Gisborne District Council

Poverty Bay Flats Geological and Conceptual Hydrogeological Models

TECHNICAL REPORT

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EXECUTIVE SUMMARY

GDC retained Wallbridge Gilbert Aztec (WGA) and AQUASOIL Ingenieure & Geologen GmbH (Aquasoil) to develop two numerical models of the Poverty Bay Flats and adjacent areas important for the simulation of groundwater flows to and underneath the flats. The key overall objective of this project is to develop a definitive and defensible groundwater model simulating the geology and hydraulic behaviour of the aquifers beneath the Poverty Bay Flats. This modelling is being undertaken in collaboration with council staff as well as working with Mana Whenua to build an understanding of the groundwater system as well as how the model was built and can be used for future resource management planning.

The first two stages of this overall model building programme were the development of Geologic and Hydrogeologic conceptualisations of the Poverty Bay Flats groundwater system. These conceptualisations form part of the standard process when constructing 3D numerical models of groundwater systems.

Conceptualisations the geology involves understanding the how various geologic units, boundaries and properties are laid out relative to the area being modelled as well as how they interact with each other. Geologic conceptualisations are based on the lithology provided form bore drilling information along with geologic studies done of the area. This information is then used to build the geologic model for the area which provides the physical framework for the hydrogeologic numerical model. The hydrogeologic conceptualisation essentially is developed to understand how water enters, moves through and exists the model as groundwater flow. This conceptualisation is then used to set up the numerical model during the calibration and validation again using real world data and the geologic framework to formulate a final numerical model.

The conceptual geological model of the Poverty Bay Flats can be represented as a roughly triangular 3-dimensional prism of thick silt and clay deposits alternating with substantially thinner gravel and sand deposits. This prism is bounded laterally to the east and west, and vertically by Tertiary age siltstones and locally sandstones (Figure 9). The prism has its greatest thickness at the southern end of the flats, close to or beyond the coastline.

The youngest gravel deposits, representing the coastal sand deposits of the Te Hapara Sand and the Waipaoa River deposits of the Shallow Fluviatile Gravels, are close to or at the surface. Older buried gravels, representing the Waipaoa, Makauri and Matokitoki sandy gravels deposited by the Waipaoa River, generally increase in depth from north to south. These buried gravel deposits merge toward the northern end of the Poverty Bay Flats, close to the mouth of the Waipaoa River valley, and are separated by increasing thicknesses of silt deposits toward the south. The Te Hapara Sand and the Makauri Gravel appear to extend offshore at the southern end of the flats.

The gravels have been predominantly deposited by the Waipaoa River. A branch of the Matokitoki Gravel, which appears to represent a buried river channel extending underneath Gisborne and becoming shallower toward the southeast, is likely to consist of sediments derived from the Waimata River catchment. An interpreted branch of the Makauri Gravel, which extends westward under the Te Arai River terrace, is likely to consist of sediments derived from the Te Arai River catchment.

The hydrogelogic conceptualistion of the Poverty Bay Flats is built upon a combination of the information generated from hydrogeologic data as well as information generated from the geologic and numerical model modelling process.

Quaternary sedimentary deposits form the geologic depositional units beneath the Poverty Bay Flats which are sourced from infill from the river valleys that are eroded from the Tertiary rocks in surrounding hills. The depth of the Poverty Bay Flats groundwater system is at least 225 m below groundwater level (bgl). Sea level rises and falls from 70,000 years to present day have also acted to influence the geology and groundwater system beneath the Poverty Bay Flats. Sea levels changes range from 120 m lower up to two to three metres higher than current mean sea levels. Sea levels have remained relatively stable for the past 6,000 years but are now being influenced by global effects of climate change.

From the ground surface through to the basement bedrock, there are 10 unique units of aquifers and aquitards which form the Poverty Bay Flats groundwater system. The aquifers tend to be composed of riverine deposited alluvium while the aquitards tend to be formed from geologic sources of silts and mudstones or from marine sediments or swamp deposits. There are five main aquifers which underlie the Poverty Bay Flats (from shallower to deeper): Te Hapara Sand, Shallow Fluviatile, Waipaoa, Makauri and Matokitoki Aquifers. None of the aquifers are continuous across the full extent of the Poverty Bay Flats. The aquifers range in confinement from shallow unconfined aquifers to the deeper confined aquifers. The spatial distribution of the three deeper and more productive aquifers are shown in Figure 4.

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

A breakdown of the various hydrogeologic features of this aquifer system starts with an understanding that the groundwater system within the Quaternary alluvial deposits of the Poverty Bay Flats is considered to mainly be restricted to these deposits, with the basement Tertiary siltstones and claystones representing the boundary to the groundwater system. The shallowest aquifers extend northward from the Poverty Bay Flats as components of the valley fill alluvium within the Waipaoa River valley. There are two unconfined shallow aquifers, the Shallow Fluviatile Aquifer and the Te Hapara Sand Aquifer, are expressions of two different sedimentary depositional environments from the recent past. These two aquifers are laterally connected, both with each other and with the Waipaoa River.

Both aquifers receive spatially distributed rainfall recharge on a seasonal basis as well as receiving recharge from the Waipaoa River and from streams intersecting their footprints. They both discharge groundwater to the Waipaoa River and, in the case of the Te Hapara Sand Aquifer, to an intensive network of artificial drainage channels and a few channelized streams. The Te Hapara Sand Aquifer also discharges groundwater to the ocean along the coastline. Groundwater abstraction from these aquifers is limited and is unlikely to lead to extensive drawdown of the groundwater table.

The Waipaoa Aquifer is represented as two separate units in the geological and conceptual groundwater models, with both units consisting of fluviatile gravel deposits. The main body of the Waipaoa Aquifer extends southward from the northern end of the flats, increasing in depth from north to south. Recharge to the main body of the aquifer is primarily from the overlying Shallow Fluviatile Aquifer at the northern end of the Poverty Bay Flats. Groundwater seepage through this unit is expected to be toward the south but no clear discharge zone has been identified.

A southeastern gravel bed, interpreted as being an extension of the Waipaoa Aquifer, underlies the flats in the area around Gisborne at approximately the same depth as the main body of the aquifer. It is of limited extent and the recharge and discharge zones for this branch of the aquifer are not clearly defined. However, this branch of the Waipaoa Aquifer does react to pumping from the underlying Matokitoki Aquifer.

The Makauri Aquifer is by far the most extensive and most highly utilised aquifer underlying the Poverty Bay Flats. It increases in depth from north to south and is interpreted to extend offshore under Poverty Bay. Interpretation of winter hydraulic gradients within the aquifer indicates that the primary recharge area is at the northern end of the Poverty Bay Flats. Water from this aquifer is in high demand to support the horticultural industry in this region. Heavy seasonal pumping leads to extensive drawdown of the groundwater pressure under the northern half of the Poverty Bay Flats, with the drawn-down heads being locally below sea level. The interpreted natural discharge zone for the Makauri Aquifer is offshore, implying a hydraulic connection between the aquifer and the ocean. Should groundwater pressures within the Makauri Aquifer drop underneath coastline, the interpreted offshore discharge zone may represent a saline water intrusion risk to the aquifer.

The western section of the Makauri Aquifer, to the west of the Waipaoa River, has been reported as containing saline groundwater. The aquifer in this area is interpreted as being highly confined with limited throughflow. Groundwater quality monitoring indicates the seasonal pumping of water from the aquifer may be leading to the movement of saline water from this area toward the heavily pumped area to the northeast.

Abstraction of water from the Makauri Aquifer does not generally appear to influence groundwater pressures in the overlying Waipaoa Aquifer or the underlying Matokitoki Aquifer. However, a pumping test performed on the Matokitoki Aquifer close to Gisborne resulted in drawdown in groundwater pressure in the Makauri Aquifer. A successful MAR injection trial has been performed since 2017 targeting the Makauri Aquifer, with further investigations of potential MAR opportunities being considered.

The Matokitoki Aquifer is the deepest aquifer underlying the Poverty Bay Flats, with the main body of the aquifer increasing in depth from north to south. A branch of the aquifer extends to the southeast beneath Gisborne, with this branch becoming shallower toward the south.

The main recharge area for the Matokitoki Aquifer is considered to be at the northern end of the Poverty Bay Flats, where it rises to intersect overlying aquifers. Groundwater flows within the main body of the aquifer are interpreted to be from north to south, although a discharge zone is not clearly defined. No clear discharge zone for the main body of the Matokitoki Aquifer has been identified although an offshore discharge to the ocean is unlikely.

A secondary recharge area is interpreted to be at the southeastern end of the Poverty Bay Flats, in the area of Gisborne. Groundwater flows within the southeastern branch of the aquifer are either from east to west or from south to north. Groundwater pressures in this branch of the aquifer are flowing artesian and it is interpreted that groundwater from this branch of the aquifer discharges either westward into the main body of the Matokitoki Aquifer or upward into the overlying Makauri and Waipaoa Aquifer.

Although groundwater abstraction from the Matokitoki Aquifer is limited due to its depth, the southeastern branch of this aquifer has been accessed by two bores that serve as an emergency water supply for Gisborne. A pumping test performed on these bores resulted in groundwater drawdown in the overlying Makauri and Waipaoa Aquifers, which is interpreted as being due to the Matokitoki Aquifer rising toward the southeast and becoming physically connected to the overlying aquifers.

The conceptualisation of the Poverty Bay groundwater system documented in this report provides guidance for the development of a calibrated transient numerical model simulating this system. Sufficient data is available to provide for the calibration and validation of the numerical model. Also, the available dataset covers a period dating back to the early 1980's, which provides a very good baseline for numerical modelling of future groundwater management scenarios.

Revision History

Rev	Date	Issue	Originator	Checker	Approver
A	23/02/2022	Draft	BS	BB	BB
B	14/02/2023	Final	BS	BB	BB

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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. Within the Tairawhiti region resource consents have been granted authorising the irrigation of 7,120 ha, 96% of which is on the Poverty Bay Flats. There has been a 51% increase in area consented for irrigation in the region since 2006.

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, with approximately 900,000 m^3 being abstracted during the summer irrigation season.

Reviews of groundwater levels in aquifers underlying the Poverty Bay Flats have identified declining groundwater pressure trends (e.g., Moreau et al 2020). These trends are linked to increasing groundwater abstraction for irrigation purposes. Continuation or exacerbation of these trends has been identified by the Gisborne District Council (GDC) as presenting environmental, economic, cultural, and social risks linked to water flow and supply reliability issues. GDC considers most of the aquifers to be fully-allocated or over-allocated and no new consents for groundwater abstraction are being issued.

A “paper-based” reduction in the allocation to horticulturists from the Makauri Aquifer has been implemented by GDC. The first stage was to reduce the allocation from approximately 8,000,000 m^3/year to approximately 1,800,000 m^3/year. A further reduction is to occur in 2023, with the allocation limit being set at 1,700,000 m^3/year. This limit still far exceeds the current average annual abstraction from the Makauri Aquifer of 900,000 m^3/year. Therefore, these changes in allocation do not address the abstraction rates that are causing the observed declines in groundwater pressures.

Management of groundwater quality is of equally pressing concern to GDC. A groundwater quality conceptualisation for the Poverty Bay Flats is documented in a separate report (WGA 2022b), which should be read in conjunction with this report. Key concerns identified in the groundwater quality conceptualisation report include:

1. The eastward movement of saline groundwater within the Makauri Aquifer from a poorly defined Off the aquifer to the west of the Waipoua River.
2. The northward movement of seawater within the Te Hapara Sand Aquifer toward the Awapuni Moana area close to the coast.
3. The potential for seasonal reversal of vertical hydraulic gradients within aquitards that form protective layers above the confined aquifers that represent the main sources of irrigation water for the region.

A Managed Aquifer Recharge (MAR) trial has been operating at Kaiaponi since 2017. Outcomes from the trial to date indicate MAR can be a viable tool to help slow and reverse the declining groundwater level trends in the Makauri Aquifer. The successful implementation of a wider Groundwater Replenishment Scheme may help GDC to address overallocation issues.

In order to enhance understanding of the outcomes from groundwater management options for this area, GDC has commissioned a numerical groundwater model for this purpose. The model is to be used by GDC, in conjunction with a community engagement process, to support the development of scenarios leading to sustainable groundwater management options for the Poverty Bay Flats.

1.2 METHODOLOGY OVERVIEW

GDC has retained Wallbridge Gilbert Aztec (WGA) and AQUASOIL Ingenieure & Geologen GmbH (Aquasoil) to develop two numerical models of the Poverty Bay Flats and adjacent areas important for the simulation of groundwater flows to and underneath the flats. The key overall objective of this project is to develop a definitive and defensible groundwater model simulating the geology and hydraulic behaviour of the aquifers beneath the Poverty Bay Flats. This modelling is being undertaken in collaboration with council staff.

The two numerical models consist of:

1. A numerical model of the geology of the sedimentary deposits underlying the Poverty Bay Flats, connected river valleys and the near offshore zone within Poverty Bay.
2. A numerical model of the groundwater system underlying the Poverty Bay Flats, connected river valleys and the near offshore zone within Poverty Bay.

The numerical geology model is to provide a geological structure on which the groundwater model is to be based.

The general objectives of the numerical model(s) include:

1. <u>Identifying and filling data gaps</u>: the model should enable the hydrological and hydrogeological structures and characteristics of the groundwater systems to be better understood. The model should also enable key areas to be identified where additional information could result in significant improvements to the understanding of the Poverty Bay groundwater system.
2. <u>Surface water / groundwater connectivity</u>: the model should enable an improved understanding of surface water / groundwater interaction and the general layout and behaviour of boundaries between aquifers and surface water bodies. The model is to be scalable to what factors control and influence water bodies at the regional scale. This scalability is also to assist with determining effects at regional, Freshwater Management Unit and water management zone levels. The model results are intended to be used to improve the understanding of the effectiveness of current GDC policy, management, and actions.
3. <u>Groundwater flows and volumes</u>: quantify the flow and volume of water in the various Poverty Bay Flats aquifers.
4. <u>Sustainable groundwater utilisation</u>: evaluate sustainable groundwater allocation rates of take and annual volumes and their effects on surface water bodies including springs.
5. <u>Sustainability risks</u>: understand areas of risk arising from groundwater utilisation, including the risk of saline water mobilisation within aquifers and saltwater intrusion to aquifers.
6. <u>Groundwater level limits</u>: support the development and implementation of groundwater level limits for the Poverty Bay aquifers.
7. <u>Proving and scaling groundwater solutions</u>: simulate solutions can be developed to improve the quantity of groundwater, such as water take efficiency measures, MAR and enhancing natural recharge mechanisms.

8. Future Pressures on Freshwater: increasing pressures (e.g., population & economic growth and climate change), are impacting groundwater quantity and quality. Scientific evidence is required for groundwater management and allocation to support future policy/urban planning and adaption. The model is intended to provide management tools and data to respond to pressures on quantity over the medium to long term (approximately 10 years). The model is intended to enable forecasts of future flows, to accurately evaluate the effects and implications from various recharge and withdrawal scenarios. The groundwater flow model is also intended to support the simulation of groundwater quality trends arising from various predictive abstraction scenarios.

Key modelling objectives related to the implementation of MAR to enhance the resilience and security of the groundwater resources underlying the Poverty Bay Flats include:

1. Provide guidance on the number and layout of MAR bores necessary to meet the goals of maximum salinity and water level benefits while injecting a minimum of 600,000 m^3 per annum.
2. Evaluate potential impacts from injection under pressure (head above ground at injection bore).
3. Predict the potential for artesian pressure conditions in third party bores from a preferred MAR layout, which may present risks of flooding and/or damage to private property.
4. Track the recharge water plume resulting from a MAR programme.

1.3 REPORT STRUCTURE

This report documents the development of the geological model for the Poverty Bay Flats and the primary associated river valleys. This report also documents the conceptual hydrogeological model for the area, on which the numerical groundwater model is to be based. The numerical groundwater model is documented in a separate report by AquaSoil. This report should therefore be read in conjunction with the AquaSoil report.

Sections 0 and 1.5 of this report summarise the model development process and the modelling philosophy followed throughout this project.

Section 2 of this report summarises geological investigations and interpretations undertaken over the past 40 years to present a conceptual geological model for the Poverty Bay Flats and associated river valleys. The objective of this section is to provide an understanding of the expected layouts of the aquifers and how these layouts came to be.

Section 3 of this report summarises the numerical geological model for the Poverty Bay Flats, with detailed descriptions and maps provided in associated appendices.

Section 4 of this report presents the conceptual groundwater model for the Poverty Bay Flats, based on the outcomes of the numerical geological modelling and hydrogeological investigations and interpretations undertaken in the region over the past 40 years. Section 4 also summarises the assumptions incorporated in the conceptual groundwater model and some of the interpretation issues that may be further evaluated through the numerical modelling process.

Section 5 of this report presents a summary of the conceptual groundwater model.

1.4 MODEL DEVELOPMENT PROCESS

The development process for the geological model incorporates three basic components:

1. Development of a conceptual geological model based on accumulated work carried out and documented over the past 40 years. The conceptual model does not describe the geological strata in detail but rather describes the depositional environment of the strata beneath the Poverty Bay Flats. It also provides guidance with respect to general strata thicknesses and depths for comparison with the numerical model to be developed from geological logs of holes drilled in the Poverty Bay Flats area.
2. Conversion of the existing GDC lithological database from holes drilled in the Poverty Bay Flats area into a database format that can be utilised for numerical modelling purposes. This conversion includes a review of the lithological information to verify that the descriptions are reasonable and consistent for the purposes of numerical modelling.
3. Development of a numerical geological model based primarily on interpretation of the drillhole data provided by GDC. This numerical modelling effort is guided by a clear understanding of the depositional environment and stratigraphy of lithological units documented in the conceptual geological model.

The subsequent development of the numerical groundwater model is based on a combination of the conceptual geological model (documented in this report) and the numerical geological model (documented in a separate report). The numerical geological model is used to provide a 3D structure on which the groundwater model is constructed.

1.5 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 model for the Poverty Bay Flats groundwater system is to revert to first principles applied in stepwise fashion:

1. Develop a clear understanding of the coastal and fluviatile depositional environment as it evolved while the sedimentary deposits beneath the Poverty Bay Flats were being emplaced.
2. Convert this understanding into a clear description and layout of the geological units expected to occur within the Poverty Bay Flats stratigraphic sequence.
3. Develop a numerical geological model of the Poverty Bay Flats stratigraphic sequence based on the interpretation of drillhole data and informed by the understanding of the depositional environment.

4. Thirdly, develop a clear understanding of the hydraulic characteristics of the geological units, the groundwater flow patterns within those units and the groundwater flows into and out of the geological system.
5. Convert this understanding into a clear hydrogeological model of the Poverty Bay Flats stratigraphic sequence and connected groundwater systems.
6. Identify assumptions, data interpretations, issues, and possible anomalies in contributing information that may require testing and verification, either through the numerical groundwater modelling process or though possible future field investigations.

2 CONCEPTUAL GEOLOGICAL MODEL

2.1 INTRODUCTION

The conceptual geological model for the Poverty Bay Flats is based on accumulated work carried out and documented over the past 40 years. The conceptual model describes the depositional environment of the strata beneath the Poverty Bay Flats. It also provides guidance with respect to the expected strata layout, thicknesses, and depths, to support the development of the numerical geological model as described in Section 3 below. The conceptual model has been developed based on information provided in published papers and reports, with the list of referenced material provided in Section 6.

2.2 TOPOGRAPHY

The Waipaoa River receives water from a catchment of approximately 2,165 km^2, with its headwaters rising to elevations of over 1,000 mRL in the hill country of the Raukumara Range to the northwest of Gisborne. It flows southward for over 80 km, crossing the Poverty Bay Flats before discharging into Tūranganui-a-Kiwa/Poverty Bay.

Tūranganui-a-Kiwa/Poverty Bay is a sheltered semi-circular bay, approximately 63 km^2 in area. It extends toward the northeast to Tuamotu Island and Tuaheni Point and is bounded to the south by Young Nicks Head (Te Kuri). Coastal processes along the western edge of Poverty Bay have formed a sand beach backed by sand dunes enclosing estuaries and lagoons. The Poverty Bay Flats lie behind these coastal dunes.

The Poverty Bay Flats cover an area of about 200 km^2 comprising the coastal alluvial floodplain of the Waipaoa River and extending inland for about 20 km to Ormond, at an altitude of about 20 mRL (Figure 1). Alluvial terraces extend upstream from Ormond, on both sides of the Waipaoa River, for more than 30 km, passing Te Karaka and Whatatutu. Narrower alluvial terraces also extend westward from the Poverty Bay Flats along Te Arai River and Whakaahu Stream.

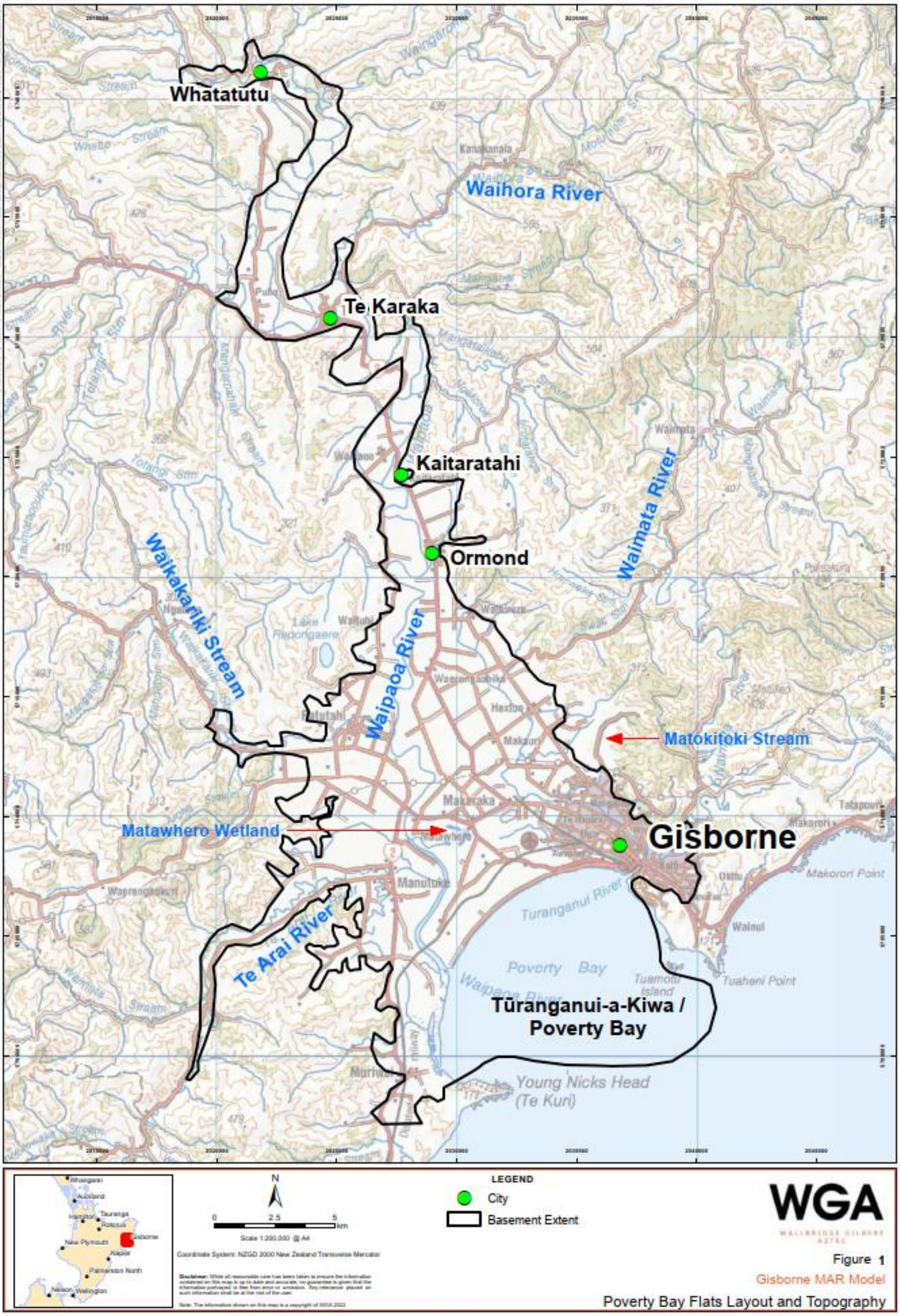

Figure 1: Poverty Bay Flats Layout and Topography

2.3 PRE-QUATERNARY ROCKS

The basement rock of the Waipaoa River catchment is highly indurated and fractured greywacke of Cretaceous age. These greywackes form the Raukumara Range where it intersects the northern and northwestern edges of the catchment. Greywacke is presumably also present at depth beneath the Poverty Bay Flats, although none of the drillholes in this area have intersected greywacke basement.

The hills that form the eastern and western sides of the Poverty Bay Flats, together with much of the Waipaoa River catchment, are predominantly composed of Miocene age massive or thinly bedded siltstone and mudstones of the Tolaga Group (Mazengarb & Speden 2000). A few localised outcrops of Pliocene sandstones of the Mangaheia Group are present forming hillslopes to the east and west or Ormond.

Tertiary rocks intersected in drillholes that have penetrated through the younger Quaternary sediments of the Poverty Bay Flats are predominantly described as siltstones and mudstones in the drillhole logs.

The Tertiary rocks have been subjected to tectonic uplift and are consequently faulted and fractured. Faults have been mapped in these rocks on the eastern and western sides (Mazengarb & Speden 2000). The Arakihi and Waerengaokuri Faults have been mapped as substantial northeast trending faults that extend underneath the Poverty Bay Flats. To the west and north of Whatatutu, in the middle reaches of the Waipaoa River valley, is an extensive area of heavily deformed allochthonous rocks and melange. Although these allochthonous rocks locally bound the northern tip of the groundwater model area, they are predominantly composed of siltstones and are not likely to be of significance in terms of groundwater flows.

The sedimentary deposits of the Poverty Bay Flats infill a river valley basin eroded into the underlying Tertiary rocks. In the central area of the basin, interpretation of the geological log from bore GPC008 (Brown 1984) indicates the depth to basement is at least 225 m (Figure 2).

As the Wairoa River basin is a buried river valley, the valley invert can reasonably be expected to deepen toward the coast unless tectonic movement has changed the gradient following the start of infilling. Drillhole interpretation by Brown (1995) suggests the buried invert of the river valley intersects the current coastline approximately midway between Gisborne and Muriwai (Figure 2). Interpreted tectonic uplift and subsidence rates (Berryman et al 2000) suggest that the deepest part of the basin identified by Brown (1995) may have been lower than its current level when the valley infilling process started (Figure 3).

2.4 EARLY PLEISTOCENE ROCKS

Localised remnants of early Pleistocene fluviatile gravels and sands belonging to the Matokitoki Member of the Maungatuna Formation (not to be mistaken with the late Pleistocene Matokitoki Gravels described in Section 2.5.4) are present on the hills to the east of the Poverty Bay Flats and on each side of the Waipaoa River valley (Neef et al 1996). The Matokitoki Member, together with other units of the Maungatuna Formation, is generally perched on top of older pre-Quaternary rocks that form the hills on the northern side of the Poverty Bay Flats (Section 2.3). Although the Maungatuna Formation is locally thick enough to extend substantially below the adjacent Poverty Bay Flats surface (Brown 1995), there is no evidence that the Matokitoki Member extends beneath the later Pleistocene and Quaternary alluvial deposits of the Poverty Bay Flats (Neef et al 1996).

2.5 LATE PLEISTOCENE DEPOSITIONAL ENVIRONMENT

2.5.1 Sea Level Changes

Greywacke rocks of the Raukumara Range have periodically contributed significantly to gravel and sand strata underlying terraces within the Waipaoa River valley. Late Quaternary and Holocene age buried gravels underlying the Poverty Bay Flats are also predominantly derived from this Cretaceous sandstone (Brown 1995). However, where sedimentary gravels are locally derived from erosion of the Tertiary rocks from hill country to the east and west of the Flats, clasts from the older Cretaceous rocks are not expected to be present. This differentiation of source materials for the gravel aquifers is important for interpretation of aquifer layouts (refer Section 2.5.5), hydraulic characteristics, connections (refer Section 4) and recharge.

At the time of the last glaciation (70 to 14 thousand years (ka) before present (BP)), the sea level was approximately 120 m lower than at present (Taylor 1994, Spratt & Lisiecki 2016). At that time the coastline has been interpreted as being located approximately 30 km to the east of the present coast (Brown 1995). During this glaciation, gravel, sand and silt derived from the Raukumara Range infilled the Waipaoa River valley creating a series of aggradational river terraces (refer Section 2.5). One of these aggradational terraces can be linked to the deepest of the known aquifers underlying the Poverty Bay Flats, the Matokitoki Aquifer (Refer Section 4.5.2).

Sea levels subsequently rose during the Holocene with a high-stand being reached at approximately 8.1 to 7.24 ka BP, before sea levels declined again to the current mean sea level. This high-stand has been interpreted at approximately two to three metres higher than the current mean sea level (Clement et al 2016). Since approximately 6 ka BP, sea level has been essentially stable (Gibb 1986).

2.5.2 Marine sediment and swamp deposits (Aquitard 1)

The oldest Quaternary alluvium infilling the deepest coastal sections of the Poverty Bay Flats basin are marine and swamp silt and clay deposits (Brown 1995). The maximum thickness of these fine-grained deposits is uncertain as these deposits increase in thickness toward the south and are known to extend offshore.

For the purposes of clarity in the geological modelling descriptions, and continuity with the hydrogeological modelling, these fine-grained deposits are collectively called Aquitard 1 in this report. Shallower fine-grained units are also called aquitards, for the same reason, numbered from deepest to shallowest.

2.5.3 Waipaoa 2 to Waipaoa 4 Terraces

The Waipaoa-4 terrace (Figure 4) is the highest and oldest of the recognised aggradation terraces in the Waipaoa River catchment. It consists of a thick sequence of overbank silts (5-10 m) over a poorly defined thickness of gravel. The Waipaoa-4 terrace may be related to cool climate, low stand sea-level episodes at either 90 ka BP or 110 ka BP (Berryman et al 2000).

The Waipaoa-3 terrace remnants (Figure 4) are positioned approximately 15 m to 30 m below the Waipaoa-4 terrace. The terrace consists of 2 m to 4 m thickness of aggradation gravel together with overbank and loess deposits. The terrace is interpreted to have formed approximately 65 ka BP (Berryman et al 2000).

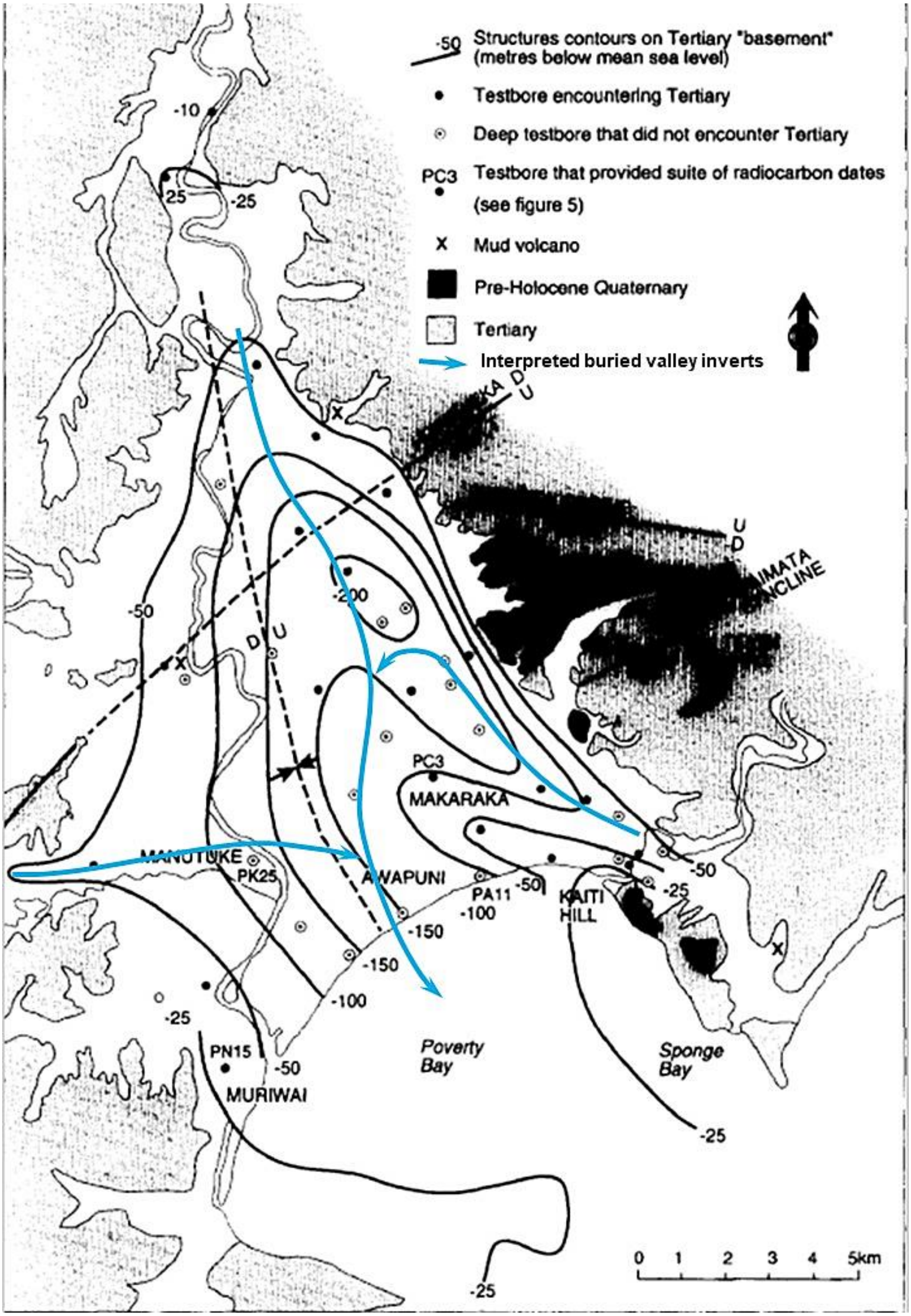

Figure 2: Contours Indicating Base of Quaternary Deposits (Brown 1995)

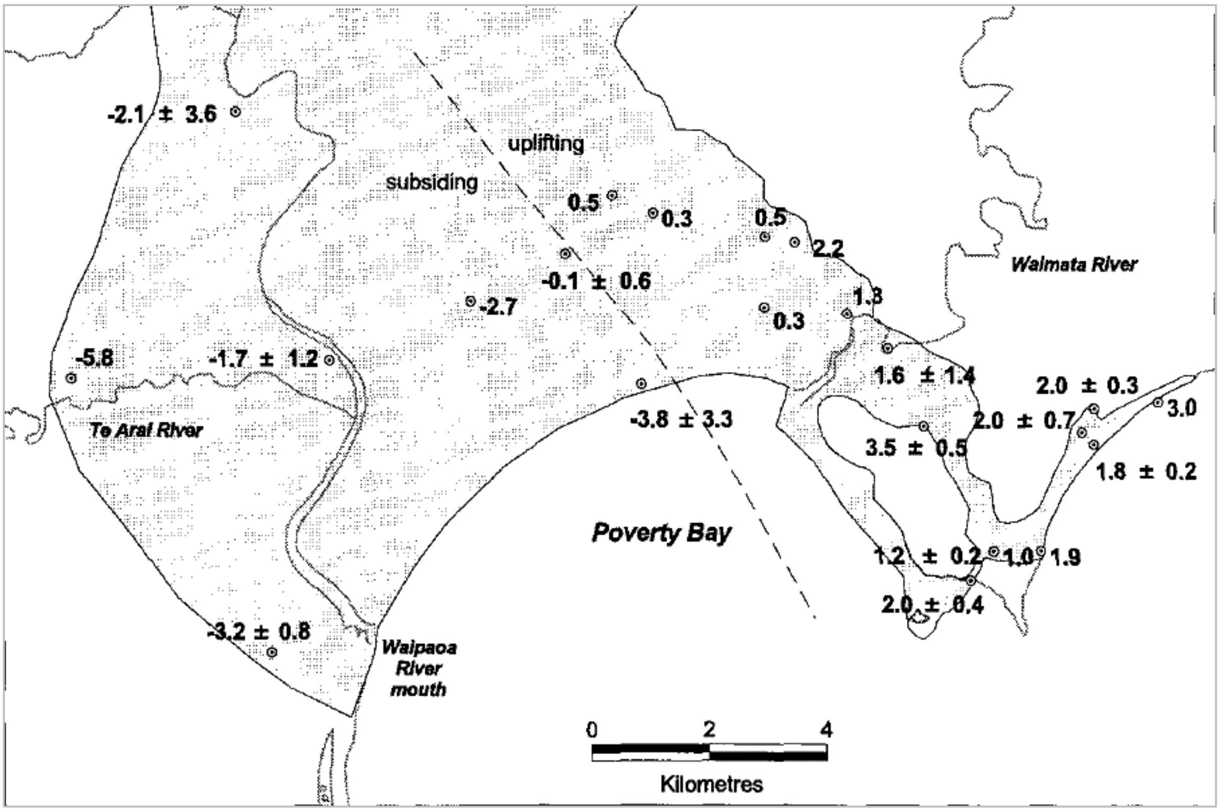

Figure 3: Poverty Bay Flats Uplift/Subsidence Rates in mm/year (Berryman et al 2000)

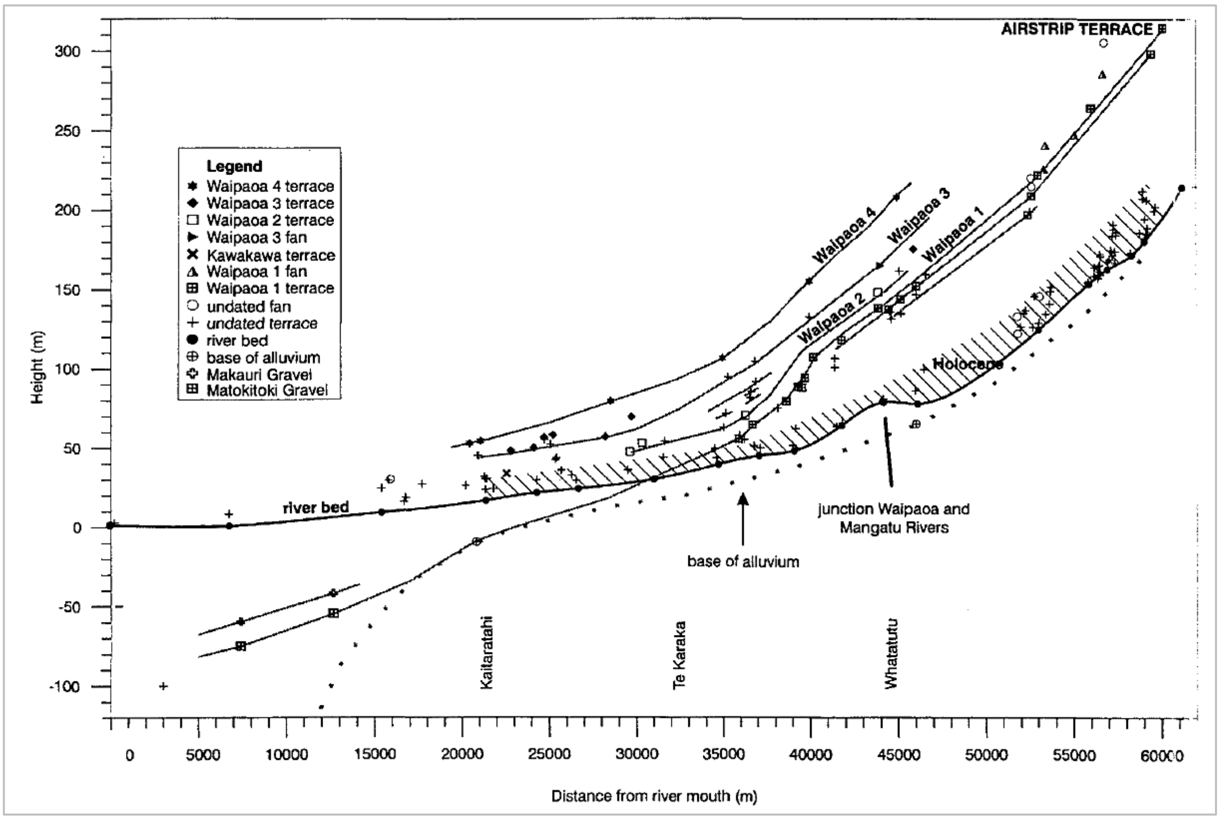

Figure 4: Waipaoa River Terraces, Riverbed and Aquifer Profiles (Berryman et al 2000)

The scattered remnants of the Waipaoa-2 terrace (Figure 4) are positioned approximately 10 m above the Waipaoa-1 terrace at Whatatutu but have greater separation further downstream, particularly near Te Karaka. This terrace is associated with a gravel thickness of only approximately 1 m to 2 m. The terrace is interpreted to have formed approximately 30 to 32 ka BP (Berryman et al 2000).

2.5.4 Waipaoa-1 Terrace (Matokitoki Gravel)

The widespread Waipaoa-1 aggradation terrace (Figure 5) becomes emergent above the modern flood plain a few kilometres upstream from Te Karaka (Figure 4). At the "Airstrip" in Mangatu Forest, approximately 60 km upstream from the coast, this terrace has risen to a height of approximately 120 m above the modern river level. The Matokitoki Gravel underlying the Poverty Bay Flats is interpreted as being the downstream buried equivalent of the Waipaoa-1 terrace gravel (Berryman et al 2000). The Waipaoa-1 terrace development is interpreted as having been coincidental with or initiated before the deposition of the 22.6 ka BP Rerewhakaaitu Tephra and completed by approximately 18 ka BP (Marden et al. 2008).

The elevation of the Waipaoa-1 terrace (Matokitoki Gravel) gravels decreases from approximately 300 mRL 60 km upstream from the coast to approximately 30 mRL 31 km upstream from the coast (Figure 5, Figure 6). This is an overall gradient of approximately 9 m/km along the 29 km course of the river. If measured in a straight line (approximately 12 km), the overall terrace gradient increases to approximately 23 m/km. Beneath the Poverty Bay Flats the Matokitoki gravel occurs at depths from 50 m to 80 m bgl (Brown 1995). Beneath the northern end of the flats the Matokitoki Gravel is expected to be at shallower depth and may merge into the overlying Makauri, Waipaoa and Shallow Fluviatile gravel deposits, making differentiation difficult.

The Waipaoa-1 terrace (Matokitoki Gravel) gravel deposit varies in thickness with increasing distance from the coast:

Approximately 60 km upstream from the coast the gravel is up to 30 m thick (Gage & Black 1979).

Approximately 44 km upstream from the coast, near the junction of the Mangatu and Waipaoa Rivers, its thickness is variable and reaches a maximum of approximately 15 m (Berryman et al 2000).

Approximately 33 km upstream from the coast the gravel is approximately 9 m thick (Berryman et al 2000).

Beneath the Poverty Bay Flats the Matokitoki Gravel is 10 m to 20 m thick (Berryman et al 2000).

At the coastal edge of the Matokitoki Gravel, it is reasonable to expect to find beach sand deposits marking the coastline of that time, similar to the Te Hapara Sands of today. It is also reasonable to expect to find relics of freshwater sedimentary overbank, lagoonal, estuarine and swamp deposits bounding the inland edges of the Matokitoki Gravel. However, these fine-grained freshwater deposits may not be easy to differentiate from older shallow marine deposits or from younger silt and clay rich deposits that overlie the Matokitoki Gravel.

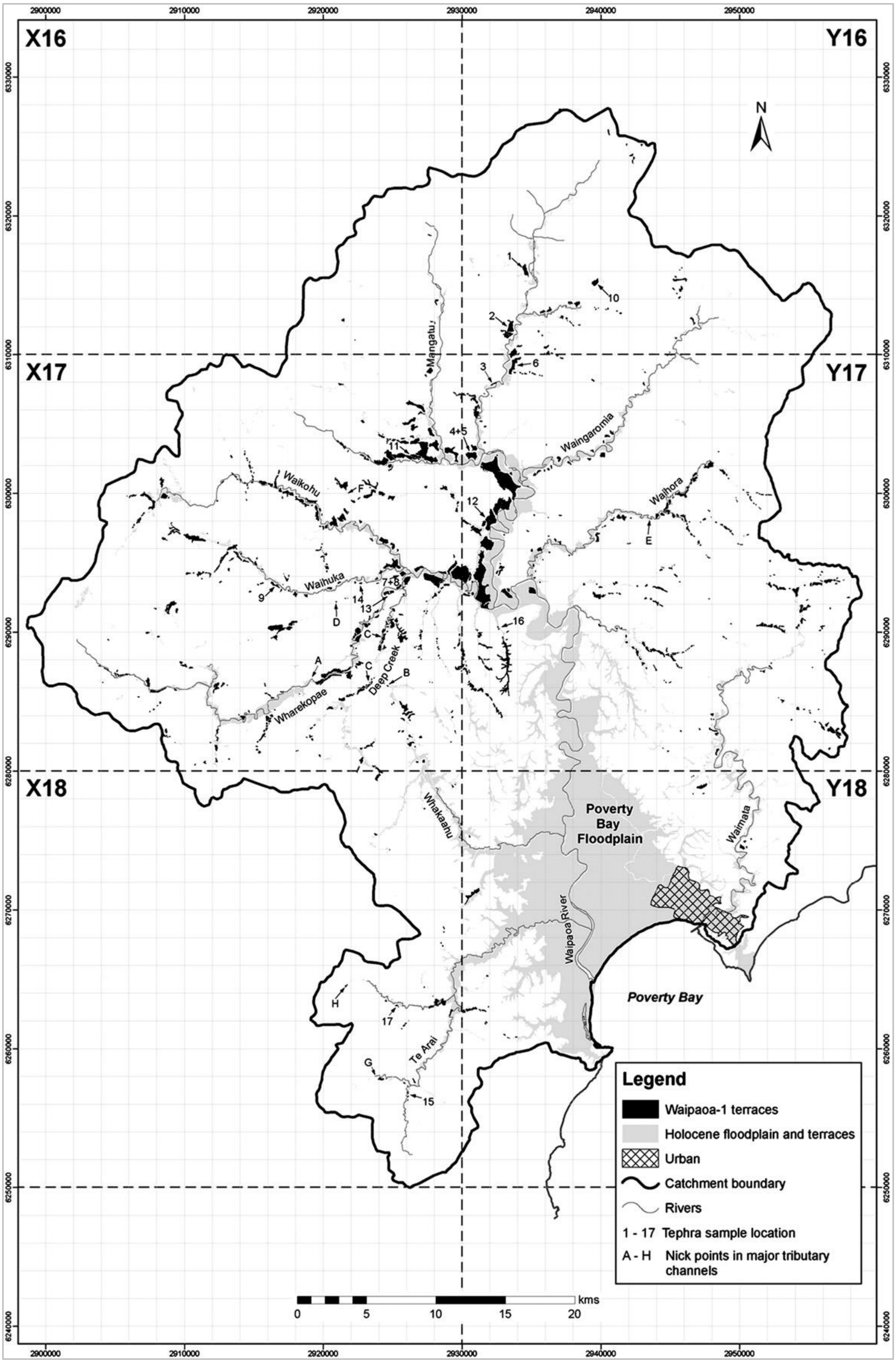

Figure 5: Distribution of the Waipaoa-1 Aggradation Terrace (Marden et al 2008)

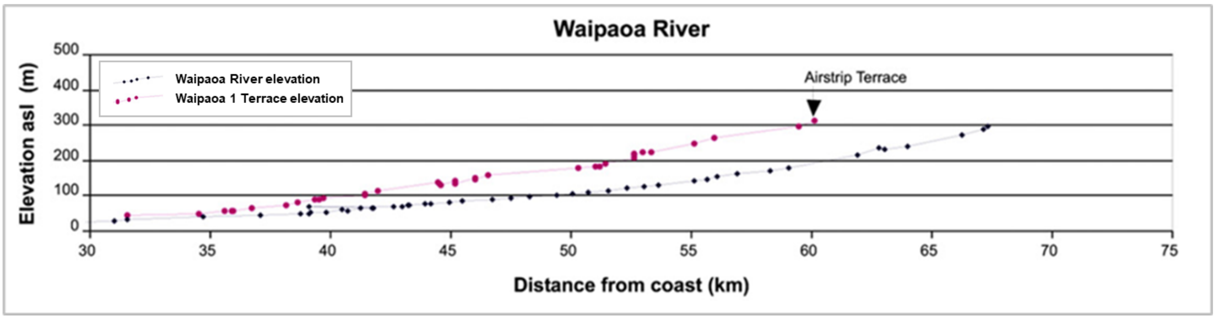

Figure 6: Waipaoa-1 Terrace and Waipaoa River Main Stem Profiles (Marden et al 2008)

2.5.5 Secondary Matokitoki Gravels

Erosion during last glaciation was not limited to the Waipaoa River headwaters in the north of the catchment. Erosion of the lower hills on the western and eastern sides of the catchment was also contributing to the depositional system under the Flats. This erosional process appears to have created valley fill and possibly fan gravel deposits along the edge of the main valley.

These secondary gravel deposits, apparently of a similar age to the Matokitoki Gravels, are likely to be exclusively derived from Tertiary age siltstones, sandstones and limestones as there are no exposed greywacke rocks in their contributing catchments. The difference in their expected composition may help in future interpretation of gravel units of similar ages beneath the Poverty Bay Flats.

One example of a secondary gravel deposit has been identified underlying Gisborne (Taylor 1994). An interpreted river valley paleochannel buried beneath the city trends from southeast to northwest, with the former headwaters being in the Waimata River catchment. The valley invert appears to be characterised by buried stream gravel deposits that are intersected at progressively greater depths toward the northwest. The interpreted gradient of these gravels is substantially steeper than those of most other fluviatile deposits beneath the Flats, as indicated by Taylor's interpretation of the geological cross section (Figure 7). This interpretation of the Matokitoki Gravels rising to intersect overlying Makauri Gravels is supported by data from a pumping test performed in this area (refer Section 4.4.4). Observed hydraulic reactions to this test indicated the Makauri Aquifer (associated with the Makauri Gravels) reacted to the test, which was performed on the Matokitoki Aquifer.

Interpretation of the local sedimentary geology for the pumping test described above (Works 1988) suggested that gravel deposits intersected during drilling of the production bore and some of the nearby bores were significantly deeper than would have been expected for Matokitoki Gravels. It is possible these secondary gravels were not linked to specific erosional periods, such as the Waipaoa-1 Terrace. The interpretation from Works (1988) suggests gravel deposition in these areas may have started prior to deposition of the Matokitoki Gravels and continued after the Matokitoki Gravels were buried by finer sediments. The source of the gravels appears to have been the Waimata River catchment.

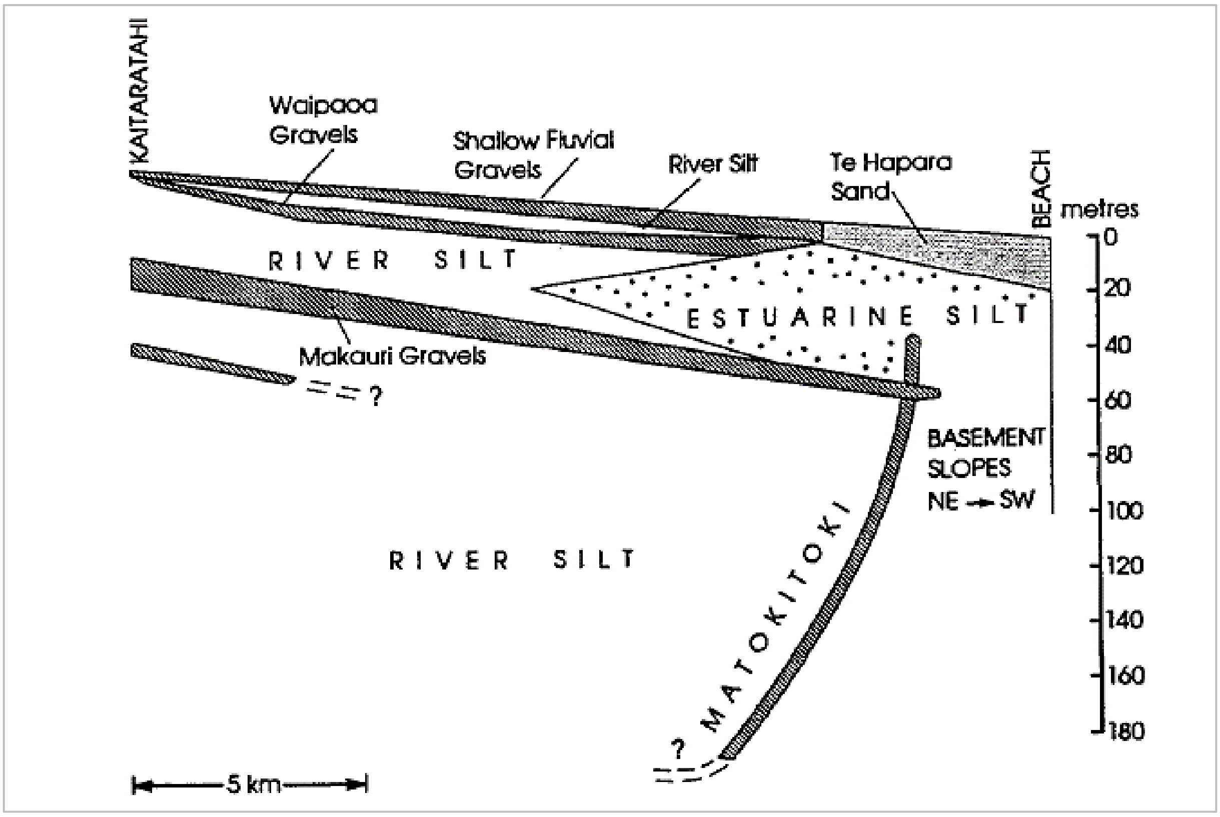

Figure 7: Reverse Gradient of Matokitoki Secondary Gravels beneath Gisborne (Taylor 1994).

Monitoring and interpretation of groundwater quality in the Makauri Gravels (Makauri Aquifer) has identified an area at the eastern side of the Poverty Bay Flats where water quality is improving (Golder 2021, GDC per comm). This groundwater quality improvement suggests either:

1. A possible hydraulic connection between the Makauri Gravels and overlying shallower gravels or the ground surface. Gravel channel fill deposits representing buried stream valleys with steep gradients beneath the eastern side of the Poverty Bay Flats could potentially link broader gravel deposits in the area. Other physical evidence for such features is currently lacking, although the depositional environment is similar to that described for the steeply dipping southeastern section of the Matokitoki Gravels as described above.
2. Groundwater contributions through the bedrock on the margins of the Poverty Bay Flats. These contributions could be through the primary rock mass porosity, although the bedrock in this area is predominantly fine-grained. More likely is the potential for groundwater inflows along faults and fracture zones, as described in Section 2.6.8.

Further investigation and interpretation work in combination with the hydrogeological modelling will be needed to clarify the exact nature of the connection described above.

2.6 HOLOCENE DEPOSITIONAL ENVIRONMENT

2.6.1 Overview

Following the last glaciation, erosion of exposed Cretaceous and Tertiary rocks and the early valley infill sediments within the Waipaoa River catchment occurred. This erosion, combined with downstream sediment deposition, resulted in Holocene river channel and overbank deposits infilling the Poverty Bay Flats (Brown 1995). Holocene age beach, estuarine, lagoonal, swamp and fluvial channel and overbank sediments overlie the sediments deposited during the last glaciation.

Rising sea levels caused the shoreline to retreat until most of the Poverty Bay Flats area was beneath sea level at about 7 to 6 ka BP (Figure 8). The shoreline at this time corresponded to the Holocene sea level high-stand (refer Section 2.5.1). Subsequent small declines in sea level combined with the deposition of sediment in the Poverty Bay Flats area resulted in the shoreline progressively advancing to its current position.

Brown and Elmsly (1987) informally delineated four zones of distinct gravel river channel deposits underlying the Poverty Bay Flats. The Matokitoki (refer Section 2.5.4) and Makauri Gravels were deposited when sea level was lower than that of the present. The Waipaoa Gravel and the Shallow Fluvial Gravel were deposited under current sea level conditions (Brown 1995)

Holocene sediment accumulation under the Poverty Bay Flats and the near offshore environment appears to have been continuous, although at varying rates, following the deposition of the Matokitoki Gravel. To date there has been no documented evidence of significant erosional features within the Holocene sedimentary deposits.

2.6.2 Quiet Depositional Period 1 (Aquitard 2)

Following the deposition off the Matokitoki Gravel, the erosional environment in the upper catchment became less active. The deposition environment across the Poverty Bay Flats became dominated by the accumulation of fine-grained silts and clays. The thickness of these fine-grained deposits increases eastward toward the present-day coastline.

For the purposes of the groundwater modelling (refer Section 4), these fine-grained deposits have been termed Aquitard 2. These deposits overlie the Matokitoki Gravel, where it is present, and otherwise lie on top the fine-grained sediments of Aquitard 1. In the latter case, did may be no depositional hiatus or physical feature to distinguish between the sediments of Aquitard 1 and Aquitard 2.

2.6.3 Fluviatile Depositional Period 2 (Makauri Gravels)

The 9 - 11 ka BP Makauri Gravel indicates the position and elevation of the Waipaoa River during a more active erosional period in the catchment. A fluviatile delta was developing, expanding into the ancestral Poverty Bay. Some of the Makauri Gravel is inferred to be derived from upstream reworking of gravel correlated with the Waipaoa-1 terrace gravels (Brown 1995).

The Makauri Gravel (Brown, 1984) represents a series of gravel channel deposits intersected in drillholes at depths ranging from 25 m bgl at Kaitaratahi to 70 m bgl at Patutahi (Brown 1995). Silt, wood and shell fragments are locally present in drillhole cuttings of the Makauri Gravel, suggesting a marginal marine or beach depositional environment in these areas (Brown 1995).

Several lines of evidence indicate the Makauri Gravel deposits extend at least as far as the current shoreline and perhaps for two to three kilometres offshore:

- Drill holes close to the current coastline have intersected gravel deposits interpreted as belonging to the Makauri Gravel.

- Groundwater monitoring and interpretation (refer Section 4) indicates that at least some of the groundwater flows within the Makauri Gravel (Makauri Aquifer) discharge offshore (Golder 2017, Golder 2021). An interpretation of the groundwater gradients indicates these discharges occur within two kilometres offshore.

- Side-scan surveys of the seabed offshore from Gisborne (Nelson & Healy 1984) have identified shallow features in the seabed that may correspond to groundwater discharge features (refer Section 4.6.6).

Radiocarbon dating of interbedded organic material (wood) suggests that the Makauri Gravel was deposited about 12,000 to 9,000 years BP when the postglacial sea level was rising rapidly in response to climate warming (Brown 1995).

Groundwater drawdown and recovery patterns are consistent across the Makauri Aquifer, with a seasonal water level fluctuation generally between 2 m and 6 m (Golder 2014b). This consistency indicates the Makauri Gravel is strongly connected across their full extent underneath the Poverty Bay Flats (Golder 2014b). However, local erosional or depositional gaps in the gravel beds may be present.

The Makauri Gravel is expected to converge with the underlying Matokitoki Gravel beneath the upstream end of the Poverty Bay Flats. The Makauri Gravel was deposited in a high energy fluvial environment. Consequently, the Waipaoa River at that time may have partially or completely eroded the Matokitoki Gravel before depositing the Makauri Gravel in its place.

Historically, a gravel aquifer extending westward from the western side of the Waipaoa River has been called the West Saline Aquifer (Barber 1993). A branch of this aquifer is interpreted to extend westward from the Poverty Bay Flats underneath the Te Arai River valley flats. Several water bores drilled within the Te Arai River valley are screened at an elevation consistent with that of the Makauri Gravel further east. Conceptually, it is reasonable to assume this gravel was deposited under the same environmental conditions as the Makauri Gravel and is laterally continuous with the Makauri Aquifer.

Information provided by the Treaty Partners indicates the water taken from this western saline aquifer area is too salty for horticultural irrigation use. The observed movement of saline water from the western margin of the clearly defined Makauri Aquifer eastward toward the areas of most intensive groundwater abstraction also supports the interpretation that the western saline aquifer area is hydraulically continuous with the Makauri Aquifer.

However, there are no geological logs available from the GDC database to confirm the sequence of gravel and fine-grained deposits in the Te Arai River valley or for most of the area previously defined as the West Saline Aquifer. Furthermore, water quality monitoring of wells located close to the Waikakariki Stream appear to be screened at shallower depths than expected for the Makauri Aquifer, also indicates groundwater much more saline than would be expected in shallower aquifers. Consequently, a clear and unambiguous interpretation of aquifer extent, continuity and interconnection in this area could not be achieved to support the geological modelling of this area.

In summary, the numerical geological model is constructed based on best available drillhole geological logs and observed outcrops, with a conservative approach taken with respect to uncertainty. Similarly the numerical groundwater model is based on the existing geological information and does not represent the potential full extent of the Makauri Aquifer across the western saline area. It is reasonably expected that both models may be adjusted in the future once further field information becomes available to address the uncertainties in this area.

2.6.4 Quiet Depositional Period 2 (Aquitard 3)

Following the deposition of the Makauri Gravel, the erosional environment in the upper catchment again became less active. The deposition environment across the Poverty Bay Flats became dominated by the accumulation of fine-grained silts and clays. The thickness of these fine-grained deposits increases eastward toward the present-day coastline. These fine-grained deposits are considered to extend beyond the current shoreline overlying the Makauri Gravels.

For the purposes of the groundwater modelling, these fine-grained deposits have been termed Aquitard 3. These deposits overlie the Makauri Gravel, where it is present, and otherwise lie directly on top of the fine-grained sediments of Aquitard 2. In the latter case, there may have been no depositional hiatus and no physical feature to distinguish between the sediments of Aquitard 2 and Aquitard 3. Aquitard 3 is considered to confine the Makauri Aquifer offshore.

2.6.5 Fluviatile Depositional Period 3 (Waipaoa Gravels)

The Waipaoa Gravel (Brown and Elmsly 1987) is a series of gravel, sand and silt, terrace, fan and channel deposits of the Waipaoa River formed during the period of stable sea level and accelerated coastal progradation during the period from about 7 to 5 ka BP. The Waipaoa Gravel infills a meandering river channel at depths of approximately 10 m to 30 m bgl. It is interpreted to extend down the Waipaoa River valley from approximately Te Karaka onto the Poverty Bay Flats as far as Waerengaahika (Brown 1995). At its coastal end, the Waipaoa Gravel interfingers with beach sand and dune deposits as well as swamp, estuary and lagoon deposits. An estuary developed behind the coastal dune complex at that time, covering much of the Poverty Bay Flats area to the east of the Waipaoa River.

The Waipaoa Gravel is expected to converge with the underlying Makauri Gravel beneath the upstream end of the Poverty Bay Flats. As the Waipaoa Gravel was deposited in a high energy fluvial environment, the Waipaoa River at that time may have partially or completely eroded the Makauri Gravel before depositing the Waipaoa Gravel in its place.

2.6.6 Quiet Depositional Period 3 (Aquitard 4)

Following the deposition of the Waipaoa Gravel, the deposition environment across the Poverty Bay Flats again became dominated by the accumulation of fine-grained silts and clays in a coastal estuarine environment. For the purposes of the groundwater modelling, these fine-grained deposits have been termed Aquitard 4.

These deposits overlie the Waipaoa Gravel, where it is present, and otherwise directly overlie the fine-grained sediments of Aquitard 3. In the latter situation there may be no depositional hiatus or physical feature to distinguish between the sediments of Aquitard 3 and Aquitard 4.

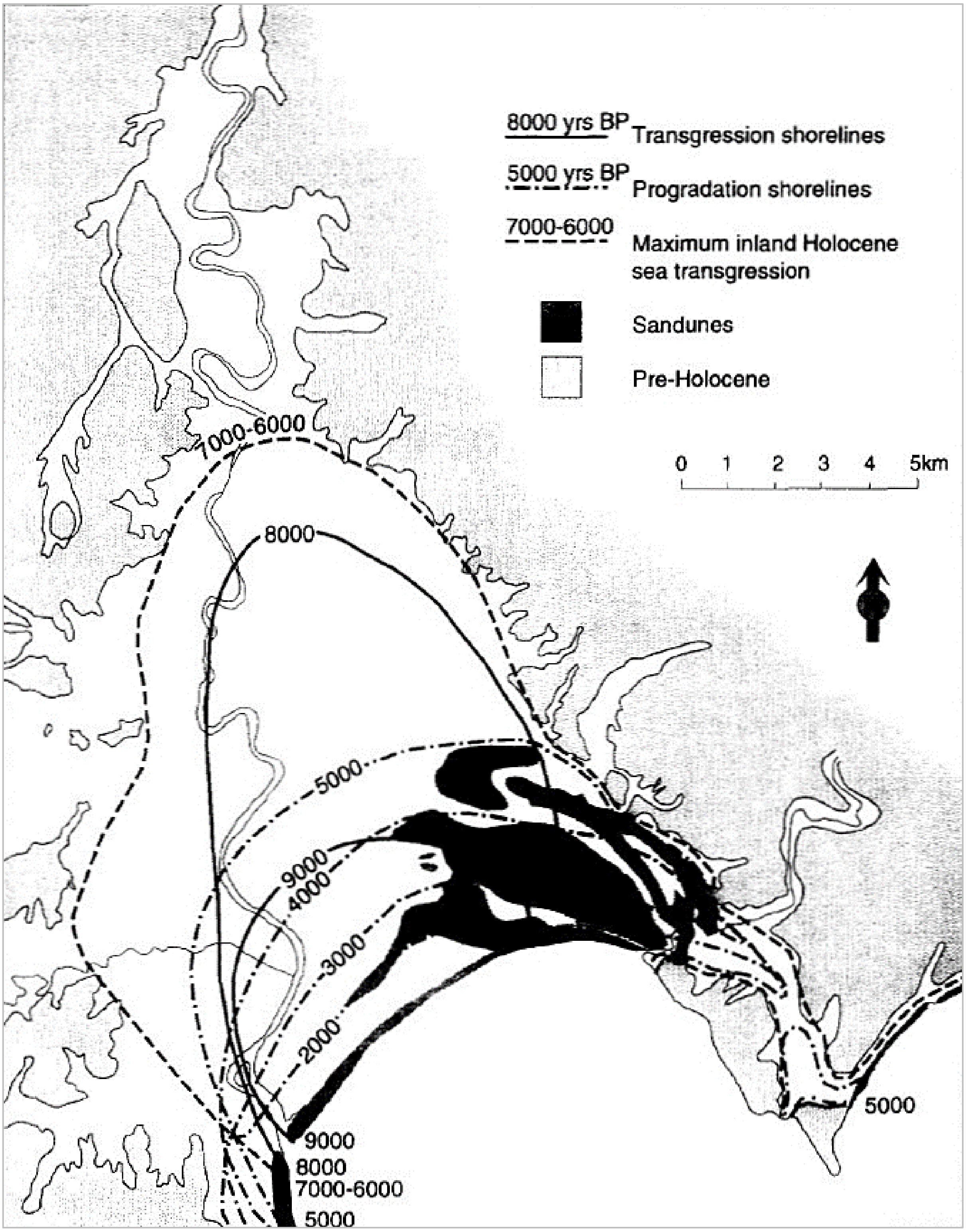

Figure 8: Holocene Marine Transgression and Progradation Shorelines (Brown 1985)

2.6.7 Fluviatile Depositional Period 4 (Shallow Fluviatile Gravels and Te Hapara Sand)

Near surface gravel and sand deposits up to 10 m thick are located close to the present course of the Waipaoa River. These fluviatile deposits are termed the Shallow Fluviatile Gravels and they represent late Holocene deposits of the river beneath and around its current channel. Consequently, the Shallow Fluviatile Gravels can be interpreted as extending continuously from upstream end of the Poverty Bay Flats, as far upstream as Kaitaratahi, out to the current coastline. These deposits also interfinger with the Te Hapara Sands forming a characteristic coastal depositional sequence.

Prograding shorelines along the Poverty Bay coast dating from 5 ka BP to the present are indicated by sand ridges, sand dunes and swales (Pullar and Warren 1968). These beach and dune sands, termed the Te Hapara Sands, have been deposited along the coastline to depths of approximately 20 m. The most recent dunes are aligned parallel to the present coastline from Young Nicks Head around Poverty Bay to Kaiti Beach and enclose the almost infilled Awapuni Lagoon adjacent to the Waipaoa River mouth. The sandy deposits of the Te Hapara Sands extend offshore, becoming finer with increasing distance from the coast.

An extensive estuary associated with fine-grained swamp and estuarine deposits developed behind these dunes as far inland as Ormond. These estuarine deposits locally overlie buried coastal Te Hapara Sands deposits.

The Treaty Partners have pointed out that the Waipaoa River used to discharge to the ocean through the Awapuni Moana area rather than at its current mouth. This advice is supported by an old map for the area presented in a paper by Williams (1888), which shows the mouth of the river was further north than its present location up until 1841. Although not identified in drillhole geological logs, it is reasonably possible that gravels deposited by the Waipaoa River may underlie parts of the Awapuni Moana area and the adjacent dunes along the coastline. However, potential occurrence of gravels has not been incorporated in the numerical models developed for this project because of the lack of supporting drillhole data.

2.6.8 Structural Deformation

Late Quaternary fault scarps have been documented (Berryman 2000) from faults offsetting the Tertiary age rocks in the Gisborne area (Figure 9). It is probable that further faults have been active during the deposition period of the sediments underlying the Poverty Bay Flats but the scarps have not been preserved in the landscape. Berryman et al (2009) investigated activity on the Repongaere Fault close to Ormond, which has previous been described as the only known active fault trace in the area (Read & Sritharan 1993). The investigation determined that offsets along this fault have occurred twice during the past 13,800 years, with each event displacing the fault by between 0.4 m and 1.1 m. This cumulative level of displacement is unlikely to completely offset and disconnect a gravel aquifer of the Poverty Bay Flats, except perhaps in a marginal area where the aquifer is thin.

There is currently no convincing evidence that the Makauri Gravel has been offset by fault activity to the extent that groundwater flows have become disconnected or significantly restricted by the displacements (refer Section 4). As the Makauri Gravel underlies much of the Poverty Bay Flats, this implies that the same would apply to the younger gravel aquifers.

It is possible that faults in the Tertiary rocks adjacent to the Poverty Bay Flats may be characterised by permeability higher than that of the surrounding rock mass. This is the case for the Brewery Spring Fault (refer Section 4.6.5). Such faults may contribute recharge to the aquifers underlying the flats. However, there is currently no evidence that such recharge flows may be having any significant effect on the water balance for the Poverty Bay Flats aquifers.

There are a number of tectonically produced folds have been mapped or inferred in the Tertiary rocks forming the hillsides on either side of the Poverty Bay Flats. These folds generally trend northeast – southwest. No documentation reviewed during this project has indicated that folding has had a significant influence on the aquifers underlying the Poverty Bay Flats. Furthermore, there is currently no convincing evidence that tectonic folds are having a detectable influence on groundwater flows in these aquifers.

2.7 SUMMARY

The conceptual geological model of the Poverty Bay Flats can be represented as a roughly triangular 3-dimensional prism of thick silt and clay deposits alternating with substantially thinner gravel and sand deposits. This prism is bounded laterally to the east and west, and vertically by Tertiary age siltstones and locally sandstones (Figure 9). The prism has its greatest thickness at the southern end of the flats, close to or beyond the coastline.

The youngest gravel deposits, representing the coastal sand deposits of the Te Hapara Sand and the Waipaoa River deposits of the Shallow Fluviatile Gravels, are close to or at the surface. Older buried gravels, representing the Waipaoa, Makauri and Matokitoki sandy gravels deposited by the Waipaoa River, generally increase in depth from north to south. These buried gravel deposits merge toward the northern end of the Poverty Bay Flats, close to the mouth of the Waipaoa River valley, and are separated by increasing thicknesses of silt deposits toward the south. The Te Hapara Sand and the Makauri Gravel appear to extend offshore at the southern end of the flats.

The gravels have been predominantly deposited by the Waipaoa River. A branch of the Matokitoki Gravel, which appears to represent a buried river channel extending underneath Gisborne and becoming shallower toward the southeast, is likely to consist of sediments derived from the Waimata River catchment. An interpreted branch of the Makauri Gravel, which extends westward under the Te Arai River terrace, is likely to consist of sediments derived from the Te Arai River catchment.

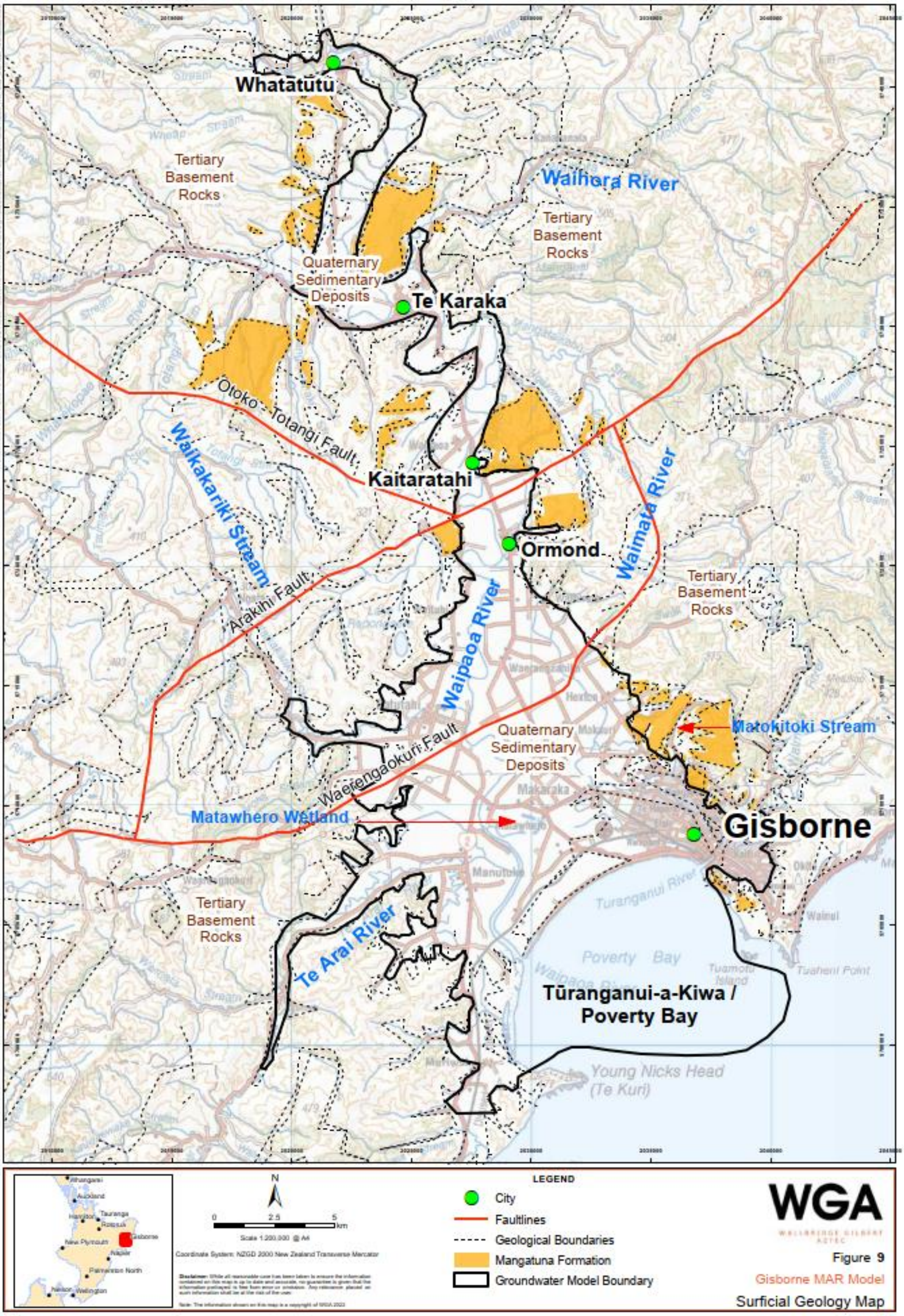

Figure 9: Surficial Geology Map

3 NUMERICAL GEOLOGICAL MODEL

3.1 MODEL DEVELOPMENT PROCESS

The numerical geological model for the Poverty Bay area has been developed using the GeoModeller 4 software package following a development process consisting of seven steps:

1. Validate the GDC bore database and interpret the lithological descriptions into simplified lithological identifiers.
2. Import the modified bore database into the Geomodeller software package.
3. Import the surface topography and offshore bathymetry.
4. Create two-dimensional (2D) cross-sections to support lithological unit interpretation.
5. Interpret lithological units between drillhole logs within the cross-sections, laterally and transversely across the Poverty Bay Flats.
6. Generate three-dimensional (3D) surfaces for the defined lithological units based on interpolation between the interpreted drillhole logs and lithological cross sections.
7. Review and validate the 2D and 3D model outputs, to inform refinement of drillhole and hydro-stratigraphic unit interpretation. This is an iterative process that feeds back to Task 4 and leads to a progressive revision and improvement of the 3D model.
8. Produce an optimised 3D numerical geological model for the Poverty Bay Flats.

The iterative process described for Tasks 5 to 7 above is not one of simply improving the “fit” of the hydro-stratigraphic unit surfaces to the lithological descriptions from the geological logs. It also requires a clear understanding of the depositional environment and the hydraulic behaviour of the aquifers to support the production of a viable geological model that can be used as the basis for the planned hydrogeological model. The following sections of this report summarise the numerical model structure and development.

3.2 BORE DATABASE INTERPRETATION

GDC maintains a bore database containing the name, location, depth, drill date and lithological descriptions for all bores drilled in the region. The lithological description field in this database consists of one word, several words or a sentence used to describe the geology of each drillhole interval. This description is generally copied directly from driller’s logs.

Due to the inconsistency of the descriptions and the occasional complexity of the sentence structure and terminology, a set of standardised lithological descriptors was needed. These descriptors were divided into three data entry fields: primary lithology, secondary lithology, tertiary lithology or material compositions such as wood, shell, etc.

The drillers descriptions of materials intersected by the drillholes are highly variable. Consequently, interpretative decisions regarding the descriptions of the material intersected have occasionally been made for consistency. These decisions generally relate to how the drillhole log descriptions have been applied to the data entry fields and would not significantly affect the understanding of the behaviour of the materials in terms of groundwater transmission. As such, the conversion of the free-form descriptions from the drillhole logs into more consistent field-based descriptions is not expected to influence the identification and interpretation of lithological units (e.g., aquifer and aquitard units) during the numerical modelling process.

3.3 NUMERICAL MODEL CONSTRUCTION

3.3.1 Topographic and Bathymetric Surface

As a first step to model construction the topography derived from LIDAR data provided by GDC was imported to define the upper surface of the model. Bathymetric data, also provided by GDC, was used to define the marine topography offshore, extending out beyond the limits of Poverty Bay. Both topographic and bathymetric data was imported into the model as a grid with approximately 10 m horizontal spatial resolution. The LIDAR data is expected to have a vertical accuracy of better than 0.2 m averaged across each grid cell.

This grid resolution was chosen following a trial to determine a reasonable balance between model run time and accuracy of the topographic data. Taking into account the scale of the model and the density of available drillhole data, increasing the grid resolution would not improve the model accuracy in terms of lithological unit interpretation.

3.3.2 Drillhole Log Import

All of the geological logs for drillholes listed in the GDC database have been imported into the geological model. The ground surface elevation for each geological log has been referenced to the topographic elevation in the model at the location of the drillhole provided by GDC. The exact locations of numerous drillholes in the database provided have not been confirmed to within the nearest 10 m, which is the spatial resolution of the topographic grid derived from the LIDAR data (refer Section 3.3.1). Therefore, the allocation of ground elevations to the drillhole logs incorporates some inaccuracy due to the uncertainty in drillhole locations. This uncertainty has not resulted in significant issues with respect to interpretation of the extent and continuity of geological units underlying the Poverty Bay Flats.

3.3.3 Cross Section Interpretation

Vertical 2D cross-sections were created across the Poverty Bay area to align with bores that contain good lithological descriptions (Figure 10). The cross sections were evenly spaced and generally aligned north-northwest to south-southeast (referred to as North-South sections) and east to west.

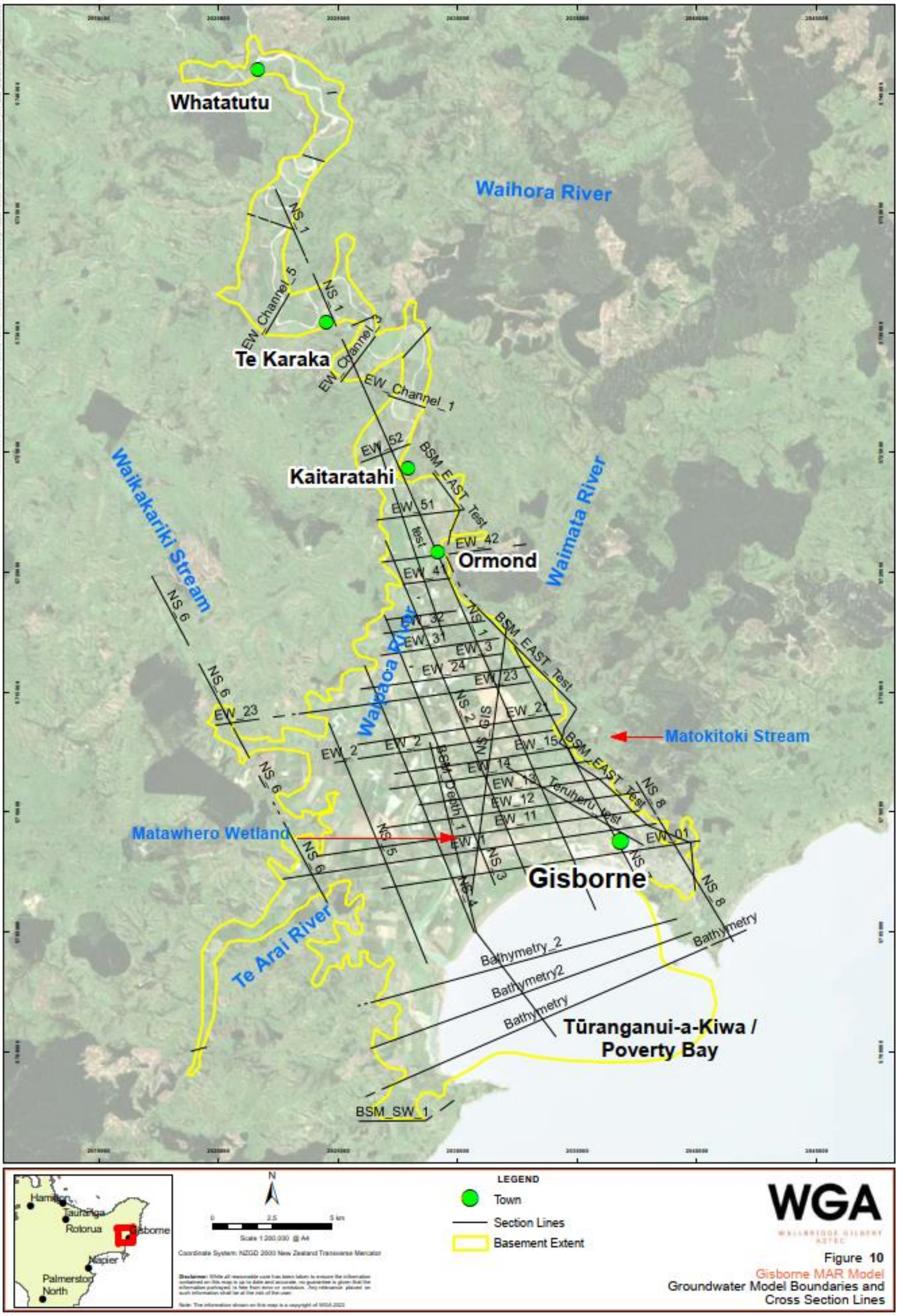

Figure 10: Groundwater Model Boundary and Cross-Section Lines

As the geological model is to form the basis for a numerical groundwater model, a key consideration in developing the cross-section grid was to provide an even and reasonably dense coverage for geological and hydrostratigraphic interpretation across the Poverty Bay Flats. Several cross sections were also installed at an angle to the main grid (Figure 10), primarily to help address specific questions regarding the interpretation of localised connections and gradients within the gravel deposits.

Three offshore cross sections, referred to in Figure 10 as bathymetry sections, have been incorporated in the numerical modelling process even though there is no offshore drillhole data on which to base the geology for these sections. These cross sections have been utilised for numerical purposes to enable the extension of the modelled basement, Makauri Aquifer and Te Hapara Sand model surfaces offshore from the coastline.

Upstream from Kaitaratahi there are relatively few drillholes with associated geological logs. Additionally, these drillholes tend to be located in clusters. Cross sections developed to represent the Quaternary stratigraphy within the Waipaoa River valley upstream from Kaitaratahi are in areas where there are drillhole logs on which to base the stratigraphic interpretation. Consequently, the cross sections are poorly distributed up the valley.

Numerical issues arose with using GeoModeller to interpolate lithological units between clustered cross sections along a relatively narrow winding valley. Consequently, the numerical model was not developed to the north of Kaitaratahi. The same issues arose in simulating the Te Arai River valley and the Waikakariki Stream valley in the numerical geological model. In each case the numerical model terminates where the stream valleys widen out to merge with the Poverty Bay Flats.

The geological interpretation of aquifer extents and elevations in the valleys of the Waipaoa River, Te Arai River and Waikakariki Stream has been completed through manual interpretation of the available information and extrapolation of these units using professional judgement. These interpreted aquifer areas have been incorporated directly into the FEFLOW groundwater model.

The interpretation of lithological connections and continuity within the numerical model is based initially on the establishment of the 2D cross sections aligned with a series of drillholes with reliable and appropriately detailed lithological logs. The stratigraphic sequence and the expected depths of specific lithological units is broadly understood based on the conceptual geological model. The hydro-stratigraphic units are interpreted and allocated to specific lithological units in drillholes that have well-defined geological logs. Surfaces marking the top and bottom of key units (generally aquifers but also the basement, if intersected) are interpolated between drillholes within individual cross sections using GeoModeller.

The elevations, thicknesses and gradients of the key hydro-stratigraphic units are then considered for drillholes with poorer geological logs. Interpretative decisions are made regarding the correlation of hydro-stratigraphic units between drillholes, with consistency of interpretation being a key objective. The correlation of units between drillholes starts from the better, more reliable, drillhole logs and works outward to the lower quality or less reliable logs.

For the purposes of the Poverty Bay geological model, a higher emphasis has been placed on lithological unit continuity and smoothness than on 100% faithfulness to the geological logs. This decision on emphasis was reached through discussions with GDC in response to:

1. The variable quality of the drillhole logs, with drillhole dates covering a range of more than 50 years and the drilling objectives varying from hole to hole.
2. Drillholes that are close together having geological logs that differ substantially. Potential reasons for the dissimilar logs include different drilling dates, drilling objectives, drilling techniques and documentation quality.
3. A tendency for absolute faithfulness to drillhole logs to lead to models with highly compartmentalised aquifers, as occurred in the model documented by White et al (2012). Analyses of groundwater level trends undertaken to date (Golder 2014a, Moreau et al 2020) has shown that the aquifers underlying the Poverty Bay Flats tend to be hydraulically well connected laterally and not compartmentalised.

The interpreted lithological unit surfaces in each cross section were then compared with similar interpretations undertaken for intersecting and adjacent parallel cross sections. The key objective was to provide consistency of interpretation across the entire modelled area. A secondary objective was to identify areas where discrepancies in geological interpretation arose. Such discrepancies generally arose in areas where aquifer splits occur or where drillhole density is low. Where such areas were identified, interpretative decisions were reached regarding the aquifer connections. These decisions prioritised for checking during the numerical groundwater modelling process and may also be explored during future field investigations.

3.3.4 Generation of 3D Geologic Model

Once the hydro-stratigraphic layer interpretation process for the cross sections was completed, a 3D geological model for the Poverty Bay Flats area was generated using GeoModeller. The 3D numerical model was produced through interpolating hydro-stratigraphic surfaces between the cross sections. As described above, an emphasis was placed on surface continuity and consistency.

Once the 3D model has been generated, it is subjected to an iterative review and adjustment process that includes:

1. An interactive visual check of aquifer layouts within the 3D GeoModeller package against the simulated lithological sequences in the drillholes incorporated in the model. As the drillholes and their interpreted lithological sequences are visible in the model, this process enables a first-pass reality check of the model.
2. A comparison of interpreted lithological sequences in the drillholes against the 3D simulated lithological surfaces as they intersect the drillhole.
3. A review of contour maps for the top surface of each lithological unit and the isopach (unit thickness) maps for the same units provides an overview of the general trends across the model. Anomalies such as “bullseye” features on these maps are indicative of potential issues such as misinterpreted unit correlations.
4. A review of screened intervals in wells that have no associated geological logs or other geological information. It is reasonably expected that the screened intervals should correspond with one of the modelled aquifers.

As issues are identified through the above checks, the unit correlations in the cross sections and within the drillhole logs are reconsidered and, if appropriate, corrected. After a series of model versions, the improvements with each successive iteration become minor and the review process concludes with a final model version.

3.4 3D GEOLOGICAL MODEL RESULTS

The lithological units identified through the numerical modelling process (Table 1) generally reflect those described in the conceptual geological model (refer Section 2.6). The extents of the lithological units identified through this modelling process are summarised in Figure 11 and Figure 12. The hydrostratigraphic names corresponding to various lithological units are also presented in (Table 1).

The numerical model includes one layer that was not incorporated in the conceptual geological model. A surficial layer needed to be incorporated in the model to account for soils, artificial materials and shallow materials not described in the geological logs for various reasons. This layer is defined to include all materials between the ground surface and the shallowest specifically identified lithological unit, whether that unit is the Te Hapara Sand, the Shallow Fluviatile Gravel, Aquitard 4 or another lithological unit. As the shallowest materials described in the drillhole logs are highly variable, the nature of this layer has simply been left as “Undefined” for the purposes of the geological modelling (Table 1).

Three components of the hydrostratigraphic system have been identified or better defined through the numerical modelling process.

Firstly, interpretation of the layout of the Waipaoa Gravel suggests that there may be two separate gravel units of similar age and depth within the sedimentary sequence (Figure 12). Conceptually, the Waipaoa Gravel consists of fluviatile gravels deposited by the Waipaoa River. However, the layout of the gravel beds identified through the numerical modelling process suggest a second unit consisting of gravels derived principally from the Waikata River catchment may also be present. This second unit is referred to as Waipaoa Aquifer 2 in Figure 12. This interpretation is tentative, subject to further investigation through the groundwater modelling process, through future pumping tests or through analysis of samples obtained during drilling.

Secondly, it has been known for some time that the Makauri Gravel underlying a localised area in the centre of the Poverty Bay Flats consists of at least two gravel beds separated by a fine-grained intervening layer (Figure 12). For example, two separate gravel beds interpreted as belonging to the Makauri Gravel were intersected during drilling and installation of the trial MAR bore (Golder 2017a). The numerical model confirms the interpretation that the Makauri Gravel consists of at least two gravel layers in this area. However, the correlation of these beds between drillholes and the continuity of the lower bed is unclear due to substantial gaps in the drillhole coverage. Drillholes in this area of multiple beds often terminated in the first gravel bed intersected. Due to uncertainty regarding the interpretation of the split beds, the uppermost gravel bed consistent with the level of the Makauri Gravel has been defined as the Makauri Gravel for the purposes of the geological model. No model layer has been allocated for the lower bed.

Thirdly, the general layout of the southeastern branch of the Matokitoki Gravel bed has been confirmed as consistent with the interpretation by Taylor (1994) (refer Section 2.5.5). This branch of the gravel bed is represented in the numerical geological model and will be incorporated into the numerical groundwater model. It remains unclear to what extent the main body of the Matokitoki Gravel and the southeastern branch apparently derived from the Waimata River catchment are connected. The current version of the numerical model incorporates a substantial connection between these two gravel beds and refers to them cumulatively as the Matokitoki Gravel. This interpreted physical connection will be incorporated into the groundwater model. This aspect of the geological interpretation is subject to further investigation through the upcoming groundwater numerical modelling, through new pumping tests or through interpretation of samples from future drillholes.

Table 1: Hydrostratigraphic Units

Lithological Unit	Hydrostratigraphic Unit	Lithological unit	Aquifer / Aquitard
Undefined	Undefined	Undifferentiated shallow material, highly variable, predominantly soils, locally includes artificial fill.	Undefined
Te Hapara Sand	Te Hapara Sand Aquifer	Coastal shelly beach and dune sands	Aquifer
Shallow Fluviatile Gravels	Shallow Fluviatile Aquifer	Fluviatile sandy and silty gravel deposits	Aquifer
Aquitard 4	Aquitard 4	Silts and clays, locally shelly or with wood fragments, deposited in a low energy coastal flood plain, estuarine, or deltaic environment.	Aquitard
Waipaoa Gravel 1	Waipaoa Aquifer	Fluviatile sandy, silty, gravel deposits derived from the Waipaoa River.	Aquifer
Waipaoa Gravel 2		Fluviatile sandy, silty, gravel deposits potentially derived from either the Waipaoa River or the Waimata River catchment.	Aquifer
Aquitard 3	Aquitard 3	Silts and clays, locally shelly or with wood fragments, deposited in a low energy coastal flood plain, estuarine, or deltaic environment.	Aquitard
Makauri Gravel	Makauri Aquifer	Fluviatile sandy, silty, gravel deposits	Aquifer
		Silts and clays, locally shelly or with wood fragments, deposited in a low energy coastal flood plain, estuarine, or deltaic environment. Incorporated into Aquitard 2 in numerical model.	Aquitard (1)
Makauri Gravel lower split		Localised sandy, silty, gravel fluviatile gravel deposits. Not defined as a layer in the geological model and not defined in the numerical groundwater model.	Aquifer (2)
Aquitard 2	Aquitard 2	Silts and clays, locally shelly or with wood fragments, deposited in a low energy coastal flood plain, estuarine, or deltaic environment.	Aquitard
Matokitoki Gravel	Matokitoki Aquifer	Fluviatile sandy silty gravel representing buried extension of Waipaoa 1 river terrace.	Aquifer
Matokitoki Gravel		Buried stream valley infill sandy silty gravels probably derived from the Waimata River catchment.	Aquifer
Aquitard 1	Aquitard 1	Marine or coastal swamp silt and clay deposits.	Aquitard

Notes:
1) This aquitard is generally included as part of the Aquitard 3 due to the inconsistent and apparently discontinuous nature of the lower Makauri Aquifer split.
2) Interpretation of the continuity, layout and elevation of this aquifer split is problematic from the available drillhole data.

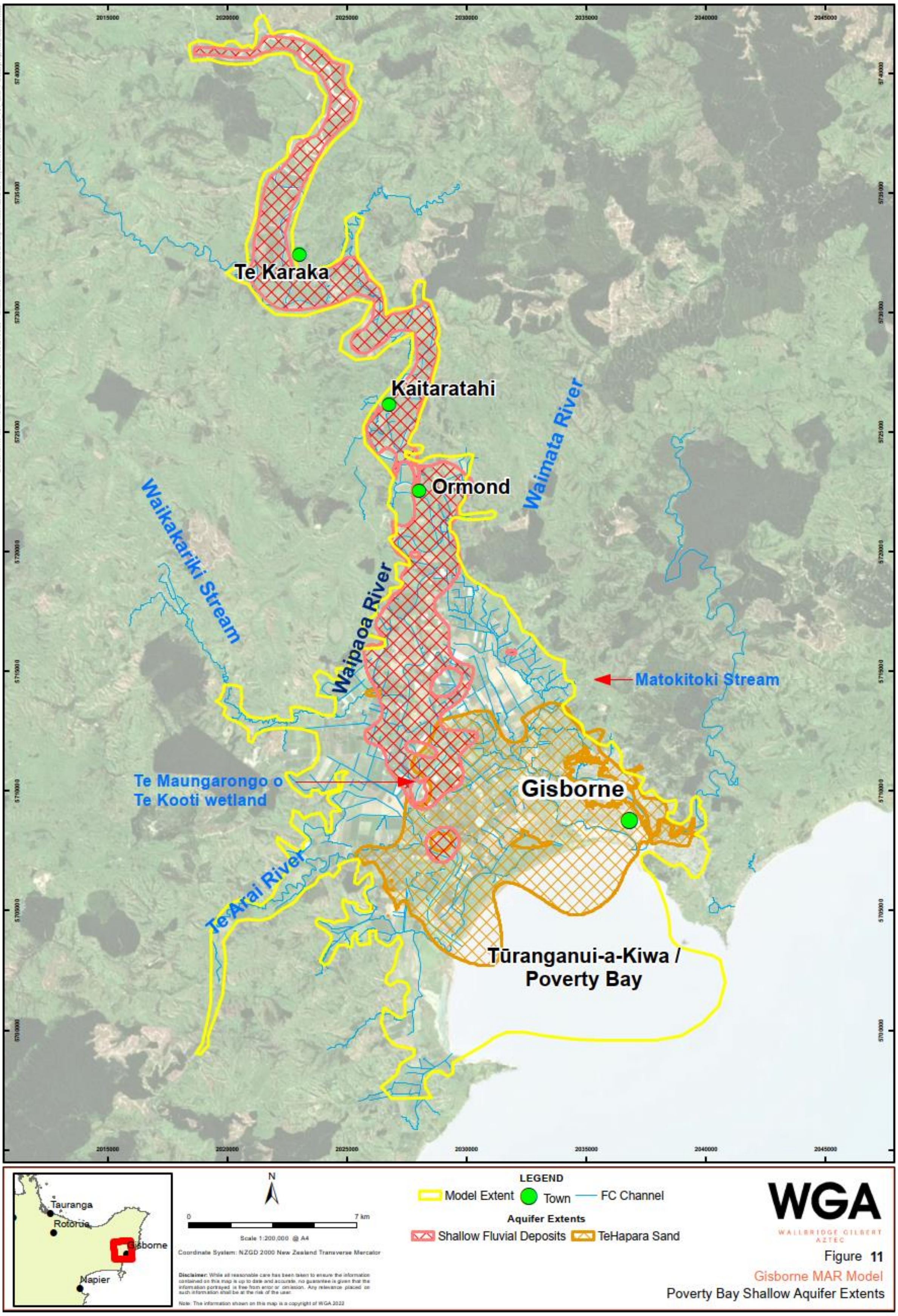

Figure 11: Poverty Bay Shallow Aquifer Extents

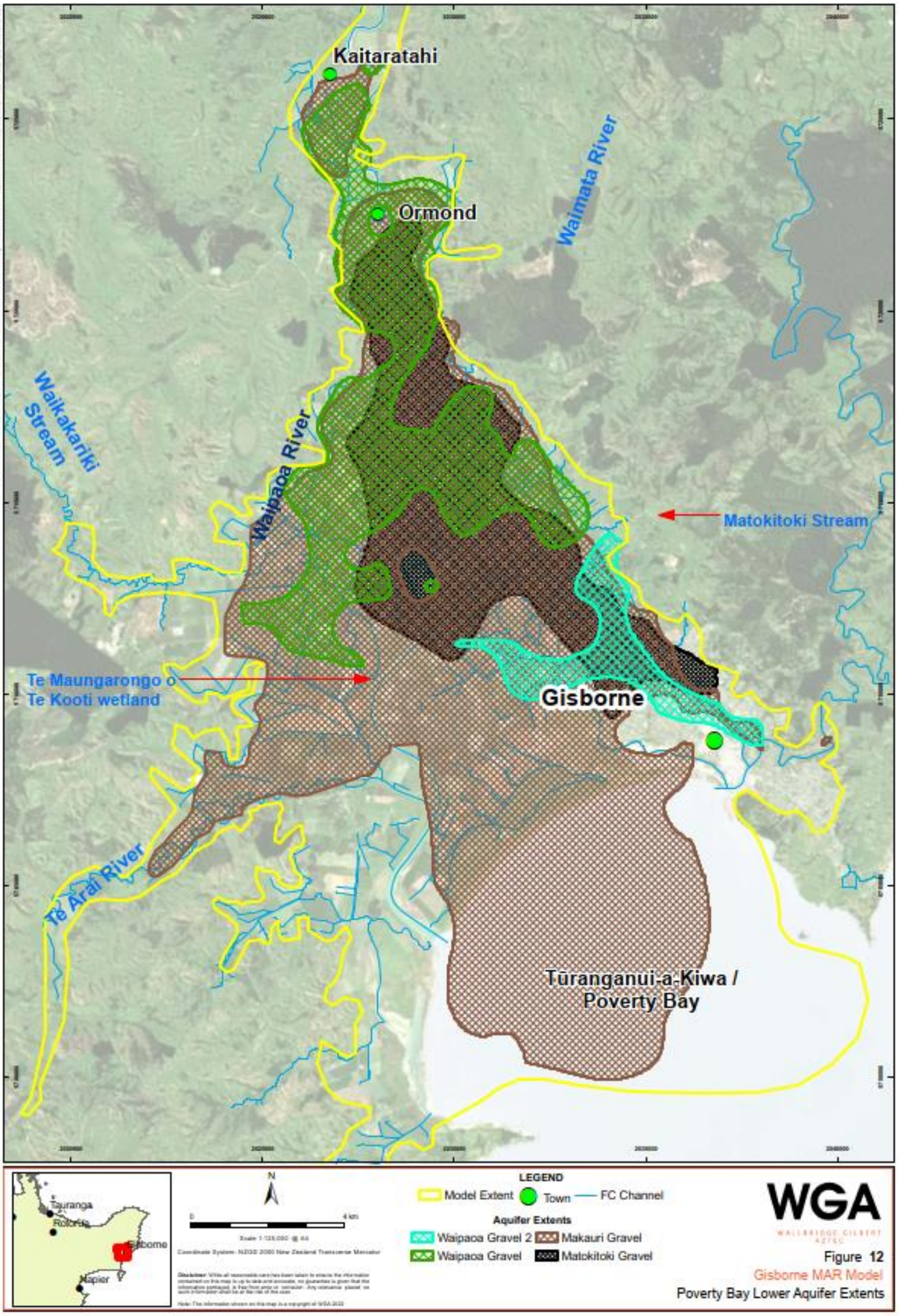

Figure 12: Poverty Bay Deeper Aquifer Extents

A discontinuous layer representing surficial undifferentiated materials needed to be spatially incorporated into the geological model as undefined material (Table 1). This is simply because the geological logs from numerous drillholes describe the shallowest materials intersected as “soil”, “fill”, provide other generalised descriptions or simply leave the shallowest horizon blank. In the numerical this space between the ground surface and the shallowest clearly defined unit needed to be filled and the designation is as presented in Table 1. In the numerical groundwater model (AQUASOIL 2022) a thin “undifferentiated” surficial layer has also been incorporated with permeabilities generally in the range indicative of clean sand or sandy loam. Localised partial confinement of the shallow aquifers by surficial swamp deposits, which has been identified in some pumping test reports, has not been simulated in the model.

3.5 COMPARISON WITH PAST MODELS

WGA is aware of two existing 3D models of the Quaternary sedimentary sequence underlying the Poverty Bay Flats. A groundwater model generated by Golder (2021) suggests the interpreted Poverty Bay aquifers are laterally more extensive than those modelled by WGA. In contrast, a geological model generated by White et al (2012) indicates the gravel beds underlying the Poverty Bay Flats are substantially more compartmentalised and discontinuous than those modelled by WGA. These two models differ substantially in their interpretation of aquifer (or gravel bed) extent and continuity beneath the flats.

The differences between these two models appear to have arisen from different emphasis placed on gravel bed continuity when undertaking the statistical analysis and different allocation of gravels intersected in drillholes to previously defined aquifers. In developing the models, both White et al (2012) and Golder (2021) appear to have relied heavily on statistical interpretation of the geological data from the drillhole database held by GDC. Neither model appears to have benefitted from a detailed review of the drillhole data prior to its use in the statistical analysis. Furthermore, in neither case does the model development appear to take significant account of the depositional environment of the sands and gravels that form most of the aquifers underlying the Poverty Bay Flats when considering aquifer extent and continuity.

In developing the current model, WGA has invested considerable effort in the informed interpretation of the geological sequences based on the known depositional environment of the gravel beds. This interpretation is supported by a detailed knowledge of the hydraulic behaviour of the aquifers and the hydraulic interactions between aquifers. The resulting modelled geology is considered to be more consistent with the observed geological characteristics and hydrogeological behaviour of the aquifers underlying the Poverty Bay Flats than either of the above models.

Furthermore, the process of developing the geological model has resulted in predictions of characteristics of the gravel aquifers that may be tested and verified in the future. This process is presented in detail in Section 4.12. The calibration and validation process for the planned numerical groundwater model also provides opportunity to test the geological interpretation of aquifer extents and continuity.

4 CONCEPTUAL GROUNDWATER MODEL

4.1 OVERVIEW

The hydrogeological conceptualisation of the system as presented in the following sections of this report is a critical contributing component to the development of a numerical model for this system. The conceptualisation is developed to ensure all significant inflows to, and outflows from, the groundwater system have been identified, their locations defined and the volumetric flows for each component approximated.

The lateral and vertical extent of the groundwater model is defined during the conceptualisation to enable the numerical model to incorporate all significant factors affecting groundwater flows in the area of interest, including groundwater abstraction. The conceptualisation also provides guidance on the aquifer and aquitard hydraulic properties that control groundwater flow paths within the model.

The planned numerical groundwater model is to be run on a transient basis, to enable the simulation of seasonal variations in climate and groundwater usage. A decision was made at the conceptualisation stage through discussions with GDC staff to initially run the numerical groundwater model using monthly stress periods. This decision takes into account limitations on some of the available data, such as groundwater abstraction records. Inputs to the transient model are therefore averaged on a monthly basis.

4.2 CLIMATE AND DISTRIBUTED GROUNDWATER RECHARGE

Average annual rainfall increases from less than 1,000 mm at Gisborne to approximately 1,400 mm in the upper Waipaoa River catchment (

Table **2**). Of these totals, approximately 60 % falls during the autumn and winter months of March through to August. Average monthly potential evapotranspiration substantially exceeds monthly rainfall from October through to February (Figure 13).

Spatially distributed rainfall recharge to the Poverty Bay Flats aquifers is considered to predominantly occur through the period March to August annually. Although irrigated areas have increased over time as the horticultural industry in the region has expended, most of the irrigation is designed to maintain soil moisture levels through the main summer crop production period. Irrigation practices on the horticultural areas of the Poverty Bay Flats are relatively efficient and do not appear to lead to widespread and frequent exceedance of the soil water holding capacity. For the purposes of the groundwater modelling, it is assumed that distributed groundwater recharge to the unconfined aquifers is predominantly limited to the period March to August annually. Monthly recharge is calculated for the numerical model by subtracting potential evapotranspiration from rainfall on a monthly basis.

Table 2: Monthly Average Rainfall and Potential Evapotranspiration

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

Notes: 1) 1981 – 2010 (Chappell 2012)

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

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

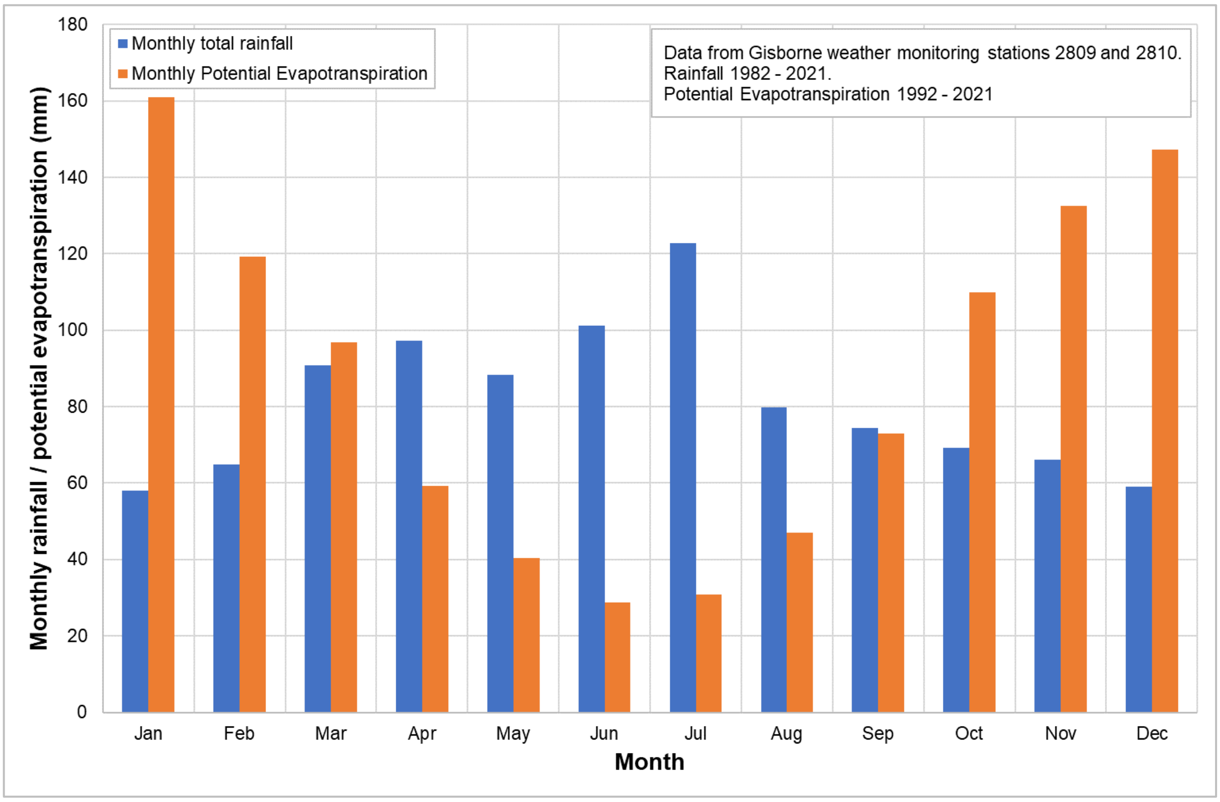

Figure 13: Average Monthly Rainfall and Potential Evapotranspiration at Gisborne

4.3 MODEL EXTENTS

4.3.1 Model Spatial Extents – Basement

The lateral and vertical boundaries to the groundwater model are based on the key assumption that groundwater flows through the Tertiary rock mass into the Quaternary sedimentary deposits of the Poverty Bay Flats are negligible. For numerical model, the Tertiary basement rock mass is considered to be effectively impermeable and therefore excluded from the numerical groundwater model.

Drillhole logs from bores that intersect the underlying rocks generally describe the basement as a siltstone or papa, supporting the above assumption, although sandstones have on occasion been identified when intersected in drillholes. Earlier interpretation of the Poverty Bay groundwater system identified only isolated aquifers within the Tertiary rocks along the eastern and western edges of the basin (Taylor 1984). More recent interpretations and modelling of the Poverty Bay groundwater system have also incorporated this key assumption (Golder 2014, 2021; White et al 2012).

The lateral boundaries of the model are defined along the foot of the hillslopes surrounding the Poverty Bay Flats, as shown in Figure 14. These boundaries also extend northward on either side of the Waipaoa River valley and along the sides of the Te Arai River valley (refer Section 4.3.2).

The base of the model is defined as the base of the Quaternary deposits within the Poverty Bay basin. The base of the Quaternary sedimentary deposits, which represents the base of the groundwater model, is poorly defined under the Poverty Bay Flats due to the lack of deep drillholes (refer Section 2.3). However, the basal Quaternary deposit underlying much of the flats is a marine silt and clay unit that is considered to behave as an efficient aquitard. Therefore, good control on the depth to basement in the central area of the groundwater model is not deemed necessary for the purpose of numerical modelling. Although the basal aquitard is included for completeness, the effective base of the groundwater model is the base of the Matokitoki Aquifer.

The contours presented in Figure 14 representing the base of the model to not extend up the tributary valleys or to the full extent of the model offshore. This reflects the lack of drillhole geological data outside the contoured area for incorporation into the geological model. The surface for the base of the numerical groundwater model in the tributary valleys and in the upper reaches of the Waipaoa Review valley has been derived separately by extrapolating the adjacent hillslopes downward under the valley fill alluvium. The interpreted base of the Quaternary alluvium model was then adjusted to ensure the invert for each valley has a consistent gradient toward the coast. The outcomes have been validated against data from water bores that do not have associated geological logs, to confirm the terminal depth of the bore or the screened interval is within the interpreted alluvium.

4.3.2 Model Spatial Extents – Waipaoa River and Tributary Stream Valleys

The northern end of the groundwater model has been defined in the Waipaoa River valley slightly upstream from Whatatutu (Figure 1). The Waipaoa River flows from the north to the south across the model area. Substantial tributary streams include the Te Arai River, Whakaahu Stream, Waikohu River, Waingaromia River and Mangatu River. However, few water bores have been drilled in the upper reaches of the Waipaoa River, upstream from Te Karaka, or along secondary rivers and streams outside the Poverty Bay Flats area. The lack of bores drilled along these rivers and streams is due to relatively small demand for water in these areas, the use of surface water takes to supply these demands and the limited extent and thickness of coarse-grained Quaternary sediments for groundwater production.

It is unlikely that groundwater seepage within the valley fill deposits along tributary streams to the Waipaoa River will contribute significantly to flows within the Poverty Bay Flats groundwater system. Consequently, the conceptual groundwater model excludes most of these tributary streams from simulation in the numerical model. Exceptions are the Te Arai River, Waikakariki Stream and the Waimata River (Figure 1).

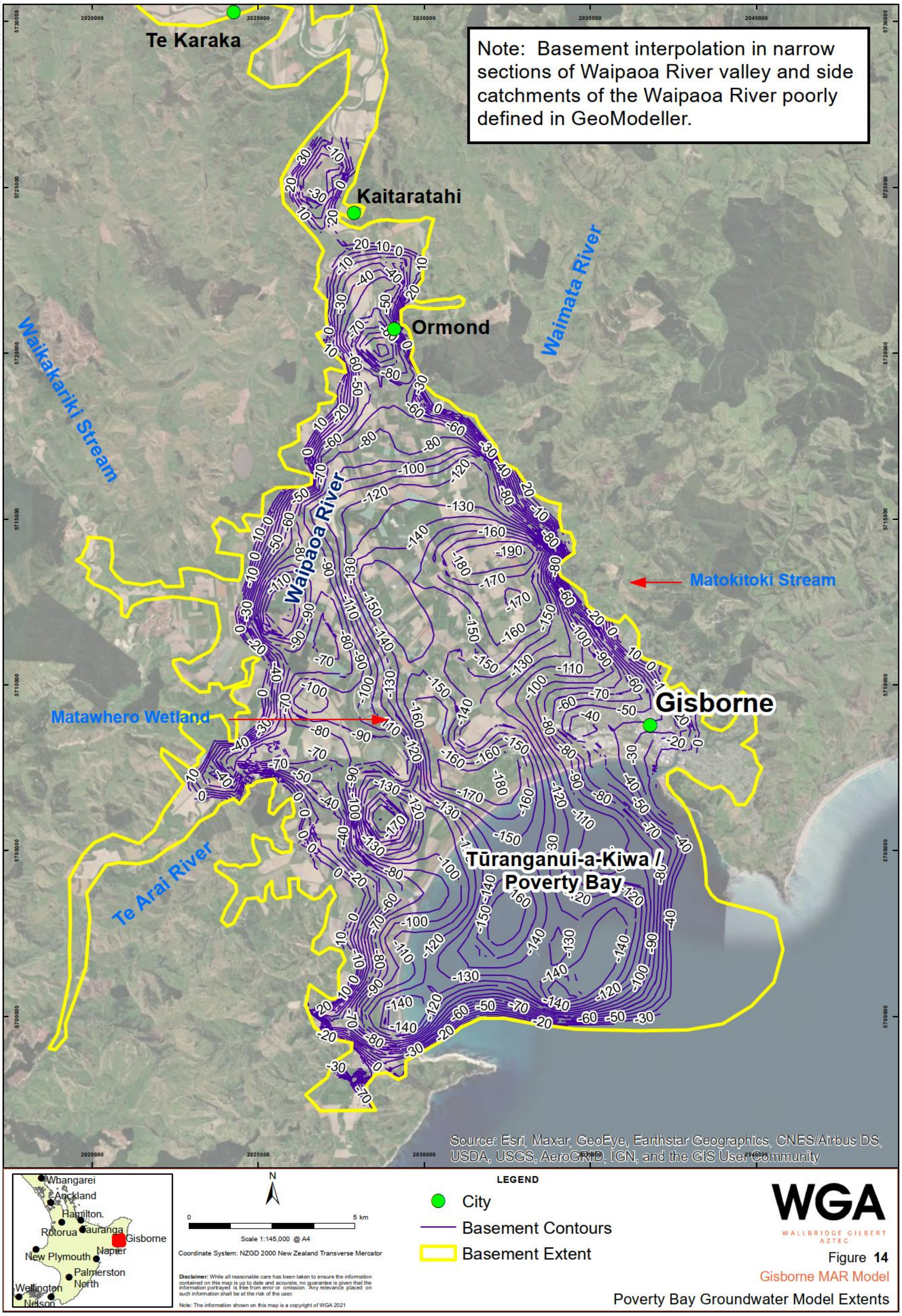

Figure 14: Poverty Bay Groundwater Model Lateral Boundaries and Basement Contours

The Te Arai River overlies the western section of the Makauri Aquifer, which is characterised by saline groundwater. Interpretation of the placement of water bore screens, groundwater quality data and the geometric layout of the aquifer in the Te Arai River valley suggests there is a limited or negligible hydraulic contact between the Makauri Aquifer and the Te Arai River. Furthermore, there is no indication of a shallower aquifer in the valley fill deposits underlying this river. However, the presence of the aquifer in this valley opens up the possibility that there may be some interaction between the aquifer and the overlying surface water system in this area. The numerical geological model did not simulate the Makauri Aquifer in the Te Arai River valley due to a lack of drillhole logs from this area. However, the numerical groundwater model will include the aquifer based on water bore screened intervals.

An extension of the groundwater model to include the lower reaches of the Waikakariki Stream has been done simply on the basis that a similar extension to the Makauri Aquifer may underlie the floor of this valley. This decision and its application in the numerical model provide for possible future adjustments to the groundwater model in this area if necessary.

A short section of the Waimata River valley south of Gisborne is incorporated in the conceptual and numerical model. This section of river valley has been retained to provide flexibility for the possible incorporation of an additional hydraulic boundary condition into the numerical groundwater model. The source of groundwater recharge to a southern branch of the Matokitoki Aquifer (Figure 12) is currently unclear (refer Section 4.4.4) and some of it may derived from a buried river channel in this valley. Therefore, space has been provided in the numerical model to establish an appropriate hydraulic boundary condition in this area if necessary.

4.4 HYDROSTRATIGRAPHIC LAYOUT

4.4.1 Overview

A hydrostratigraphic summary of the lithological units derived from the numerical geological model is provided in Table 1. None of the aquifers listed in Table 1 are continuous across the full extent of the Poverty Bay Flats. Their extents are summarised in Figure 11 and Figure 12. A north-south cross section from the geological model through the middle of the Poverty Bay Flats, which includes intersects of all of the defined aquifers, is presented in Figure 15 for reference.

In areas where aquifers merge through an older deeper aquifer rising to intersect a shallower younger aquifer, the hydraulic characteristics and behaviour of the younger aquifer are considered to prevail for groundwater modelling purposes. In effect, the more recent river activity is considered to have eroded and reworked the older aquifer materials, with these older materials being replaced by newer deposits.

The Te Hapara Sand Aquifer and the Shallow Fluviatile Aquifer are of similar ages, interfinger with each other (Figure 11) and are both considered to act as unconfined or locally semi-confined aquifers (Figure 15). The degree of confinement depends on the exact nature of the shallow undifferentiated materials that are present at surface. Any partial confinement has generally been indicated by local pumping tests on these materials returning storativity results less than 0.01, which is considered less than reasonable for an unconfined sandy or gravelly aquifer.

The geological modelling results indicate the Waipaoa Aquifer is predominantly confined except at its northern end, where it rises to intersect the Shallow Fluviatile Aquifer at the southern end of the Waipaoa River valley (Figure 12). Disconnected gravel horizons at similar elevations to the main Waipaoa Aquifer have been interpreted as belonging to this unit, even though they may be hydraulically disconnected.

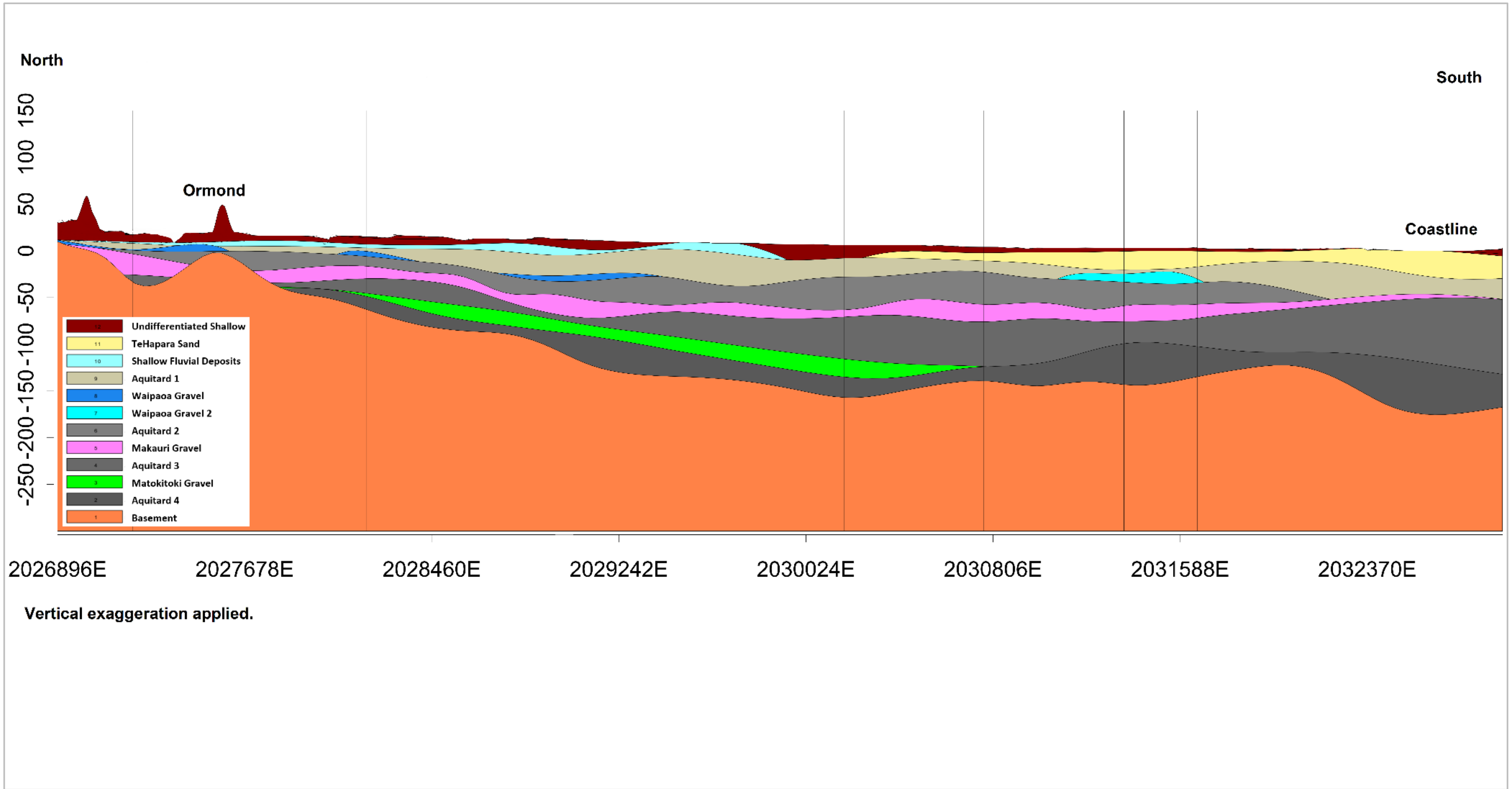

Figure 15: Representative North – South Geological Cross Section of the Poverty Bay Flats

The Makauri Aquifer is the primary productive aquifer in the region and is interpreted to be effectively continuous within its footprint area (Figure 12). Drilling has identified that this aquifer is locally separated into two splits. The upper split is defined as the Makauri Aquifer by default; however, this does vary based on interpretation of the local drillhole logs and elevations of the gravel deposits. The Makauri Aquifer is predominantly fully confined, except at its northern end where it rises to intersect the Waipaoa Aquifer and Shallow Fluviatile Aquifer.

The Matokotoki Aquifer is the oldest and deepest of the aquifers present beneath the Poverty Bay Flats (Figure 15). It is interpreted to as being effectively lithologically continuous and hydraulically connected within its footprint. This aquifer is characterised as having at least two spatially distinct components with different gravel sources, gradients, and potentially hydraulic characteristics. The is characterised as being predominantly fully confined. However, hydraulic testing of the aquifer close to Gisborne has indicated that the Matokotoki Aquifer is hydraulically connected to overlying aquifers in this area.

The aquitard layers have been interpreted as consisting of silt or clay rich overbank, lagoon or estuary deposits, with the exception of Aquitard 4. This is the oldest of the aquitard layers and is interpreted as being a deposited shallow low energy marine environment. The thickness of each of the aquitard layers is interpreted to increase towards the coast, leading to an increasing degree of deeper aquifer confinement in this direction.

4.4.2 Aquifer Extents and Layout

In defining the extent of the aquifers in the conceptual groundwater model it is important to recognise a key difference compared to the modelling process followed in the development of the numerical models. The aquifers in both numerical models have been defined strictly and conservatively based on drillhole geological logs data. The aquifers in these models have not been extended significantly beyond the areas where this data is available, even where other observations such as drillhole depths or screened intervals indicate aquifers extend substantially further than defined in the models. This conservative approach was taken because the development of 3D aquifer surfaces would be indefensible without supporting geological data.

In contrast, more freedom of interpretation has been accepted in developing the conceptual groundwater model. For example, the conceptual groundwater model incorporates:

1. The western saline area of the Makauri Aquifer as spatially extending underneath the Te Arai River flats, based on known drillhole screen depths.
2. The Matokitoki Aquifer extended significantly further southward compared to its extent in the numerical model, based on two deep bores with known drillhole screen depths and groundwater quality data.
3. The Te Hapara Sand extending further along the coastline to the south of the Waipaoa River mouth, based on surface geological mapping.

Both numerical models have been set up to enable the aquifers to be extended appropriately once supporting geological data becomes available or if a more extended interpretation of the aquifers is sought for comparison purposes.

This contrast in model development methodologies has resulted in a few monitoring wells screened in known aquifers being located outside the footprint of the associated aquifer as defined in the numerical geological and groundwater models. Such monitoring wells have no geological log and, in most cases, geological logs from other nearby bores do not show any gravel deposits at depths appropriate to the aquifer linked to the monitoring well. These anomalous monitoring wells, which are identified in maps in the AQUASOIL (2022) report, highlight the difficulty in defining localised aquifer continuity where the geological information may not be of the highest quality.

The lateral extents of the aquifers defined for the Poverty Bay Flats as set out in Table 1 are presented in Figure 11 and Figure 12. The lateral extents of the aquifers presented in these figures correspond to the sand and gravels beds of the same names. These aquifer extents are derived from numerical geological modelling of the stratigraphic sequence underlying the Poverty Bay Flats.

The southeastern branch of the Matokitoki Aquifer, as described in Sections 2.5.5 and 0, is considered to be physically and hydraulically connected with the main body of the Matokitoki Aquifer. For the purposes of the current groundwater modelling these two areas are treated as a single aquifer. It is known that the Matokitoki Aquifer extends further to the south than is shown in Figure 12, as two deep drillholes closer to the coast are screened at elevations that would be consistent with the Matokitoki Aquifer. However, no geological logs are available for these drillholes and the extent, thickness and characteristics of the aquifer in this area are unclear. The numerical models therefore terminate the Matokitoki Aquifer at the southernmost point where the aquifer can be clearly described.

An aquifer consistent in depth with the Makauri Aquifer appears to underlie the alluvial terraces on either side of the Te Arai River, as described in Section 2.6.3. Although several bores are screened in this aquifer, there are no geological logs available and there is no record of current water use from any of these bores. Historical information and guidance from the Treaty Partners indicates the groundwater in this area has elevated salinity and is of poor quality leading to the limited development of water supply bores over the years. This description is supported by current groundwater quality records from the Makauri Aquifer indicating increasing salinity toward the west from the Waipaoa River. This western saline aquifer area is considered to be an extension of the Makauri Aquifer. Maps showing chloride concentrations recorded from the aquifers underlying the Poverty Bay Flats are presented in the groundwater quality conceptualisation report (WGA 2022b).

The Waipaoa Aquifer as shown in Figure 12 is separated laterally into two units, based on the geological drillhole logs. This may reflect the reality of the aquifer layout or it may be an artifact of poor drillhole logging. For the purposes of the conceptual groundwater model, this layout has been accepted. This layout is similarly represented in the numerical groundwater model (AQUASOIL 2022).

4.4.3 Aquitard Extents and Layout

The aquitards listed in Table 1 are by default considered to be laterally continuous within the extents of the Quaternary sedimentary deposits underlying the Poverty Bay Flats. The exceptions to this aquitard continuity occur in areas where the deeper aquifers rise to meet overlying aquifers, in which case the intervening aquitards pinch out (refer Section 4.4.4).

The aquitards are generally assumed to lap directly onto the basement surface at the edges of the basin. The base case conceptual model for the groundwater system does not include localised exceptions to this assumption. However, there are a few areas along the northern edge of the model where groundwater level or quality monitoring data indicate this assumption may not be valid, as documented in Sections 4.4.4 and 4.6.8. This assumption is subject to review through the calibration process for the numerical model.

The aquitard thicknesses and lateral extents have not been specifically defined in the geological model, as these aspects of the model are controlled by the elevations and thicknesses of the aquifers and the elevation of the basement surface.

4.4.4 Aquifer Interconnections

Northern end of Poverty Bay Flats

There are numerous lines of evidence supporting the conclusion that the Waipaoa, Makauri and Matokitoki Aquifers intersect or interact hydraulically with the Shallow Fluviatile Aquifer and the Waipaoa River at the northern end of the Poverty Bay Flats close to Ormond or within the Waipaoa River valley. These lines of evidence include:

- The gravel beds that constitute the Waipaoa, Makauri and Matokitoki Aquifers become progressively shallower toward the north.
- The gradient of the piezometric surface within the Makauri Aquifer during winter indicates a consistent groundwater flow direction from north to south, indicating a primary recharge area at the northern end of the Poverty Bay Flats (refer Section 4.8).
- It becomes increasingly difficult to statistically differentiate between groundwater hydrographs from monitoring wells screened in the Makauri and the Waipaoa Aquifers close to the northern end of the Poverty Bay Flats (refer Section.

Gisborne City area

A branch of the Matokitoki Aquifer underlies Gisborne to the southeast of the main body of the aquifer (Figure 11). This branch is interpreted as consisting of buried valley fill deposits and deepens toward the north, which is the reverse trend to that of the main aquifer system. This branch of the Matokitoki Aquifer is characterised by flowing artesian groundwater pressures (static groundwater heads higher than the overlying ground surface). The aquifer recharge area needs to be above the local ground level of the Poverty Bay Flats in order to generate the observed flowing artesian pressures. The recorded static water levels suggest groundwater seepage flows from east to west within this branch, implying a recharge area along the eastern edge of the aquifer, although there is uncertainty regarding this interpretation (refer Section 4.8.1).

Barber (1993) indicated the quality of groundwater from bores screened in this branch of the Matokitoki Aquifer is better than in the main body of the aquifer and the age of the water is less than 200 years. Both of these observations suggest the recharge zone for this branch of the Matokitoki Aquifer differs from that associated with the main body of the aquifer.

Two emergency water supply bores for Gisborne have been installed approximately 10 m apart, close to the intersection of Nelson and Cameron Roads, with their screens in the branch of the Matokitoki Aquifer at a depth of 98 m below ground level. In 1988 a 21-day constant rate pumping test was performed by pumping these bores simultaneously at a combined average rate of 98 L/s (Works Consultancy 1988). The effects of this pumping test were monitored in nine observation bores screened in various aquifers (Figure 16). Drawdowns of at least 6.8 m were recorded from observation bores screened in the Matokitoki Aquifer up to 3.1 km from the production bores. Drawdowns in response to the test were also observed in bores screened in the Makauri and Waipaoa Aquifers. The interpretation of the observed effects was that this branch of the Matokitoki Aquifer has direct hydraulic connections to overlying aquifers (Figure 17) in an area to the east of the production bores (Works Consultancy 1988). No analysis of the pumping test for hydraulic conductivity and storativity was documented in the 1998 report.

The interpretation of the combined lines of evidence provided above strongly indicates that the southeastern branch of the Matokitoki Aquifer close to Gisborne:

- Consists of gravels sourced from a catchment to the southeast of Gisborne.
- May have hydraulic characteristics different to those that apply to the main body of the Matokitoki Aquifer.
- Is recharged from an elevated area to the east or southeast of Gisborne, which results in flowing artesian pressures within this aquifer branch.
- Is hydraulically connected to the Makauri and Waipaoa Aquifers close to Gisborne.
- Has a hydraulic gradient that indicates groundwater flows within this aquifer branch toward the west or northwest.

It is important recognise that although the conceptual groundwater model incorporates the above interconnection of aquifers beneath Gisborne, and it is an important feature of the mode, there is insufficient geological information available to support the simulation of such an interconnection in the numerical model. This strict approach to the numerical modelling has been taken because a freer and less defensible approach to the geological modelling, combined with problematic definition of hydraulic boundary conditions could easily lead to the substantial overestimation of potential recharge to the confined aquifers.

4.5 HYDROGEOLOGICAL PROPERTIES

4.5.1 Introduction

A summary of the hydraulic properties of the aquifers underlying the Poverty Bay Flats is provided in Table 3. The full data set of the aquifer test results provided by GDC, from which information in Table 3 is presented in Appendix A.

The pumping tests from which these hydraulic parameters have been derived are generally of reasonable quality to provide guidance on the local behaviour of the targeted aquifers. Numerous tests have been performed on the Makauri Aquifer, which provides confidence that the cumulative results represent a good indication of the hydraulic behaviour of this aquifer. The pumping test datasets for the other aquifers are more limited (Table 3) and the degree of uncertainty around the hydraulic characteristics of these aquifers is correspondingly greater.

The pumping tests performed on bores across the Poverty Bay Flats range from stepped-rate tests covering a period of about three hours through to several constant-rate tests of up to three days and one constant rate test over a period of 21 days. Most of the stepped rate tests were performed simply to define the bore yield and efficiency, with no observation bore monitored. Some of the extended constant rate tests benefitted from the monitoring of an observation bore but not all. Documentation of the 21-day test on the emergency water supply bores for Gisborne did not include analysis of the test for aquifer hydraulic properties. A detailed review of the documented pumping test analyses has not been undertaken for the purposes of this report.

Some of the storativity results documented in Table 3 need to be considered in light of the degree of aquifer confinement indicated. For example, the range of storativity results documented for the Shallow Fluviatile Aquifer ranges from 1.7×10^{-4} to 2.3×10^{-1}. This range covers aquifer conditions ranging from fully confined to fully unconfined. Consequently, this range is considered to be more appropriately indicative of the combined storativity and specific yield range for the aquifer.

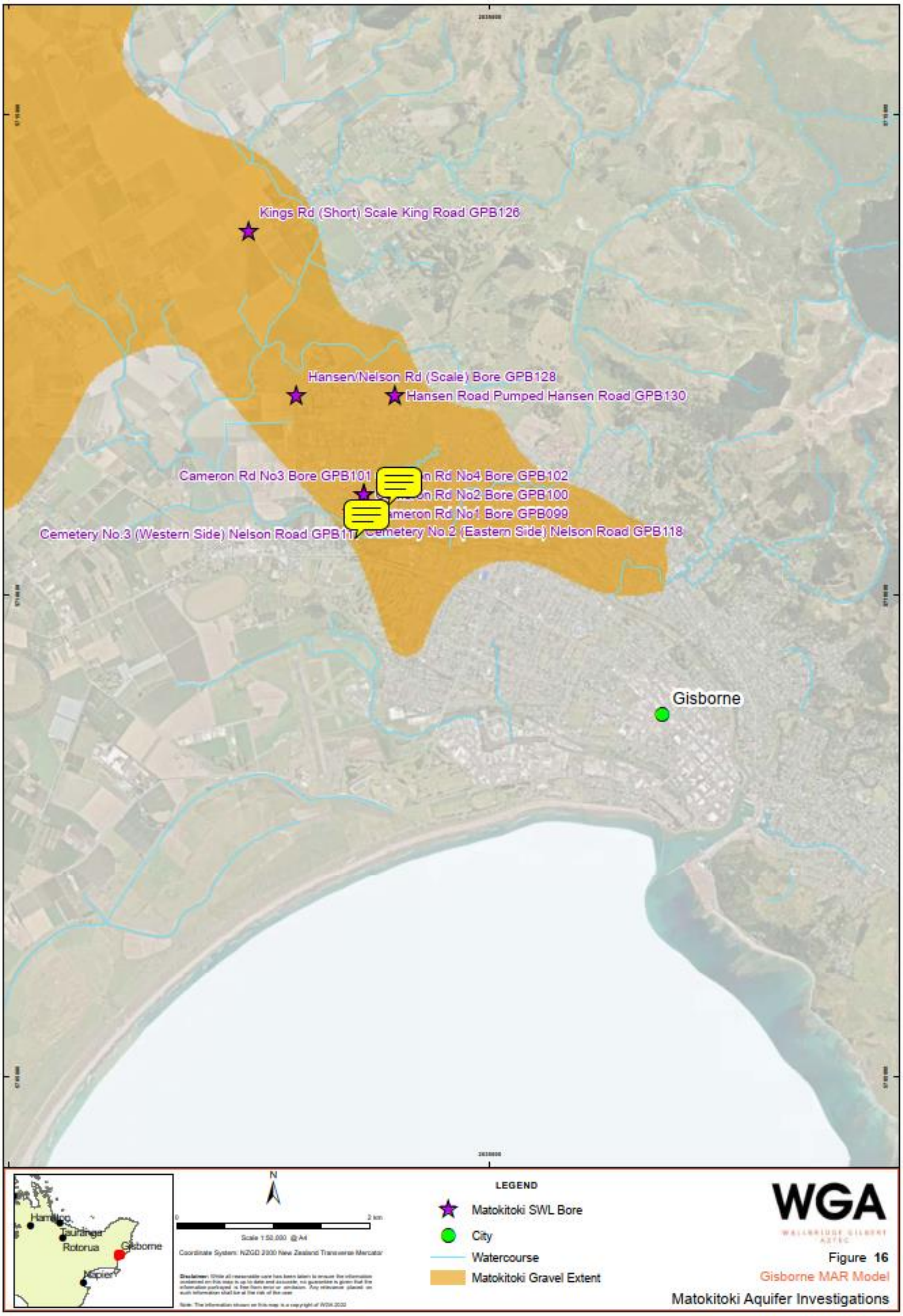

Figure 16: Matokitoki Aquifer Investigations Map

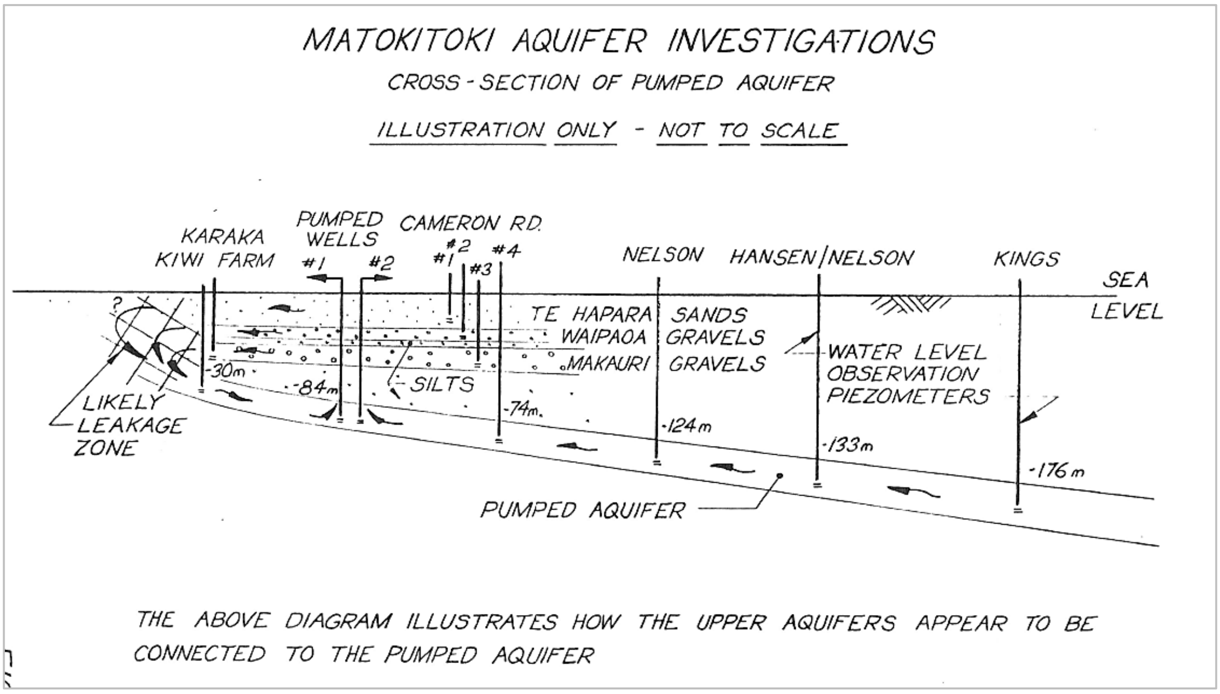

Figure 17: Interpreted Aquifer Response to Pumping Test (Works Consultancy 1988)

Table 3: Aquifer Hydrogeologic Parameters Summary

Parameter [1,2]	Tests	Full range		Expected range [3]	
		Lower	Upper	Lower	Upper
Te Hapara Sand					
Transmissivity	2	260	270	TBD [4]	TBD [4]
Hydraulic conductivity	2	43	90	40	100
Storativity [5]	2	6.7×10^{-4}	1.5×10^{-3}	S 7.0×10^{-4} S_Y 1.5×10^{-1}	S 1×10^{-3} S_Y 2.3×10^{-1}
Shallow Fluviatile Aquifer					
Transmissivity	10	120	1,372	250	840
Hydraulic conductivity	4	26	187	26	187
Storativity [6]	8	1.7×10^{-4}	2.3×10^{-1}	S 7.0×10^{-4} S_Y 1.5×10^{-1}	S 6×10^{-3} S_Y 2.3×10^{-1}
Waipaoa Aquifer					
Transmissivity	6	44	960	140	470
Hydraulic conductivity	4	8	240	25	240
Storativity [7]	3	7.3×10^{-4}	9.6×10^{-2}	S 1×10^{-4} S_Y 1×10^{-1}	S 1×10^{-3} S_Y 2×10^{-1}
Makauri Aquifer [8]					
Transmissivity	28	75	2,500	500	1,200
Hydraulic conductivity	21	9	320	26	76
Storativity	21	1×10^{-5}	1.5×10^{-2}	1.0×10^{-5}	1.0×10^{-3}
Matokitoki Aquifer					
Transmissivity	4	26	566	50	500
Hydraulic conductivity	3	10	74	10	75
Storativity	2	1.0×10^{-4}	6.8×10^{-5}	1.0×10^{-5}	1.0×10^{-4}

Notes:

1) Full datasets provided in Appendix A.

2) Transmissivity in units of m^2/day, hydraulic conductivity in units of m/day, storativity in units of m^{-1}. All hydraulic conductivity values represent horizontal hydraulic conductivity.

3) In some cases the expected range exceeds the full observed range because very few pumping tests have been performed on the aquifer.

4) To be determined (TBD) through groundwater modelling. Highly dependent on accumulated sand thickness.

5) Storativity values indicate confined aquifer conditions. Not applicable as specific yield in unconfined conditions.

6) Data interpreted to provide expected ranges for both storativity and specific yield.

7) Expected storativity range taken from Makauri Aquifer pumping test results (refer to Section 4.5.3).

8) Refer to Section 4.5.3 for derivation of expected parameter ranges.

4.5.2 Matokitoki Aquifer

Starting with the deepest of the aquifer systems, the Matokitoki Aquifer is expected to generally behave as a highly confined aquifer with low inflows through the overlying and underlying sediments aquitard and the basement rock mass. The aquifer transmissivity range (Table 3) indicates it can be moderately productive for water supplies.

The degree of aquifer confinement is expected to be reduced in two areas (for details refer to Section 4.4.4):

- At the northern end of the flats, where the rising Matokitoki Aquifer merges with younger shallower aquifers.
- At the southeast end of the flats, where a branch of the Matokitoki Aquifer becomes connected to overlying shallower aquifers.

Of the bores screened in the Matokitoki Aquifer and subjected to hydraulic testing (Table B1), bores GPB039 and GPB130 may be targeting the south-eastern branch of the aquifer that is interpreted to consist of a buried valley fill deposit under Gisborne city. The gravels in this sub-unit are likely to be different in both grain size distribution and hydraulic parameters from the main body of the Matokitoki Aquifer. For this reason, the hydraulic parameters generated from analysis of the test performed on GPB175 (Table B1), may be the only ones available that relate to the main body of the Matokitoki Aquifer.

4.5.3 Makauri Aquifer

Due to the importance of the Makauri Aquifer as a groundwater source for the Poverty Bay and the number of hydraulic tests performed on this aquifer, the hydraulic test results have been summarised graphically for transmissivity (Figure 18), hydraulic conductivity (Figure 19) and storativity (Figure 20). The expected ranges of these parameters for the Makauri Aquifer as a whole are summarised in Table 3.

A review of the test results indicates the outer edges of the Makauri Aquifer footprint are characterised by lower transmissivity. This effect may be a combination of the aquifer thinning in these areas and the grain size distribution becoming finer toward the outer edges of the aquifer.

The Kaiaponi MAR trial has provided a key dataset for calibration of the groundwater model. Furthermore, the pumping tests undertaken as part of this trial provide one of the most reliable sets of aquifer parameters for the Makauri Aquifer (Golder 2020a, b). These results, summarised in Table 4, and provide good guidance on the hydraulic behaviour of the Makauri Aquifer in the central area of the Poverty Bay Flats.

4.5.4 Waipaoa Aquifer

Only six pumping tests have been performed on the Waipaoa Aquifer and analysed (Table B3). The results summarised in Table 3 indicate a moderately productive aquifer with varying degrees of confinement.

The storativity results for the Waipaoa Aquifer (Appendix A) come from tests on two bores, GPE026 (two observation bores) and GPG075 (one observation bore), with the results varying over two orders of magnitude. Both of these bores are located at the northern end of the Poverty Bay Flats. The range of hydraulic parameters may reflect differences in the aquifer as it merges with other aquifers, or potentially in the interpretation of which aquifer the bore is screened in. This uncertainty can be addressed as the modelling progresses.

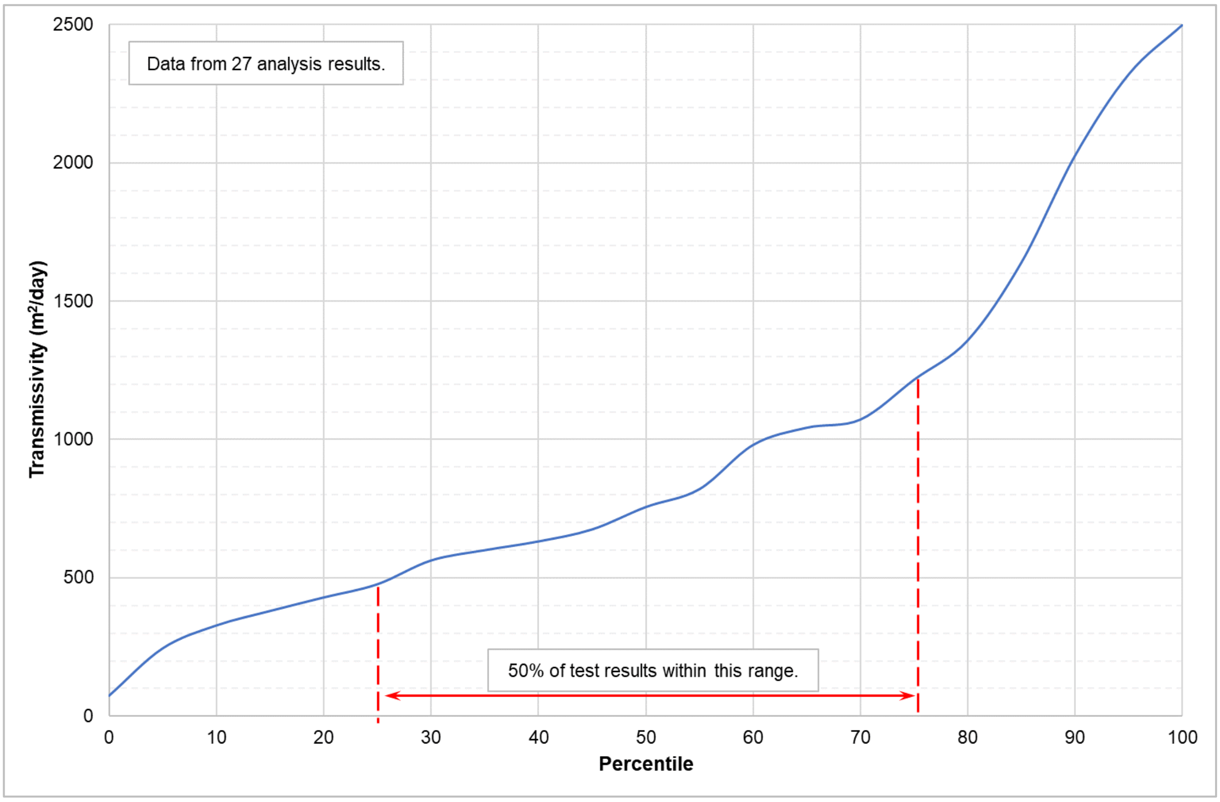

Figure 18: Makauri Aquifer Transmissivity Results Distribution Curve

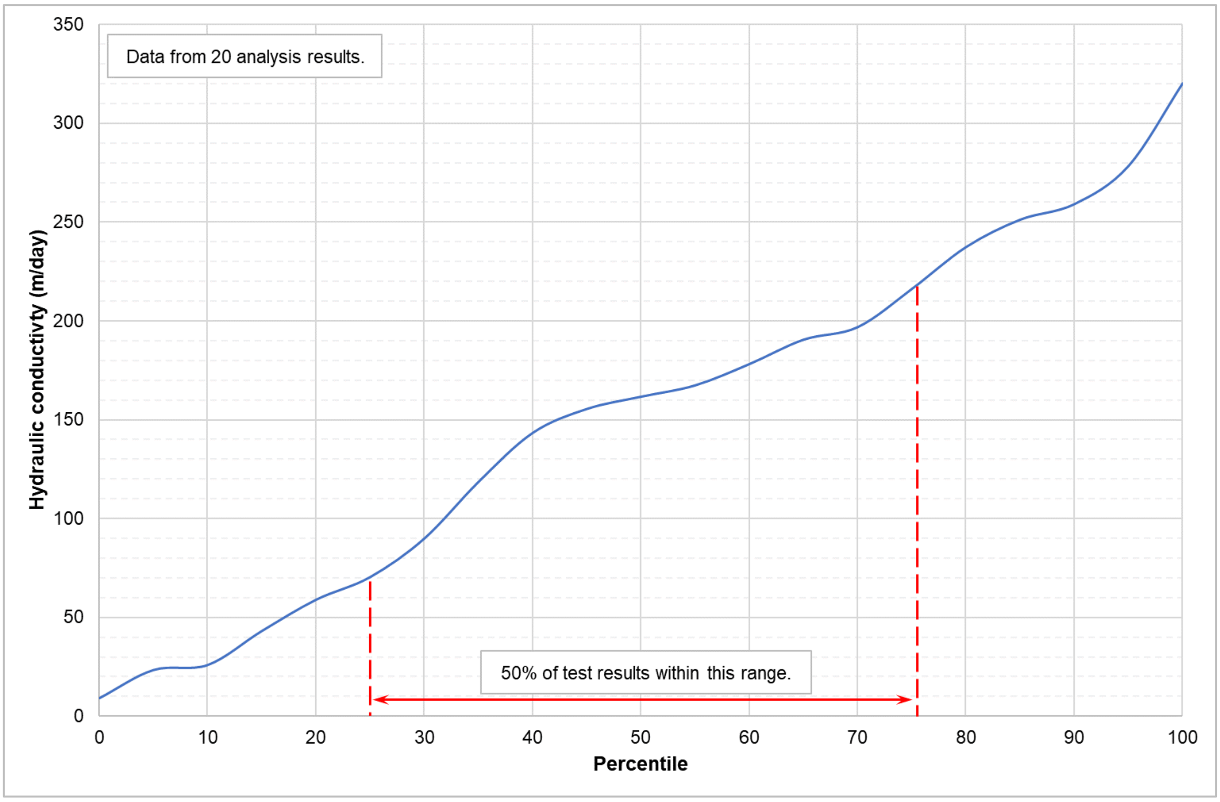

Figure 19: Makauri Aquifer Hydraulic Conductivity Results Distribution Curve

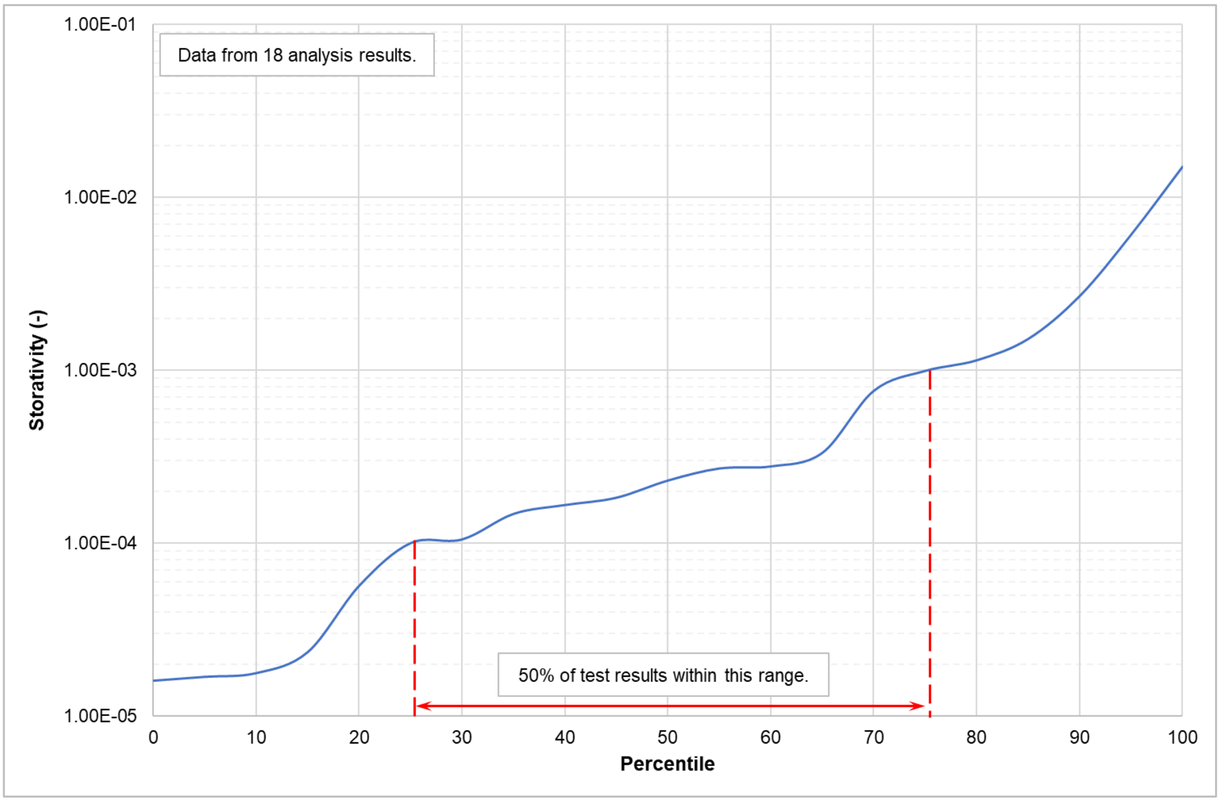

Figure 20: Makauri Aquifer Storativity Results Distribution Curve

Table 4: Makauri Aquifer Hydraulic Parameters Derived from MAR Trial (Golder 2017a)

Test curve analysis	Distance from injection bore (m)	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storativity (m^3/m^3)
Injection bore (GPE066) drawdown	-	250	80	
Injection bore (GPE066) recovery	-	600	200	
Pilot monitoring bore (GPE065) drawdown	23	770	260	3×10^{-4}
Pilot monitoring bore (GPE065) recovery	23	600	200	
GPE010 drawdown	190	780	260	1.6×10^{-5}
GPE010 recovery	190	610	210	
GPE030 drawdown	365	760	250	1.8×10^{-5}
GPE030 recovery	365	580	190	
Interpreted parameter ranges		600 - 780	200 - 260	1×10^{-5} – 2×10^{-5}

4.5.5 Shallow Fluviatile Aquifer

The Shallow Fluviatile Aquifer is generally considered to be a moderately productive, near surface aquifer with limited capacity to accept drawdown, as indicated by the hydraulic parameters summarised in Table 3. Barber (1993) indicated the highest yielding wells are located in former river channels containing gravel and coarse sand.

It is generally considered to be an unconfined aquifer subject to spatially distributed rainfall recharge and a direct hydraulic connection to the Waipaoa River. However, the storativity results from hydraulic tests performed on this aquifer (Table B4) are all indicative of a leaky confined to fully confined aquifer. It is possible all of the bores tested were located in areas where the aquifer is somewhat confined by layers of fine over-bank deposits. Taking into account the descriptions of the materials that make up the Shallow Fluviatile Aquifer, specific yields for unconfined areas of the aquifer are reasonably expected to be within the range from 0.1 to 0.2.

4.5.6 Te Hapara Sand

The Te Hapara Sand Aquifer is generally considered to be a moderately productive near surface aquifer, with limited capacity to accept drawdown and subject to intensive drainage. Only two pumping tests in the GDC database have been attributed to the Te Hapara Sand (Table 3). Barber (1993) indicated "the permeability of the aquifer decreases to the southwest, with the silt content of the sand increasing towards the present day Waipaoa and Taruheru River channels".

The Te Hapara Sand Aquifer is generally unconfined although it becomes partially confined by silty river and swamp deposits inland from the coast (Barber 1993). Only two storativity results have been derived from hydraulic tests performed on this aquifer (Table B5), with both indicative of leaky confined to fully confined aquifer conditions. Both of these tested bores are located in areas where the aquifer appears to be somewhat confined by swamp deposits. Taking into account the nature of these sands, specific yields for unconfined areas of the aquifer are reasonably expected to be within the range from 0.1 to 0.2.

The Te Hapara Sand Aquifer is subject to spatially distributed rainfall recharge and has direct hydraulic connections to the Waipaoa River and the coast. Additionally, the intensive drainage network established to enable the conversion of land for agricultural use is likely to strongly influence groundwater flow directions and levels within the Te Hapara Sand Aquifer.

4.5.7 Aquitard Properties

Only three hydraulic tests have been identified that have resulted in reliable data with respect to the behaviour of aquitards in the Poverty Bay area. All three of these tests were performed on the Makauri Aquifer and the results consequently apply specifically to Aquitard 2. However, as previously documented (Section 4.4.3), each of the aquitards except Aquitard 4 are considered to have been deposited in similar geological environments. The hydraulic behaviour of the numerical groundwater model in the groundwater model is not expected to be sensitive to the hydraulic parameters applied to the marine silts and clays of Aquitard 4.

Of the three tests listed in Table 5, the analysis results derived from the MAR trial site are the most reliable. Therefore, the vertical hydraulic conductivity for the aquitard sediments is considered to most likely be within the range from 1×10^{-3} to 6×10^{-3} m/day. It is reasonable to expect that the vertical hydraulic conductivity derived from these tests would also apply to the other aquitards.

Table 5: Hydraulic Properties for Aquitard 2 Based on Tests Performed on the Makauri Aquifer

Parameter	Units	GPE065 (1)	GPF074	GPF147
Leakance (K'/b')	m/day/m or 1/m	2.5×10^{-5} to 1.6×10^{-4}	5×10^{-4}	5×10^{-5}
Aquitard thickness (b') (2)	m	40	40	50
Aquitard vertical hydraulic conductivity (K')	m/day	1×10^{-3} to 6×10^{-3}	2×10^{-2}	2×10^{-3}

Notes: 1) Analysis from MAR trial programme (Golder 2017).
2) Approximated from drillhole log attached to the pumping test.

4.6 HYDROGEOLOGIC BOUNDARY CONDITIONS

4.6.1 Spatially Distributed Recharge

Spatially distributed recharge results from a combination of rainfall and irrigation. River and stream channel recharge are covered in Section 4.6.2. In general, irrigation is intended to provide sufficient soil moisture to support ideal crop growing conditions. Over-irrigation leading to the excess water recharging shallow aquifers is not considered to be a common situation in Poverty Bay's primarily high-value horticulture farm systems. Although summer irrigation followed by a significant storm event may result in enhanced short-term recharge to shallow aquifers, also it is not considered to be a significant contributing factor to the groundwater budget for the model.

An initial estimate derived from Golder's (2021) steady state modelling of the Poverty Bay area indicated rainfall recharge rates as follows:

- Grassland areas 42 % of winter rainfall Averaging 1.71 mm/day.
- Forest areas 38 % of winter rainfall Averaging 1.55 mm/day.
- Cropped areas 53 % of winter rainfall Averaging 2.15 mm/day.
- Urban areas 27 % of winter rainfall Averaging 1.08 mm/day.

Following discussions with GDC staff, the above values were accepted as indicative of distributed recharge under current climate conditions, with effective recharge only occurring during a five-month period from May to September annually. It is accepted that heavy rainfall events outside this period contribute to groundwater recharge, as well as possible over-irrigation. However, these are not considered for the purpose of this modelling.

Following calibration, the steady state numerical model incorporated a distributed recharge rate that increases slightly from south to north, reflecting slightly different annual average rates at the Gisborne EWS and Gisborne AWS climate monitoring stations (AQUASOIL 2022). Overall, the average distributed recharge for the model was equivalent to approximately 1.63 mm/day over a five month recharge period.

The predictive models documented in the modelling summary report (WGA 2022b) take into account changing rainfall patterns and therefore recharge rates based on climate change projections. These changes in projected recharge are presented in the modelling summary report (WGA 2022b), which documents the predictive model scenarios developed under this project.

4.6.2 Waipaoa River Interaction

Water levels in the Waipaoa River are monitored at several points within the model area. Past investigations have identified that the river is directly linked to the Shallow Fluviatile Aquifer, sections of the Te Hapara Sand Aquifer and the upper reaches of the Waipaoa Aquifer. This connection is demonstrated through specific characteristics of the groundwater hydrographs from monitoring wells installed in bores at the upper end of the Poverty Bay Flats (refer Section 4.7). These hydrographs show rapid aquifer responses to high water events and subsequent recoveries. The river both recharges the shallow aquifers and drains these aquifers, depending on the relative water levels in the river and the aquifer.

The Waipaoa River has been interpreted as being a significant source of recharge to the groundwater system of the Poverty Bay Flats. This interpretation is based on the shallow aquifer responses to water level fluctuations in the river, the hydraulic connection between the shallower and deeper aquifers at the northern end of the Poverty Bay Flats and the measured hydraulic gradients within the Makauri Aquifer transmitting groundwater from the north toward the south.

4.6.3 Streams and Drainage Systems

An intensive artificial drainage system has been installed to manage both groundwater levels and run-off from intensive rainfall events. This system likely acts to both recharge the shallow aquifers and drain these aquifers. A simplified drainage system layout reflecting the main drains and streams has been incorporated into the conceptual model as adequate for the simulation of the shallow aquifers in the groundwater model. This potential for water to flow in both directions between the simulated surface water bodies and the underlying aquifers has been incorporated in the numerical model and described in the AQUASOIL (2022) report.

Secondary rivers, such as the Te Arai River, may contribute recharge to the deeper groundwater aquifers, although there is little evidence of this in the data reviewed to date. Elevated salinity in Makauri Aquifer water to the west of the Waipaoa River suggests the groundwater recharge from either distributed rainfall or river infiltration is limited in this area.

Run-off from the surrounding hillsides outside the modelled areas may contribute to seasonal recharge, through:

- Focused recharge along the toe of the hillslopes.

- Focused recharge to the shallow aquifers from stream channels that drain the surrounding catchments.

The numerical groundwater model has not included enhanced recharge resulting from run-off from the surrounding hillsides or the streams as it was fond to be unnecessary to achieve an acceptable model calibration. The potential effects of possible spatially distinctive and focused run-off recharge may be an investigation topic for future modelling projects.

The area between the Waipaoa River, Gisborne Airport and the coastline was a wetland (Awapuni Moana) prior to the installation of drainage and remains subject to periodic inundation. Simulation of the drainage system across this area is important to enable the modelling of shallow coastal groundwater levels under current conditions. Furthermore, an understanding of the behaviour of these drains in managing groundwater levels under rising sea levels is important when considering future scenarios in the numerical modelling programme.

4.6.4 Wetlands

A key cultural taonga and environmental feature of the Poverty Bay Flats is the Te Maungarongo o Te Kooti wetland (also known as the Matawhero wetland). This wetland lies in an oxbow of the Waipaoa River, closed off from the river in 1948 during development of the Waipaoa Flood Control Scheme. It is likely that gravels of the former river bed still provide a hydraulic connection between the river and the wetland underneath the river stopbank.

The Te Maungarongo o Te Kooti wetland receives water from a localised area of drainage channels. When the water level in the wetland exceeds approximately 2.4 mRL can flow from the wetland through an open channel to the Waipaoa River. Water levels in the wetland are likely to control water levels in the surrounding drains and Te Hapara Sand Aquifer, which would be directly hydraulically linked to the wetland. Water levels in the wetland, which have been monitored manually at monitoring point GPC029 (Figure 24) since 1986, have varied between 1 mRL and 3.3 mRL. The wetland peak water levels follow peak flows in the adjacent Waipaoa River, with a small delay. It is reasonably expected that high flows in the river result in seepage flows into the wetland; reversing during low flow periods in the river. The water storage capacity of the wetland is expected to buffer the magnitude of local groundwater level fluctuations in the surrounding Te Hapara Sand Aquifer.

4.6.5 Springs

Written records of only two springs have been found in the information reviewed to date (Figure 9). The only documentation of flows from a spring are for the Brewery Spring (Zemansky 2007). The documented flows of approximately 1.6 L/s are most likely to arise from seepage flows along the Brewery Spring Fault (Neef & BottrilL 1992). Zemanski (2007) also notes the presence of a second spring, the Acton Spring, in close proximity to the Brewery Spring but the exact location and discharge flow is not documented.

During the model training workshops with GDC and their Treaty Partners, cultural history has provided some additional useful context regarding the behaviour of streams in the modelled area. The Matokitoki Stream north of Gisborne was recognised as a reliable source of good quality water derived from springs in the catchment. The hillslopes on either side of this stream are at least partially made up of mixed gravels, sands and silts of the early Pleistocene Mangatuna Formation, which could be the source of these spring flows.

4.6.6 Offshore Aquifer Extents and Ocean Hydraulic Interfaces

The geological modelling has identified only two of the Poverty Bay aquifers that extend as far as the present coastline and beyond: the Te Hapara Sand Aquifer and the Makauri Aquifer. WGA's interpretation of the drillhole data with regards the extent and layout of the Waipaoa Aquifer indicates this aquifer does not extend as far as the coastline (refer Section 3.4). There is no indication of a hydraulic connection between the Waipaoa Aquifer and the ocean.

The geological modelling indicates the Matokitoki Aquifer terminates on the landward side of the coastline and is completely overlain by the Makauri Aquifer (Figure 11). Any possible attenuated offshore connection between the Matokitoki Aquifer and the ocean would be via the Makauri Aquifer. At its southern limit the Matokitoki Aquifer is separated hydraulically from the Makauri Aquifer by a thick aquitard.

The Te Hapara Sand Aquifer is unconfined at the coast and in the shallow offshore area. The direct hydraulic connection between the aquifer and the aquifer means that drawdown of groundwater levels onshore may lead to saline water intrusion to the shallow aquifer. Drainage of the former Awapuni Moana wetland during conversion of the coastal area of the Poverty Bay Flats to pasture has influenced groundwater pressures in the Te Hapara Sand Aquifer behind the current shoreline. Groundwater seepage from the ocean to the drainage systems has been recognised by GDC as presenting a saline water intrusion risk along this section of the coast.

The Makauri Aquifer is interpreted from the geological modelling as a confined aquifer extending offshore. However, two observations suggest that at least some of the natural groundwater flows through this aquifer discharge to the ocean offshore:

- The gradient of the winter piezometric surface indicates groundwater is moving past the coastline offshore within the Makauri Aquifer (refer Section 4.8).
- Shallow offshore seabed features described as shallow inverted cones or "pockmarks" identified by Nelson & Healy (1984) may represent gas or groundwater discharge points. These identified features are at least two kilometres offshore (Figure 21) and are highly unlikely to represent a groundwater discharge zone for the Te Hapara Sand Aquifer. The only realistically reasonable source of groundwater discharging to this area is the Makauri Aquifer.

No specific hydraulic interconnection through the aquitards above the Makauri Aquifer to the ocean is included in the conceptual groundwater model, with the overlying aquitard considered to be continuous and homogeneous in terms of the model hydraulic properties. This assumption was tested and confirmed during the calibration process. .

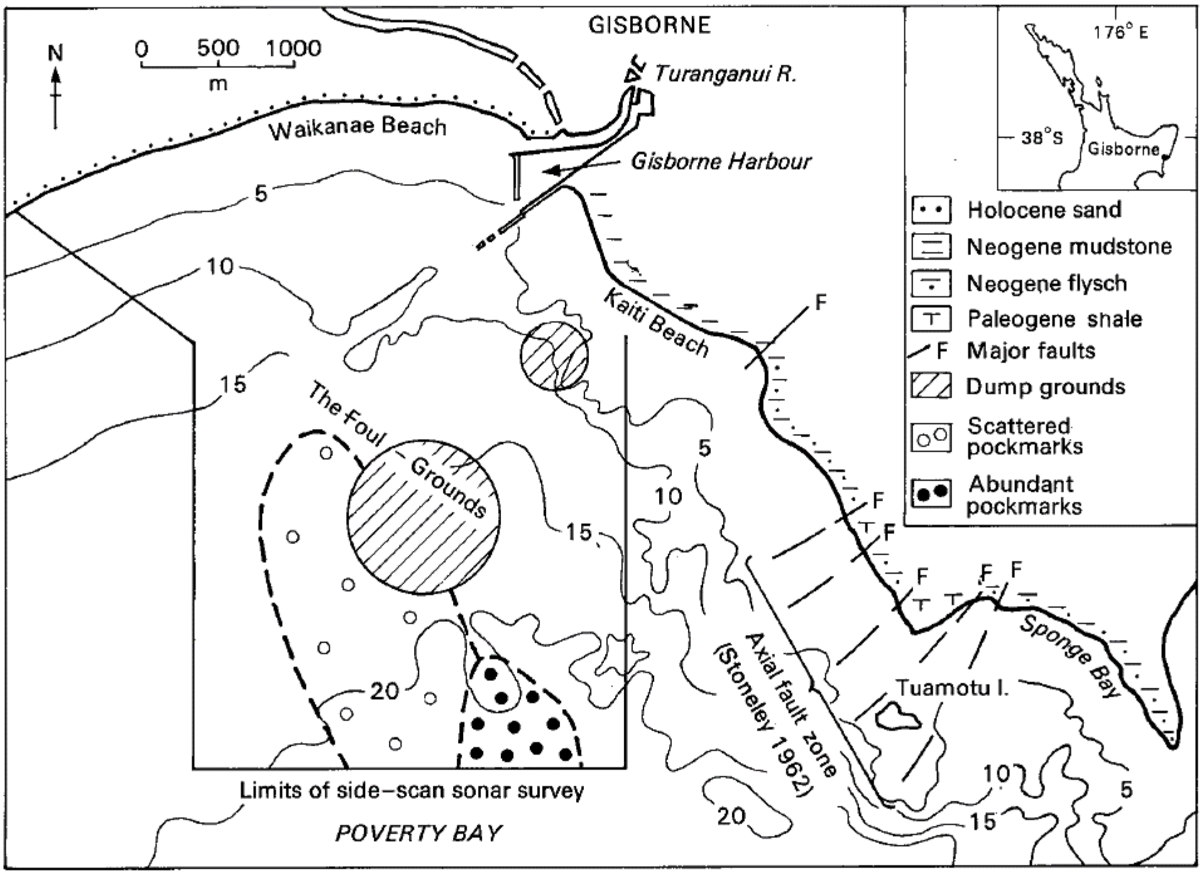

Figure 21: Distribution of Offshore Gas or Groundwater Discharge Features (Nelson & Healy 1984)

4.6.7 Groundwater Abstraction

Monthly groundwater abstraction data has been compiled by GDC for takes authorised by resource consents from Poverty Bay Flats bores. This is an extensive dataset, with maps and tables being updated at the time this report was being produced. A summary of the groundwater take dataset to be used in the numerical groundwater model is to be presented in the documentation for that model.

For guidance, an indication of the rate of annual groundwater abstraction for the period 2008 to 2015, differentiated by aquifer, is presented in Figure 22. Groundwater abstraction from the Makauri Aquifer substantially exceeds the combined abstractions from all of the other aquifers. The bores linked to the largest abstractions are associated with irrigated horticulture focused on the northern half of the Poverty Bay Flats (Figure 23). The locations of the main groundwater production bores in the Makauri Aquifer correspond to the area of substantial groundwater drawdown in the Makauri Aquifer as described in Section 4.8.2.

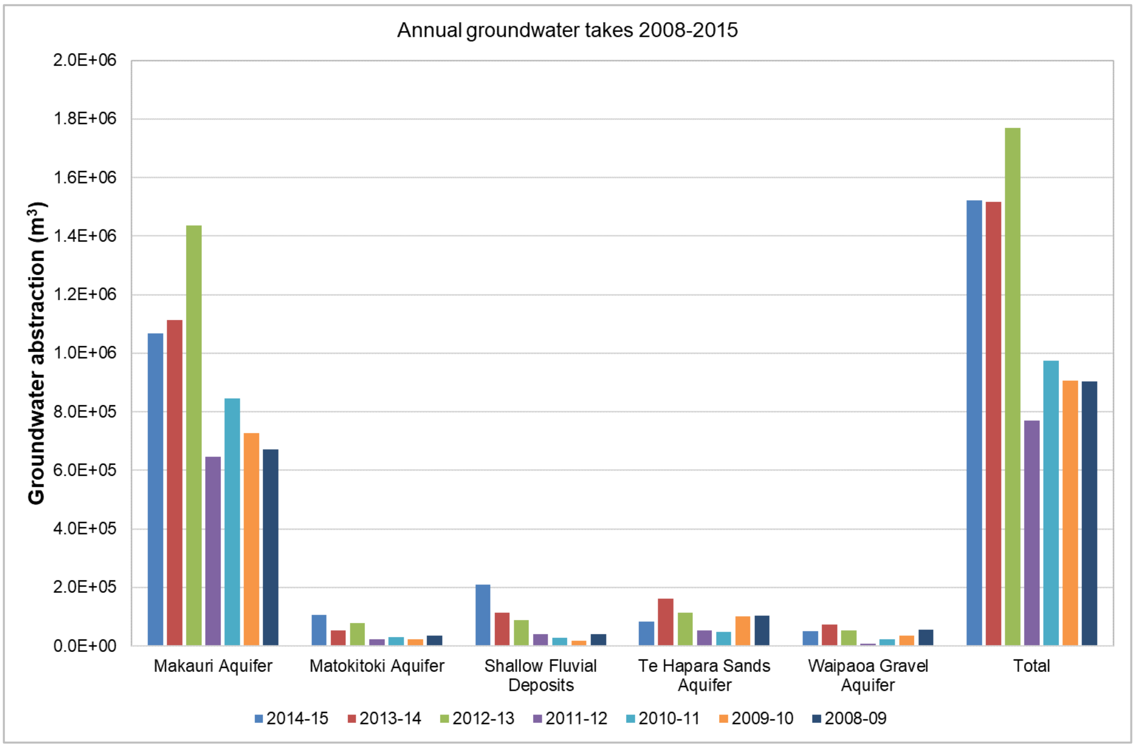

Figure 22: Annual Groundwater Abstraction by Aquifer 2008 - 2015

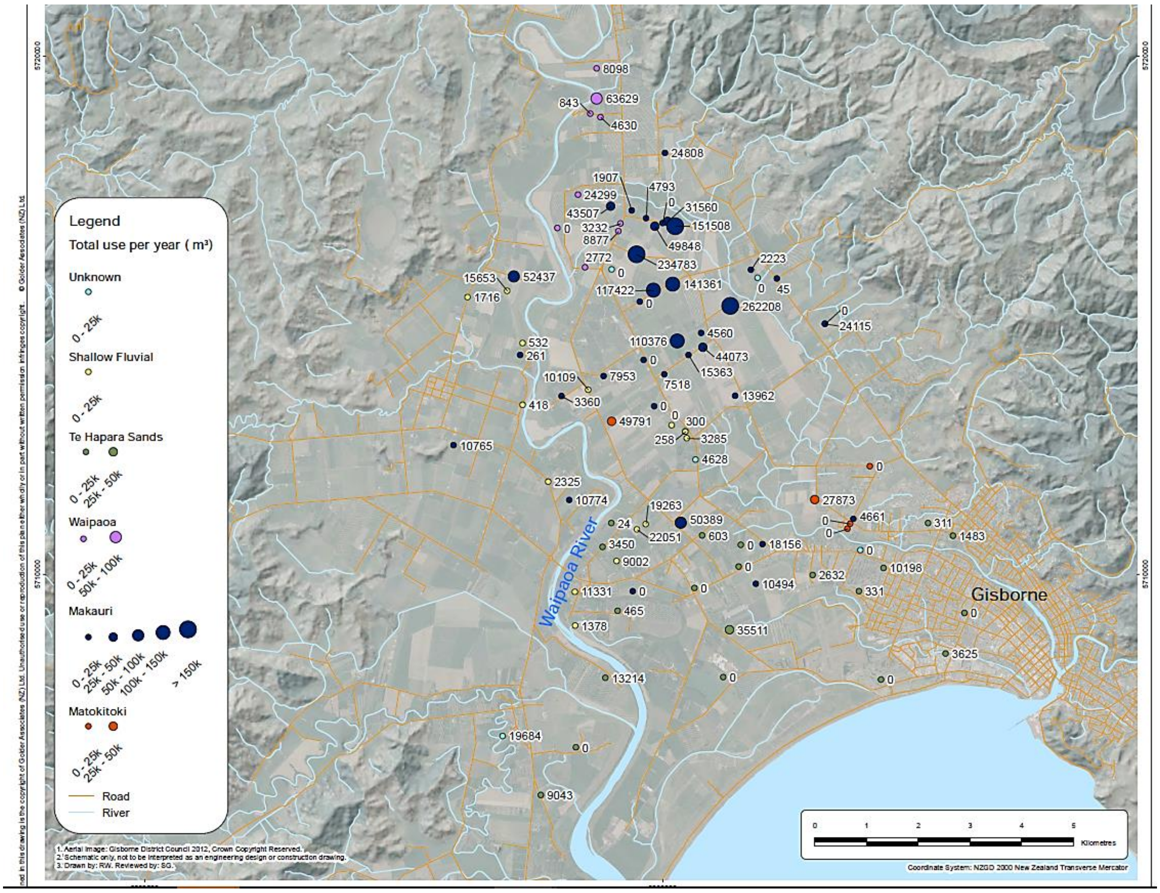

Figure 23: Locations of Bores Linked to the Largest Consented Groundwater Abstractions (Golder 2015).

4.6.8 Eastern Boundary of Model

Monitoring of groundwater quality along the eastern edge of the Makauri Aquifer has identified a few areas where chloride concentrations in the groundwater are decreasing. This has been taken as an indicator of potential additional recharge occurring close to the eastern edge of the Poverty Bay Flats.

Consideration was given to incorporating additional hydraulic boundary conditions along the edge of the model to support simulation of this 'freshening' of the aquifer water. However, the exact mechanism and route by which additional recharge could be reaching the Makauri Aquifer is unclear and several possibilities may be envisioned. Each possibility would not only result in additional water reaching the Makauri Aquifer but also the underlying and overlying aquifers. Taking the uncertainty into account, as well as the difficulty in defending any specific conceptualisation and therefore the volumes of water potentially introduced to the aquifers, a decision was reached to apply a conservative approach and not incorporate some form of enhanced recharge to the model in this area.

4.7 GROUNDWATER HYDROGRAPHS

The groundwater level datasets for three monitoring wells pods, which were established in the early 1980s, provide guidance on the hydraulic behaviour of the key Poverty Bay aquifers.

The first pod, located on Caesar Road close to the intersection with Ormond Road, consists of four bores that have been used to monitor groundwater levels in the Waipaoa and Makauri Aquifers (Figure 24) since 1984. Three of the monitoring wells show similar groundwater level trends, consistent with the behaviour of the Makauri Aquifer (Figure 25). Seasonal groundwater level fluctuations in the Makauri Aquifer exceed those of the Waipaoa Aquifer in magnitude, partly due to the increasing seasonal groundwater abstraction from the Makauri Aquifer. Additionally, groundwater pressures in the Makauri Aquifer are lower than in the overlying Waipaoa Aquifer, indicating a downward pressure gradient and corresponding downward seepage flows from the Waipaoa Aquifer to the Makauri Aquifer in this area. The area around Ormond in the mouth of the Waipaoa River valley is interpreted as being the main recharge area for both aquifers.

The second set of bores, located on Ferry Road (Figure 24), have been used to monitor groundwater levels in the Waipaoa and Makauri Aquifers close to the Waipaoa River some five kilometres south of the Caesar Road monitoring site since 1984 (Figure 26). The groundwater level records in this area do not indicate any clear vertical hydraulic gradient. However, the bores monitoring the Waipaoa Aquifer show strong seasonal peaks followed by recession curves similar to what would be expected from river recharge. In contrast, the Makauri Aquifer records indicate a strong influence from seasonal groundwater abstraction. The observed groundwater level drawdowns have become progressively deeper over time, as the groundwater abstraction rates have increased to meet increasing horticultural demands. This trend in increasing groundwater drawdown is consistent across most of the footprint of the Makauri Aquifer (Moreau et al 2020), indicating a strong lateral hydraulic continuity within this aquifer.

The third set of monitoring bores, located on Cameron Road (Figure 24), have been used to monitor groundwater levels in the Matokitoki Aquifer, the Makauri Aquifer and the Te Hapara Sand Aquifer since about 1982 (Figure 27). The groundwater level trends observed from these bores indicate a strong upward hydraulic gradient, from the Matokitoki Aquifer toward the Makauri Aquifer and the overlying Te Hapara Sand aquifer. This vertical hydraulic gradient indicates the deeper aquifer is hydraulically connected to a recharge zone that is of higher elevation than the ground surface at the monitoring site. This interpretation is consistent with the geological interpretation of a branch of the Matokitoki Aquifer underlying this area of the Poverty Bay Flats that receives recharge from the south, close to Gisborne.

4.8 GROUNDWATER FLOW PATTERNS

4.8.1 Matokitoki Aquifer

There are insufficient groundwater monitoring wells screened in the main body of the Matokitoki Aquifer to provide a detailed piezometric map for this aquifer. However, several general features of the expected flow regime provide guidance for the conceptual groundwater model as described below.

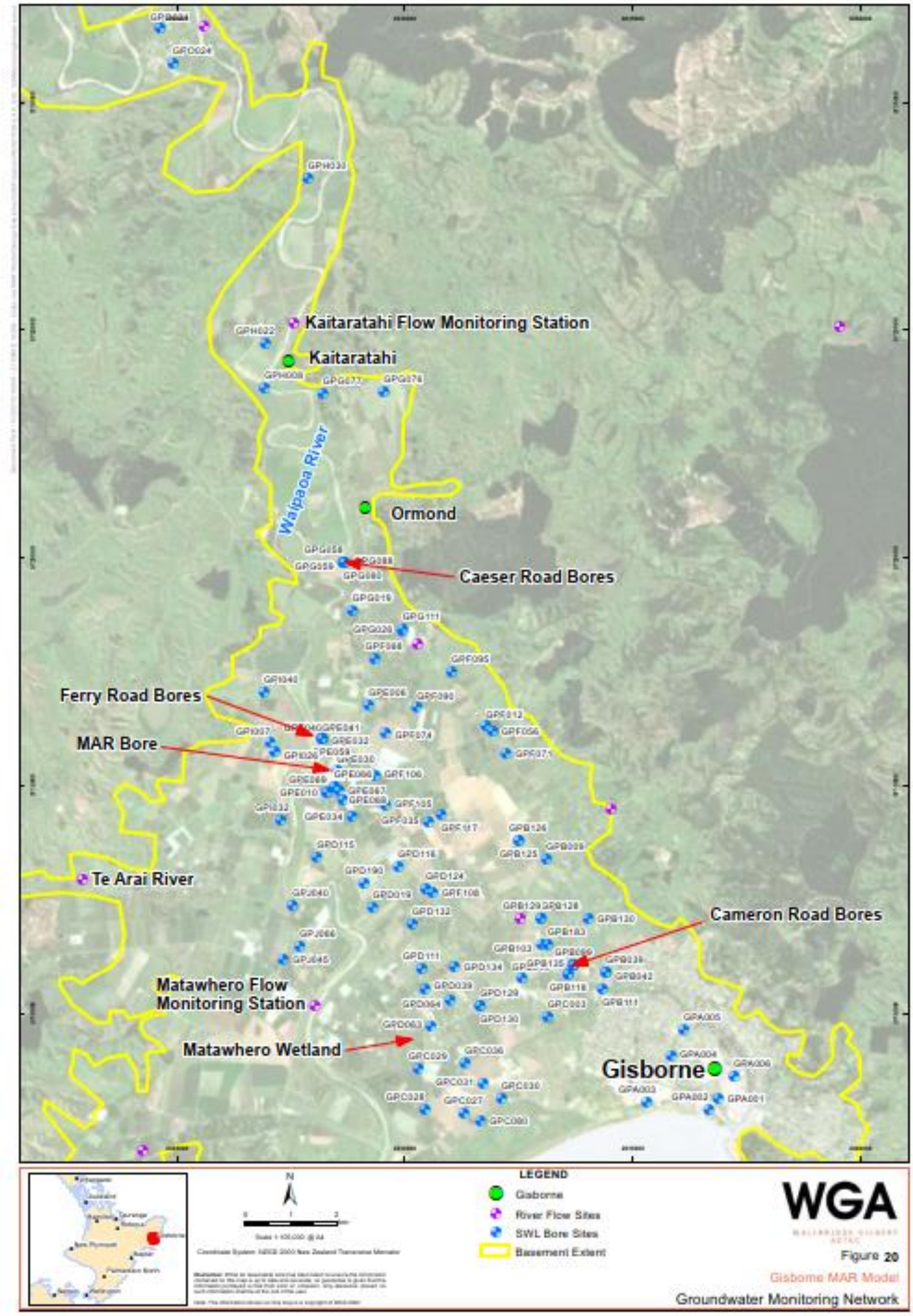

Figure 24: GDC Groundwater Monitoring Network (GDC, 2021)

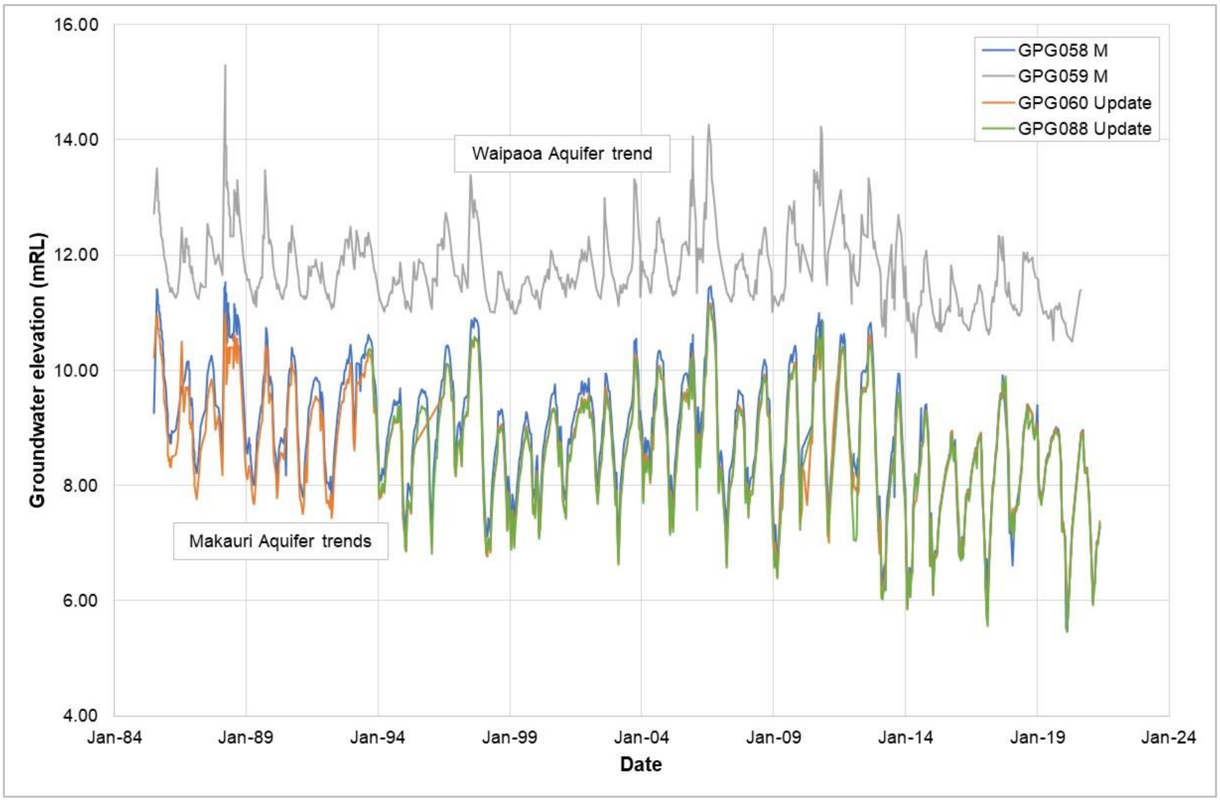

Figure 25: Caesar Road Monitoring Bore Groundwater Level Datasets

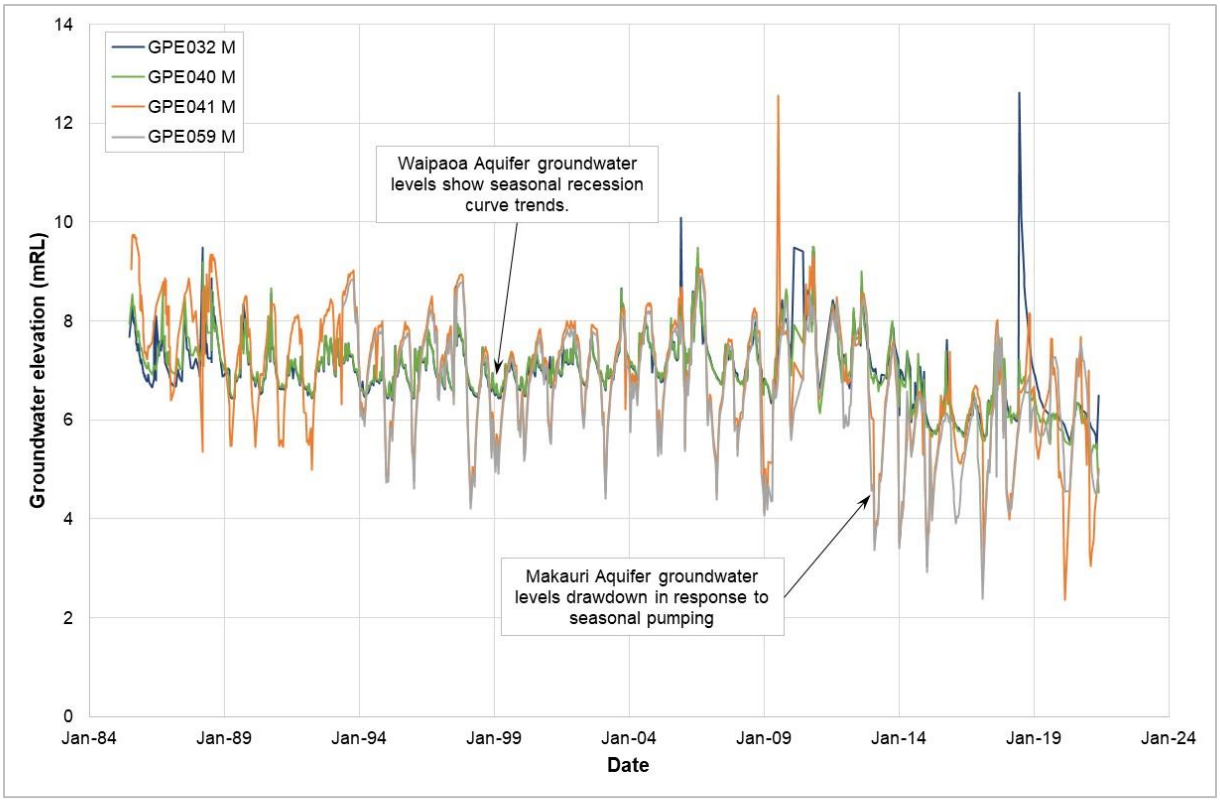

Figure 26. Ferry Road Monitoring Bore Groundwater Level Datasets

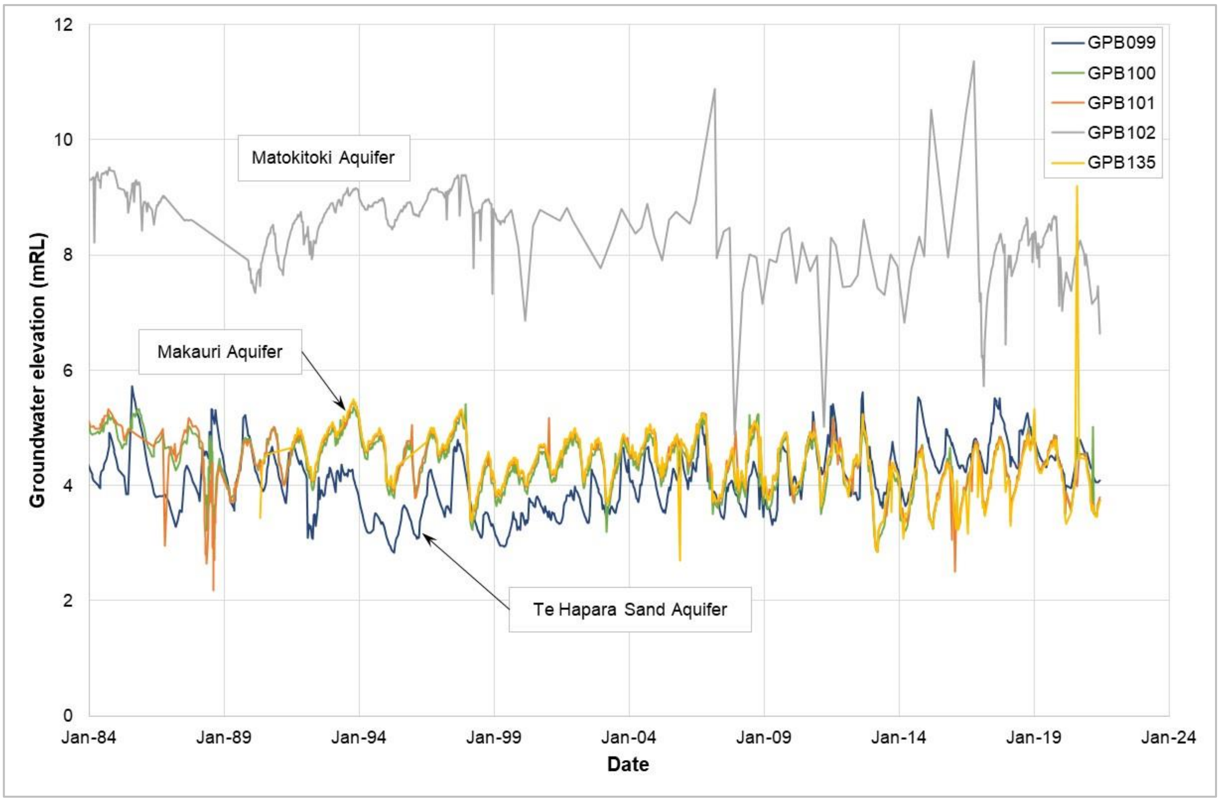

Figure 27. Cameron Road Monitoring Bore Groundwater Level Datasets

The Matokitoki Aquifer increases in depth from north to south and is interpreted as physically connecting to shallower aquifers at its northern end. Groundwater flows within the main body of the Matokitoki Aquifer are interpreted to be north to south, sourced from a main recharge area close to the mouth of the Waipaoa River valley at Ormond. However, there are no clear groundwater discharge zones or pathways from the Matokitoki Aquifer to the overlying Makauri Aquifer or to the ocean. To maintain a natural water balance in the Matokitoki Aquifer there must be a discharge seepage flows. It appears most likely that this discharge occurs toward the southern end of the known Matokitoki Aquifer extents. This interpretation is subject to review during the numerical modelling process.

Groundwater flows within the southern branch of the Matokitoki Aquifer underlying Gisborne city have been interpreted from groundwater level data derived from four monitoring wells (Figure 24). Although the simplest interpretation of the groundwater gradient indicates a flow from west to east, there are several unresolved issues with this interpretation. The observed groundwater pressures in some of these monitoring wells are flowing artesian (i.e., above ground level). The recharge source is unclear although it may be from early Pleistocene rocks on the hillslopes to the east of Gisborne, which would also help to explain the flowing artesian pressures. The discharge flow paths from this branch of the aquifer are also unclear due to uncertainties regarding the interpretation of this area of the geological model. The upward hydraulic gradient observed at the Cameron Road bores (Figure 27) indicates possible upward seepages to overlying aquifers. These issues are considered in more detail in Section 4.4.4.

4.8.2 Makauri Aquifer

Winter season groundwater flows in the Makauri Aquifer are from north to south, consistent with the groundwater pressure gradients (Figure 28). Key features of the winter piezometric surface are:

- The apparent steepening of the piezometric gradient in the mouth of the Makauri River valley.
- An even piezometric gradient across the Poverty Bay Flats toward the ocean.

Summer groundwater flows within the Makauri Aquifer are heavily modified from the winter flow pattern due to the groundwater abstraction summarised in Section 4.6.7. Piezometric maps presented by Golder (2014b, 2021) indicate substantial groundwater drawdown to the east of SH2, toward the upper end of the flats. The summer piezometric surface presented in Figure 29 from Golder (2021) may understate the extent and magnitude of the seasonal drawdown.

An older piezometric map of winter conditions identified groundwater levels in the core of the main abstraction area as being below mean sea level (Golder 2014b). This earlier work suggested that pumping induced reversal of groundwater gradients could extend as far as the coastline, raising the concern of potential saline water intrusion to the aquifer.

4.8.3 Other Aquifers

The main Waipaoa Aquifer is characterised by a groundwater gradient from north to south, with the primary recharge zone within the lower stretch of the Waipaoa River Valley. The pressures in the aquifer vary seasonally in response to rainfall recharge and recharge from the Waipaoa River. There are also numerous relatively small water takes from the aquifer that exacerbate the seasonal variability in groundwater levels. There is however no clear groundwater discharge zone at the confined southern end of the aquifer. The geological model results indicate the Waipaoa Aquifer does not reach the coastline or extend offshore (Section 3.4). The numerical geological model calibration process should provide further guidance in this matter.

As described in Section 3.4, the numerical geological modelling results indicate there may be a secondary component to the Waipaoa Aquifer consisting of gravels sourced from the Waimata River catchment. Assessments still need to be undertaken to evaluate the hydraulic gradients and seasonal groundwater level variations in this section of the Waipaoa Aquifer.

The current geological model outcomes indicate the Waipaoa Aquifer consists of two separate gravel beds. Taking into account this updated interpretation of the aquifer layout, the hydraulic gradients within these separate sections of the aquifer are uncertain. It is expected that the numerical groundwater model can provide guidance on the groundwater flow directions and hydraulic gradients within the Waipaoa Aquifer sections.

The groundwater gradients and flow directions within the Shallow Fluviatile Aquifer and the Te Hapara Sand Aquifer are interpreted to vary in response to seasonal rainfall recharge, water levels in the Waipaoa River and the layout of the secondary streams, wetlands and drainage systems. Groundwater flow rates within these aquifers are expected to be similarly variable. No piezometric surface has been derived to date for either the Shallow Fluviatile Aquifer or the Te Hapara Sand Aquifer. Piezometric surfaces for these aquifers are expected to be one of the outcomes derived from the numerical groundwater model.

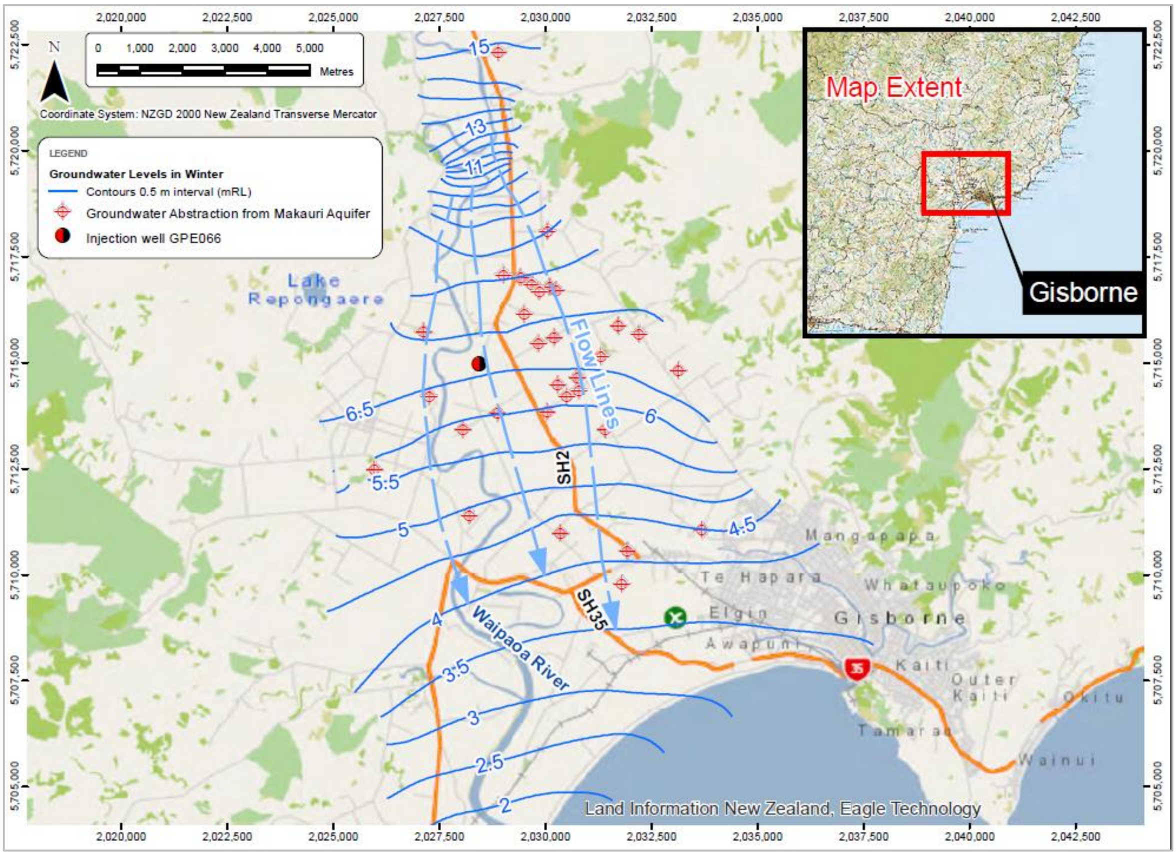

Figure 28: Makauri Aquifer Winter Piezometric Surface (from Golder 2021)

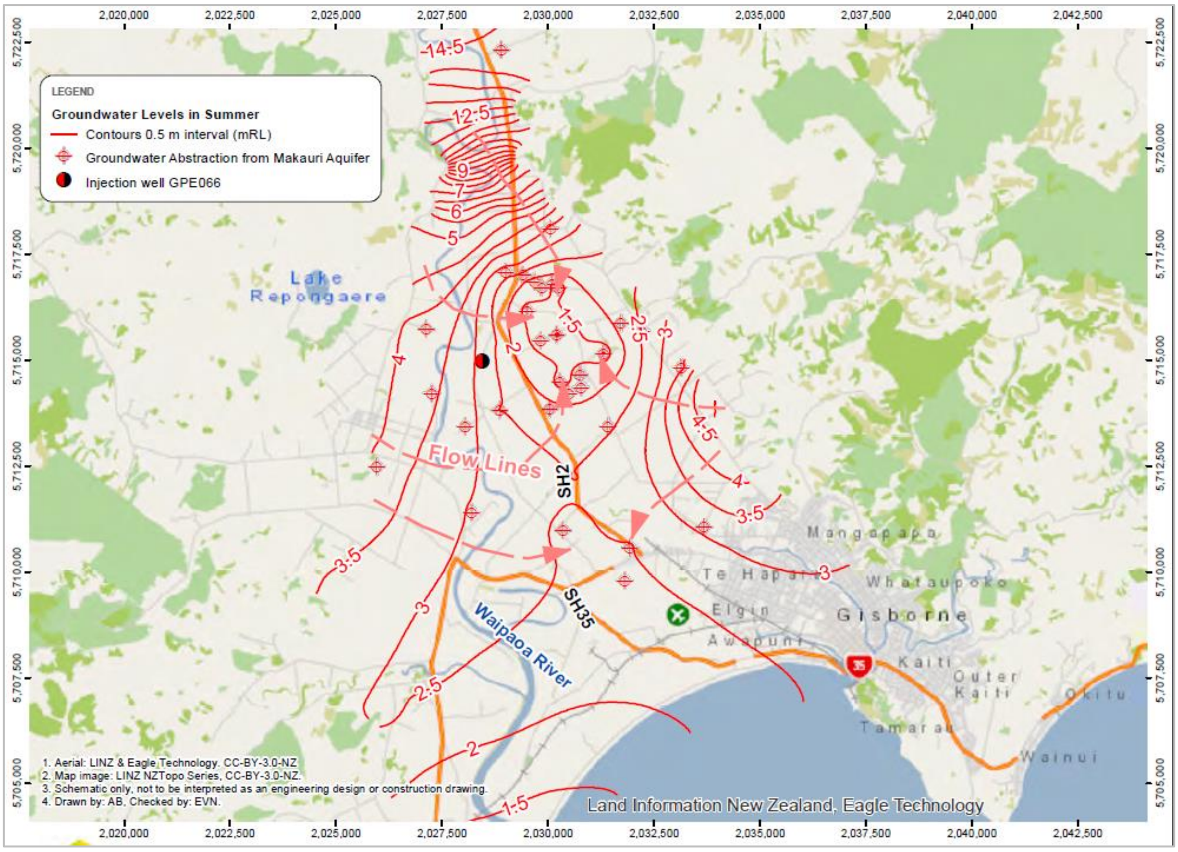

Figure 29: Makauri Aquifer Summer Piezometric Surface (from Golder 2021)

4.9 GROUNDWATER QUALITY

Groundwater quality distribution and trends are addressed in the separate groundwater quality conceptualisation report (WGA 2022b). A summary of groundwater types within the Makauri and Matokitoki Aquifers based on water quality has also been recently presented in a report by Golder (2021). However, some general aspects of the quality of groundwater in the aquifers underlying the Poverty Bay Flats are important within the scope of this groundwater flow modelling project.

Past assessment of seasonal changes in hydraulic gradients within the Makauri Aquifer (Golder 2014b) has identified that the hydraulic gradient within the aquifer may shift from offshore to onshore due to groundwater abstraction during dry years. WGA is not aware of any water quality evidence to indicate saline water intrusion is occurring to the Makauri Aquifer along the coast.

Groundwater in the Makauri Aquifer to the west of the Waipaoa River (western saline aquifer area) is mineralised and anoxic with elevated salt concentrations, compared to Makauri Aquifer groundwater to the east of the river (WGA 2022b). When considered in terms of the conceptual groundwater model, this general salinity distribution suggests the Makauri Aquifer to the west of the river receives limited recharge from overlying aquifers or rainfall (refer Section 4.8.2). As previously described for the section for the Makauri Aquifer underlying the Te Arai River (refer Section 4.3.2), this poorer water quality is interpreted to be indicative of limited groundwater through-flow and longer residence times in the aquifer. However, two wells located close to the Waikakariki Stream (GPJ005 and GPJ078) are screened at shallower depths that would be consistent with the Makauri Aquifer and yet are characterised by elevated groundwater salinity. These observations mean further field investigations are required to address uncertainty in the understanding of the geometry, hydraulic behaviour, and water quality of the Makauri Aquifer western saline area.

Additionally, the groundwater quality conceptualisation has identified that the deep aquitards underlying the Poverty Bay Flats may act as salt reservoirs contributing to salt loads in the aquifers. The salt in the deeper aquitards may be a relic of the marine environment in which these fine-grained sediments were deposited (WGA 2022b).

Makauri Aquifer groundwater monitoring over the past three decades has indicated an area along the eastern edge of the Poverty Bay Flats to the north of Waimata Valley Road (Figure 1) is characterised by low electrical conductivity water. This observation implies this water has relatively low salinity compared to water in the wider aquifer, indicative of a potential area of groundwater recharge. This trend is considered further in the groundwater quality conceptualisation report (WGA 2022b).

Saltwater intrusion along the coast in response to drainage of the Awapuni Moana area has been the subject to numerous investigations as documented in the groundwater quality conceptualisation report (WGA 2022b). Conceptually, there is a gentle hydraulic gradient from the ocean toward the drains in the Awapuni Moana area. Although this hydraulic gradient varies in response to tidal fluctuations and rainfall patterns, groundwater quality monitoring indicates there is a groundwater flow from the ocean toward the drains, which is partially density driven.

At the time of report, WGA understands that GDC is developing an exploratory drilling and monitoring programme in 2023, 2024 which will greatly help to better understand the western aquifer geology and water quality conditions.

4.10 GROUNDWATER AGE

During the 1980's and 1990's a considerable number of groundwater samples were obtained from bores across the Poverty Bay Flats and analysed for hydrogen and carbon isotopes. The results from these analyses, interpreted groundwater ages and implications for groundwater recharge were documented in a paper by Taylor (1994). This paper presented a considerable amount of information, with a short summary of the conclusions provided below.

- The Shallow Fluvial Aquifer contained groundwater of very recent origin, with recharge from the river and from incipient rainfall.
- The Waipaoa Aquifer was interpreted as connecting to the Waipaoa River downstream of the narrow river valley area north of Kaitaratahi. The tritium content of the ground water the recharge occurred after the start of nuclear testing.
- The Makauri Aquifer was interpreted as receiving recharge from the Waipaoa River near to or upstream from Kaitaratahi. The interpreted ages for the groundwater samples tested were less than 100 to 200 years. The tritium measurements indicated that the aquifer did not respond to groundwater abstraction by stimulating the recharge of significant amounts of recent water.
- Water from the Matokitoki Aquifer at its southern end near Gisborne had an inferred average age of 4,300 years although the author indicated there was a possibility that the ages may have been underestimated by up to 1,300 years.

Groundwater age data from recent sampling and analysis of groundwater undertaken by Groundwater and Nuclear Science Consulting (GNS) has been provided by GDC (Table 6). The samples are from bores screened predominantly in the Makauri Aquifer and the groundwater ages support the earlier interpretation from Taylor. The groundwater ages in Table 6 will be used to support calibration of the numerical groundwater model.

Table 6: Groundwater Sample Ages (GNS unpublished data)

Site	Aquifer	NZTM_Easting	NZTM_Northing	Exponential Piston Model ratio (%)	Mean Residence Time (years)
GPB102	Matokitoki	2033820	5710963	0.43	185
GPC031	Te Hapara Sand	2031318	5708657	2.6	50
GPC062	Te Hapara	2030217	5706652	0.43	130
GPD130	Makauri	2031636	5710162	0.43	170
GPE006	Waipaoa	2029193	5716763	0.38	44
GPF090	Makauri	2030247	5716709	0.43	125

4.11 GROUNDWATER BUDGET

Groundwater budgets have been obtained from work undertaken by GNS (White et al 2021) and summarised in Table 7 and Table 8. These budgets are considered to be preliminary, to be updated in accordance with updated groundwater abstraction data. The definitions of the flow components are provided on the following page.

Table 7: Preliminary Poverty Bay Groundwater Budget Under Natural Flows (White et al 2012)

Aquifer	P (l/s)	Q^{GW}_{IN} (l/s)	Q^{SW}_{GW} (l/s)	Q^{GW}_{TR} (inflow) (l/s)	ET (l/s)	Q^{GW}_{BF} (l/s)	U (l/s)	Q^{GW}_{TR} (outflow) (l/s)	Q^{GW}_{COUT} (l/s)	Balance (l/s)
Te Hapara Sand	1500	0	0	300	1200	0	0	0	600	0
SFA/Waipaoa Gravel	2500	0	600	0	2000	800	0	300	0	0
Makauri	0	0	0	0	0	0	0	0	0	0
Matokitoki	0	0	0	0	0	0	0	0	0	0
Total	4000	0	600	300	3200	800	0	300	600	0

Note: This budget assumes groundwater abstraction is zero.

Table 8: Preliminary Poverty Bay Groundwater Budget Incorporating Total Groundwater Abstraction of 275 L/s (White et al 2012)

Aquifer	P (l/s)	Q^{GW}_{IN} (l/s)	Q^{SW}_{GW} (l/s)	Q^{GW}_{TR} (inflow) (l/s)	ET (l/s)	Q^{GW}_{BF} (l/s)	U (l/s)	Q^{GW}_{TR} (outflow) (l/s)	Q^{GW}_{COUT} (l/s)	Balance (l/s)
Te Hapara Sand	1500	0	0	67	1200	0	42	0	325	0
SFA/Waipaoa Gravel	2500	0	600	0	2000	800	17	283	0	0
Makauri	0	0	0	157	0	0	157	0	0	0
Matokitoki	0	0	0	59	0	0	59	0	0	0
sum	4000	0	600	283	3200	800	275	283	325	0

P	Precipitation recharge.
ET	Evaporative losses.
Q^{SW}_{IN}	Groundwater inflows from surface water bodies (Waipawa River).
Q^{GW}_{TR}	Groundwater transfer between aquifers.
Q^{GW}_{BF}	Groundwater discharges as base flows to surface water bodies.
Q^{GW}_{COUT}	Groundwater discharges across the coastline to the ocean.
U	Groundwater abstraction (Use)

Several important factors should be noted with regards the groundwater balances presented in Table 7 and Table 8.

1. The balance in Table 7 shows no natural through-flow for either the Makauri Aquifer or the Matokitoki Aquifer. WGA considers this to be incorrect as several lines of evidence indicate natural throughflow contributes to both aquifers.

2. The balances in Table 7 and Table 8 indicate a lack of natural groundwater discharges from the Makauri Aquifer. Our conceptual groundwater model indicates an offshore discharge is likely to be occurring.

3. The Waipaoa Aquifer and the Shallow Fluviatile Gravel Aquifer need to be considered separately in the water balance calculations.

4.12 CONCEPTUAL MODEL ASSUMPTIONS AND ISSUES

4.12.1 Introduction

As identified in the modelling philosophy presented at the start of this report, the development of the numerical groundwater model for the Poverty Bay Flats required initial assumptions which are based on the interpretation of available data. As the model was developed, some of these initial assumptions were built into the numerical model whilst others were refined based on model behaviour during the iterative calibration process. In areas where sufficient data is lacking, a degree of uncertainty around the extent and hydraulic behaviour of an aquifer remains following the completion of any numerical modelling programme. Throughout the process, other new but informed assumptions and interpretations have also arisen as part of this process. A summary of these are compiled in this section for clarity, together with suggestions for methods of testing and verifying these key factors. Included in this list are key issues that may need to be investigated and addressed through future numerical groundwater modelling or field investigations work. Also presented below are suggestions for testing and verifying these assumptions.

4.12.2 Model Geometry

4. The numerical geological modelling process places a higher emphasis on lithological unit continuity and smoothness than on complete faithfulness to the geological logs (refer Section 3.1). This assumption has been tested and validated through the numerical groundwater model calibration process. However, there are several places where aquifer continuity or connectivity remains unclear.

    - In the geological model the Waipaoa Aquifer is represented as consisting of two physically separate aquifers of similar age. This interpretation has been carried through into the groundwater model. However, this interpretation may have arisen due to the Waipaoa gravel beds not being clearly identified in drillhole logs of questionable quality. Monitoring wells that screened at the level of the Waipaoa Aquifer but lack geological logs are located between the two areas of defined Waipaoa Aquifer, suggesting these two sections of aquifer may be physically connected. However, the numerical groundwater model did not require such a connection to achieve an acceptable calibration.

    - The conceptual groundwater model has the southeastern branch of the Matokitoki Aquifer rising and connecting to higher aquifers, as discussed in the next section. This interpretation is supported by observations but not necessarily by interpretations from drillhole geological logs. The uncertainty regarding the geological interpretation in this area has affected the localised calibration of the numerical model, as described in greater detail in the following section.

1. Analysis of the geological logs indicates the Makauri Aquifer is locally split vertically into more than one bed, separated by an intervening fine-grained aquitard. As presented in Section 3.3, it has been generally assumed for modelling purposes that the upper gravel bed represents the Makauri Aquifer. The lower gravel bed (aquifer split) occupies an area central to the Poverty Bay Flats and appears to be laterally physically and hydraulically connected to the overlying gravel bed.

    - As the lower gravel bed is locally thicker than the upper bed, clarification of the connections between the two and any differences in hydraulic behaviour may help inform the design of any future water bores in the affected area.

2. The geological model suggests the Te Hapara Sand Aquifer is not continuous along the coast between Gisborne and the mouth of the Waipaoa River. This interpretation arose from the presence of only one drillhole with a geological log that did not identify Te Hapara Sands in the shallowest section of the drillhole. It is more likely that this geological log was poorly described and the Te Hapara Sand is continuous along this coast, as indicated by the continuity of surficial sand deposits in this area. This issue in interpretation may be addressed in future model variants when field information has been collected.

3. The western edge of the Makauri Aquifer is poorly defined by drilling and geological logs, as described in the following section. This issue leads to a range of possible interpretations for aquifer continuity and connectivity in this area. As this issue is strongly linked to water quality and hydraulic boundary conditions, it is discussed in greater detail in the following section.

4.12.3 Hydraulic Boundary Conditions

5. The basement Tertiary rock mass surrounding the Quaternary sedimentary deposits of the Poverty Bay Flats is assumed to be effectively impermeable for the purposes of the groundwater modelling. Therefore, the numerical groundwater model has not been extended beyond the Quaternary deposits (refer Section 3.1). However, there are a range of observations that suggest this interpretation may not be valid everywhere.

    - Flowing artesian groundwater pressures have been observed in the southeastern branch of the Matokitoki Aquifer, which implies that a nearby groundwater recharge zone is located at an elevation above the general ground level for the Poverty Bay Flats terrace. In effect, some localised recharge for the confined aquifers may be derived from elevated ground outside the Quaternary sediments of the Poverty Bay Flats.

    - Trends of decreasing groundwater salinity have been observed in some areas along the eastern edge of the Makauri Aquifer. These trends suggest there may be localised recharge to the confined aquifers in these areas.

    - A few small springs are known to be present within the modelled area. These springs discharge to surface close to the toe of the hillslopes along the eastern side of the flats. These flows appear to be derived from seepage through localised sandstones and conglomerates overlying other fine-grained Tertiary rocks (refer Section 4.5.5) or along faults (refer Section 2.6.8). Although these flows are small on a regional scale, an improved understanding of these behaviour of these springs may help verify the key assumption that the basement rock mass can be left out of the model.

    - Bore GPF056, located close to Gray's Bush, is screened from 108 m to 111 m below ground level in the Matokitoki Aquifer. This bore is recorded as having a flowing artesian static water level approximately 3 m above ground level (Golder 2021). Analysis of water samples from GPF056 indicates the groundwater in the aquifer around this bore is oxygenated with relatively low concentrations of dissolved solids compared to water from other nearby bores screened in the Matokitoki Aquifer (Golder 2021). Bore GPF056 is also located in line with a basement fault identified in the GNS geological map of the area. These features of the groundwater system suggest localised recharge to the Matokitoki Aquifer from the nearby hills to the east. The presence, nature and potential flow capacity of this recharge pathway remains to be confirmed.

    - This assumption of basement impermeability may be tested through the numerical groundwater model calibration process and through future development of a groundwater quality model and through future field investigations.

6. The branch of the Matokitoki Aquifer interpreted as extending southward beneath Gisborne City and becoming shallower toward the south is linked to several assumptions and hydrogeological interpretation issues.

    - The sediments in this branch of the aquifer are interpreted to be sourced from the south rather than the Waipaoa River. This can be tested through sampling and analysis of the aquifer gravels during any future drilling in this area. The lack of greywacke clasts in the samples would verify this geological interpretation.

    - The groundwater monitoring data suggests an east to west hydraulic gradient within this branch of the aquifer. However, there are only four groundwater level monitoring wells in this area on which to base the hydraulic gradient interpretation and other interpretations are possible.

    - The recharge zone for this branch of the aquifer is unclear. Groundwater pressures in some of the bores screened in this branch of the Matokitoki Aquifer are flowing artesian (i.e., above ground level), which is unusual in bores on the Poverty Bay Flats. The hydraulic gradient interpretation suggests recharge occurs along a short section of the eastern edge of this branch of the aquifer, fed from the adjacent early Pleistocene Maungatuna Formation strata at elevations above the adjacent flats. However, further investigations of the geology and hydraulic characteristics of this geological unit and groundwater gradients within the Matokitoki Aquifer would be required to verify this interpretation.

    - A version of the numerical groundwater model was developed to test the effect the addition of a seepage boundary condition along the northern edge of the Poverty Bay Flats would have on model outcomes (AQUASOIL 2022). Predictably, the model calibration in terms of groundwater pressures in the southern branch of the Matokitoki Aquifer improved. However, AQUASOIL also highlighted the issues that arise out of simply applying localised hydraulic boundary conditions to improve model “calibration” without having a very good understanding of the behaviour of the groundwater system in the area of concern. Simply introducing more water to the model without understanding the real-world limits to this process leads to overly optimistic water allocation outcomes

    - Interpretations regarding the geometric layout of this branch of the Matokitoki Aquifer are complicated by the lack of drillhole data in some key areas. It is not clear how this branch connects physically and hydraulically with the main body of the Matokitoki Aquifer under the Poverty Bay Flats. At present it is assumed that the only direct connection is at the northern end of the branch aquifer. However, a wider connection toward the west is also possible. Further field investigations may be required to resolve this issue.

    - The above issues are important as the Cameron Road bores that were installed to supply emergency drinking water for Gisborne draw water from this branch of the Matokitoki Aquifer. Our understanding of their capacity to supply water over an extended period at the required delivery rate depends on the resolution of the above issues.

7. The southern limit of the Makauri Aquifer, and the natural discharge area for groundwater flows within the aquifer, is interpreted as being offshore (Figure 11). This interpretation suggests a hydraulic connection between the southern end of the aquifer and the overlying ocean. An improved understanding of any such connection is important to support an informed assessment of the risk of saline water intrusion to the Makauri Aquifer from the ocean.

    - The numerical groundwater model produced an acceptable calibration without the need to invoke any special hydraulic connections between the Makauri Aquifer and the ocean. Therefore, no further model investigations have been made into this interpretation.

8. Historically, a gravel aquifer extending westward from the western side of the Waipaoa River has been defined as the West Saline Aquifer. A branch of this aquifer is interpreted to extend westward from the Poverty Bay Flats up the Te Arai River valley. There are no geological logs available from the GDC database to confirm the sequence of gravel and fine-grained deposits in the Te Arai River valley. However, several water bores drilled in this area are screened at an elevation consistent with that of the Makauri Gravel further east. Conceptually, it is reasonable to assume this gravel was deposited under the same environmental conditions as the Makauri Gravel and is laterally continuous with the Makauri Gravel. This assumption has been incorporated in the numerical geological model.

    - The quality of the groundwater in this aquifer area has historically been considered poor with elevated salinity and iron and there are no consented users of water from this area. Some of the groundwater quality monitoring wells screened in the Makauri Aquifer close to the Waipaoa River have recorded an increasing trend in salinity. An improved understanding of the hydraulic connection between the western saline aquifer area and the main body of the Makauri Aquifer is important to inform the assessment of the risk to Makauri Aquifer water quality to the east of the Waipaoa River.

5 SUMMARY

A numerical geological model and a conceptual groundwater model of the Poverty Bay Flats has been developed and documented in this report to support the development of a numerical groundwater model of this area. The groundwater model is being developed to support GDC in its understanding of the groundwater resource and to enable GDC to test a series of scenarios for future groundwater management in this area.

The conceptual groundwater model of the poverty Bay Flats is based on the outcomes from the numerical geological modelling work described in this report and the information on the groundwater system presented in Section 4 of this report. The conceptual model is summarised below in graphical form as a series of maps representing the groundwater systems for the shallow unconfined aquifers (Figure 30), the Waipaoa Aquifer (Figure 31), the Makauri Aquifer (Figure 32) and the Matokitoki Aquifer (Figure 33). In each map the general groundwater recharge and discharge zones are identified, together the seepage flow paths through the body of the aquifer, if clearly defined from interpretation of existing groundwater monitoring data. The areas where interconnections between aquifers have been identified, such as at the northern end of the Poverty Bay Flats, are defined and the groundwater flow direction (upward or downward) described.

In summary:

- The groundwater system within the Quaternary alluvial deposits of the Poverty Bay Flats is considered to mainly be restricted to these deposits, with the basement Tertiary siltstones and claystones representing the boundary to the groundwater system. Some potential limited exceptions to this interpretation have been identified and documented in Section 4.6.8 of this report. Overall, the groundwater system consists predominantly of a series of fluviatile gravel aquifers, hydraulically separated for much of their extent by thick silt beds that form efficient aquitards. The shallowest aquifers extend northward from the Poverty Bay Flats as components of the valley fill alluvium within the Waipaoa River valley.

- Two unconfined shallow aquifers, the Shallow Fluviatile Aquifer and the Te Hapara Sand Aquifer, are expressions of two different sedimentary depositional environments from the recent past (Figure 30). These two aquifers are laterally connected, both with each other and with the Waipaoa River.

  Both aquifers receive spatially distributed rainfall recharge on a seasonal basis as well as receiving recharge from the Waipaoa River and from streams intersecting their footprints. They both discharge groundwater to the Waipaoa River and, in the case of the Te Hapara Sand Aquifer, to an intensive network of artificial drainage channels and a few channelized streams. The Te Hapara Sand Aquifer also discharges groundwater to the ocean along the coastline. Groundwater abstraction from these aquifers is limited and is unlikely to lead to extensive drawdown of the groundwater table.

- The Waipaoa Aquifer (Figure 31) is represented as two separate units in the geological and conceptual groundwater models, with both units consisting of fluviatile gravel deposits. The main body of the Waipaoa Aquifer extends southward from the northern end of the flats, increasing in depth from north to south. Recharge to the main body of the aquifer is primarily from the overlying Shallow Fluviatile Aquifer at the northern end of the Poverty Bay Flats. Groundwater seepage through this unit is expected to be toward the south but no clear discharge zone has been identified.

  A southeastern gravel bed, interpreted as being an extension of the Waipaoa Aquifer, underlies the flats in the area around Gisborne at approximately the same depth as the main body of the aquifer. This southeastern branch of the aquifer does not appear to be physically connected to the main body of the aquifer. It is of limited extent and the recharge and discharge zones for this branch of the aquifer are not clearly defined. However, this branch of the Waipaoa Aquifer does react to pumping from the underlying Matokitoki Aquifer,

- The Makauri Aquifer (Figure 32) is by far the most extensive and most highly utilised aquifer underlying the Poverty Bay Flats. It increases in depth from north to south and is interpreted to extend offshore under Poverty Bay.

  Interpretation of winter hydraulic gradients within the aquifer indicates that the primary recharge area is at the northern end of the Poverty Bay Flats. Water from this aquifer is in high demand to support the horticultural industry in this region. Heavy seasonal pumping leads to extensive drawdown of the groundwater pressure under the northern half of the Poverty Bay Flats, with the drawn-down heads being locally below sea level. The interpreted natural discharge zone for the Makauri Aquifer is offshore, implying a hydraulic connection between the aquifer and the ocean. Should groundwater pressures within the Makauri Aquifer drop underneath coastline, the interpreted offshore discharge zone may represent a saline water intrusion risk to the aquifer.

  The western section of the Makauri Aquifer, to the west of the Waipaoa River, has been reported as containing saline groundwater. The aquifer in this area is interpreted as being highly confined with limited throughflow. Groundwater quality monitoring indicates the seasonal pumping of water from the aquifer may be leading to the movement of saline water from this area toward the heavily pumped area to the northeast.

  Abstraction of water from the Makauri Aquifer does not generally appear to influence groundwater pressures in the overlying Waipaoa Aquifer or the underlying Matokitoki Aquifer. However, a pumping test performed on the Matokitoki Aquifer close to Gisborne resulted in drawdown in groundwater pressure in the Makauri Aquifer. A successful MAR injection trial has been performed since 2017 targeting the Makauri Aquifer, with further investigations of potential MAR opportunities being considered.

- The Matokitoki Aquifer (Figure 33) is the deepest aquifer underlying the Poverty Bay Flats, with the main body of the aquifer increasing in depth from north to south. A branch of the aquifer extends to the southeast beneath Gisborne, with this branch becoming shallower toward the south.

  The main recharge area for the Matokitoki Aquifer is considered to be at the northern end of the Poverty Bay Flats, where it rises to intersect overlying aquifers. Groundwater flows within the main body of the aquifer are interpreted to be from north to south, although a discharge zone is not clearly defined. No clear discharge zone for the main body of the Matokitoki Aquifer has been identified although an offshore discharge to the ocean is unlikely.

A secondary recharge area is interpreted to be at the southeastern end of the Poverty Bay Flats, in the area of Gisborne. Groundwater flows within the southeastern branch of the aquifer are either from east to west or from south to north. Groundwater pressures in this branch of the aquifer are flowing artesian and it is interpreted that groundwater from this branch of the aquifer discharges either westward into the main body of the Matokitoki Aquifer or upward into the overlying Makauri and Waipaoa Aquifer.

Although groundwater abstraction from the Matokitoki Aquifer is limited due to its depth, the southeastern branch of this aquifer has been accessed by two bores that serve as an emergency water supply for Gisborne. A pumping test performed on these bores resulted in groundwater drawdown in the overlying Makauri and Waipaoa Aquifers, which is interpreted as being due to the Matokitoki Aquifer rising toward the southeast and becoming physically connected to the overlying aquifers.

The conceptualisation of the Poverty Bay groundwater system documented in this report provides guidance for the development of a calibrated transient numerical model simulating this system. Sufficient data is available to provide for the calibration and validation of the numerical model. Also, the available dataset covers a period dating back to the early 1980's, which provides a very good baseline for numerical modelling of future groundwater management scenarios.

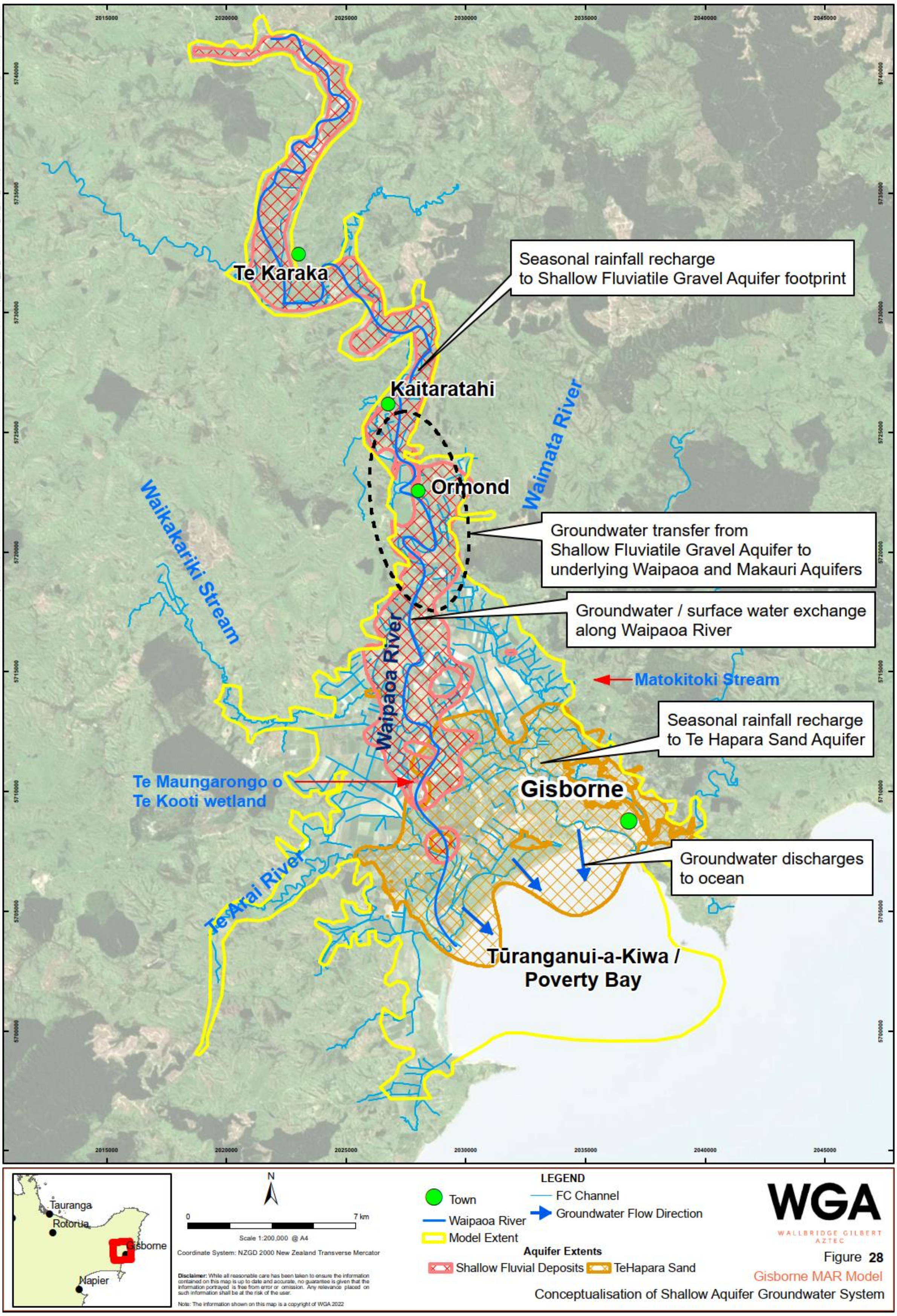

Figure 30: Conceptualisation of Shallow Aquifer Groundwater System

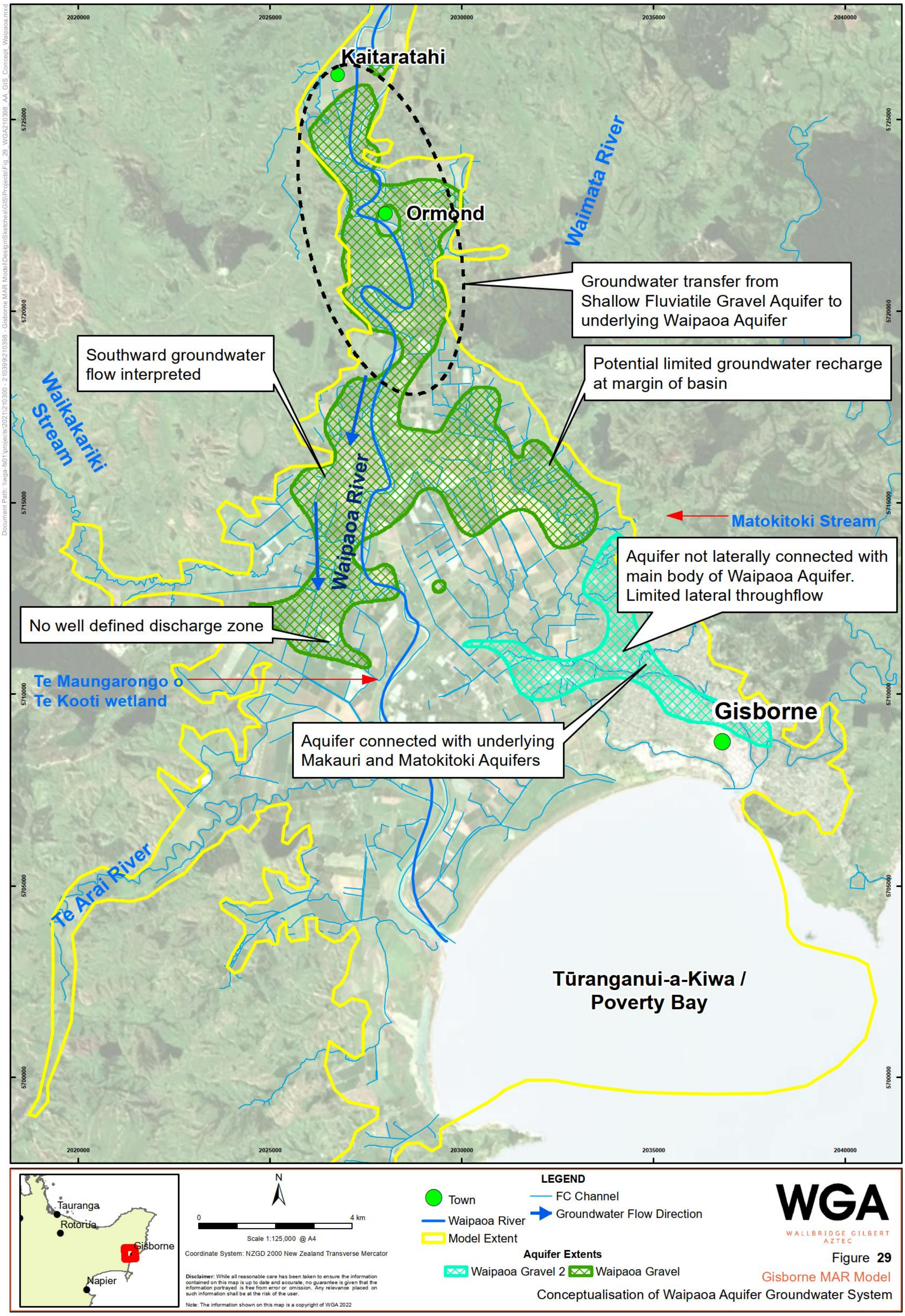

Figure 31: Conceptualisation of Waipaoa Aquifer Groundwater System

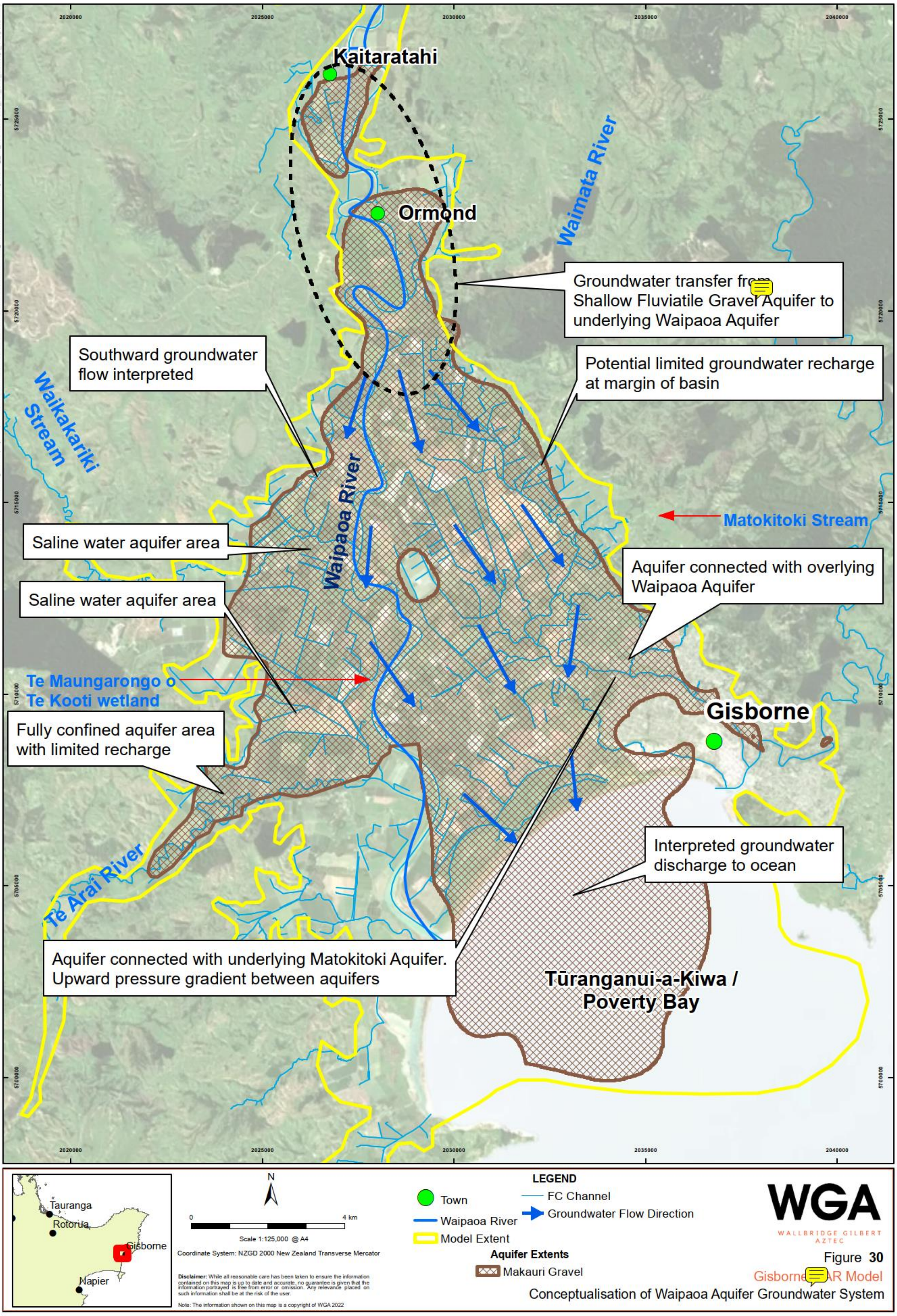

Figure 32: Conceptualisation of Makauri Aquifer Groundwater System

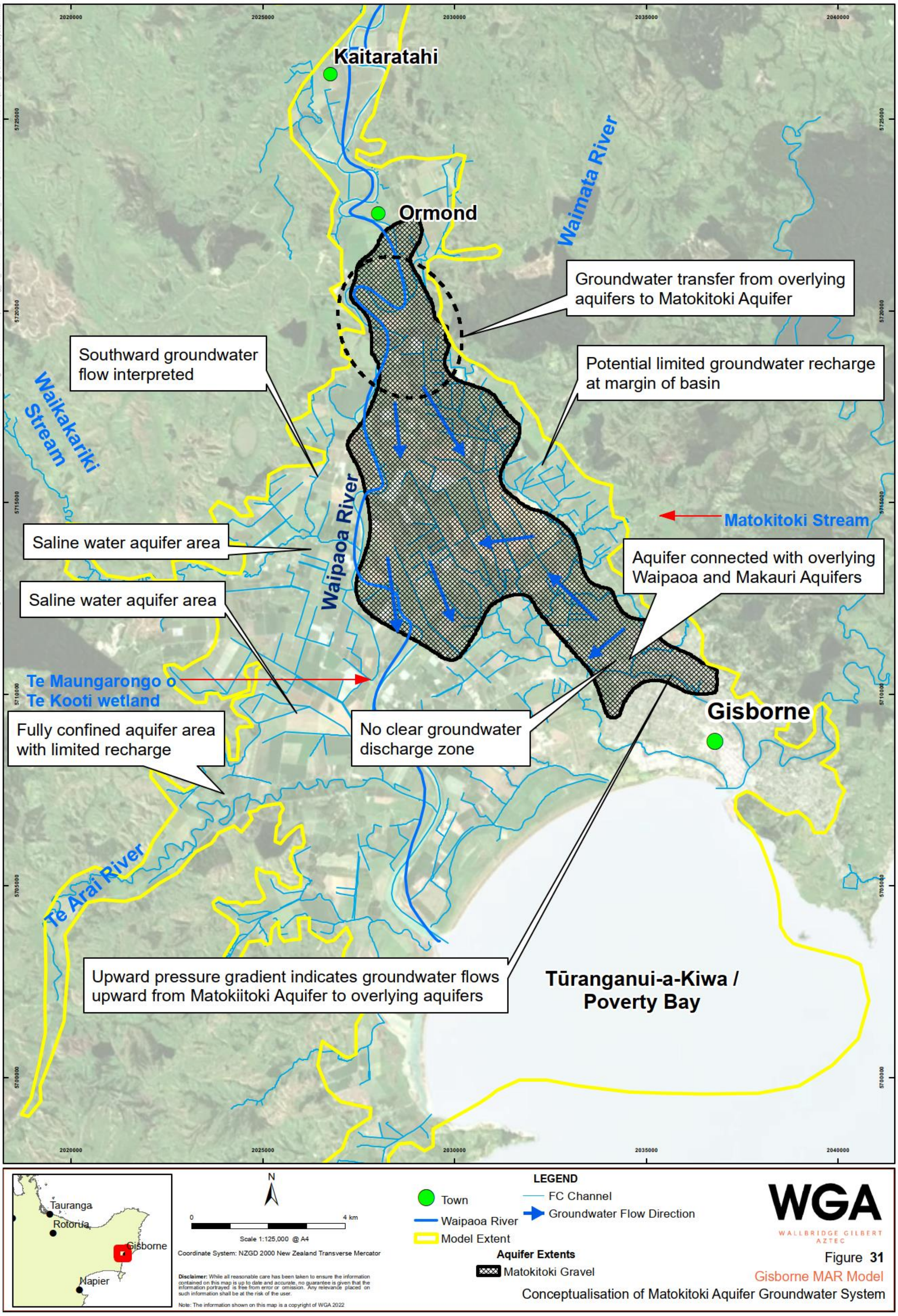

Figure 33: Conceptualisation of Matokitoki Aquifer Groundwater System

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APPENDIX A

AQUIFER TEST RESULTS DATASET

Table B1: Matokitoki Aquifer Hydraulic Parameters Derived from GDC Database

Bore ID	Aquifer thickness (m)	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)	Storage coefficient (-)
GPB039	4.0	41.6	10.4	-
GPB082	-	26	-	1.0×10^{-4}
GPB130	2.7	200	74	-
GPB175	17.5	566	32	6.8×10^{-5}

Table B2: Makauri Aquifer Hydraulic Parameters Derived From GDC Database

Bore ID	Aquifer thickness (m)	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)	Storage coefficient (-)
GPD007	-	383	-	1.7×10^{-5}
GPD008	4	680	170	2.8×10^{-5}
GPD089	4.5	1,155	257	1.2×10^{-3}
GPD115	3.5	456	130	-
GPD135	5.8	424	73	2.7×10^{-4}
GPD194	8	366.5	46	-
GPE010	-	610	210	1.6×10^{-5}
GPE030	-	580	190	1.8×10^{-5}
GPE034	4	1,280	320	-
GPE065	-	600	97	1.0×10^{-4}
GPF024	9.2	235	26	-
GPF035	6	945	158	1.7×10^{-4}
GPF064	5	1,380	276	1.5×10^{-4}
GPF068	4.5	1,053	234	-
GPF074	12.1	2,312	191	2.7×10^{-4}
GPF092	8.6	75	9	1.0×10^{-4}
GPF109	-	1,620	-	-
GPF111	12.1	1,839	152	1.1×10^{-3}
GPF112	10	2,500	250	8.1×10^{-4}
GPF117	17	1,048	62	1.9×10^{-4}
GPF147	-	2,326	-	3.1×10^{-4}
GPG042	-	667	-	4.5×10^{-3}
GPG046	-	769	-	-
GPG076	-	273	-	-
GPG077	-	757	-	1.5×10^{-2}
GPI040	21	500	24	1.9×10^{-3}
GPJ066	6.1	1,006	165	

Table B3: Waipaoa Aquifer Hydraulic Parameters Derived from GDC Database

Bore ID	Aquifer thickness (m)	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)	Storage coefficient (-)
GPD019	-	418	-	-
GPE026	4.0	960	240	9.6×10^{-2} 6.3×10^{-3} (1)
GPG051	6.3	160	25	-
GPG061	17.0	139	8	-
GPG075	6.0	473	79	7.3×10^{-4}
GPO002	-	44	-	-

Note: Values from analysis of drawdown curves at two observation bores.

Table B4: Shallow Fluviatile Aquifer Hydraulic Parameters Derived from GDC Database

Bore ID	Aquifer thickness (m)	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)	Storage coefficient (-)
GPD003	-	707	-	6.2×10^{-3}
GPD025	9.6	247	26	8.3×10^{-4}
GPD049	4.6	841	183	8.7×10^{-3}
GPD059	3.3	618	187	1.7×10^{-4}
GPD124	5.2	400	77	7.0×10^{-4}
GPF118	-	120	-	
GPG054	-	627	-	6.0×10^{-4}
GPJ011	-	1,372	-	4.9×10^{-3}
GPJ075	-	125 - 219	-	
GPO027	-	1,146	-	2.3×10^{-1}

Table B5: Te Hapara Sands Aquifer Hydraulic Parameters Derived from GDC Database

Bore ID	Aquifer thickness (m)	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)	Storage coefficient (-)
GPC040	6.0	260	43	1.3×10^{-3}
GPD113	3.0	270	90	6.7×10^{-4}

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