Gisborne District Council

# Poverty Bay Flats Conceptual Groundwater Quality Model – Salinity

**TECHNICAL REPORT**

Project No. WGA210398
Doc No. WGA210398-RP-HG-0005
Rev. B
21 October 2022

## Revision History

| Rev | Date | Issue | Originator | Checker | Approver |
|---|---|---|---|---|---|
| **A** | 25/08/2022 | Gisborne District Council | BAS | CHO | RJB |
| **B** | 21/10/2022 | Gisborne District Council | BAS | RJB | RJB |
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# 1 INTRODUCTION

## 1.1 BACKGROUND

The Poverty Bay Flats in the Tairawhiti (Gisborne) region of New Zealand covers an area totalling approximately 18,500 ha.  Much of this area is covered by 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.

Five main aquifers underlie the Poverty Bay Flats: Te Hapara Sand, Shallow Fluviatile, Waipaoa, Makauri and Matokitoki Aquifers.  The largest groundwater abstraction by volume is from the Makauri Aquifer.  Gisborne District Council (GDC) has identified groundwater level and quality trends as presenting future environmental, economic, cultural, and social risks.  GDC considers most of the aquifers to be fully-allocated or over-allocated and no new consents for groundwater abstraction are being issued.

GDC commissioned Wallbridge Gilbert Aztec (WGA) and AQUASOIL Ingenieure & Geologen GmbH (AquaSoil) to undertake the development of a numerical geological and groundwater flow models to enhance understanding of the outcomes from groundwater management options for Poverty Bay Flats.  The outcomes from this work have been documented in separate reports as described in Section 1.4.

During the development of the Groundwater Quantity model, GDC, Mana Whenua and the community stakeholders were engaged through a series of modelling workshops.  Part of these efforts was to share with the community from the start, how the model was being build and what resource questions it was being designed to address.  This process also helps to educate the general public generally on how the Poverty Bay groundwater system works conceptually and what the potential challenges are around longer-term resource management.  As part of the community engagement process, the community was asked to formulate general questions about Poverty Bay aquifers for the purpose of developing specific numerical modelling scenarios.  These questions ranged from ‘what would happen if we turned off all the pumps’, through to ‘how could MAR be potentially used to better manage the system?’.

One of the key issues that arose during these workshops from GDC staff, the council members and Mana Whenua was around groundwater quality changes.  This led GDC to request that the capability to model groundwater quality be incorporated into the numerical model.  It was recognised that adding groundwater quality into the model whilst already constructing a groundwater quantity model would influence the project schedule including potentially changing the community engagement process.

Through consultation with GDC, WGA and AquaSoil worked to clarify which of the potential water quality parameters might be best incorporated ‘during’ the model build process whilst coming up with recommendations for the other quality parameters were likely of interest.  It was clearly recognised that many of the potential water quality parameters of interest would likely require significant preliminary field work and/or supporting modelling efforts in order to be able to model them properly.

Some of other water quality parameters might require significant structural (e.g., grid mesh, etc) changes to the quantity model in order to effectively represent them. Also informing this consultation process was a consistent interest by GDC, Mana Whenua and the community stakeholders on salinity. Concerns over coastal saline intrusion (related to climate change and over pumping) as well as the movement of native saline groundwater conditions found in the western area of the Poverty Bay Flats. During the consultation a preliminary review of GDC groundwater quality database indicated that salinity would be best suited for a 'first cut' and groundwater quality modelling. Salinity (chloride) was also a conservative parameter to model in FeFlow and would not require major changes in the numerical modelling process to progress. The culmination of this consultation process was GDC deciding for the WGA-AQUASOIL team to progress building salinity water quality modelling into the FeFlow groundwater quantity model.

In order to proceed with that instruction, WGA and AquaSoil were required to develop a conceptualisation of salinity distribution and transport for the Poverty Bay Flats groundwater system (this report) to support the numerical model development. WGA continued to review GDC groundwater quality database for other parameters of interest evaluating the amount of data, the quality of the data and other modelling needs such as spatial and temporal distributions. As part of that process, GDC requested that the data be summarised, and the results of key parameters be presented in a series of groundwater quality heat maps. The conceptualisation and the heat map summaries are documented in this report.

GDC subsequently commissioned WGA and AquaSoil to undertake the development of a numerical groundwater quality model to be superimposed on the groundwater flow model. This report documents the conceptual groundwater quality model for salinity

## 1.2 MODELLING PHILOSOPHY

The following extracts from published material summarise the role of the conceptual model with respect to the overall modelling process.

> "*Every model has as its foundation a conceptual model. The conceptual model is the basic idea, or construct, of how the system or process operates; it forms the basic idea for the model (or theory).*" (Bredehoeft 2005).
>
> *"A conceptual model contains numerous qualitative and subjective interpretations. The appropriateness of the conceptual model cannot be tested until a numerical model is built and comparisons between field observations and model simulation results are made. Thus one of the most useful things about a numerical model is that it provides a tool to test and improve the conceptual model of a field site. It also provides a guide to future data collection, particularly in those cases where additional data are needed in order to produce a conceptual model consistent with field observations."* (Zheng and Bennett 1995).
>
> *". . . conceptual and numerical modelling should be viewed as an iterative process in which the conceptual model is continuously reformulated and updated."* (Zheng and Bennett 1995).

WGA's philosophy towards developing the conceptual salinity groundwater quality model for the Poverty Bay Flats groundwater system is to revert to first principles:

- Firstly, develop a clear understanding of the distribution of chloride within the sedimentary deposits beneath the Poverty Bay Flats and the trends in chloride concentration over time.

- Secondly, convert this understanding into a clear description of the distribution of chloride within the sedimentary deposits beneath the Poverty Bay Flats appropriate to serve as a starting condition for the numerical groundwater quality model.

- Thirdly, provide a series of groundwater monitoring datasets for chloride to serve as numerical model calibration datasets.

## 1.3 REPORT SCOPE

The conceptual model for the groundwater quality components of this project is documented in the following sections of this report. For the purposes of this project, groundwater quality modelling has focused on the movement of chloride within the groundwater system of the Poverty Bay Flats.

An initial conceptual groundwater quality model was developed by WGA in conjunction with GDC specialists. It was recognised at the time of development that this initial model would probably require adjustment as the modelling process progressed. This initial conceptual model was used to inform the initial numerical groundwater quality model developed by AquaSoil.

During the numerical modelling process, it was confirmed that the initial conceptual model could be improved within the available time frame. Consequently, the conceptual model was adjusted, and the numerical model improved accordingly.

The scope of this report is to document:

1. The current conceptual groundwater quality model for salinity on which the numerical groundwater quality model is based.
2. The adjustments made to the conceptual model for salinity in response to knowledge gained through the modelling process.
3. Recommendations with regards to potential future improvements to the groundwater quality model for salinity
4. A review of the GDC groundwater quality database for other quality parameters and a summary of their distribution via a series of heat maps.

## 1.4 ASSOCIATED REPORTS

This report should be read in conjunction with two separate reports:

1. The report documenting the geological and conceptual hydrogeological models of the Poverty Bay Flats produced by WGA (WGA 2022).
2. The report documenting the numerical groundwater flow and water quality model developed using the FEFLOW modelling code produced by AquaSoil (2022).

# 2 DATA REVIEW

## 2.1 METHODOLOGY

The salinity groundwater quality modelling process is based on a clear understanding of the groundwater and surface water quality trends, both spatial and temporal, over the past 30 years across the Poverty Bay Flats. These trends have been derived from analysis of water quality data focused on salinity provided by GDC from the council's environmental database. A stepwise data quality control process followed by an analysis and review process has been undertaken to support the development of the conceptual salinity groundwater quality model. For the purpose of this modelling report, the modelling of salinity is discussed in terms of chloride concentrations, which is the parameter used for this process. The overall modelling and water quality database review process and the outcomes are summarised in this report.

In general, the following steps have been followed in the development of the conceptual salinity groundwater model for the Poverty Bay Flats.

1. Designation of key and secondary parameters of interest. Whilst other parameters were of interested, GDC requested the salinity (in the form of chloride) but progressed for this particular modelling process.
2. Completion of a water quality database review for quality assurance purposes (refer to Section 2). This provided specific information needed for salinity modelling process, but also was used to evaluate other parameters of interest for future modelling efforts.
3. Review of the association of bores used for groundwater quality monitoring purposes within specific aquifers underlying the Poverty Bay Flats.
4. Assessment of the spatial and temporal trends for chloride within the aquifers underlying the Poverty Bay Flats and linked surface water bodies.
5. Development of a conceptual groundwater quality model for the Poverty Bay Flats, based on the outcomes from the existing numerical groundwater flow modelling programme and an understanding of the chloride trends within the aquifers.

The conceptual groundwater quality model is to be used inform the development of new numerical groundwater salinitymodels, which have two components:

1. One model is to simulate historical groundwater trends, to verify that the numerical model is functioning appropriately and can be used to simulate future groundwater quality trends.
2. A series of predictive models are to be used to evaluate the effects of climate change and future water use trends on groundwater quality in the form of chloride.

## 2.2 PARAMETER REVIEW AND KEY PARAMETER DESIGNATION

The GDC environmental database includes groundwater quality data for a wide range of parameters. However, the amount of data available for many parameters is limited for reasons that will not be discussed in this report. As salinity (chloride) was chosen by council as the focal parameter to model, the review of the database was solely done to inform the feasibility of modelling other parameters in future modelling efforts.

A review of all water quality parameters that may be important in informing decisions to be made with respect to future groundwater usage and management was undertaken in conjunction with GDC staff. The review took into account the amount of data available for each parameter and the spatial and temporal distribution of that data. For example:

- Chloride and electrical conductivity data is available for numerous monitored bores covering a period of more than three decades.

- *E. coli* data is generally available as one-off samples from individual bores and the bores sampled are almost exclusively screened in shallow unconfined aquifers.

The review also took into account concerns raised by GDC, Treaty Partners and existing water users when considering parameters for conceptual and potentially numerical modelling. Concerns identified include:

1. Salinity trends and management options specific to:
   a) Saline areas of the Makauri Aquifer to the southwest of the Waipaoa River.
   b) Saline water intrusion along the coast as related to current conditions and under the predicted influence of climate change and sea level rise.
   c) Using Managed Aquifer Replenishment (MAR) to help manage saline water intrusion or to generate usable fresh-water resources in areas where the natural groundwater is too saline for irrigation or potable purposes.
2. Groundwater user concerns:
   a) High dissolved iron contents in groundwater, which inhibits the use of groundwater for some irrigation purposes.
   b) Highly saline groundwater in some areas and trends of increasing salinity that inhibit the use of groundwater for potable and irrigation purposes.
   c) Nutrient concentrations (nitrate-N) in shallow unconfined aquifers.
3. Future use of the numerical model to evaluate water quality implications arising from the potential implementation of a new MAR site or a wider Groundwater Replenishment System design.
   a) Risks arising from the introduction of pathogens to groundwater at a MAR site.
   b) Risks of water quality changes arising from changes in the oxidising / reducing state of the groundwater around MAR sites.

The review indicated that the key parameter for initial water quality modelling is salinity, specifically chloride content of the groundwater, for the following reasons:

1. Chloride concentrations have been monitored in numerous bores and in each of the aquifers underlying the Poverty Bay Flats for several decades.
2. Clear chloride spatial and temporal trends have been identified in many areas of the aquifers.
3. There are clear potential risks to cultural values and water supply security that may arise as a result of on-going groundwater abstraction and projected climate change effects such as sea level rise and changing rainfall patterns.

4. Chloride is considered to be conservatively transported within an aquifer, without precipitation or reactions with the aquifer matrix materials (rock mass).

For the above reasons chloride has been used as the default quality parameter being progressed through the groundwater quality modelling and predictive scenarios assessment process.

The predictive chloride results from the numerical modelling as presented in the AquaSoil (2022) report vary from scenario to scenario due to differences in the simulated groundwater flow regimes. The input parameters for water quality (chloride) do not themselves change between scenarios.

A high-level summary of the assessment of other water quality parameters agreed on with GDC staff is provided in Section 5.

## 2.3 MONITORED BORES ASSOCIATION WITH DEFINED AQUIFERS

A review has been undertaken of groundwater quality monitoring well screen elevations compared to defined aquifer elevations in the same area. The objective of the review was to confirm that the water quality data from each monitored bore was allocated to the correct aquifer.

In the case of the shallow unconfined aquifers, review of the aquifer extents simulated in the geological model identified some discrepancies in monitoring well allocations between the Te Hapara Sand and the Shallow Fluviatile Gravel. However, in practical terms these discrepancies have no implications for the interpretation of groundwater quality in the shallow aquifers. The two aquifers are hydraulically continuous and interpretation of groundwater quality trends spatially and temporally

Overall, the existing designation of aquifers to groundwater quality monitoring wells in the GDC database is considered accurate and reliable for the purposes of evaluating water quality trends, both spatially and temporally.

# 3 SALINITY MODELLING CONCEPTUALISATION

## 3.1 INTRODUCTION

Modelling of groundwater salinity across the Poverty Bay Flats is founded on the existing conceptual and numerical groundwater flow models for the area. The simulation of chloride transport within the groundwater system assumes that the transport is conservative in nature. In effect, once chloride is introduced to the groundwater model it is transported in accordance with groundwater flow patterns without biogeochemical interactions with the aquifer matrix.

A starting chloride distribution within the groundwater system of the Poverty Bay Flats is defined based on groundwater quality observations from the period 1992 to 2000. Chloride is not subsequently introduced to the model except via a designated groundwater recharge process or through a designated hydraulic boundary such as the Waipaoa River. Chloride is not removed from the conceptual model except through discharges via designated hydraulic boundaries. These hydraulic boundaries are described in separate reports documenting the groundwater flow model of the Poverty Bay Flats (WGA 2022, AquaSoil 2022).

## 3.2 CONCEPTUAL GROUNDWATER QUALITY BOUNDARY CONDITIONS

### 3.2.1 Pacific Ocean

Sea water contains an approximate chloride concentration of 20,000 mg/L. Although this concentration varies slightly from location to location, this approximation is reasonable for the purposes of simulating saline water intrusion to coastal aquifers. The steady state hydraulic boundary simulating the ocean along the coastline of the Poverty Bay Flats is to be defined with a constant concentration of 20,000 mg/L. The harbour area of Tūranganui River is also characterised with chloride concentrations equivalent to sea water (refer Section 4.2.2).

### 3.2.2 Waipaoa River

Chloride concentrations have been monitored in the Waipaoa River at Kanakanaia and at the Matawhero Bridge since 1982. Data recorded during the period from 1992 to 2000 has been used to define the in-stream chloride concentrations for modelling purposes (Figure 1). The concentration reporting limits prior to 1992 and following 2000 were 5 mg/L or greater, which affects the concentration statistics for these periods. As the chloride reporting limit for the period from 1992 to 2000 was 1 mg/L or less, this dataset was used to assess appropriate average river water chloride concentrations for modelling purposes.

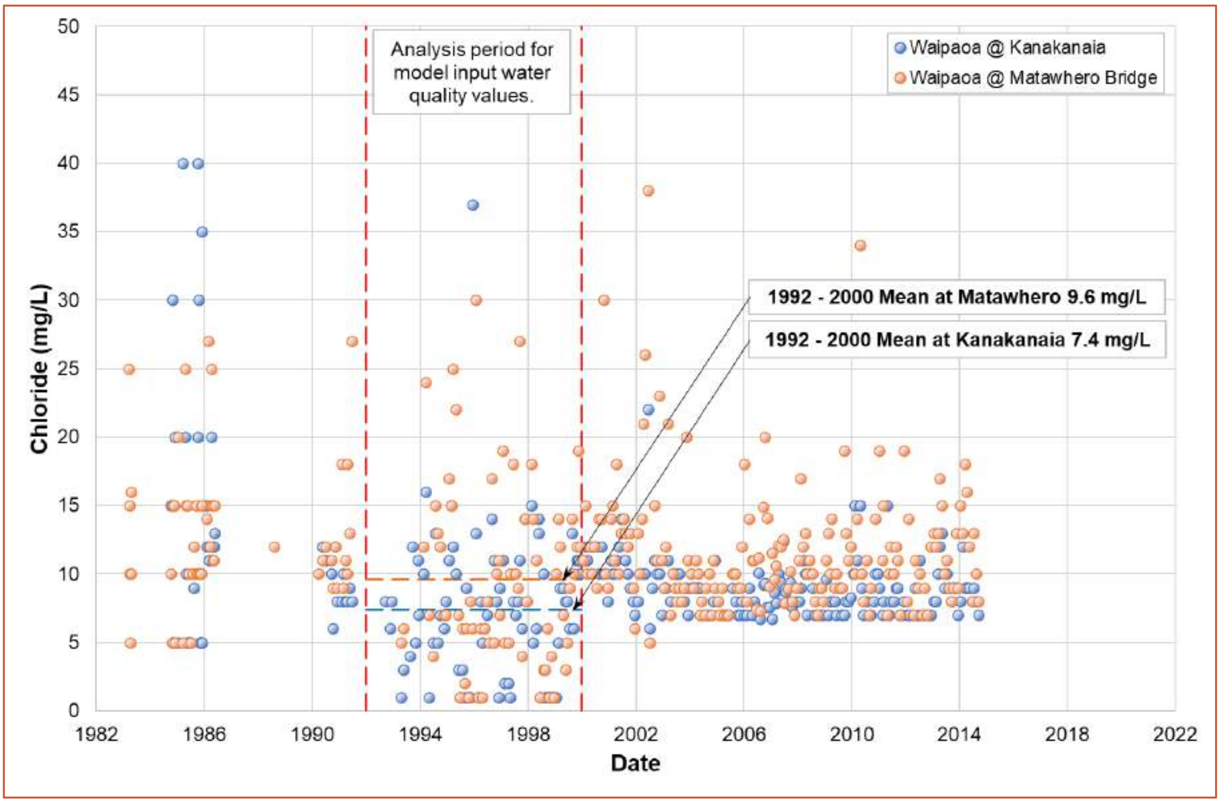



**Figure 1: Waipaoa River chloride concentrations 1982 – 2015**

Many more field electrical conductivity measurements for the Waipaoa River water have been made since 1980 than chloride analyses. A review of the field electrical conductivity measurements was undertaken to confirm that the chloride concentrations recorded between 1992 and 2000 were not anomalous (Figure 2). The review indicated that field electrical conductivity measurements made at Kanakanaia have not changed substantially since 1988. This implies that the average chloride concentration at the Kanakanaia monitoring station has been relatively stable through this period.

Although there is a broad correlation between field electrical conductivity and chloride concentration in the Waipaoa River water quality data (Figure 3), this correlation is associated with a significant scatter in the data. There is sufficient chloride data from monitoring of Waipaoa River water quality for the purposes of groundwater quality modelling. Therefore, this correlation has not been used to increase the number of chloride records for the Waipaoa River.

A corresponding correlation between field electrical conductivity and chloride concentration for groundwater across the Poverty Bay Flats is presented in Figure 4, with the axes presented in the same scale as Figure 3. The correlation between chloride and electrical conductivity in groundwater is considerably more complex than the same correlation for Waipaoa River water. This increased complexity is likely to be principally due to variations in the lithologies through which the groundwater has flowed and variations in local land use.

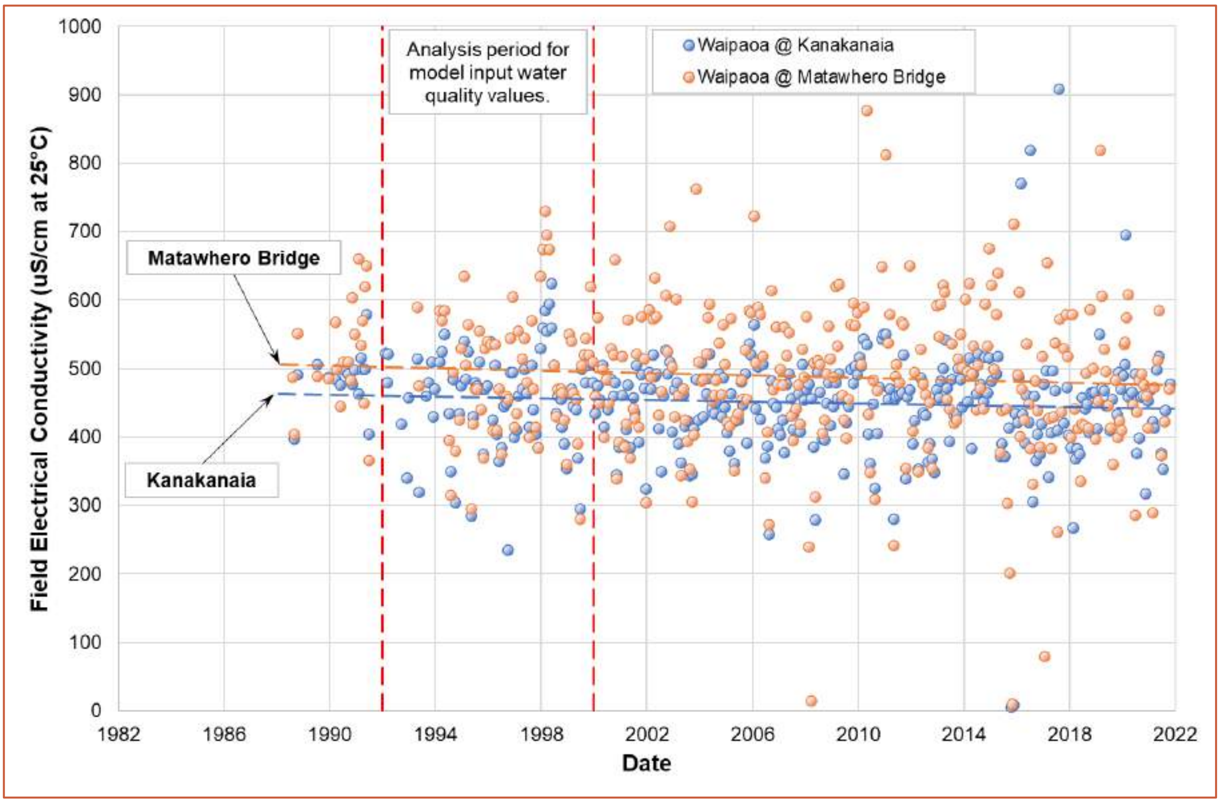



**Figure 2: Waipaoa River electrical conductivity measurements 1988 – 2022**

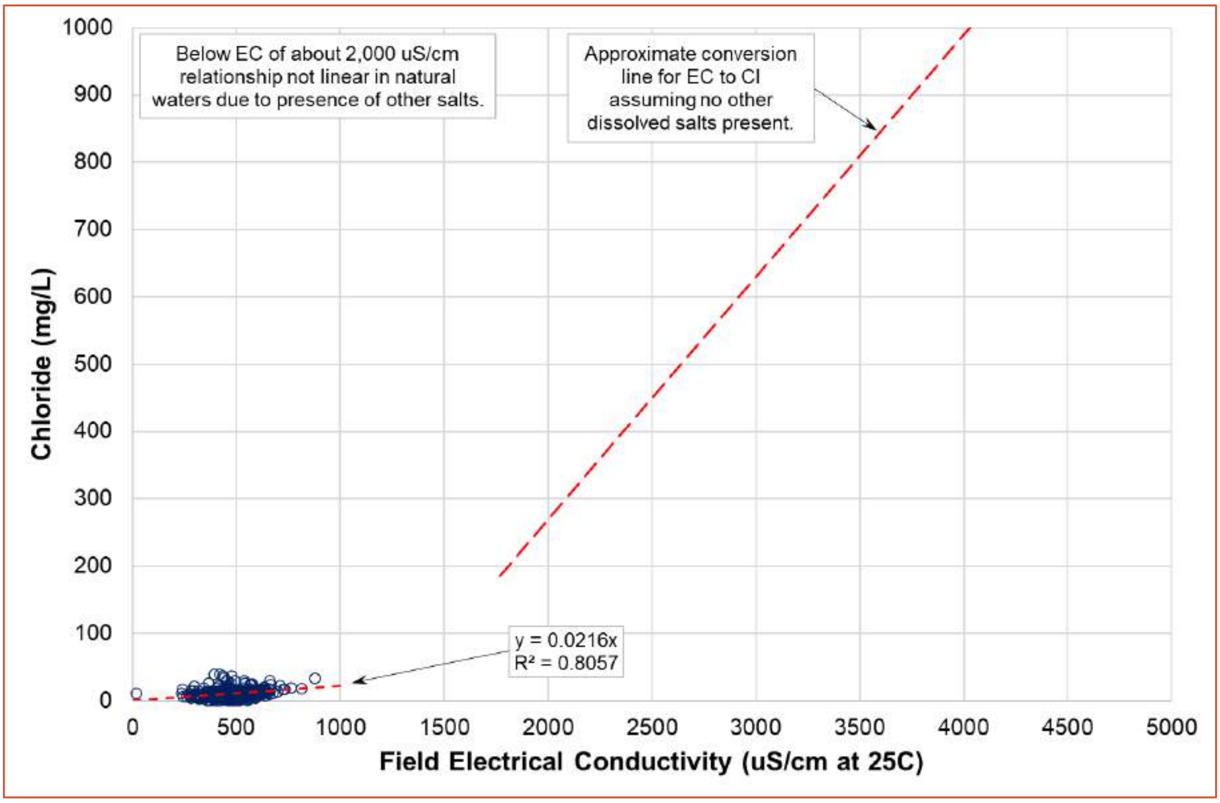



**Figure 3: Waipaoa River chloride concentrations compared to electrical conductivity**

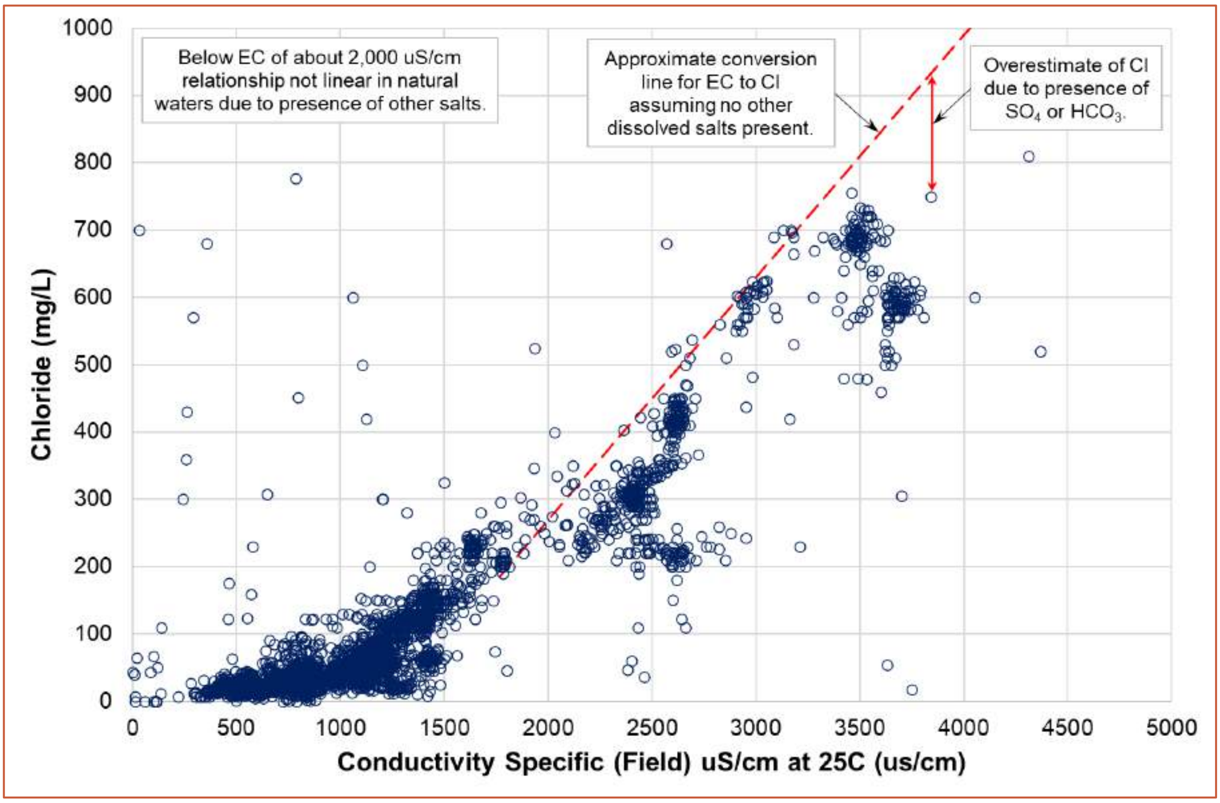



**Figure 4: Poverty Bay Flats groundwater chloride correlation with electrical conductivity**

The average chloride concentration in Waipaoa River water measured at Kanakanaia for the period 1992 to 2000 was 7.4 mg/L. This is considered an appropriate chloride concentration for the Waipaoa River when modelling groundwater interaction with the river in the stretch within the Waipaoa River valley. As the average chloride concentration in the river water increases downstream, the average measured concentration for the same period at Matawhero Bridge of 9.6 mg/L is appropriate for the characterisation of the Waipaoa River as it crosses the Poverty Bay Flats.

For modelling purposes, it has been assumed that sea water does not intrude from the coastline upstream into the Waipaoa River (refer Section 4.2.2).

### 3.2.3 Surface Recharge Salinity

Chloride concentrations in surface recharge to shallow groundwater are primarily dependent on two factors:

1. Land use and associated potential leaching of chloride from the soils, including any potential concentration of salts in the soils through evaporative processes.
2. On-shore winds transporting saline water from the ocean and depositing it on the land.

Direct measurements of the chloride contributions from these two factors have not been made across the Poverty Bay Flats. Therefore, chloride concentrations measured in the shallow unconfined aquifers have been used as an indicator of the surface recharge concentration.

A selection of shallow bores screened in the Te Hapara Sand Aquifer have been identified from the GDC environmental database that have groundwater quality records indicating:

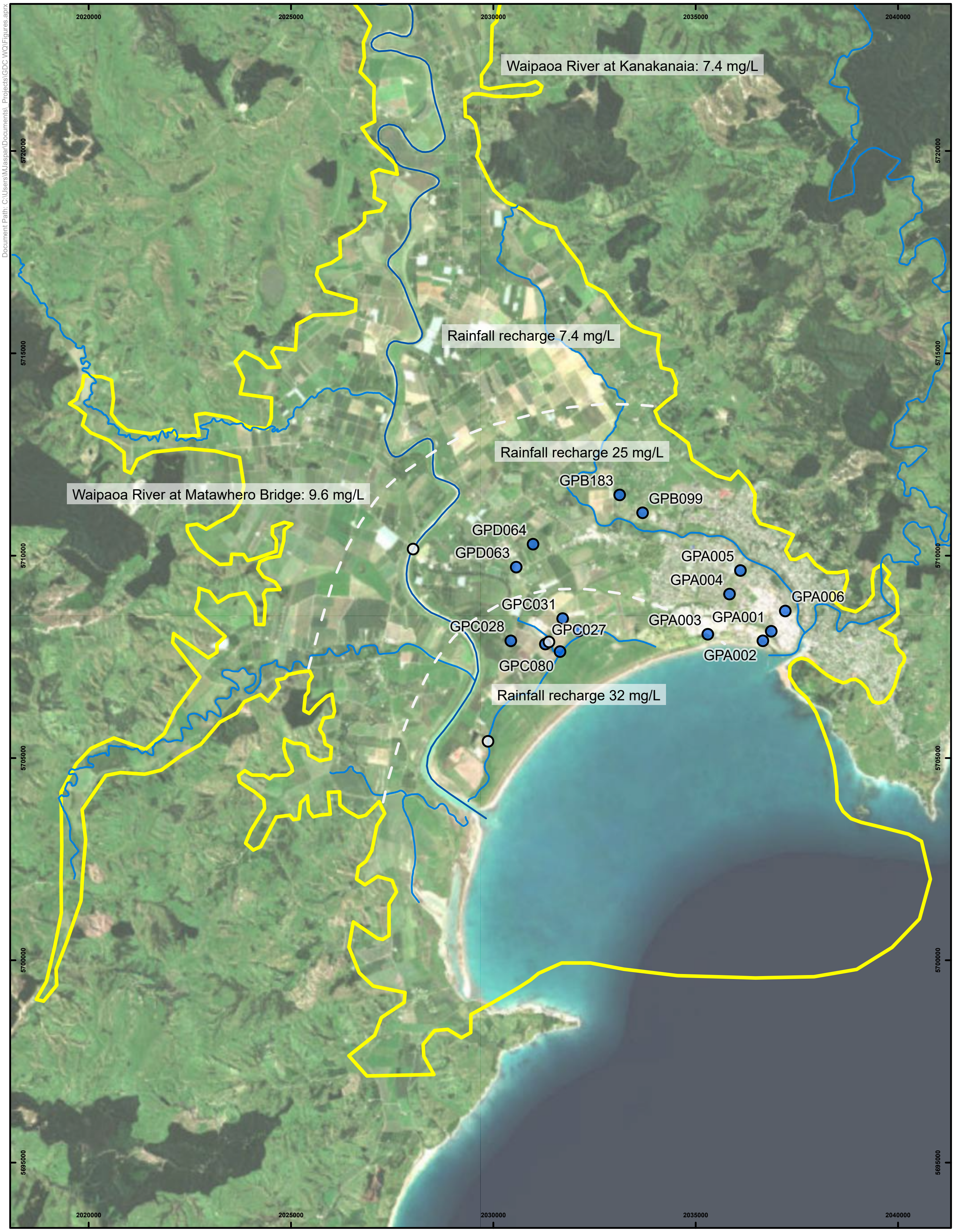
- The bores have been monitored for water quality over several decades.

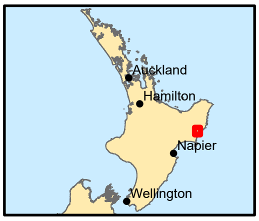
- Each bore has at least 50 chloride results recorded.
- The surrounding groundwater quality has been stable over this period.
- No indications of water quality effects arising from saline water intrusion or from interaction with the Waipaoa River.

The chloride results from five monitored bores that met these criteria are summarised in Table 1. Based on the chloride data from these bores, three chloride recharge zones have been defined for the Poverty Bay Flats (Figure 5). The recharge chloride concentration of 7.4 mg/L applied to the most inland zone is based on the assumption that this recharge is likely to reflect run-off water quality from the wider upstream catchment, as indicated by the average concentration detected at the Waipaoa River monitoring station at Kanakanaia (Section 3.2.2).

**Table 1: Average chloride concentrations measured in shallow bores**

| Bore ID | Number of samples | Average chloride concentration (mg/L) |
|---|---|---|
| **Inland** | | |
| **GPB099** | 129 | 24 |
| **GPA004** | 100 | 25 |
| **Coastal** | | |
| **GPC027** | 66 | 32 |
| **GPC028** | 74 | 44 |
| **GPC030** | 80 | 17 |




N

0 0.5 1 1.5 2 2.5 3 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**

- Surface Water Quality Site
- Groundwater Monitoring Bore
- Indicative Recharge WQ Zone
- Waipaoa River
- Rivers / Streams
- Model Extent

WGA

WALLBRIDGE GILBERT AZTEC

Figure 5

Gisborne MAR Model

Shallow recharge chloride concentrations across Poverty Bay Flats

The validity of these recharge concentrations has been checked through comparison with correct concentrations recorded from shallow bores that did not meet the selection criteria listed above. Many of these bores have few readings associated with them, are significantly affected by coastal saline water intrusion or appear to be significantly influenced by localised changes in land use over time. Therefore, the review has not been done on a statistical basis but rather to confirm that the conceptual recharge concentrations generally reflect the lower third of concentrations recorded in shallow bores across the Poverty Bay Flats. The results of this review confirm that recharge concentrations shown in Figure 5 are reasonable for the purposes of groundwater quality model conceptualisation.

#### 3.2.4 Makauri Aquifer – Western Saline Area

The geological and numerical groundwater flow models of the Poverty Bay Flats incorporate a limited extent of Makauri Aquifer to the west of the Waipaoa River (AquaSoil 2022; WGA 2022). The precise extent of the Makauri Aquifer is poorly defined due to a lack of geological logs for holes drilled to an appropriate depth in this area. As previously noted, the geological model has been based almost entirely on data from drillhole geological logs. A conservative approach to the modelling has been taken in that aquifer extends have not been extended beyond what can be fully justified from the geological logs. Consequently, the Western Saline Area of the Makauri Aquifer is not physically represented in the numerical model although the capacity is present to represent this area once supporting data becomes available.

Despite the lack of geological data, there are a few bores that have been drilled to levels equivalent to those expected for the Makauri Aquifer in this area. Specifically, several bores within the terrace area of the lower Te Arai River valley have been screened at depths that would coincide with the Makauri Aquifer level (Figure 6). There are no groundwater take consents associated with these bores and it is not clear if there is any active groundwater pumping from these bores.

GDC has long recognised that groundwater salinity increases to the west of the Waipaoa River, with this area of the aquifer being previously designated the Western Saline Aquifer (Barber 1993). Guidance provided by a Treaty Partner indicates that the salinity of water obtained from at least one of these bores was inappropriate for irrigation. However, no water quality samples from the deep bores within the indicative western saline area are recorded in the GDC groundwater quality database.

Guidance on the potential quality of groundwater in this area comes from four sources:

1. Water quality trends recorded from monitored bores GPD115, GPI032 and GPJ040, each of which are screened in the Makauri Aquifer and are located on the eastern edge of the interpreted saline area (Figure 6).

   Although the Makauri Aquifer groundwater chloride concentration at GPI032 has decreased over time, samples obtained in 1985 indicate concentrations of between 250 mg/L and 300 mg/L in this area (Figure 7). The concentration decrease over time is likely to be linked to changes in groundwater flow patterns within the aquifer during the same period. Conversely, chloride concentrations recorded from GPD115 and GPJ040 have increased over time, with no indication that this increasing trend is stabilising. Concentrations in GPJ040 currently exceed 300 mg/L.

2. Water quality data from monitored bore GPJ078, which is located within the saline aquifer area (Figure 6) and is interpreted as being screened in the Waipaoa Aquifer. However, the high chloride concentrations detected in samples from this bore are indicative of concentrations found in the deeper aquifer groundwater (Figure 8)

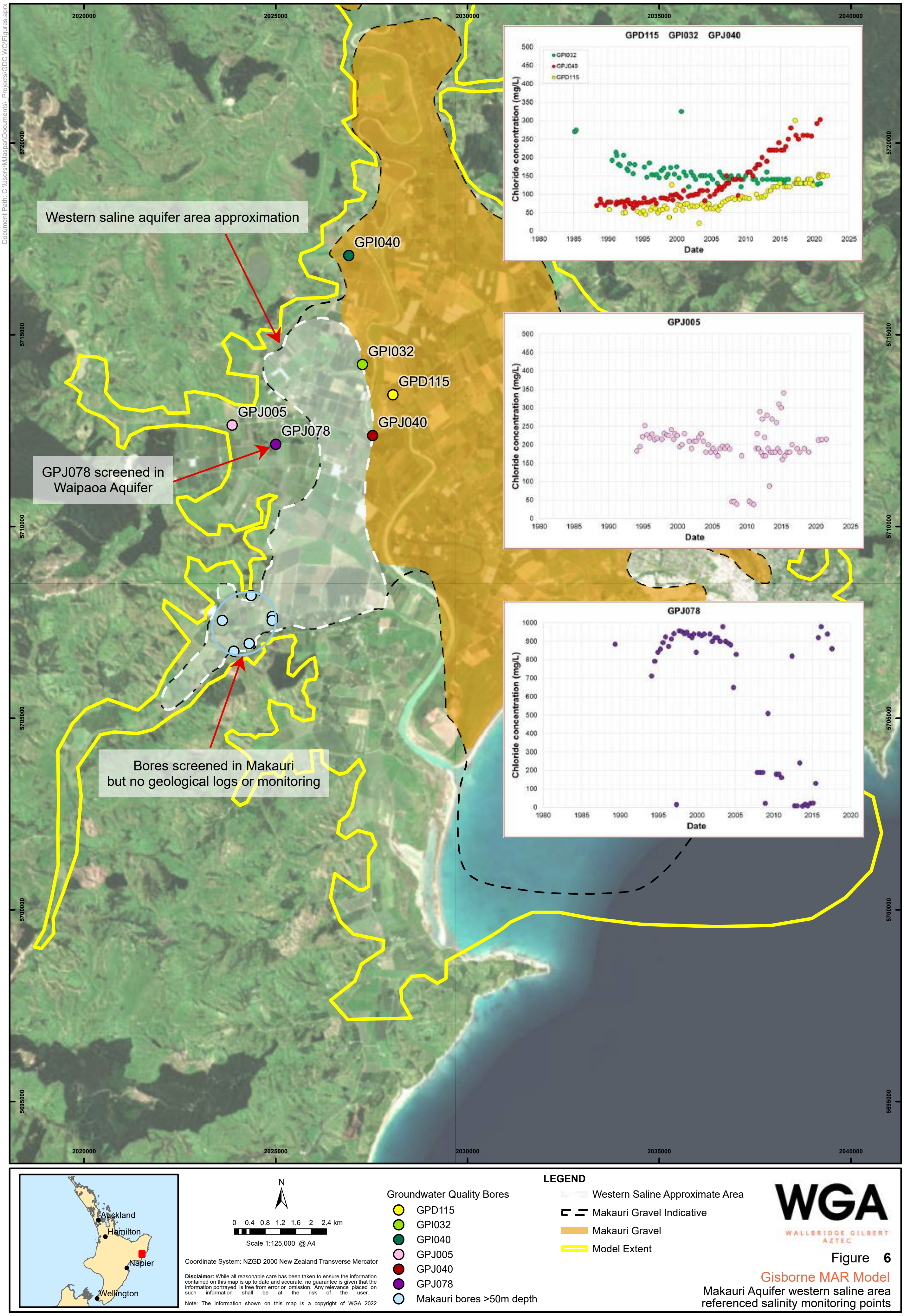



Figure 6
Gisborne MAR Model
Makauri Aquifer western saline area referenced salinity monitoring points

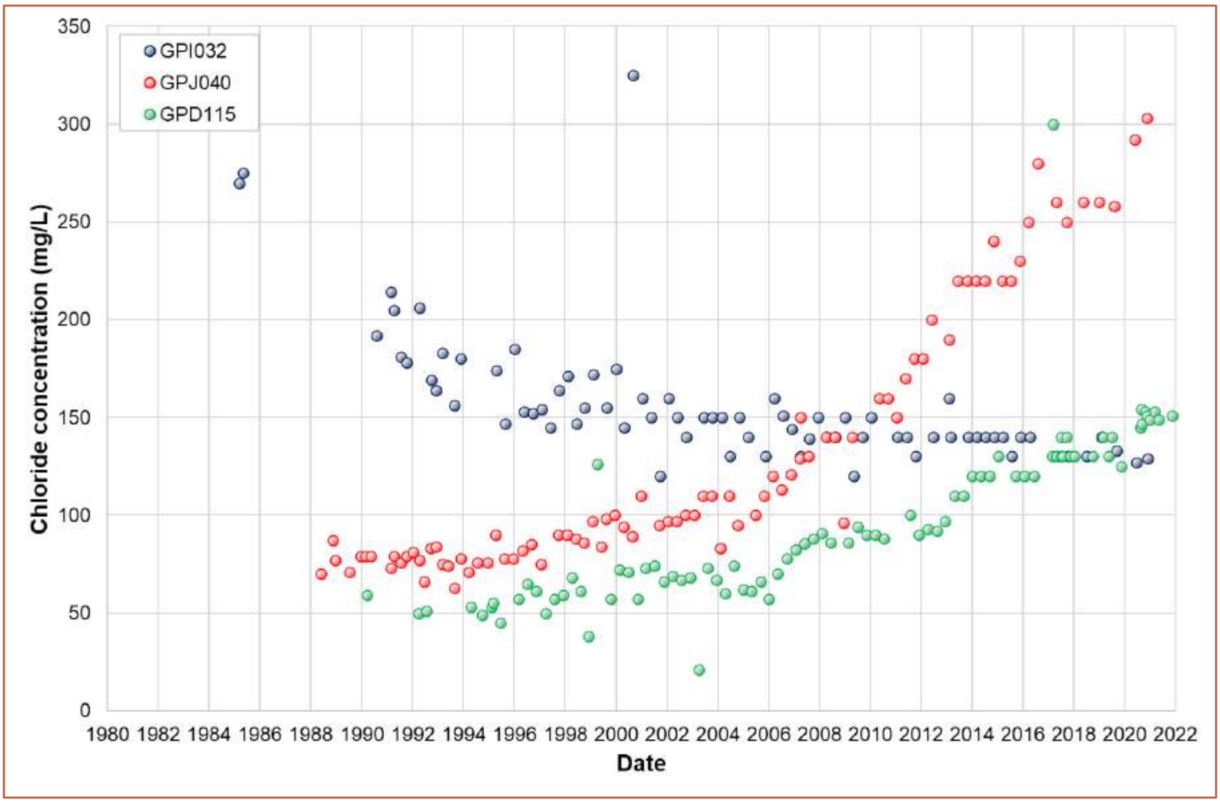



**Figure 7: Western Makauri Aquifer monitoring well chloride concentration trends**

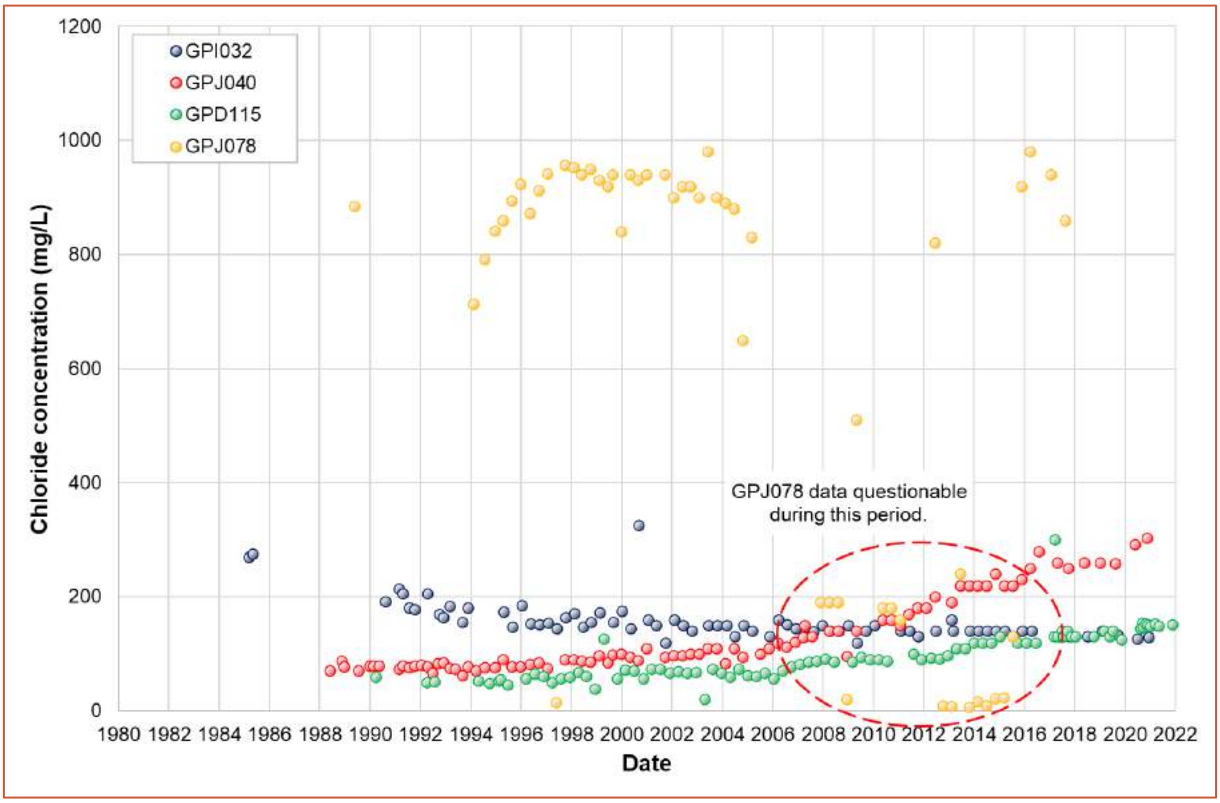



**Figure 8: Western Makauri Aquifer and GPJ078 (Waipaoa Aquifer) chloride concentrations**

Well GPJ078, located to the southwest of GPJ040 (Figure 6), has no geological log but is screened at a depth of approximately 30 m, which is more consistent with the Waipaoa Aquifer level than the Makauri Aquifer. Monitoring of this well has returned some of the highest chloride concentrations measured from any of the aquifers of the Poverty Bay, with concentrations regularly between 800 mg/L and 1,000 mg/L (Figure 8). Although the chloride data from this well between 2006 and 2016 is questionable, partly due to its inconsistency with the corresponding electrical conductivity data, the higher concentrations detected during other periods appear to be valid data.

3. Water quality data from monitored bore GPJ005, which is located at the western edge of the Poverty Bay Flats (Figure 6) but has no geological log or information on the bore depth or screened interval.

   Water obtained from bore GPJ005 has elevated chloride concentrations compared to the main body of the Makauri Aquifer. Detected concentrations generally fall within the range from 150 mg/L to 300 mg/L, which is consistent with the concentrations detected in water from GPD115, GPI032 and GPJ040.

For comparison purposes, chloride data from monitored bores screened in the Makauri (GPJ040), Waipaoa (GPJO78), and deeper Matokitoki (GPD129 and GPD134) aquifers are presented in Figure 9.

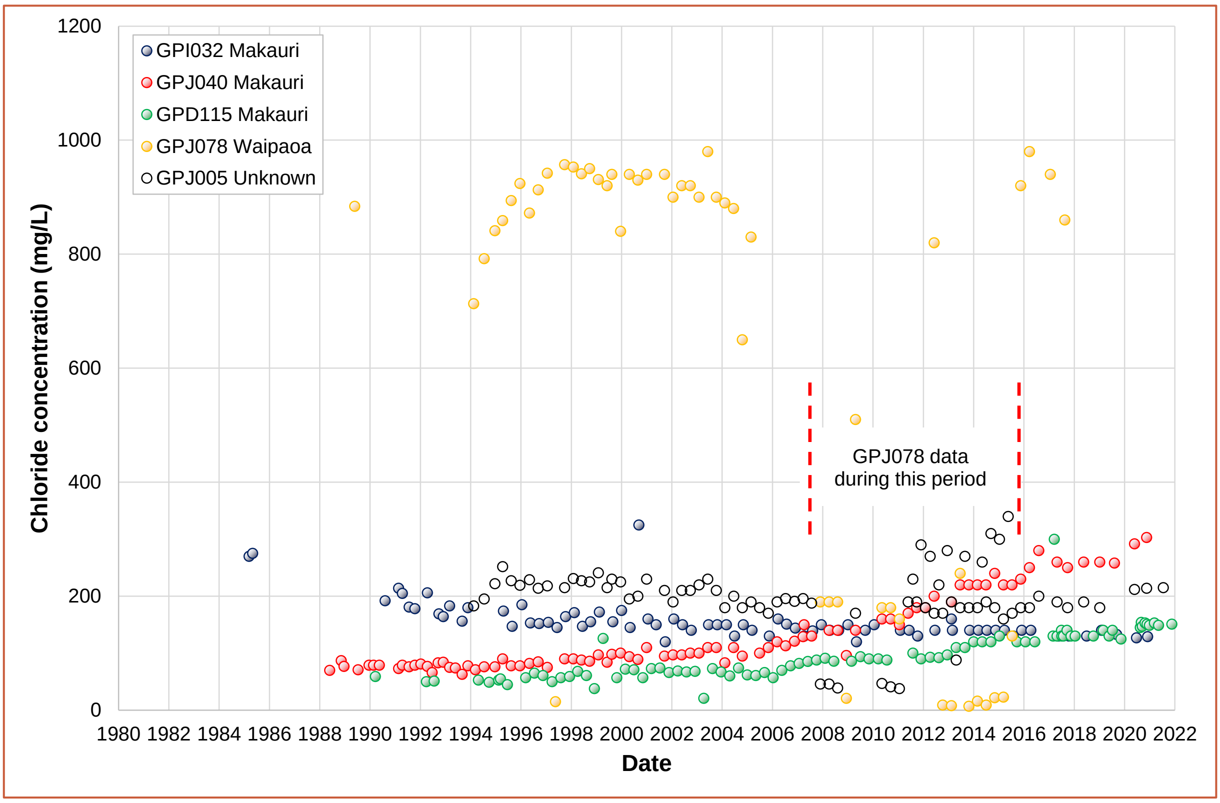



**Figure 9: Western Makauri Aquifer and GPJ078 (Waipaoa Aquifer) chloride concentrations**

It was agreed with GDC that an average chloride concentration of 680 mg/L (GPD124) recorded from bore GPD124 in the deeper Matokitoki Aquifer would be used as a proxy for the groundwater quality in the western saline area in the conceptual salinity model. This decision took into account:

- The uncertainty regarding the hydraulic connection between the Waipaoa Aquifer at GPJ078 and the Makauri Aquifer.

- The rising chloride trends in GPD115 and GPJ040.

None of the bores within this area that are deep enough to intersect the Makauri Aquifer have been geologically logged, leading to uncertainty regarding the extent and layout of this area of aquifer. For this reason the numerical groundwater flow model does not simulate the western saline area of the Makauri Aquifer. Consequently, for the purpose of the numerical groundwater quality simulation a groundwater quality boundary condition has been defined along the western side of the simulated Makauri Aquifer to partially represent the saline water area of aquifer.

The possibility that the elevated chloride concentrations in bores GPJ078 and GPJ005 arise from upward leakage along poorly constructed bores has been considered. However, there is no indication that either of these bores was drilled to a depth corresponding to that expected for the Makauri Aquifer in this area, even if the well screen was installed at a higher elevation. Consequently, poor bore construction has been discarded as a reason for the observed elevated chloride concentrations.

The source of the chloride present in the Western Saline Area is not clear from available information. The elevated salinity is most likely a relic of the settlement depositional period, as described in Section 3.3 below. If this is the case, the elevated salinity concentrations detected would suggest limited groundwater recharge and slower groundwater flows through this area. However, this mechanism does not explain some of the elevated concentrations observed in shallower bores in this area (e.g. GPJ078 in Figure 8).

## 3.3 OTHER CHLORIDE SOURCES

The general observed trend of increasing chloride concentration with increasing aquifer depth has implications with respect to the source of the chloride in the groundwater.

Much of the fine-grained sediments that form the aquitards separating the aquifers under the Poverty Bay Flats are marine deposits. Deposition of the fine-grained sediments that form the aquitards would have simultaneously resulted in the capture of marine water within the pore spaces. As the sedimentary pile thickened and the load increased, much of the stored saline water would have been ejected as the sediments compacted. The remaining pore water would have been relatively immobile due to the low hydraulic conductivity of the aquitard materials and the low natural hydraulic gradients within the aquitards.

The final retreat of the coastline southward toward its current position was essentially complete by approximately 2,000 years before present (Brown 1985). After this time the direct introduction of marine water to the sedimentary deposits under the Poverty Bay Flats effectively ceased. Further introduction of saline water to the sedimentary deposits was probably limited to the coastal estuarine areas that were subject to tidal flushing and through density-driven intrusion along the coastline. Much off the salinity detected in the deeper aquifers may be a relic of the sediment depositional period.

Over the past few thousand years the saline water in the sediments has been progressively replaced by distributed freshwater recharge from the surface. This process would have occurred more rapidly across the northern half of the Poverty Bay Flats due to the overall downward hydraulic gradient in this area. Further south the process would have been slower as the hydraulic gradients would have been upward.

Increased groundwater abstraction over the past few decades has seasonly changed the hydraulic gradients within aquitard units. However, it is not clear that these changes in groundwater flow patterns would have resulted in changes to observed groundwater quality in the aquifers. Chloride concentrations recorded from many of the monitored bores are unchanged over the past four decades. In other bores he observed increases or decreases in salinity appear to relate primarily two changes in lateral rather than vertical flow rates. In some areas the pumping may be resulting in increased surface recharge and an apparent freshening of the aquifer. In other areas, such as the western edge of the Makauri Aquifer, water is being drawn from saltier areas towards fresher areas of the aquifer.

## 3.4 CONCEPTUAL SALINITY GROUNDWATER QUALITY MODEL

### 3.4.1 Introduction

The following sections specify the conceptualisation of the groundwater quality model within the framework of the existing conceptual Poverty Bay Flats groundwater flow model. Therefore, it is important that the report documenting the conceptual groundwater flow model (WGA 2022) has been read and a good understanding of the flow model gained to support an understanding of the following sections.

A key assumption incorporated into the conceptual groundwater quality model is that there is no geochemical interaction between the groundwater and the sediments that comprise both the aquifers and the aquitards. This assumption means that the sediments do not contribute to the chloride load in the groundwater or reduce that load in any way. The conceptual groundwater quality model assumes that chloride is conservatively transported within the groundwater system.

The conceptual groundwater model has been adjusted through the modelling process and it has been recognised that the deeper aquitards underlying the poverty Bay flats are likely to be repository of relic saline water left over from the depositional period (refer Section 3.3). At present the numerical groundwater quality model does not incorporate this “relic seawater” concept, as additional data on groundwater in the aquitards is required to support this aspect of the modelling.

A second key assumption incorporated into the conceptual groundwater quality model is that density dependent flows within the groundwater system are only significant in a localised area adjacent to the shoreline. As the numerical FEFLOW model does not incorporate a facilitate the simulation of density dependent flows, the conceptual model assumes that the interface between saline water and freshwater is effectively vertical within any single aquifer.

It should be noted that the numerical groundwater quality model being developed using the FEFLOW software package has the capacity to incorporate geochemical interactions between the settlements and the associated groundwater. This capacity may be important when developing models to simulate the transport of other parameters, such as pathogens, nutrients and dissolved oxygen.

### 3.4.2 Shallow Unconfined Aquifers

For the purposes of modelling chloride transport in groundwater, the Shallow Fluviatile Gravel Aquifer and the Te Hapara Sand Aquifer are conceptually considered to behave as a single shallow aquifer. This shallow aquifer is predominantly unconfined and is directly connected hydraulically to the ocean along the coastline, and to the Waipaoa River and to the natural streams and artificial drainage systems crossing the Poverty Bay Flats.

Rainfall recharge to the shallow groundwater system is characterised to be influenced by onshore winds carrying chloride in storm spray. This effect is considered to decline with increasing distance from the coast. The rainfall recharge chloride concentrations are taken to be reflected in shallow groundwater chloride concentrations, which also decrease with increasing distance from the coast. We recognise that onshore winds are not the only potential source of chloride to the shallow groundwater, with various land uses also influencing the groundwater recharge concentrations. We also recognise that saline water intrusion along the coast leads to locally elevated concentrations. However, the average chloride concentration trends reflecting as presented in Figure 5.

The hydraulic boundary representing the ocean in the baseline model is set at 0 mRL. The ocean and the harbour area of Tūranganui River is defined with a chloride concentration of 20,000 mg/L, as appropriate for sea water (refer Section 3.2.1). A default longitudinal dispersivity coefficient of 0.1 for the transport of chloride under the coastal dunes is allocated in the conceptual model and is subject to calibration in the numerical model.

Initial chloride concentrations in the shallow groundwater system for simulation of groundwater trends observed over the past 30 years are defined to match the recharge concentrations presented in Figure 5. The model is subsequently free to simulate changes in shallow groundwater quality in accordance with the transport of chloride by simulated groundwater flows.

No chloride reservoir is incorporated in the aquifer matrix or the overlying soils horizons. No geochemical interaction between the aquifer and aquitard matrix materials and the associated groundwater is incorporated in the groundwater quality model. Incorporation of these aspects of chloride transport into the numerical model would require additional information regarding the geochemical characteristics and behaviour of the aquitard materials, which is not currently available.

The shallow groundwater system functions in a dynamic equilibrium with the Waipaoa River, receiving water from the river during high flow periods and losing water to the river during low flow periods. The chloride concentration applied to the river is 7.4 mg/L, as derived from river water quality monitoring at Kanakanaia (refer Section 3.2.2). Chloride concentrations in shallow groundwater on either side of the river are expected to be strongly influenced by the river water quality due to this exchange process. The available groundwater quality monitoring data does not provide reliable indications as to how far from the river this exchange process operates.

Streams and artificial drainage systems are simulated as drains in the groundwater flow model. Simulated drains can remove water from the flow model but not introduce water to the flow model. Similarly, drains can remove chloride from the model but not introduce chloride to the model. Specific issues that may arise with respect to groundwater quality simulation due to the use of drains to simulate surface water bodies include:

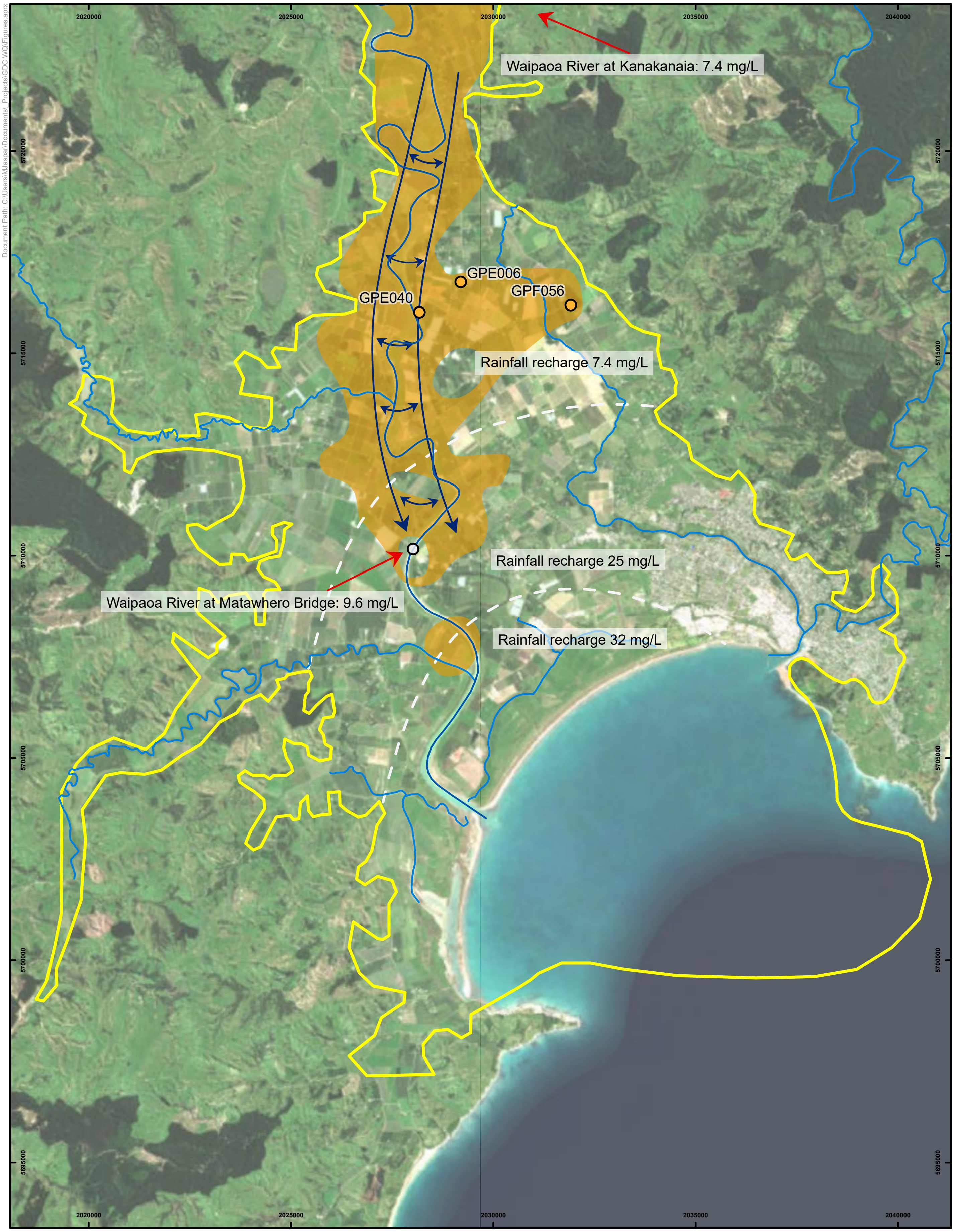
1. Streams receiving run-off water from the surrounding hillsides may act to recharge the shallow groundwater system with low chloride water during high flow periods.
2. Coastal stretches of rivers, streams and drains, other than the Waipaoa River, may receive tidal inflows of saline water. As these features are all simulated as drains in the groundwater flow model, any potential recharge of saline water from these features to the surrounding groundwater is not simulated by the current model (refer Section 4.2.2).

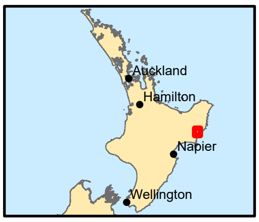
For the purpose of the current modelling programme, it is assumed that the above limitations will not have a significant or extensive effect on the valid simulation of shallow groundwater quality.

Saline water intrusion within the shallow unconfined aquifer along the coast has probably increased over time since drainage of the Awapuni area during the 1950s and 1960s. Investigation of current groundwater quality and levels in the Awapuni area (Fenemore & Hancock 2018) has demonstrated the groundwater and drainage system in this area shows highly complex behaviour in terms of groundwater levels, flow patterns and water quality trends. A clear conceptual understanding of the mechanisms generating observed water quality trends in the Awapuni area was not achieved during that investigation. Issues included:

1. The effect of floodgates on water quality in the upstream drains.
2. Discrepancies between groundwater and surface water elevations that could not be easily explained.
3. Water quality trends at some monitoring points that could not be easily explained.
4. Guidance provided by Treaty Partner representatives indicated that the Waipaoa River once discharged to the ocean at the northern end of the Awapuni Moana area, rather than at the southern end as it does today. A map dating from 1888 (Williams 1988) supports this guidance in stating that the river discharged to the north of its present mouth until 1841. This former riverbed may be marked by buried river gravels similar to those of the Shallow Fluviatile Gravel Aquifer. Although geological logs from drillholes have not identified such gravels between Awapuni Moana and the coastline, this possible gravel bed remains a potential route for saline water intrusion to Awapuni Moana.

The regional scale simulation of groundwater flow and quality is expected to provide guidance on the behaviour of the groundwater system at Awapuni. However, the level of model detail required to simulate the groundwater quality observations documented in Fenemore & Hancock (2018) report is beyond the scope of the regional scale numerical groundwater model. The reader is referred to work documented by Golder (2019, 2020) for a more focused assessment of saline water intrusion in this area.

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Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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**LEGEND**

Groundwater Monitoring Bore Chloride (mg/L)
- 500 - 1000
- 200 - 500
- 100 - 200
- 75 - 100
- 50 - 75
- 25 - 50
- 0 - 25

- Surface Water Quality Site
- Indicative Recharge WQ Zone
- River Exchange
- Waipaoa River
- Rivers / Streams
- Shallow Fluvial Deposits
- Model Extent

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Figure 10
Gisborne MAR Model
Conceptual model of Shallow Fluviatile Gravels Aquifer salinity

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Figure 11
Gisborne MAR Model
Conceptual model of Te Hapara Sands Aquifer salinity

### 3.4.3 Waipaoa Aquifer

Two separate areas of Waipaoa Aquifer have been defined through the geological modelling process and incorporated into the numerical groundwater flow model (WGA 2022, AquaSoil 2022). For the purposes of this report, these two aquifer areas are labelled Waipaoa 1 Aquifer and Waipaoa 2 Aquifer (Figure 12) and are treated similarly in terms of the water quality conceptualisation.

***Waipaoa 1 Aquifer***

The aquifer area defined in the geological model as Waipaoa 1 becomes progressively deeper from north to south. The aquifer is unconfined to the north and is interpreted as being hydraulically continuous with the Shallow Fluviatile Gravel Aquifer in this area. The Waipaoa 1 aquifer becomes progressively more highly confined towards the south, as the overlying aquitard thickens.

Chloride concentrations in water recharging the Waipaoa 1 aquifer at the north are considered to reflect groundwater quality in the Shallow Fluviatile Gravel Aquifer in this area (7.4 mg/L). Groundwater quality records for the Waipaoa 1 aquifer indicate chloride concentrations average approximately 25 mg/L across the aquifer (Figure 13). This concentration is applied as a starting concentration for the model simulating historical groundwater conditions.

All of the monitored bores presented in Figure 13 appear to show trends of decreasing chloride concentrations over time. Although these apparent trends may be artifacts of data scatter, they may also be indicating gradual freshening of the groundwater over time in response to ongoing abstraction from the aquifer.

***Waipaoa 2 Aquifer***

The aquifer defined in the geological model as Waipaoa 2 is generally fully confined. In addition to slow recharge through the overlying aquitard, direct hydraulic connections with overlying aquifers may be present at the northern and eastern sides of the defined Waipaoa 2 aquifer.

There are only two bores screened in the Waipaoa 2 aquifer that have been monitored for groundwater quality. Review of the chloride data from GPB042 and GPB083 has found no indication of increasing or decreasing chloride concentrations over time (Figure 14). Since 1990 the recorded concentrations have predominantly been between 30 and 50 mg/L. This concentration is slightly higher than in the Waipaoa 1 aquifer but there is no indication that the difference is due to saline water intrusion from the ocean.

The average recorded chloride concentration in GPB042 is 48 mg/L. The average recorded chloride concentration in GPB083 over a shorter monitoring period is 39 mg/L (Figure 14). The initial groundwater concentration in the Waipaoa 2 aquifer has been distributed accordingly as presented in Figure 12.

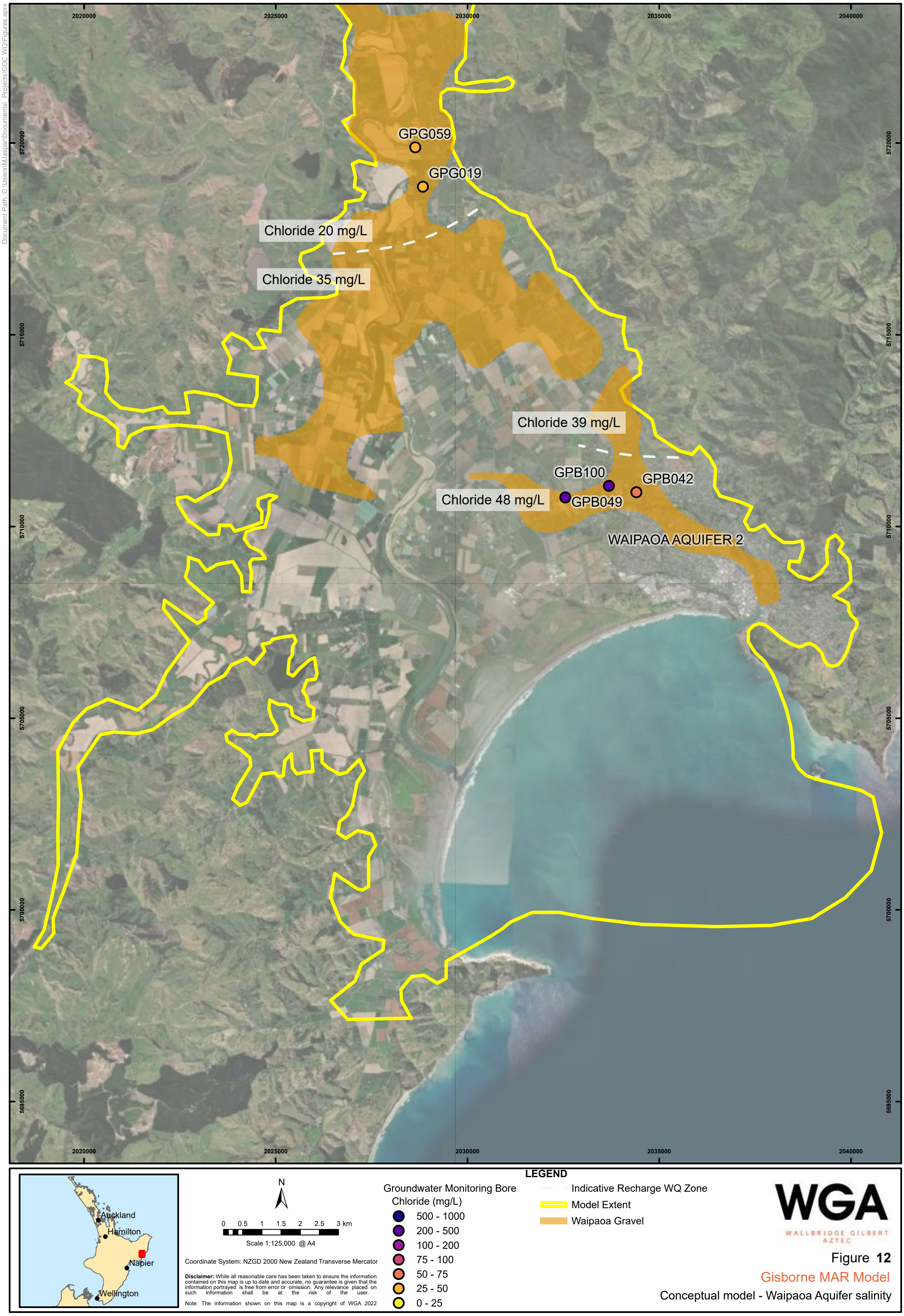


Figure 12
Gisborne MAR Model
Conceptual model - Waipaoa Aquifer salinity

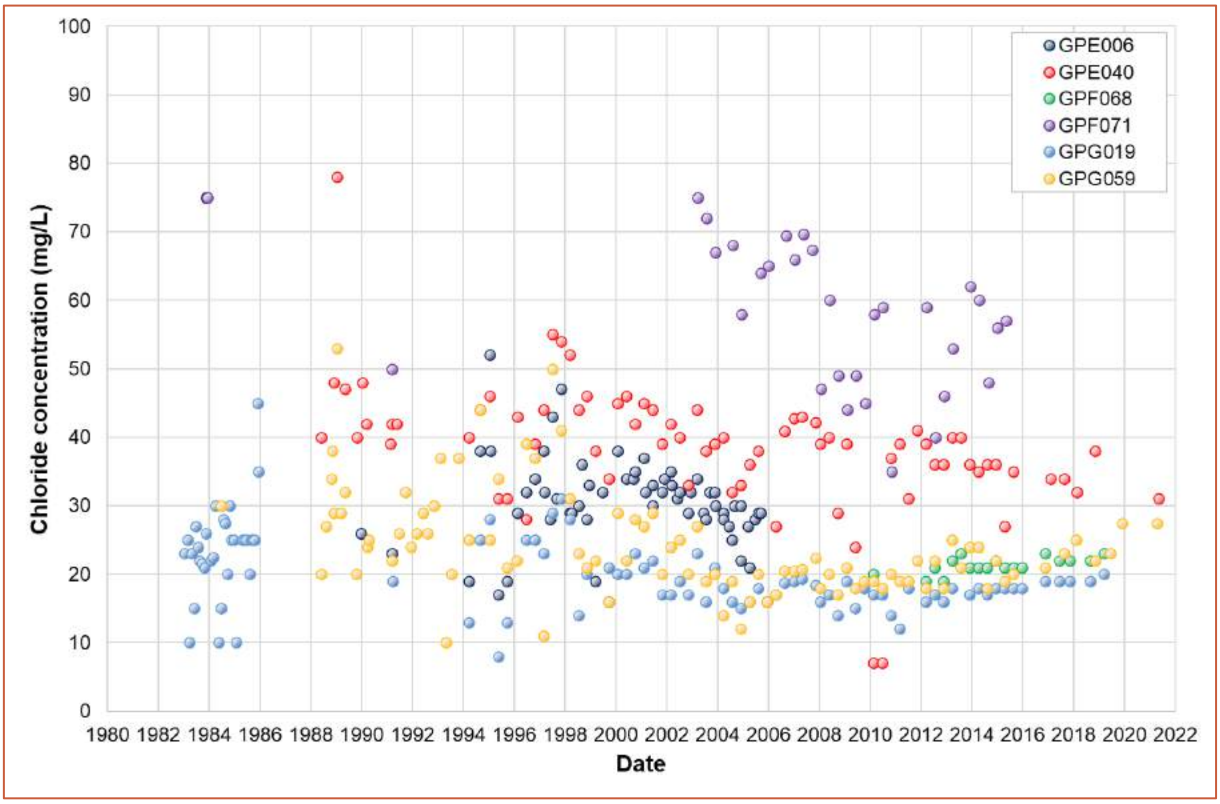


**Figure 13: Waipaoa 1 Aquifer chloride concentrations**

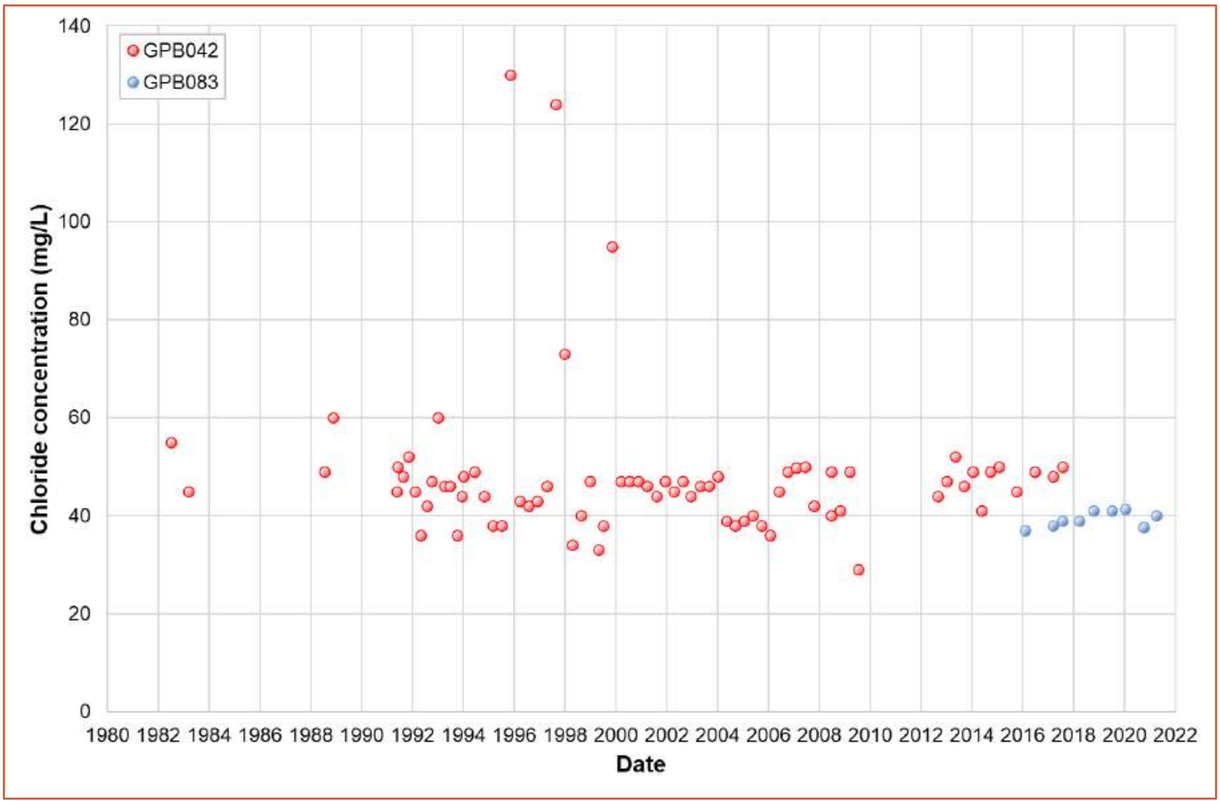


**Figure 14: Waipaoa 2 Aquifer chloride concentrations**

### 3.4.4 Makauri Aquifer

The Makauri Aquifer becomes progressively deeper and more highly confined from north to south, with a corresponding increasing thickness in the overlying aquitard. The aquifer is unconfined to the north and is interpreted as being hydraulically continuous with the Shallow Fluviatile Gravel Aquifer within the Waipaoa River valley. At its south-eastern edge, immediately to the north or east of Gisborne City, the Makauri Aquifer is hydraulically connected to the overlying Waipaoa Aquifer. There is no incontrovertible evidence of a direct hydraulic connection between the Makauri Aquifer and the ocean, although the aquifer does extend offshore.

Chloride concentrations in water recharging the Makauri Aquifer at the north are considered to reflect groundwater quality in the Shallow Fluviatile Gravel Aquifer in this area (7.4 mg/L). Further south the chloride concentrations increase with increasing aquifer depth and interpreted age of groundwater (Figure 15, Figure 16). Chloride data from the Cameron Road No5 monitoring bore (GPB135) is anomalously high (exceeding 500 mg/L) in comparison with most other monitoring bores screened in the Makauri Aquifer. This elevated data is represented in Figure 16, but has not yet been incorporated into the groundwater quality model because it is not conceptually clear where the salt originates. Similarly, chloride records from nearby monitoring bore GPC003 also exceed 500 mg/L for periods. However, the results from this bore vary substantially through the monitored period and again the source and variability in salt concentrations are not conceptually clear. GPC data is not represented in Figure 16 due to the inconsistent chloride concentration record.

Groundwater chloride concentrations for monitored bores screened in the Makauri Aquifer have been assessed for the period prior to 2000. Chloride concentrations recorded from monitored wells across the northern third of the defined aquifer average approximately 40 mg/L (Figure 17). The average chloride concentration recorded in the southernmost monitored wells screened in this aquifer is approximately 120 mg/L. As the southern limit of the aquifer remains undefined from drilling, and is expected to be offshore, extrapolation of this concentration gradient suggests higher chloride concentrations are likely to be present in this aquifer further to the south.

Based on available information, it is considered very likely that the Makauri Aquifer is hydraulically continuous with the western saline area of aquifer documented in Section 3.2.4. As the extent and layout of this western saline area of aquifer is poorly defined, a western water quality boundary condition to the Makauri Aquifer is defined in lieu of more reliable data. This boundary condition is set at 680 mg/L chloride (refer to Section 3.2.4).

It is recognised in setting this boundary condition that the numerical flow model does not fully simulate the western saline area of the aquifer due to the lack of information regarding its properties, layout and extent. Consequently, the numerical model is likely to underestimate the extent to which saline water may be drawn eastward from this boundary condition in response to groundwater abstraction. This is an area of the numerical model that may be improved after further information becomes available from field investigations (refer to Section 4.3).

Increasing or decreasing trends in chloride concentrations over time at specific monitored wells have been principally observed close to the western saline aquifer area (Figure 6 and Figure 7):

- Concentrations in JPD115 have increased from approximately 50 mg/L prior to 2000 to over 150 mg/L in 2022.
- Concentrations in JPI032 have decreased from approximately 270 mg/L in 1985 to approximately 130 mg/L in 2022.
- Concentrations in JPJ040 have increased from approximately 70 mg/L prior to 1996 to over 300 mg/L in 2022.

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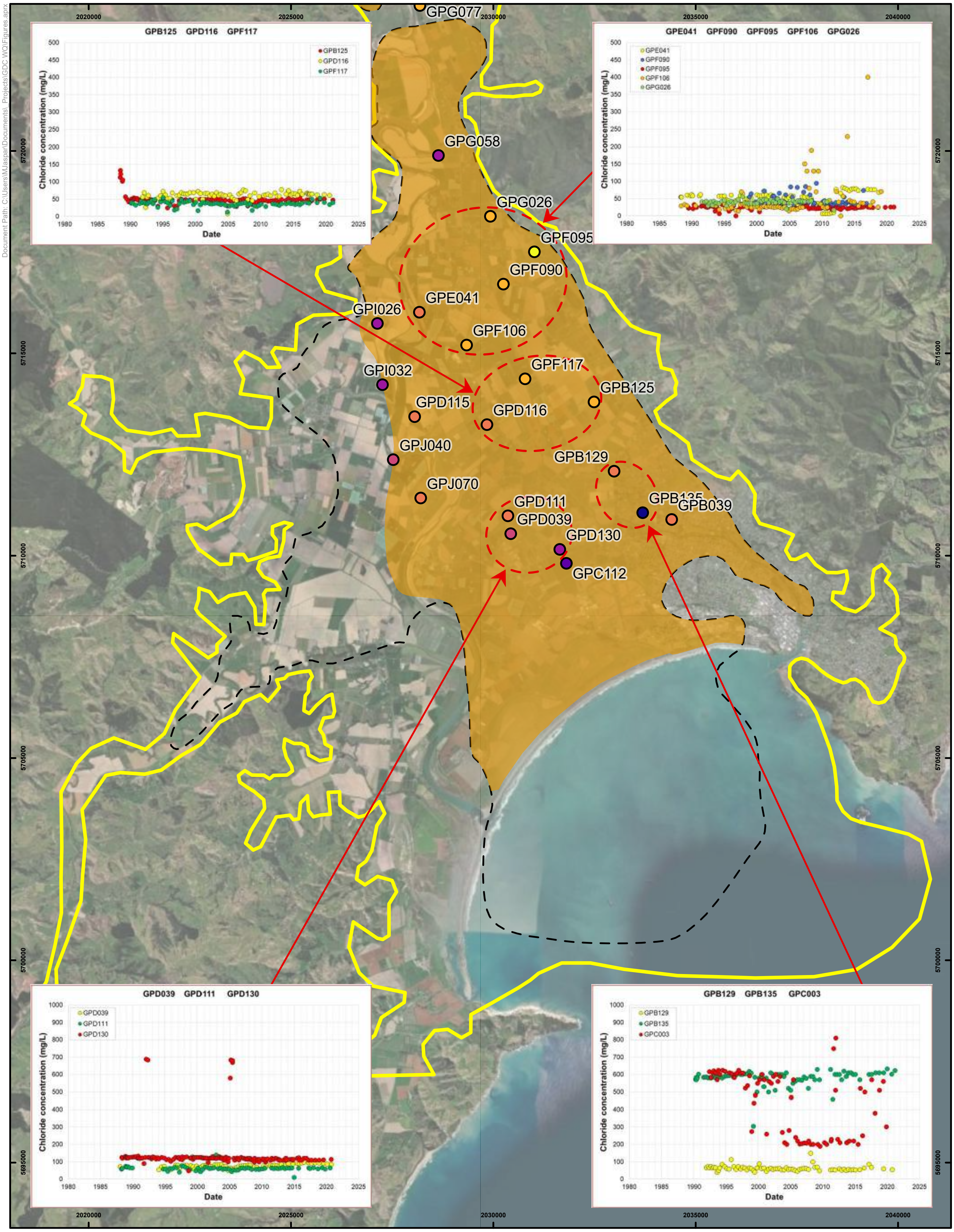


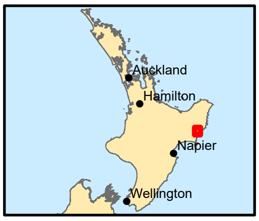


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Scale 1:125,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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**LEGEND**

Groundwater Monitoring Bore Chloride (mg/L)
- 500 - 1000
- 200 - 500
- 100 - 200
- 75 - 100
- 50 - 75
- 25 - 50
- 0 - 25

- Makauri Gravel
- Makauri Gravel Indicative
- Model Extent

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Figure 15

Gisborne MAR Model

Makauri Aquifer chloride observations

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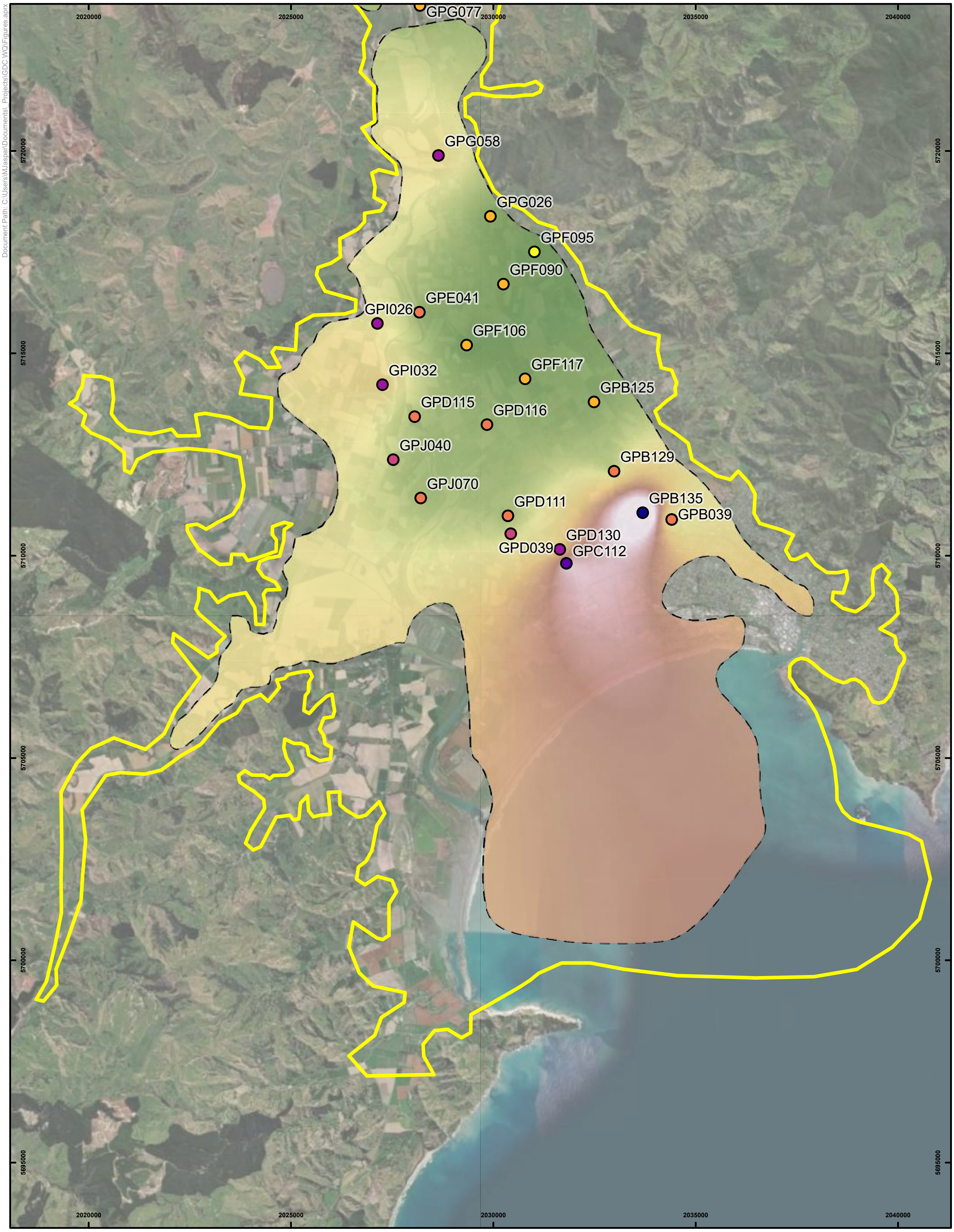


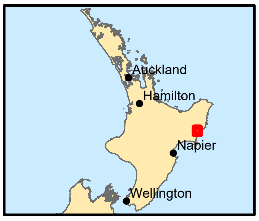


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Scale 1:125,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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**LEGEND**

Groundwater Monitoring Bore Chloride (mg/L)
- 500 - 1000
- 200 - 500
- 100 - 200
- 75 - 100
- 50 - 75
- 25 - 50
- 0 - 25

Indicative Chloride Distribution (mg/L)
- 575
- 24

Makauri Gravel Indicative

Model Extent

WGA
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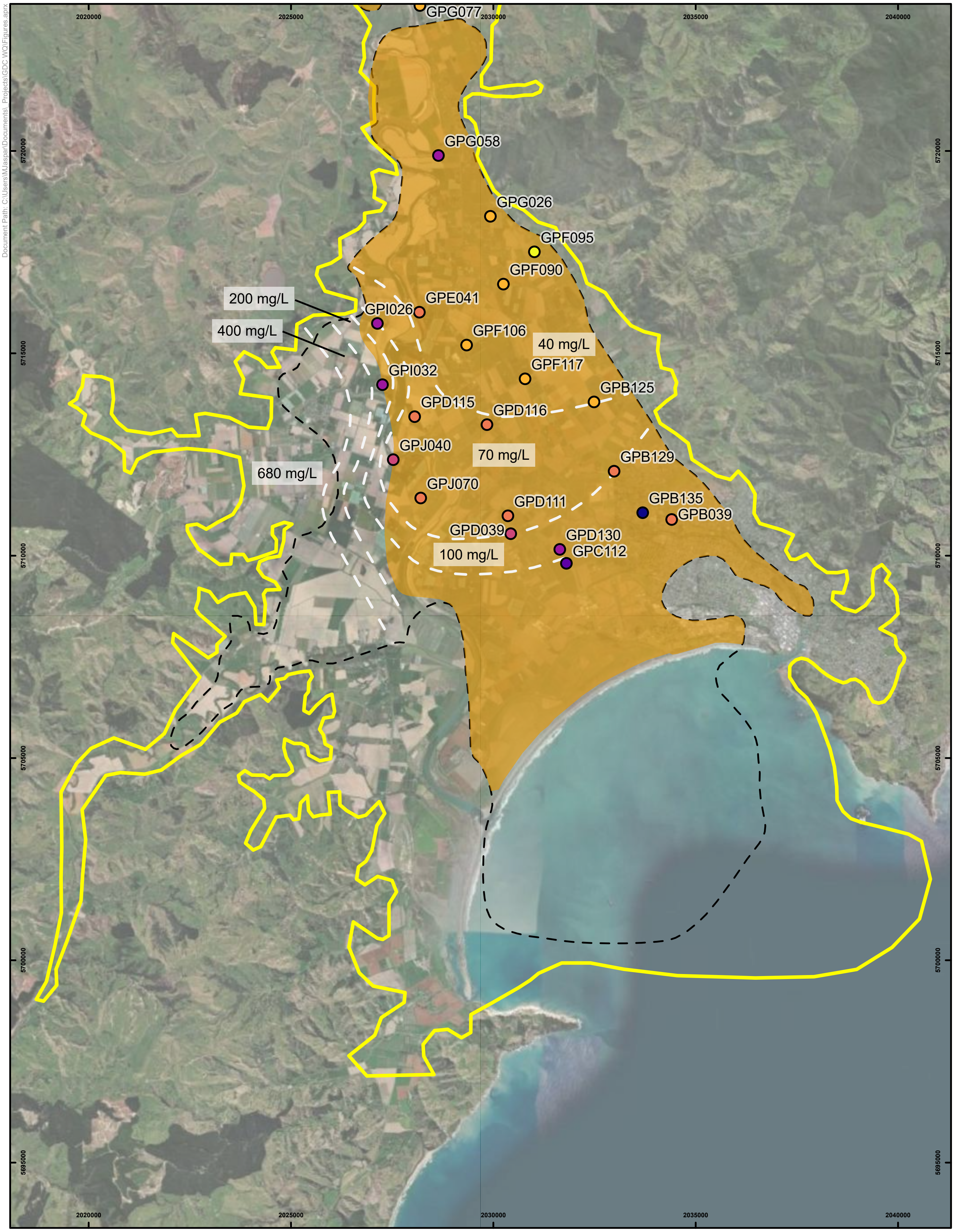
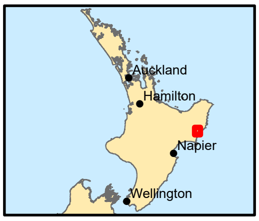
Figure 16

Gisborne MAR Model

Makauri Aquifer chloride distribution map

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Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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**LEGEND**

Groundwater Monitoring Bore Chloride (mg/L)

- 500 - 1000
- 200 - 500
- 100 - 200
- 75 - 100
- 50 - 75
- 25 - 50
- 0 - 25

- Indicative Recharge WQ Zone
- Makauri Gravel Indicative
- Makauri Gravel
- Model Extent

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Figure 17

Gisborne MAR Model

Conceptual model - Makauri Aquifer chloride

Each of these trends is expected to be occurring in response to changes in groundwater flow patterns arising from increasing groundwater abstraction from the Makauri Aquifer over time. An abstraction-induced increase in recharge to the northern end of the aquifer may be resulting in a progressive decrease in chloride concentrations within the northern end of the Makauri Aquifer. Conversely, increased pumping may be drawing saline water eastward from the western saline area of the aquifer

Initial numerical modelling of groundwater quality has identified that the aquitard overlying the Makauri Aquifer is very likely to be contributing saline water flows to the Makauri Aquifer (as discussed in Section 3.3). The initial test model indicated that if this were not the case significant reductions in chloride concentrations within the Makauri Aquifer would be expected to be much more widespread than has been observed. However, at this stage no adjustment has been made to the numerical model to take into account the potential “relic seawater” in the aquitard pore spaces as additional information on pore water quality in the aquitard would be required to support his model adjustment.

#### 3.4.5 Matokitoki Aquifer

The main body of the Matokitoki Aquifer becomes progressively deeper and more highly confined from north to south, with a corresponding increasing thickness in the overlying aquitards. The aquifer is unconfined to the north and is interpreted as being hydraulically continuous with the overlying aquifers within the Waipaoa River valley. Groundwater flow within the main body of the aquifer is interpreted as being from north to south (WGA 2022).

The southern end of the Matokitoki Aquifer has not been delineated through drillhole data. The southernmost drillhole that has an associated geological log and intersects the main body of the Matokitoki Aquifer is GPD132. The geological model of the Poverty Bay Flats, which is based primarily on drillhole geological logs, does not show the aquifer extending significantly to the south of GPD132. In contrast, the screen depths and groundwater quality monitoring records from GPD129 and GPD134 indicate the Matokitoki Aquifer extends at least one kilometre further south than indicated in the geological model.

A branch of the Matokitoki Aquifer extending to the southeast beneath Gisborne City becomes progressively shallower toward the south. The southern extent of this branch has not been delineated through drillhole data. This branch has been interpreted as representing fluviatile gravels deposited within a northward flowing paleochannel of the Waimata River (WGA 2022).

Chloride concentrations in the main body of the Matokitoki Aquifer generally increase toward the south, reflecting greater distance from the interpreter to recharge zones and increasing age of groundwater. Minor chloride concentration trends reflecting increasing or decreasing concentrations at individual bores have been detected (Figure 18). However, overall there is no indication that chloride concentrations in the main body of the Matokitoki Aquifer are changing significantly over time.

Chloride concentrations in the south-eastern branch of the Matokitoki Aquifer are substantially lower than in adjacent sections of the main body of the aquifer (Figure 20). This difference has been interpreted as being indicative of a different recharge zone for the south-eastern branch of the aquifer. this interpretation supports the interpretation of groundwater flow patterns as documented in the conceptual modelling report for the groundwater flow model (WGA 2022).

Two anomalous records with respect to chloride concentrations have been identified from monitored bores screened in the Matokitoki Aquifer.

1. Monitoring well GPG088 is located at the southern end of the Matokitoki River valley (Figure 21). It is close to the interpreted recharge zone for the Matokitoki Aquifer. However, the concentrations recorded from this monitored well have generally been between 200 mg/L and 250 mg/L (Figure 18). These concentrations are more consistent with an area of the aquifer located substantially further south. In fact, the observed concentrations are not consistent with expected concentrations for any of the aquifers underlying the Poverty Bay Flats at this point. No reason for the inconsistent concentrations has been identified yet.
2. The chloride concentrations recorded from monitoring well GPD132 are substantially underrepresented when compared to the electrical conductivity data from the same well (Figure 19). This under-representation implies other salts form a greater proportion of the dissolved solids in the groundwater at this well then in most other aquifers areas underlying the Poverty Bay Flats. No further interpretive work has been undertaken to evaluate major ion distributions within the aquifers underlying the Poverty Bay Flats. Consequently, no conceptual reason for this inconsistency has been identified to date.

There is no incontrovertible evidence of a direct hydraulic connection between the southern end of the Matokitoki Aquifer and the overlying Makauri Aquifer or the ocean. There is no available evidence to indicate whether the Matokitoki Aquifer extends offshore or not.

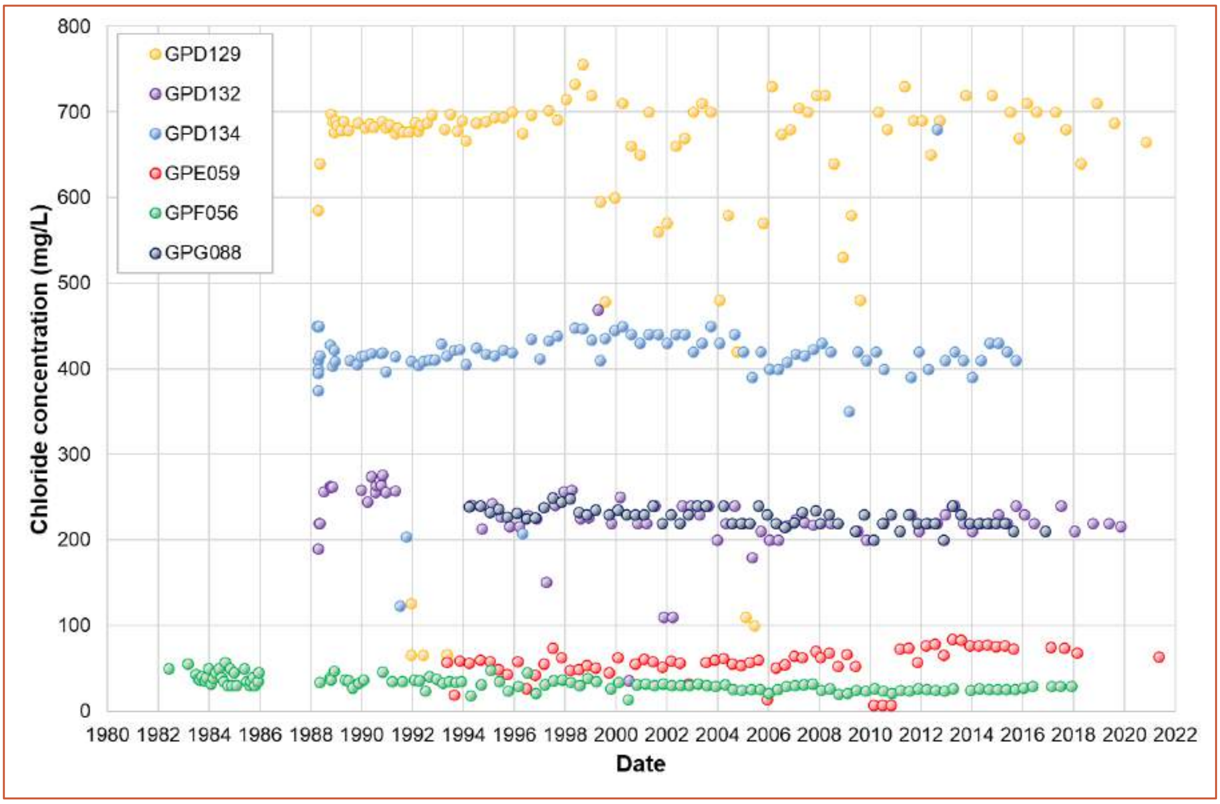



**Figure 18: Chloride concentrations recorded from Matokitoki Aquifer**

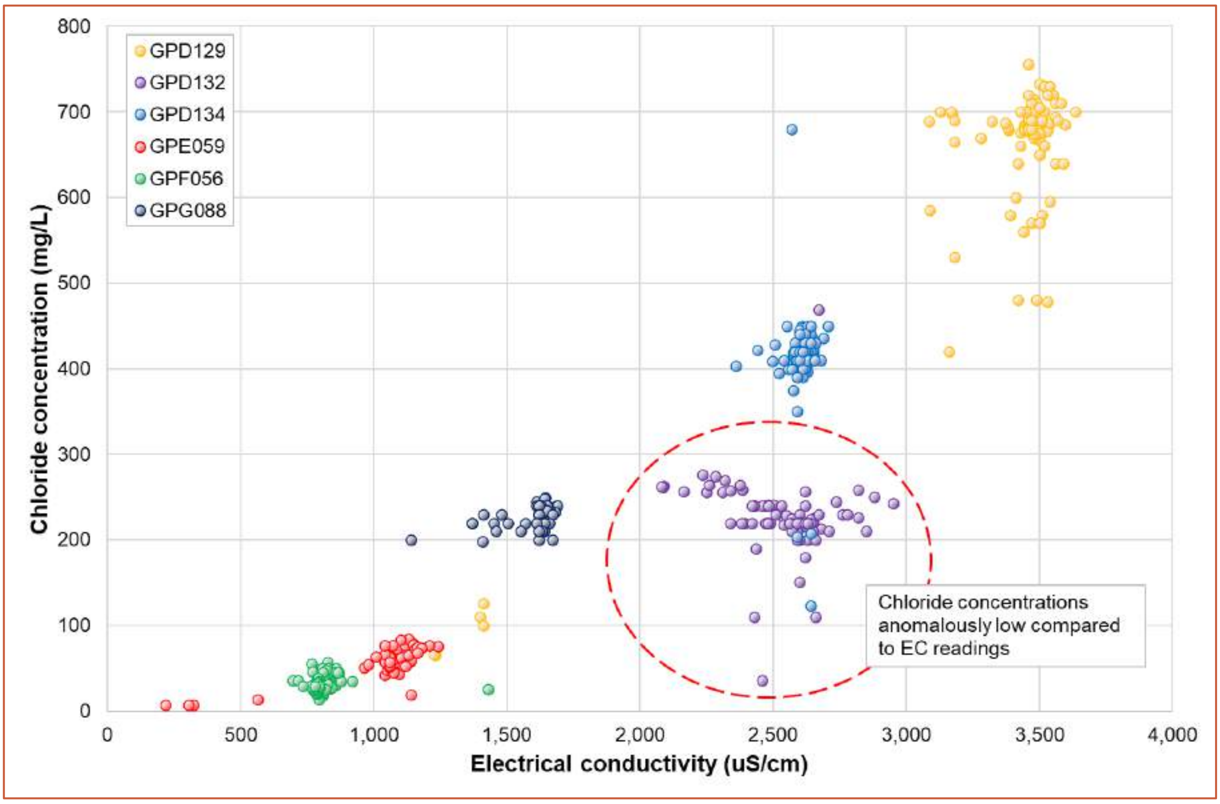



**Figure 19: Groundwater chloride versus electrical conductivity – Matokitoki Aquifer**

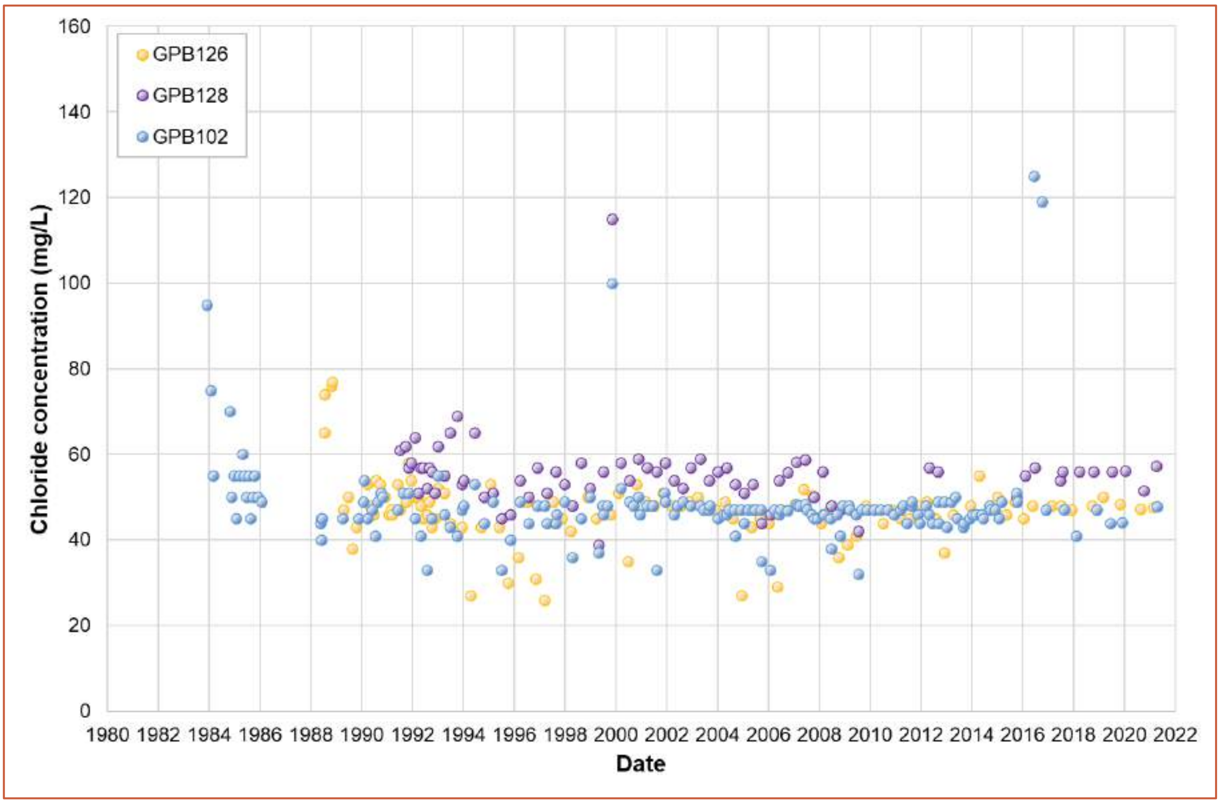
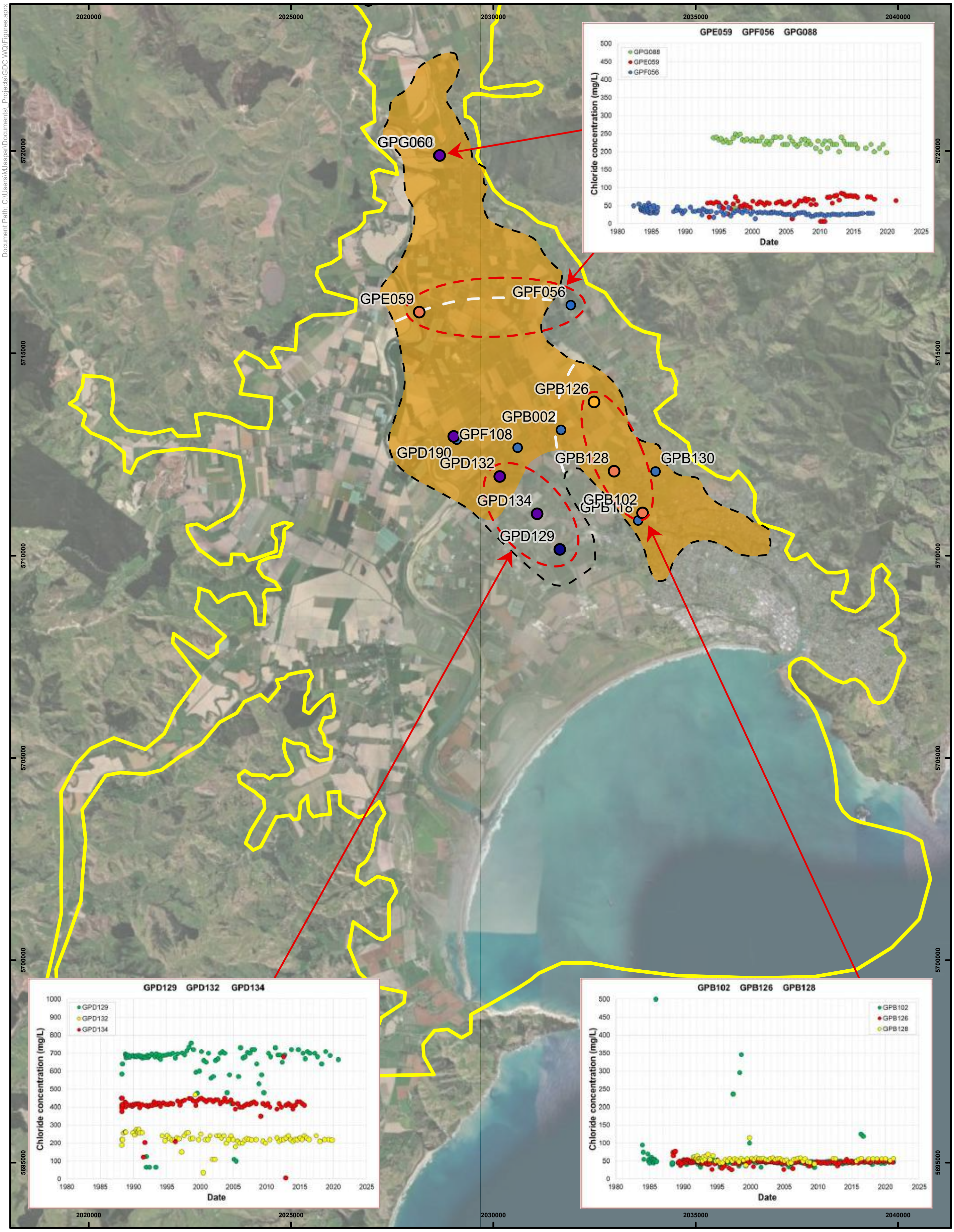
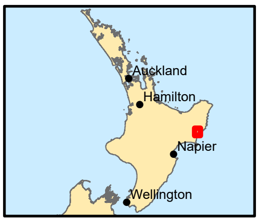



**Figure 20: Chloride concentrations recorded from Matokitoki Aquifer south-eastern branch.**

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Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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**LEGEND**

Groundwater Monitoring Bore Chloride (mg/L)

- 500 - 1000
- 200 - 500
- 100 - 200
- 75 - 100
- 50 - 75
- 25 - 50
- 0 - 25

- Indicative Recharge WQ Zone
- Matokitoki Gravel
- Model Extent
- Matokitoki Gravel Indicative

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Figure 21

Gisborne MAR Model

Matokitoki Aquifer chloride distribution map

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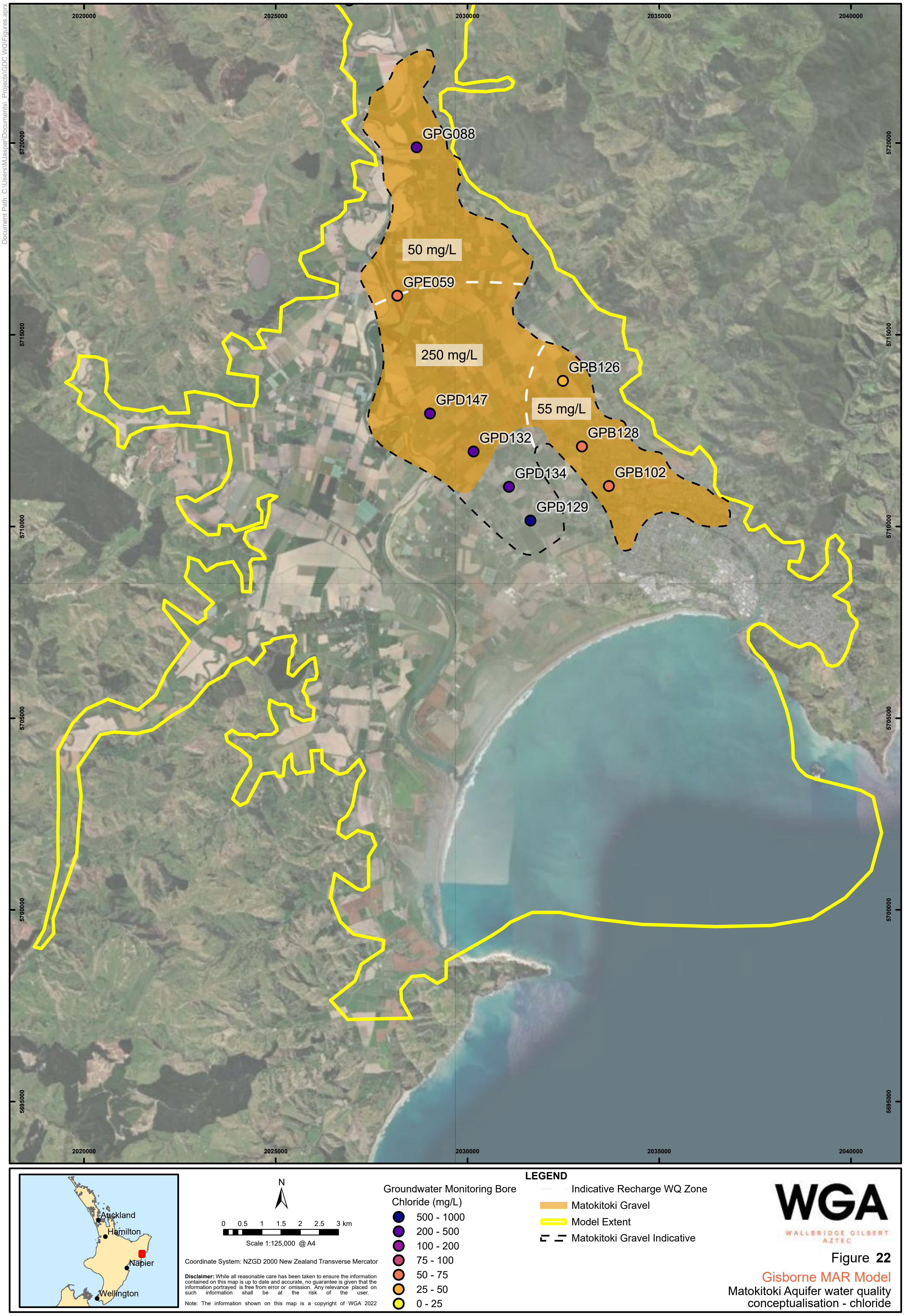


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Figure 22

Gisborne MAR Model

Matokitoki Aquifer water quality conceptualisation - chloride

### 3.4.6 Aquitards

A preliminary conceptualization of the aquitards beneath the Poverty Bay Flats made no allowance for the presence of saline water in the aquitards. This preliminary assumption was known to be unlikely but was incorporated in the first numerical model trial to determine whether the assumption was important for the simulation of groundwater quality in the confined aquifers.

The first numerical water quality model trial to simulate historical chloride trends identified that each of the confined aquifers exhibited decreasing chloride concentrations, both in terms of distribution across the aquifers and in concentrations at specific monitoring points. However, these trends have not been observed in groundwater quality monitoring data acquired over the past 30 years, except in localised areas. Adjustment of the groundwater quality boundary conditions within realistic ranges resulted in very limited improvements to model outcomes.

The outcomes from the first numerical model trial led to reconsideration of the conceptualisation of the aquitard role in groundwater quality behaviour under the Poverty Bay Flats. No data is available from the GDC water quality database regarding the quality of groundwater within the aquitards. Furthermore, no samples of aquitard material where available from any drilling operation performed during the development of this model. Therefore, several fundamental questions linked to gaps in the available information arise:

1. Is the groundwater chloride concentration within each aquitard the same or does it differ between aquitards?
2. Does the groundwater chloride concentration laterally or vertically within each aquitard?
3. Is there a chloride “reservoir” linked to the sediment matrix of the aquitards, which could influence the dissolved chloride concentration in groundwater moving through the aquitards?

At this stage there is insufficient information available to answer the above questions and recommendations regarding filling these information gaps are presented in Section 4.

Effects arising from the potential eastward movement of saline water from the western saline area of the Makauri Aquifer are a key factor to be investigated using the groundwater model. It was considered unlikely that simply defining a constant chloride concentration boundary along the western edge of the Makauri Aquifer would introduce a mass load to the model sufficient to simulate the observed water quality trends along the western side of the simulated Makauri Aquifer. For this reason, a constant concentration boundary has also been conceptualised for the aquitard overlying the western edge of the Makauri Aquifer. This boundary is expected to enhance the chloride mass load introduced to the model in this area, which was observed in the numerical model outcomes (AquaSoil 2022).

## 3.5 CALIBRATION OBSERVATIONS

GDC has been monitoring groundwater quality across the Poverty Bay Flats since the early 1980s. This comprehensive groundwater quality dataset has been accessed to provide calibration targets for the groundwater quality model. The key groundwater quality datasets from individual monitored wells generally cover more than 20 years of sampling. However, shorter data sets have been included for model calibration where the wells are located in areas of specific conceptual interest and where there is a lack of data from other monitored wells.

Some of the calibration datasets for chloride from individual wells operated in figures within the main body of this report. A more comprehensive summary of the calibration data sets is documented in Appendix A.

## 3.6 PREDICTIVE MODEL SCENARIOS

### 3.6.1 Introduction

A range of predictive groundwater numerical models have been developed to investigate the effects arising from different future climate, groundwater abstraction and groundwater management scenarios. Most of these simulated scenarios do not have groundwater quality improvement as a key objective of the scenario. Rather, changes in groundwater quality arising as an outcome of the simulation indicate the effects of changed groundwater flow patterns on the starting groundwater quality defined for the simulation.

The numerical groundwater flow model for the Poverty Bay Flats is considered to be appropriately calibrated for the intended purposes, in accordance with Australian groundwater modelling guidelines (Barnett et al 2012). However, development of the corresponding numerical groundwater quality model has highlighted issues that mean a fully calibrated groundwater quality model based on the available geological, hydrogeological and geochemical information available for the Poverty Bay Flats is very difficult to achieve. Key issues in achieving appropriate calibration to the groundwater quality observation datasets include:

1. A lack of information on the geochemical behaviour of the aquitards, which represent most of the accumulated Quaternary sediments underlying the Poverty Bay Flats and contribute significant spatially distributed recharge to the aquifers.
2. Uncertainty regarding the layout of the western saline area of the Makauri Aquifer, any possible interconnections between aquifers in this area and the quality of groundwater within this area.
3. The complexity of the observed behaviour of the interconnected groundwater / surface water system in the Awapuni area. There is a reasonable amount of information and data available for this area, from past investigations and ongoing monitoring. However, difficulties with interpreting the information have meant a clear conceptualisation of the behaviour of this interconnected system has not been achieved at the level of detail required to achieve a high-quality numerical groundwater quality model calibration for this area.

Although full numerical model calibration for water quality has proven problematic, the numerical model is appropriate for use in simulating and evaluating comparative changes in groundwater quality, with comparisons being done between predictive scenario outcomes.

### 3.6.2 Saline Water Intrusion in Response to Climate Change

All of the predictive simulations developed for the groundwater flow model, with the exception of the Managed Aquifer Recharge (MAR) scenario, retain the same water quality boundary conditions as have been applied to the calibration model. The differences between the models related entirely to changed hydraulic boundary conditions. Consequently, the outcomes of each of the predictive models relate entirely to changes in groundwater flow patterns in response to the changed hydraulic boundary conditions. For reference, a table summarising the differences between each of the simulated scenarios is presented in Appendix B.

Overall, there is sufficient information to enable a good quality simulation of saline water movement into and through the aquifers of the Poverty Bay Flats. A number of assumptions and limitations have been incorporated into the groundwater quality simulation, as set out in Section 4. It is considered that the assumptions built into the model are reasonable and the model can be used to produce reasonable water quality projections over a period of several decades.

There is some evidence to indicate that climate change may, under certain circumstances lead to increasingly saline shallow groundwater recharge.  This trend would be primarily linked to offsetting a decrease in low salinity rainfall through increased irrigation with slightly higher salinity water.  This trend may be exacerbated by increased evaporative losses from surficial soils and an associated increase in salts within the soils.  Although this concept is easy to describe, simulating these effects is highly complicated and problematic to defend scientifically.  These effects are expected to be relatively small compared to the issues of saline water intrusion and movement within the aquifers.

### 3.6.3 MAR Sites and/or Scheme Modelling Capability

The conceptualization of a MAR site or scheme can take numerous forms.  For example, the infiltration of water via recharge basins, the recharge of groundwater via a bore or the combined recharge and recovery of water via a bore.  In each case the hydraulics of the MAR site or scheme is controlled by the operational practice at the site.  The water quality component of the site or scheme is linked directly to the expected quality of the source water and of any treatment undertaken prior to recharge.

The numerical groundwater flow model has been designed to simulate one example of a MAR scheme (WGA 2022) but can equally be used to simulate any other MAR scheme that is focused on direct recharge of the sedimentary deposits underlying the Poverty Bay Flats.  Similarly, the numerical groundwater quality model can be used to simulate chloride changes arising in the Poverty Bay Flats aquifers arising from any MAR scheme, provided it is appropriately conceptualised and the source water quality and planned water treatment systems are understood.

# 4 ASSUMPTIONS, LIMITATIONS AND RECOMMENDATIONS

## 4.1 MODEL ASSUMPTIONS

Several assumptions have been incorporated into the conceptual model of groundwater quality. These assumptions are in addition to the assumptions built into the groundwater flow model and are summarised as follows:

1. It has been assumed that historically observed chloride concentrations in spatially distributed surface recharge, defined through the proxy of shallow groundwater chloride concentrations, will not change during the simulated periods of the predictive models. Uncertainty around this assumption is discussed in Sections 3.6 and 4.2.3. However, WGA concludes that it is an acceptable assumption for the purposes of comparative water quality trends assessment.
2. The absolute concentrations generated by the numerical model are of less importance than the differences in concentrations generated by different predictive models.
3. It has been assumed that density dependent groundwater flow linked to differences in salinity concentrations, as discussed in Section 4.2.1, will not have a significant effect on model outcomes. Recommendations regarding additional work to test the validity of this assumption are presented in Section 4.3. However, bearing in mind that the predictive models are intended to provide comparative outcomes, this assumption is considered reasonable and acceptable with respect to the model purposes.
4. Several assumptions were incorporated into the groundwater quality conceptualisation with respect to initial chloride distributions and chloride behaviour within the aquifer system. It was assumed that:
   - The initial chloride concentration within each aquitard is zero. The implications of this assumption are summarised in Section 3.4.6.
   - The lateral variation in initial chloride concentration within an aquitard matches the concentration in the immediately underlying aquifer, as described in the above sections.
   - The lateral variation in initial concentration in the deepest aquitard matches the concentration in the immediately overlying aquifer, as described in the above sections.
   - There is no interaction between the aquitard matrix and the groundwater, which means chloride is not released from the sediments over time, with the exception of the following area.
   - The aquitard above the saline boundary condition along the western edge of the Makauri Aquifer should act as a source of constant saline water recharge to the underlying aquifer. In effect, this incorporation of an additional groundwater quality boundary condition is intended to replicate some of the potential effects of the western saline area on the Makauri Aquifer.

## 4.2 MODEL LIMITATIONS

### 4.2.1 Coastal Saline Water Interface Modelling

At the coastal interface between fresh groundwater systems and the ocean, the movement of saline water onshore is governed by a range of factors:

1. The density of sea water, which is approximately 1.025 tonnes/$m^3$ compared to the density of fresh water of approximately 1.0 tonnes/$m^3$. This density differential leads to an interface forming between fresh and saline water within coastal aquifers that have direct hydraulic connections to the sea. The approximate form and location of this interface generally depends on three factors:
   a) The structure of the aquifer, including the saturated thickness of the aquifer and the degree of aquifer confinement.
   b) The hydraulic gradient within the aquifer. Natural hydraulic gradients within aquifers are almost exclusively toward the sea. However, groundwater abstraction and land drainage can result in the reduction or reversal of these hydraulic gradients.
   c) The rate of groundwater flow through the aquifer, which is dependent on the above two factors and the hydraulic conductivity of the aquifer matrix.

   The conceptual groundwater model recognises the clear role density dependent flow has to play in the potential for saline water intrusion to the coastal aquifers, with the expectation that this effect will be most pronounced in the Awapuni Moana area. A separate body of work has been undertaken on this issue by Golder and documented in a 2019 report as referred to in Section 4.2.2 below. The numerical model developed for this regional scale project does not incorporate density dependent flow and is likely to understate the degree of saline water intrusion that is presently occurring and may occur in the future in the Awapuni Moana area. Density dependent flow may be incorporated into the numerical model in a future iteration if required. We also note that the incorporation of density dependent flow into the model is unlikely to change the overall conclusions of the modelling programme documented in the WGA and AquaSoil reports for this project.

2. Tidal fluctuations and wave motion.
   a) Tidal fluctuations against low-lying coastal sand aquifers similar to the Te Hapara Sand result in saline water being recharged to the aquifer up to the high tide level, which may be a significant distance from the mean sea level. The tidal motion also induces fluctuations in hydraulic pressure within the aquifer resulting in higher unconfined groundwater levels in coastal sand aquifers than would be expected based on an assessment using mean sea level (Pauw et al 2014). Although this is a recognised effect, there is insufficient published research available to make an informed estimate of the magnitude of this effect. Site-specific investigations may be required to clarify the magnitude of this effect along the Poverty Bay coastline.
   b) Investigations internationally into saline water movement in low-lying coastal sand aquifers similar to the Te Hapara Sand have shown that saline water movement in the near shore aquifer is influenced by wave motion and storm surges (Huizer et al 2017, Pauw et al 2014). Both large waves and storm surges contribute to the transport of saline water further inland than would be predicted by groundwater quality modelling utilising a steady-state coastal hydraulic boundary set at mean sea level. Typically, site-specific investigations are required to quantify and clarify the magnitude of this kind of effect in coastline aquifer systems.
3. Simulation of saline water within the groundwater system between the Awapuni Drains and the coast is complicated by several contributing factors.
   a) Treaty Partners have advised that the mouth of the Waipaoa River was formerly much closer to Gisborne City than its current position. The former riverbed was not identified during assessment of the geological logs and the geological modelling process. However, differentiating riverbed deposits within the Te Hapara Sand was not a focus of the geological modelling process. If buried fluviatile gravel deposits marking the former riverbed are present at shallow depth within the Te Hapara Sand deposits, this may increase focused saline water intrusion at shallow depth inland from the coast.

b) The Awapuni drains (Figure 11), as with other drains in the model, are simulated as constant head features. In other words, the water level within the drains and the hydraulic behaviour of the drains is considered to be constant. In reality, this is not the situation, as has been documented in a report by Fenemore & Hancock (2018). The hydraulic behaviour of the drains is heavily influenced by the operation of a floodgate installed at the discharge point to the Waipaoa River. Additionally, chloride concentrations in the drain water are considered to be influenced by leakage past the floodgate during high tide periods.

### 4.2.2 Saline Water Intrusion to Streams and Rivers

The Waipaoa River is subject to tidal fluctuations near the coast (Golder 2018). However, flows in the river are expected to be large enough under most conditions to ensure that tidally induced reversal of flow at the coastline does not occur. Furthermore, it is also assumed that outflows from the river are sufficient to ensure that a saline water wedge does not form along the bed of the river inland from the coastline. The possibility of saline water flowing inland from the mouth of the river has been discussed with GDC staff and no indication of saline water movement inland from the coastline has been identified.

A flood gate has been installed on the Awapuni Drain where it discharges to Waipaoa River. This flood gate is intended to prevent flows from the Waipaoa River into the Awapuni Drain catchment during high tide periods. However, it is known that some leakage occurs (Fenemore & Hancock 2018).

A study on the groundwater of the Awapuni Moana area, undertaken by Golder and documented in a reports to GDC dates 2019 and 2020, had a strong focus on saline water intrusion to this area of the Te Hapara Sand Aquifer. These reports were not available to WGA during development of the conceptual and numerical groundwater models under the current project. For this reason, the conceptual and numerical model reports produced documenting the current modelling programme reference the material contained in the recent Golder report. It is recognised that the Golder report and the supporting work undertaken for that report are likely to provide further insights into the groundwater behaviour in the Awapuni Moana area. Therefore, any future assessment of the shallow groundwater system at Awapuni Moana should take into account the outcomes from both bodies of work.

The Tūranganui River is tidal and assumed to be transient saline upstream to the confluence of Waimata River and Taruteru River. Tūranganui River's tributaries, Waimata River, Taruteru River and Waikanae Creek are also subject to tidal fluctuations. The distance to which elevated salt concentrations may be detected upstream in these water bodies is unclear and this factor has not been incorporated in the groundwater quality modelling.

### 4.2.3 Land Use Changes

General changes to land uses may be confidently predicted for periods of years to perhaps decades. However, land use changes are driven by a range of factors that are not necessarily predictable even when these factors first become evident (e.g. national and regional policy changes, changes in horticultural production economics). Land use changes may directly influence groundwater quality within the areas of change. For example, the potential for increased salinity in shallow groundwater due to the use of deep groundwater for irrigation. Consequently, longer predictions of groundwater quality trends are subject to increasing uncertainty for this reason alone.

## 4.3 CONCEPTUAL MODEL CONVERSION TO NUMERICAL MODEL

The numerical model developed by AQUASOIL was as faithful to the conceptual groundwater quality (chloride) modal as possible. The simulation of the western saline area of the Makauri Aquifer required the application of water quality boundary conditions that are only partial representations of the actual situation in this area. This partial representation of the western saline area stems from the Makauri Aquifer being incompletely represented in this area, for reasons discussed in the report documenting the conceptual hydrogeological model (WGA2022a).

# 5 WATER QUALITY DISTRIBUTIONS AND HEAT MAPS

## 5.1 BACKGROUND

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. As discussed earlier, the decision to incorporate salinity (chloride) into the numerical quantity model was done before a full review of all water quality parameters could be completed. However, as part of the forward planning for GDC future modelling efforts, a review of the data available for a range of parameters is presented in this section.

As salinity in the form of chloride concentration was chosen as the key parameter for incorporation into the groundwater model (Section 2.2). To summarise the review of the groundwater quality database for salinity and other potential parameters, WGA has generated distribution maps (heat maps) for each of the parameters considered are presented in this report, for completeness.

The GDC database has been compiled and data interpolated for parameters related to nutrient load, microbiology, salinity, and redox state. The interpolated heat maps (presented in Appendix C) provide a view 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 show the interpreted relative distribution of aquifer geochemistry parameters and should be considered as indicative only due to the relative lack of data. 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. Therefore, these maps are presented as point locations with a colour ramp rather than interpolated surfaces. A summary of the technical methodology used to produce these maps along with copies of the derived heat maps are provided in Appendix C.

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, is outside scope of this project. The objective of this 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.

## 5.2 INTERPRETATION

### 5.2.1 Introduction

The heat maps in Appendix C present interpreted concentration distributions for water quality by parameter, aquifer, and bidecadal period. They are intended to provide an indication of changes in water quality distributions across the aquifers underlying Poverty Bay Flats. The maps do not provide a detailed representation of groundwater quality at specific positions within the various aquifers. Even at specific monitored bore locations the maps simply represent average values or detection counts over 20-year periods. Where there are a small number of data points with valid result following the selection procedure described above, the interpolated or extrapolated water quality trends may indicate higher or lower values than would be expected in reality.

A few of the maps in Appendix C present data from bores located outside the indicated extents of the associated aquifer. This apparent anomaly is due to the conservative approach taken to the geological modelling of the aquifers. The extent of the indicated aquifer has been based purely on interpretation of the geological logs from drillholes. The aquifer has not been extended substantially beyond areas where there is confirmed geological information demonstrating the presence of the aquifer. Furthermore, aquifers are in some places represented as being discontinuous due to the presence of deep drill holes with geological logs that do not identify a shallow aquifer. This may simply be an artefact of poor geological logging of the drillhole. The monitored well presented on the map as being outside the indicated aquifer extent will not have an associated geological log. However, for the purposes of groundwater quality assessment, the monitored world has been allocated to the appropriate aquifer.

The following sections provide a high-level interpretation of key features of the heat maps presented in Appendix C.

### 5.2.2 Shallow Aquifer system

Chloride concentrations (Figure C1) tend to be elevated in monitor wells located close to the coast, especially in the Awapuni Moana area. Concentrations in this area tended to increase between the two analysis periods. Further discussion on the chloride trends is presented earlier in this report.

Sulphate concentrations (Figure C25) do not appear to show consistent spatial trends across the shallow aquifers. A slight trend towards decreasing concentration over time is indicated.

Ammoniacal nitrogen (Figure C5) detected in the shallow aquifers are generally below 1 g/m $NH_4$-N, which is to be expected in a generally oxidising groundwater environment. This observation has not changed over time. Similarly, nitrate nitrogen concentrations are generally below 1 g/m $NO_3$-N, with the exception of groundwater around GPD139. Due to the position of this bore, its water quality has an unwarranted effect on the indicated nitrate nitrogen trends across the aquifer.

The concentration trends for total iron (Figure C17) and total manganese (Figure C29) are similar. For both parameters the monitoring wells close to the Waipaoa River appear to be detecting elevated concentrations compared to monitoring wells in the wider aquifer. This appearance may be an artefact of the locations of wells monitored for iron and manganese rather than a real effect. Also, the bores monitored for iron are focused around the Awapuni Moana area and along the river, which results in a deceptive indication of iron distribution in the wider shallow aquifer system.

Dissolved oxygen concentrations are also distributed unevenly across the shallow aquifer's (Figure C13) with no specific trends identified. In contrast, the maps of biochemical oxygen demand (BOD) suggest the demand is highest in groundwater in Awapuni Moana area. Again, this may simply represent an outcome of the monitoring being more intensive in this area.

*E coli* is being detected in shallow groundwater, as would be expected. The number of detections is low, with no particular indication of a trend in detection counts across the shallow aquifers.

Overall, this high-level survey of the groundwater quality data indicate a potential trend in chloride concentrations close to the coast, as discussed earlier in this report. Additionally, there may be a correlation between groundwater iron concentrations and a possible area of water exchange with the Waipaoa River.

### 5.2.3 Waipaoa Aquifer

Chloride (Figure C2) in the combined Waipaoa Aquifers indicates a trend of increasing concentration with aquifer depth and presumably groundwater age. This increase is most pronounced where the two aquifer areas approach each other. Further discussion on the chloride trends is presented earlier in this report. The lowest concentrations are interpreted as being indicative of areas where active aquifer recharge is occurring.

Overall, sulphate concentrations (Figure C26) tend to be low; less than 5 $g/m^3$. The anomalous concentration linked to monitoring well GPG059 is not indicative of incorrect aquifer identification for this well as the concentrations would stand out as anomalous for any of the aquifers.

Ammoniacal nitrogen (Figure C6) tends to be higher in the southeastern branch of the aquifer than the main aquifer body. In contrast to chloride, there does not appear to be a trend of increasing concentration with aquifer depth or groundwater age. There is too limited nitrate data to interpret.

The concentration trends for total iron (Figure C18) and total manganese (Figure C30) in the main body of the Waipaoa Aquifer are similar, suggesting decreasing concentrations with aquifer depth and groundwater age. However, these trends are strongly influenced by the data from GPG076, raising questions regarding the source of the water to this well. No specific reliable concentration trends for iron or manganese have been identified for the southeastern branch of the Waipaoa Aquifer.

There is too limited dissolved oxygen data to interpret. The data for biochemical oxygen demand and *E. coli* are insufficient to meet the assessment criteria.

Overall, this high-level survey of the groundwater quality data indicates a trend of increasing chloride concentration with aquifer depth and presumably also groundwater age. None of the other trends identified are considered strong trends.

Bearing in mind the need to manage future groundwater quality, it may be useful to undertake period is sampling for dissolved iron and manganese in combination with dissolved oxygen and biochemical oxygen demand to understand the trends in these parameters.

### 5.2.4 Makauri Aquifer

Chloride concentrations (Figure C3) tend to increase from north to south through the Makauri Aquifer, indicating a trend of increasing concentration with aquifer depth and groundwater age. The maps present insufficient data in the southeastern branch of the Makauri Aquifer to support any interpretation on chloride trend in this area. Both chloride maps (Figure C3) indicate elevated chloride concentrations along the western edge of the aquifer, reflecting the effects of the western saline aquifer area. However, the data averaging process used to generate these maps has led to the higher concentrations measured in bores in this area being understated in the maps.  These trends and the interpretation are addressed in greater detail in Section 3.4.4.

Sulphate concentrations (Figure C27) do not appear to show consistent spatial trends across the Makauri Aquifer.  A general trend of decreasing concentration across the aquifer over time is indicated.

Dissolved oxygen concentrations recorded from the Makauri Aquifer (Figure C15) indicate a general trend of decreasing concentration from north to south, reflecting the corresponding change from an oxidising geochemical environment to a reducing environment from north to south.  Elevated dissolved oxygen concentrations in monitored wells GPF117 and GPB125 support the interpretation of a possible focused recharge to the Makauri Aquifer to the east of these wells.

Ammoniacal nitrogen concentrations increase from north to south across the Makauri Aquifer (Figure C7).  This concentration trend reflects the increasing depth, degree of aquifer confinement, groundwater age, decrease in dissolved oxygen and corresponding increasingly reducing geochemical environment in the aquifer toward the south.  There is insufficient data in the southeastern branch of the Makauri Aquifer to support any interpretation on ammoniacal nitrogen trend in this area.  Overall, the data indicates there is negligible nitrate-nitrogen in the Makauri Aquifer groundwater.  This observation supports the interpretation of the aquifer as being principally characterised by a reducing geochemical environment.

The concentration trends for total iron (Figure C19) and total manganese (Figure C31), both spatially across the aquifer and temporally, are highly influenced by data from a few monitored wells.  It is recommended that a review of the water quality data to differentiate between total and dissolved metal concentrations be undertaken to inform an interpretation of trends for these metals in the Makauri Aquifer.

The data for biochemical oxygen demand insufficient to meet the assessment criteria and the *E. coli* detections recorded for the Makauri Aquifer are negligible.

Overall, this high-level survey of the groundwater quality data for the Makauri Aquifer indicates a trend of increasing chloride and ammoniacal nitrogen and decreasing dissolved oxygen from north to south, reflecting the increasing depth, degree of aquifer confinement, groundwater age and increasingly reducing geochemical environment in the aquifer toward the south.

### 5.2.5 Matokitoki Aquifer

Chloride concentrations (Figure C5) tend to increase from north to south across the main body of the Matokitoki Aquifer, indicating a trend of increasing concentration with aquifer depth and groundwater age.  In contrast, the chloride concentrations recorded from the southeastern branch of the Matokitoki Aquifer are relatively low, supporting the interpretation of a different groundwater source to the main aquifer, as discussed in Section 3.4.5.

Sulphate concentrations (Figure C28) do not appear to show a spatial trend across the Matokitoki Aquifer.  A general trend of decreasing concentration across the aquifer over time is indicated.

Ammoniacal nitrogen concentrations increase from north to south across the Matokitoki Aquifer (Figure C8), reflecting the increasing depth, degree of aquifer confinement and presumably groundwater age in the aquifer.  Ammoniacal nitrogen in the southeastern branch of the Matokitoki Aquifer appear to be elevated in comparison to concentrations recorded across much of the main body of the aquifer.  There is only one monitored well, GPB102, with sufficient nitrate-nitrogen data to meet the assessment criteria.

The concentration trends for total iron (Figure C19) and total manganese (Figure C31), both spatially across the aquifer and temporally, are highly influenced by data from a few individual monitored wells. It is recommended that a review of the water quality data to differentiate between total and dissolved metal concentrations be undertaken to inform an interpretation of trends for these metals in the Matokitoki Aquifer.

There are insufficient dissolved oxygen records for this aquifer to enable a heat map to be produced or any reasonable spatial or temporal interpretation to be provided.  The data for biochemical oxygen demand insufficient to meet the assessment criteria and *E. coli* detections recorded for the Matokitoki Aquifer are negligible.

Overall, this high-level survey of the groundwater quality data for the Matokitoki Aquifer indicates a trend of increasing chloride and ammoniacal nitrogen from north to south, reflecting the increasing depth, degree of aquifer confinement and presumably groundwater age in the aquifer toward the south.  The southeastern branch of the aquifer is characterised by low chloride and elevated ammoniacal nitrogen concentrations relative to the rest of the aquifer.

## 5.3 SUMMARY

This review of the water quality data available for the aquifers underlying the Poverty Bay Flats has highlighted too important aspects off the water quality database available through GDC:

1. There is a large amount of water quality data available in this database to support an interpretation of the geochemical conditions in the various aquifers.
2. The data available tends to focus on specific parameters of interest at the time of sampling and on the primary productive aquifer of the area, the Makauri Aquifer.

As a result, it was concluded early in the modelling process that the only parameter offering sufficient concentration data to support the development of a numerical water quality model for the purposes of this project is chloride.  Additionally, chloride is the only one of the water quality parameters reviewed that is conservatively transported and does not react in response to aquifer redox conditions.  It also remained one of the most significant concerns that the community raised during the workshop process.  Therefore, based on being a suitable parameter to model and the community's interest in the salinity, the modelling of chloride transport was undertaken as a sole parameter simulation .

Once a groundwater quality model focusing on chloride has been developed to the stage that it can reliably reflect both absolute concentrations and spatial and temporal concentration trends, other parameters may be incorporated into this numerical model.

# 6 CONCLUSIONS

The objective this technical report was to provide a summary of key groundwater quality data for the Poverty Bay Flats and provide a water quality conceptualisation for chloride transport in the groundwater system.  This information was used to help build the transport of chloride into the Poverty Bay Flats numerical groundwater model.

The conceptual groundwater quality model as documented in this report is intended to support a comparative assessment of groundwater quality changes due to projected changes in groundwater recharge, groundwater abstraction and sea levels.  No predicted changes in recharge water quality or water quality associated with other hydraulic boundaries have been incorporated into the conceptual or numerical models.  Consequently, model outcomes with respect to groundwater quality differ principally in response to changes in groundwater abstraction and groundwater flow patterns.

The model assumptions presented in Section 4.1 and model limitations presented in Section 4.2 have been carefully reviewed in light of the model objectives.  This review indicated the conceptual groundwater quality model, and the associated numerical model are fit for the intended purposes.  Uncertainties regarding model outcomes, taking into account the period of the predictive models, have been identified and documented in this report.

The groundwater flow model, as documented in separate reports by WGA and AquaSoil, presents a conservative evaluation of the volumetric flows through the aquifers of the Poverty Bay Flats.  By extension, the groundwater quality conceptualisation and the numerical groundwater quality model are also subject to limitations and assumptions as noted above.  These limitations do not invalidate the model for the purposes of providing guidance for groundwater allocation.  they do however provide guidance with respect to the prioritisation of potential future investigations and with respect to the appropriate management off the ground water resources by GDC.

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# APPENDIX A

## GROUNDWATER QUALITY DATASETS FOR MODEL CONCEPTUALISATION

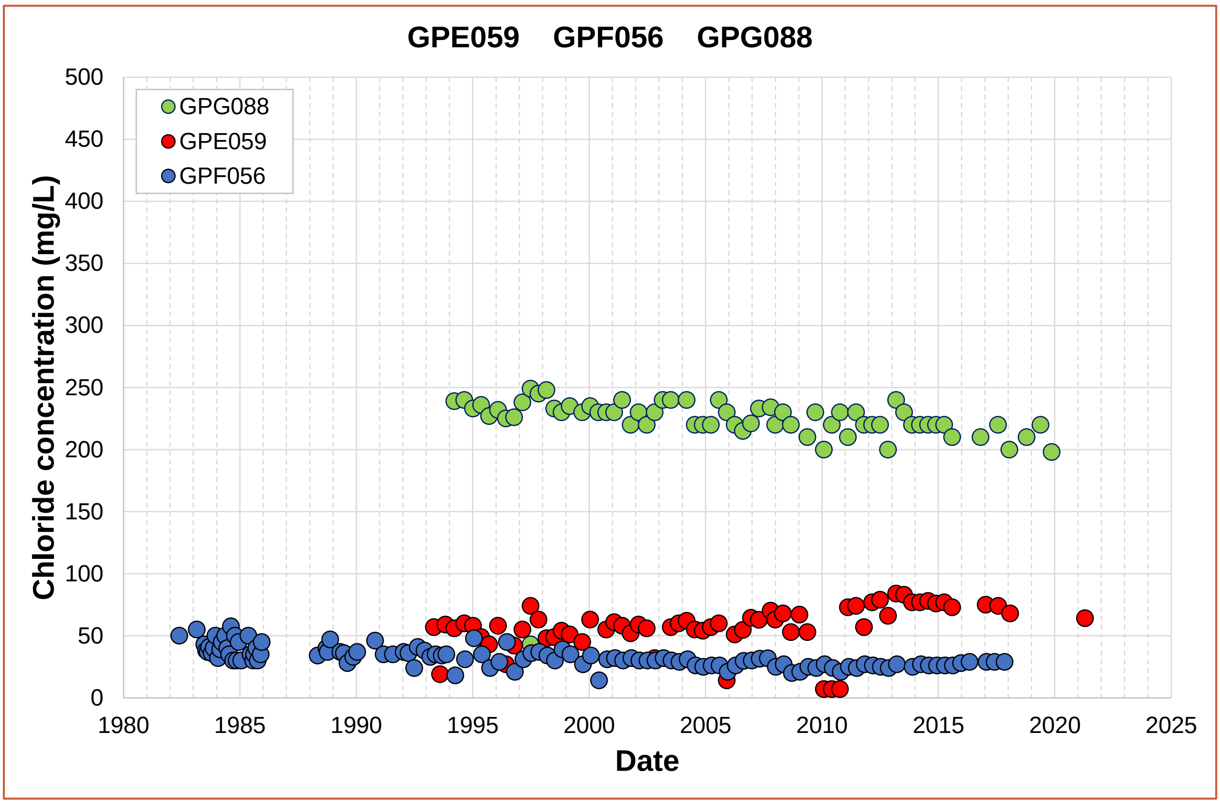



**Figure A1: Matokitoki Aquifer chloride datasets from northern group of monitoring wells**

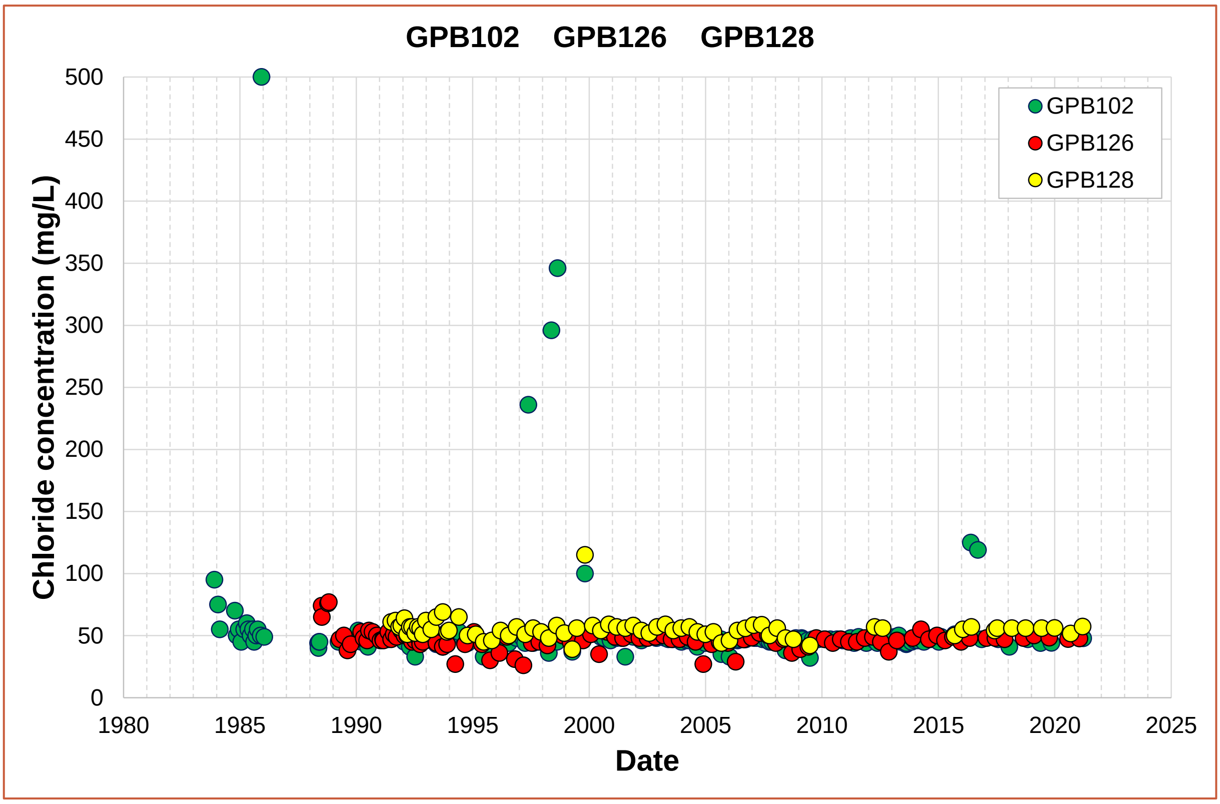



**Figure A2: Matokitoki Aquifer chloride datasets from eastern group of monitoring wells**

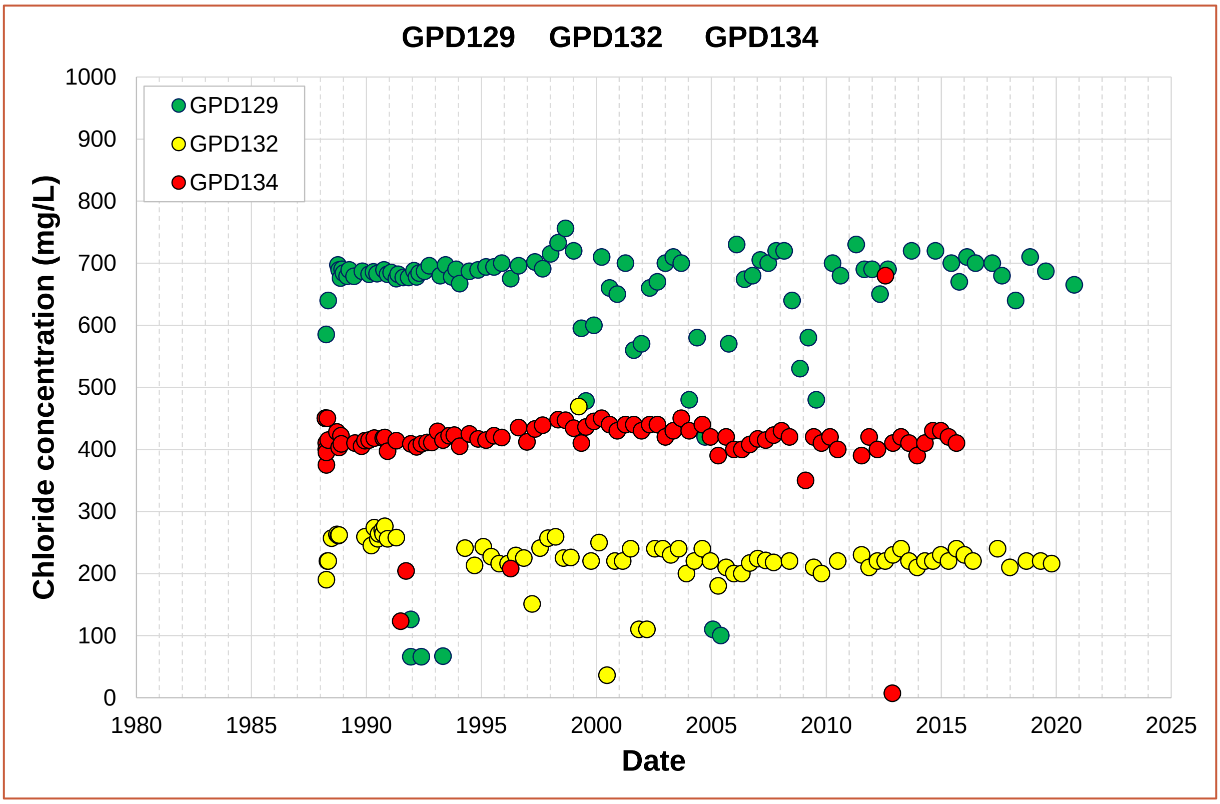



**Figure A3: Matokitoki Aquifer chloride datasets from southern group of monitoring wells**

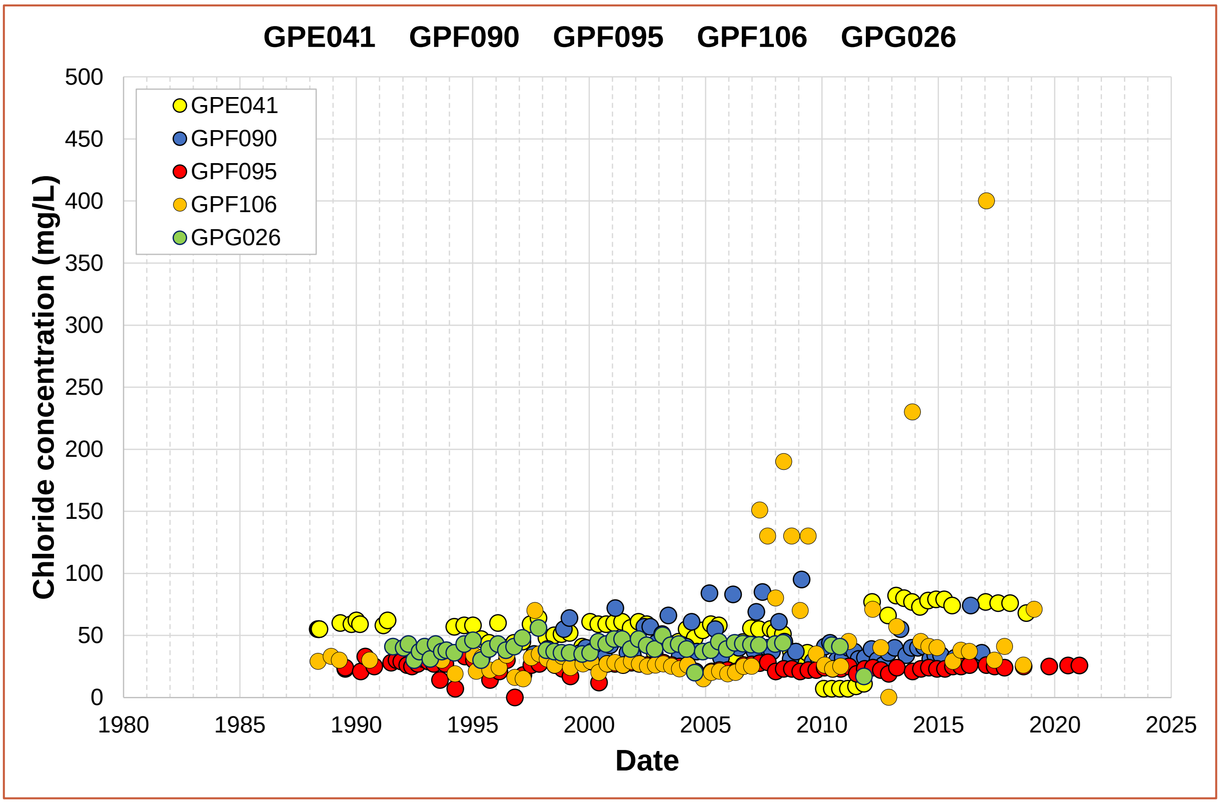



**Figure A4: Makauri Aquifer chloride datasets from northern group of monitoring wells**

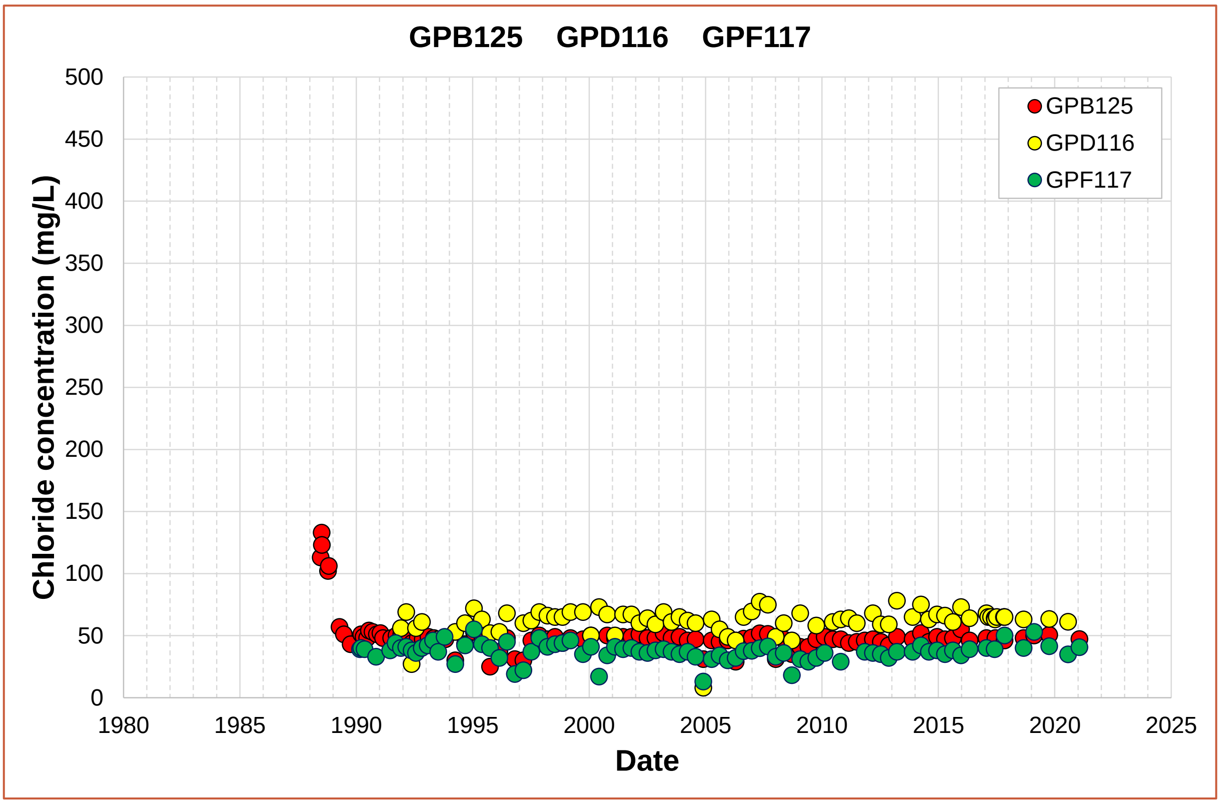



**Figure A5: Makauri Aquifer chloride datasets from central group of monitoring wells**

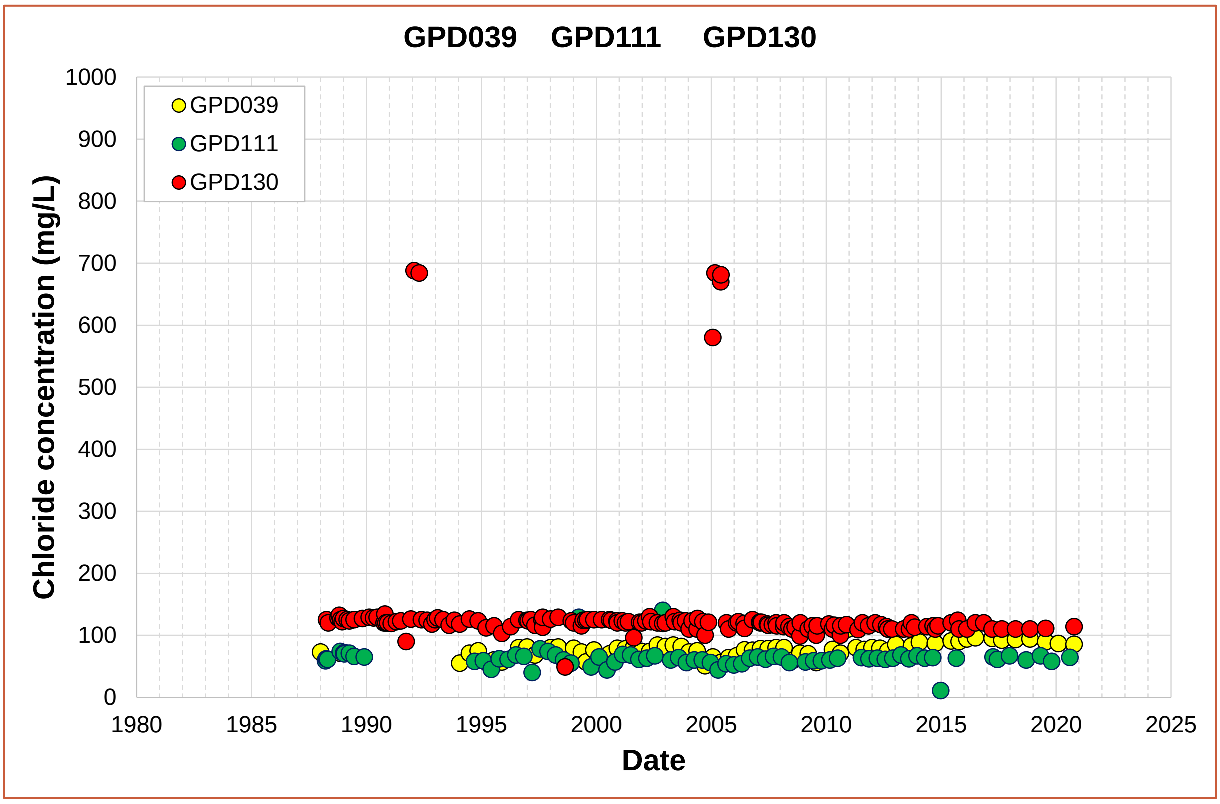



**Figure A6: Makauri Aquifer chloride datasets from southern group of monitoring wells**

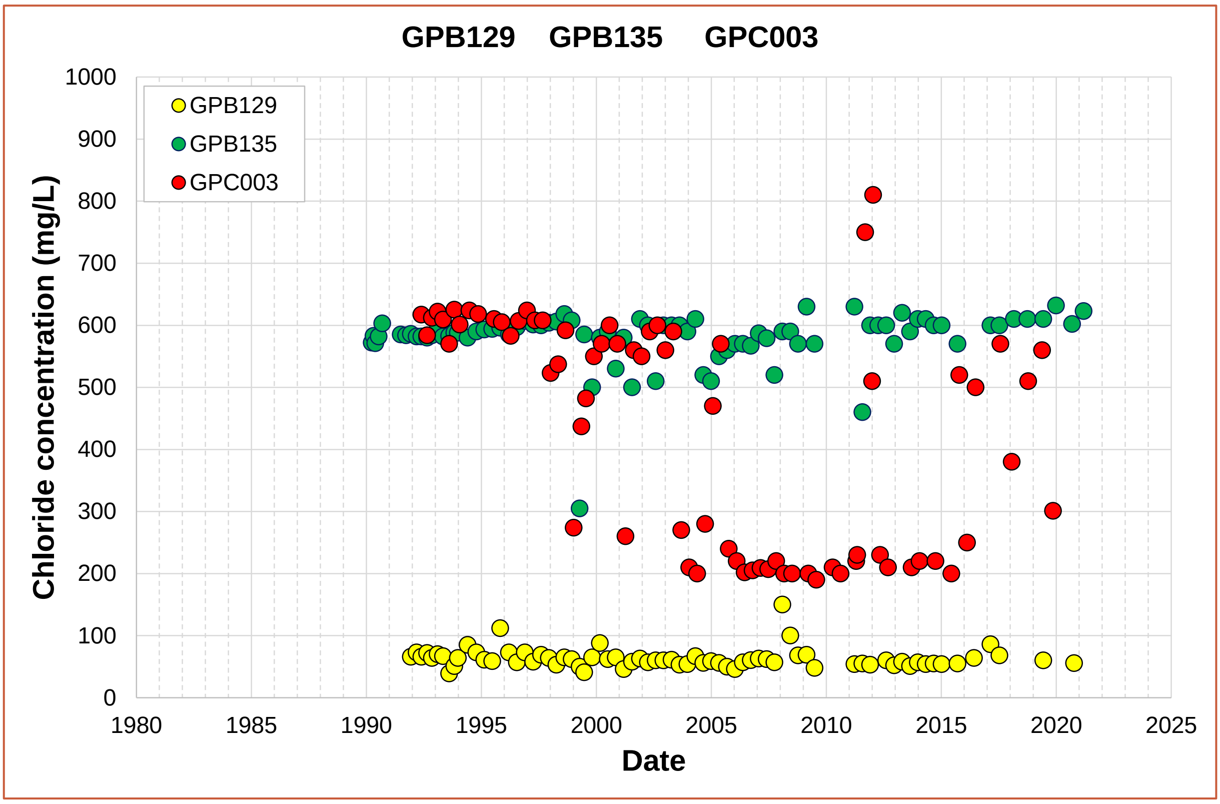



**Figure A7: Makauri Aquifer chloride datasets from southeastern group of monitoring wells**

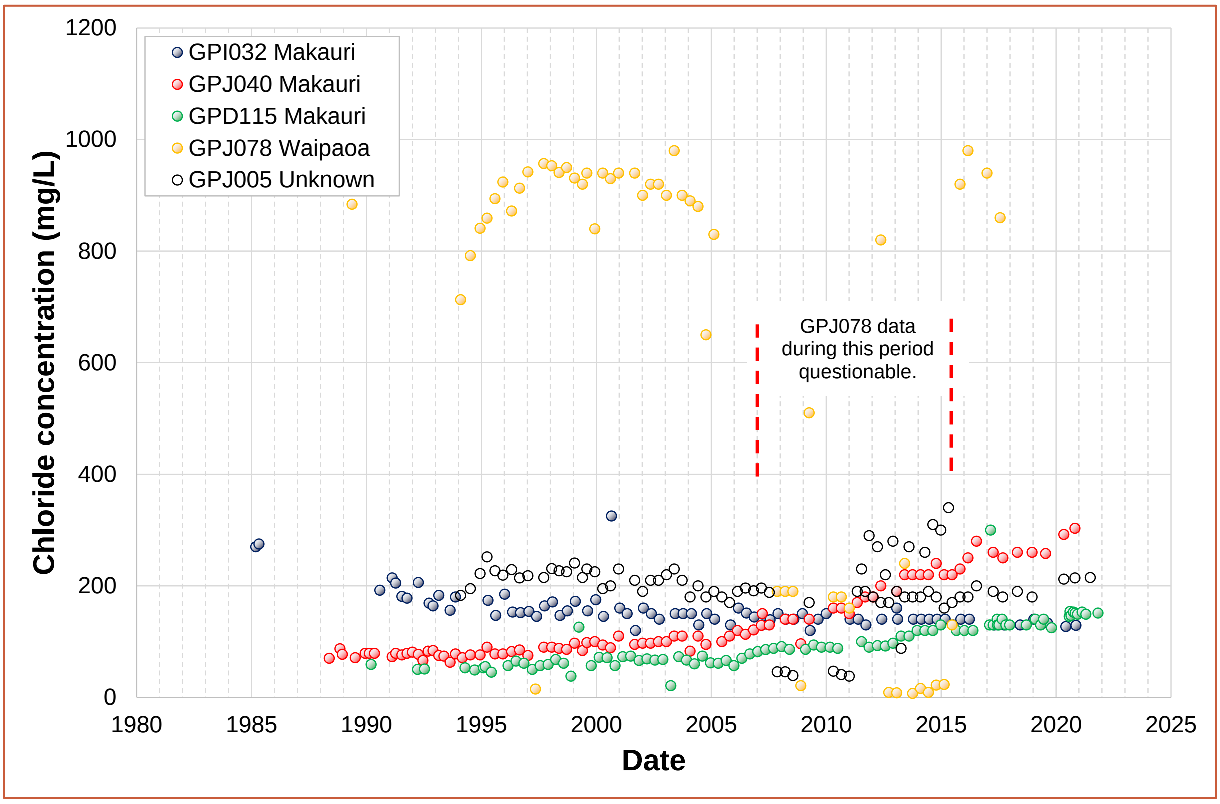



**Figure A8: Makauri Aquifer and related chloride datasets from western saline area**

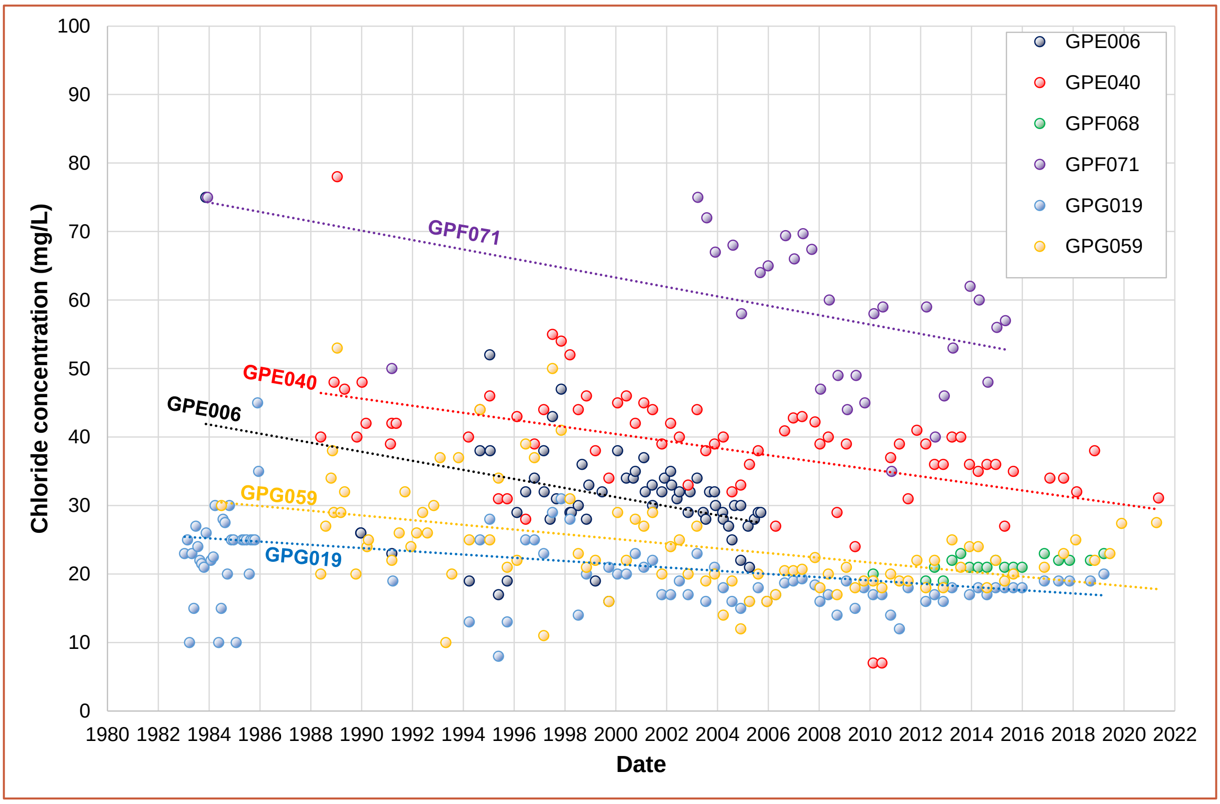



**Figure A9: Waipaoa Aquifer chloride datasets from monitoring wells**

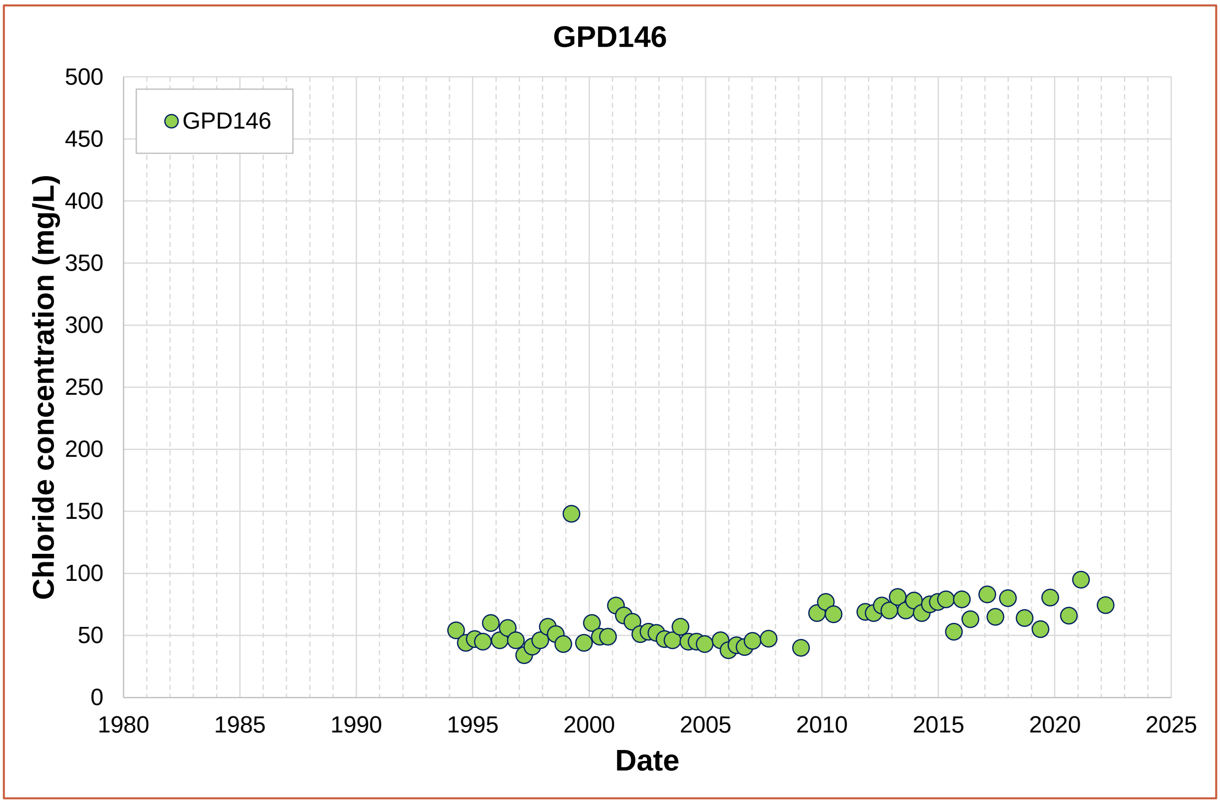



**Figure A10: Te Hapara Sand Aquifer chloride datasets from inland monitoring well**

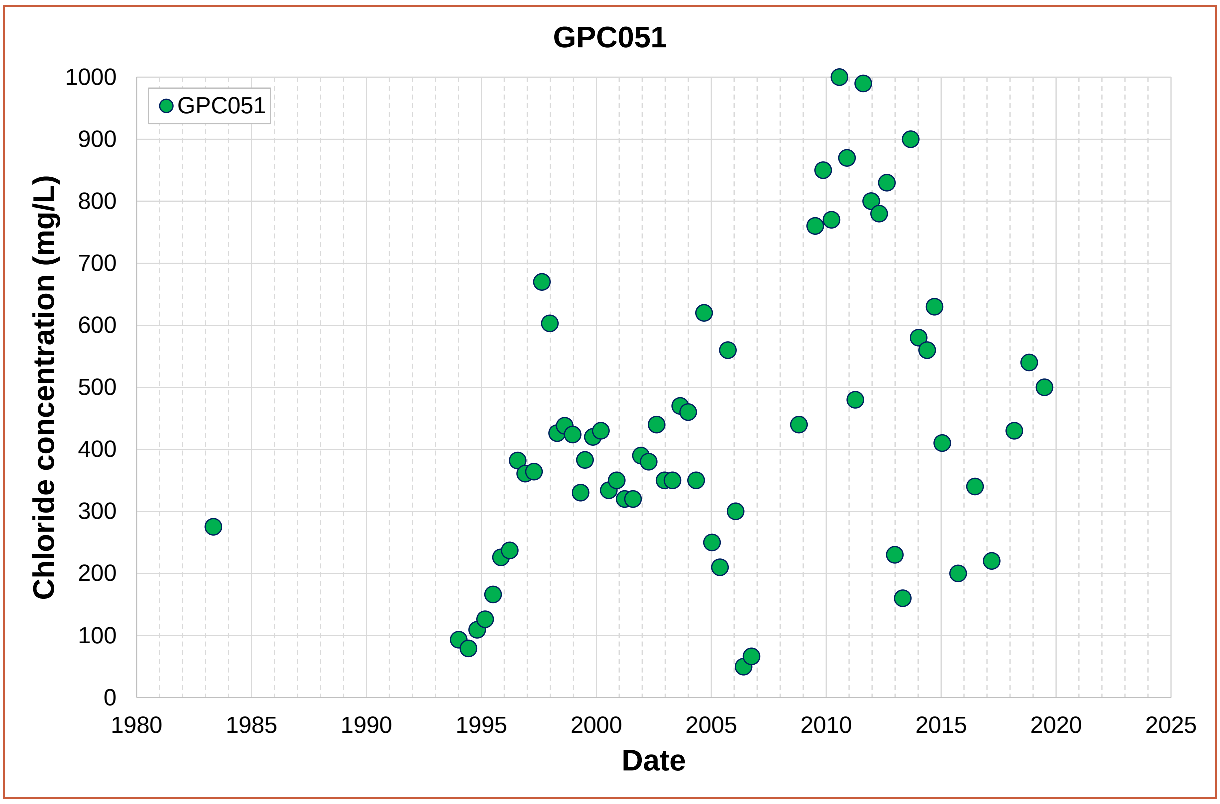



**Figure A10: Te Hapara Sand Aquifer chloride datasets from coastal monitoring well GPC051**

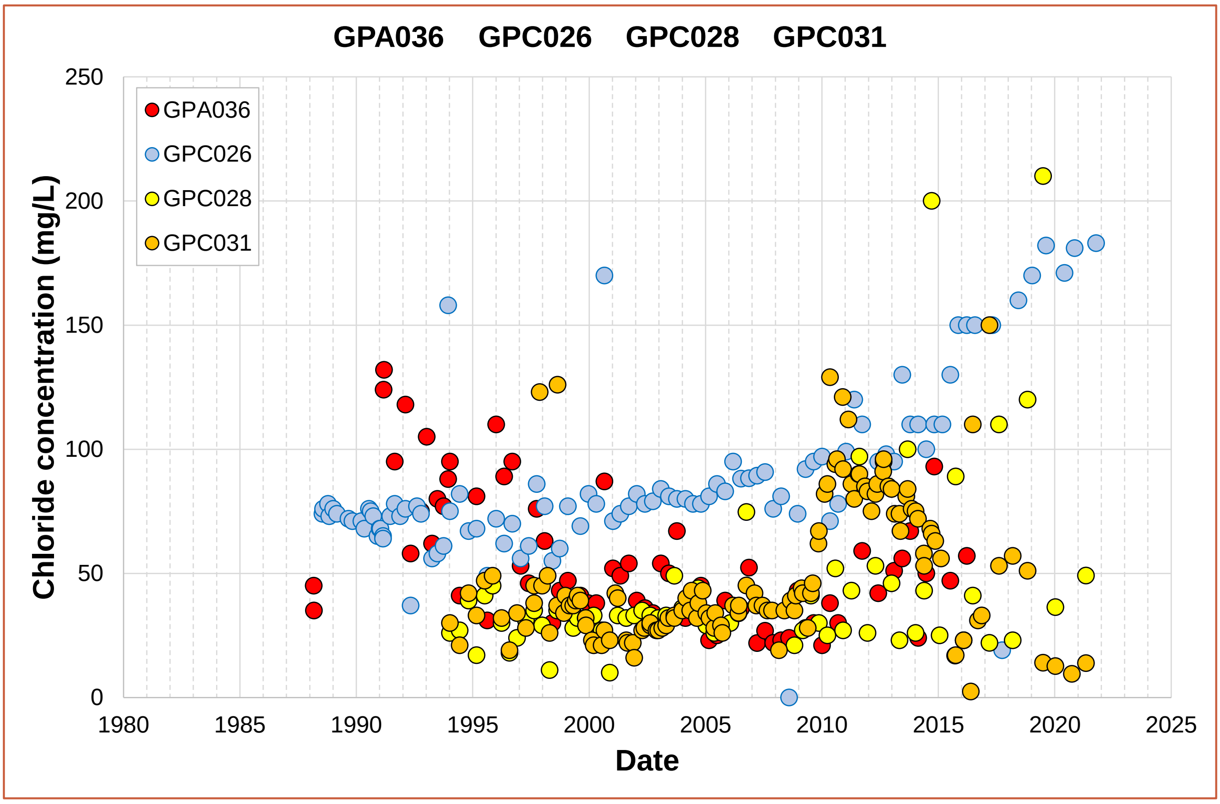



**Figure A10: Te Hapara Sand Aquifer chloride datasets from coastal monitoring wells**

# APPENDIX B

## GROUNDWATER MODELLING SCENARIOS

TO BE COPIED FROM FINAL SCENARIOS TABLES IN MODELLING SUMMARY REPORT.

# APPENDIX C

## WATER QUALITY DISTRIBUTION MAPS

## Introduction

Groundwater quality analysis results from the GDC database have been summarised and mapped for two bidecadal periods covering the distribution of parameters related to nutrients, microbiology, salinity, and redox state generated. The contoured concentration maps, or Heat Maps, provide an indicative view of the relative distribution of water quality within the five aquifers underlying the Poverty Bay Flats.

Heat 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 interpreted concentration distributions for each groundwater quality parameter are indicative only beyond the identified sampling point locations.

The bacterial content in groundwater is represented by *E. coli* counts. Due to the occasionally extreme variability of *E. coli* results, these results have been summarised as the number of detects for each bore sampled rather than the mean result. These detection counts are presented as point locations with a colour ramp applied to the location icon rather than as contoured maps.

## Data Analysis Method

A revised version of the GDC water quality database was created to handle duplicate and missing data, and the bores of interest were linked to the associated sampled aquifer. The parameters of interest that were evaluated were:

- 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 $O_2$), and
- *E. coli* (CFU/100mL).

Sample results reported as non-detects were assigned a value equivalent to half of the detection limit, with the exception of *E. coli*. The data were then imported into a Microsoft Access database, where a series of criteria were applied for interpretation purposes:

- Results where the following identification fields were missing were removed: GDC Bore ID, Date, Easting, Northing, or assigned Aquifer (bores are tapping an unknown aquifer).
- Each parameter was filtered to include only distinct, non-null values.
- Each parameter was grouped into bidecadal periods of 1980-1999 and 2000-2022, inclusive, with results outside these periods excluded from the analysis.
- For each bore, by parameter and bidecadal period, the average value, rounded to 2 decimal places, and the count of sample results were calculated.

- Finally, bidecadal results by parameter and bore were filtered to only include sample counts ≥ 10, such that the calculated average values were from at least 10 sample results for that bidecadal period and parameter.

- Since the contouring of the average results was not appropriate for *E. coli*, as sample results might vary as widely as 0 and 5400 CFU/100mL, the count of positive detections was used in place of average value.

Iron (dissolved) and Manganese (dissolved) were evaluated to help assess the groundwater redox state. However, insufficient data for these parameters meant that only a few maps could be generated for these results. For the purposes of this report, Iron (Total) and Manganese (Total) were evaluated instead of Iron (Dissolved) and Manganese (Dissolved). On review, it appears that the values recorded under these two (total) parameters may be inconsistently allocated. WGA recommends that GDC review the historical database entries for these parameters and confirm that values entered as total concentrations are totals rather than dissolved concentrations.

**Geospatial Analysis**

After the data analysis was completed, as described above, the spatial distribution of water quality results were mapped. All mapping uses the New Zealand Transverse Mercator coordinate system, and heat maps of the contoured datasets are displayed at a scale of 1:175,000. Bidecadal maps of 1980-1999 and 2000-2022 are displayed side by side for each parameter and aquifer where sufficient data available for at least one of these time periods.

Bores were symbolised by water quality result. The Jenks Natural Breaks classification and the data distribution were used to inform assignment of data ranges for each parameter along the full range of results (across aquifers and time periods). Contouring was conducted across the full range of data, with the trends being both interpolated between sampled points and extrapolated out to the full extent of the relevant aquifers. Individual standardised heat maps were produced for each parameter, aquifer, and bidecadal period.

Concentration trend analysis was conducted using the Topo to Raster method based on the average result value as a point elevation. The result trends were extrapolated to the extent of the relevant aquifer, and subsequently again masked to that boundary.

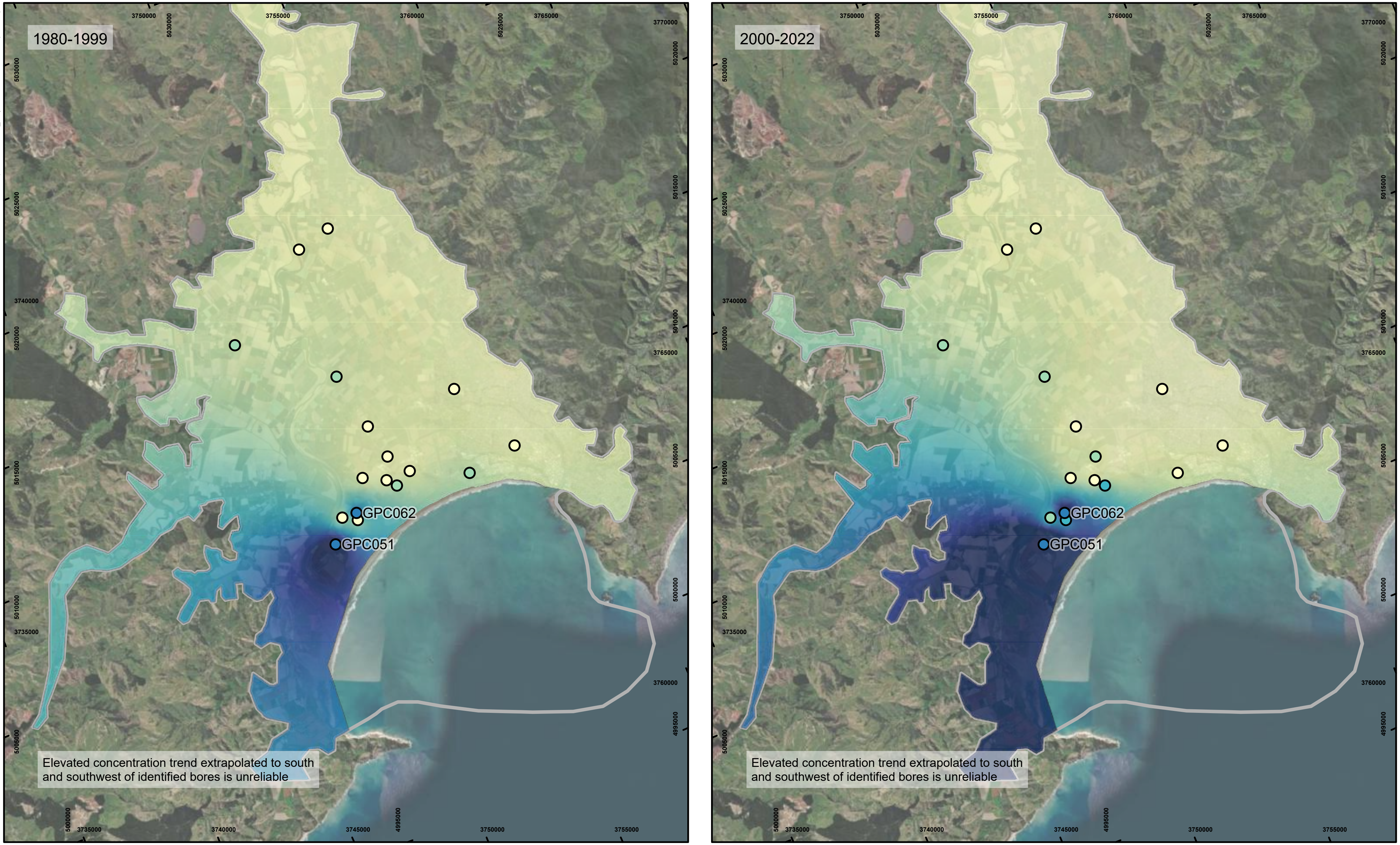
For the purpose of mapping water quality in the shallow aquifers, the Te Hapara Sand Aquifer and Shallow Fluvial Gravel Aquifer were combined into a single map representing the shallow groundwater system. The extent of the shallow system was set to the groundwater numerical model boundary.

In instances where there were insufficient data to produce an interpolated water quality surface (less than five sites with sufficient results), the maps show point data only. Likewise, where no site met the data criteria (at least 10 results for a given parameter, aquifer and bidecadal period), a map was prepared only if there was a matching map presenting data for the other time period, and a note has been added to the maps to this effect. For *E. coli* and Dissolved Oxygen, there were no data by any criteria for the 1980-1999 period, so this was noted as well. In the cases where no data met these criteria for either bidecadal period, no maps have been produced.

**Summary**

The heat maps presented in this appendix show interpreted lateral distributions of groundwater quality by parameter, aquifer, and bidecadal period. They are intended to provide an indication of changes in water quality distributions across the aquifers underlying Poverty Bay Flats. The maps do not provide a detailed representation of groundwater quality at specific positions within the various aquifers. Even at specific monitored bore locations the maps simply represent average values or detection counts over 20-year periods. Where there are a small number of data points with valid results following the selection procedure described above, the interpolated or extrapolated water quality trends may indicate higher or lower values than would be expected in reality.

The maps representing the shallow aquifers take no specific account of the interaction between groundwater and surface water bodies such as the Waipaoa River. In areas where groundwater recharge from surface water bodies takes place, it may reasonably be expected that the groundwater would be of different quality compared to areas where the recharge is entirely through distributed surface recharge.





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Chloride Cl (mg/L)
- > 500
- 200 - 500
- 100 - 200
- 50 - 100
- < 50

Heat Map (mg/L)
- 630
- 10

Model Extent

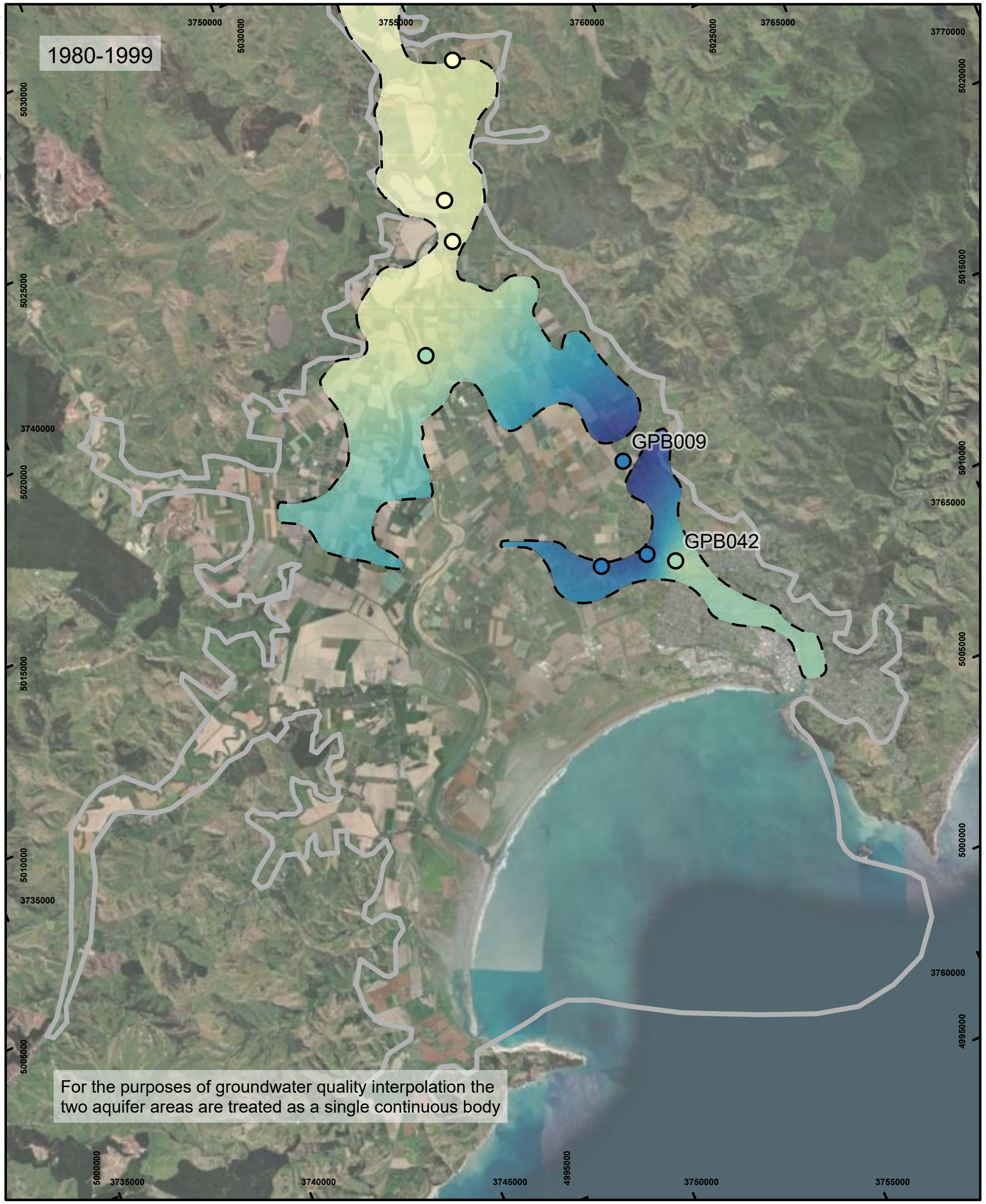
WGA

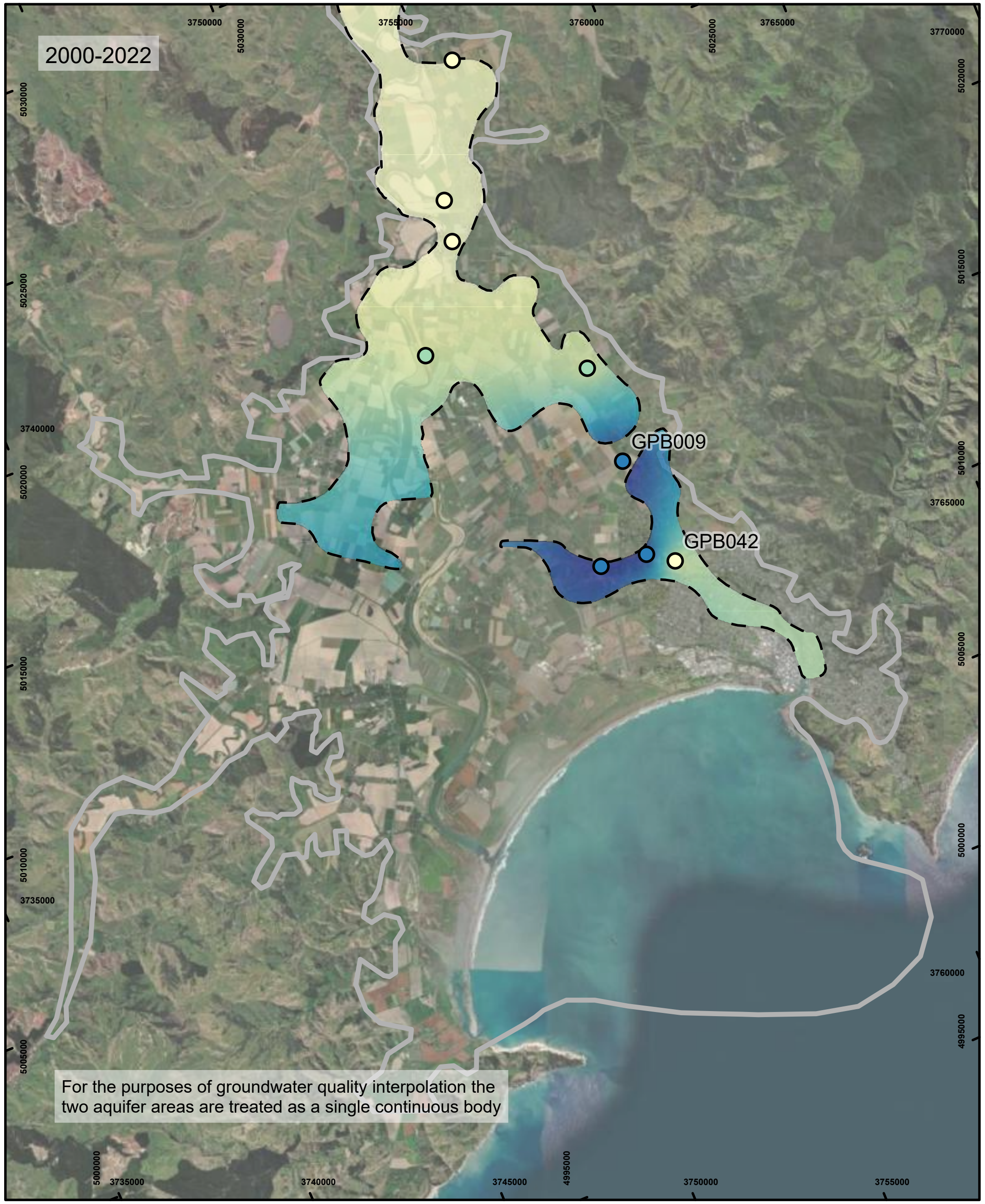
WALLBRIDGE GILBERT AZTEC

Figure **C1**

Gisborne MAR Model

Groundwater Quality Heat Maps - Chloride Cl (mg/L) in Shallow System





N

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Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Chloride Cl (mg/L)
- > 500
- 200 - 500
- 100 - 200
- 50 - 100
- < 50

Heat Map (mg/L)
- 515
- 10

Waipaoa Aquifer

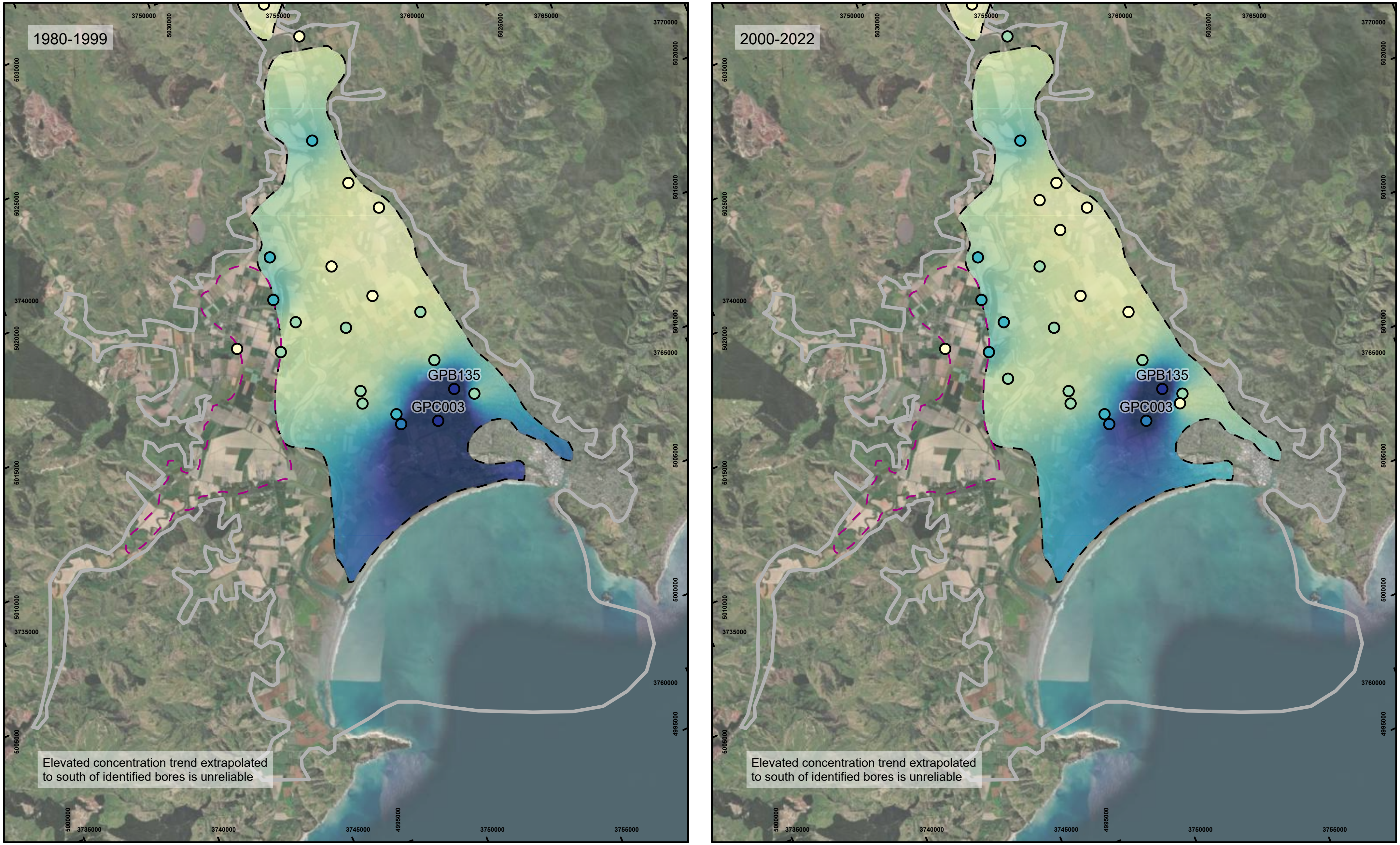
Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C2**

Gisborne MAR Model

Groundwater Quality Heat Maps - Chloride Cl (mg/L) in the Waipaoa Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Chloride Cl (mg/L)
- > 500
- 200 - 500
- 100 - 200
- 50 - 100
- < 50

Heat Map (mg/L)
- 515
- 10

Western Saline Area

Makauri Aquifer

Model Extent

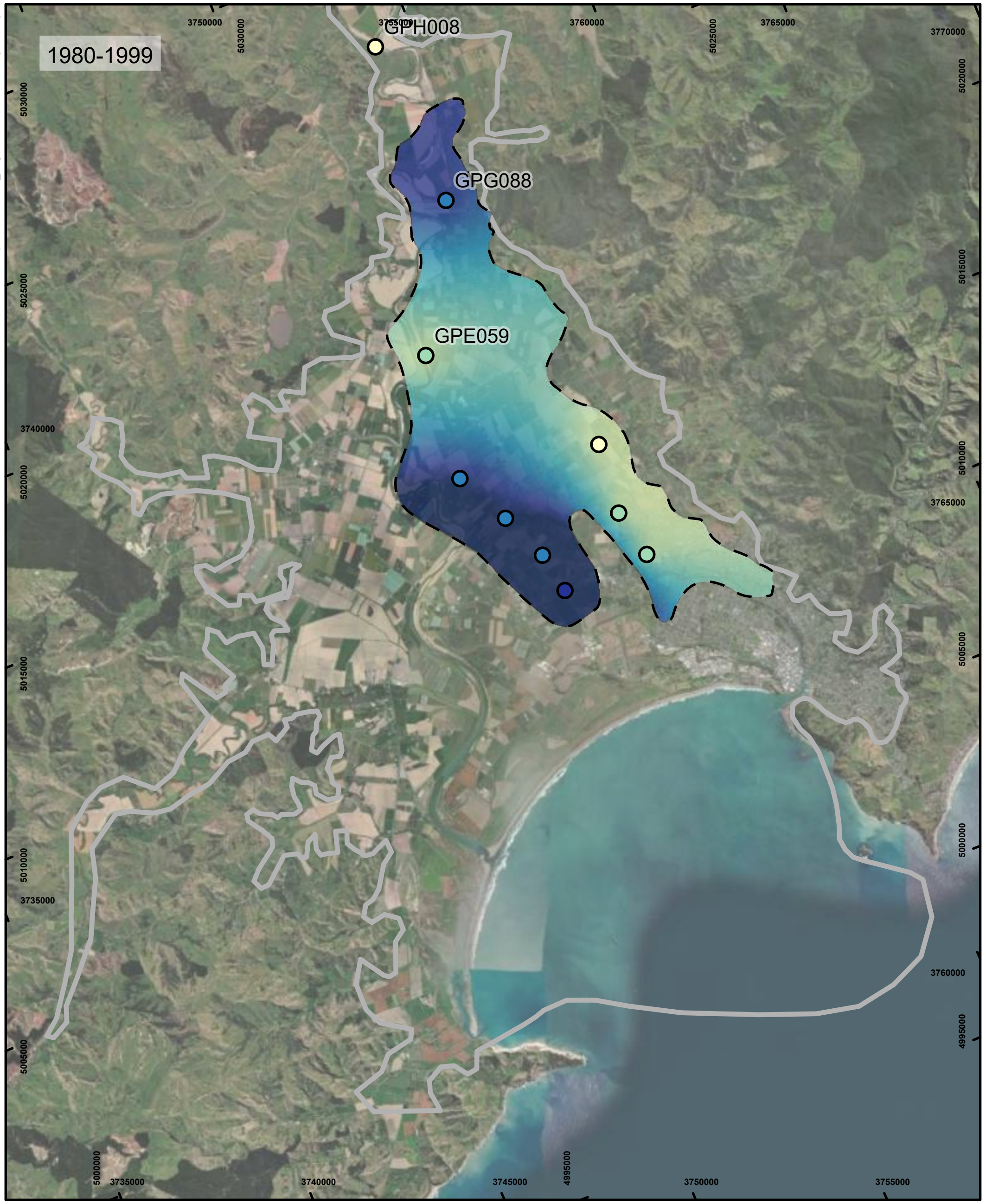
WGA

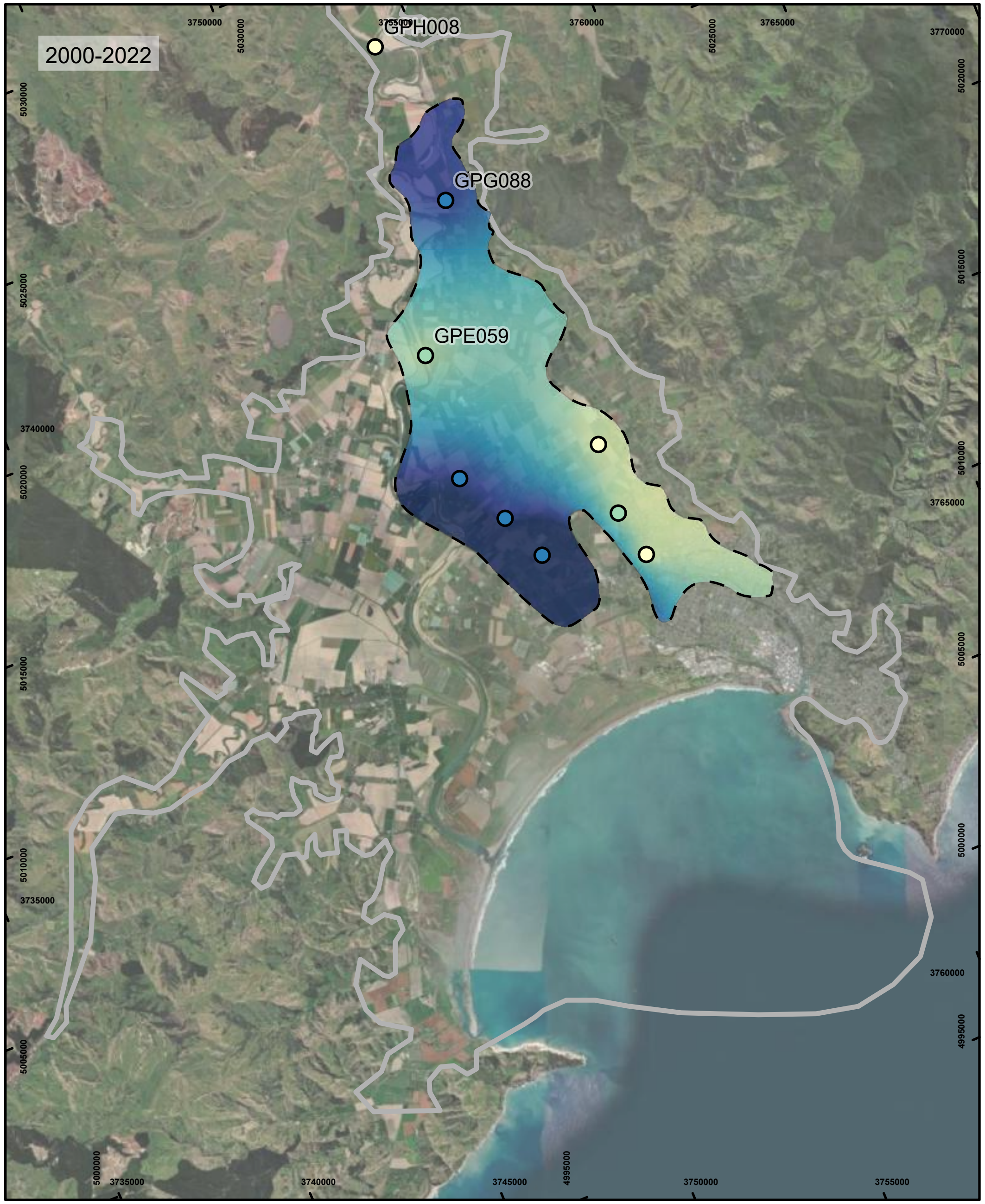
WALLBRIDGE GILBERT AZTEC

Figure **C3**

Gisborne MAR Model

Groundwater Quality Heat Maps - Chloride Cl (mg/L) in the Makauri Aquifer





0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Chloride Cl (mg/L)
- > 500
- 200 - 500
- 100 - 200
- 50 - 100
- < 50

Heat Map (mg/L)
- 630
- 10

Matokitoki Aquifer

Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C4**

Gisborne MAR Model

Groundwater Quality Heat Maps - Chloride Cl (mg/L) in the Matokitoki Aquifer




Scale 1:175,000 @ 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**

Ammoniacal Nitrogen As N (mg/L)

- > 8
- 5 - 8
- 2 - 5
- 1 - 2
- < 1

Heat Map (mg/L)

- 14
- 0

Model Extent

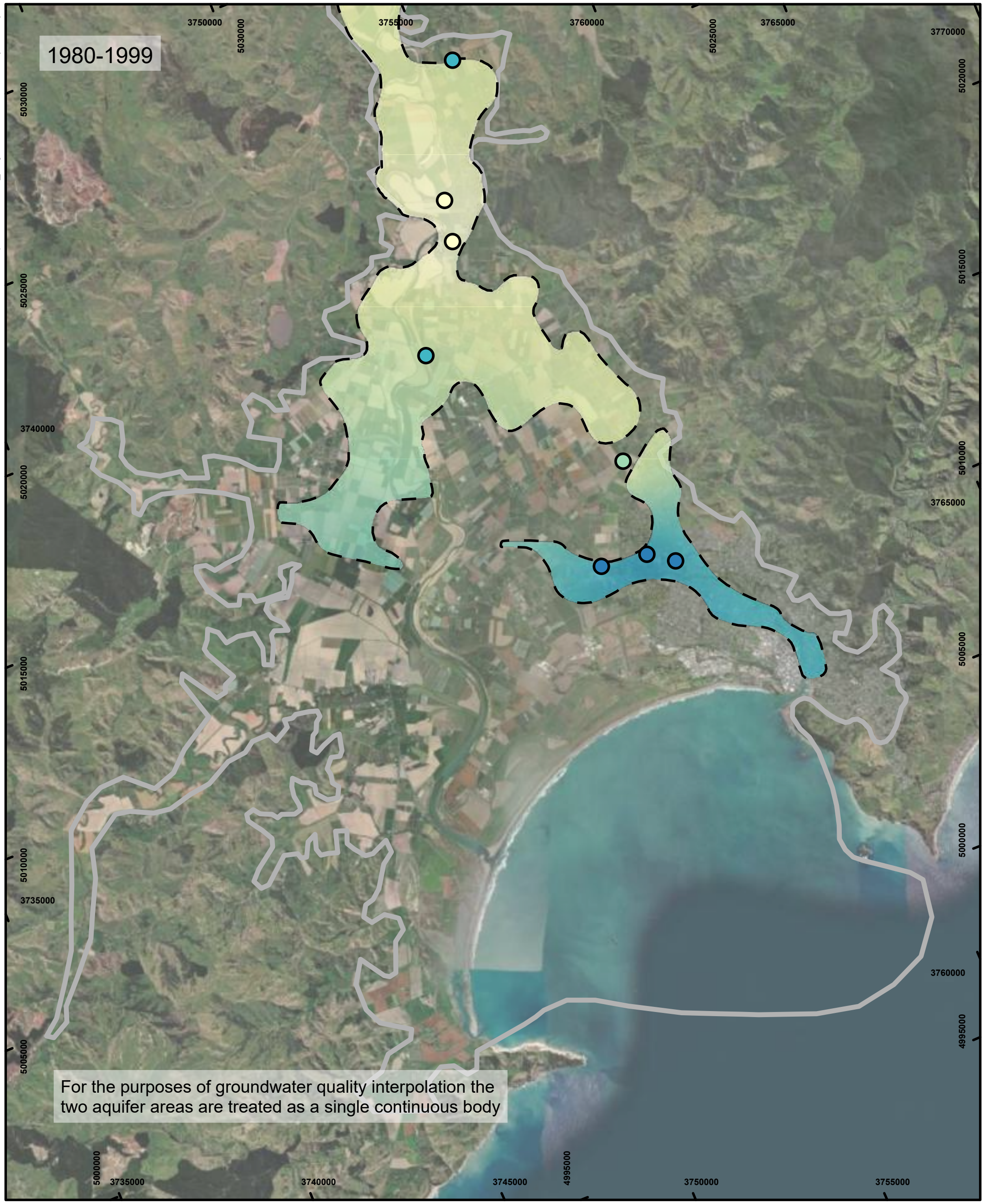
WGA

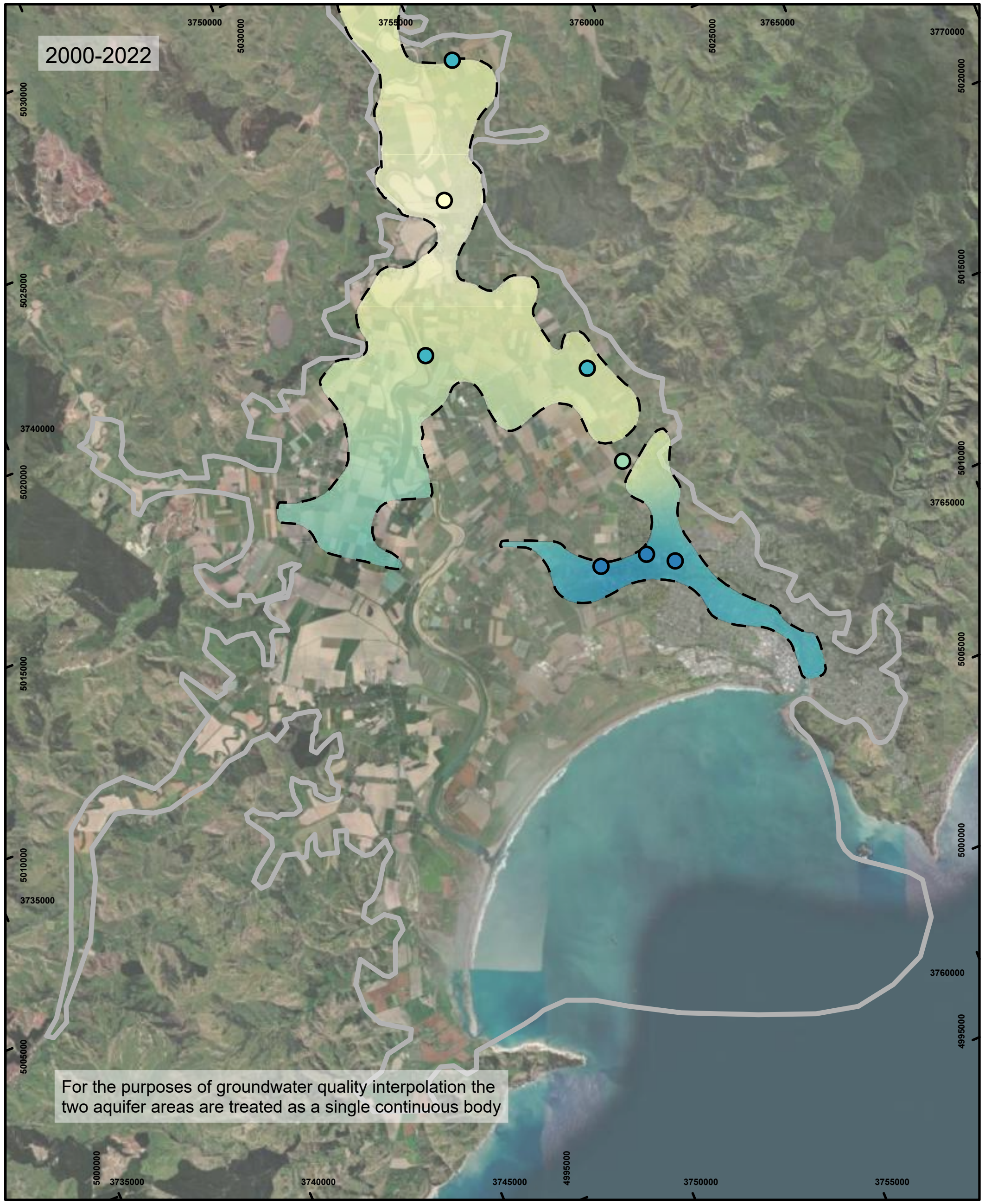
WALLBRIDGE GILBERT AZTEC

Figure C5

Gisborne MAR Model

Groundwater Quality Heat Maps - Ammoniacal Nitrogen As N (mg/L) in the Shallow System





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Scale 1:175,000 @ 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**

Ammoniacal Nitrogen As N (mg/L)
- > 8
- 5 - 8
- 2 - 5
- 1 - 2
- < 1

Heat Map (mg/L)
- 14
- 0

Waipaoa Aquifer

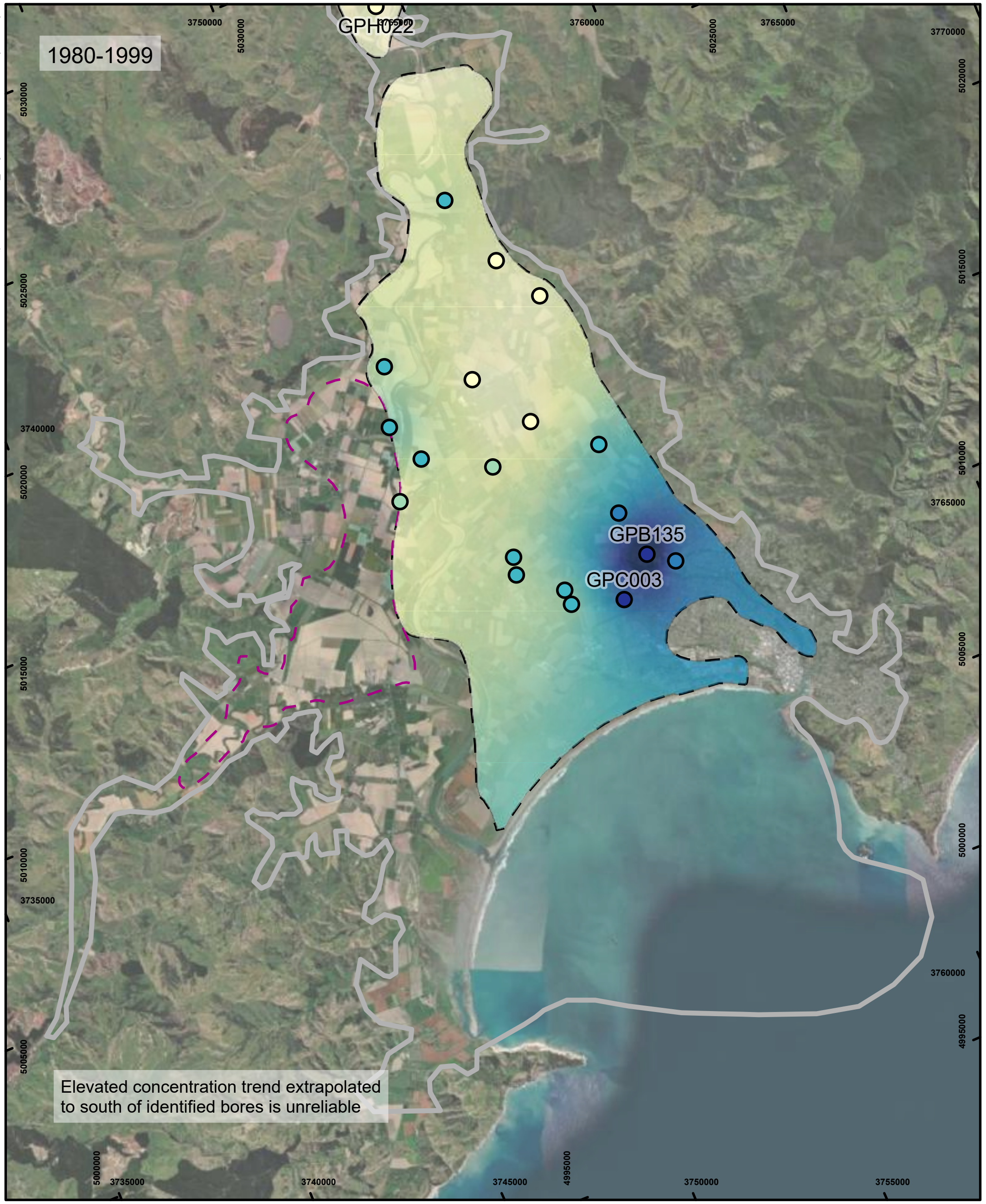
Model Extent

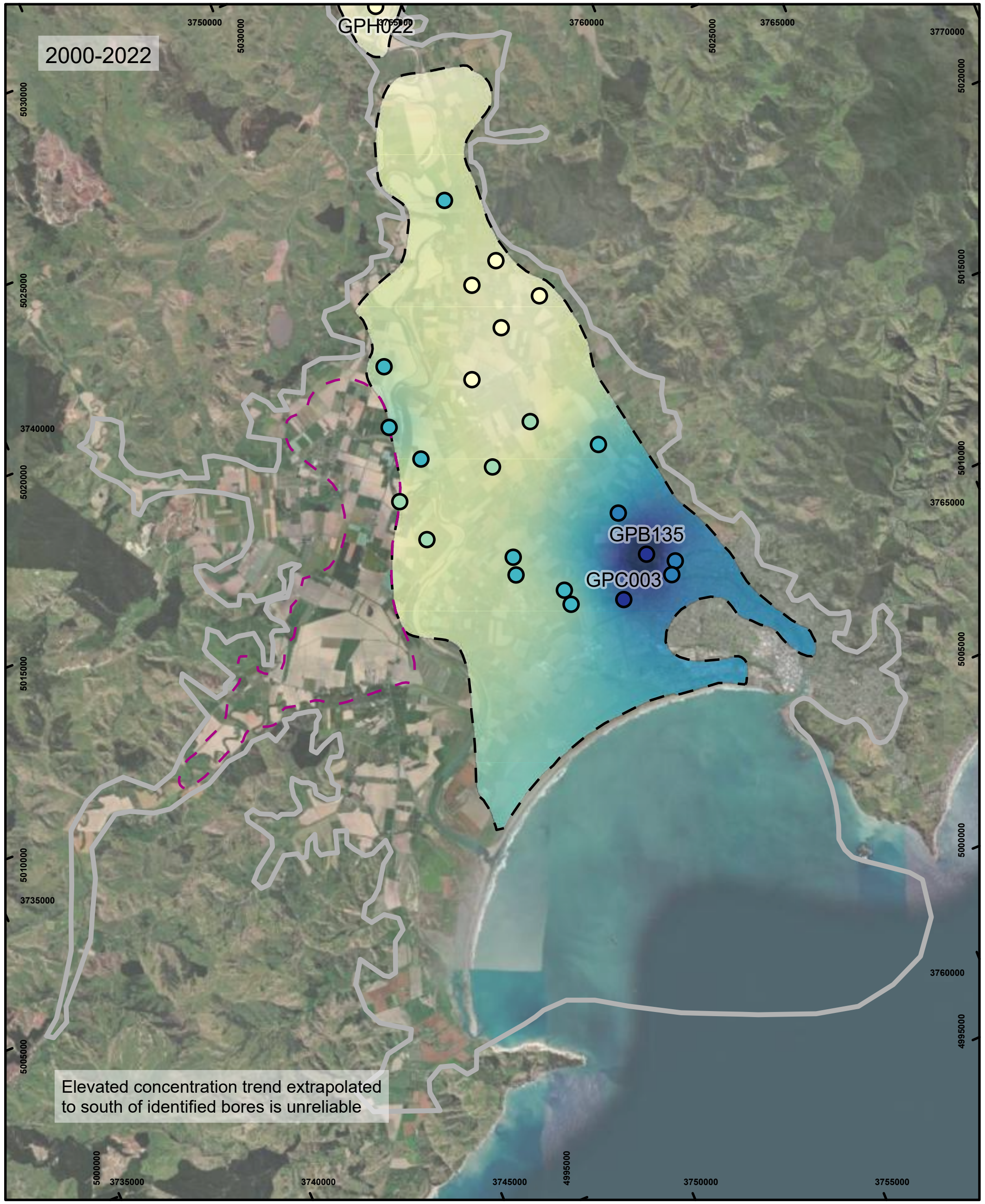
WGA
WALLBRIDGE GILBERT AZTEC

Figure **C6**

Gisborne MAR Model

Groundwater Quality Heat Maps - Ammoniacal Nitrogen As N (mg/L) in the Waipaoa Aquifer





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Scale 1:175,000 @ 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**

Ammoniacal Nitrogen As N (mg/L)
- > 8
- 5 - 8
- 2 - 5
- 1 - 2
- < 1

Heat Map (mg/L)
- 14
- 0

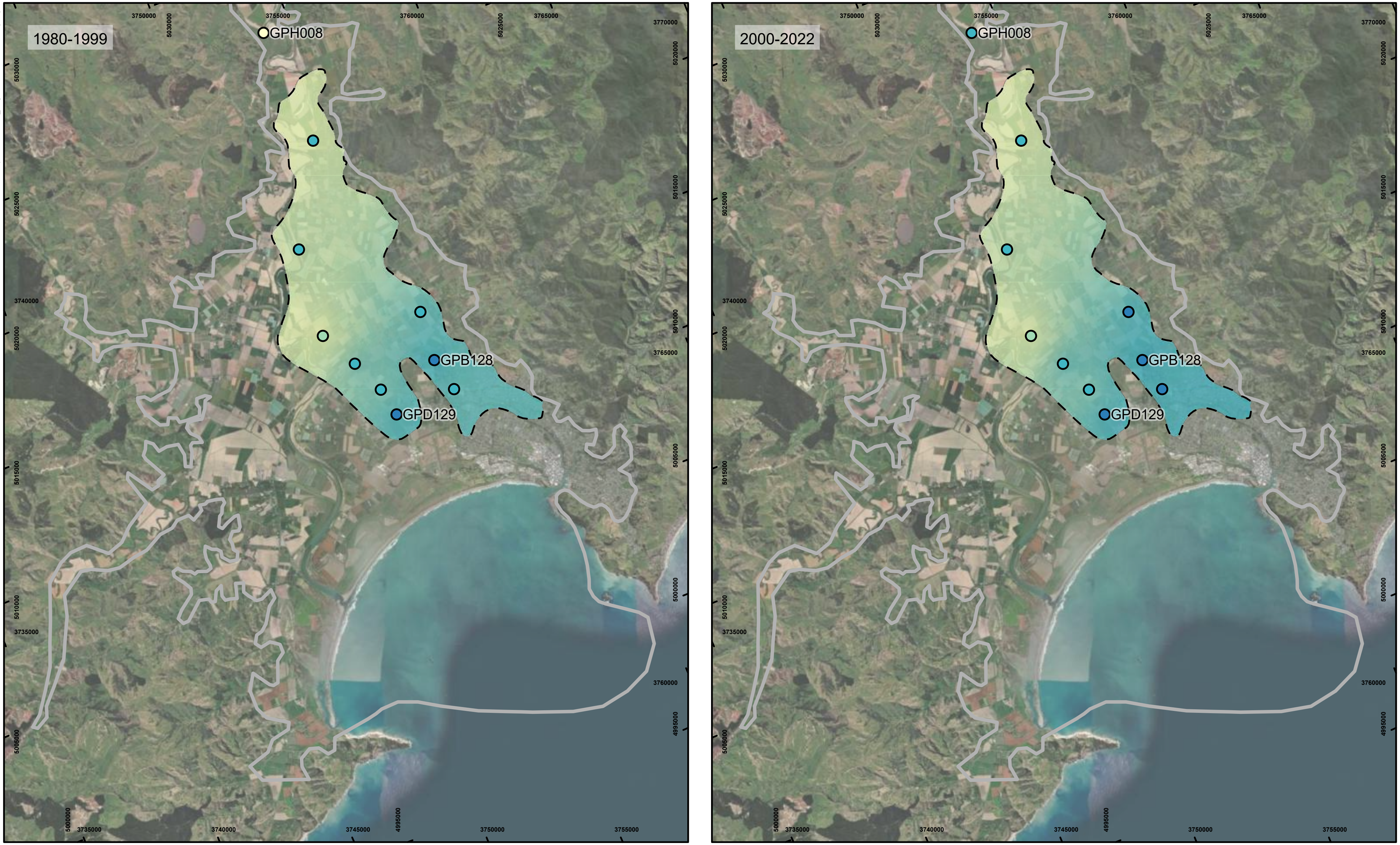
- Western Saline Area
- Makauri Aquifer
- Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C7**

Gisborne MAR Model

Groundwater Quality Heat Maps - Ammoniacal Nitrogen As N (mg/L) in the Makauri Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Ammoniacal Nitrogen As N (mg/L)
- > 8
- 5 - 8
- 2 - 5
- 1 - 2
- < 1

Heat Map (mg/L)
- 14
- 0

Matokitoki Aquifer

Model Extent

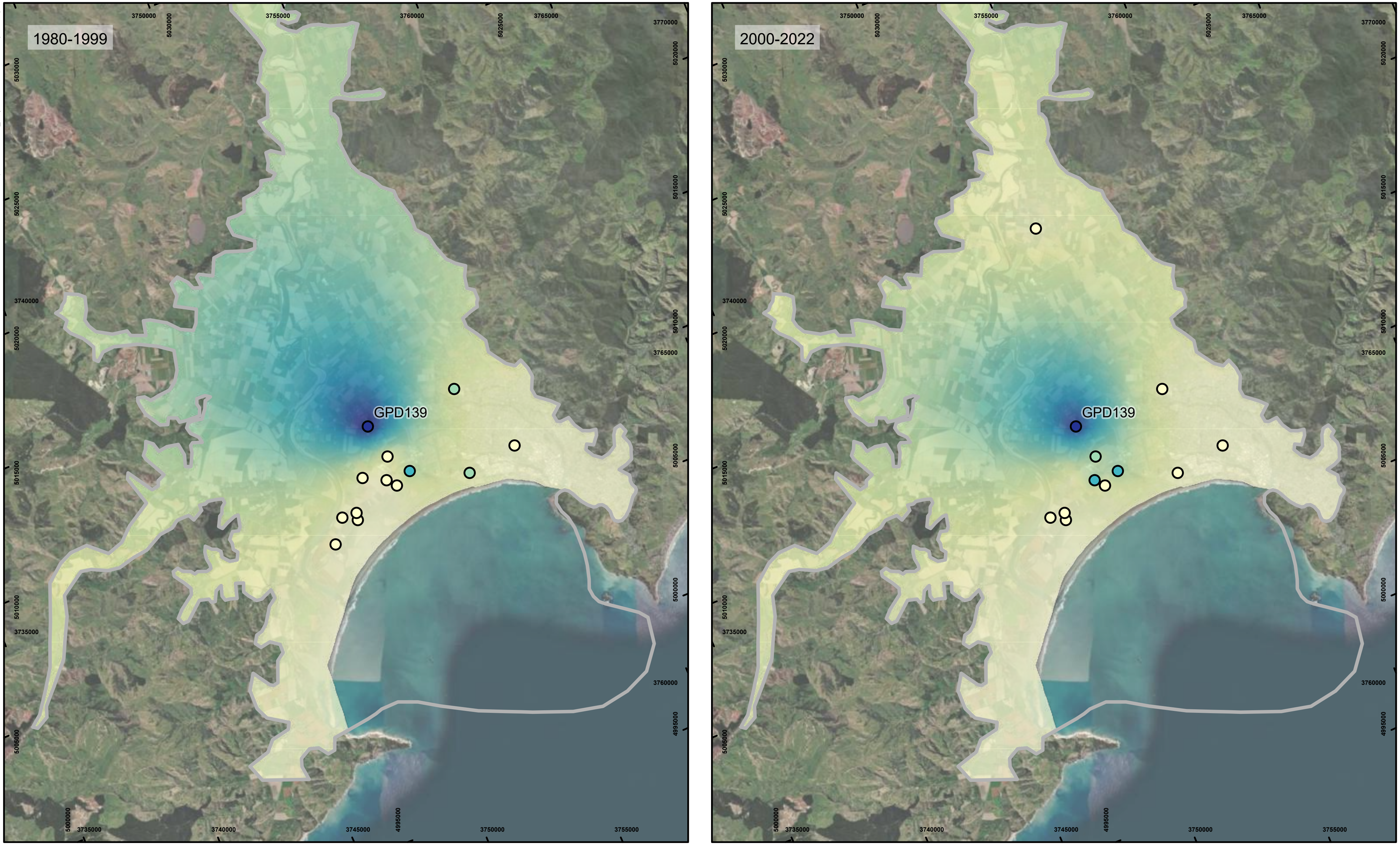
WGA

WALLBRIDGE GILBERT AZTEC

Figure **C8**

Gisborne MAR Model

Groundwater Quality Heat Maps - Ammoniacal Nitrogen As N (mg/L) in the Matokitoki Aquifer





N
0 1,000 2,000 3,000 4,000 m
Scale 1:175,000 @ 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**

Nitrate As N (mg/L)
- > 2
- 1 - 2
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

Heat Map (mg/L)
- 3.4
- 0

Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C9**
Gisborne MAR Model
Groundwater Quality Heat Maps - Nitrate As N (mg/L) in the Shallow System

Document Path: C:\Users\MJaspar\Documents_Projects\GDC WQ\Heat Maps IDs.aprx




N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Nitrate As N (mg/L)
- > 2
- 1 - 2
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

Waipaoa Aquifer

Model Extent

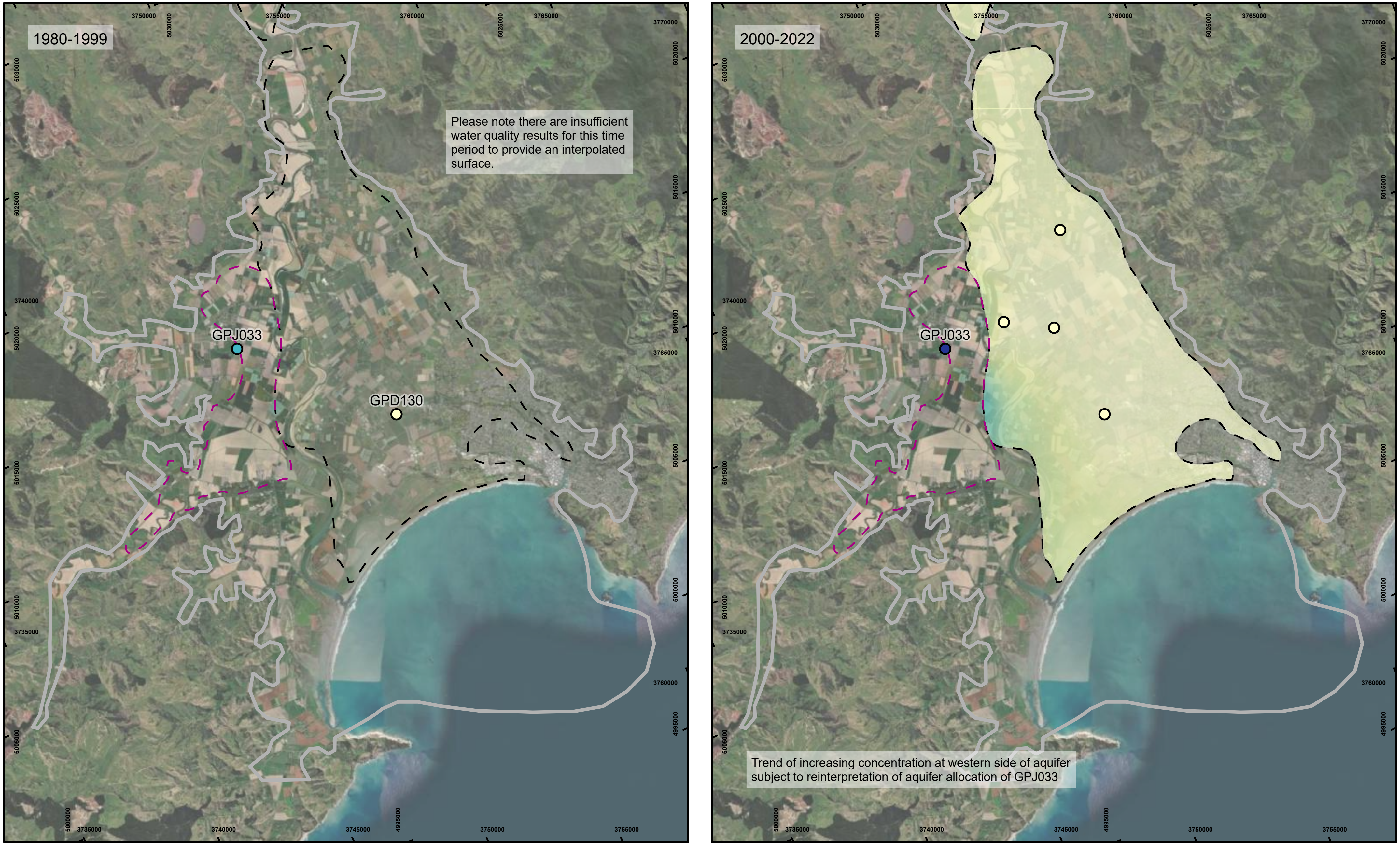
WGA

WALLBRIDGE GILBERT AZTEC

Figure **C10**

Gisborne MAR Model

Groundwater Quality Heat Maps - Nitrate As N (mg/L) in the Waipaoa Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Nitrate As N (mg/L)
- > 2
- 1 - 2
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

Heat Map (mg/L)
- 3.4
- 0

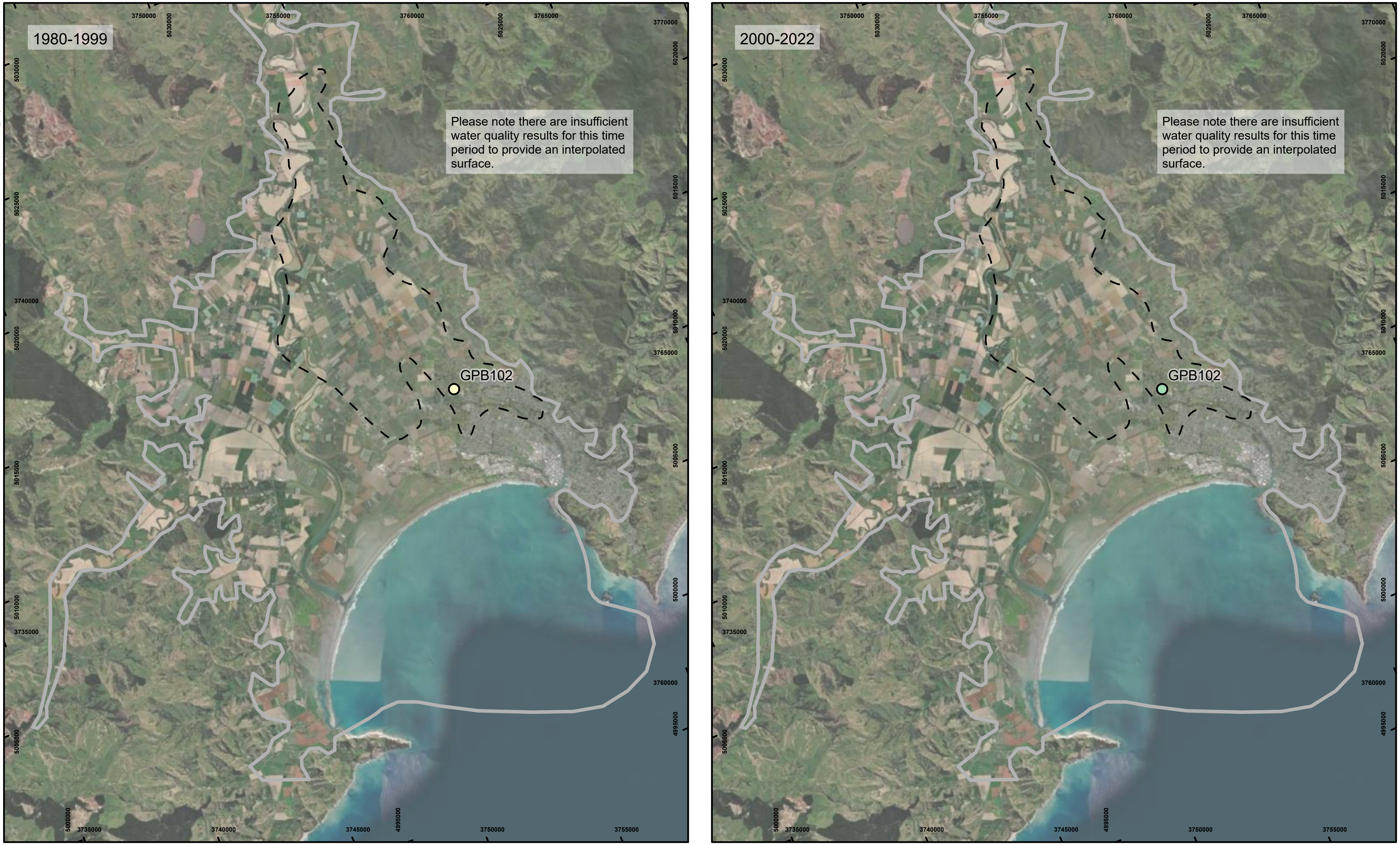
- Western Saline Area
- Makauri Aquifer
- Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C11**

Gisborne MAR Model

Groundwater Quality Heat Maps - Nitrate As N (mg/L) in the Makauri Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Nitrate As N (mg/L)
- > 2
- 1 - 2
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

Matokitoki Aquifer

Model Extent

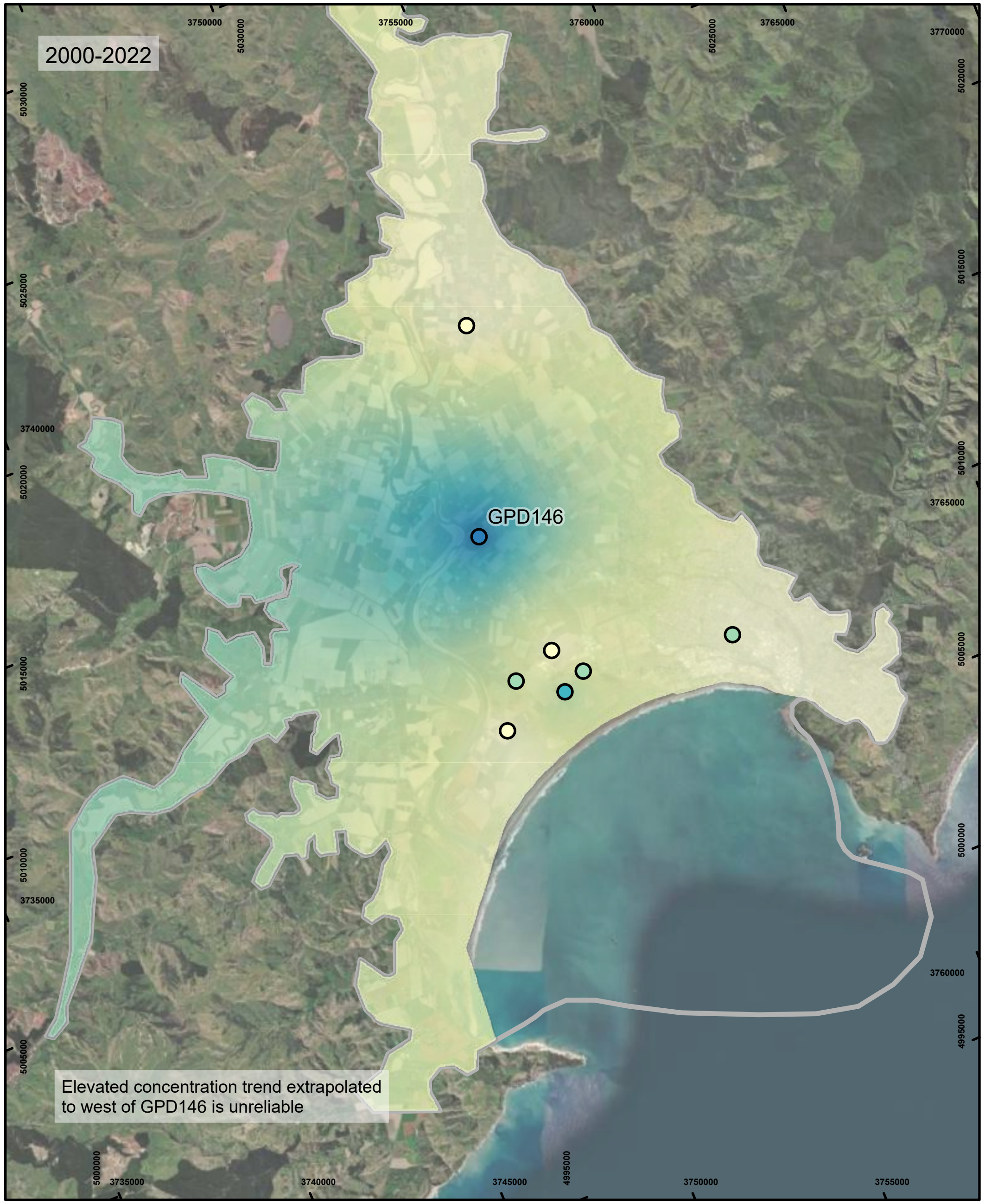
WGA

WALLBRIDGE GILBERT AZTEC

Figure **C12**

Gisborne MAR Model

Groundwater Quality Heat Maps - Nitrate As N (mg/L) in the Matokitoki Aquifer



Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

**LEGEND**

Dissolved Oxygen (g/m3)
- > 6
- 4 - 6
- 2 - 4
- 1 - 2
- < 1

Heat Map (g/m3)
- 8
- 0

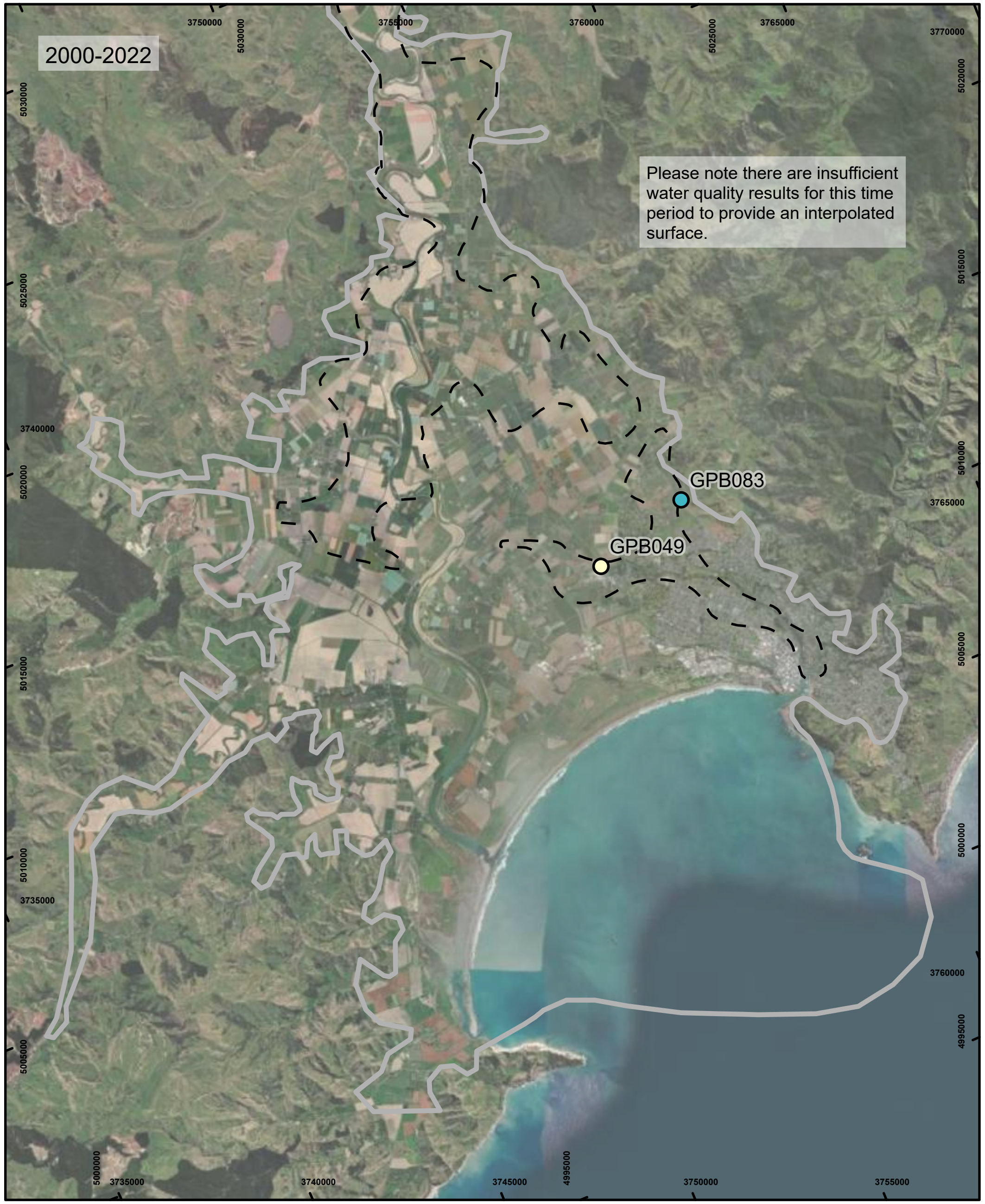
Model Extent

WGA

Figure **C13**

Gisborne MAR Model

Groundwater Quality Heat Maps - Dissolved Oxygen (g/m3) in the Shallow System



N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Dissolved Oxygen (g/m3)
- > 6
- 4 - 6
- 2 - 4
- 1 - 2
- < 1

Waipaoa Aquifer

Model Extent

WGA

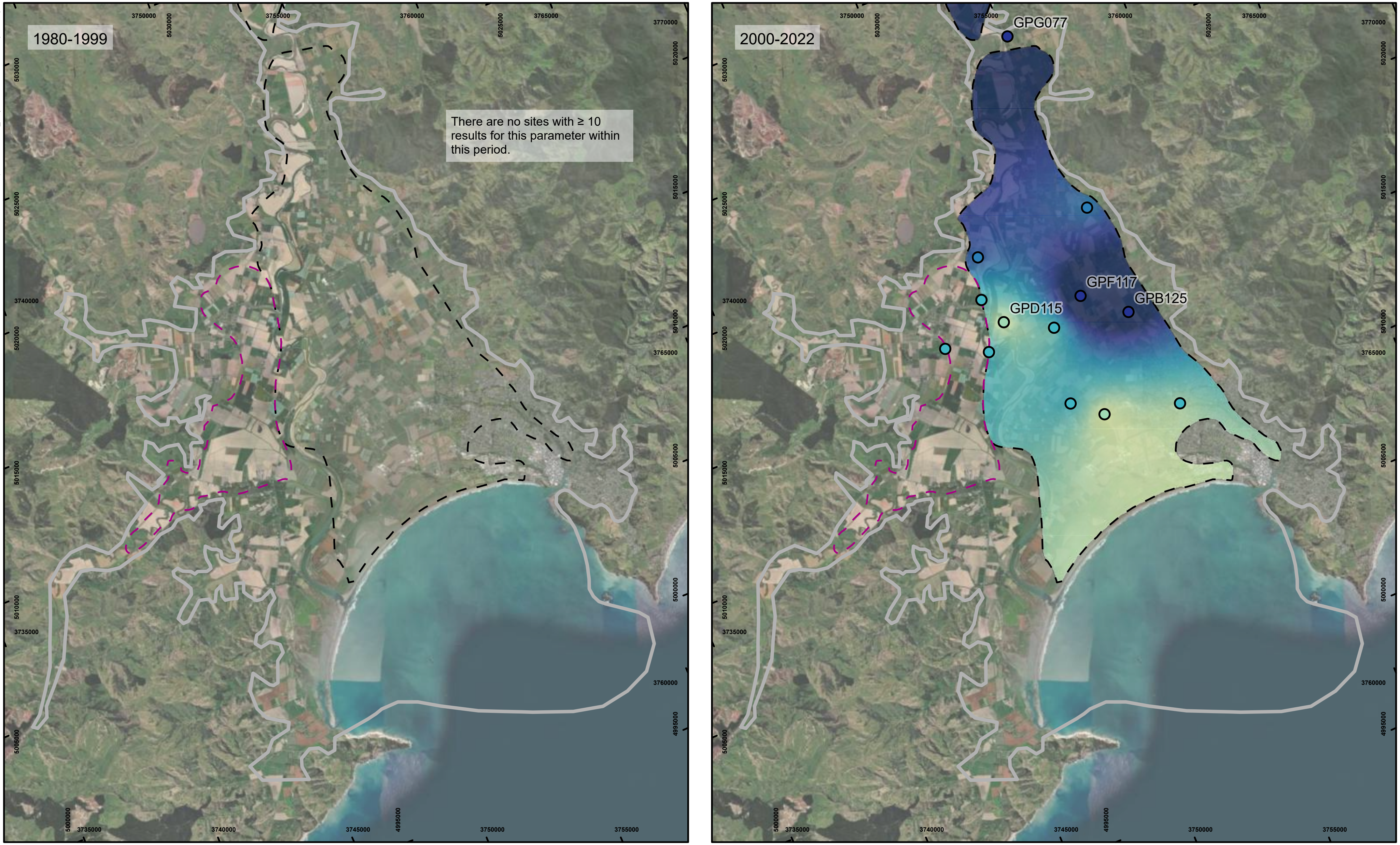
WALLBRIDGE GILBERT AZTEC

Figure **C14**

Gisborne MAR Model

Groundwater Quality Heat Maps - Dissolved Oxygen (g/m3) in the Waipaoa Aquifer

Document Path: C:\Users\MJaspan\Documents_Projects\GDC WQ\Heat Maps.aprx





0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Dissolved Oxygen (g/m3)
- > 6
- 4 - 6
- 2 - 4
- 1 - 2
- < 1

Heat Map (g/m3)
- 8
- 0

- Western Saline Area
- Makauri Aquifer
- Model Extent

WGA

WALLBRIDGE GILBERT AZTEC

Figure **C15**

Gisborne MAR Model

Groundwater Quality Heat Maps - Dissolved Oxygen (g/m3) in the Makauri Aquifer




N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Dissolved Oxygen (g/m3)
- > 6
- 4 - 6
- 2 - 4
- 1 - 2
- < 1

Matokitoki Aquifer

Model Extent

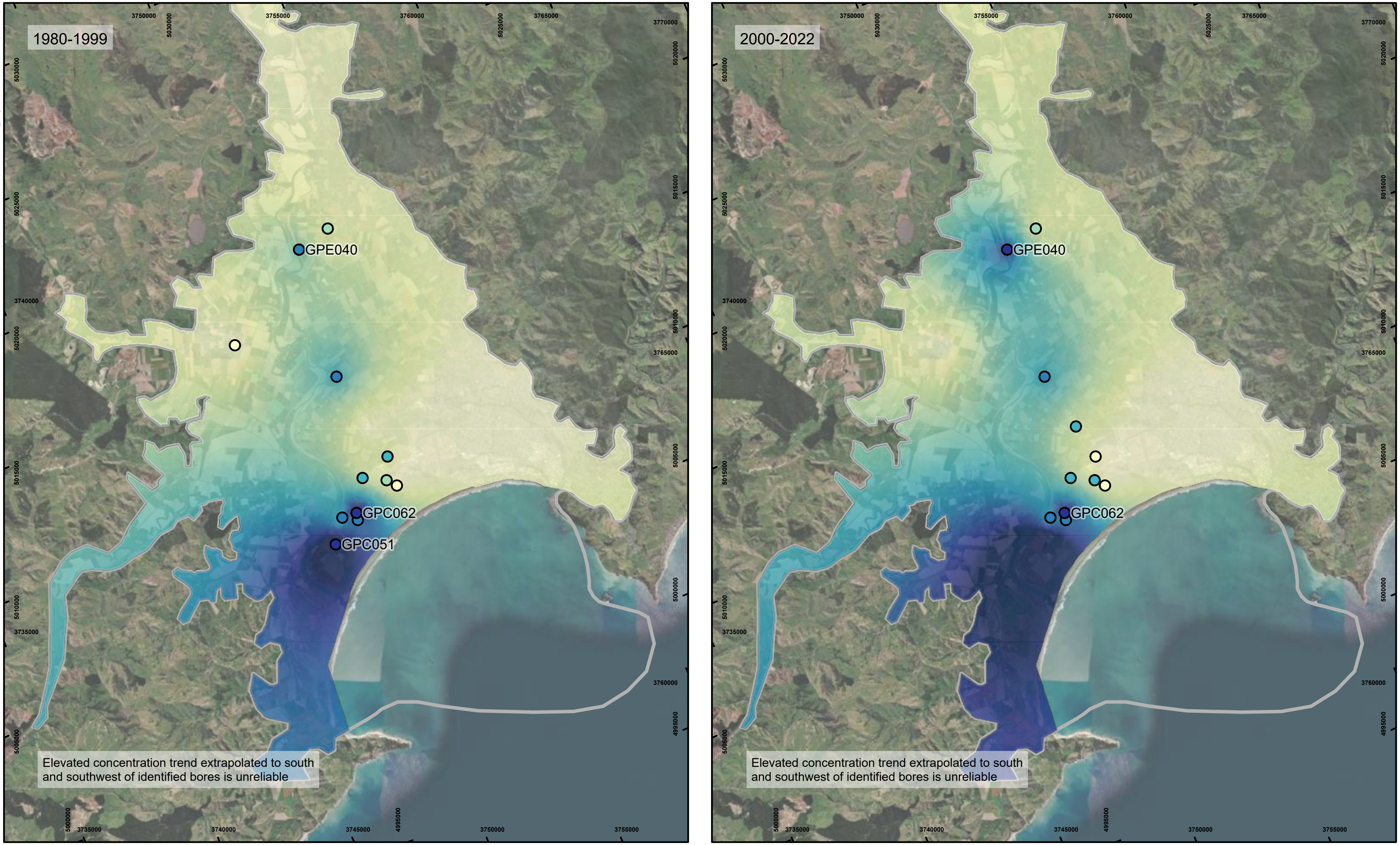
WGA

WALLBRIDGE GILBERT AZTEC

Figure **C16**

Gisborne MAR Model

Groundwater Quality Heat Maps - Dissolved Oxygen (g/m3) in the Matokitoki Aquifer




Document Path: C:\Users\MJaspar\Documents_Projects\GDC WQ\Heat Maps IDs.aprx


N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Iron Total (mg/L)
- > 10
- 5 - 10
- 2 - 5
- 1 - 2
- < 1

Heat Map (mg/L)
- 24
- 0

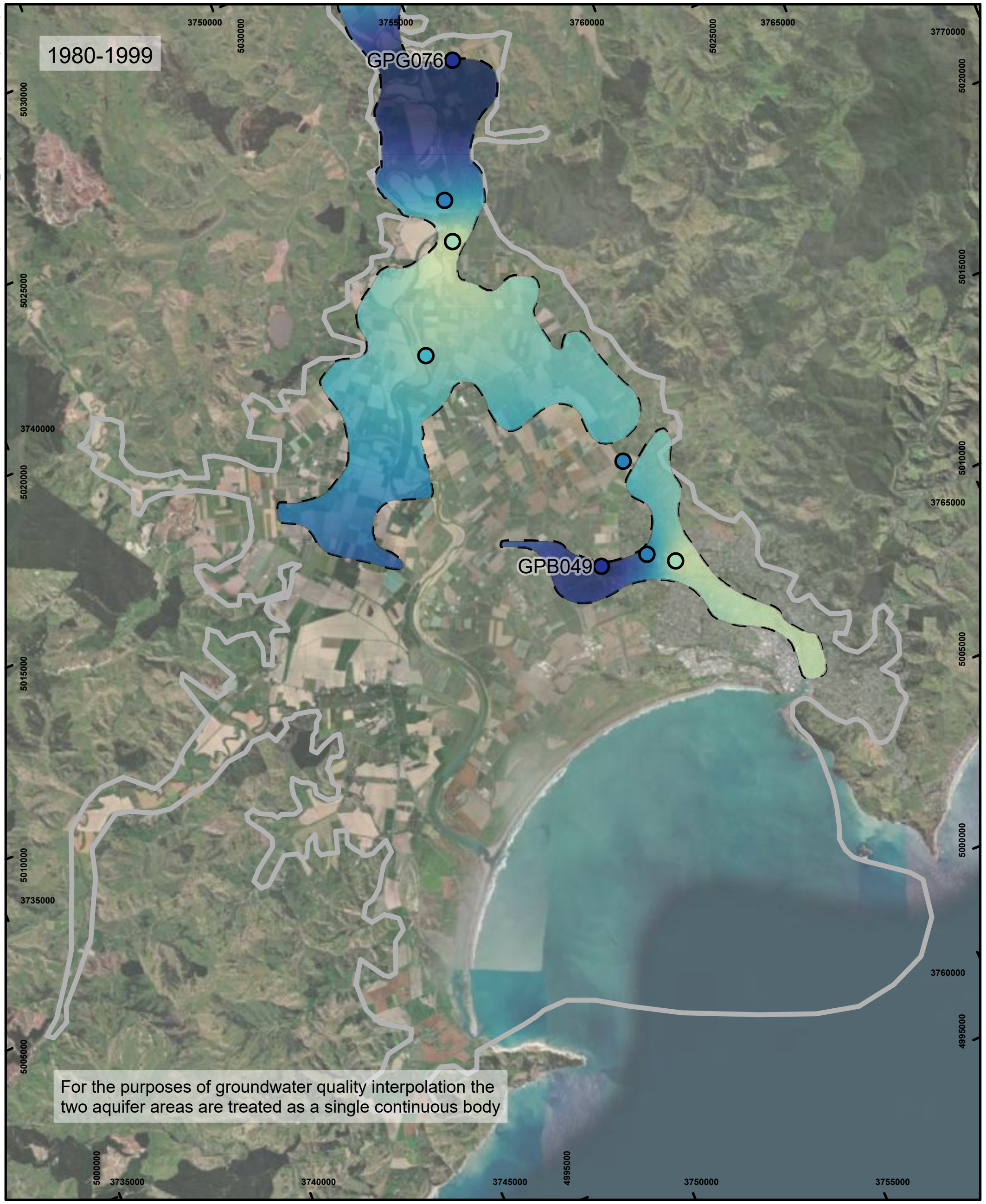
Model Extent

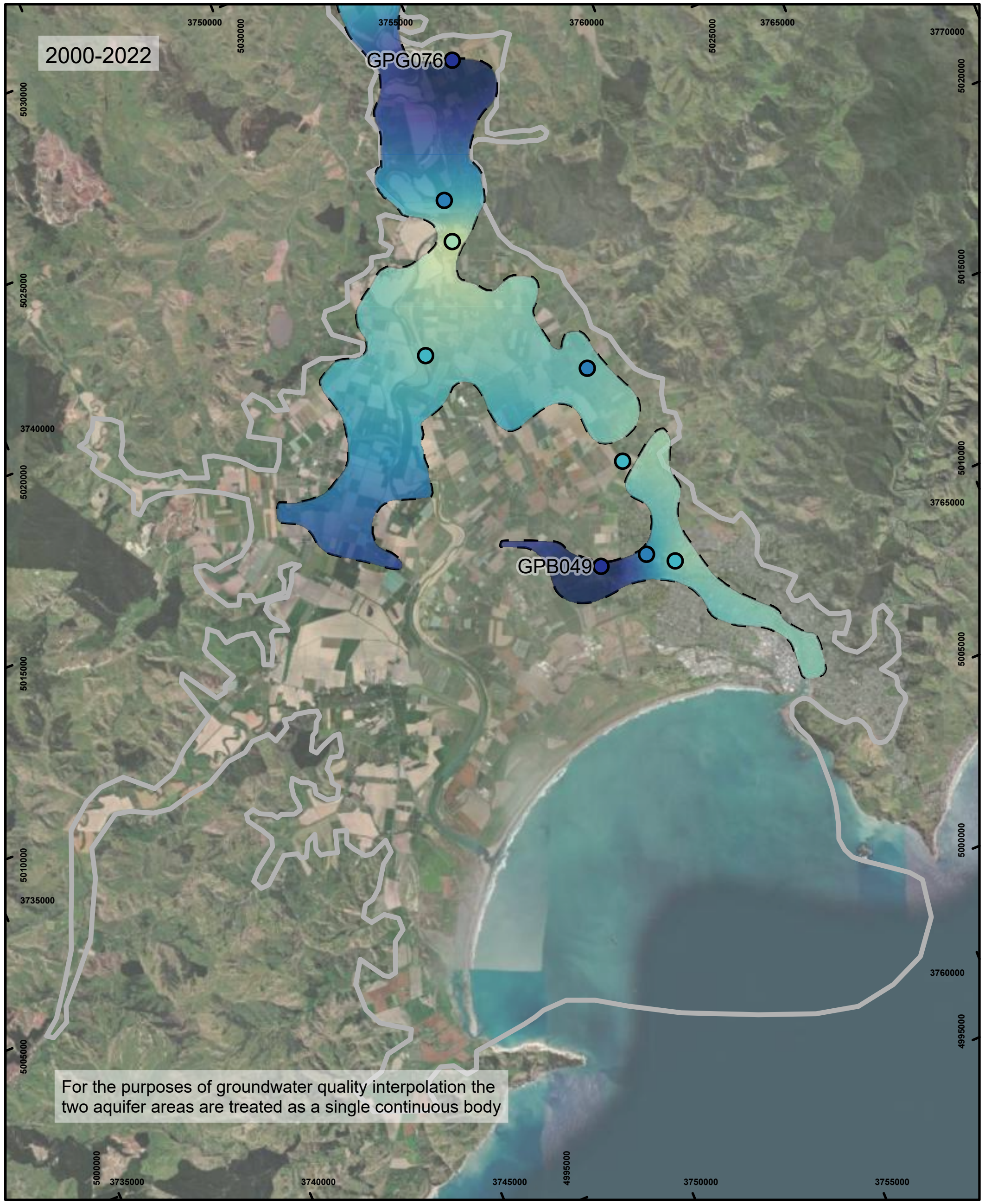
WGA
WALLBRIDGE GILBERT AZTEC

Figure **C17**

Gisborne MAR Model

Groundwater Quality Heat Maps - Iron (Total) (mg/L) in the Shallow System





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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

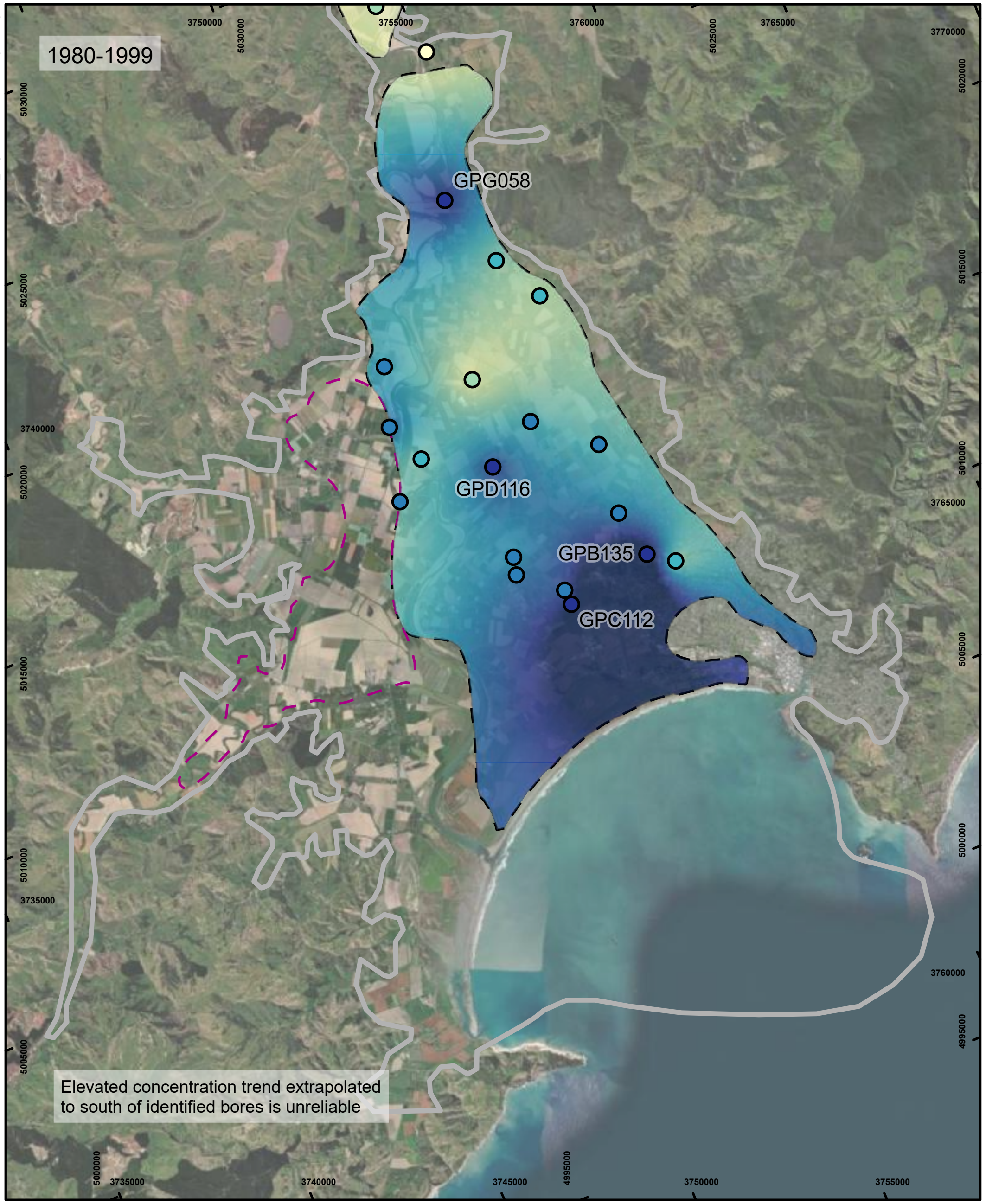
**LEGEND**

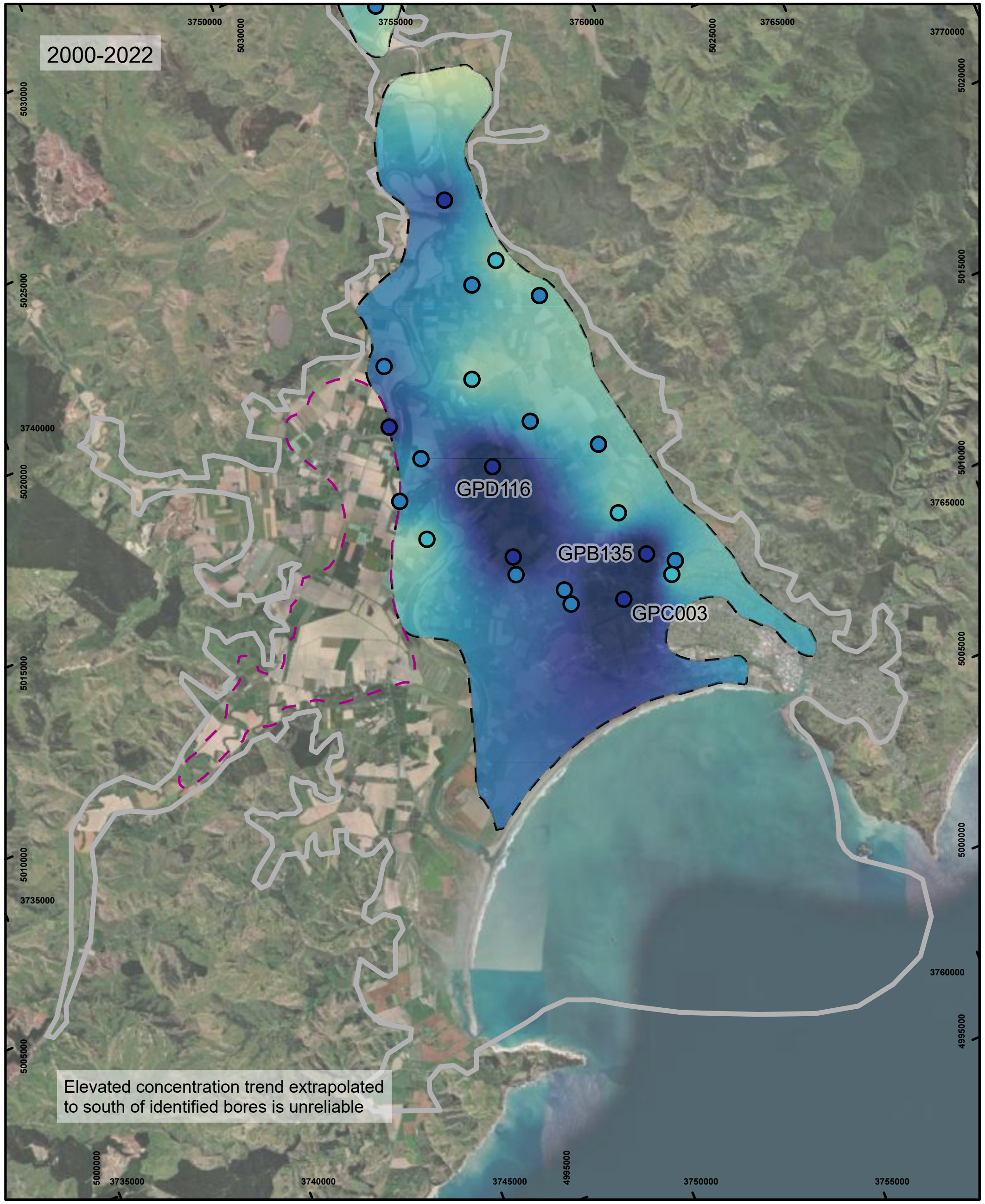
Iron Total (mg/L)
- > 10
- 5 - 10
- 2 - 5
- 1 - 2
- < 1

Heat Map (mg/L)
- 24
- 0
- Waipaoa Aquifer
- Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C18**
Gisborne MAR Model
Groundwater Quality Heat Maps - Iron (Total) (mg/L) in the Waipaoa Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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 reliance 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**

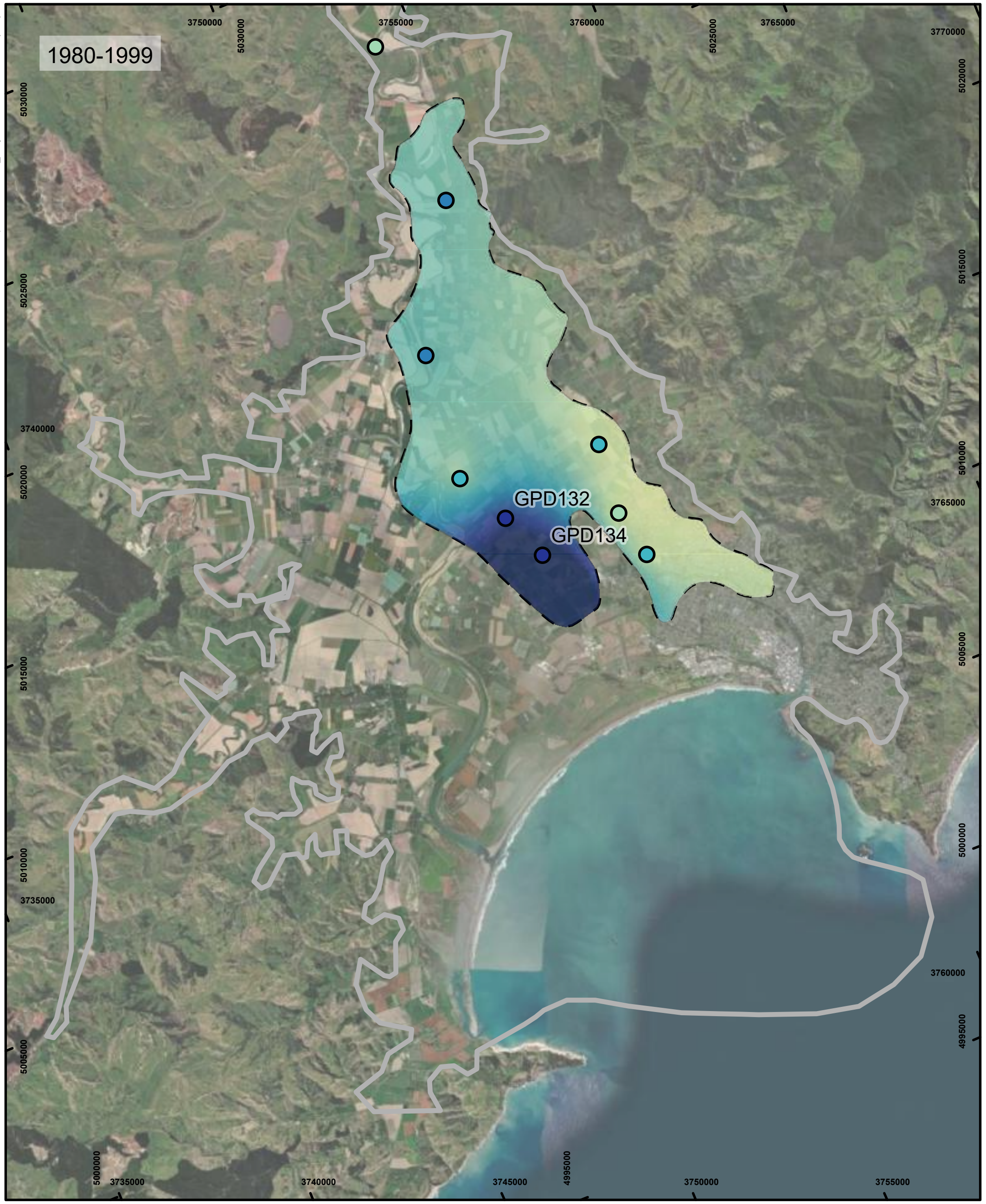
Iron Total (mg/L)
- > 10
- 5 - 10
- 2 - 5
- 1 - 2
- < 1

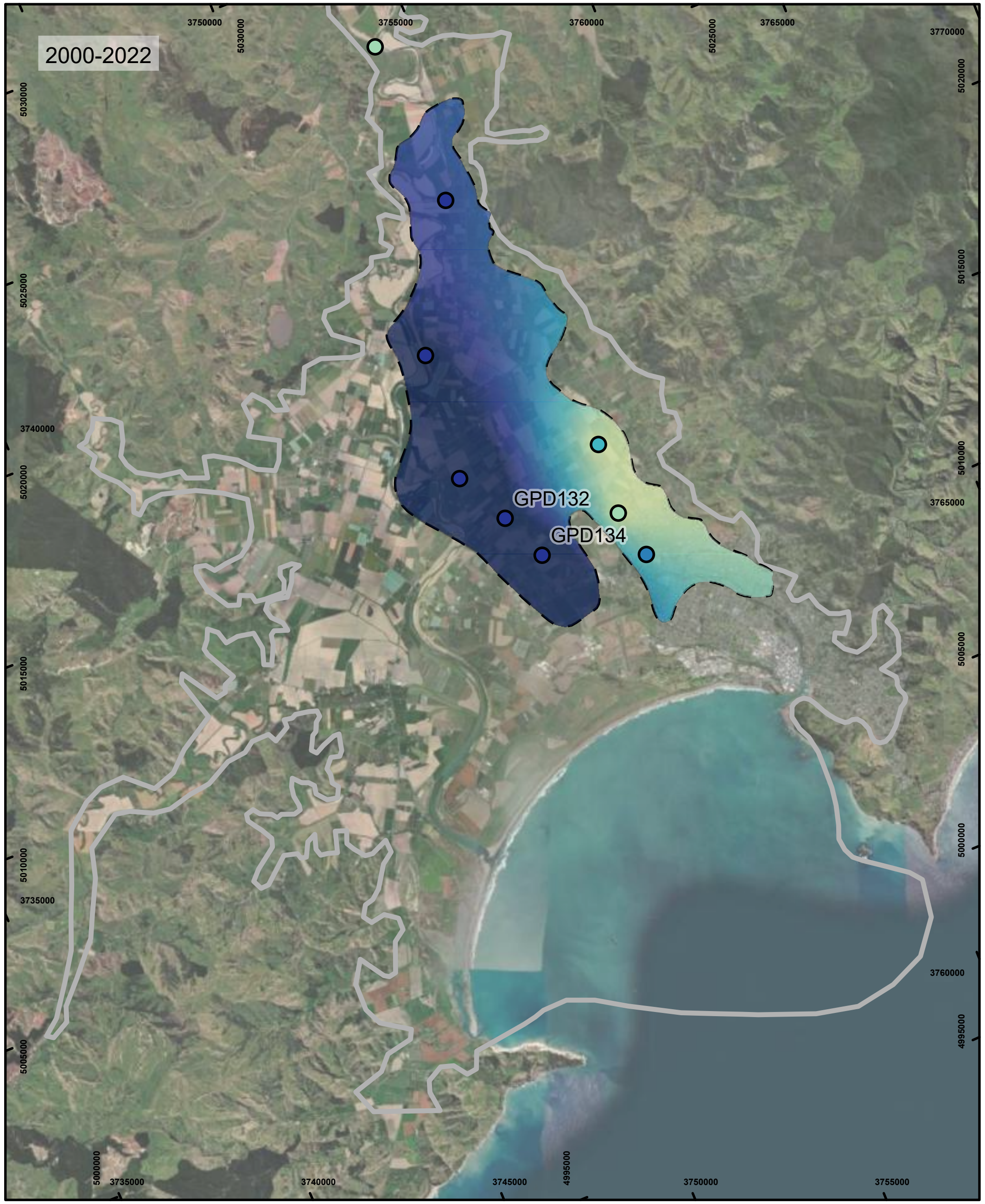
Heat Map (mg/L)
- 24
- 0

- Western Saline Area
- Makauri Aquifer
- Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C19**
Gisborne MAR Model
Groundwater Quality Heat Maps - Iron (Total) (mg/L) in the Makauri Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Iron Total (mg/L)
- > 10
- 5 - 10
- 2 - 5
- 1 - 2
- < 1

Heat Map (mg/L)
- 24
- 0

Matokitoki Aquifer

Model Extent

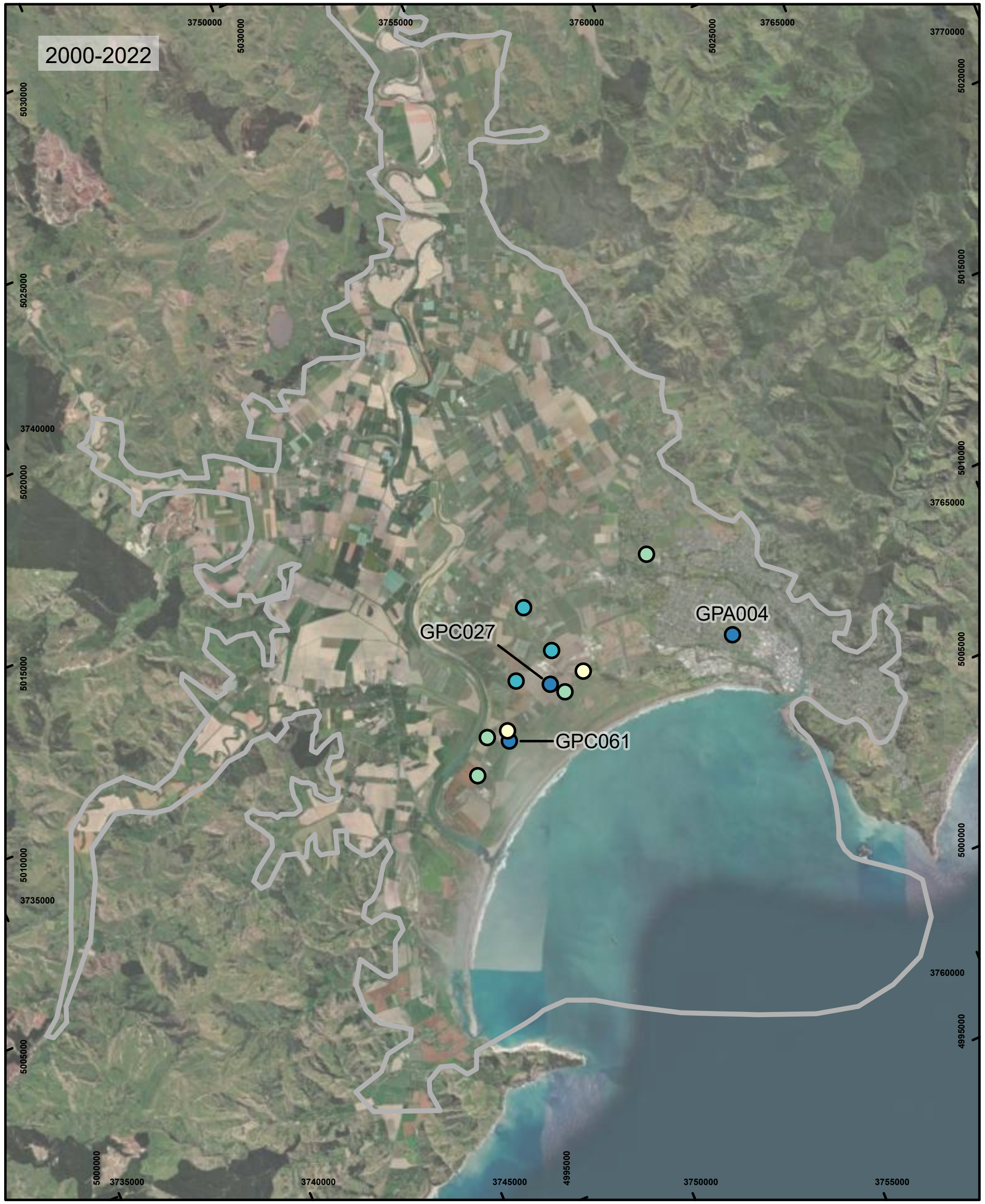
WGA
WALLBRIDGE GILBERT AZTEC

Figure **C20**

Gisborne MAR Model

Groundwater Quality Heat Maps - Iron (Total) (mg/L) in the Matokitoki Aquifer

Document Path: C:\Users\MJaspar\Documents_Projects\GDC WQ\Heat Maps IDs.aprx



N
0 1,000 2,000 3,000 4,000 m
Scale 1:175,000 @ 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**

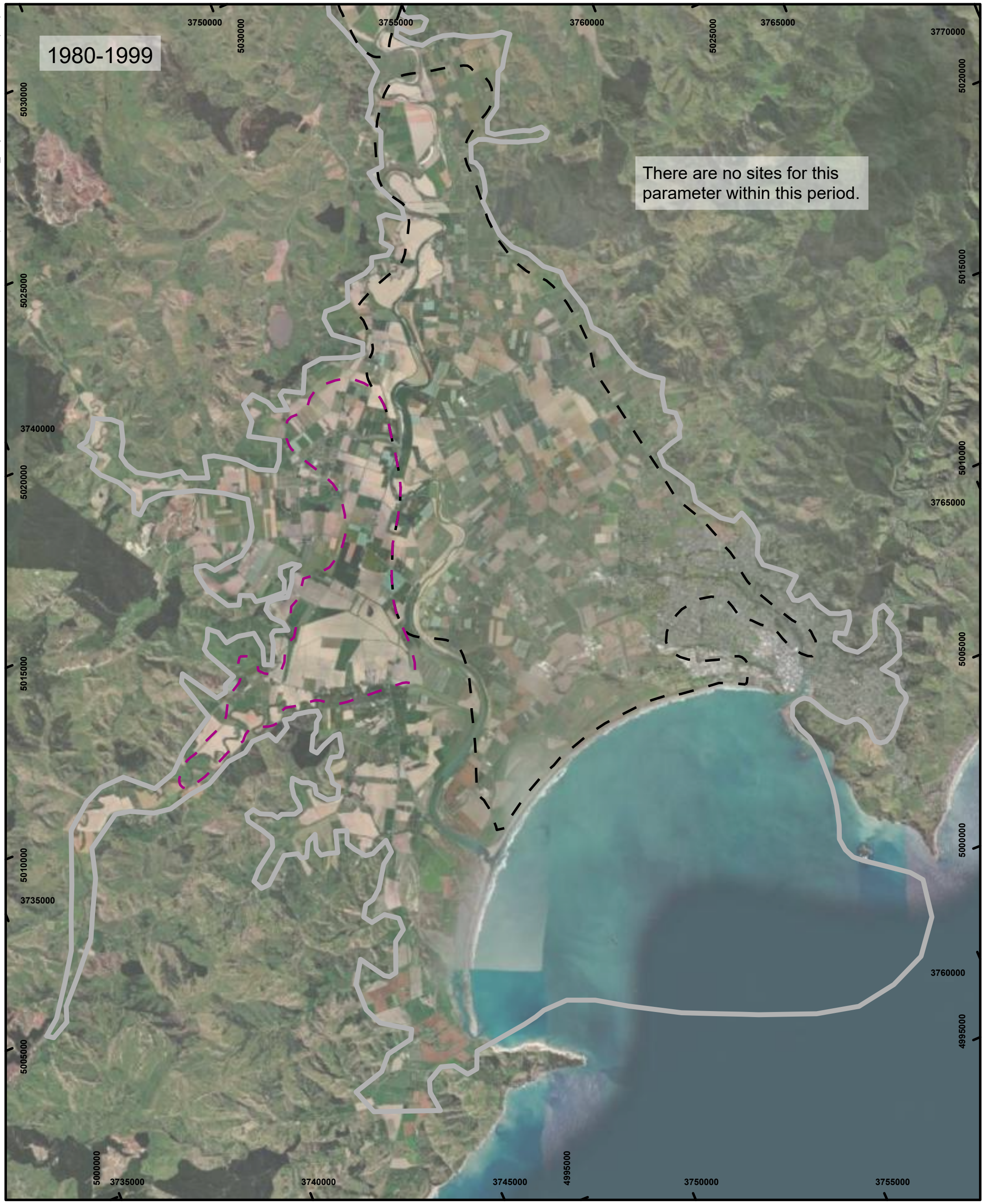
E Coli (# detects)
- 7
- 5
- 4
- 2
- 1

Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C21**
Gisborne MAR Model
Groundwater Quality Heat Maps - *E. Coli* (# detects) in the Shallow System

Document Path: C:\Users\MJaspan\Documents_Projects\GDC WQ\Heat Maps.aprx






Scale 1:175,000 @ 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

E Coli (# detects)
- 7
- 5
- 4
- 2
- 1

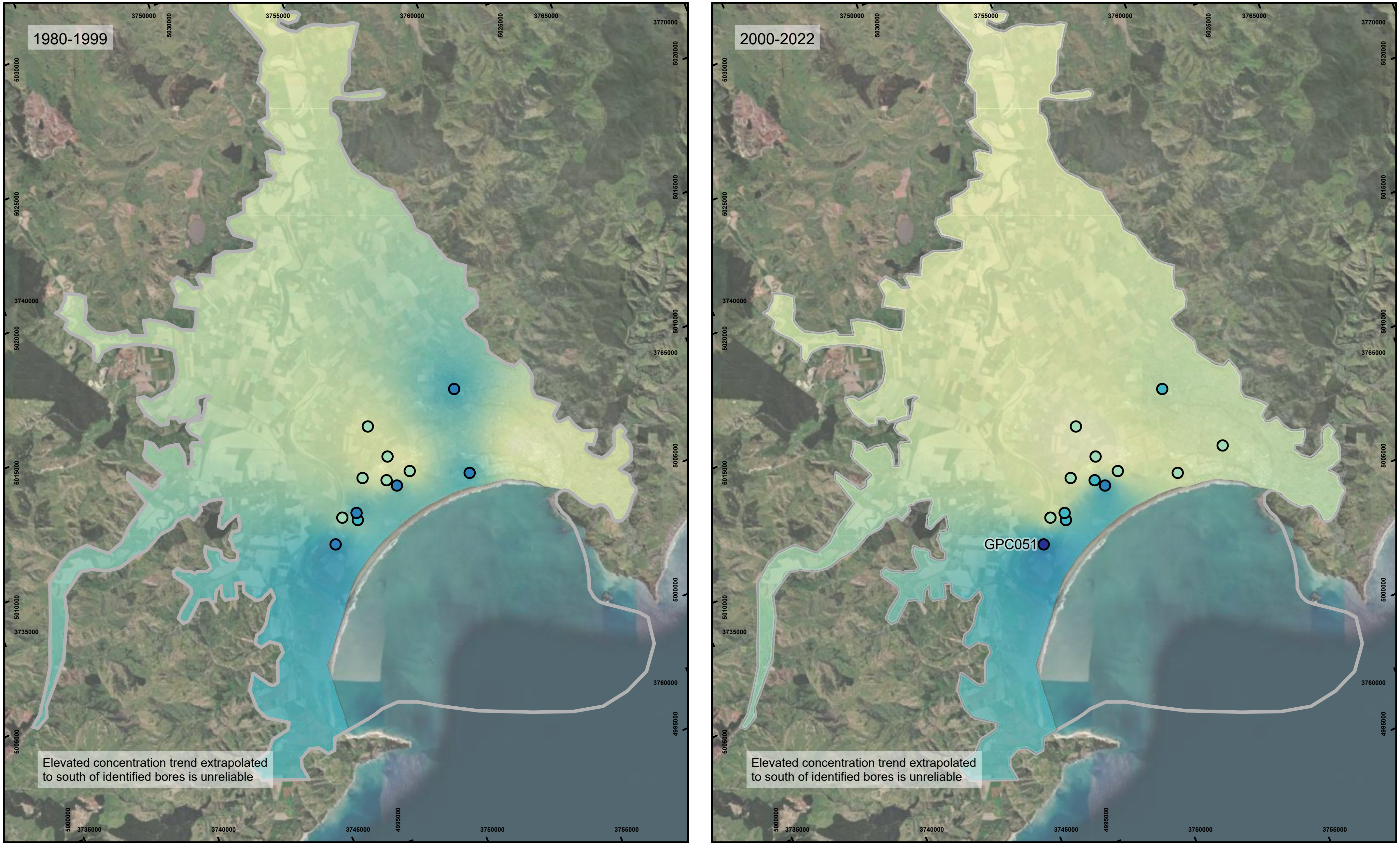
**LEGEND**
- Makauri Aquifer
- Western Saline Area
- Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C22**

Gisborne MAR Model

Groundwater Quality Heat Maps - *E. Coli* (# detects) in the Makauri Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Biochemical Oxygen Demand O2 (mg/L)
- > 2
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- > 0.5

Heat Map (mg/L)
- 3
- 0

Model Extent

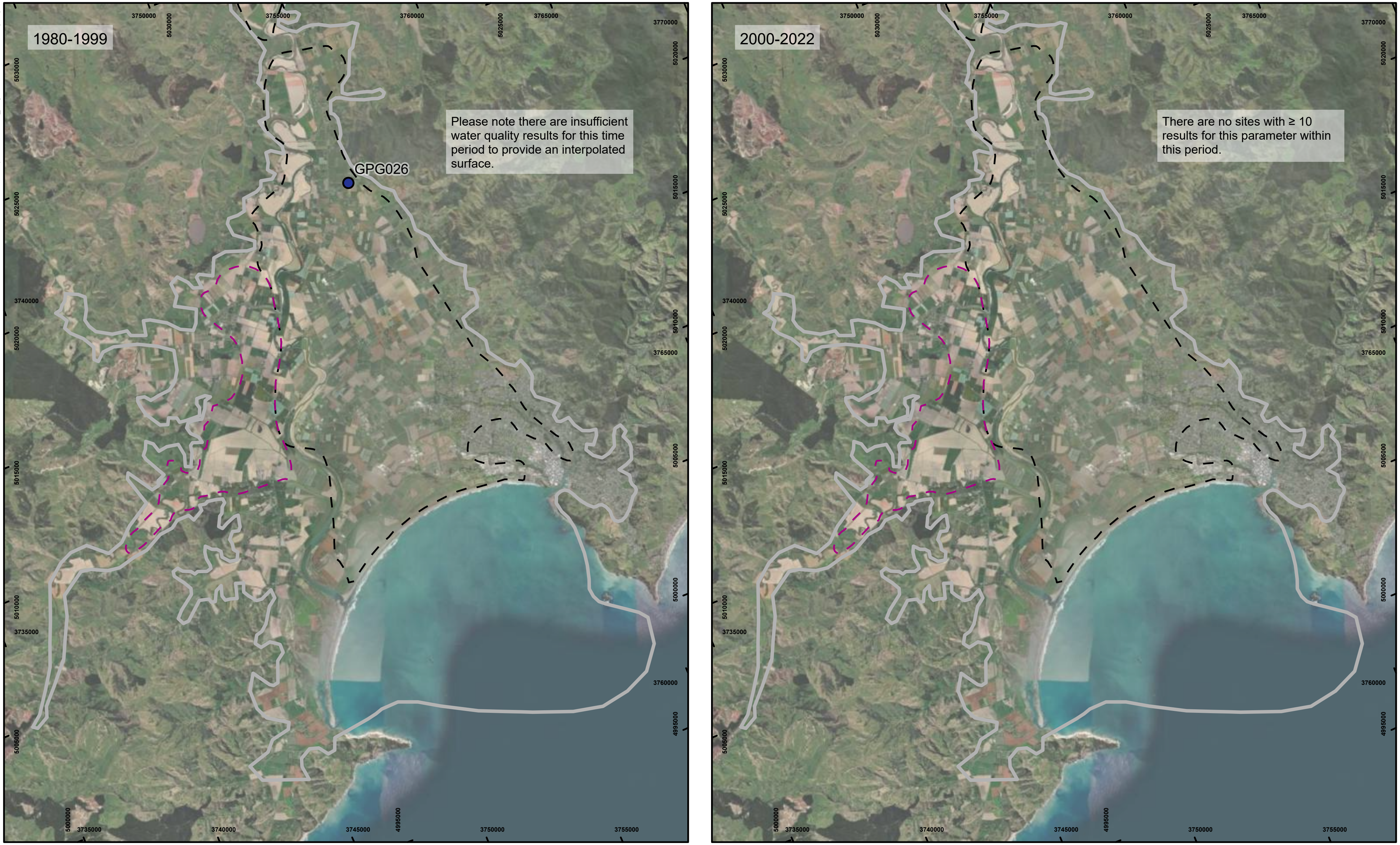
WGA

WALLBRIDGE GILBERT AZTEC

Figure **C23**

Gisborne MAR Model

Groundwater Quality Heat Maps - Biochemical Oxygen Demand O2 (mg/L) in the Shallow System





0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Biochemical Oxygen Demand O2 (mg/L)
- > 2
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- > 0.5

- Western Saline Area
- Makauri Aquifer
- Model Extent

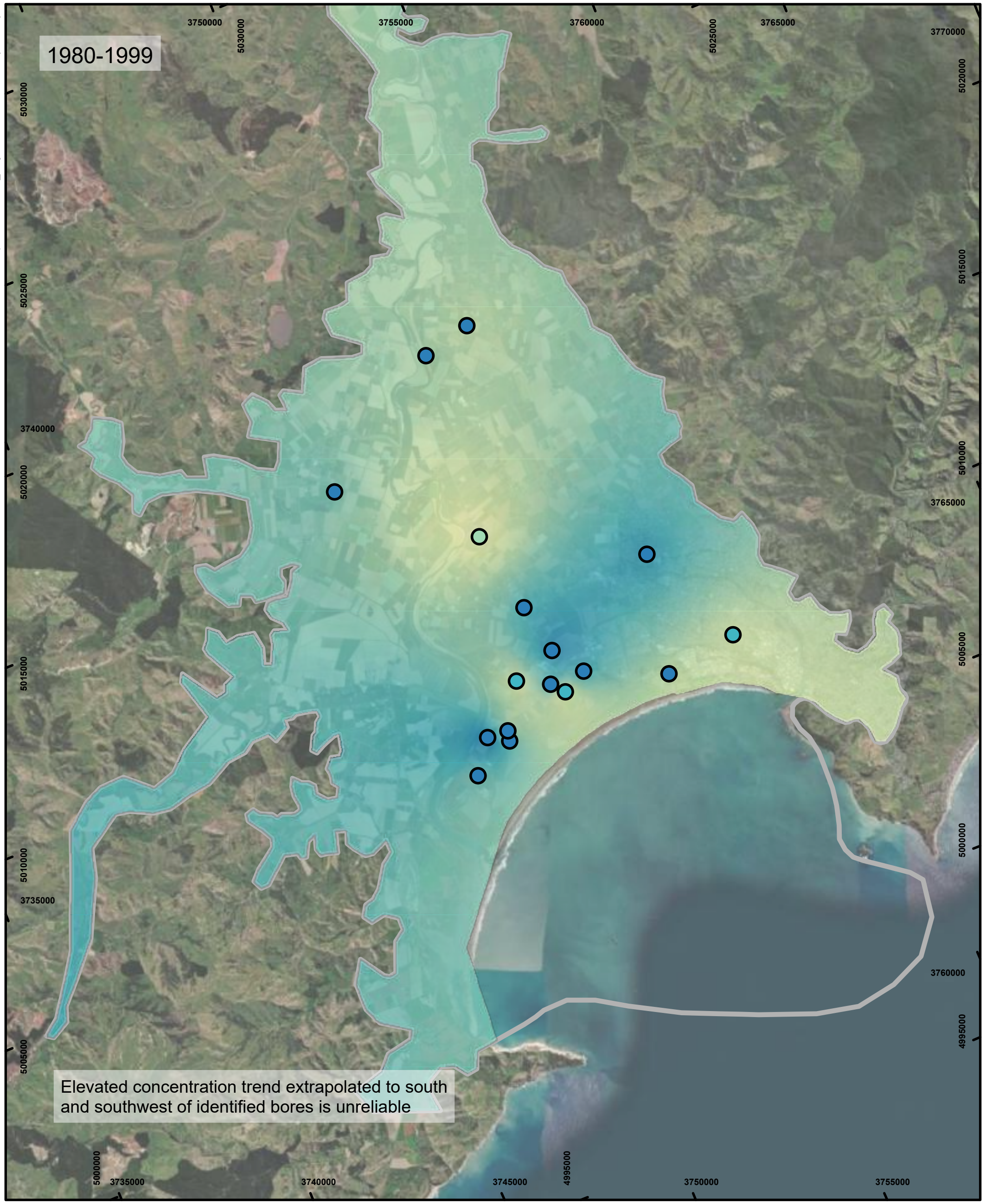
WGA

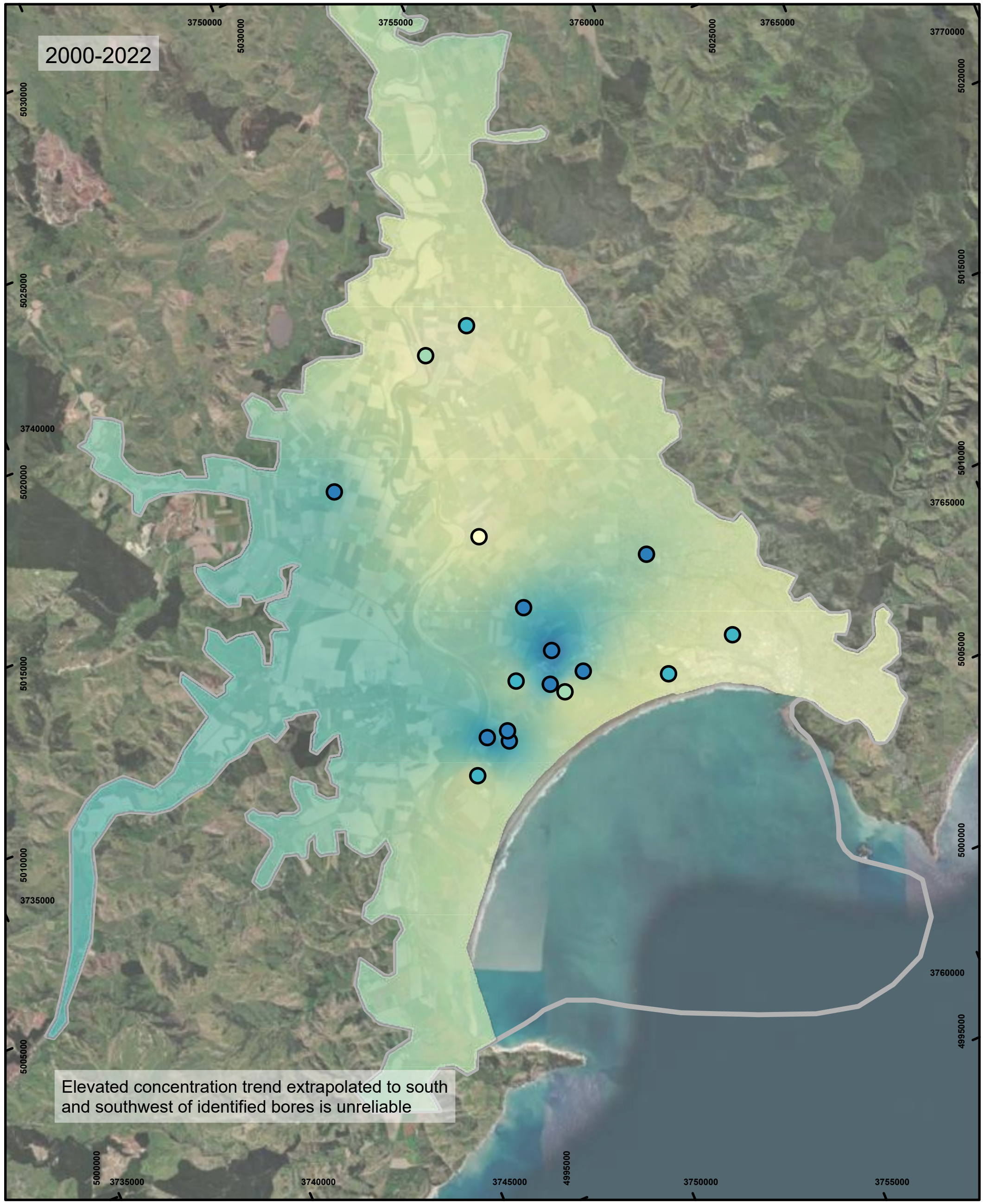
WALLBRIDGE GILBERT AZTEC

Figure **C24**

Gisborne MAR Model

Groundwater Quality Heat Maps - Biochemical Oxygen Demand O2 (mg/L) in the Makauri Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Sulphate (g/m3 SO4)
- > 100
- 20 - 100
- 5 - 20
- 1 - 5
- < 1

Heat Map (g/m3 SO4)
- 215
- 0

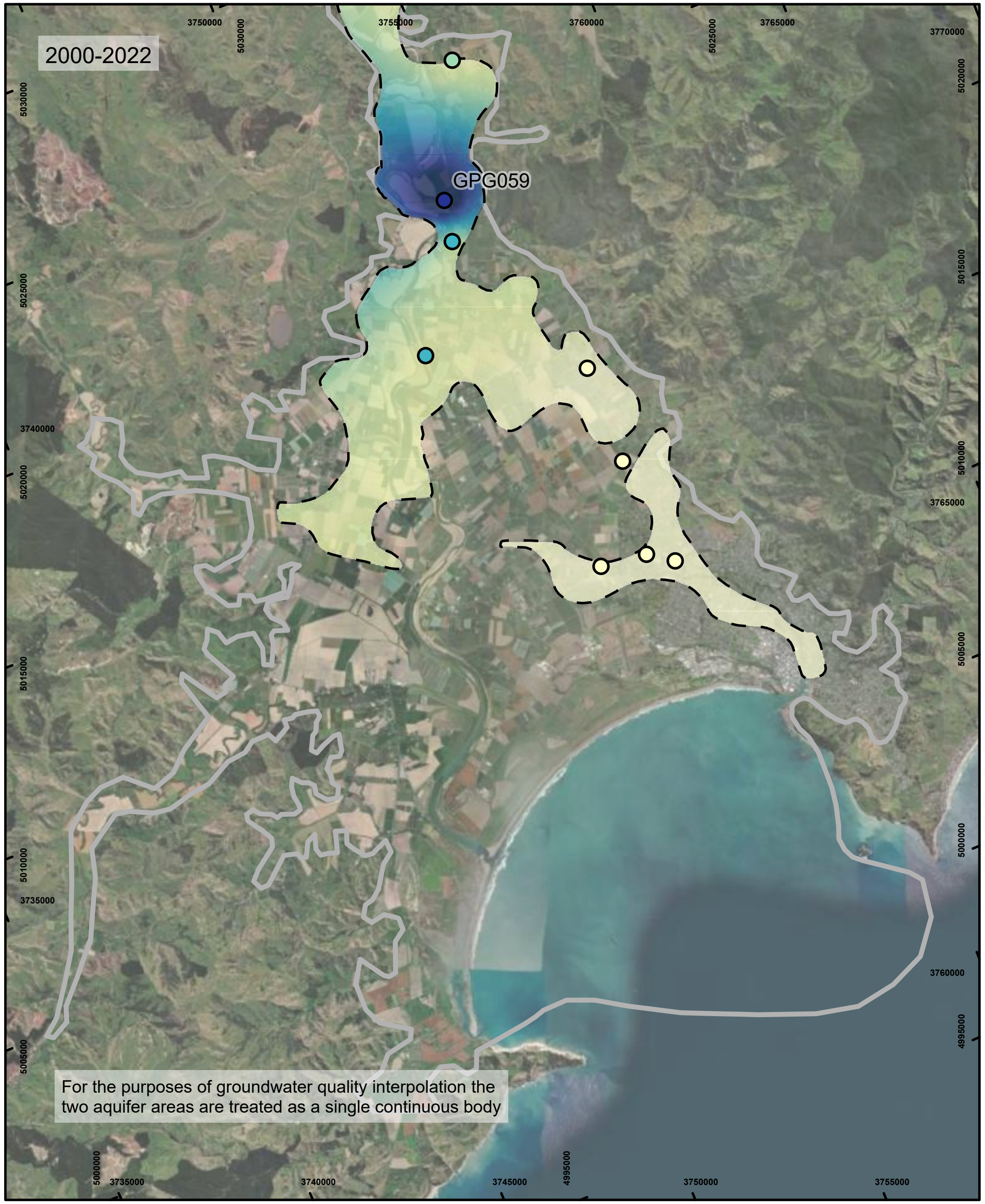
Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C25**

Gisborne MAR Model

Groundwater Quality Heat Maps - Sulphate (g/m3 SO4) in the Shallow System



N
0 1,000 2,000 3,000 4,000 m
Scale 1:175,000 @ 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**

Sulphate (g/m3 SO4)
- > 100
- 20 - 100
- 5 - 20
- 1 - 5
- < 1

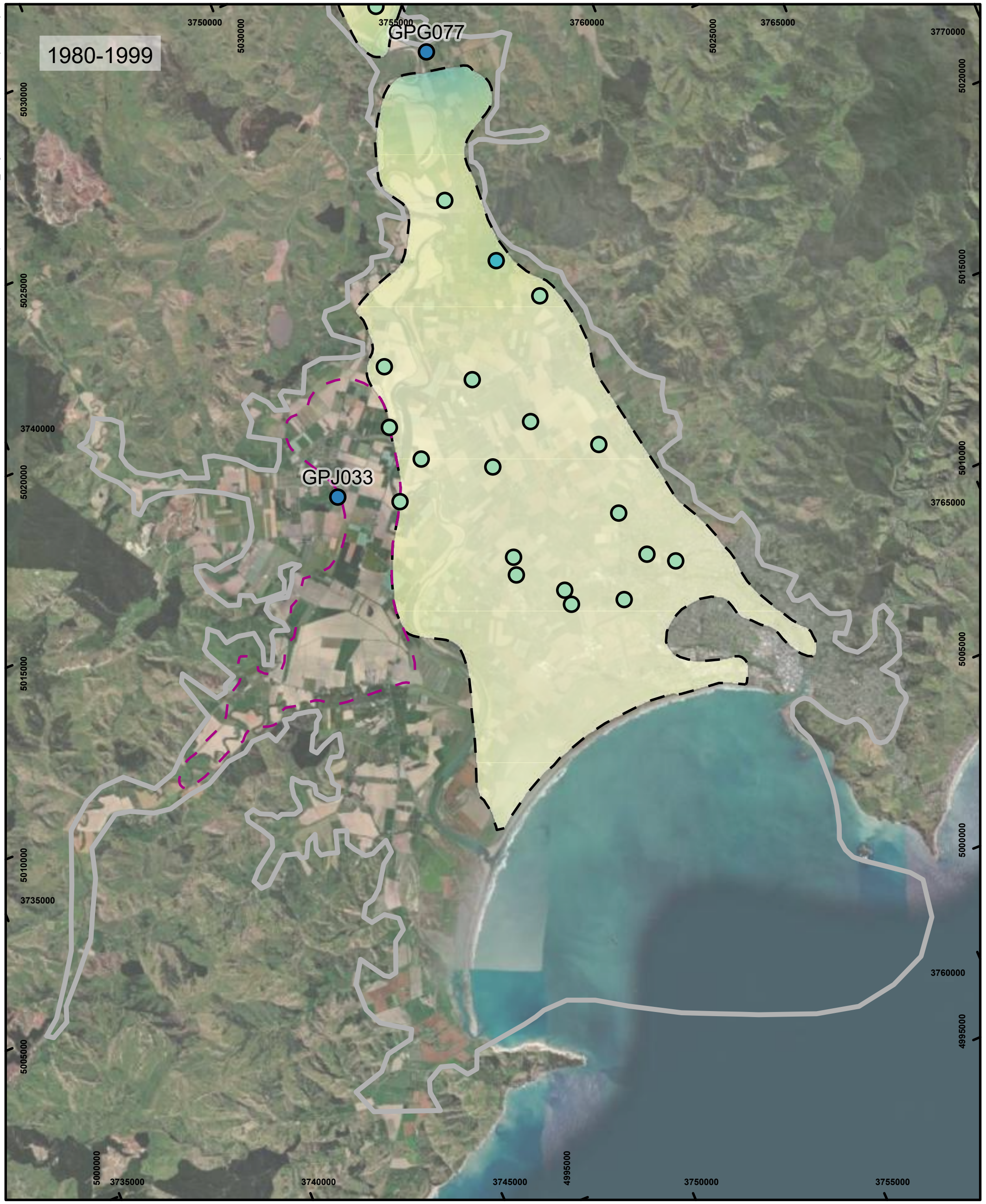
Heat Map (g/m3 SO4)
- 215
- 0

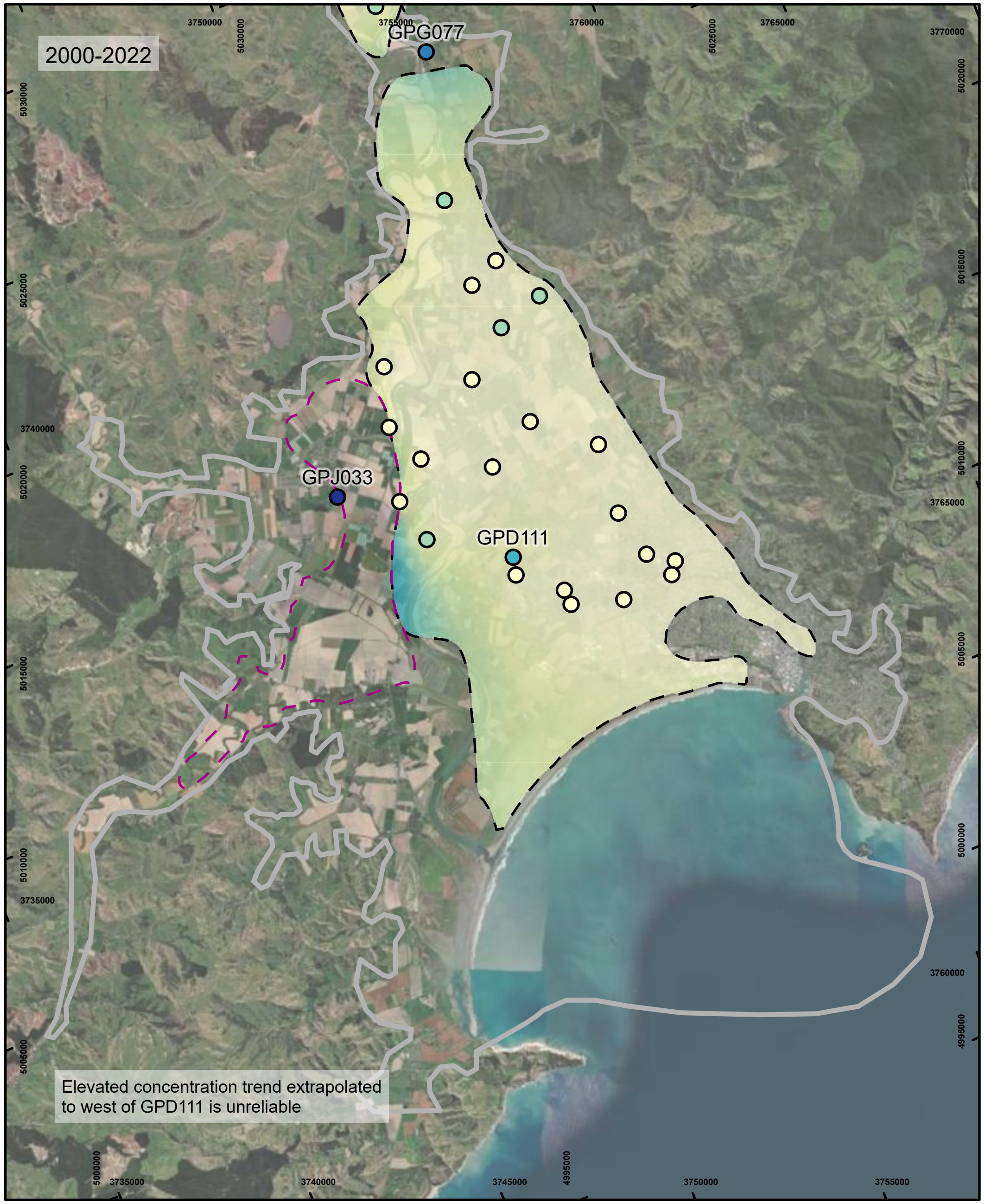
Waipaoa Aquifer
Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure **C26**
Gisborne MAR Model
Groundwater Quality Heat Maps - Sulphate (g/m3 SO4) in the Waipaoa Aquifer


Document Path: C:\Users\MJaspar\Documents_Projects\GDC WQ\Heat Maps IDs.aprx





0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ 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**

Sulphate (g/m3 SO4)
- > 100
- 20 - 100
- 5 - 20
- 1 - 5
- < 1

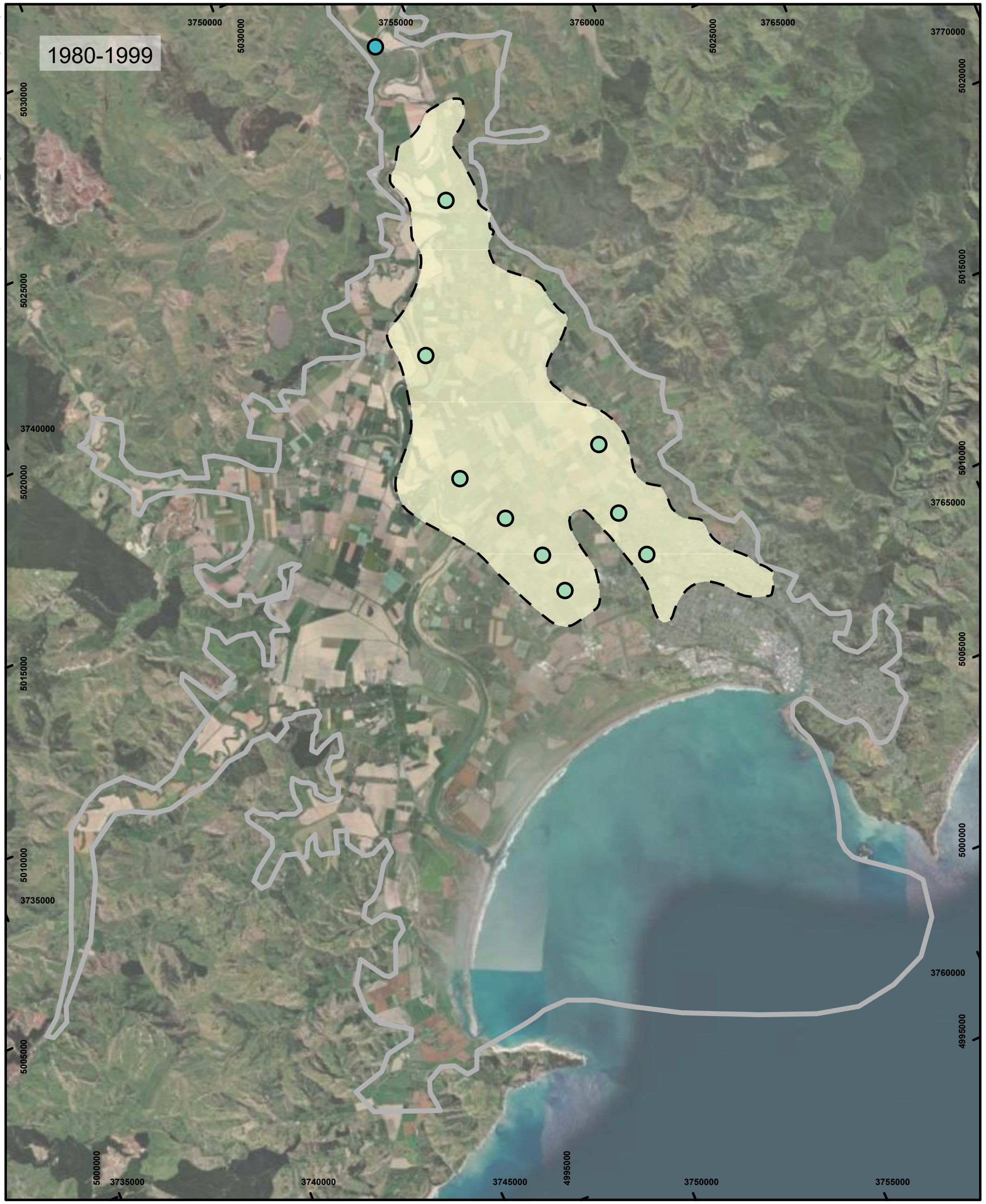
Heat Map (g/m3 SO4)
- 215
- 0
- Western Saline Area
- Makauri Aquifer
- Model Extent

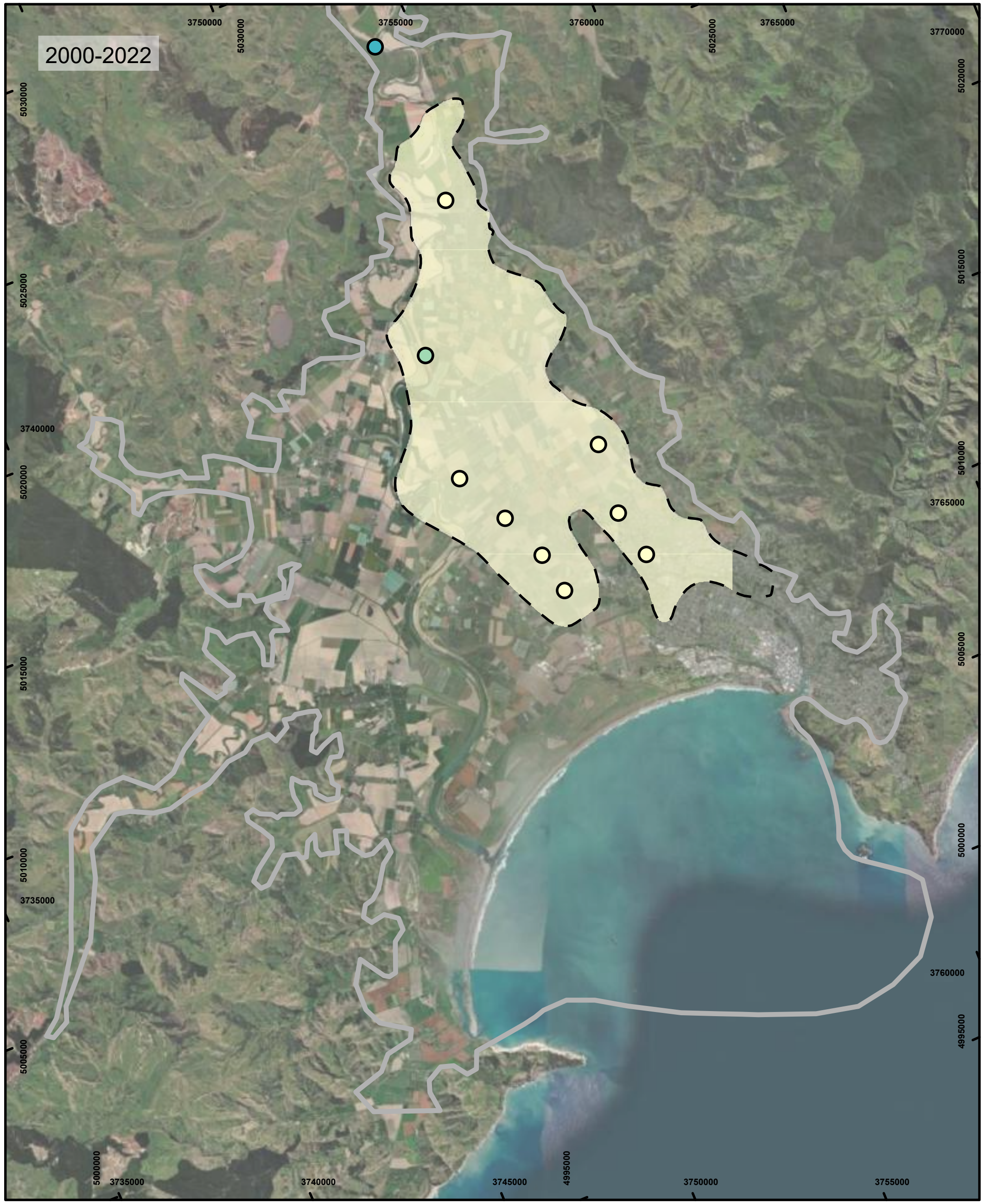
WGA
WALLBRIDGE GILBERT AZTEC

Figure **C27**

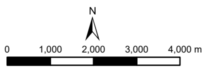
Gisborne MAR Model

Groundwater Quality Heat Maps - Sulphate (g/m3 SO4) in the Makauri Aquifer








Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Sulphate (g/m3 SO4)
- > 100
- 20 - 100
- 5 - 20
- 1 - 5
- < 1

Heat Map (g/m3 SO4)
- 215
- 0

Matokitoki Aquifer

Model Extent

WGA

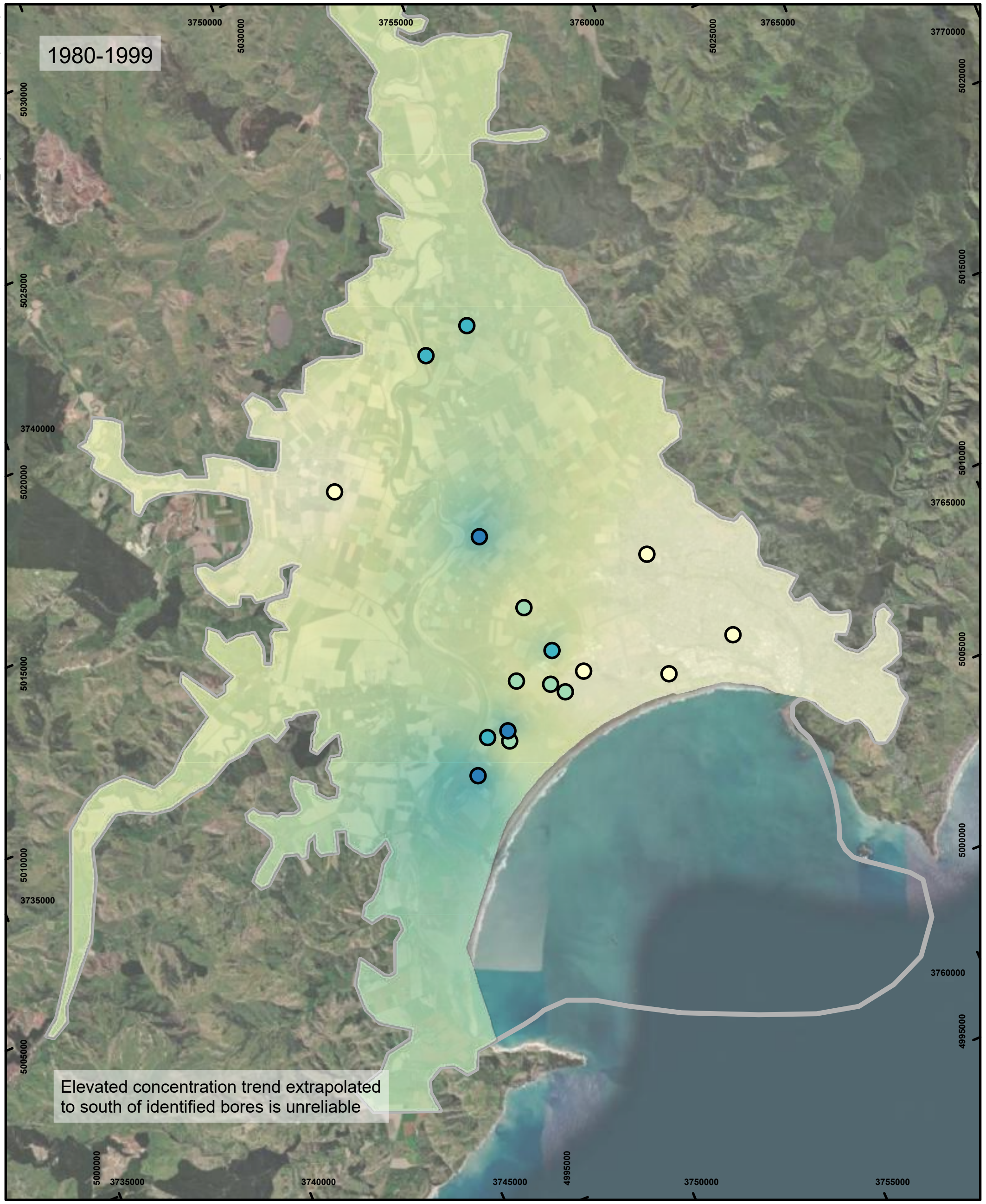
WALLBRIDGE GILBERT AZTEC

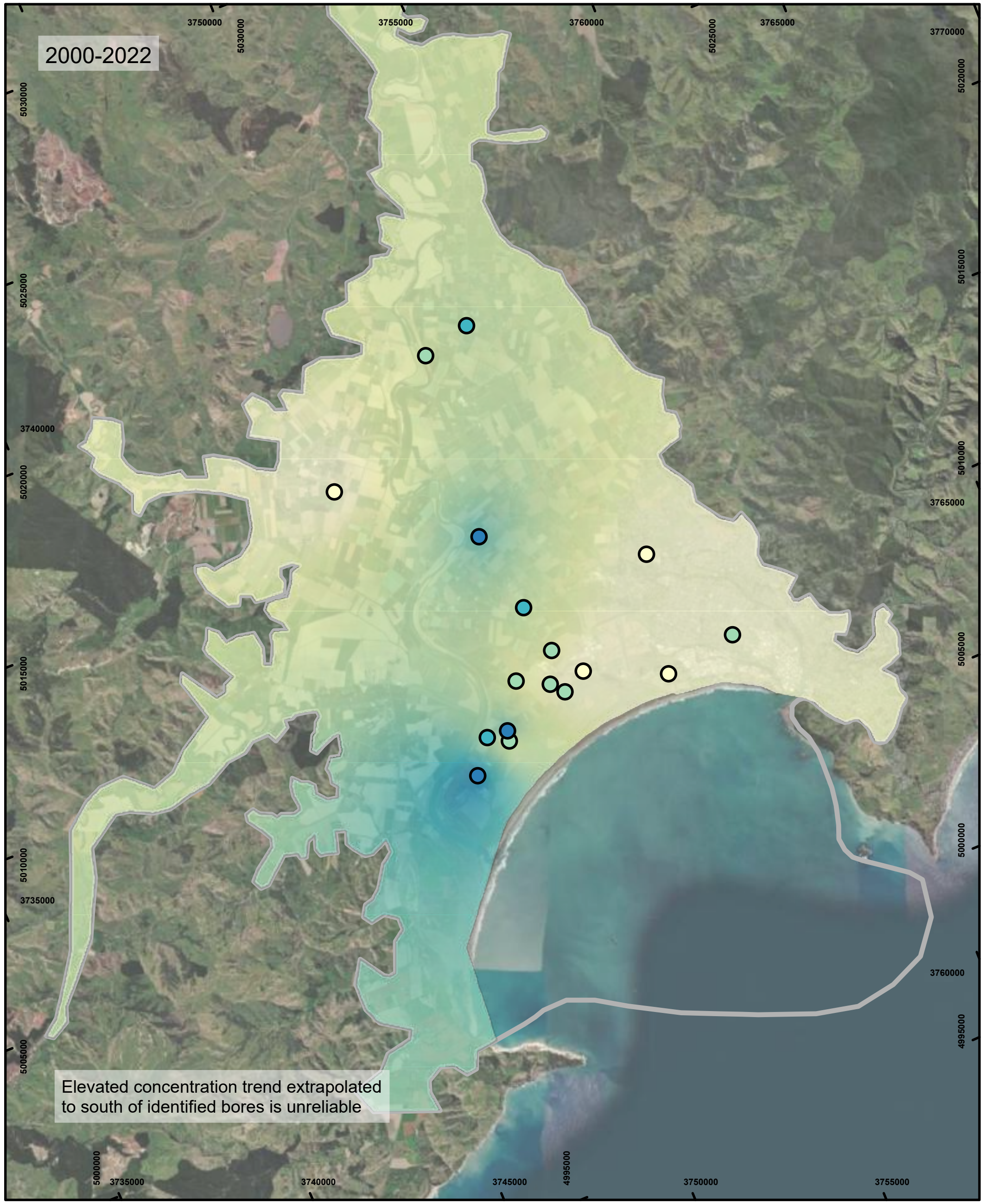
Figure **C28**

Gisborne MAR Model

Groundwater Quality Heat Maps - Sulphate (g/m3 SO4) in the Matokitoki Aquifer

Document Path: C:\Users\MJaspar\Documents_Projects\GDC WQ\Heat Maps IDs.aprx





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Manganese (mg/L)
- > 5
- 1 - 5
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

Heat Map (mg/L)
- 8
- 0

Model Extent

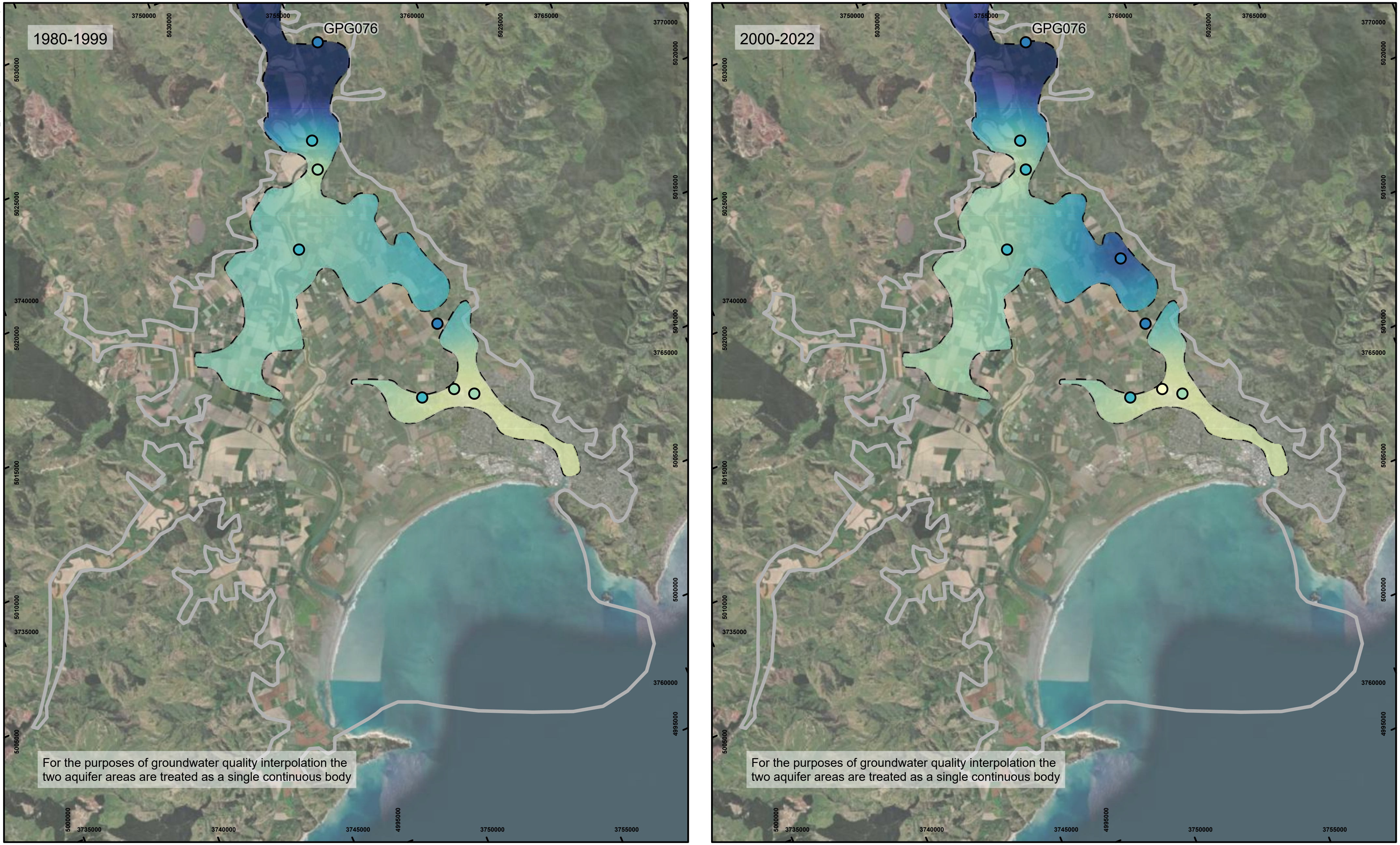
WGA

WALLBRIDGE GILBERT AZTEC

Figure **C29**

Gisborne MAR Model

Groundwater Quality Heat Maps - Manganese (mg/L) in the Shallow System





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Manganese (mg/L)
- > 5
- 1 - 5
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

Heat Map (mg/L)
- 8
- 0

Waipaoa Aquifer

Model Extent

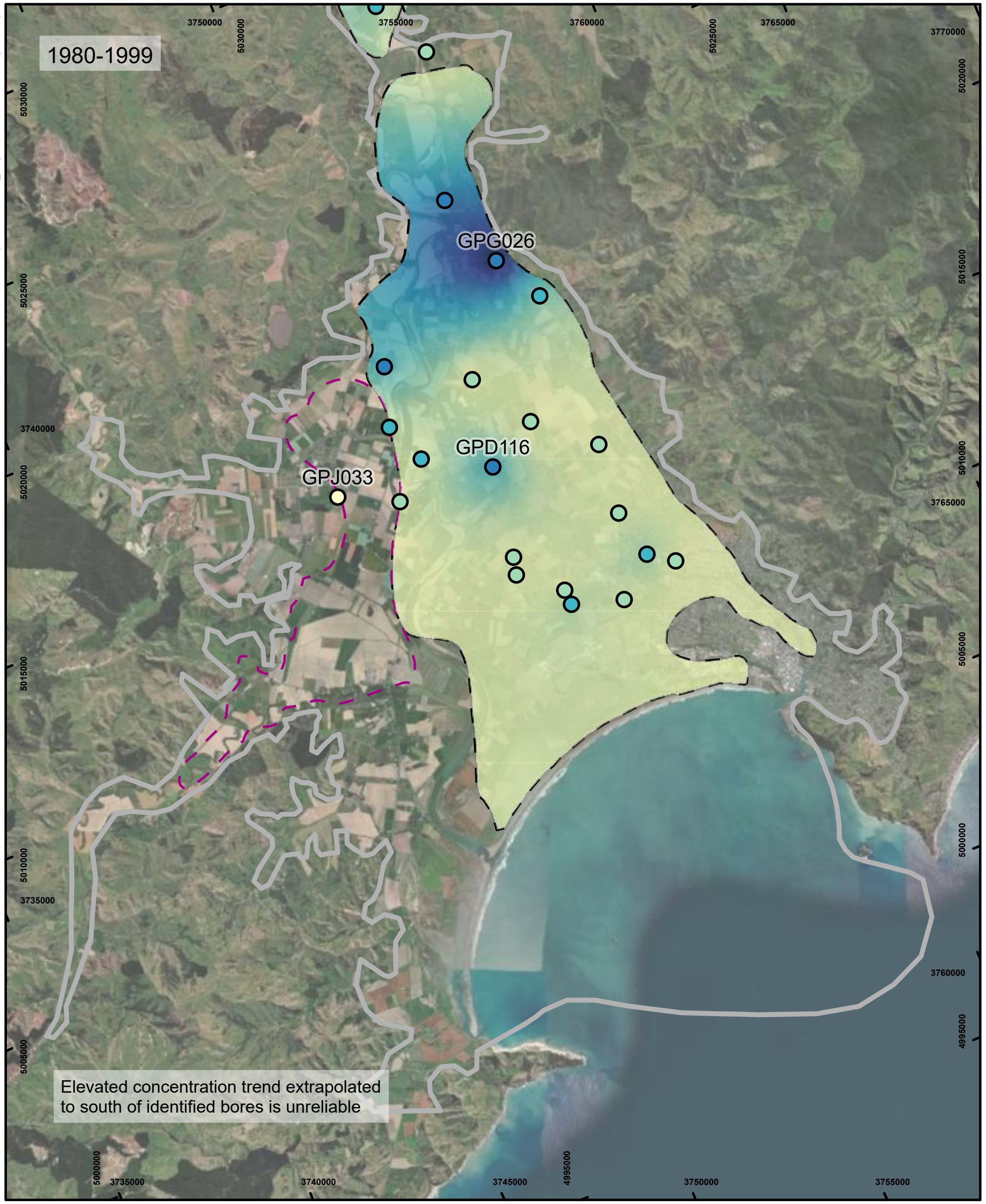
WGA

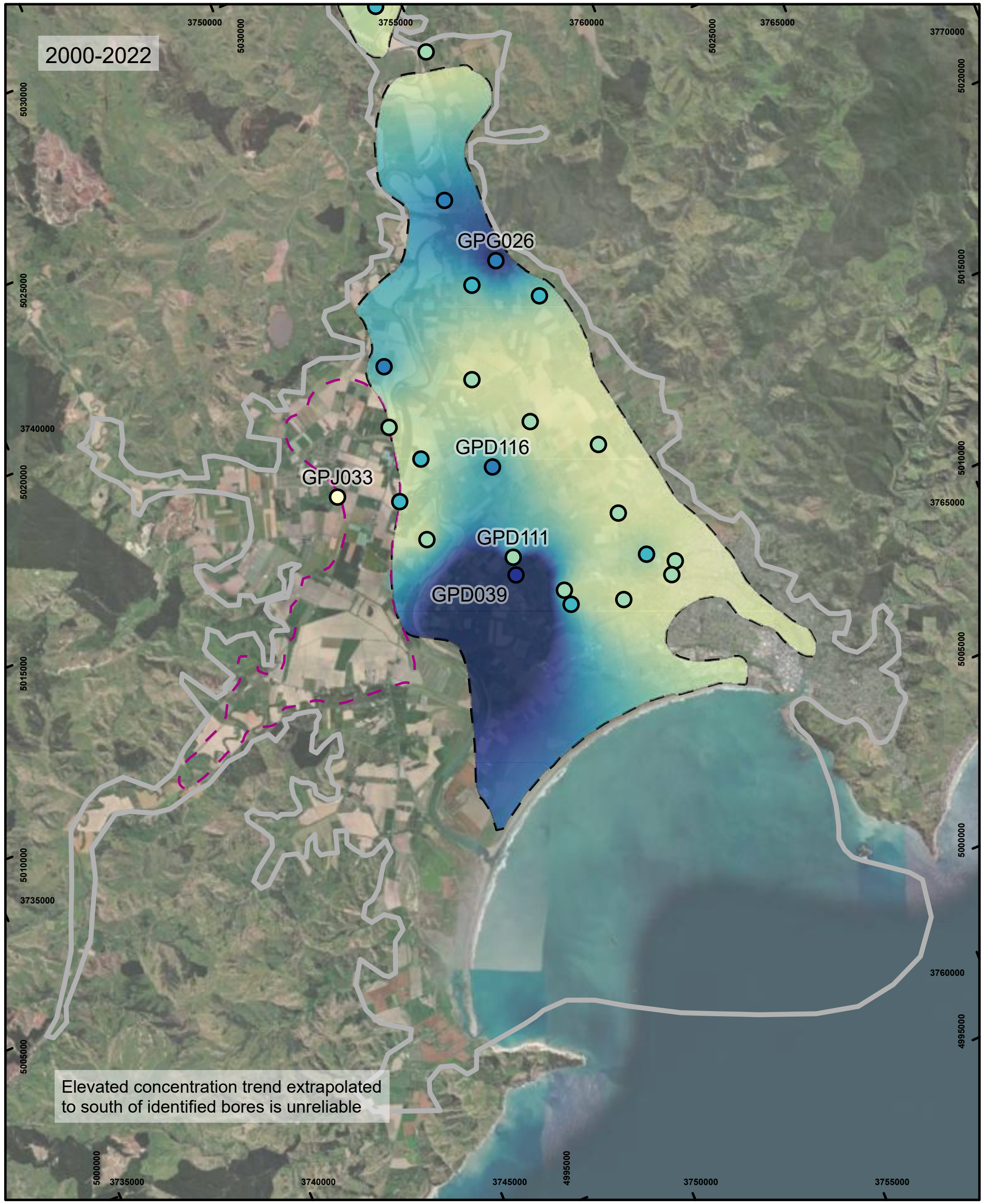
WALLBRIDGE GILBERT AZTEC

Figure **C30**

Gisborne MAR Model

Groundwater Quality Heat Maps - Manganese (mg/L) in the Waipaoa Aquifer





Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

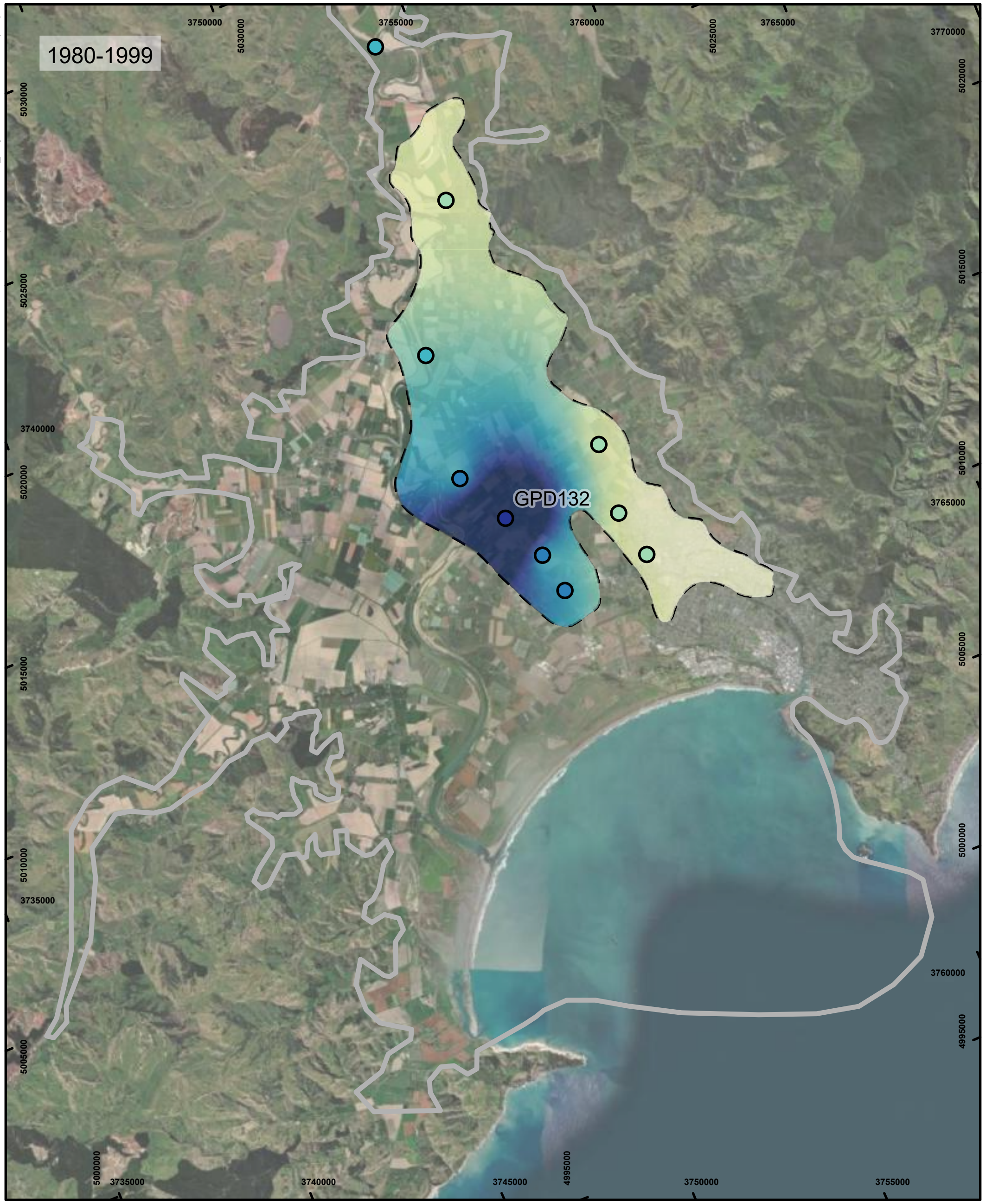
Manganese (mg/L)
- > 5
- 1 - 5
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

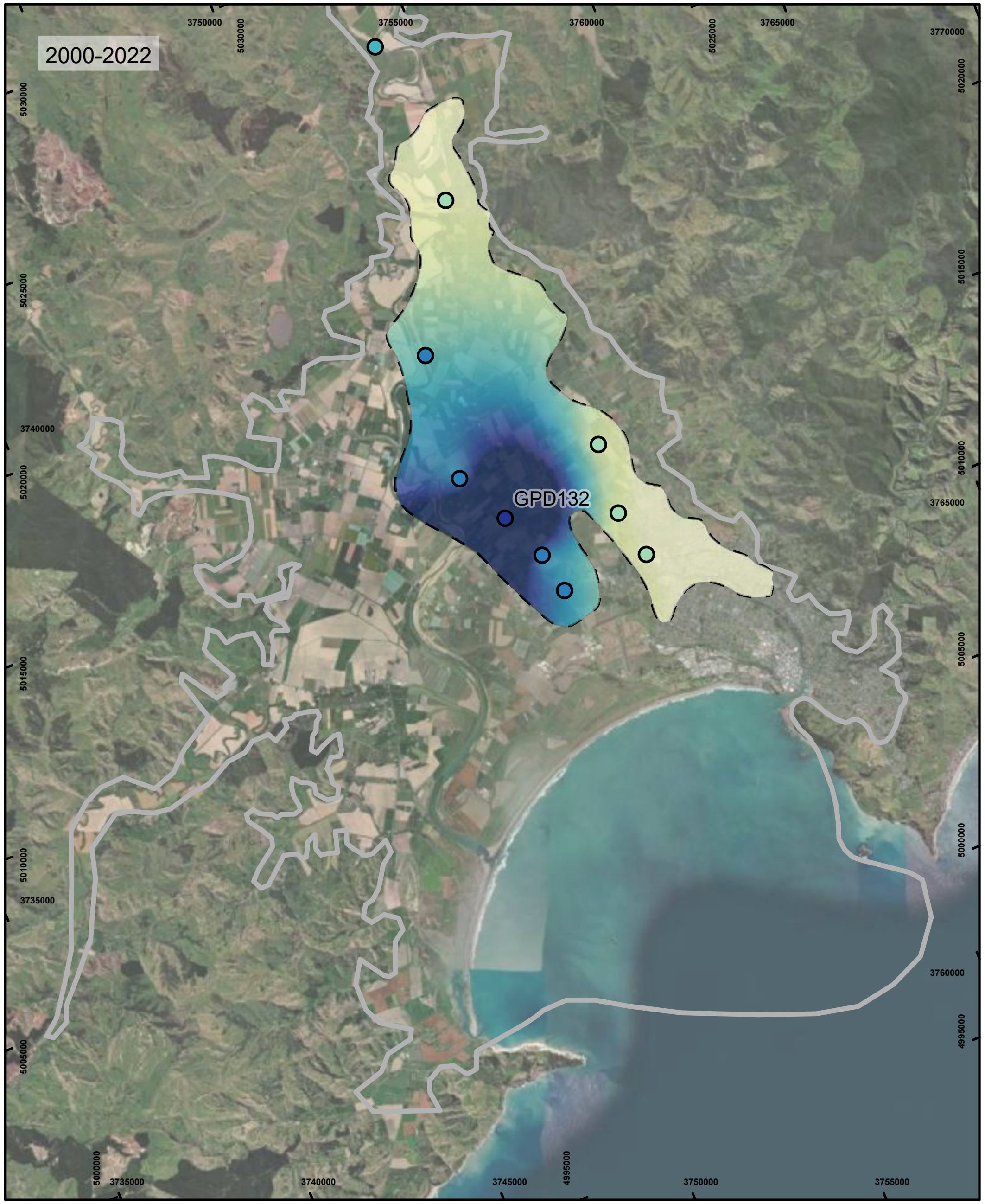
Heat Map (mg/L)
- 8
- 0

- Western Saline Area
- Makauri Aquifer
- Model Extent

WGA
WALLBRIDGE GILBERT AZTEC

Figure C31
Gisborne MAR Model
Groundwater Quality Heat Maps - Manganese (mg/L) in the Makauri Aquifer





N

0 1,000 2,000 3,000 4,000 m

Scale 1:175,000 @ A4

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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

**LEGEND**

Manganese (mg/L)
- > 5
- 1 - 5
- 0.5 - 1
- 0.1 - 0.5
- < 0.1

Heat Map (mg/L)
- 8
- 0

Matokitoki Aquifer

Model Extent

WGA

WALLBRIDGE GILBERT AZTEC

Figure **C32**

Gisborne MAR Model

Groundwater Quality Heat Maps - Manganese (mg/L) in the Matokitoki Aquifer

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