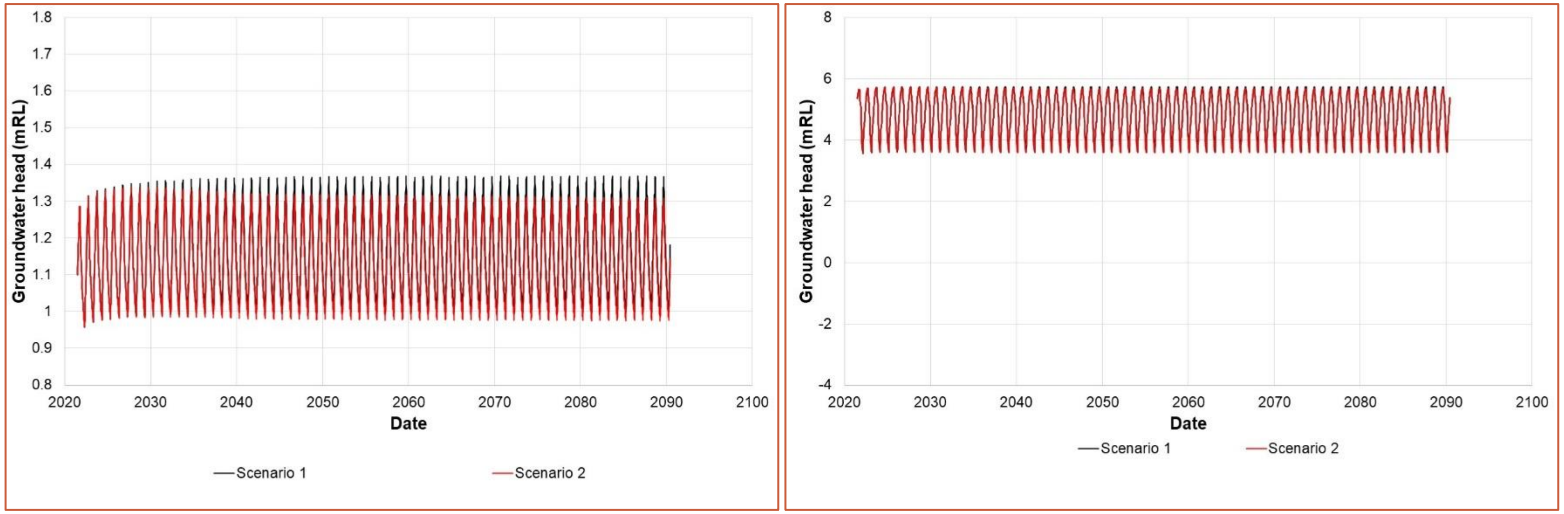


Figure 22: Scenario 2 Hydrographs for Te Hapara Sand (GPA003 left) and Makauri (GPJ040 right) Aquifers

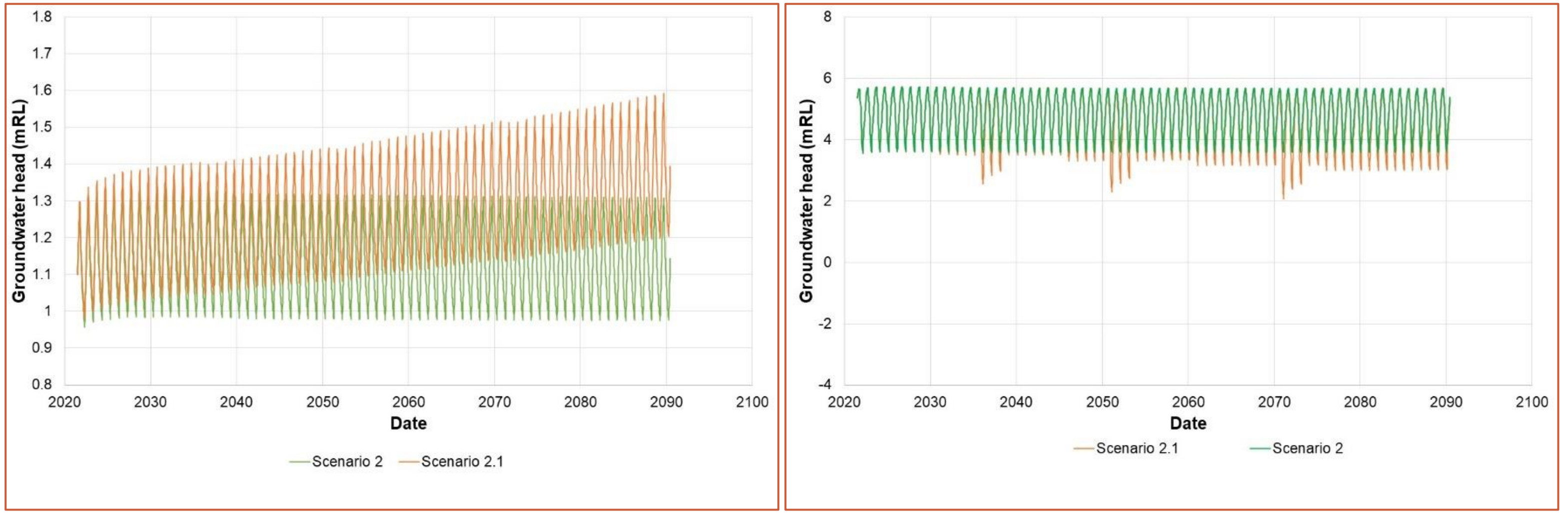


Figure 23: Scenario 2.1 Hydrographs for Te Hapara Sand (GPA003 left) and Makauri (GPJ040 right) Aquifers

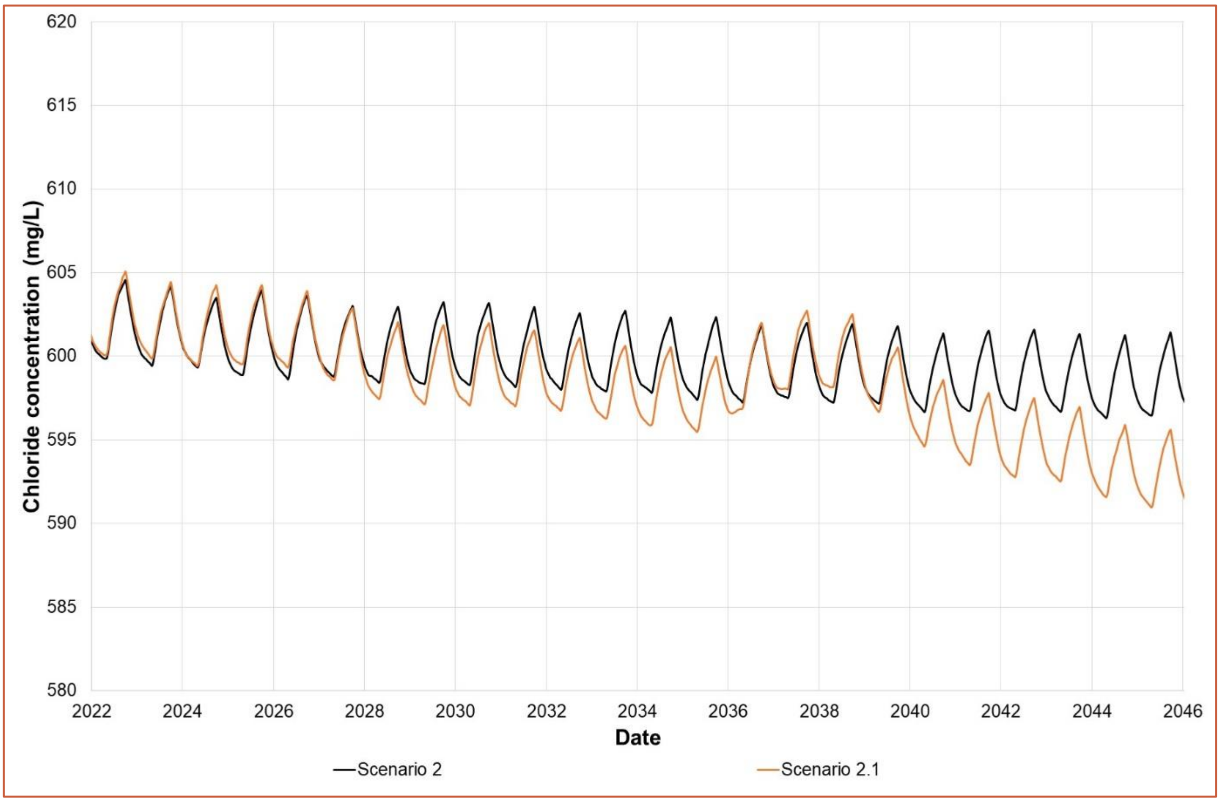


Figure 24: Baseline Chloride Projections, Seaward End (Observation Point 1) of Transect 1, Te Hapara Sand Aquifer

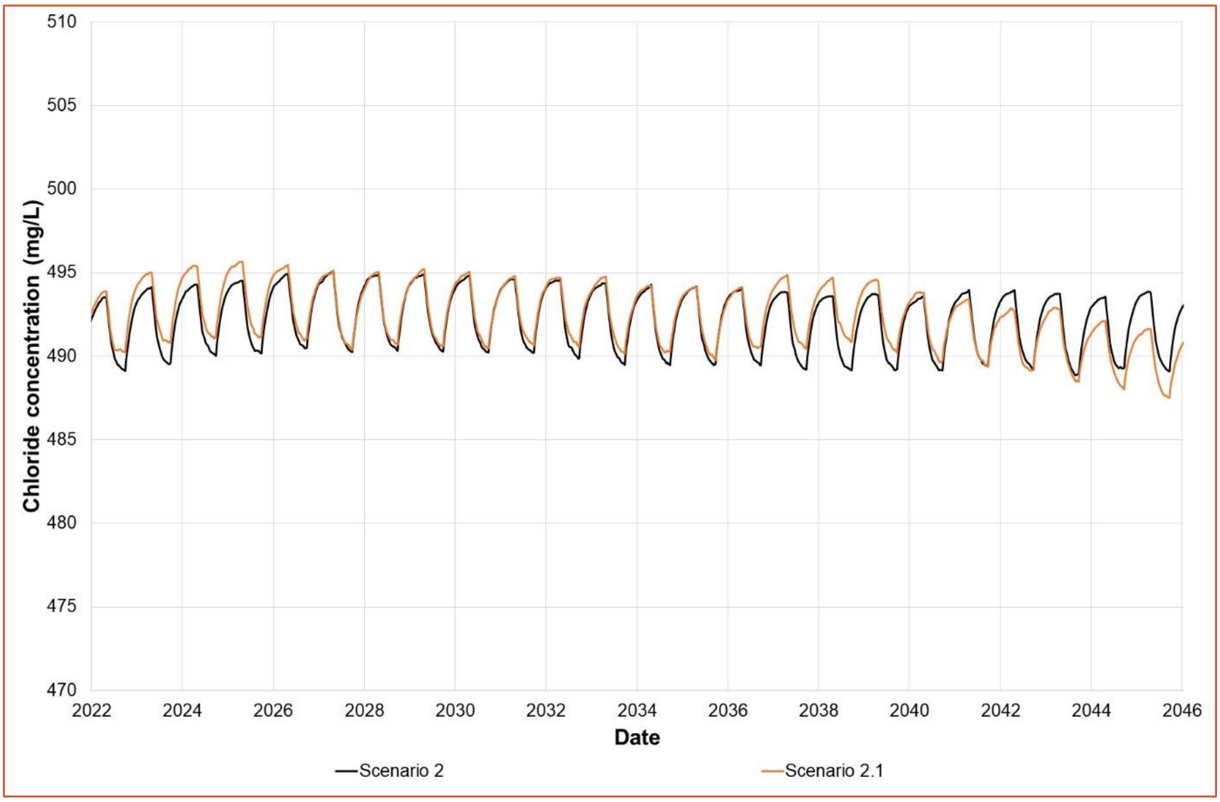


Figure 25: Baseline Chloride Projections, Seaward End (Observation Point 1) of Transect 3, Te Hapara Sand Aquifer

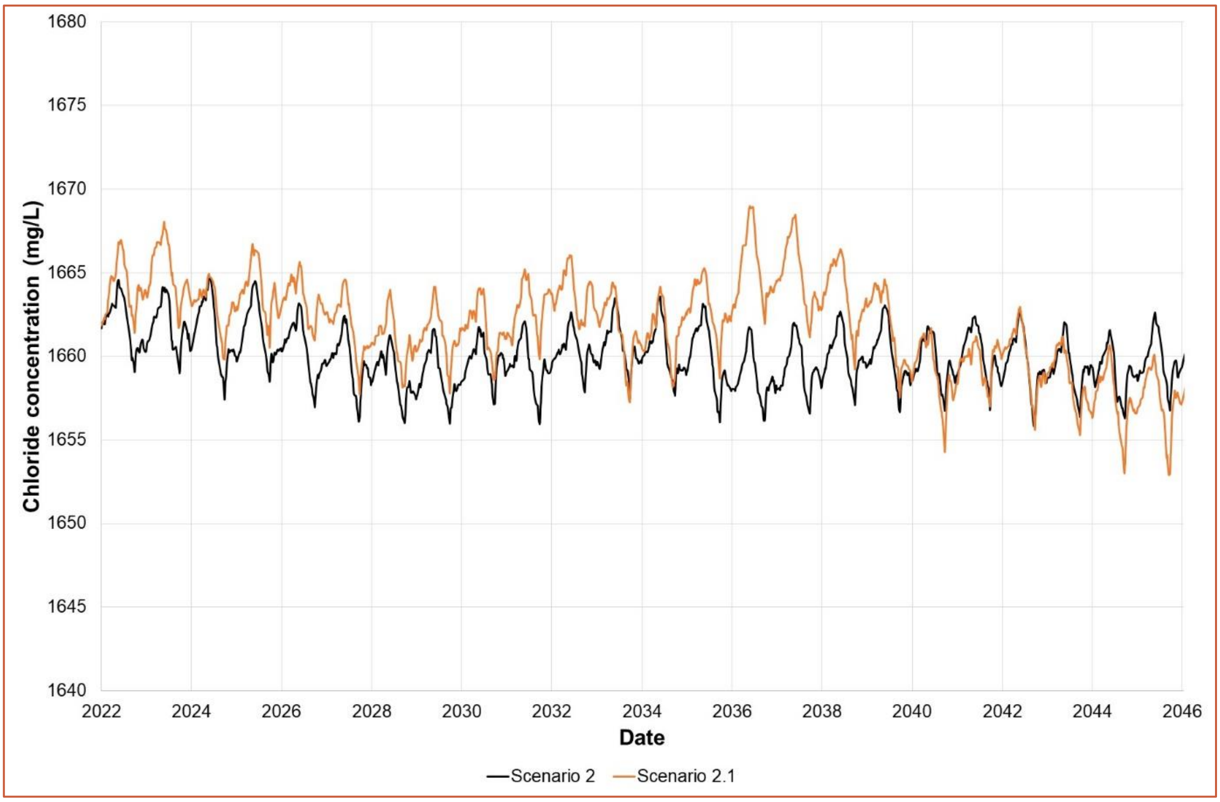


Figure 26: Baseline Chloride Projections, Seaward End (Observation Point 1) of Transect 2, Te Hapara Sand Aquifer

4.5.4 Scenario 3.1 – Natural State (3.1)

The results documented in this section for Scenario 3.1 are compared to the outcomes from Scenario 2.1 as presented in Section 4.5.3.

Drought events under Scenario 3.1 do not have a significant effect on the groundwater levels under Scenario 3.1. Droughts in each of the other modelled scenarios are predominantly expressed through increased groundwater pumping. No groundwater abstraction is simulated in Scenario 3.1, which means drought conditions have no effect on groundwater under this scenario.

Te Hapara / Shallow Fluviatile Aquifers. When compared to Scenario 2.1, ceasing groundwater pumping results in a progressive increase in groundwater level over time. This rise results in a minor (<0.1 m) increase in late winter groundwater levels linked to the projected sea level rise at GPA003 by 2045 (Figure 27).

Waipaoa Aquifer. When compared to Scenario 2.1, Scenario 3.1 results in substantially reduced summer drawdown with late summer groundwater levels being approximately 1.4 m higher at GPE040. Late winter groundwater levels are higher than under Scenario 2.1, with a difference of approximately 0.1 m by 2045.

Makauri Aquifer. When compared to Scenario 2.1, Scenario 3.1 results in greatly reduced summer drawdown with late summer groundwater levels being approximately 2 m higher at GPJ040. Late winter groundwater levels are also higher than under Scenario 2.1, with a difference of approximately 0.2 m by 2045 (Figure 28, Figure 29). The largest improvement in late winter groundwater levels is in the area shaded yellow shown in Figure 29.

Matokitoki Aquifer. When compared to Scenario 2.1, Scenario 3.1 results in a minor increase in late winter groundwater levels at GPB102 in the Matokitoki Aquifer by 2045. Although a seasonal fluctuation is still evident, the lack of pumping leads to groundwater levels being approximately 1.5 m higher in late summer.

Salinity

Water quality projections for Transects 1 and 3 (Figure 19) between the coast and Awapuni Moana indicate the movement of saline water inland toward the Awapuni drains under Scenario 3.1 will continue in response to sea level rise.

The eastward movement of saline water from the western saline area of the Makauri Aquifer is projected to cease under Scenario 3.1. However, there is no indication that observed historical increases in salinity in the aquifer will be reversed.

Cultural Indicators

Under Scenario 3.1, groundwater levels are projected to increase at Te Waiohiharore (GPA003) by 2045 but this appears to be mainly linked to projected sea level rise rather than the close of abstraction. The model indicates no substantial increase in saline water movement from the ocean toward Te Waiohiharore.

Groundwater levels under Scenario 3.1 increased at Awapuni Moana (GPC080 and GPC094), resulting in increased flows to Awapuni Moana drains. Although these changes appear mainly linked to projected sea level rise, the model indicates no substantial increase in saline water movement from the ocean toward the drains at Awapuni Moana.

Surface Water Ecosystems

Waipaoa River summer base flows are projected to increase under Scenario 3.1, due to reduced losses from the river to adjacent shallow aquifers. However, changes in groundwater levels in the adjacent Shallow Fluviatile Aquifer are minimal.

Summer water levels in Te Maungarongo o Te Kooti Rikirangi Wetland (GPC029) are projected to increase by 50 mm by 2045, with winter water levels being unaffected.

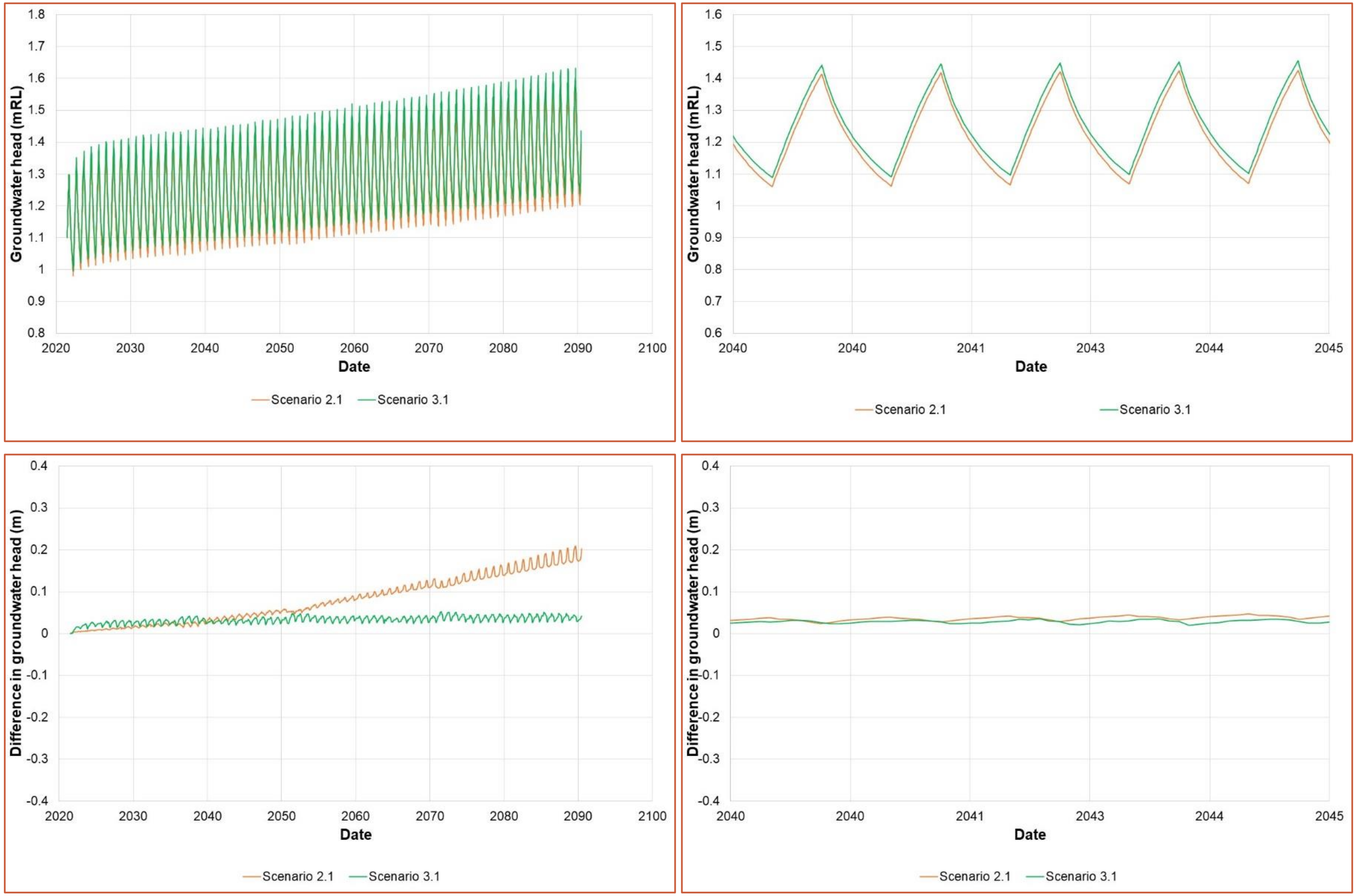


Figure 27: Effects of Scenario 3.1 on Te Hapara Sand Aquifer at GPA003

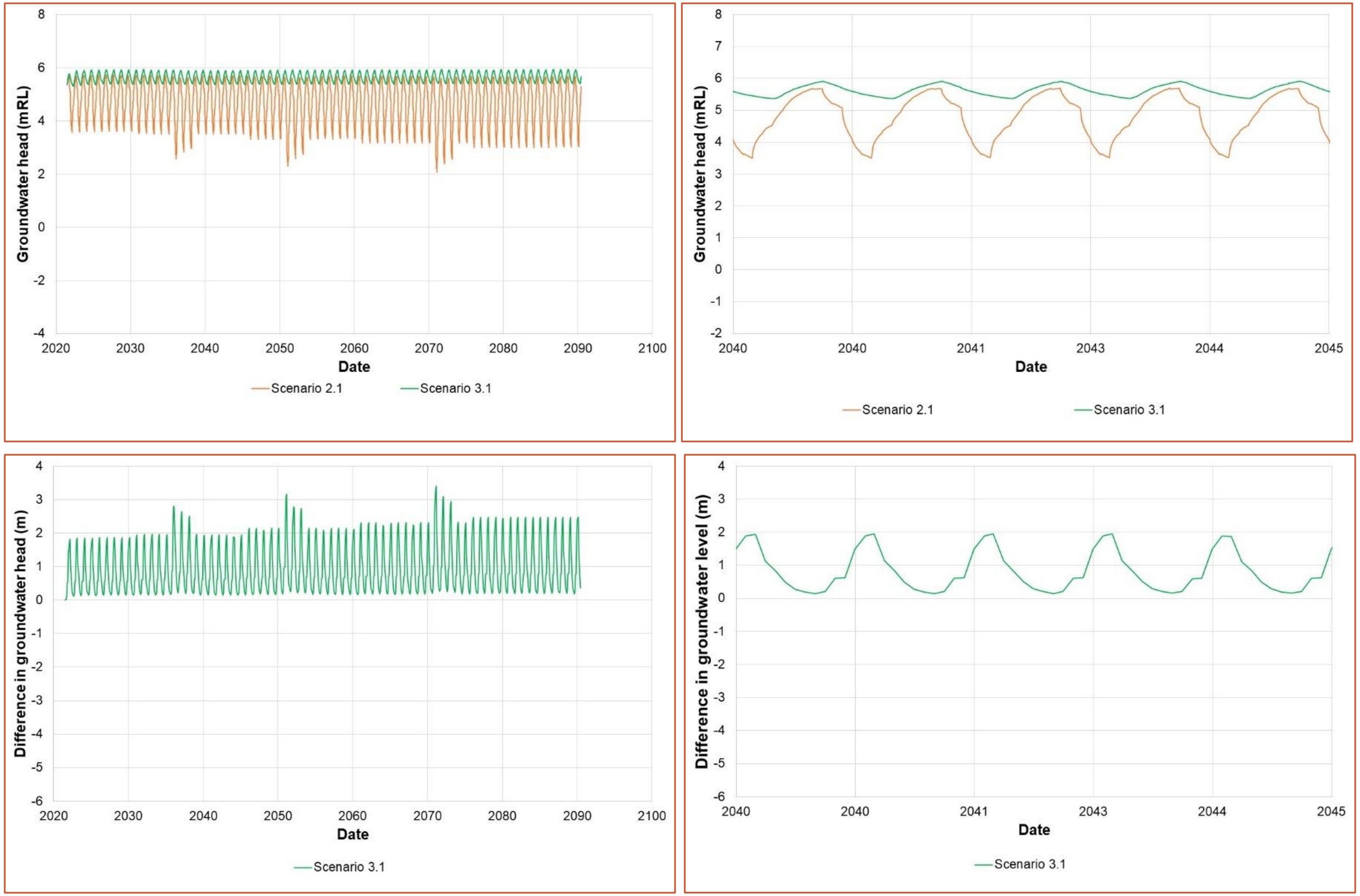


Figure 28: Effects of Scenario 3.1 on Makauri Aquifer at GPJ040

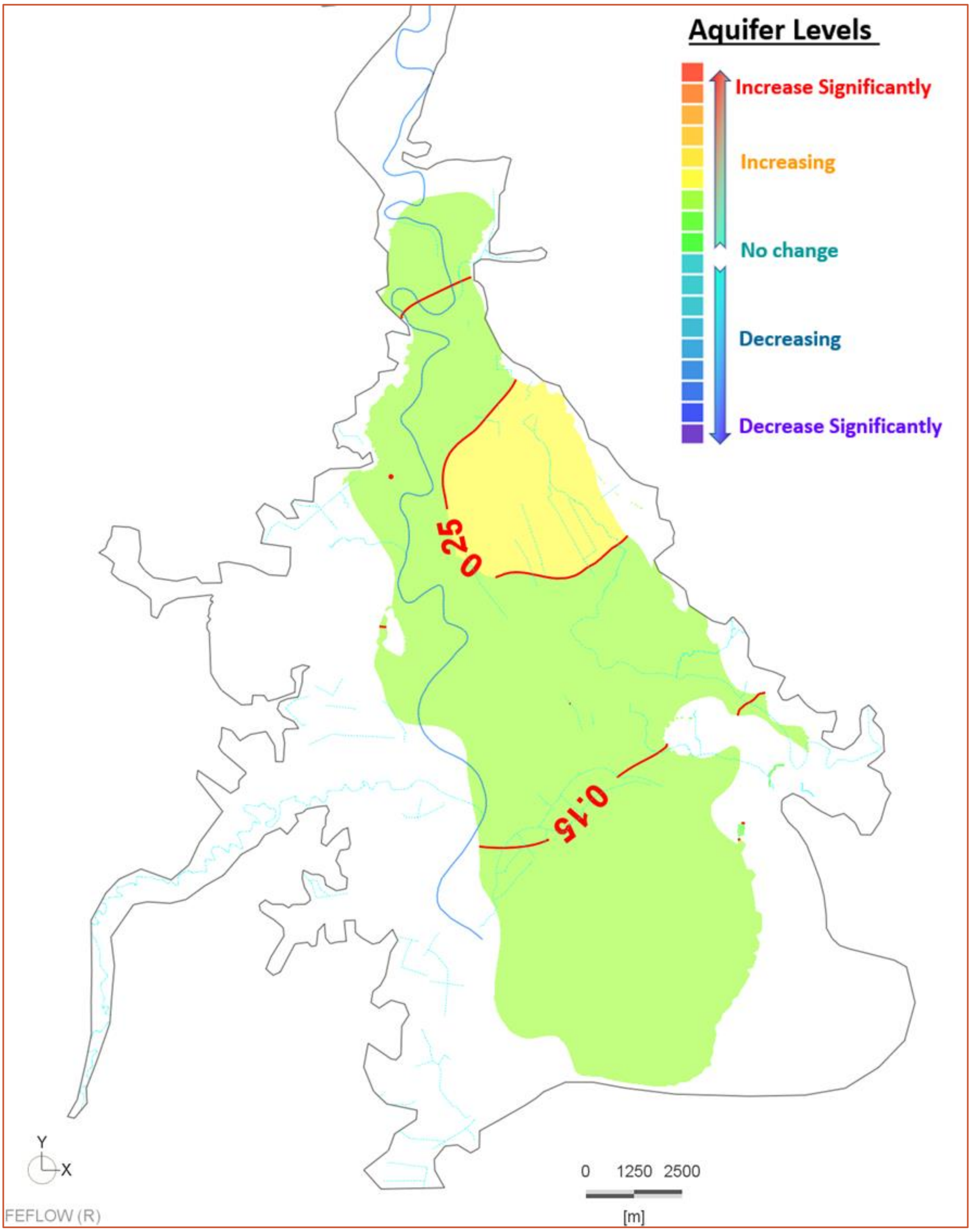


Figure 29: Effects of Scenario 3.1 on Makauri Aquifer – September 2045

4.5.5 Scenario 4.1 – Current Consented Allocation

The results documented in this section are compared to the outcomes from Scenario 2.1 presented in Section 4.5.3.

The effects of droughts are increased under this scenario as the modelled groundwater pumping is increased to offset the drought conditions.

Te Hapara / Shallow Fluviatile Aquifers. When compared to the Scenario 2.1, increasing abstraction to the currently consented limits (Scenario 4.1) initially results in a small additional drawdown in groundwater level. Over time this additional drawdown is offset near the coast (e.g., at GPA003) by the rise in sea level leading to a small long-term increase in groundwater level compared to the baseline. Additional pumping during drought periods results in minor increased drawdown throughout the drought years.

Waipaoa Aquifer. When compared to Scenario 2.1, Scenario 4.1 results in a substantial decrease in late summer groundwater levels in the main body of the Waipaoa Aquifer. By 2045 this additional late summer drawdown is approximately 4.2 m, as measured at GPE040. Increased pumping in response to extended droughts results in additional drawdowns of approximately 7.3 m compared to Scenario 2.1 by 2045. Additional drawdown under late winter conditions is approximately 0.3 m by 2045.

Makauri Aquifer. When compared to Scenario 2.1, Scenario 4.1 results in a substantial increase in drawdown. At GPJ040 there is an increase in drawdown of approximately 3 m by 2045, with additional pumping during drought periods leading to further drawdown of approximately 1.8 m (Figure 30 and Figure 30). The Makauri Aquifer reacts more than the other aquifers under Scenario 4.1 because it is the main focus of groundwater abstraction for horticultural use. Groundwater levels in the Makauri Aquifer already drop below today's mean sea level due to summer pumping and the additional abstraction is projected to worsen that situation.

Matokitoki Aquifer. When compared to the Scenario 2.1, Scenario 4.1 results in groundwater being drawn down by a further 3.1 m at GPB102 in the Matokitoki Aquifer by 2045. Late winter groundwater levels are also drawn down by approximately 0.4 m. In response to the simulated droughts the drawdown of up to 5.2 m means groundwater levels in the Matokitoki Aquifer drop below today's mean sea level.

Salinity

Scenario 4.1 water quality projections for Transects 1 and 3 (Figure 19) between the coast and Awapuni Moana indicate the movement of saline water inland toward the Awapuni drains will increase in response to sea level rise and the increase in groundwater abstraction.

Under Scenario 4.1 the eastward movement of saline water from the western saline area of the Makauri Aquifer is projected to increase in response to increased drawdown in the main areas of horticultural abstraction.

Cultural Indicators

Groundwater levels increased at Te Waiohiharore (GPA003) by 2045 but this is mainly linked to projected sea level rise. Under Scenario 4.1 the model indicates a small increase in saline water movement from the ocean toward Te Waiohiharore.

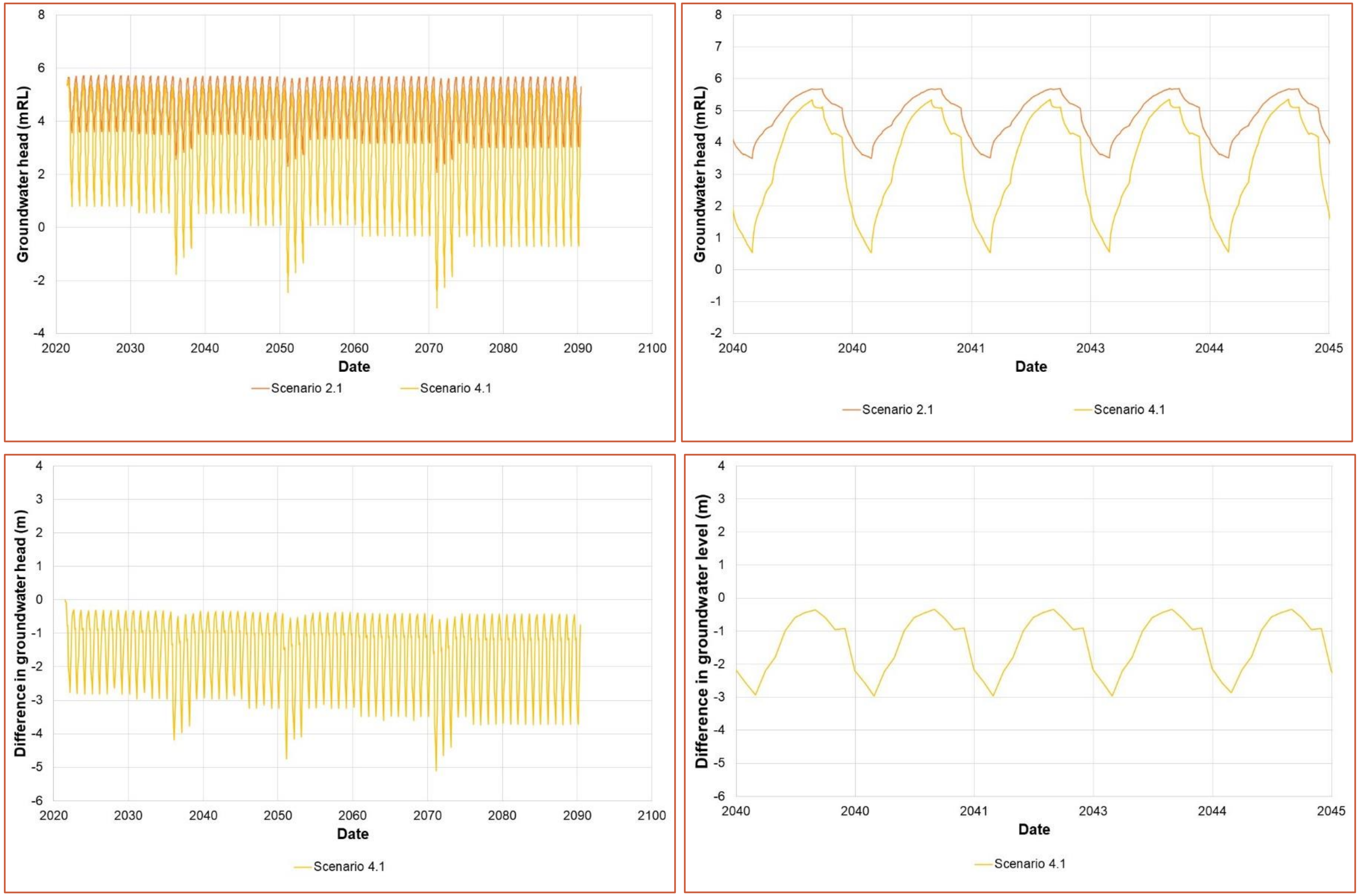


Figure 30: Effects of Scenario 4.1 on Makauri Aquifer at GPJ040

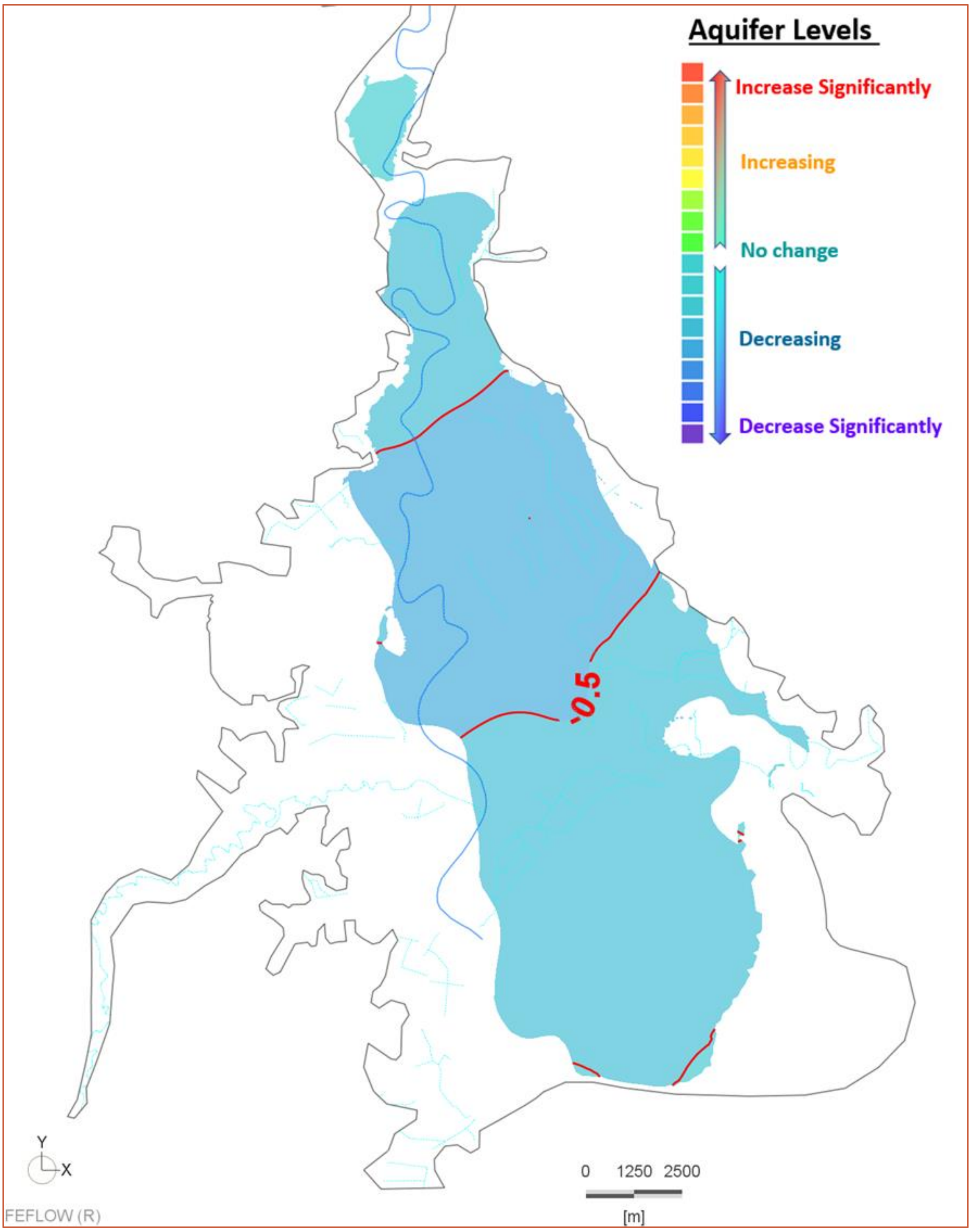


Figure 31: Effects of Scenario 4.1 on Makauri Aquifer – September 2045

Under Scenario 4.1 groundwater levels decreased or showed no change at Awapuni Moana (GPC080 and GPC094) through to 2045. Flows of groundwater to Awapuni Moana drains decreased through the coming five decades although this trend reversed toward the end of the simulated period due to ongoing sea level rise. These changes are mainly linked to projected sea level rise. Sea level rise presents ongoing risk of increased salinity in groundwater and surface drains at Awapuni Moana under this scenario.

Surface Water Ecosystems

Under Scenario 4.1 Waipaoa River summer base flow decreases due to increased losses from the river to adjacent shallow aquifers. Changes in groundwater levels in the adjacent Shallow Fluviatile Aquifer are minimal.

Summer water levels in Te Maungarongo o Te Kooti Rikirangi Wetland (GPC029) decreased by 2045, with winter water levels being unaffected. The projected decrease of approximately 200 mm and the associated decrease in wetland throughflows during summer may have an effect on the wetland ecosystem.

4.5.6 Scenario 5.1 – Groundwater Replenishment (MAR)

The results documented in this section are compared to the outcomes from the Scenario 2.1 presented in Section 4.5.3.

Te Hapara / Shallow Fluviatile Aquifers. When compared to Scenario 2.1, Scenario 5.1 results in no significant change to groundwater levels in the shallow aquifers.

Waipaoa Aquifer. When compared to Scenario 2.1, the application of enhanced replenishment results in small increases in groundwater levels in the main body of the Waipaoa Aquifer during both late summer and late winter months by 2045. These increases are approximately 0.75 m in late winter and 0.4 m in late summer. Similar seasonal increases in groundwater levels compared to Scenario 2.1 occur under drought conditions.

Makauri Aquifer. When compared to Scenario 2.1, Scenario 5.1 results in an increase in groundwater levels exceeding two metres at GPJ040 by 2045. As the simulated replenishment is focused on the irrigation shoulder seasons, there is only a minor increase in the aquifer groundwater levels through the winter (See Figure 31 and Figure 32).

Matokitoki Aquifer. When compared to Scenario 2.1, Scenario 5.1 results in an increase in groundwater levels of approximately 0.9 m during late summer at GPB102 in the Matokitoki Aquifer by 2045. In contrast, the MAR programme does not significantly influence late winter groundwater levels.

Salinity

Under Scenario 5.1, water quality projections for Transects 1 and 3 (Figure 19) between the coast and Awapuni Moana indicate the movement of saline water inland toward the Awapuni drains will continue in response to sea level rise.

The aquifer replenishment scenario is the only scenario whereby a clear improvement (decrease) in chloride concentrations in groundwater along the western side of the Makauri Aquifer is projected through to 2045.

Cultural Indicators

Scenario 5.1 produces no significant difference from Scenario 2.1 when considering the effects on Te Waiohiharore, Te Maungarongo o Te Kooti Rikirangi Wetland and the Awapuni Moana area.

Surface Water Ecosystems

Scenario 5.1 produces no significant difference from Scenario 2.1 when considering the effects on surface water bodies and the associated ecosystems.

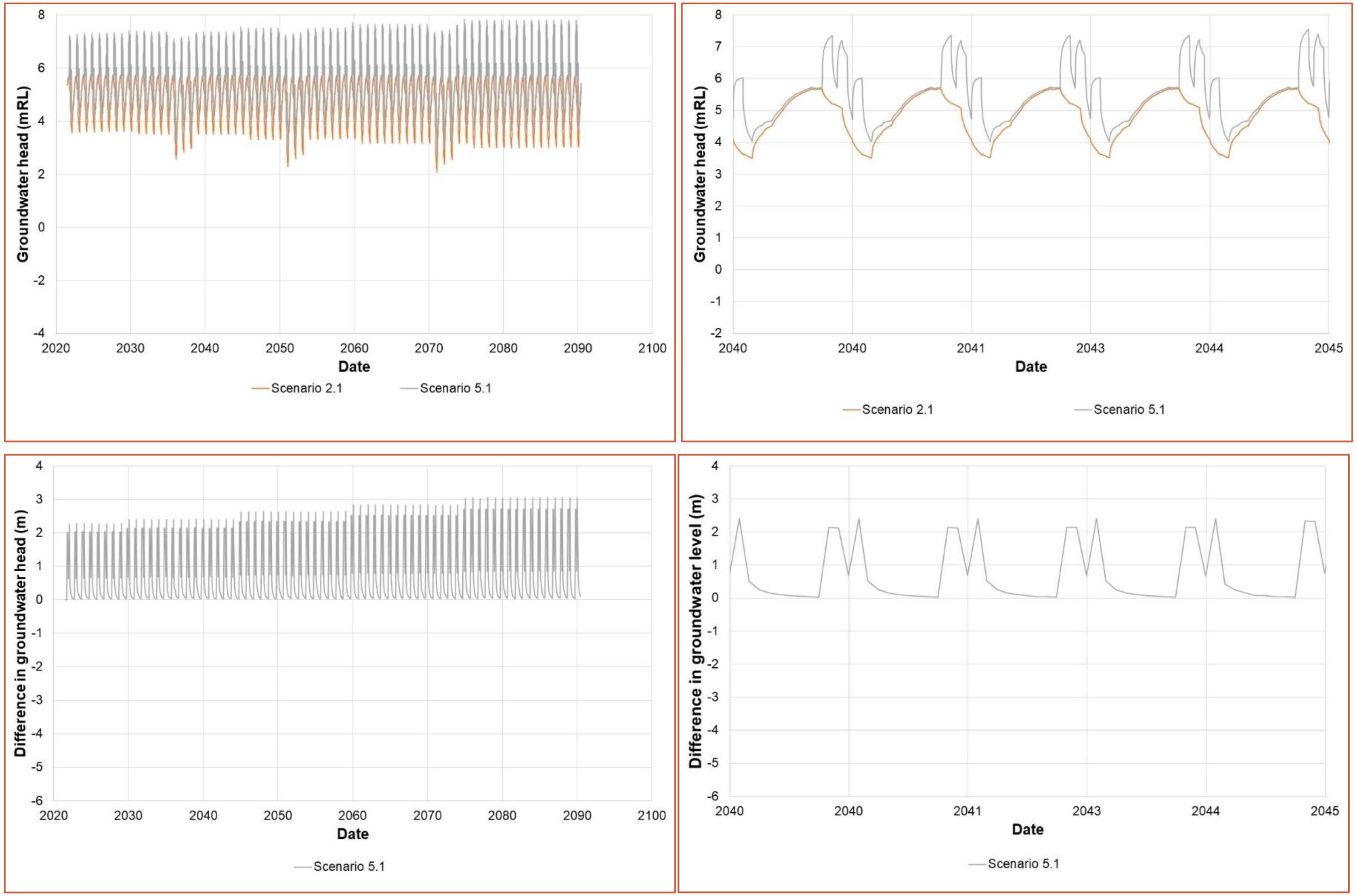


Figure 32: Effects of Groundwater Replenishment Scenario on Makauri Aquifer at GPJ040

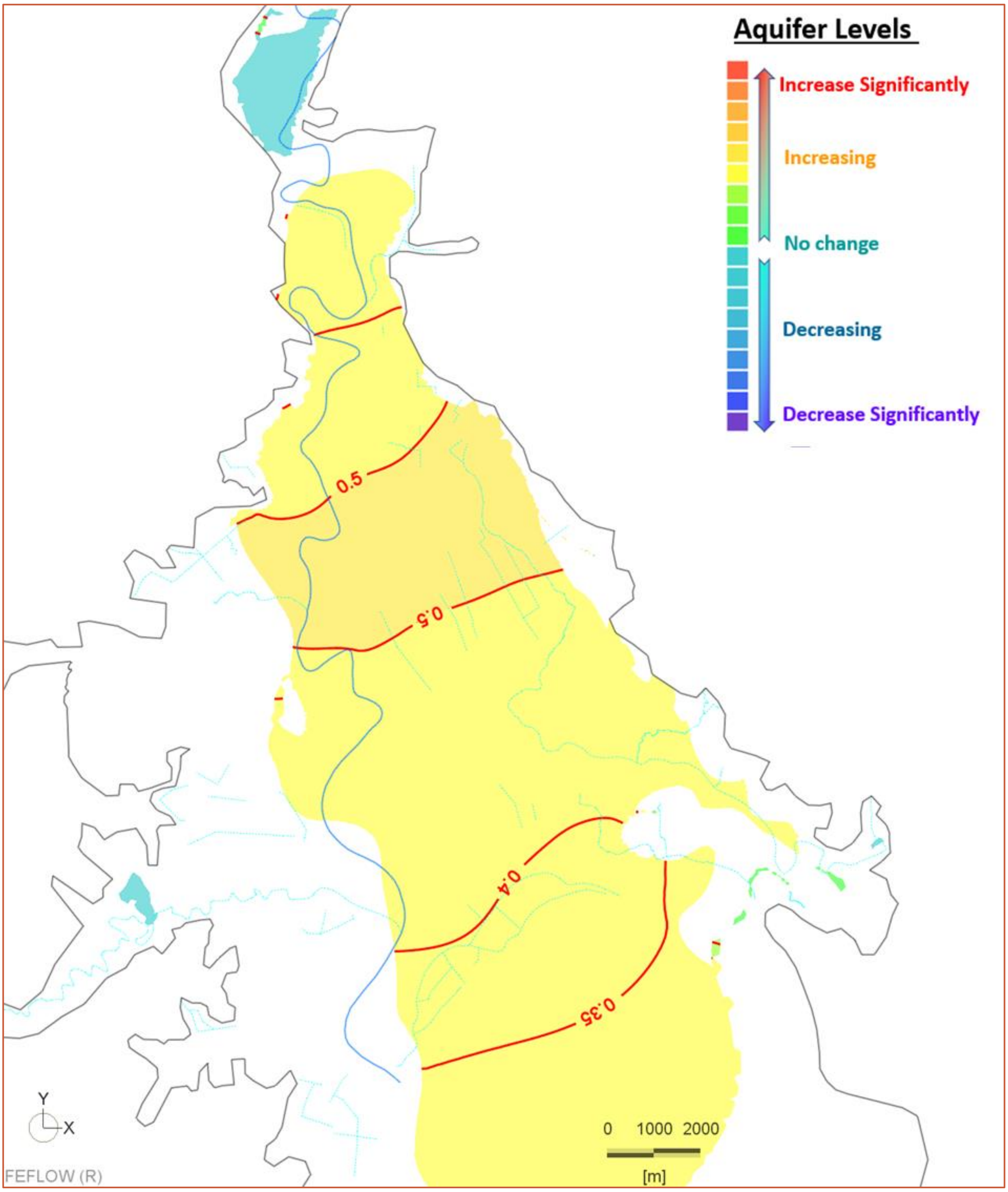


Figure 33: Effects of Groundwater Replenishment (5.1) on Makauri Aquifer – February 2090

4.5.7 Scenario 7.1 – Sustainable Allocation

The modelling undertaken to determine a 'sustainable allocation' scenario was iterative, where abstraction rates were adjusted and the model re-run to establish aquifer responses. The amount of annual groundwater abstraction was reduced to the point whereby groundwater levels do not drop below the Scenario 2.1 levels in late summer through to 2050. Abstraction was adjusted on a percentage basis, applied equally to all production bores simulated in the model. As different aquifers respond to abstraction changes in different ways, the main focus of Scenario 7.1 modelling was to manage groundwater pressures in the Makauri Aquifer, which is currently subject to the greatest abstraction stress.

Climate driven stresses on the groundwater system under 'normal' years are projected to change over time. Furthermore, GDC considered it unreasonable to prevent users from temporarily increasing seasonal abstraction in response to major drought events. Therefore, the model results do not indicate a single 'sustainable allocation' value that applies consistently into the future.

The iterative modelling results indicate that a reduction in total groundwater abstraction of 15% from the amounts allowed for under Scenario 2.1 should enable groundwater levels to be managed without further drawdown in summer levels below those already observed. In effect, the drawdowns simulated during the third drought event do not exceed the groundwater drawdowns that have been observed in response to historical drought events.

For comparison purposes, groundwater abstraction from the Poverty Bay Flats aquifers has been documented for six separate years, as identified in Figure 34. These years are paired, with each pair including the final 'normal' rainfall year before a simulated drought and the first year of the following drought. The total groundwater volumes taken from the aquifers during these years are presented in Table 12.

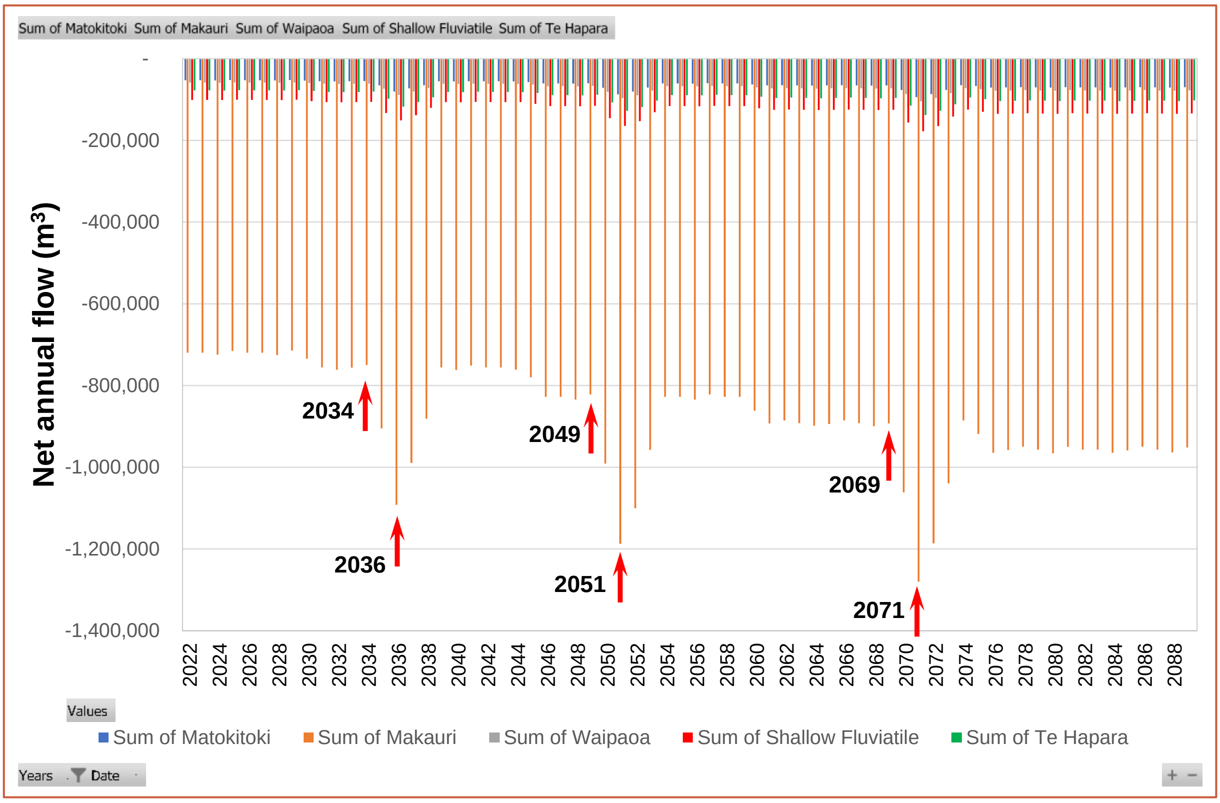


Figure 34. Interrogated for Groundwater Take Volumes Showing Simulated Influence of Increasing Climate Change Effects (All Aquifers)

The annual abstraction volumes presented in Table 12 and Table 13 indicate that the aquifers have the capacity to provide water to deal with exceptional climate events. This conclusion reflects the observed recovery in aquifer pressures following historical droughts, as documented in Section 3.5.1.

Defining a 'sustainable allocation' based on the abstraction rates simulated for 'normal' rainfall years under Scenario 7.1 does not consider the capacity of the aquifers to respond to abnormal events. However, defining a 'sustainable allocation' based on the abstraction calculated as necessary to deal with the simulated drought years under Scenario 7.1 would be equally inappropriate, as full utilisation of such an annual allocation would lead to outcomes like those generated by Scenario 4.1.

Table 12: Groundwater Volumes Taken at Selected Years from Defined Aquifers.

Year	MATOKITOKI AQUIFER	MAKAURI AQUIFER	WAIPAOA AQUIFER	SHALLOW FLUVIATILE GRAVEL AQUIFER	TE HAPARA SAND AQUIFER
2034 (normal)	54,936	749,751	61,039	105,566	80,712
2036 (drought)	80,267	1,092,169	88,997	151,064	117,517
2049 (normal)	60,244	821,680	66,877	115,621	88,438
2051 (drought)	87,318	1,187,168	96,689	164,659	127,707
2069 (normal)	65,407	892,940	72,735	125,256	96,153
2071 (drought)	94,152	1,280,076	104,256	177,546	137,701

Table 13: Total Groundwater Volumes Abstracted Under Scenario 7.1

PERIOD	SCENARIO 2.1 ABSTRACTION (m^3/year) (1)	SCENARIO 7.1 ABSTRACTION (m^3/year) (2)
2029 through to 2044, 'normal' years only.	1,247,400	1,060,290
2035/36 (First simulated drought - Year 1)	1,862,210	1,582,879
2036/37 (First simulated drought - Year 2)	1,680,707	1,428,601
2037/38 (First simulated drought - Year 3)	1,593,709	1,354,653
2044 through to 2059, 'normal' years only.	1,366,200	1,161,270
2050/51 (Second simulated drought - Year 1)	2,199,181	1,869,304
2051/52 (Second simulated drought - Year 2)	1,984,835	1,687,110
2052/53 (Second simulated drought - Year 3)	1,882,094	1,599,780

Note: 1) Model results sourced from AQUASOIL (2022) report, Table 5-5.
2) Model results sourced from AQUASOIL (2022) report, Table 5-9. Totals differ slightly from the sum of aquifer abstractions presented in Table 12 due to differences in the calculation periods.

The results documented in this section are compared to the outcomes from Scenario 2.1 presented in Section 4.5.3.

Te Hapara/Shallow Fluviatile Aquifers. When compared to Scenario 2.1, Scenario 7.1 results in a small progressive increase in groundwater level over time. This increase is practically the same as that resulting from the baseline + climate change scenario (Figure 35).

Waipaoa Aquifer. When compared to Scenario 2.1, Scenario 7.1 results in insignificant changes in groundwater levels during late winter months by 2045. Small increases of approximately 0.3 m occur in groundwater levels in the main body of the Waipaoa Aquifer during late summer months by 2045. Similar increases in late summer groundwater levels compared to Scenario 2.1 occur under drought conditions.

Makauri Aquifer. When compared to Scenario 2.1, Scenario 7.1 results in a small increase in groundwater levels of approximately 0.3 m during the late summer irrigation period at GPJ040 by 2045. Increases during other times of the year are less (Figure 36 and Figure 37).

Matokitoki Aquifer. When compared to Scenario 2.1, Scenario 7.1 results in an increase in groundwater levels of approximately 0.2 m during late summer at GPB102 by 2045. The reduction in pumping does not have a significant effect on late winter groundwater levels.

Salinity

Water quality projections for Transects 1 and 3 (Figure 19) between the coast and Awapuni Moana indicate the movement of saline water inland toward the Awapuni drains shown no significant difference from Scenario 2.1 outcomes.

Under Scenario 7.1 the eastward movement of saline water from the western saline area of the Makauri Aquifer is projected to continue but not increase in the rate of movement.

Cultural Indicators

Under Scenario 7.1 groundwater levels increased at Te Waiohiharore (GPA003) by 2045 but this is mainly linked to projected sea level rise. The model indicates no substantial increase in saline water movement from the ocean toward Te Waiohiharore.

Under Scenario 7.1 groundwater levels increased at Awapuni Moana (GPC080 and GPC094), resulting in increased flows to Awapuni Moana drains. Although these changes appear mainly linked to projected sea level rise, the model indicates no substantial increase in saline water movement from the ocean toward the drains at Awapuni Moana.

Surface Water Ecosystems

Under Scenario 7.1 summer water levels in Te Maungarongo o Te Kooti Rikirangi Wetland (GPC029) only decrease by 2045, with winter water levels being unaffected. The projected change of 20 mm is unlikely to have a significant effect on the wetland ecosystem.

Under Scenario 7.1 Waipaoa River summer base flow increased due to reduced losses from the river to adjacent shallow aquifers. Changes in groundwater levels in the adjacent Shallow Fluviatile Aquifer are minimal.

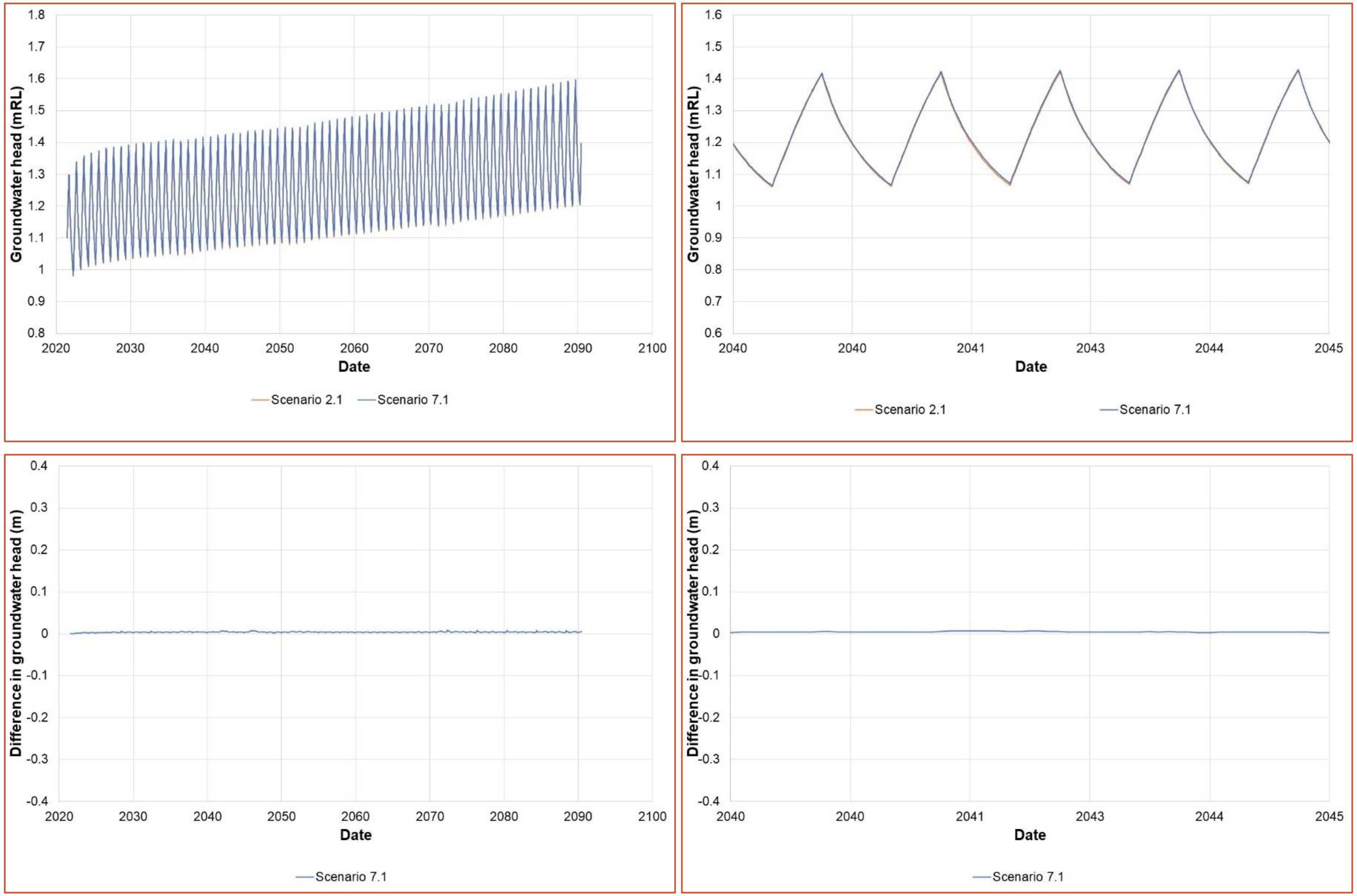


Figure 35: Effects of Sustainable Allocation Scenario on Te Hapara Sand Aquifer at GPA003

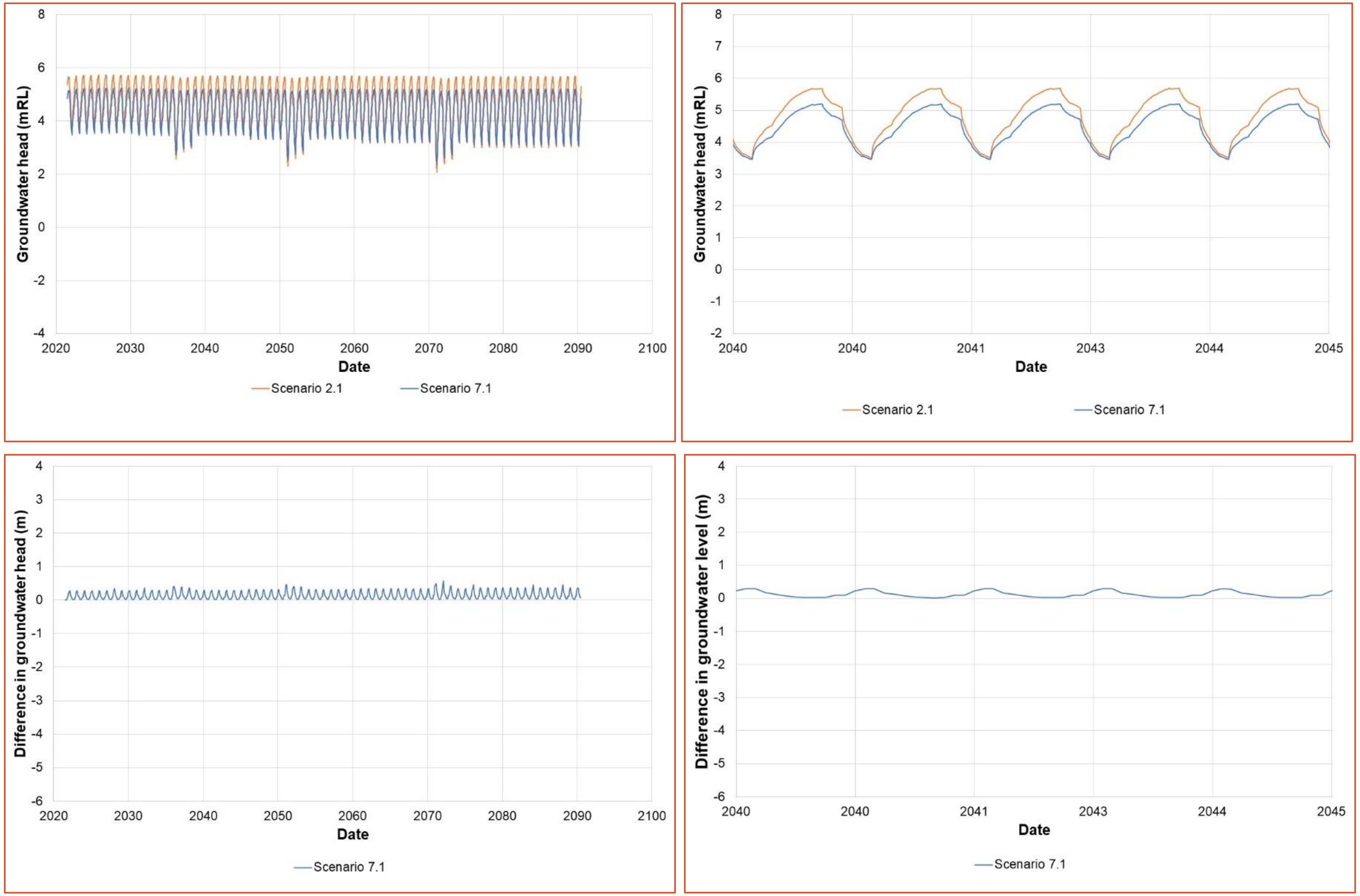


Figure 36: Effects of Sustainable Allocation Scenario on Makauri Aquifer at GPJ040

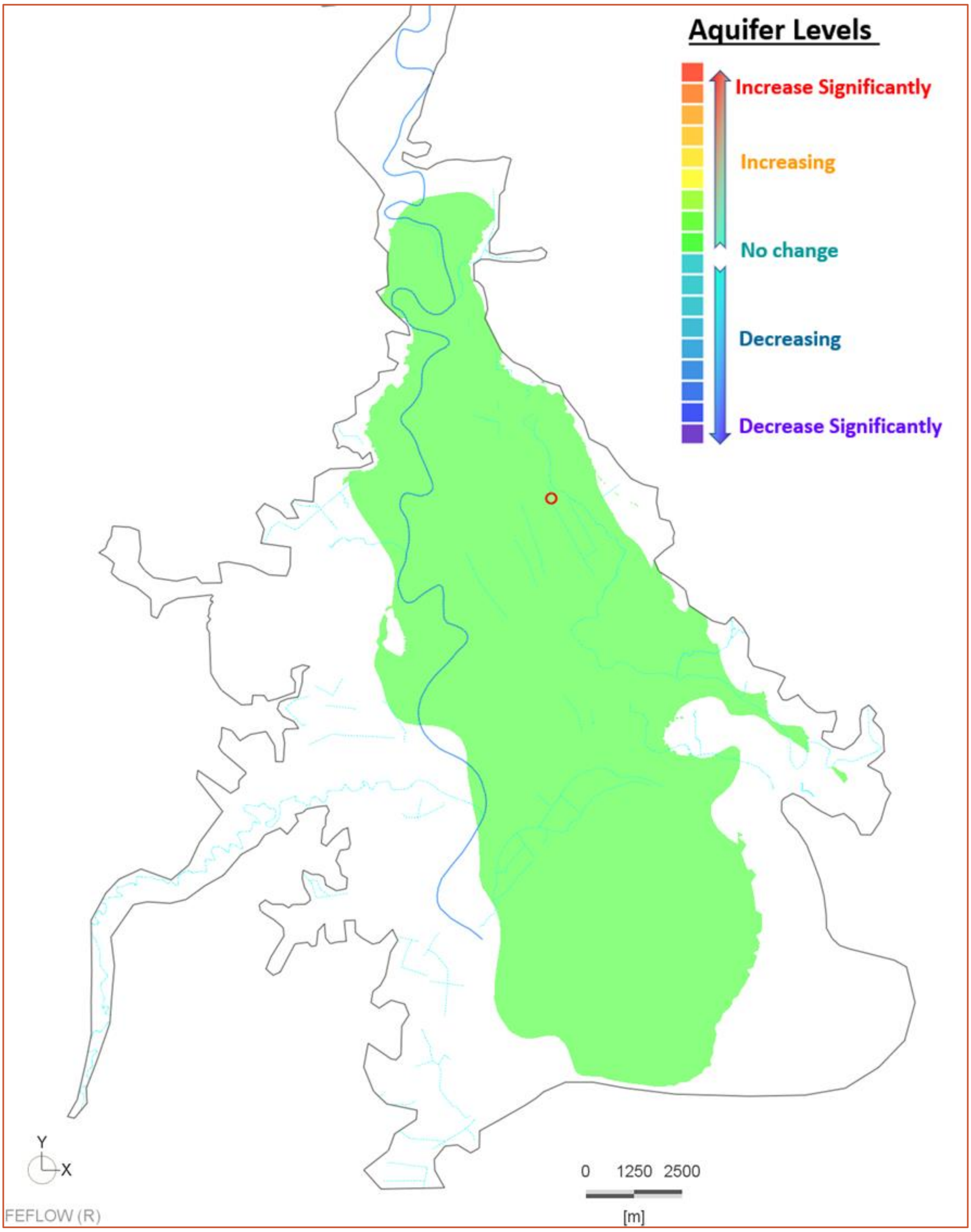


Figure 37: Effects of Scenario 7.1 on Makauri Aquifer – September 2045

4.6 AQUIFER WATER BALANCES

4.6.1 Introduction

Water balances for the aquifers underlying the Poverty Bay Flats for each of the simulated Round 2 scenarios are summarised in tables presented in Appendix C. The water balance outcomes presented in Appendix C focus on total annual inflow and total outflow volumes for individual aquifers and annual pumped MAR and abstraction volumes for the same aquifers.

Spreadsheets providing full model outcomes in terms of aquifer groundwater flow balances for each of the Round 2 simulations have been provided separately to GDC. These spreadsheets provide simulation results for each modelled timestep and compilations of inflows and outflows on an annual basis.

Volumetric groundwater storage has not been tracked in the FEFLOW model, with groundwater levels being used as the key indicator of storage condition. The main reasons groundwater storage has not been tracked for the aquifers are:

1. The confined aquifers have a negligible change in stored water, year on year. Seasonal changes in groundwater storage in the underlying and overlying aquitards may equal or exceed the storage changes in a confined aquifer. Groundwater storage changes in the aquitards are difficult to quantify and to allocate to individual aquifers for water budget purposes.
2. There is substantially less information available on aquifer and aquitard storage characteristics than on the permeability characteristics for the corresponding units. Therefore, the uncertainty attached to any calculated storage is large relative to any potential annual change in annual water storage.
3. The annual changes in groundwater storage in the confined aquifers are likely to be very small compared to the overall volume of groundwater stored in the aquifers and aquitards underlying the Poverty Bay Flats.
4. Operationally, changes in groundwater pressures and levels are far more important and can be more easily monitored than changes in stored water volumes.

For the purposes of calculating aquifer water budgets, it is assumed that annual changes in stored water volumes within each aquifer are negligible.

4.6.2 Reporting Periods

For the purposes of Regional Plan reviews, GDC requested aquifer budgets for the years 2025, 2035 and 2045. However, the agreed model scenario setups do not lend themselves well to reporting aquifer budgets for these precise years. For example, 2035 is impacted by the early stages of a simulated drought season (Figure 38). Additionally, model results vary slightly year on year, even if the model input stresses in terms of rainfall and irrigation demands remain stable for several years. Therefore, ‘normal’ years are better evaluated by averaging the results from periods covering several similar years.

Furthermore, planning groundwater budgets based on ‘normal’ year rainfall and irrigation requirements does not take into account the need to plan for and accommodate significant drought periods. Calculating fixed groundwater allocations based on ‘normal’ years may not provide sufficient flexibility to address short term water supply security issues that may arise out of significant droughts. Therefore, aquifer water budgets for key drought years have also been evaluated.

To better inform GDC on the simulated annual groundwater budgets for each scenario, a series of reporting periods have been designated, as shown in Figure 38. Average annual water budgets for each simulated scenario are calculated for each of the designated reporting periods. In the case of the deepest drought years, identified by arrows in Figure 38, the budgets relate to a single modelled year. Note: the modelled year is the calendar year (Jan to Dec) rather than an irrigation year (Jul to Jun). The tables presented in Appendix C summarising annual water budgets under each model scenario has one column covering each designated reporting period. The groundwater budgets for the Makauri Aquifer presented in Section 4.6.3 are also summarised against these reporting periods. The 'normal' periods and drought years identified in Figure 38 approximately correspond to the reporting years for the assessment of annual flow budgets to surface waters (Figure 34).

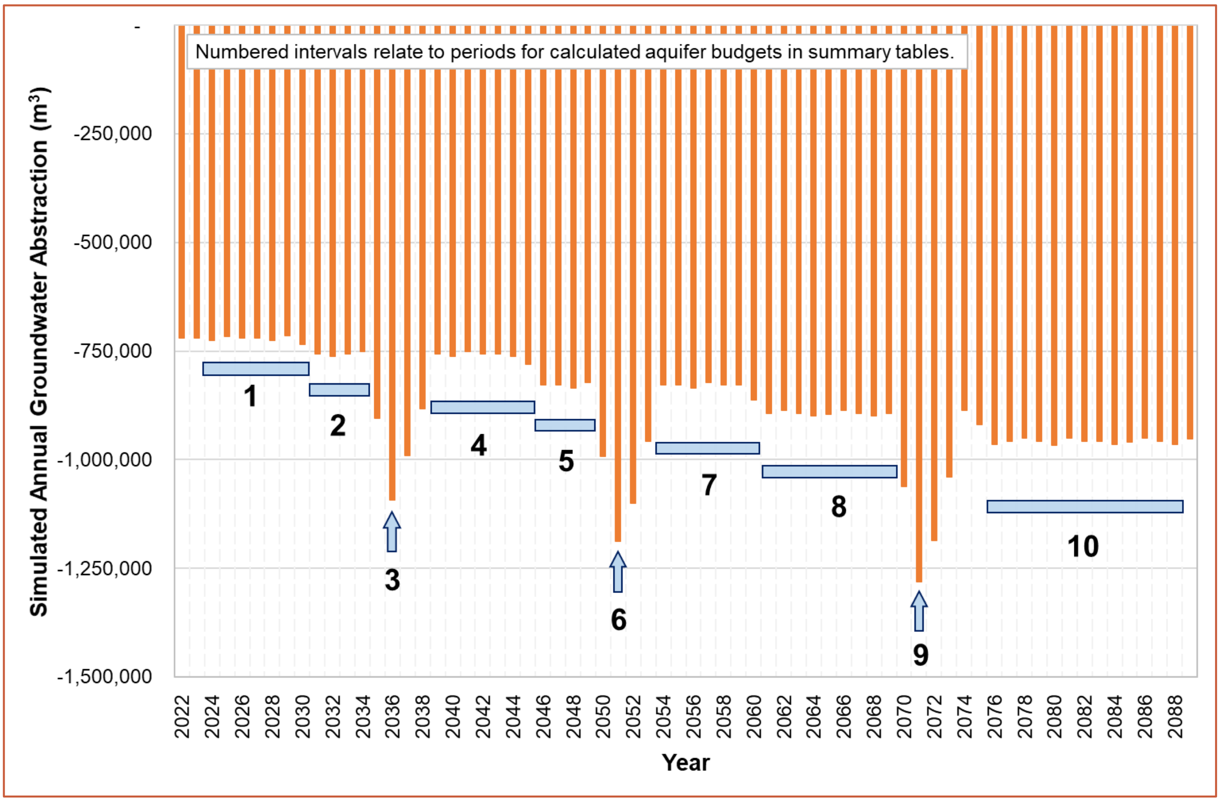


Figure 38: Designated Reporting Periods for Aquifer Water Budgets

4.6.3 Makauri Aquifer Water Budgets

As an example of the aquifer water budget outcomes, the results for the Makauri Aquifer derived from each of the simulated projection scenarios are summarised in Table 14. Presented are total annual inflows and total annual outflows to and from the aquifer, together with annual enhanced recharge amounts and annual groundwater abstraction amounts. Table 14 does not present all components of the aquifer budgets. However, it does represent the total through-flow for the aquifer and the manageable components of the aquifer water budgets (abstraction and enhanced recharge) for the listed scenarios. The key points to be taken from Table 14 relate to the lines of red text in the table. The Periods refer to the modelled time periods and droughts presented in Figure 38.

Table 14: Example Water Budget: Makauri Aquifer Total and Manageable Water Balance Components Under Different Projection Scenarios

Scenario / Parameter	Annual groundwater flows – averages for defined periods / single year result for defined drought years									
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10
	2024 - 30	2031 - 34	2036	2039 - 45	2046 - 49	2051	2054 - 60	2061 - 69	2071	2076 - 88
Scenario 1.1 Current										
Total inflow	2,494,108	2,494,987	2,504,212	2,494,932	2,494,743	2,494,887	2,495,961	2,493,581	2,494,953	2,495,312
Total outflow	-2,494,088	-2,494,992	-2,504,683	-2,494,940	-2,494,745	-2,494,903	-2,496,029	-2,493,540	-2,494,971	-2,495,349
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-846,909**	**-846,860**	**-853,482**	**-847,130**	**-846,860**	**-846,710**	**-847,902**	**-846,185**	**-846,710**	**-847,447**
Scenario 2.1 Climate Change + Droughts										
Total inflow	2,490,192	2,514,172	2,820,313	2,507,311	2,563,888	2,896,820	2,562,698	2,609,959	2,973,276	2,660,561
Total outflow	-2,490,269	-2,514,180	-2,818,835	-2,507,484	-2,563,879	-2,894,435	-2,562,909	-2,609,883	-2,970,762	-2,660,676
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-849,307	-889,204	-1,284,812	-894,032	-973,833	-1,396,668	-979,256	-1,049,148	-1,505,972	-1,126,868
Scenario 3.1 Natural State										
Total inflow	1,944,269	1,978,778	1,946,260	1,931,345	1,929,473	1,796,652	1,948,212	1,903,661	1,759,470	1,913,493
Total outflow	-1,944,224	-1,979,088	-1,946,489	-1,931,325	-1,929,449	-1,795,506	-1,948,380	-1,903,482	-1,758,204	-1,913,548
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Scenario 4.1 Current Consented Allocation										
Total inflow	3,338,650	3,414,394	4,309,787	3,410,181	3,573,808	4,571,541	3,575,818	3,729,429	4,830,299	3,885,291
Total outflow	-3,338,644	-3,414,166	-4,307,013	-3,410,691	-3,573,397	-4,566,944	-3,576,142	-3,730,010	-4,827,589	-3,885,420
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-1,911,232**	**-2,001,210**	**-2,893,421**	**-2,011,630**	**-2,191,450**	**-3,147,745**	**-2,203,238**	**-2,361,132**	**-3,391,550**	**-2,535,750**
Scenario 5.1 Groundwater Replenishment										
Total inflow	2,771,767	2,806,104	3,066,442	2,809,198	2,884,317	3,165,624	2,892,116	2,956,777	3,262,168	3,031,424
Total outflow	-2,771,810	-2,806,138	-3,065,107	-2,809,284	-2,884,335	-3,163,365	-2,892,294	-2,956,702	-3,259,733	-3,031,492
Wells recharge	**607,435**	**630,230**	**629,568**	**644,692**	**690,216**	**690,000**	**702,949**	**744,354**	**744,000**	**797,878**
Wells abstraction	-849,327	-889,223	-1,284,757	-894,059	-973,819	-1,396,708	-979,275	-1,049,177	-1,506,016	-1,126,802
Scenario 7.1 Sustainable Allocation										
Total inflow	2,400,094	2,418,995	2,669,898	2,411,918	2,457,528	2,729,815	2,455,969	2,493,772	2,791,689	2,533,194
Total outflow	-2,400,161	-2,419,011	-2,668,753	-2,412,080	-2,457,525	-2,727,888	-2,456,149	-2,493,704	-2,789,548	-2,533,209
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-721,933**	**-755,822**	**-1,092,173**	**-760,163**	**-827,734**	**-1,187,168**	**-832,523**	**-891,821**	**-1,280,076**	**-957,962**

Note: Values in red font indicate key differences when compared to Scenario 2.1., Periods refer to Periods shown in Figure 38.

Scenario 1.1, which represents a continuation of the current baseline based on the existing climate and groundwater abstraction conditions, shows no significant change in any of the water budget components into the future. Given the measurable effects being witnessed from climate change, this is not considered a realistic scenario for future prediction purposes. Scenario 2.1, which incorporates the added climate change effects including regular simulated droughts and increasing demands, shows an ongoing increase in groundwater abstraction from the Makauri Aquifer. The total inflows and total outflows for the aquifer remain well balanced into the future, even during drought years. This implies that the additional abstraction is accommodated by increasing downward flows from overlying aquifers and increased in flows from the northern end of the aquifer linked to the Waipaoa River. However, the increased abstraction does then result in decreasing groundwater pressures within the aquifer.

Scenario 3.1, in which all groundwater abstraction has ceased, shows a significant reduction in aquifer through flow. This outcome highlights the effect pumping has on groundwater flows into the aquifer. Increased pumping is associated with both increased pressure drawdown, which then causes increased recharge to the aquifer from surrounding strata and a new dynamic equilibrium is reached. Conversely, reducing the annual volumes of water abstracted does not automatically mean the aquifer inflows and outflows become more balanced. Such a reduction simply leads to a different flow and pressure equilibrium. This aspect of groundwater management for the Poverty Bay is considered further in Section 5.3.

Scenario 5.1, in which groundwater replenishment to the Makauri Aquifer is applied, indicates that enhancing recharge results in a significant increase in outflows to the adjacent strata. Although groundwater abstraction volumes under this scenario are simulated as in Scenario 2.1, the total outflows from the aquifer are substantially higher. These outflows will be partly accommodated in storage within the overlying and underlying strata which would then be available for drawdown during subsequent years. Some of these outflows will also move to overlying and underlying aquifers through diffuse seepage, leading to groundwater pressure increases in these aquifers.

Scenario 7.1, which represents a nominal sustainable allocation scenario, shows reduced abstractions under ‘normal’ years for much of the projected future. However, it does include an allowance for increased pumping in response to drought years in response to climate change effects. The simulations indicate winter high groundwater pressures would recover following these increased drought year abstractions, even though it may take several years for this to occur. This scenario is discussed further in the Section 5.3.

THE Tairāwhiti Resource Management Plan (TRMP) is slated to be prepared and ready for publication consultation in 2024. This plan will include Freshwater Planning chapter which this model is anticipated to provide input for decision making.

4.7 VERTICAL HYDRAULIC GRADIENTS

One of the key concerns with respect to protection of groundwater quality in the confined aquifers is the maintenance of vertical hydraulic gradients between aquifers. Groundwater seepage flows from higher pressure to lower pressure areas, both within aquifers and between aquifers. In natural groundwater recharge areas, the hydraulic gradients tend to be downward, with the shallow aquifer's having a higher groundwater pressure. In areas where the confined aquifers are discharging groundwater toward surface, the deeper aquifer will have a higher pressure than overlying shallow aquifers.

In terms of potential risk to groundwater quality arising from human activity, in most cases contaminants are transported in accordance with groundwater flow patterns.

In the case of the confined aquifers underlying the Poverty Bay Flats, issues of potential concern are:

1. Changes in the distribution of existing contaminants (salt) in the aquifers or adjacent aquitards in response to changes in groundwater flow patterns.
2. Enhanced saline water intrusion to the aquifers along the coastline (salt) in response to projected changes in sea level or drawdown in aquifer hydraulic pressures.
3. Reversal of hydraulic gradients in areas that were formerly relatively protected from contaminant risks due to natural upward groundwater flows.

The first two issues have been addressed elsewhere in this report (Sections 4.4.4 and 4.5). The third issue is considered below.

Vertical hydraulic gradients between the confined aquifers and the shallow unconfined aquifers vary across the Poverty Bay Flats. A detailed description of the distribution of vertical gradients between aquifers under existing and projected conditions is outside the scope of this summary report. Plots of vertical hydraulic gradients have been presented for selected monitored wells to support model documentation in numerous sections of the AQUASOIL (2022) report. However, the concepts and consequences of changes in vertical hydraulic gradients under the different modelled projections can be demonstrated by summarising the model outcomes for one representative bore, GPD129, located in the southern central area of the Poverty Bay Flats.

Under winter conditions the Matokitoki and Makauri aquifers at GPD129 have higher simulated groundwater pressures than the overlying Waipaoa and shallow unconfined aquifers under existing conditions (Figure 39). Groundwater pressure and therefore seepage flows between the deeper and shallower aquifers are upward. This pattern does not change substantially between modelled Scenarios. Scenario 4.1, in which current groundwater allocation is fully utilised, shows the largest impact on winter hydraulic gradients at this location. Even under this scenario the hydraulic gradients remain upward. The main simulated winter groundwater head differential is between the Makauri and Waipaoa Aquifers.

In contrast, the simulated vertical hydraulic gradients at GPD129 during summer (Figure 40) show substantial differences between scenarios, even though this bore is not in the main area of groundwater abstraction. Under Scenario 2.1, in which climate change projections are considered, the simulated pressure at each of the aquifers is similar and the modelled upward hydraulic gradient has effectively disappeared. Under Scenario 4.1, in which current groundwater allocation is fully utilised, the vertical hydraulic gradient between the Waipaoa Aquifer and the Makauri Aquifer has reversed. Although this means that the Makauri Aquifer is now receiving groundwater additional recharge from the overlying aquifers in this area, it also means that any contaminants in the overlying aquifers may be drawn downward toward the Makauri Aquifer.

The consequences of groundwater management measures applied under Scenarios 3.1, 5.1 and 7.1 are also clear to see in Figure 40. Scenario 3.1, which incorporated no groundwater abstraction, shows summer groundwater levels and pressure gradients very similar to the winter conditions. Scenario 7.1 results indicate the upward summer hydraulic gradient at GPD129 has been maintained, although at a somewhat reduced gradient. The application of enhanced recharge under Scenario 5.1 also helps to protect the upward summer hydraulic gradient at GPD129, even though the closest simulated MAR locations are approximately five kilometres northwest from GPD129.

The model results from GPD129, as summarised in Figure 39 and Figure 40, do not represent an extreme range of effects arising from the various scenarios. The seasonal effects of pumping induced drawdown increase to the north of GPD129, as do the effects of the simulated enhanced recharge programme. This section of the report simply indicates the relative effects from the various projection scenarios that may be reasonably expected to apply across much of the southern Poverty Bay Flats.

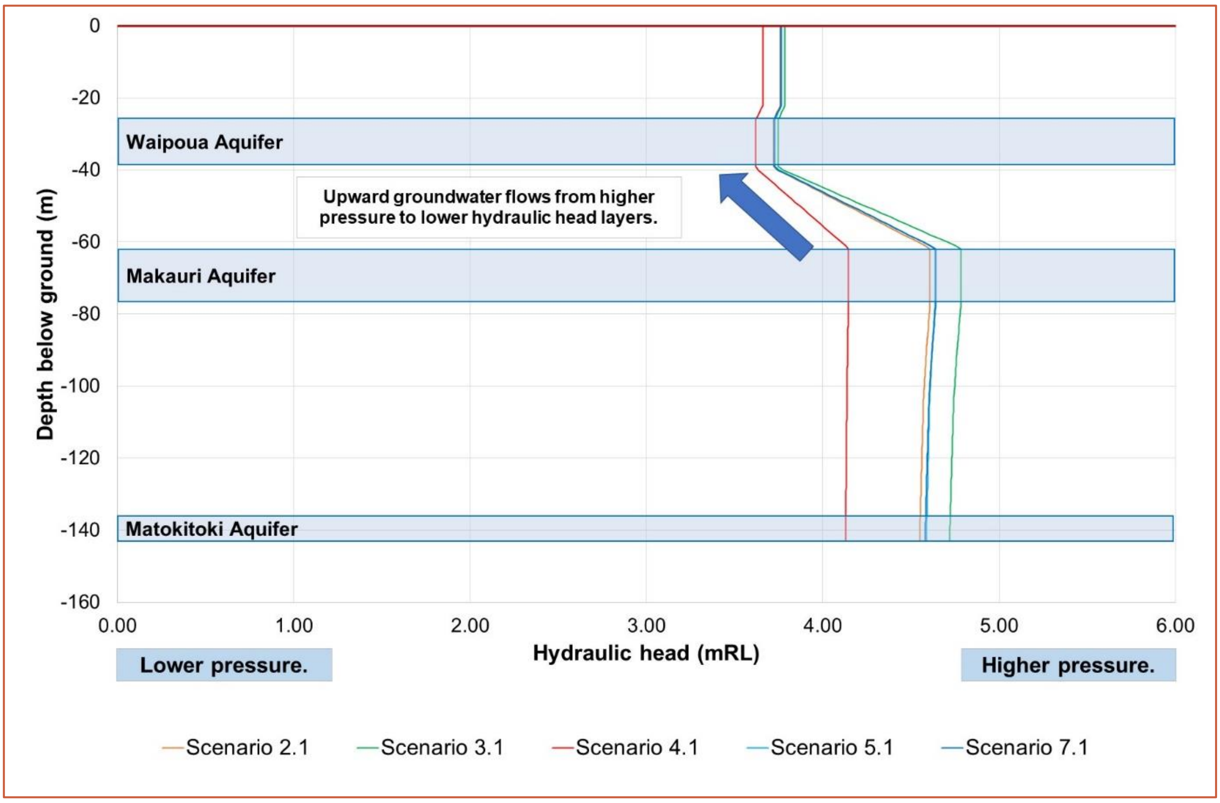


Figure 39: Winter Vertical Hydraulic Gradients at Monitored Well GPD129

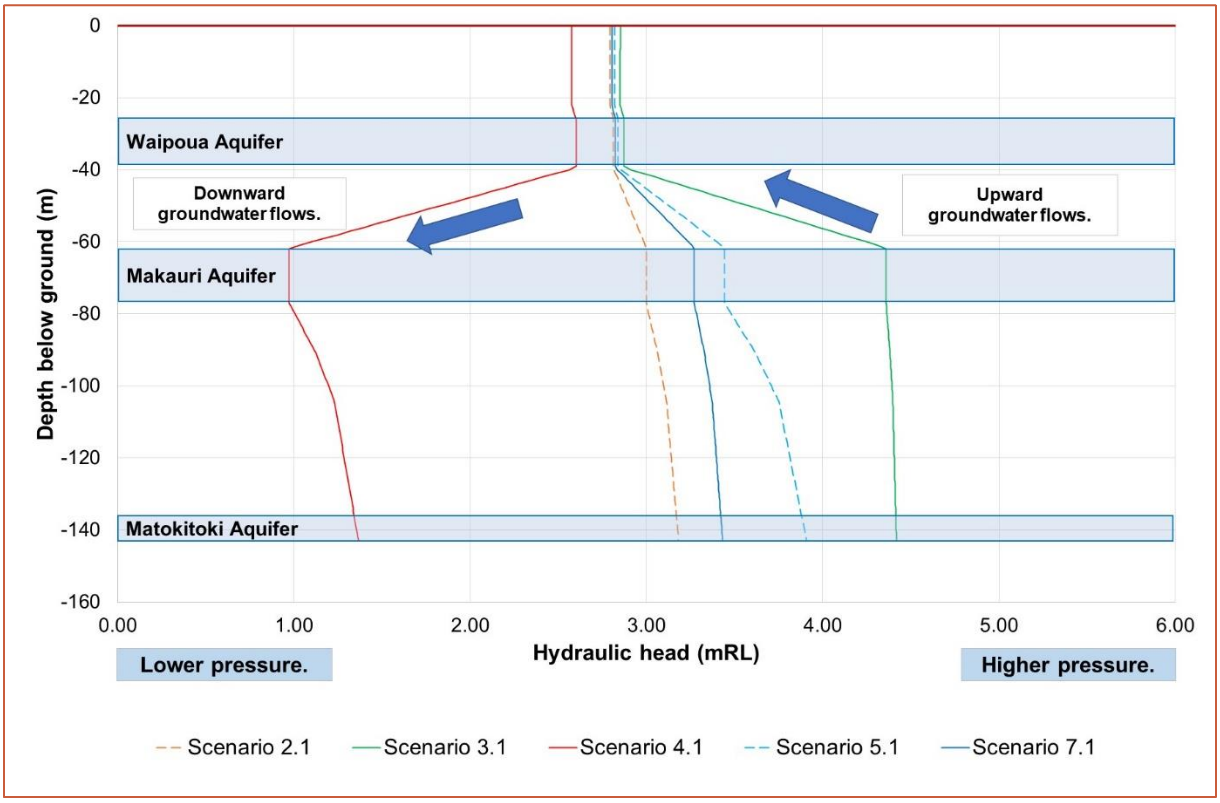


Figure 40: Summer Vertical Hydraulic Gradients at Monitored Well GPD129

4.8 SCENARIO ASSUMPTIONS AND LIMITATIONS

There are several areas where a defensible conceptual groundwater model was unable to be developed that exactly matched the field observations. In some cases, there was more than one reason for a discrepancy for a specific area, but insufficient field data was available to support one concept over another. Collective decisions were made by the team (WGA, GDC and AQUASOIL) regarding how to proceed with the numerical model. In each case the modelling team have taken the more conservative and defensible option when faced with such choices. In making these choices we have:

- Avoided extrapolating aquifer extends beyond what can be reasonably defined from the drillhole geological database, even when we consider that the aquifer very likely extends further based hydraulic behaviour. The one exception to this is the Makauri Aquifer, which is extended offshore for several reasons, with the extent of this extrapolation being evaluated in the conceptualisation report (WGA 2022a).
- Avoided incorporating hydraulic boundary conditions that could improve the statistical "model calibration" but are conceptually indefensible and would potentially lead to an inappropriate addition of water to the aquifers under some of the predictive scenarios.

WGA considers that it is better to know where the model has less than ideal performance and having some understanding of the reasons for the issue than to force the calibration and subsequently produce over-optimistic long-term predictive outcomes.

The main areas that come to mind where these decisions have been made are:

- The western saline area of the Makauri Aquifer
- The eastern edge of the Matokitoki Aquifer
- The southern extents of the Makauri and Matokitoki aquifers toward the coastline and potentially offshore

Western Saline Area of Makauri Aquifer

It is reasonably clear that the Makauri Aquifer extends further to the west than is represented in the numerical model, including under the Te Arai River flats. However, there is a lack of geological information from drilling in this area. Furthermore, the information that does exist on bore structures and groundwater quality appears locally contradictory. No satisfactory conceptualisation of the Makauri Aquifer structure in this area of the model has been achieved. Therefore, rather than incorporating a questionable interpretation of the aquifer layout and behaviour, the simulation of the western saline area of the Makauri Aquifer has been excluded from the numerical groundwater flow model. Chloride is introduced to the western edge of the Makauri Aquifer through applying groundwater quality boundary conditions that support a partial simulation of groundwater quality trends in this area. Although acceptable for the purposes of this modelling programme, we recognise that this area of the model can be significantly improved following further field investigations and testing.

Matokitoki Aquifer

The hydraulic head in the eastern part of the Matokitoki Aquifer is systematically underestimated by the model. The calibration process undertaken on the numerical model has shown that the issue is not related to the hydraulic parameters applied to aquifers and aquitards. This underestimation is caused by a structural deficiency incorporated in the conceptual and numerical models, which in turn is caused by a lack of knowledge of the aquifer structure in the area.

The underestimation of the hydraulic heads could be addressed numerically through providing a source of lateral seepage inflow to the model from the east. However, this addition of groundwater is difficult to support conceptually. There are limited areas of Tertiary age sandstones forming hills to the east of the area affected, just outside the model boundary. If recharge to these Tertiary sandstones was flowing to the Matokitoki Aquifer, this would help to address the head underestimation issue. This possibility was considered and discounted during conceptualisation of the groundwater flow model. Tertiary siltstones underlying the sandstones would act to restrict potential seepage flows down into the confined aquifers. Furthermore, similar inflows should affect groundwater levels in the Makauri Aquifer and there is no evidence of this occurring.

It was decided to accept a poorer groundwater level calibration in this area rather than applying a questionable hydraulic boundary condition to introduce lateral inflows to the aquifer and thereby achieve a "better" calibration. Additional inflow to the model that is not supported by any acceptable conceptual hydrogeological understanding would make the model less conservative because of the additional availability of water. Such a boundary condition would support increased or even almost unlimited groundwater abstraction from this area of the Matokitoki Aquifer. Such an outcome is unlikely to reflect the reality of the Matokitoki Aquifer hydraulic behaviour.

It is important to recognise that a more “statistically accurate” model calibration is not a goal in itself. Furthermore, WGA consider that a model should not be built and calibrated independent of its intended application. In this case, the main application is the testing of the effects of groundwater abstraction and climate change on the groundwater system. Therefore, this “fit for purpose” model is a little conservative in its approach. The calibration process must support a predictive model that is as reliable as possible. Where uncertainties or calibration discrepancies arise, these can provide guidance for further field observations and testing, followed by subsequent improvement of the conceptual and numerical models. This process is referred to in the modelling philosophy presented in the conceptual groundwater modelling report (WGA 2022).

5 MODEL APPLICATIONS AND IMPLICATIONS

5.1 QUALITATIVE SUMMARY OF SCENARIO OUTCOMES

Modelled scenario outcomes have been interpreted to provide qualitative responses to the questions that have arisen out of the community engagement workshops held in 2022 (Table 15). Simulation of the various scenarios described in this report does not provide absolute answers to all of the questions. However, the results do provide guidance on which groundwater management measures can help to begin to develop management options to address key areas of community concern. This information can inform the development of a combination of mitigations and management measures that may be incorporated in the upcoming GDC regional planning process.

In review of qualitative summary results, it is important to note that the baseline Scenario 1.1 model results indicate a ‘stay the same’ outcome for Poverty Bay aquifers. Whilst WGA acknowledges that the monitoring data indicates ‘worsening’ trends in groundwater levels, the baseline scenario was established as a steady-state reference condition. The model outcomes indicate that trends of increasing salinity in some aquifer areas can be expected to continue, even if nothing else changes.

The climate change effects incorporated into Scenario 2.1 result in worse outcomes for aquifer groundwater levels, cultural, surface ecosystems and salinity. As the outcomes from all the following scenarios are compared against Scenario 2.1, the increasing water demands and therefore abstraction, coupled with sea level rise and declining natural recharge have an overarching effect across all the scenario qualitative comparisons. Incorporated into this baseline scenario were also evaluation of the community questions were specific to the effects of extreme dry weather and climate change. Whilst the effects of these issues form the basis of all the modelled scenarios, the only scenarios that offer potential long term aquifer status improvements in the face of climate change are linked to substantially reducing the amount of water abstracted or increasing the amount of water being replenished.

The worst model outcomes arise from Scenario 4.1 Entitled Full Allocation, where every year (year in year out) groundwater abstraction is used to the full extent of the current 2021 paper allocation. As individual groundwater abstraction consents are designed to provide enough allocation to provide irrigators with water through drought periods, the year-to-year use of all allocated water is not considered a reasonable expectation. During a particularly wet summer, for example, the pumping of groundwater would not be needed or desired due to the costs of applying water to already wet crops and orchards. Under this scenario the model indicates worse outcomes across all of the assessment categories.

With respect to the cultural indicators assessed, none of the modelled scenarios lead directly to improved outcomes. This does not mean that improvements for culturally important are not achievable as many of the modelled options were not spatially located or conceptually designed to specific benefit cultural values. However, it does provide guidance on the nature of how these envisioned groundwater issues impact on cultural values and provides an opportunity to develop mitigations that potentially could be designed to address these issues. There are four main reasons why improvements against cultural value criteria were not achieved by any of the models:

1. The cultural values, as with the other values considered, have been focused on a narrow range of agreed criteria. Cultural values may indeed have better outcomes if measured against other criteria under some of the simulated scenarios, but the existing models have focused on monitoring the agreed criteria.
2. The effects of climate change have overriding long-term impacts on each of the chosen cultural criteria against which the models have been assessed. In fact, even if groundwater abstraction were to cease (Scenario 3.1) the model indicates sea level rise and changes in rainfall patterns are likely to override any potential positive changes in groundwater levels and flows. For example, a close of groundwater abstraction will not necessarily prevent coastal saline water intrusion and associated water quality impacts on coastal springs.
3. Surface drainage systems which have a direct effect on the cultural values have not been changed in the models. Some of the coastal effects on shallow groundwater are related to drainage rather than groundwater abstraction. Therefore, the effects are consistently worsened simply as a consequence of sea level rise.
4. Enhanced replenishment was applied to one small area under Scenario 5.1. Although this recharge led to positive outcomes for several of the values considered, it was applied in an area distant to any of the cultural values under consideration. If the aquifer replenishment had been applied in different places in order to safeguard particular issues, for example perhaps targeting the key cultural indicators, the outcomes would potentially have been different.

The models indicate likely improvements to some values under the Natural State (3.1), Replenishment (5.1) and Sustainable Rate (7.1) scenarios. Each of these scenarios works to pull one of the two main levers (groundwater replenishment and abstraction allocation management) that GDC have to better manage the Poverty Bay aquifer system: take less water out or recharge more clean water in.

Reducing the rate at which water is taken out of the aquifers (Scenario 7.1) results in improved aquifer and ecosystem outcomes but does not change the outcomes for the chosen cultural criteria or salinity indicators. Turning off all groundwater pumping (Scenario 3.1) would result in groundwater levels and baseflows in the surface water ecosystems increasing. However, salinity issues are unlikely to be reversed (and therefore are considered to stay the same) and cultural indicators are still likely to worsen, as discussed above. The modelled enhanced replenishment into the Makauri Aquifer (Scenario 5.1) would also locally improve aquifer levels and reduce water moving from other aquifers to offset abstraction. But the simulated enhanced recharge is not likely to significantly influence the surface water systems due to its focus on a deep confined aquifer. The model outcomes do suggest that strategically located replenishment is the only scenario variant that offers potential opportunities in saline water intrusion management.

The results of the Exploratory Scenario modelling process have provided a spectrum of possible mitigations and management options that may be used to better inform management planning for the Poverty Bay groundwater system. The FeFlow numerical groundwater model can be used to help bring together aspects of various scenarios into a cohesive set of measures to address the identified issues propagated by climate change.

5.2 KEY RISKS

It is important to keep the following key objectives of the groundwater modelling project in mind when considering the outcomes from the numerical modelling.

1. What are the risks to water supply security, cultural and environmental values arising from the "business as usual" Scenario 2.1?
2. Do the other simulated scenarios address the identified risks to water supply security, cultural and environmental values?
3. Do the other simulated scenarios provide guidance with respect to addressing the identified risks

Based on the outcomes from the "business as usual" Scenario 2.1, the key risks to water supply security, cultural and environmental values are:

1. On-going pumping causing an eastward spread of saline water into the Makauri Aquifer from the Western Saline Aquifer.
2. Pumping causing saltwater from the ocean entering the Makauri Aquifer.
3. Pumping causing reduced flows in the Waipaoa River during summer.
4. Sea level rise causing increased flows from the ocean toward Awapuni Moana, leading to increased salt concentrations in the drains.
5. Ongoing overarching and increasing effects of climate change to the sustainability of this groundwater system.

Monitoring of the groundwater system has shown that some of these effects are already happening. The following sections consider aspects of the risks listed above and summarised in Table 15 and their management options.

Table 15: Qualitative Responses to Community Questions Based on Model Outcomes

Summary Community Questions	Investigation Exploratory Scenarios (1)		Human Usage	Aquifer Status	Cultural	Surface Water Ecosystems	Salinity
What is the current status of the different aquifers and are they declining? How is climate change including extreme dry weather (droughts) expected to impact groundwater?	Baseline	1.1	Current	Stay the Same	Stay the Same	Stay the Same	Worsen
	Baseline + Climate Change	2.1	Current	Worsen	Worsen	Worsen	Worsen
What effects would occur if Te Mana O Te Wai was placed above commercial use?	Natural State	3.1	Zero	Improve	Worsen	Improve	Stay the Same
What happens if allocations are used to full entitlement?	Entitled Allocation	4.1	Full 2021 Allocation	Worsen	Worsen	Worsen	Worsen
What effect would replenishment have on groundwater levels?	Groundwater Replenishment	5.1	Current	Improve	Worsen	Stay the Same	Improve
What is a sustainable allocation rate?	Sustainable Allocation	7.1	*Variable*	Stay the Same	Worsen	Improve	Worsen

Note: 1) A Scenario 6.0 related to groundwater replenishment was generated for the 1st round of model scenarios but was incorporated into Scenario 5.1 in the 2nd round.

5.3 SUSTAINABLE ALLOCATION

In terms of this groundwater modelling process, a general definition of sustainable allocation has been provided in Section 3.5.6. As described in the AquaSoil (2022) report, a simplified numerical definition of sustainable abstraction has been applied when modelling Scenario 7.1. In effect, the amount of simulated abstraction was reduced to a degree that groundwater levels and hydraulic potential do not decline below currently observed levels. This was achieved in the modelled scenario for the period through to 2050, after which further reductions in abstraction rates or the use of other tools would be necessary to prevent drawdowns exceeding the currently observed ones.

The reduction in groundwater abstraction by approximately 15%, as simulated under Scenario 7.1 and documented in Appendix C, results in groundwater pressures not declining below what has already been observed through until 2050. Base flows in surface water bodies increased in this scenario, with implied improvements in surface water ecosystems. However, this scenario did not result in key agreed cultural and water quality values being protected.

The concept of a sustainable groundwater allocation is intimately linked to the values that GDC is seeking to protect, and the ‘real world’ means that may be available for management. The results from each of the modelled scenarios, combinations of the modelled scenarios and any future modelled scenario should be considered in terms of protecting ‘real world’ values rather than simply and solely seeking to maintain groundwater levels.

Climate change complicates the evaluation because changing weather patterns will lead to ongoing increases in other stresses on the freshwater ecosystems, culturally valued features, and water quality conditions which are not directly linked to the changes in groundwater. Therefore, the management settings and techniques used to protect these values will require a comprehensive approach including land use, river management and human water supplies. The mitigations applied in the shorter term will likely need to be augmented and changed over the longer term as climate change effects become more pronounced.

The overall model results indicate increased pumping up to the currently consented allocation limit does not present a significant risk to regional water supply security in terms of the volumes of groundwater available. Increased modelled pumping from baseline conditions causes groundwater levels to be drawn down further but the system subsequently stabilises in a dynamic equilibrium at a lower level. Increased abstraction from each aquifer is balanced by increased diffuse inflows from adjacent strata, higher aquifers and from surface water bodies. Eventually, increased takes even from confined aquifers result in reduced base flows in surface water bodies.

The outcomes from the various scenarios do not indicate there is a tipping point at which climate change does not enable the groundwater system to reach stability or a new dynamic equilibrium. In each of the simulations, a clear dynamic equilibrium has been reached even under the most extreme of the climate projections.

The modelling indicates that any on-going pumping leads directly to some of the issues listed above getting worse and even reverting to natural state conditions (no pumping) does not lead to the aquifer returning to its natural state salinity levels. The cumulative model outcomes indicate the agreed objectives for groundwater management, as summarised in Table 15, can only be achieved through applying a range of water management techniques to manage all of the issues facing the Poverty Bay Flats groundwater system.

5.4 POTENTIAL USE OF TRIGGERS FOR GROUNDWATER MANAGEMENT

Triggers defined in groundwater monitoring and management plans have been used in many parts of New Zealand to support the management of groundwater resources. In some cases, councils have established triggers that are practical and help to proactively manage the quantity and quality of groundwater relative to abstraction and changes in quality. In other instances, arbitrary triggers have been set that are not linked to how aquifers respond to seasonal pumping and recovery periods. In some cases, poorly conceived and implemented triggers have led to significant on-going consent compliance and resource management issues for both water users and regional council management staff.

The use of triggers coupled with the establishment of dedicated sentinel monitoring wells in the Poverty Bay Flats could help GDC staff to manage key groundwater management issues including over abstraction and the degradation of groundwater quality. For example, triggers may be useful to help:

a) Manage the risk of declining water storage in the Makauri Aquifer through the establishment of winter groundwater recovery targets.

b) Protect groundwater quality through the use of sentinel salinity monitoring wells along the fringes of the western saline Makauri Aquifer area. Such sentinel wells could be linked to the application of targeted recharge (with freshwater MAR) coupled with allocation management to stablise and potentially reverse salinity movement toward the more productive parts of the aquifer.

c) Reduce the risk of on-going and increasing saline water intrusion to the coastal Te Hapara Sand Aquifer and possible saline water intrusion to the coastal Makauri Aquifer through the establishment of coastal sentinel monitoring wells. The water quality and level observations from these wells could be used to measure the potential impacts of sea level rise, saline water intrusion and aquifer pressure drawdown on the groundwater resource security.

Section 3.5.1 of this report summarises declining groundwater pressure trends in several of the Poverty Bay Flats groundwater aquifers. Figure 11 presents an example of hydraulic head trends in the Makauri Aquifer at monitoring well GPJ040 that demonstrate declining winter/wet season recovery levels over time. One potential application of trigger levels linked to a sentinel well like GPJ040 would be to define a series of late winter groundwater levels (seasonal peaks). These levels would then be linked to an integrated management strategy with the objective of stabilising any declining trend in winter levels, achieving a recovery in these levels and then enhancing the utilisation of water from the aquifer without increasing the risk to future groundwater resource security. Figure 41 provides a conceptual schematic of this type of groundwater management and trigger regime which could be incorporated into a community developed groundwater management strategy process.

A set of winter trigger levels for sentinel wells could be developed through a Solutions Scenario modelling process and working with Mana Whenua and the wider community. Potentially coupling the application of enhanced groundwater replenishment techniques with adaptable allocation criteria through a regional planning process should encourage the establishment and monitoring of adaptive management measures to increase groundwater security. The establishment of these winter trigger level objectives could be informed by the modelling process, and then adapted as the actual physical mitigations take effect.

The establishment of triggers without corresponding clear and practical measures to enable users to be able to comply to the intended objectives, particularly when faced with increasing pressures from climate change, will very probably result in difficulties achieving the intended objectives. In this situation fixed objectives may be difficult or even impossible to achieve whilst also providing security of supply for those how rely on the sustainable use of this resource.

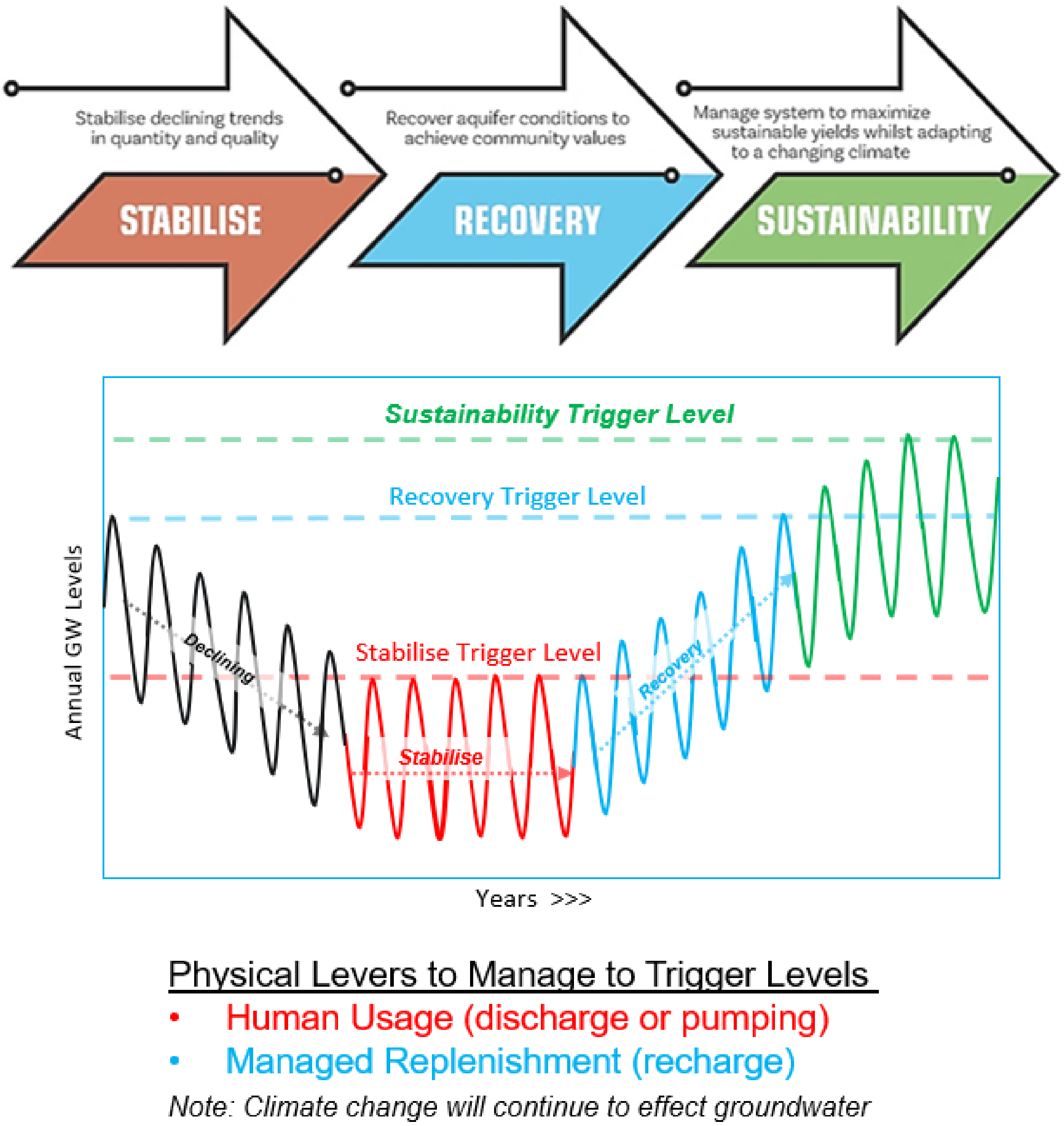


Figure 41: Conceptualised Application of Winter Trigger Levels Within a Groundwater Adaptive Management Strategy

5.5 MANAGEMENT RECOMMENDATIONS AND TRIGGERS

Based on discussion with GDC staff during a project completion workshop, WGA has provided the following management recommendations for the next phase of Solutions Scenario modelling and regional planning and science programme development (See process outlined in Figure 10).

5.5.1 Western Makauri Aquifer Salinity Management

Both the groundwater quality modelling and observed groundwater salinity trends along the western side of the Makauri Aquifer indicate continued pumping at the current rate will lead to the ongoing spread of saline water within the aquifer. It was not clear from the model results exactly how far the saline water might spread. However, there is also a balancing effect as pumping also causes additional fresh water to be drawn into the aquifer from the recharge areas at the northern end of the Poverty Bay Flats. It would take a long time for the saline water distribution within the Makauri Aquifer to reach a new balance.

Reducing the rate of modelled groundwater pumping slowed the spread of saline water within the aquifer. However, the spread was not stopped or reversed by simply reducing the pumping rate. Ceasing all pumping under the natural state scenario stopped further spread of saline water in the aquifer but it did not reverse the observed salinity changes in the short to medium term. The only scenario that presented an opportunity to reverse the observed spread of saline water in the western Makauri Aquifer was the MAR option.

It is important to reiterate here that our understanding of the extent and behaviour of the western saline area of the Makauri Aquifer is restricted by the lack of information about this area of the aquifer. It is likely that the projected spread of saline water in the western Makauri Aquifer under most predictive scenarios, including Scenario 2.1, has been underestimated. Field investigations leading to improvements in the conceptual and numerical models could address this shortcoming.

Aquifer interconnection in the western saline area of the Makauri Aquifer remains unclear. At least two wells used for groundwater quality monitoring and screened at shallower depths than the projected Makauri Aquifer elevation are characterised by elevated chloride concentrations in the water. These observations suggest an interconnection between the Waipaoa Aquifer and the Makauri Aquifer in the western area. However, until further drilling and lithology information is available for this interconnection, a clear conceptual model of these interactions is difficult conclude. Therefore the numerical model does not incorporate either aquifer extending out to these two monitoring wells.

Management Measures

Of the Exploratory Scenarios simulated, only the MAR scenario offered a clear option for the management of potential saline water spread within the Makauri Aquifer. Only one MAR scheme has been simulated under this project, with relatively small and focused recharge area. If the management of saline water spread in the Makauri Aquifer is an object of such a scheme, other recharge site layouts may be more effective in achieving this objective.

The simulated MAR scheme layout was not optimised in the modelled scenario for the purposes of managing saline water spread within the aquifer. Therefore, a separate assessment would be required to evaluate the effectiveness of different MAR scheme layouts and appropriate recharge rates.

The simulation of the MAR scheme, together with the field trials undertaken at Kaiaponi by GDC, has confirmed that focused recharge of clean water to the confined Makauri Aquifer results in a localised store of freshwater that does not move rapidly away from the recharge site. This concept (Figure 42) could form the basis for enhancing usable water resources within the western saline aquifer area.

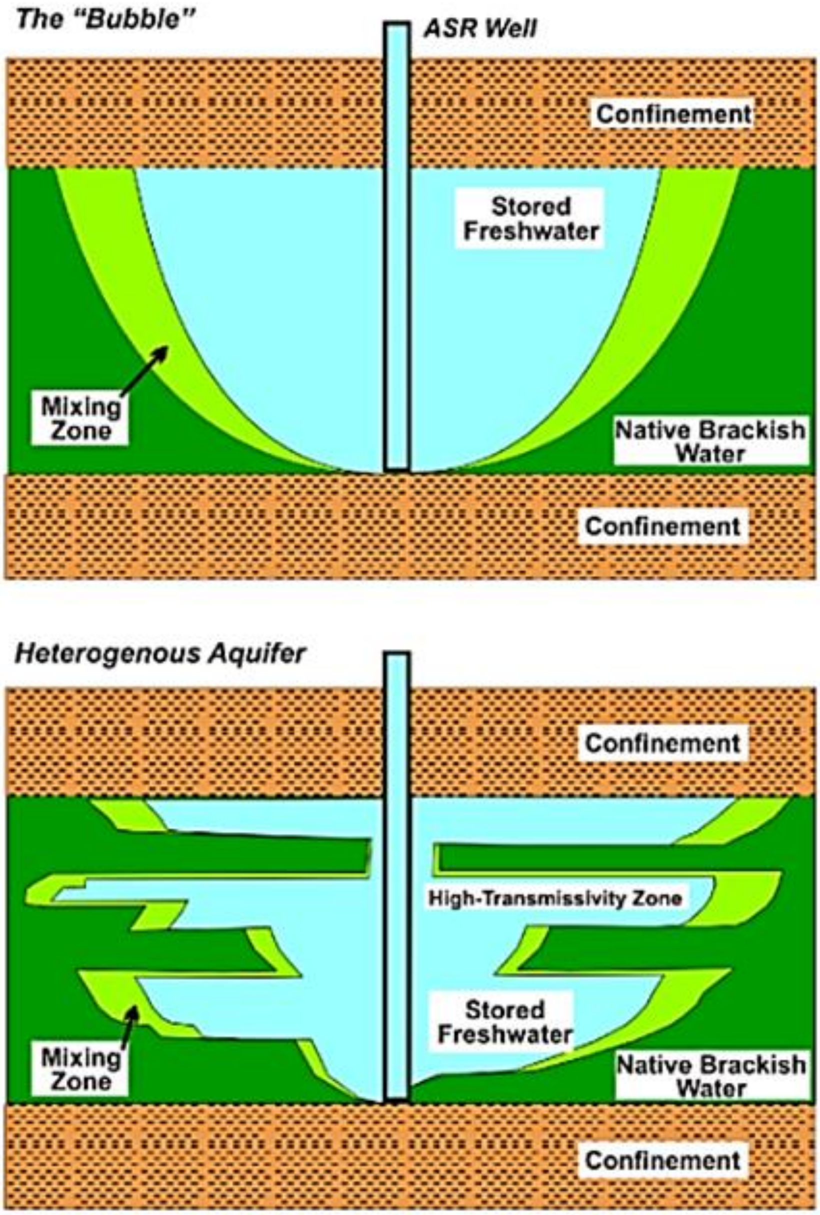


Figure 42: Aquifer Storage and Recovery Concepts (Maliva et al 2007)

<u>Monitoring and Sentinel Wells</u>

Existing monitoring of Makauri Aquifer groundwater levels and quality at GPI032, GPJ040 and GPD115 provide appropriate indicators of water quality and level trends in the western section of the Makauri Aquifer. We recommend the use of these monitoring wells as Sentinel Wells. Sentinel Wells are monitoring wells which have trigger levels for level and quality (often with electrical conductivity automated monitoring).

Additional groundwater quality and level monitoring is recommended for the Makauri Aquifer to the south of the above wells. Two additional Sentinel Wells could be designated or installed as part of future investigations into the western saline area of the Makauri Aquifer.

5.5.2 Coastal Saltwater Intrusion to Makauri Aquifer

The numerical modelling did not show any indication of saline water intrusion from the ocean to the Makauri Aquifer under the simulated Exploratory Scenarios. Appropriate calibration of the model was achieved without the need to conceptualise a direct hydraulic connection between the ocean and the aquifer. However, a slow and delayed interaction between the Makauri Aquifer, the overlying shallow aquifers and the ocean does occur in the model.

It is important to take a conservative position with respect to protecting groundwater quality in the confined aquifers underneath the coast as salinity is difficult to reverse. Drawdown of groundwater pressure in the Makauri Aquifer underneath the coast and offshore presents a clear risk off saline water intrusion developing. At present the groundwater pressure gradients between the Makauri Aquifer and the overlying shallow aquifers are upwards. The model outcomes suggest that these gradients may reverse seasonally under some groundwater increased pumping conditions, with sea level rise contributing to this change. In other words, groundwater flows that are currently upward in the area of the coast could reverse and become seasonally downward.

Further use of the Feflow model to help better quantify the consequences of saline intrusion and develop spatially specific policies or solutions is recommended for GDC to develop management policies.

<u>Management Measures</u>

The groundwater model outcomes suggest that two management options are available, should saline water intrusion become a real prospect rather than a modelled risk. A reduction in pumping from the aquifer at risk could be implemented, with the mitigation effect being immediate. The outcomes from the MAR scenario also indicate that implementing a MAR scheme close to the coast could effectively form a barrier to saline water intrusion to the confined aquifers.

<u>Monitoring and Sentinel Wells</u>

It is important to understand and monitor groundwater levels and pressure gradients close to the coast. This is a key factor enabling informed decisions on groundwater management for the confined aquifers in this area. There are currently no existing deep monitoring wells that are in a suitable location for this purpose.

We recommend that a set of monitoring wells be installed between the Awapuni Moana area and the coast. At a minimum, two wells could be installed with screens in the Te Hapara Sand Aquifer and the Makauri Aquifer. The drilling could extend to a depth that would potentially intersect any coastal section of the Matokitoki Aquifer. If either the Waipaoa or the Matokitoki Aquifer is intersected during drilling, additional monitoring wells could be installed and screened in these aquifers. These monitoring wells could be classed as Sentinel Wells and used to control abstraction rates near the coast. Groundwater levels and groundwater quality at these wells is recommended be carefully monitored to determine groundwater level and quality trends.

<u>Management Triggers</u>

We consider it appropriate to define aquifer management triggers that are linked to the above recommended Sentinel Wells. The objective of setting triggers would be to ensure that hydraulic gradients between the confined aquifers and the ocean remain in an upward direction. The triggers would be defined as the difference between mean sea level at the time and the groundwater level in the underlying aquifer.

Although a trigger could be set where the groundwater level is the same is the mean sea level, this would not take into account the potential for density driven flow to occur. In other words, the heavier salty seawater can potentially move downward into an underlying aquifer even if measurements indicate an upward hydraulic gradient.

Trigger conditions would be of value because management measures could be implemented that would achieve an immediate or short-term mitigation of the situation. For example, a reduction in groundwater pumping from bores close to the coast could be considered.

5.5.3 Waipaoa River Flow Loss During Summer

The groundwater modelling outcomes have shown that increased groundwater pumping is linked to a small reduction in flows in the Waipaoa River. For example, seasonal flow losses from the Waipaoa River increase by up to 300 m^3/day (3.5 L/s) under the consented allocation scenario (paper allocation) compared to the baseline + climate change scenario (Figure 43). This change forms a very small component of the overall flow in the Waipaoa River which would need to be verified through a hydrological assessment of the river separate than this groundwater modelling process.. However, it does need to be considered in the water balance for the river. The maximum modelled seasonal flow losses from the Waipaoa River to the groundwater system under the baseline + climate change scenario is in the order of 2,300 m^3/day.

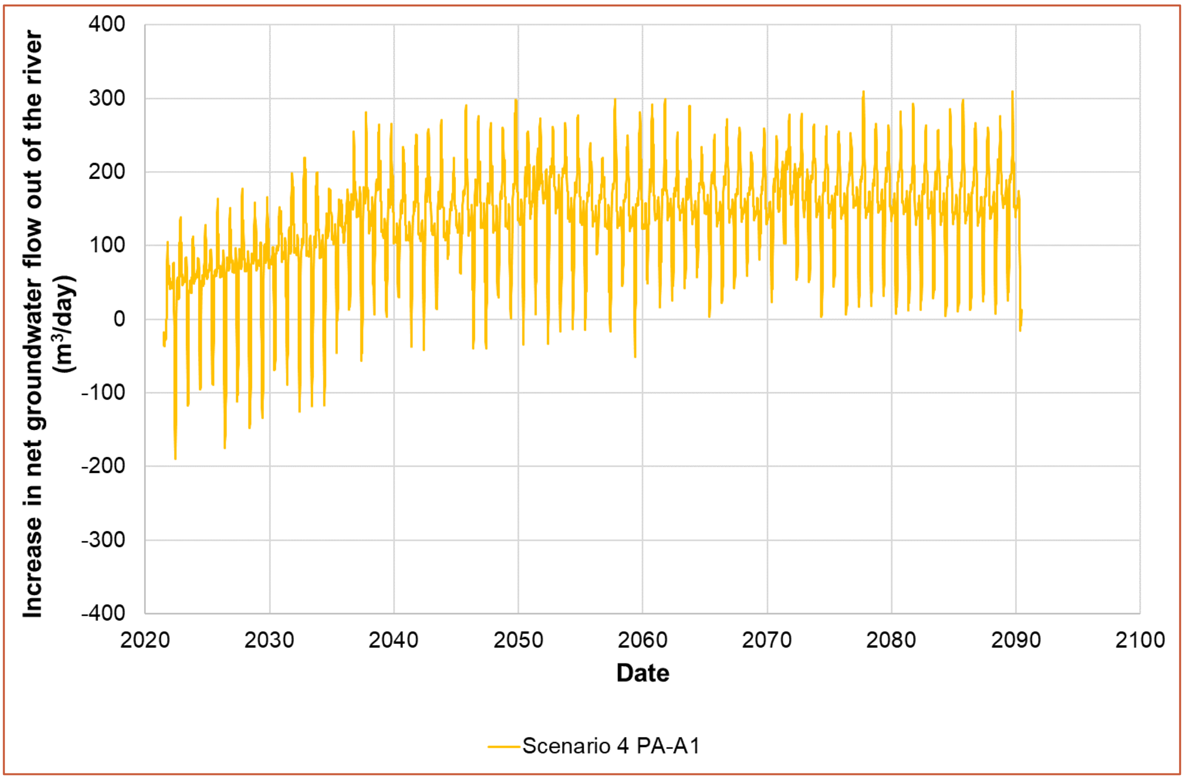


Figure 43: Reduction in Waipaoa River Flows Comparing the Consented Allocation to the Baseline + Climate Change Scenario

Management Measures

It is not clear that specific management measures need to be implemented to address the projected increases in flow losses from the Waipaoa River. Any proposed management measures would need to be considered in light of the expected ecological and cultural outcomes. Furthermore, it is not yet clear from the model outcomes what the main cause of the flow loss is. The relatively small abstractions from the shallow unconfined aquifers may be having a much larger effect on river flows than the large abstractions from the confined aquifers. This could be explored through further scenario modelling which exports the flow loss at various reaches of the river.

At this stage of the Exploratory Scenarios, we would not recommend any specific management measures be put in place.

Monitoring and Sentinel Wells

The small projected change in base flows in the Waipaoa River would be very difficult to detect using monitoring wells or river flow monitoring techniques. Changes in shallow groundwater levels that are associated with changes in Waipaoa River flows are very small and differ from well to well. Future development of Solution Scenarios of with the FEFLOW numerical modelling could be coupled with a bolt-on riverine numerical model (e.g., Mike 11) in order to improve GDC understanding of the interactions between surface and groundwater resources.

Management Triggers

No management trigger linked to groundwater levels is proposed. Any possible management trigger would need to be linked to flows in the Waipaoa River, which is outside the scope of this report.

5.5.4 Saline Water Intrusion Toward Awapuni Moana

It appears from existing observations that saline water intrusion from the ocean is already impacting on drain water quality at Awapuna Moana. However, as noted in the results section of this report, the groundwater quality model outcomes suggest that sea level rise would not lead to increased saline water intrusion through the Te Hapara Sand Aquifer toward Awapuna Moana. This appears to be a counter-intuitive outcome. Furthermore, the groundwater flow model indicates that increased sea levels lead to increased groundwater flows discharging to the Awapuna Moana drains.

The indicated groundwater flows to the Awapuna Moana drains under the baseline + climate change scenario range from 3,000 m^3/day to 13,500 m^3/day. What component of this flow comes from the ocean is not yet clear from the model. Furthermore, interpreting the effects that different modelled scenarios have on groundwater flows to these drains is complicated. This outcome reflects the difficulties in interpreting existing groundwater level and flow monitoring data from the Awapuna Moana area.

Management Measures

In light of the complicated model results, we would recommend an approach for continued and increased monitoring rather than specific management measures at this stage.

An enhanced groundwater recharge system along the sand barrier between the coastline and Awapuni Moana could potentially be used to limit and reverse further saline water intrusion to the Te Hapara Aquifer. However, simulating such a scheme was outside the scope of this project and will not be discussed further.

Monitoring and Sentinel Wells

Monitoring and Sentinel Wells between the coastline and Awapuni Moana have been proposed in Section 5.5.2 above. We recommend the installation of three Sentinel Wells in this area to monitor the effects of sea level rise on groundwater conditions within the sand barrier between the coast and Awapuni Moana.

Management Triggers

No management triggers linked to the Sentinel Wells are recommended. Such triggers would need to be linked to specific groundwater management measures and no measures have been recommended based on the outcomes of the modelling completed under this project.

5.5.5 Future Development of Other Quality Parameters

As part of the water quality conceptualisation and integration of groundwater quality into the Poverty Bay Flats Groundwater model, a copy of the GDC groundwater quality database was provided to WGA. A review of the data available for a range of parameters was undertaken. Salinity in the form of chloride concentration was taken as the key parameter for incorporation into the groundwater model.

The GDC database has been compiled and interpolated for parameters related to nutrient load, microbiology, salinity, and redox state. These maps provide an overview of the relative distribution of water quality within the aquifers underlying the Poverty Bay Flats. Maps have been prepared for each aquifer, where sufficient data is available for the various parameters covering two time periods of approximately 20 years each (1980-1999 and 2000-2022). The maps provide indicative relative distributions of aquifer geochemistry parameters. The bacterial content maps are derived from *E. coli* results, which have been mapped with respect to the number of times *E. coli* were detected in individual bores rather than the average of the detected counts. A summary of the technical methodology used to produce these maps along with copies of the derived heat maps are provided in the groundwater quality conceptualisation report (WGA 2022b).

The following parameters of interest were evaluated:

- Chloride (mg/L)
- Sulphate (mg/L SO_4)
- Iron (Total) (mg/L)
- Manganese (Total) (mg/L)
- Ammoniacal Nitrogen as Nitrogen (mg/L NH_4-N)
- Nitrate-Nitrogen (mg/L NO_3-N)
- Dissolved Oxygen (mg/L O_2)
- Biochemical Oxygen Demand (mg/L O_2)
- *E. coli* (CFU/100mL)

A full geochemical assessment of all groundwater quality parameters recorded in the GDC database, including most major ions, was outside scope of this project. The objective of this groundwater quality review is simply to document general trends in some of the water quality parameters linked to the concerns GDC has with water quality trends in the region.

6 CLOSING STATEMENT

This report summarises a comprehensive programme of community engagement and numerical modelling for the Poverty Bay Flats. The Exploratory Scenarios results and learnings from this overall process have been discussed along with some recommendations on potential future mitigations, additional resource exploratory data collection, and some guidance on GDC requested management goals. This report signifies the delivery of a fully functional numerical groundwater model for the Poverty Bay Flats and the start of the process by which groundwater management Solution Scenarios are evaluated in order to develop physical and regulatory mitigations. This modelling process has highlighted the fact that climate change is having and will have a growing influence on the way groundwater is managed in the Poverty Bay Flats and will require combinations of a mitigations in order to prepare for the effects on aquifers, water quality and cultural and environmental values.

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NIWA 2020. Climate change projections and impacts for Tairāwhiti and Hawke's Bay. Prepared for Environlink, Gisborne District Council and Hawke’s Bay Regional Council. November 2020. 247 pages.

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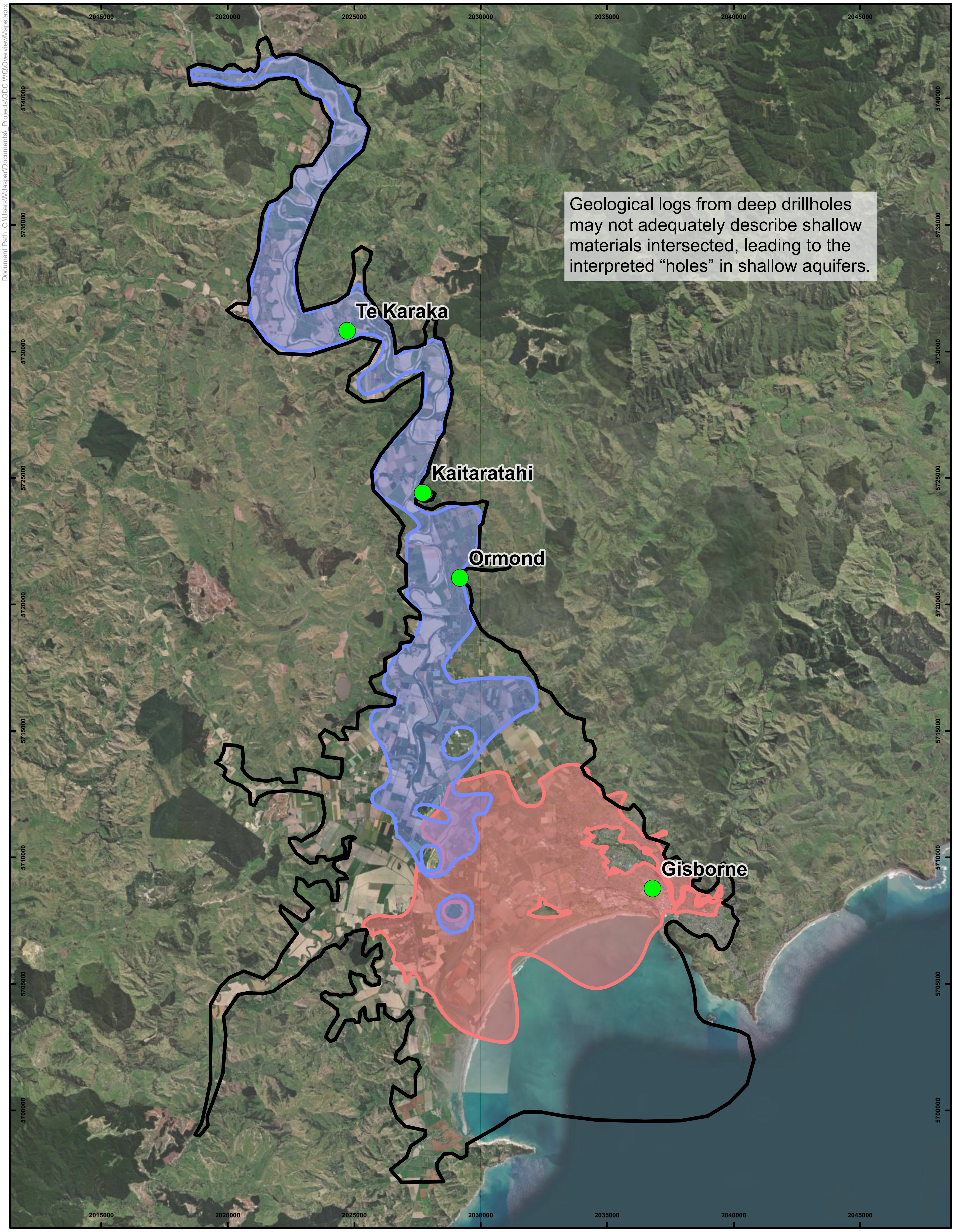
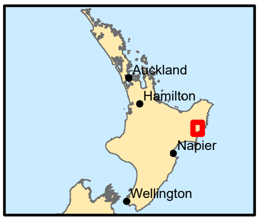
WGA 2022b. Poverty Bay Flats conceptual groundwater quality model. Report produced for Gisborne District Council by Wallbridge Gilbert Aztec. WGA report WGA210398-RP-HG-0005 Rev. B. October 2022.

APPENDIX A

AQUIFER EXTENT MAPS





N

0 0.8 1.6 2.4 3.2 km

Scale 1:200,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user.

LEGEND

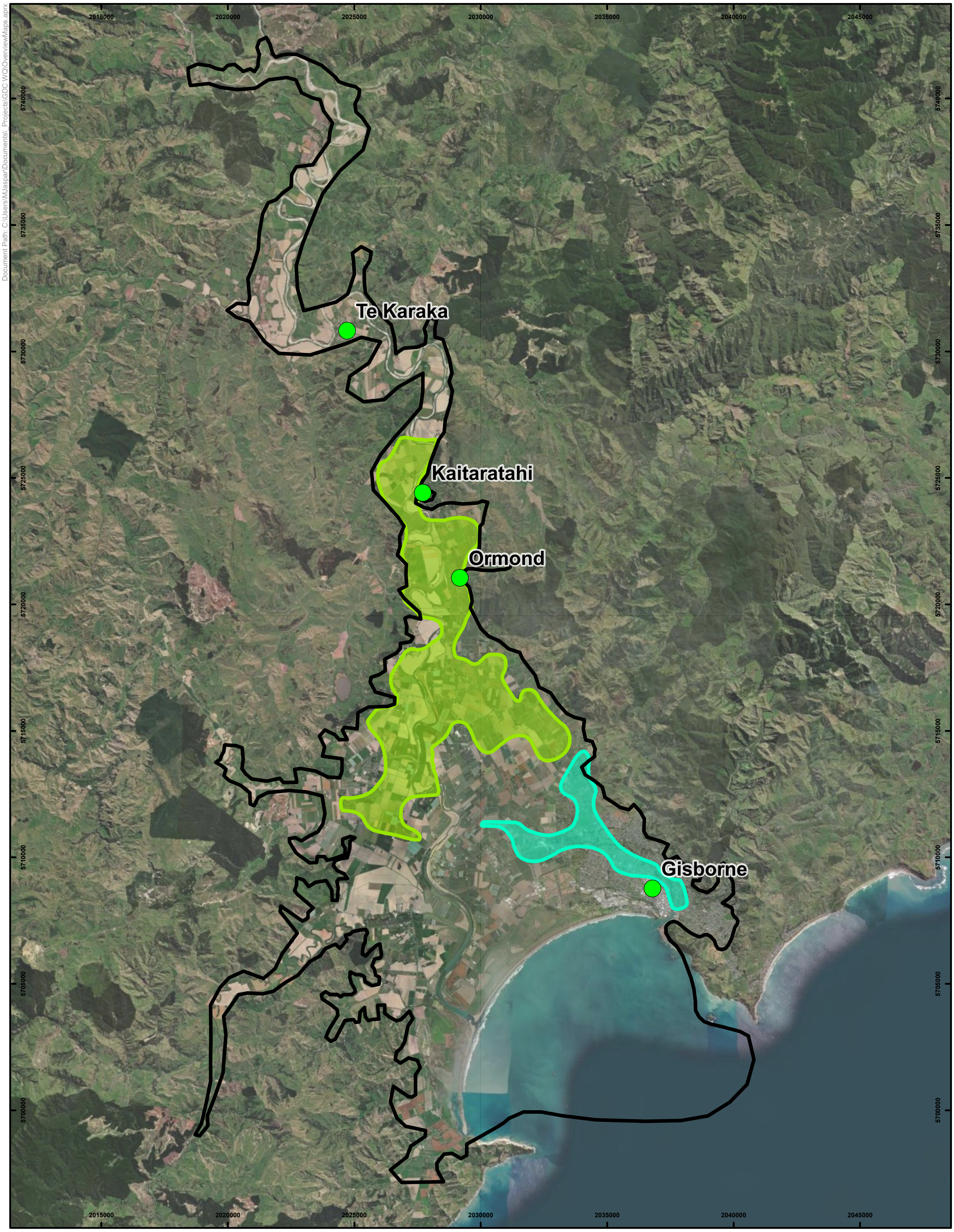
- Model Extent
- Shallow Fluvial Deposits
- Te Hapara Sands

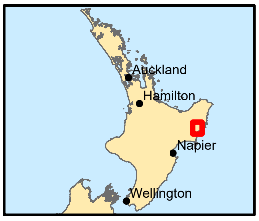
WGA
WALLBRIDGE GILBERT AZTEC

Figure **A1**

Gisborne MAR Model

Shallow Fluviatile and Te Hapara Sand Aquifer Extents





N

0 0.8 1.6 2.4 3.2 km

Scale 1:200,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user.

LEGEND

- Model Extent
- Waipaoa Gravel
- Waipaoa Gravel 2

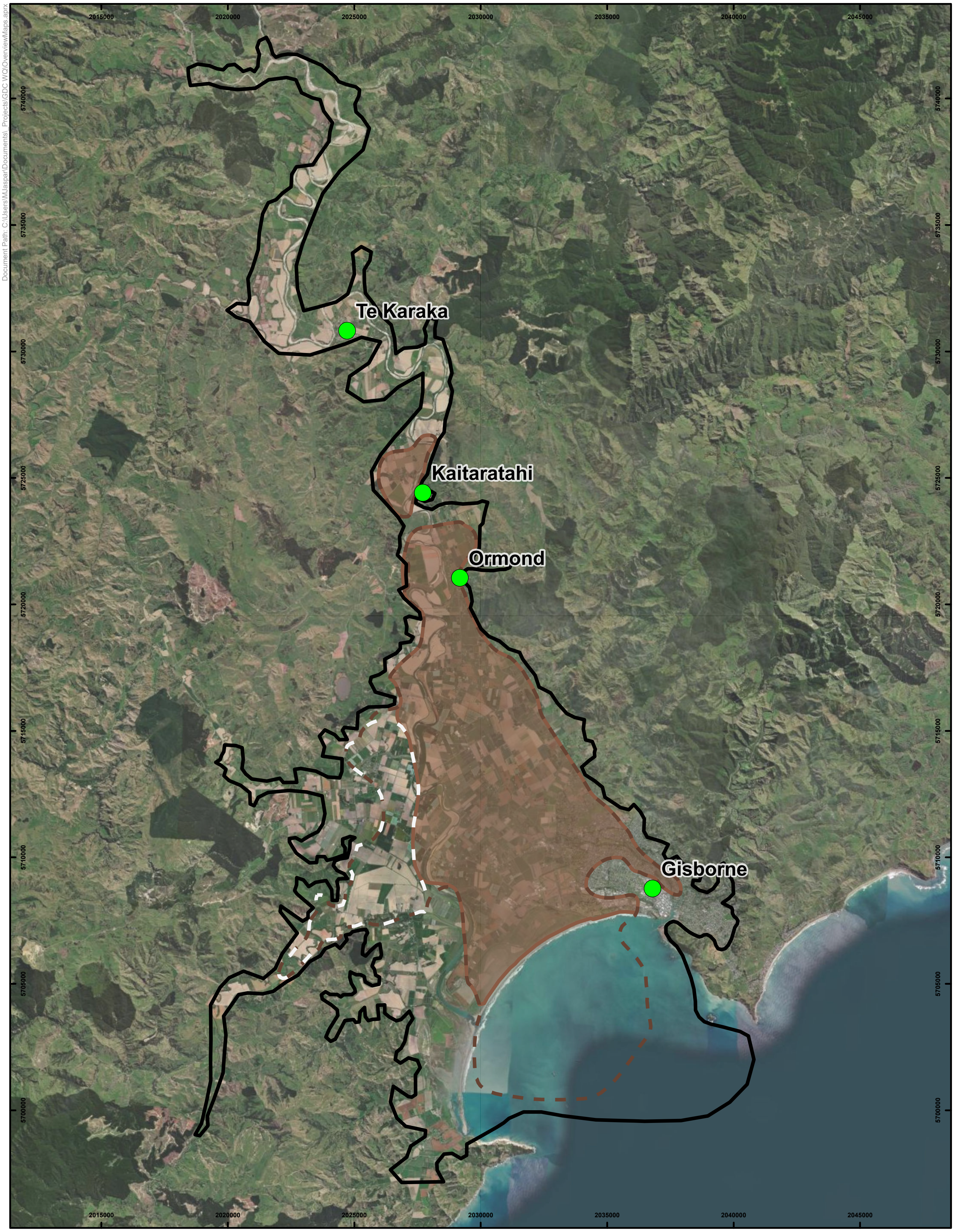
WGA

WALLBRIDGE GILBERT AZTEC

Figure **A2**

Gisborne MAR Model

Waipaoa Gravel Aquifer Extents



Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user.

LEGEND

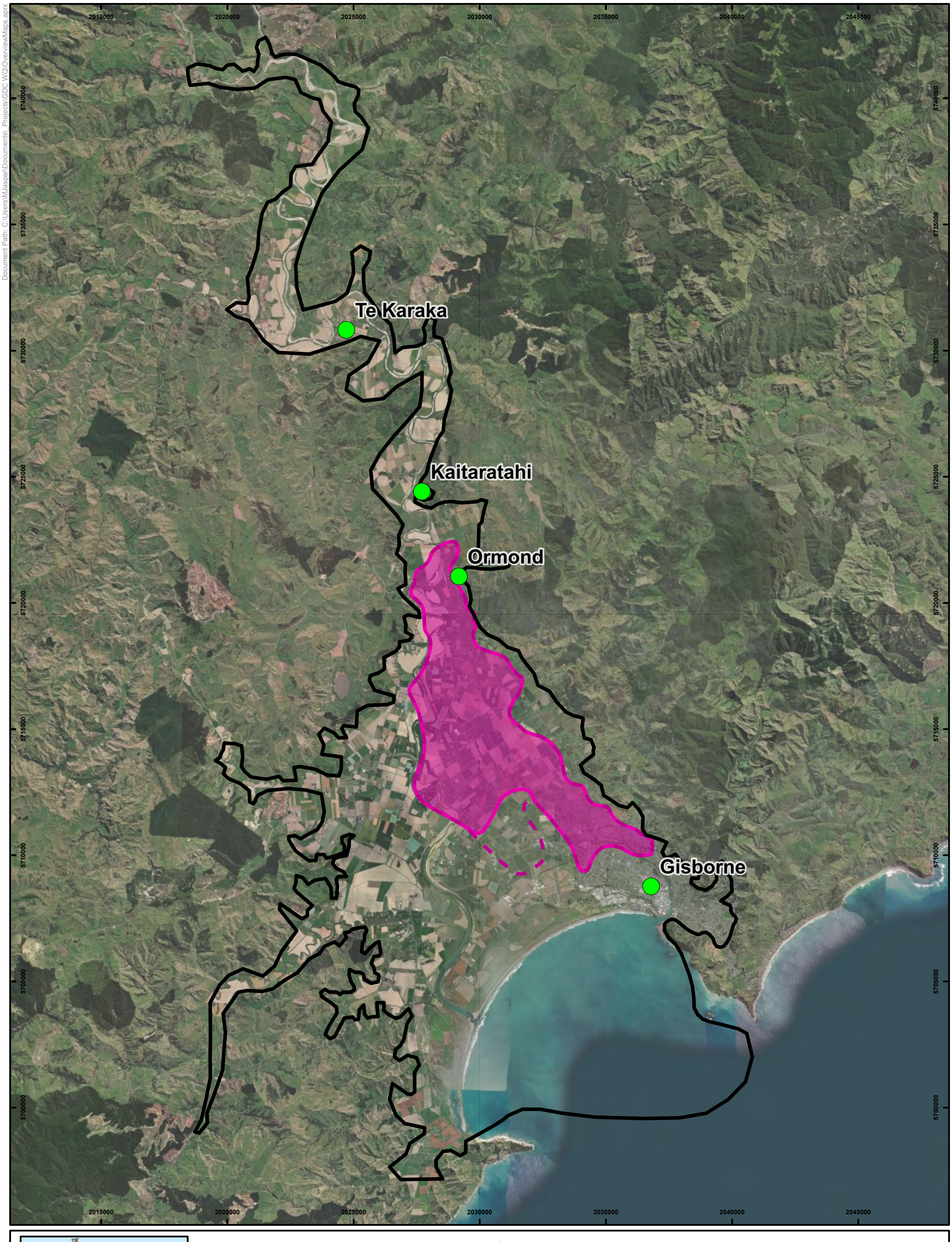
- Model Extent
- Western Saline Area - Indicative
- Makauri Gravel - Indicative
- Makauri Gravel

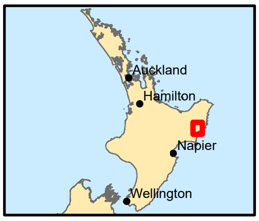
WGA
WALLBRIDGE GILBERT AZTEC

Figure **A3**

Gisborne MAR Model

Makauri Gravel Aquifer Extent





N

0 0.8 1.6 2.4 3.2 km

Scale 1:200,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no guarantee is given that the information portrayed is free from error or omission. Any relevance placed on such information shall be at the risk of the user.

LEGEND

- Model Extent
- Matokitoki Gravel - Indicative
- Matokitoki Gravel

WGA
WALLBRIDGE GILBERT AZTEC

Figure **A4**

Gisborne MAR Model

Matokitoki Gravel Aquifer Extent

APPENDIX B

GDC CLIMATE SCENARIO SETTINGS MEMORANDUM

Decision register for the Poverty Bay Flats Groundwater Model
CLIMATE CHANGE INPUT SETTINGS

First round of Scenarios

For the first round of scenarios completed in the model, climate change settings were applied to Scenarios 1-7 as only a **decrease** in rainfall rates (see RCP4.5 rainfall settings chosen in Section 1. below).

It was communicated and agreed with community that any future increase in rainfall will mostly be experienced as extreme flooding and surface runoff, therefore this has not been included in the model. It was also generally agreed upon for majority of the first round of modelling that the potential evaporation deficit (PED) could not be captured in FEFLOW as a surface interaction with the model.

However, in the last hour, the decision was made for Scenarios 8 and 9 to include additional climate change settings of sea level rise (see section 2. below), reoccurring droughts (see section 3. below) and increasing PED (see section 4. below). Due to the model's inability to capture PED from surface, the decision was made to represent PED as the additional abstraction that would be required to meet soil moisture deficits.

The chosen settings for each scenario can be viewed in Table A3-1 of the Aquasoil report.

Second round of Scenarios

Following the results of the first round of scenarios, it was observed that the impacts of climate change in Scenarios 1-7 were not significant. This was believed to be an error in decision making during scenario setting and subsequently a representation of more climate change impacts was decided upon. These are listed as below and captured in Table 4-1 of the Aquasoil report.

1. Rainfall (NIWA.2020)

Changes in rainfall rates were determined from Section 5.1 in the 2020 NIWA climate change report for Tairawhiti. Percentage decreases in rainfall were **chosen by GDC** for both RCP 4.5 and RCP 8.5.

Decrease <5 % of actual until 2040 (RCP4.5)
Decrease Summer 5-15% of actual until 2040 (RCP4.5)
Decrease Spring and Summer 5-15% of actual 2040-2090 (RCP4.5)

Decrease <10 % of actual until 2040 (RCP8.5)
Decrease Spring and Summer 5-15% of actual until 2040 (RCP8.5)
Decrease 5-15 % of actual 2040-2090 (RCP8.5)

For the purpose of step change modelling in FEFLOW, Aquasoil chose *to use the upper limits in each setting chosen.*
RCP 4.5 = -5% in 2040, -15% in Sept in 2090
RCP 8.5 = -10% in 2040, -15% in Sept 2040 and -15% in 2040-2090.

2. Sea level rise (NIWA.2017)

Changes in sea level rise follow the progressive scenarios (generic to NZ) presented in Table 10 (NIWA. 2017 and below) for RCP 4.5 and RCP 8.5, which are in groundwater terms only marginally different (Pers comm. B Sinclair, 2022).

3. Droughts (NIWA. 2013)

Total PED for 2012-2013 was the highest since the El Nino drought of 1997-1998, and about the fifth highest for the period of record since 1940 (**NIWA 2013**). Exceedances beyond the 500 PED roughly average every 7 years (Figure 2). However **Aquasoil determined** that to represent this 7 year frequency in the model, aquifer recovery generated would not be sufficient.

Therefore, three drought periods were suggested from Aquasoil. A ratio of the increased abstraction from the drought event from 2012-2015 was to reoccur in the model as the additional percentage of groundwater takes used to recover a significant drought. 3 year drought periods occur in the model from 2035-2038, 2050-2053 and 2070-2073.

See Chapter 4 and Table 4-4 in the Aquasoil report for more context.

4. PED (NIWA.2020)

PED for the Gisborne region is set at 350mm per year, this is the mid-range **chosen by GDC** from the NIWA reported 300-400 mm per year (NIWA.2020).

GDC also chose from Section 6.1 of the 2020 NIWA climate change report a change in PED to increase +125mm by 2090 (mid-range of the NIWA prediction +110-150mm until 2090 RCP4.5)

Due to the model's inability to capture PED from surface, the decision was made to represent PED as the additional abstraction that would be required to meet soil moisture deficits.

The mid-value of 125mm PED increase on the minimum current 300mm PED per year was chosen as a 42% increase in both PED and current abstraction rates by 2090.

For RCP 4.5 (all Scenarios with +CC) GDC took 15 year increments back from 2090 for the 42% increase and used a linear relationship to fill in the previous years.

Average (2008-2021) Takes to increase:
5% at 2030
15% at 2045
24% at 2060
33% at 2075 (**Aquasoil took this 33% as the final increase to 2090**)
42% at 2090 (this was disregarded in modelling)

For RCP 8.5 (Scenario 8) NIWA specifies two incremental changes. So I took the halfway point between each.

Average (2008- 2021) Takes to increase:
21% in 2030
42% at 2040
53% at 2065 (**Aquasoil took this 53% as the final increase to 2090**)
64% at 2090 (this was disregarded in modelling)

References

NIWA. 2013. The 2012-13 drought:an assessment and historical perspective. https://niwa.co.nz/sites/niwa.co.nz/files/2013-18-The%202012-13%20drought%20an%20assessment%20and%20historical%20perspective.pdf

NIWA. 2017. Coastal Hazards and Climate Change. Guidance for Local Government. coastal-hazards-guide-final.pdf (environment.govt.nz)

NIWA 2020. Climate change projections and impacts for Tairawhiti and Hawkes Bay. [NIWA Client report (gdc.govt.nz)]

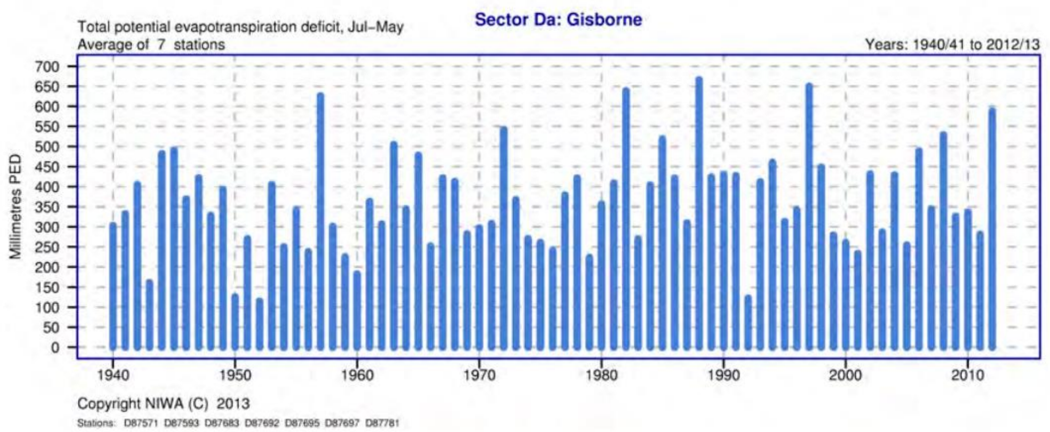
Referenced figures/data

Table 10: NIWA. 2017

Table 10: Decadal increments for projections of sea-level rise (metres above 1986–2005 baseline) for the wider New Zealand region (for the four future scenarios from figure 27)

NZ SLR scenario Year	NZ RCP2.6 M (median) [m]	NZ RCP4.5 M (median) [m]	NZ RCP8.5 M (median) [m]	NZ RCP8.5 H[+] (83rd percentile) [m]
1986–2005	0	0	0	0
2020	0.08	0.08	0.09	0.11
2030	0.13	0.13	0.15	0.18
2040	0.18	0.19	0.21	0.27
2050	0.23	0.24	0.28	0.37
2060	0.27	0.30	0.36	0.48
2070	0.32	0.36	0.45	0.61
2080	0.37	0.42	0.55	0.75
2090	0.42	0.49	0.67	0.90
2100	0.46	0.55	0.79	1.05
2110	0.51	0.61	0.93	1.20
2120	0.55	0.67	1.06	1.36
2130	0.60*	0.74*	1.18*	1.52
2140	0.65*	0.81*	1.29*	1.69
2150	0.69*	0.88*	1.41*	1.88

* Extended set 2130–50 based on applying the same rate of rise of the relevant representative concentration pathway (RCP) median trajectories from Kopp et al, 2014 (K14) to the end values of the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) projections. Columns 2, 3, 4: based on IPCC AR5 (Church et al, 2013a); and column 5: New Zealand RCP8.5 H[+] scenario (83rd percentile, from Kopp et al, 2014). Note: M = median; m = metres; NZ = New Zealand; SLR = sea-level rise. To determine the local SLR, a further component for persistent vertical land movement may need to be added (subsidence) or subtracted (uplift).



Total PED for 2012–13 was the highest since the El Nĩno drought of 1997-98, and about the fifth highest for the period of record since 1940.

Figure 1 – NIWA. 2013.

APPENDIX C

MODEL ANNUAL WATER BALANCE RESULTS SUMMARY

WATER BALANCE GUIDANCE

The water balance components indicate NET annual flows

- Positive values indicate net recharge to the groundwater system
- Negative values indicate net discharge from the groundwater system

- **Rainfall recharge** can only be positive (represents a **TOTAL IN**)
- **Consented takes** can only be negative (represents a **TOTAL OUT**)
- Most **streams and drains** can only be negative (represents a **TOTAL OUT**)
- **MAR** can only be positive (represents a **TOTAL IN**)
- **River** reaches can be positive or negative (represents a **NET FLOW**)
- **Ocean** can also be positive or negative (represents a **NET FLOW**)

A groundwater budget can be calculated from the model as a whole.

- **TOTAL IN** for overall model and specific aquifers
- **TOTAL OUT** for overall model and specific aquifers
- **CHANGE IN STORAGE** for overall model and individual aquifers

The current model version is not tracking volumetric changes in aquifer groundwater storage.

Table notes

▲ Flow rate increases (the net flow direction does not change unless specifically noted)

▼ Flow rate decreases (the net flow direction does not change unless specifically noted)

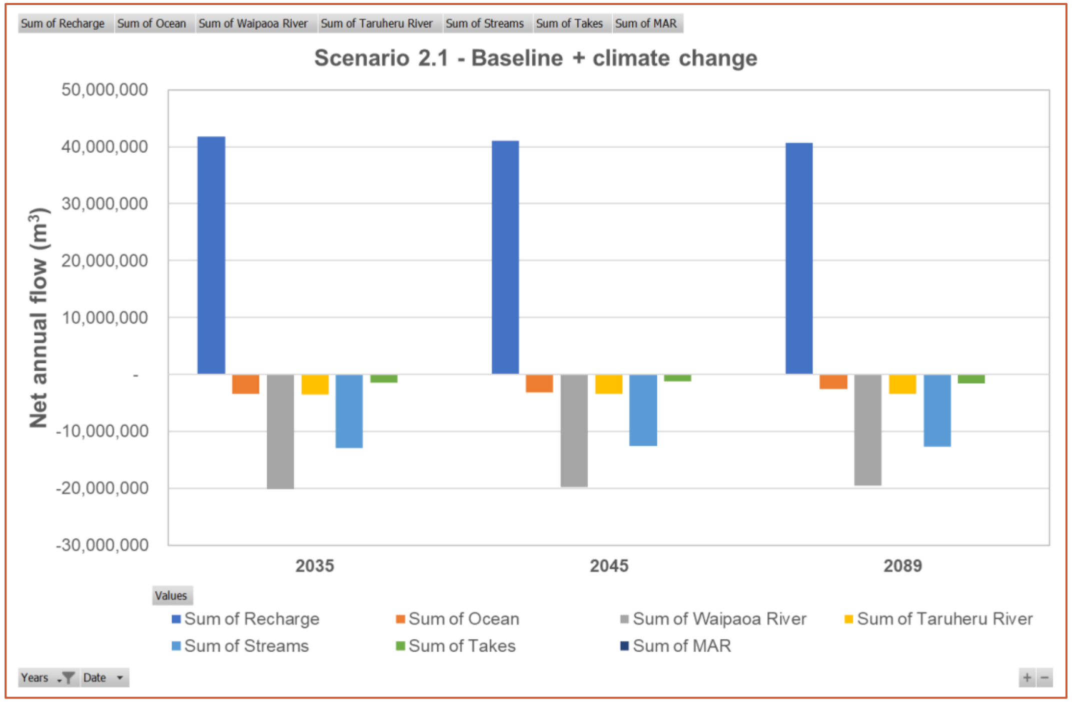
Text in **red bold font** indicates the Scenario input changes compared to Scenario 2.1.

SCENARIO 2.1 – BASELINE + CLIMATE CHANGE

Table C1: Scenario 2.1 Net Groundwater Balance

Year	Rainfall Recharge	Ocean	Waipaoa River	Taruheru River	Streams	GW Takes	MAR
2035	41,729,347	- 3,360,701	- 20,169,431	- 3,539,601	- 12,886,408	- 1,504,648	0
2045	41,047,252	- 3,194,815	- 19,722,899	- 3,436,594	- 12,563,487	- 1,263,022	0
2089	40,673,814	- 2,585,114	- 19,517,003	- 3,363,957	- 12,732,652	- 1,541,773	0

Note: positive values = net annual groundwater recharge negative values = net annual groundwater discharge All values in m^3/year.



Key Features

Declining rainfall recharge mainly leads to:

- Declining discharge to ocean over time
- Declining net discharge to Waipaoa River over time

Table C2: Scenario 2.1 Aquifer Groundwater Balance Results Summary

Aquifer / Parameter	Annual groundwater flows - averages for defined periods / single year result for defined drought years									
	2024 - 30	2031 - 34	2036	2039 - 45	2046 - 49	2051	2054 - 60	2061 - 69	2071	2076 - 88
Shallow Fluviatile / Te Hapara Sand Aquifers										
Total inflow	44,107,343	43,713,461	43,305,733	43,150,603	43,097,551	43,037,228	43,056,079	42,988,518	42,925,650	42,907,269
Total outflow	-44,228,443	-43,874,250	-43,585,349	-43,297,463	-43,237,653	-43,219,080	-43,193,680	-43,118,965	-43,109,687	-43,042,007
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-140,383	-146,942	-211,630	-147,812	-160,928	-230,027	-161,905	-173,377	-248,029	-186,232
Waipaoa Aquifer										
Total inflow	5,788,641	5,792,163	5,985,796	5,766,580	5,800,091	6,012,162	5,799,666	5,826,336	6,054,598	5,859,915
Total outflow	-5,808,936	-5,812,993	-6,011,177	-5,787,122	-5,821,761	-6,038,122	-5,821,792	-5,849,570	-6,082,972	-5,884,547
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-69,193	-72,442	-104,699	-72,845	-79,338	-113,752	-79,805	-85,472	-122,655	-91,821
Makauri Aquifer										
Total inflow	2,490,192	2,514,172	2,820,313	2,507,311	2,563,888	2,896,820	2,562,698	2,609,959	2,973,276	2,660,561
Total outflow	-2,490,269	-2,514,180	-2,818,835	-2,507,484	-2,563,879	-2,894,435	-2,562,909	-2,609,883	-2,970,762	-2,660,676
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-849,307	-889,204	-1,284,812	-894,032	-973,833	-1,396,668	-979,256	-1,049,148	-1,505,972	-1,126,868
Matokitoki Aquifer										
Total inflow	214,998	217,447	252,260	217,437	223,152	263,093	223,356	228,674	274,248	234,710
Total outflow	-215,073	-217,445	-251,676	-217,511	-223,187	-262,056	-223,484	-228,751	-273,201	-234,902
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-62,189	-65,130	-94,426	-65,459	-71,333	-102,727	-71,691	-76,859	-110,767	-82,541

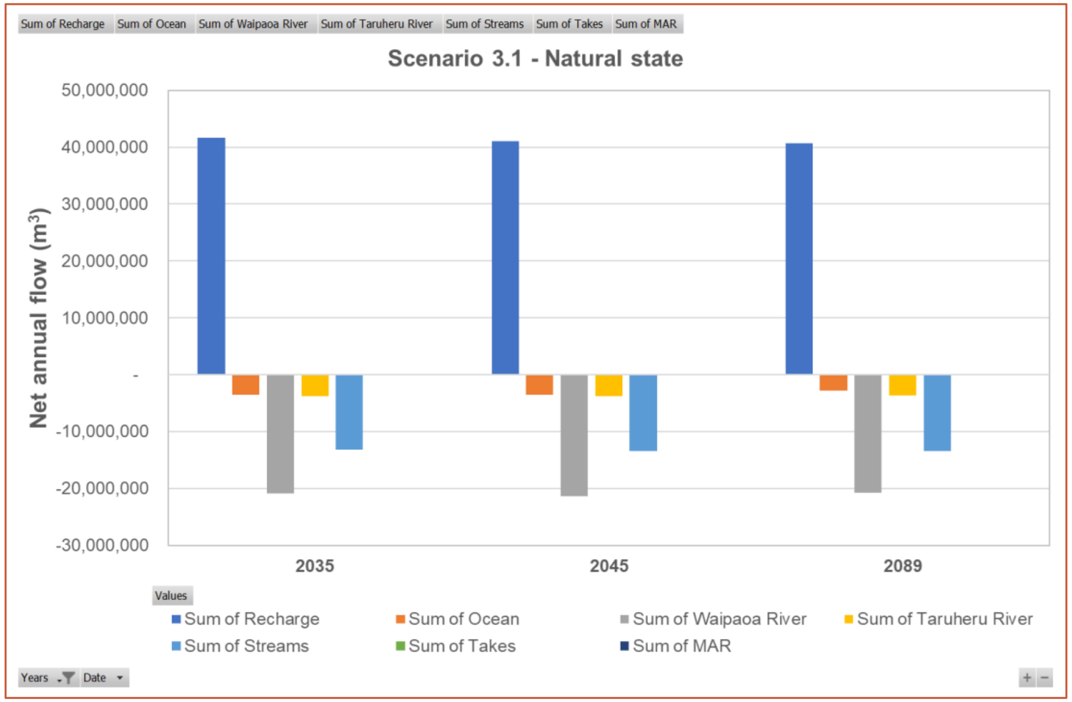
Notes: Yellow cells identify drought year outcomes.

SCENARIO 3.1 – NATURAL STATE

Table C3: Scenario 3.1 Net Groundwater Balance

Year	Rainfall Recharge	Ocean	Waipaoa River	Taruheru River	Streams	GW Takes	MAR
2035	41,711,948	▲ - 3,486,297	▲ - 20,882,686	- 3,735,576	- 13,222,727	0	0
2045	41,047,252	▲ - 3,514,542	▲ - 21,399,853	- 3,812,220	- 13,387,392	0	0
2089	40,673,815	▲ - 2,803,982	▲ - 20,701,234	- 3,697,365	- 13,419,120	0	0

Note: positive values = net annual groundwater recharge negative values = net annual groundwater discharge All values in m^3/year.



Key Features

Compared to Scenario 2.1:

- Net discharges to ocean increase
- Net discharges to Waipaoa River increase

Table C4: Scenario 3.1 Aquifer Groundwater Balance Results Summary

Aquifer / Parameter	Annual groundwater flows - averages for defined periods / single year result for defined drought years									
	2024 - 30	2031 - 34	2036	2039 - 45	2046 - 49	2051	2054 - 60	2061 - 69	2071	2076 - 88
Shallow Fluviatile / Te Hapara Sand Aquifers										
Total inflow	44,545,703	44,579,323	43,944,690	43,599,716	43,584,578	42,199,665	43,782,970	43,302,136	41,856,424	43,431,918
Total outflow	-44,622,740	-45,017,452	-44,192,457	-43,769,597	-43,759,458	-41,189,392	-44,150,216	-43,302,088	-40,859,304	-43,600,756
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	0	0	0	0	0	0	0	0	0	0
Waipaoa Aquifer										
Total inflow	5,477,100	5,569,096	5,478,295	5,440,661	5,439,378	5,081,206	5,499,671	5,383,038	5,001,859	5,428,060
Total outflow	-5,481,524	-5,574,110	-5,485,339	-5,444,743	-5,444,368	-5,083,141	-5,504,929	-5,387,947	-5,005,272	-5,433,250
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	0	0	0	0	0	0	0	0	0	0
Makauri Aquifer										
Total inflow	1,944,269	1,978,778	1,946,260	1,931,345	1,929,473	1,796,652	1,948,212	1,903,661	1,759,470	1,913,493
Total outflow	-1,944,224	-1,979,088	-1,946,489	-1,931,325	-1,929,449	-1,795,506	-1,948,380	-1,903,482	-1,758,204	-1,913,548
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	0	0	0	0	0	0	0	0	0	0
Matokitoki Aquifer										
Total inflow	179,066	182,388	179,734	178,862	178,832	166,930	180,891	177,064	163,940	178,678
Total outflow	-179,196	-182,762	-180,047	-178,991	-178,971	-166,258	-181,159	-177,087	-163,194	-178,811
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	0	0	0	0	0	0	0	0	0	0

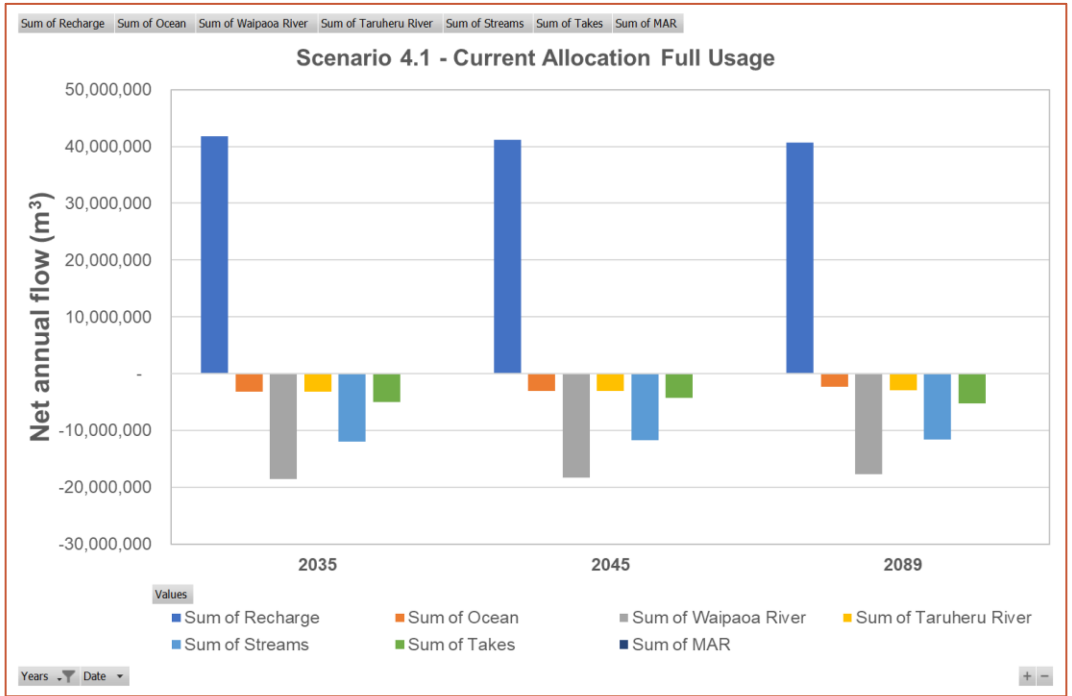
Notes: Yellow cells identify drought year outcomes.
Values in red indicate key differences from Scenario 2.1.

SCENARIO 4.1 – CURRENT ALLOCATION FULL USAGE

Table C5: Scenario 4.1 Net Groundwater Balance

Year	Rainfall Recharge	Ocean	Waipaoa River	Taruheru River	Streams	GW Takes	MAR
2035	41,729,513	- 3,131,882	▼ - 18,503,782	▼ - 3,143,464	▼ - 11,955,960	▲ **- 5,023,185**	0
2045	41,107,802	- 2,988,138	▼ - 18,294,106	▼ - 3,057,728	▼ - 11,707,063	▲ **- 4,277,026**	0
2089	40,740,429	- 2,313,761	▼ - 17,698,600	▼ - 2,885,049	▼ - 11,630,797	▲ **- 5,214,928**	0

Note: positive values = net annual groundwater recharge negative values = net annual groundwater discharge All values in m³/year.



Key Features:

Compared to Scenario 2.1, the increased groundwater takes result in:

- Net discharges to rivers decrease.
- Net discharges to streams decrease.
- Net discharge to ocean decreases

Table C6: Scenario 4.1 Aquifer Groundwater Balance Results Summary

Aquifer / Parameter	Annual groundwater flows - averages for defined periods / single year result for defined drought years									
	2024 - 30	2031 - 34	2036	2039 - 45	2046 - 49	2051	2054 - 60	2061 - 69	2071	2076 - 88
Shallow Fluviatile / Te Hapara Sand Aquifers										
Total inflow	44,018,569	43,629,001	43,411,209	43,045,976	42,996,894	43,193,179	42,948,800	42,962,695	43,176,692	42,857,088
Total outflow	-44,204,364	-43,775,068	-43,759,934	-43,147,281	-42,910,397	-43,405,319	-42,896,121	-43,042,977	-43,417,533	-42,914,452
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-1,033,039**	**-1,081,262**	**-1,555,241**	**-1,087,581**	**-1,183,938**	**-1,690,745**	**-1,191,143**	**-1,275,547**	**-1,821,891**	**-1,370,013**
Waipaoa Aquifer										
Total inflow	6,649,816	6,694,145	7,396,720	6,677,868	6,808,622	7,570,117	6,807,413	6,949,021	7,756,333	7,048,473
Total outflow	-6,655,891	-6,698,428	-7,393,174	-6,682,610	-6,813,143	-7,569,591	-6,813,421	-6,951,211	-7,757,340	-7,054,904
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-536,988**	**-562,089**	**-807,630**	**-565,403**	**-615,610**	**-880,187**	**-619,092**	**-663,396**	**-947,937**	**-712,245**
Makauri Aquifer										
Total inflow	3,338,650	3,414,394	4,309,787	3,410,181	3,573,808	4,571,541	3,575,818	3,729,429	4,830,299	3,885,291
Total outflow	-3,338,644	-3,414,166	-4,307,013	-3,410,691	-3,573,397	-4,566,944	-3,576,142	-3,730,010	-4,827,589	-3,885,420
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-1,911,232**	**-2,001,210**	**-2,893,421**	**-2,011,630**	**-2,191,450**	**-3,147,745**	**-2,203,238**	**-2,361,132**	**-3,391,550**	**-2,535,750**
Matokitoki Aquifer										
Total inflow	476,614	495,069	688,030	496,504	535,226	744,225	536,293	570,328	794,732	606,914
Total outflow	-477,231	-495,640	-686,578	-497,332	-535,625	-741,457	-537,144	-571,122	-794,074	-607,828
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-344,884**	**-361,163**	**-522,995**	**-363,032**	**-395,550**	**-569,087**	**-397,602**	**-426,184**	**-612,990**	**-457,702**

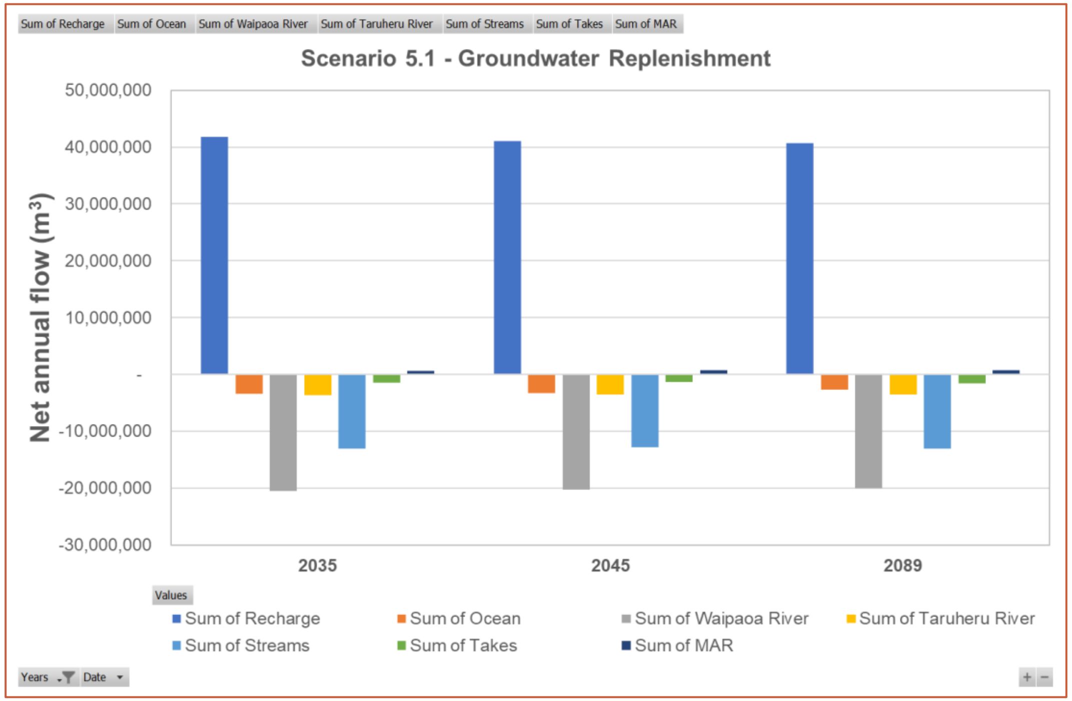
Notes: Yellow cells identify drought year outcomes.
Values in red indicate key differences from Scenario 2.1.

SCENARIO 5.1 – GROUNDWATER REPLENISHMENT

Table C7: Scenario 5.1 Net Groundwater Balance

Year	Rainfall Recharge	Ocean	Waipaoa River	Taruheru River	Streams	GW Takes	MAR
2035	41,729,332	- 3,437,776	▲ - 20,488,042	- 3,637,804	- 13,065,595	- 1,499,899	**630,000**
2045	41,047,251	- 3,300,645	▲ - 20,210,138	- 3,566,934	- 12,820,811	- 1,296,652	**691,406**
2089	40,710,194	- 2,693,638	▲ - 20,047,406	- 3,519,611	- 13,034,061	- 1,578,902	**798,443**

Note: positive values = net annual groundwater recharge negative values = net annual groundwater discharge. All values in m^3/year.



Key Features:

Compared to Scenario 2.1, the application of enhanced recharge techniques results in:

- Net discharges to Waipaoa River increase.
- Net discharges to the other surface water features also increase but to a smaller degree.

Table C8: Scenario 5.1 Aquifer Groundwater Balance Results Summary

Aquifer / Parameter	Annual groundwater flows - averages for defined periods / single year result for defined drought years									
	2024 - 30	2031 - 34	2036	2039 - 45	2046 - 49	2051	2054 - 60	2061 - 69	2071	2076 - 88
Shallow Fluviatile / Te Hapara Sand Aquifers										
Total inflow	44,315,215	43,931,203	43,481,976	43,354,350	43,319,744	43,233,312	43,282,516	43,231,707	43,128,784	43,171,299
Total outflow	-44,431,924	-44,094,260	-43,759,454	-43,511,346	-43,473,800	-43,429,747	-43,427,704	-43,367,862	-43,320,946	-43,317,548
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-140,383	-146,941	-211,634	-147,815	-160,929	-230,019	-161,899	-173,379	-248,020	-186,217
Waipaoa Aquifer										
Total inflow	5,606,355	5,602,348	5,767,132	5,576,051	5,593,662	5,774,830	5,591,372	5,603,572	5,800,439	5,619,530
Total outflow	-5,626,989	-5,623,681	-5,793,032	-5,596,945	-5,616,166	-5,800,183	-5,613,834	-5,626,845	-5,827,931	-5,644,363
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-69,182	-72,429	-104,681	-72,834	-79,329	-113,726	-79,789	-85,459	-122,626	-91,800
Makauri Aquifer										
Total inflow	2,771,767	2,806,104	3,066,442	2,809,198	2,884,317	3,165,624	2,892,116	2,956,777	3,262,168	3,031,424
Total outflow	-2,771,810	-2,806,138	-3,065,107	-2,809,284	-2,884,335	-3,163,365	-2,892,294	-2,956,702	-3,259,733	-3,031,492
Wells recharge	**607,435**	**630,230**	**629,568**	**644,692**	**690,216**	**690,000**	**702,949**	**744,354**	**744,000**	**797,878**
Wells abstraction	-849,327	-889,223	-1,284,757	-894,059	-973,819	-1,396,708	-979,275	-1,049,177	-1,506,016	-1,126,802
Matokitoki Aquifer										
Total inflow	237,033	240,150	260,418	241,405	247,756	270,983	248,987	254,533	281,300	261,576
Total outflow	-237,040	-240,152	-259,760	-241,411	-247,768	-270,038	-249,046	-254,515	-280,263	-261,609
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	-62,205	-65,148	-94,475	-65,479	-71,351	-102,771	-71,711	-76,879	-110,814	-82,560

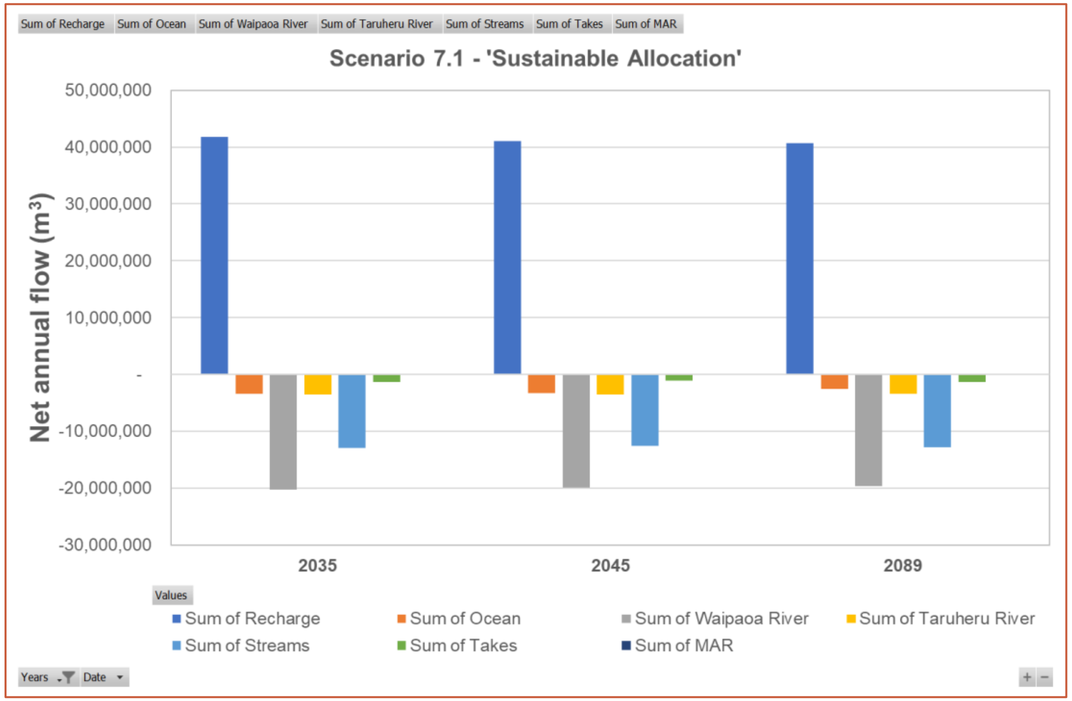
Notes: Yellow cells identify drought year outcomes.
Values in red indicate key differences from Scenario 2.1.

SCENARIO 7.1 – 'SUSTAINABLE ALLOCATION'

Table C9: Scenario 7.1 Net Groundwater Balance

Year	Rainfall Recharge	Ocean	Waipaoa River	Taruheru River	Streams	GW Takes	MAR
2035	41,729,438	- 3,380,568	- 20,254,318	- 3,566,530	- 12,941,914	**- 1,278,950**	0
2045	41,047,252	- 3,219,202	- 19,850,903	- 3,466,337	- 12,585,898	**- 1,070,878**	0
2089	40,673,814	- 2,605,719	- 19,635,724	- 3,402,168	- 12,791,495	**- 1,307,739**	0

Note: positive values = net annual groundwater recharge negative values = net annual groundwater discharge. All values in m^3/year.



Key Features:

Compared to Scenario 2.1, the reduction in groundwater takes results in:

- Groundwater discharges to most receiving waters increase .

Table C10: Scenario 7.1 Aquifer Groundwater Balance Results Summary

Aquifer / Parameter	Annual groundwater flows - averages for defined periods / single year result for defined drought years									
	2024 - 30	2031 - 34	2036	2039 - 45	2046 - 49	2051	2054 - 60	2061 - 69	2071	2076 - 88
Shallow Fluviatile / Te Hapara Sand Aquifers										
Total inflow	44,146,625	43,756,080	43,348,335	43,185,300	43,135,814	43,077,484	43,107,663	43,046,347	42,991,406	42,969,291
Total outflow	-44,270,157	-43,930,278	-43,635,353	-43,351,146	-43,293,101	-43,252,430	-43,248,610	-43,173,952	-43,144,500	-43,106,557
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-119,331**	**-124,900**	**-179,895**	**-125,682**	**-136,792**	**-195,523**	**-137,643**	**-147,378**	**-210,824**	**-158,316**
Waipaoa Aquifer										
Total inflow	5,734,814	5,735,454	5,891,570	5,710,033	5,736,186	5,909,148	5,736,648	5,755,884	5,944,465	5,779,169
Total outflow	-5,752,845	-5,754,120	-5,914,948	-5,728,414	-5,755,725	-5,931,452	-5,755,909	-5,775,868	-5,968,655	-5,800,720
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-58,816**	**-61,575**	**-88,997**	**-61,937**	**-67,441**	**-96,689**	**-67,851**	**-72,653**	**-104,256**	**-78,059**
Makauri Aquifer										
Total inflow	2,400,094	2,418,995	2,669,898	2,411,918	2,457,528	2,729,815	2,455,969	2,493,772	2,791,689	2,533,194
Total outflow	-2,400,161	-2,419,011	-2,668,753	-2,412,080	-2,457,525	-2,727,888	-2,456,149	-2,493,704	-2,789,548	-2,533,209
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-721,933**	**-755,822**	**-1,092,173**	**-760,163**	**-827,734**	**-1,187,168**	**-832,523**	**-891,821**	**-1,280,076**	**-957,962**
Matokitoki Aquifer										
Total inflow	207,290	209,088	234,486	209,031	213,159	242,565	213,267	217,018	250,702	221,450
Total outflow	-207,311	-209,114	-234,007	-209,140	-213,161	-241,880	-213,329	-216,962	-249,983	-221,458
Wells recharge	0	0	0	0	0	0	0	0	0	0
Wells abstraction	**-52,857**	**-55,360**	**-80,268**	**-55,633**	**-60,632**	**-87,318**	**-60,943**	**-65,327**	**-94,151**	**-70,163**

Note: Yellow cells identify drought year outcomes.

SCENARIO 7.1 – 'SUSTAINABLE ALLOCATION'

Table C6: Groundwater Volumes Taken at Selected Years

Year	Matokitoki Aquifer	Makauri Aquifer	Waipaoa Aquifer	Shallow Fluviatile Gravel Aquifer	Te Hapara Sand Aquifer
2034	54,936	749,751	61,039	105,566	80,712
2036	80,267	1,092,169	88,997	151,064	117,517
2049	60,244	821,680	66,877	115,621	88,438
2051	87,318	1,187,168	96,689	164,659	127,707
2069	65,407	892,940	72,735	125,256	96,153
2071	94,152	1,280,076	104,256	177,546	137,701

Note: Some annual values differ slightly from those in Table C10 due to different flow calculation methodology applied in FEFLOW.

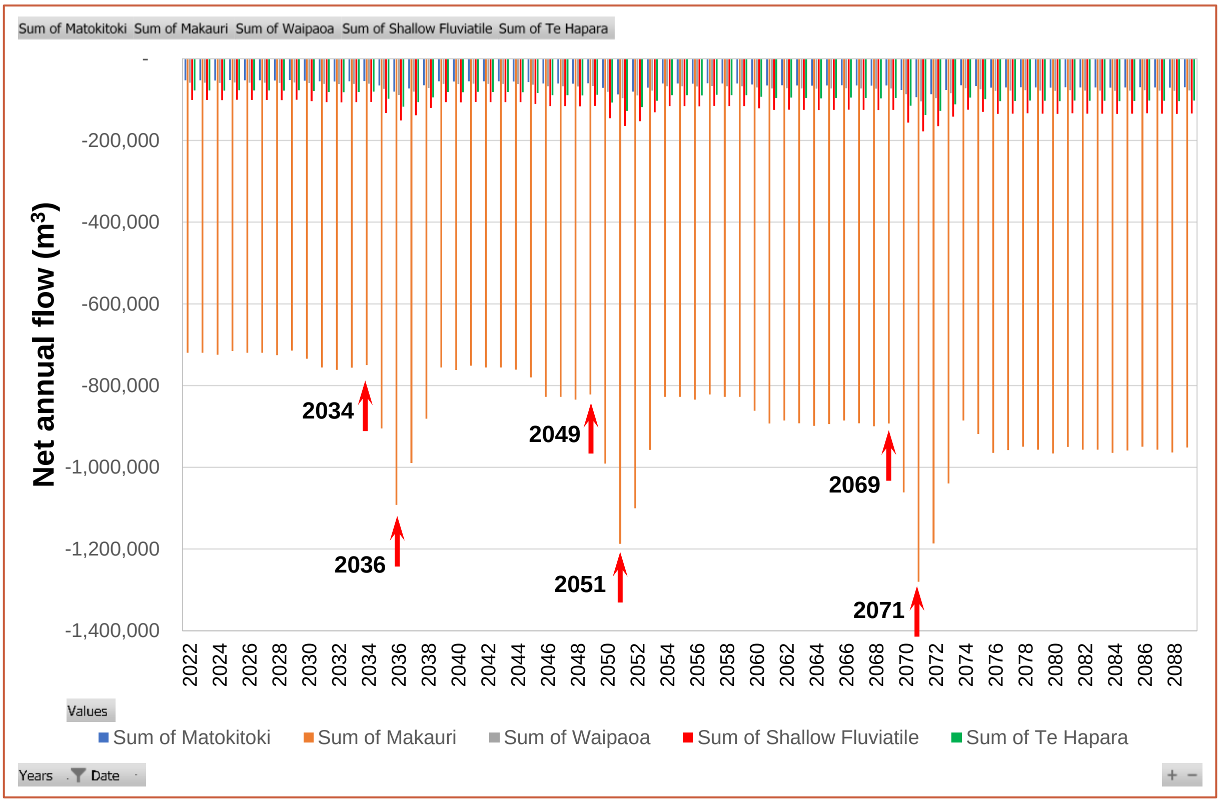


Figure C1. Years Interrogated for Groundwater Take Volumes

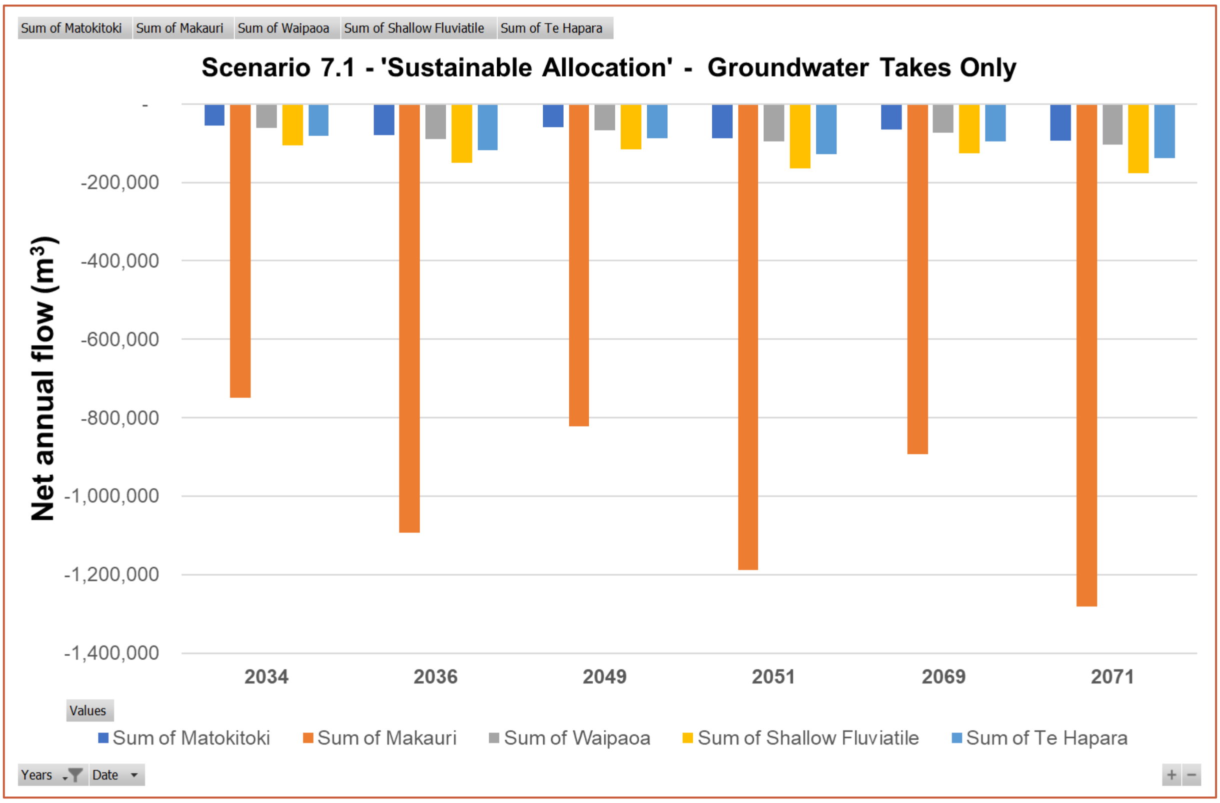


Figure C2. Comparison of Groundwater Take Volumes by Aquifer under Scenario 7.1

Table C7: Net Groundwater Balance at Decade Intervals

Scenario	Rainfall Recharge	Ocean	Waipaoa River	Taruheru River	Streams	Groundwater Takes	MAR
2035							
Scenario 2.1	41,729,347	- 3,360,701	- 20,169,431	- 3,539,601	- 12,886,408	- 1,504,648	0
Scenario 3.1	41,711,948	- 3,486,297	▲ - 20,882,686	- 3,735,576	- 13,222,727	**0**	0
Scenario 4.1	41,729,513	▼ - 3,131,882	▼ - 18,503,782	▼ - 3,143,464	▼ - 11,955,960	**- 5,023,185**	0
Scenario 5.1	41,729,332	- 3,437,776	- 20,488,042	- 3,637,804	- 13,065,595	- 1,499,899	**630,000**
Scenario 7.1	41,729,438	- 3,380,568	- 20,254,318	- 3,566,530	- 12,941,914	- 1,278,950	0
2045							
Scenario 2.1	41,047,252	- 3,194,815	- 19,722,899	- 3,436,594	- 12,563,487	- 1,263,022	0
Scenario 3.1	41,047,252	▲ - 3,514,542	▲ - 21,399,853	▲ - 3,812,220	- 13,387,392	**0**	0
Scenario 4.1	41,107,802	▼ - 2,988,138	▼ - 18,294,106	▼ - 3,057,728	▼ - 11,707,063	**- 4,277,026**	0
Scenario 5.1	41,047,251	- 3,300,645	- 20,210,138	- 3,566,934	- 12,820,811	- 1,296,652	**691,406**
Scenario 7.1	41,047,252	- 3,219,202	- 19,850,903	- 3,466,337	- 12,585,898	- 1,070,878	0
2055							
Scenario 2.1	40,673,814	- 2,585,114	- 19,517,003	- 3,363,957	- 12,732,652	- 1,541,773	0
Scenario 3.1	40,673,815	▲ - 2,803,982	▲ - 20,701,234	▲ - 3,697,365	▲ - 13,419,120	**0**	0
Scenario 4.1	40,740,429	▼ - 2,313,761	▼ - 17,698,600	▼ - 2,885,049	▼ - 11,630,797	**- 5,214,928**	0
Scenario 5.1	40,710,194	- 2,693,638	▲ - 20,047,406	- 3,519,611	- 13,034,061	- 1,578,902	**798,443**
Scenario 7.1	40,673,814	- 2,605,719	- 19,635,724	- 3,402,168	- 12,791,495	- 1,307,739	0

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