# A 3D Geological Model of the Greater Heretaunga/Ahuriri Groundwater Management Zone, Hawke's Bay


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## DISCLAIMER



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# EXECUTIVE SUMMARY

GNS Science was commissioned by Hawke's Bay Regional Council (HBRC) to build a simplified geological model for the Heretaunga Plains/Ahuriri Groundwater Management Zone as a precursor to their building a numerical groundwater flow model of the area to assist decision-making for water quality standards and sustainable groundwater management. HBRC requested that the model should be built in Leapfrog GEO, a proprietary product of ARANZ Geo Ltd.

The specific purpose for building this geological model, to create three dimensional data upon which to base a numerical groundwater flow model, has been at the heart of the model-building philosophy adopted. This report supports the geological model we have built, providing a summary of the geological background, particularly of the Quaternary geology of the area, of the geological units we have modelled, the methodology used, and the uncertainties inherent in the model.

Hawke's Bay sits on the actively deforming forearc of the Hikurangi margin and is the locus of significant historic and prehistoric seismic activity and associated deformation. This on-going deformation influences the distribution of Quaternary deposits and erosion. The Heretaunga Plains is the locus for deposition, preserving deposits representing each of the climatic oxygen isotope stages through at least the latter half of the Quaternary, due to tectonic subsidence. Within the Heretaunga Plains warm climatic phases are dominantly represented by fine grained deposits and cool climatic phases by gravels. This forms a basis for the stratigraphy of this 3D geological model.

Surface geological data from Lee et al. (2011; QMAP Hawke's Bay) provide the most reliable constraints for deposits within the area, and HBRC borelogs provide the main data used to define the subsurface stratigraphy and geometry. This report summarises the general characteristics of deposits in each of the stratigraphic units modelled.

In general terms, the Heretaunga basin is a linear, fault-bounded subsiding basin. It has been repeatedly invaded by the sea as sea-level rises following cool, low sea-level stands through the middle and late Quaternary. Estuaries that developed when sea-level approached high stands were subsequently reclaimed by alluvial processes during stabilised sea levels by development of a barrier bar and subsequent infill from debris carried by the major rivers.

Finally, the methodology used to build the model and the uncertainties inherent in the model are discussed. It is important to note that the modelled geology is stylised and simplified and that it provides an indicative estimate of materials below the ground surface. The model is particularly generalised and simplified below the top of the "last glacial" gravel surface, as data from few borelogs are available.

## Keywords

Heretaunga Plains, Heretaunga basin, Quaternary, sea level, Hawke's Bay Regional Council, groundwater, Leapfrog, geology, model, borelogs, Ngaruroro River, Tutaekuri River, Tukituki River, Napier, Hastings, Havelock North, Holocene, Last Glacial, gravel fan, beach gravels, fault, Miocene, Pliocene, estuarine, Awanui Fault, QMAP, Tukituki Fault, Ahuriri lagoon, Poukawa, elevation models, radiocarbon ages, uncertainties, LiDAR.

# 1.0 INTRODUCTION

## Aim and objectives of the project

Hawke's Bay Regional Council (HBRC) is currently reviewing the policy which underpins the management of water resources within the greater Heretaunga Plains/Ahuriri groundwater zone. One of the challenges encountered during this process is to develop a tool for setting limits for sustainable surface water flows and groundwater abstraction. A numerical groundwater flow model can be used in establishing sustainable limits, but the development of such a tool requires a thorough understanding of the geology and hydrogeology of the model area. GNS Science has been commissioned by HBRC to develop a three-dimensional geological model prior to their development of a flow model of the Heretaunga Plains gravel aquifer system. This report describes the geology of the Heretaunga Plains and surrounding areas, the methodology used for creating a 3D subsurface geological model using Leapfrog GEO software, and uncertainties incorporated within the model.

## Area of interest and definition

This study examines significant Quaternary deposits of the greater Napier and Hastings areas as well as the river deposits of the Ngaruroro River, and the enclosed Poukawa basin (Figure 1). This region is informally referred to as the Heretaunga Plains and the area beneath the Heretaunga Plains is informally referred to as the Heretaunga basin.

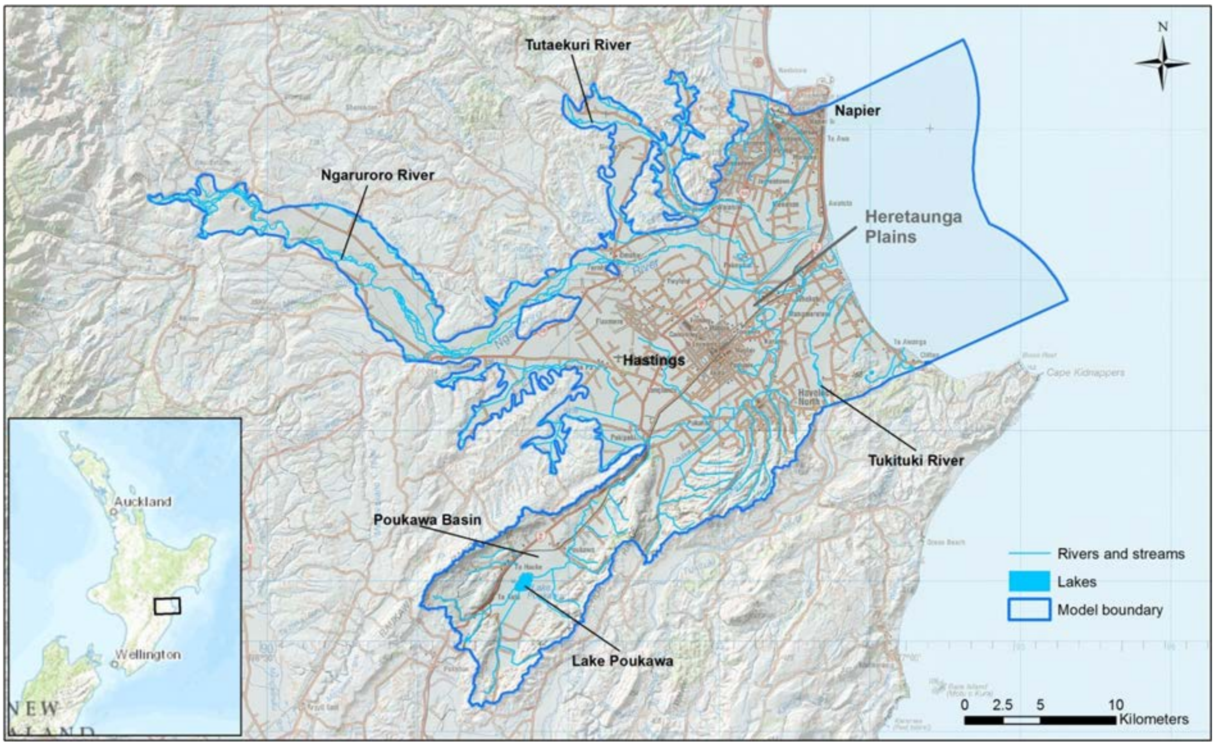


**Figure 1** Topographic map of the study area, showing the extent of the model.

## Time scale: the Oxygen Isotope Stage (OIS) nomenclature and definition of Miocene and Pliocene

In this report we divide the Quaternary Period into early, middle and late subdivisions, where the early Quaternary ranges from the base of the Quaternary[1] (2.45 million years) to 500 000 years, middle Quaternary spans 500 000–128 000 years, and late Quaternary ranges from 128 000 years to the present. Further, we use oxygen isotope stage correlations as a basis for subdividing the middle and late Quaternary epoch. The reason for this correlation is that this system differentiates periods of relatively high sea level (warm climatic times, as now) from low sea level (cold climatic times) in a series of sequentially numbered stages. The sequence of Quaternary climatic and sea level changes are represented by proxy in borelogs as alternating cycles of gravel (cold climatic) and fine grained (warm climatic) materials. This report uses the oxygen isotope stages as references to geological time as defined in the QMAP series. OIS1 represents the Holocene (Q1: 0 to 12 kyr), OIS2-4 represents the Last Glaciation (Q2 to Q4: 12 to 71 kyr), OIS5 the Last Interglacial (Q5: 71 to 128 kyr); oxygen isotope stages with even numbers prior to the Last Interglacial represent cold climatic regimes and odd numbers represent temperate (warm) climatic conditions.

The Miocene geological period ranges in age from 23.8 million years to 5.32 million years. The Pliocene geological period ranges from 5.32 million years to 1.81 million years[1].

## Units defined in the Leapfrog subsurface model

In the Leapfrog model, stratigraphic units consisting predominantly of gravel in borelogs across the Heretaunga Plains have been separated from strata dominated by other lithologies. Gravel modelling units are clearly separable in borelogs, and were chosen because they are important in hydrogeology, representing units of high hydraulic conductivity. The gravel units are stratigraphically coherent and comprise gravel and sandy gravel. Intervening units (“other lithologies”) includes sand and silt, clay and peat and comprise widespread coherent layers and are characterised by materials likely to have lower hydraulic conductivity. Identifiable gravel units incorporated within the model are:

- Five Holocene (Q1) gravel units; these are:
    - Fan gravels from the Ngaruroro River
    - Two sets of fan gravels from the Tukituki River
    - Beach gravels at Napier
    - Beach gravels at Haumoana
- A last glacial gravel unit (Q2-4)
- A penultimate glacial gravel unit (Q6).

The remainder of the units within the model are dominated by “other lithologies”. These include:

- A Holocene (Q1) unit of sand, silt, clay and minor gravels (largely enclosing the Holocene fan gravels listed above)
- A last interglacial unit
- A penultimate interglacial unit.

[1] This project uses geology and timescale from the GNS Science 1:250 000 scale QMAP map series that places the base of the Quaternary at 1.81 million years and the base of the Pliocene at 5.32 million years

## 1.1 GEOGRAPHICAL OVERVIEW

The Heretaunga Plains is a wide alluvial plain built largely of materials deposited by the Ngaruroro, Tutaekuri and Tukituki rivers. These rivers converge at the present coastline near Clive. The curving coastline to the east of the plains stretches between the isolated and elevated Scinde Island (Bluff Hill) and the high rocky cliffs of Cape Kidnappers. The former extent of Ahuriri lagoon between Napier and Bay View, uplifted and drained during the 1931 Napier Earthquake, was previously an estuary with extensive mud flats. The 1931 earthquake (and a number of other large earthquakes recorded across the region) provides evidence that active geological processes are a significant factor in the area.

Elevation of the Heretaunga Plains ranges from just below sea level (Ahuriri Lagoon and small areas around Clive) to almost 60 m above mean sea level near the Ngaruroro River in the Maraekakaho area. The plains provide an avenue through which the three major Hawke’s Bay rivers reach the sea. Since the end of the Last Glaciation, the rivers deposited gently dipping alluvial fans across the low-lying eastern part of the Heretaunga Plains and cut meandering channels. Elevated levees of sand and mud flanking present and former river channels have built up by channel-overtopping flood events. Channels, particularly of the Ngaruroro River, have a long history of avulsing to find more advantageous routes to the coast. Drainage has also been heavily modified since human settlement for flood control.

The Heretaunga Plains are flanked to the north, west and south by low-lying hills with moderate to steep slopes that generally terminate abruptly at their junction with the plains. The boundary between hills and the Heretaunga Plains is deeply incised with ridges protruding into the plains in the west at Pakipaki, Bridge Pa and Maraekakaho, and remnants of buried ridge crests emerging from beneath the plains at Pakipaki, Roys Hill, Fernhill and The Bluff. The abrupt boundary between the plains and the hills in many places represents a modified coastal cliff cut during the mid-Holocene (c. 7000 years ago), when the land now occupied by the plains was an estuary. These coastal cliffs are clearly visible at the foot of the hills behind Ahuriri Lagoon, where a deeply embayed coastline extends southward behind Taradale. A similar ancient coastline, though gently curved rather than embayed, can be seen in the Te Awanga area. Deposits of the major rivers have subsequently filled this estuary. Along the southeast side of the plains near Havelock North, the gently sloping hills dip beneath the flats close to the old river channel of the Ngaruroro River, now occupied by Karamu Stream. These gently sloping hills are incised by the Tukituki River where it emerges onto the plain.

## 1.2 GEOLOGICAL OVERVIEW

The Hikurangi Trough forms part of the Australian-Pacific plate boundary, lying 100–200 km east of Hawke’s Bay; this segment of the plate boundary became active at the start of the Miocene (around 23 million years ago). As a result of this tectonic activity, episodic uplift and subsidence occurred in different parts of the east coast of the North Island, forming localised marine basins with thick deposits of mudstone and sandstone. Further contraction between the tectonic plates during the Pliocene resulted in more uplift. Limestones were deposited along the margins of a seaway that stretched from Hawke’s Bay to Wairarapa, but the southern end of the seaway connection was closed by the end of the Pliocene and the resulting embayment was rapidly filled with terrestrial deposits eroded from the nearby uplifting axial ranges. Tephra beds in early Quaternary rocks record volcanic activity from the Taupo Volcanic Zone (TVZ) that began around 2 million years ago, with larger eruptions depositing ignimbrites at 1 million years ago. At around the same time, thick marginal marine to non-marine gravels were deposited around Cape Kidnappers and other areas of Hawke's Bay. Much of the Hawke's Bay land area had emerged by around 1.7 million years.

The Heretaunga Plains area occupies a fault-bounded depression that is around 900 m deep (Dravid & Brown 1997; or possibly up to 1600 m deep as reported in Beanland et al., 1998). A series of active faults extend from the Waipukurau area northeast to the southern margin of the Heretaunga Plains, and the Awanui and Tukituki faults most likely continue beneath the plains (Figure 3). Seismic acquisition data suggest that some inactive faults, such as the Ngaruroro River and Napier faults, lie at depth beneath the Quaternary sediments (Beanland et al., 1998; Dravid & Brown 1997).

The oldest rocks adjacent to the study area are Miocene-aged marine mudstone and sandstone that are distributed in northeast-southwest trending faulted strips from Havelock North to the coast and south to the Wairarapa area (Figure 2). Pliocene/Quaternary-aged marine limestone and sandstone overlie the Miocene rocks and form the hills that immediately surround the Heretaunga Plains, including the Roys Hill, Fernhill, the basal section of Bluff and Hospital hills, and the hills south of Hastings. Early to middle Quaternary (Black, 1992) conglomerate, pumiceous sandstone and carbonaceous mudstone are preserved at Cape Kidnappers, south of Havelock North and as isolated remnants on the hilltops west of Napier. Younger middle Quaternary alluvial fan and marine deposits were formed by rivers and coastal processes.

The interpretation of the stratigraphy of the Heretaunga Plains used here relies on a well-tested geological model based on continuing deposition within a deforming basin through the cyclical global climatic changes of the Quaternary Period.

Through the Quaternary, cyclical global climatic changes have involved climatic fluctuations (approximate periodicity of 100 000 years) between glacial (cold) events and interglacial (temperate) periods. A result of this climate change was glacio-eustatic sea level fluctuation that ranged from a few metres above the current sea level (during warm periods, such as today) to 130 m below (during the extreme glacial periods, the last of which culminated c. 20 000 years ago; Pillans et al., 1998; Siddall et al., 2003; Rabineau et al., 2006). Because the Heretaunga Plains has been continuously subsiding during at least the last 250 000 years (Dravid & Brown 1997; Beanland et al., 1998) at a rate of c. 1 m/1000 years, its sedimentary history reflects these glacial – interglacial cycles.

Alternating geological units representing warm and cold climatic cycles are stacked sequentially beneath the Heretaunga Plains. Warm climatic cycles were characterised by high sea levels, sediment carrying capacity of rivers was low (as stream gradients were low close to the coast of the day), and deposits were fine-grained. During cold climatic cycles, sea level was low, frost-related erosion in the high country was high, sediment supply to the major rivers was high, and river gradients at the Heretaunga Plains were relatively steep, because the coast line was distant near the edge of the continental shelf. Because the basin was subsiding, broad gravel plains were deposited by the braided rivers of the day.

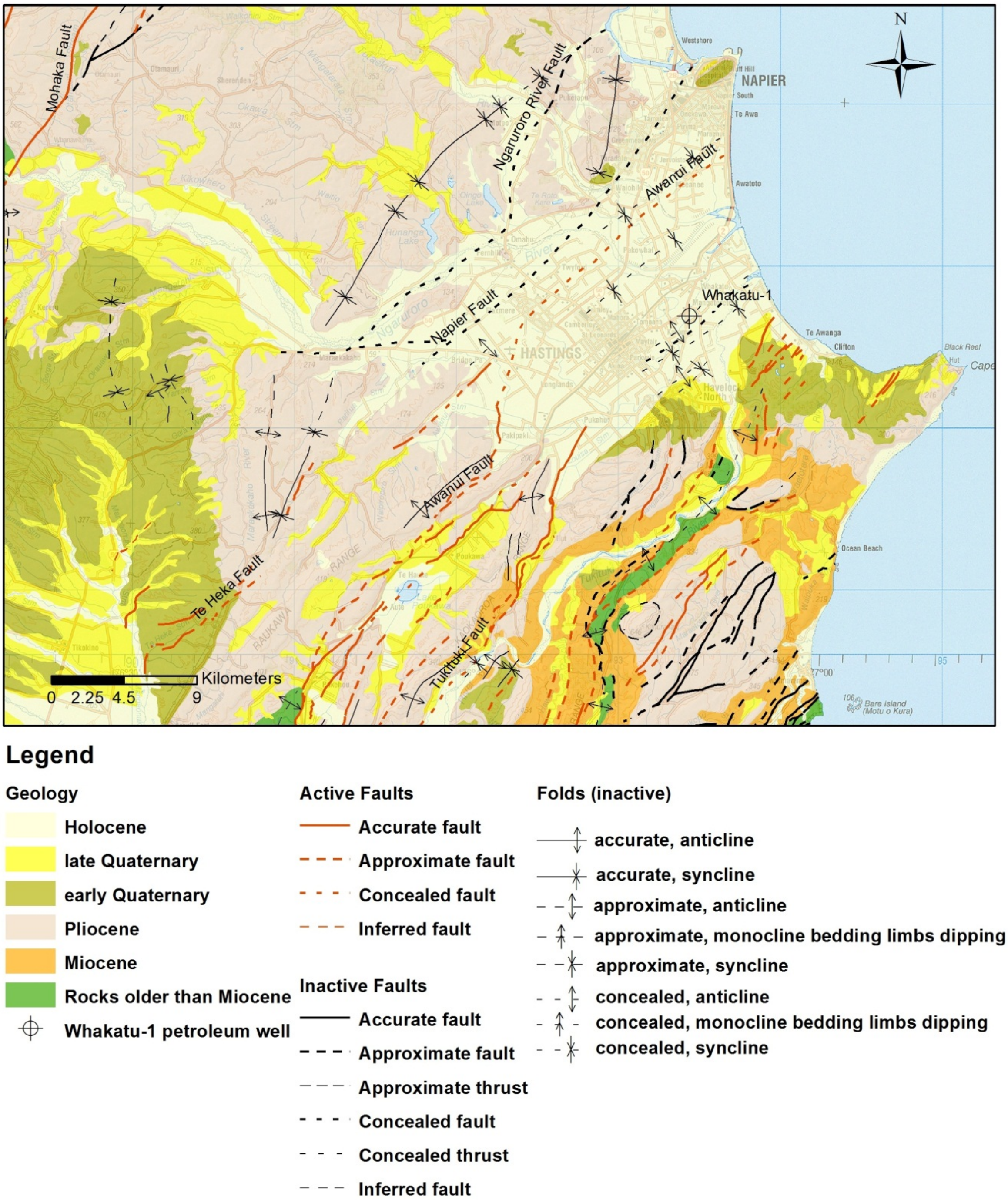


**Figure 2** Generalised geological map of the Heretaunga Plains, divided into undifferentiated units older than Miocene, Miocene, Pliocene, Quaternary and Holocene. The geology is structurally complex as faulting and folding occurred episodically throughout the Pliocene and Quaternary. “Accurate”, “approximate”, “concealed” and “inferred” refer to accuracy of the location of the fault or fold (see section on Uncertainties). Adapted from Lee et al., 2011.

At the peak of the Last Glaciation (c. 20 000 years ago) sea level reached its Quaternary low of c.120 m below the current level. The rivers and their alluvial plains extended up to 50 km offshore from the present coastline to the edge of the continental shelf. Colder temperatures of the time resulted in high erosion induced by freeze and thaw and a lower tree-line, limiting the binding of resulting debris in the upper catchments of the major rivers. As a result, large volumes of gravel were transported down the rivers and deposited across the Heretaunga Plains as river bedload when carrying capacity diminished. The plains were undoubtedly braided alluvial plains, analogous to those of present-day eastern Canterbury.

In detail, sea level change (resulting from climate change) was associated with specific depositional characteristics. For example, as climate ameliorated after the Last Glaciation, sea level rose rapidly to reach its present elevation about 7000 years ago (at a rate of almost 9 m/1000 years for much of that time; e.g., Siddall et al., 2003). As sea level rose, dunes with interdune swamps amongst them were deposited behind the shoreline. As the shoreline advanced inland with rising sea level, so did the backbeach deposits, dunefields and interdune swamps. River gravels that were deposited far from the coast were buried by these swamp and marginal marine deposits as the shoreline advanced inland. At 7000 years ago, the coastline reached its maximum inland extent, from Te Awanga to Havelock North, west of Hastings, to Taradale and Bay View (see Figure 4). The marine embayment seaward of this shoreline was the locus of sand and silt deposition. Following formation of a barrier bar near today's coastline, an estuary formed that has subsequently been filled by fine-grained estuarine and then distal alluvial deposits. These are the deposits that form groundwater aquicludes/aquitards.

Gravels of the cold climatic periods of the middle and late Quaternary represent the groundwater aquifers that are such an important resource for the region. In particular, the last glacial cycle (Q2-4) is the most important of these, as it is closest to the surface and is more directly recharged than underlying gravel units. The objective of this project is to present a simple 3D model of the spatial disposition of these gravels as a precursor to numerical groundwater flow modelling.

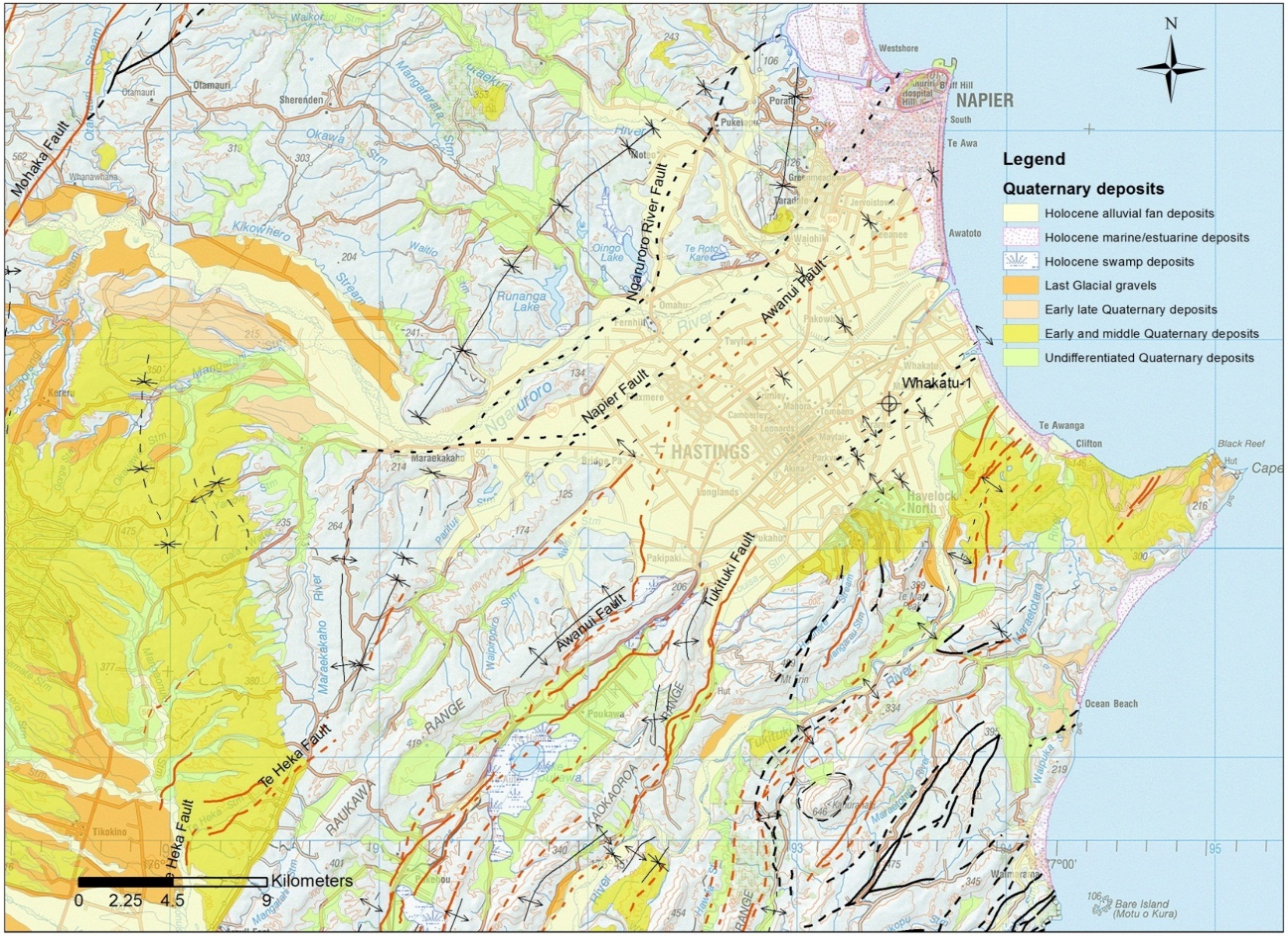


**Figure 3** The distribution of the Quaternary deposits as described in the text (simplified from Lee et al., 2011). Most of the Heretaunga Plains consist of Holocene alluvial fan deposits at the surface. Last Glacial gravels (in orange) are exposed along the banks of the Ngaruroro River and near Havelock North along the Tukituki River. See Figure 2 for descriptions of other symbols. The topographic map is from the LINZ 1:50 000 Topo50 map series.

## 2.0 GEOLOGICAL UNITS

The hill country around the Heretaunga Plains is underlain by Pliocene-aged, gently dipping limestone and sandstone units, sometimes capped by younger Quaternary marine or non-marine sandstone or conglomerate. Last Interglacial marine terraces of sandstone, mudstone and conglomerate cap the hills at Cape Kidnappers. The coastal hills south of Cape Kidnappers are mostly Miocene mudstone or older rocks. Slumping and erosion commonly occurs in the coastal areas.

Late Miocene marine rocks around the Tukituki River and at Ocean Beach are mostly alternating sandstone and mudstone or massive mudstone. The rocks strike northeast-southwest and form the northern end of the Atua Syncline that begins at Mangakuri in the south and trends northeast (see Lee et al., 2011) toward the Ocean Beach area. Early Miocene sandstone and mudstone units around Waimarama are more deformed and contain blocks of older Tertiary rocks. Petroleum well data encountered Miocene sandstone, mudstone and limestone at around 1000 m beneath the Heretaunga Plains (Whakatu-1 borelog; Ozolins & Francis 2000) and is interpreted to occur elsewhere at depth within the basin (Lee et al., 2011, cross section B-B'). Miocene rocks vary in thickness but may be up to 2000 m thick within the synclines.

Thick Pliocene limestone and sandstone form the hilly areas surrounding the Heretaunga Plains, dipping gently at 5–10 degrees and trending northeast-southwest. The limestone is hard, creamy coloured and contains many layers of shell fragments and is usually interbedded with sandstone. Surface outcrops reveal beds that are up to 300 m thick (e.g., Bland et al., 2007). The Whakatu-1 borelog, as well as seismic line interpretation, identified Pliocene rocks at around 300-500 m depth beneath the Heretaunga Plains that are several hundreds of metres thick. However, the deeper borelogs such as the 256 m deep Tollemache borelog document middle Quaternary units at the bottom of the bore (Dravid & Brown 1997), suggesting that Pliocene rocks occur at much greater depths. It is possible that movement on subsurface faults within the basin caused structural complexity, uplifting the Pliocene rocks to shallower depths. The limestones were deposited along the margins of the seaway that connected Hawke's Bay and Wairarapa.

### 2.1 EARLY AND MIDDLE QUATERNARY

Early and middle Quaternary rocks in the Hawke's Bay area belong mostly to the Kidnappers Group. This group of early to middle Quaternary terrestrial and marginal marine deposits is included within the Heretaunga basin, although it is uncertain whether it is separated from younger units by an unconformity. The group is named for a sequence of marginal marine to non-marine conglomerate, sandstone, carbonaceous mudstone, tephra and ignimbrite beds that are well exposed in the coastal cliffs between Te Awanga and Cape Kidnappers. They strike northeast-southwest and dip 10–15 degrees towards (and beneath) the Heretaunga Plains. Surface outcrops of Kidnappers Group are up to 600 m thick and subsurface thicknesses may be several hundreds of metres (e.g., Black 1992; Ozolins & Francis 2000).

The well completion report for the Whakatu-1 borelog recorded Kidnappers Group at 75 m depth. Given that Dravid & Brown (1997) recorded Q7 gravels at the base of the Awatoto (254 m) and Tollemache (256 m) borelogs, we question whether Kidnappers Group could be so shallow at the Whakatu-1 site. At least some of the materials in the interval 75–307 m interpreted as Kidnappers Group may be late middle Quaternary and early late Quaternary in age (Q7, Q6 and Q5). The difference between the Ozolins & Francis's (2000) interpretation and that adopted here may be the result of stratigraphic nomenclatural differences or possibly due to structural complexity (note the presence of a subsurface fault through the area).

Other outcrops of Kidnappers Group are less well preserved. Early Quaternary marine to marginal marine sediments of limestone, sandstone and conglomerate crop out on the hilltops above the Ngaruroro River near Fernhill and are slightly younger than the Kidnappers Group. Isolated patches of terrestrial middle Quaternary deposits occur on high, dissected terraces but the age of these deposits is poorly constrained.

## 2.2 EARLY LATE QUATERNARY DEPOSITS

This unit includes marine and alluvial and fan deposits aged between 128 000 and 71 000 years (Q5. Elevated Q5 marine benches are preserved sitting on Kidnappers Group deposits southeast of Clifton, but marine deposits of similar age are found at depth below the Heretaunga Plains, between 110 and 155 m at Awatoto (ID 3699), 90 and 144 m at Tollemache (ID 3697) and 96 and 137 m at Flaxmere (ID3698) (Dravid & Brown 1997).

In the Hawke's Bay area, surficial alluvial deposits of Q4 to Q2 age are sometimes mapped with younger deposits, as their ages are not well known and they are therefore difficult to map. In parts of New Zealand loess coverbeds overlie fluvial terraces of these ages, and are used for constraining their age; but these coverbeds are commonly absent in the Hawke's Bay area due to erosion (e.g., Litchfield & Rieser 2005). Elevated river terraces of Q4 to Q2 age exposed in the Ngaruroro and Tukituki rivers upstream from the plains dip beneath the Heretaunga Plains Holocene deposits. The top of these terraces is equivalent to the upper surface of the widely distributed and water-bearing gravels that dip beneath the plains, and is the target of most of the water bores across the plains. The fluvial deposits consist mainly of weathered gravel, overbank silts and sand. Early late Quaternary alluvial units (Q2 to Q4) are not differentiated in the model.

Two deep research holes were drilled in the Poukawa basin during 1982–84 (Hole 5, 234 m; Robinson et al., 1984) and 1997 (Lake Poukawa 97-1, 198 m; Schulmeister et al., 2001; Shane et al., 2002). The earlier drillhole, established that the Holocene sequence is less than 10 m thick immediately south of Lake Poukawa, and that Quaternary deposits are at least 235 m thick and dominated by sand, silt, clay and peat, with a number of (largely rhyolitic) tephra deposits. The later borelog, reported in a number of papers, but particularly in Shulmeister et al. (2001), McGlone (2002) and Shane et al. (2002), established a chronology for the basin based on tephra (glass geochemistry) and optically stimulated luminescence (OSL) dating. A U-Th age from peat at 143-146 m below the surface was reported as early in Q5 (c.125,000 yrs). Because the Poukawa basin is a tectonically enclosed basin, no major rivers are present, and materials recorded in deep borelogs are relatively homogeneous, differentiating materials has little hydrogeological purpose. However, these boreholes encountered groundwater at depth (Cameron et al., 2011 and references cited therein).

## 2.3 LAST GLACIAL GRAVELS

A considerable thickness of gravel was deposited by rivers during the last glaciation between 71 000–12 000 years ago (Q4 to Q2). Within the Heretaunga basin, these last glacial gravels have since been buried by younger Holocene marine and river deposits, but remnants are preserved in the river terraces exposed along the banks of the Ngaruroro River upstream from Maraekakaho and smaller terraces along the Tukituki River (Figure 3). Gravel deposits exposed below these terraces are up to 15 m thick and generally consist of unweathered, rounded greywacke gravel (Litchfield 2003). Coverbeds are rare but where found, are less than 1 m thick and consist of loess, soil or paleosols, silt and sometimes Kawakawa tephra (Litchfield & Rieser 2005). Dated samples of wood and loess confirm a last glacial age for these terraces (Litchfield & Rieser 2005).

The correlative of the last glacial surface gravels have been identified beneath the Heretaunga Plains using the borelog logs and radiocarbon ages. Most borelogs terminate at 20–50 m depth within a gravel unit at least 10 m thick. Using radiocarbon ages, Dravid & Brown (1997) demonstrated that in some places (e.g., Flaxmere, 37 m thick; Tollemache, 19 m thick; and Awatoto, 45 m thick), Holocene gravels, sometimes quite thick, lie directly upon last glacial gravels. For the purposes of this model, this issue is not important, because we are modelling hydrogeological units rather than chronostratigraphic units. We have, however, made sure that the surface marking the “base of the Holocene” (and therefore the top of the last glacial deposits) lies below the oldest Holocene radiocarbon age.

The top of these gravels defines a basin structure that dips at around 0.2° towards the basin axis from the southeast side of the basin and more steeply (c. 0.5–1°) on the northwest side.

## 2.4 HOLOCENE MARINE/ESTUARINE DEPOSITS

Following deposition of the last glacial gravels, sea level rose until it reached its present level (and maximum Holocene inland extent) c. 7000 years ago (Figure 4). At this time, the Heretaunga Plains was a broad embayment. The Ngaruroro, Tutaekuri and Tukituki rivers deposited their bedloads into the embayment, and ultimately a barrier bar (tombolo) was built south from Scinde Island along the present day coast by longshore drift and an estuary was formed.

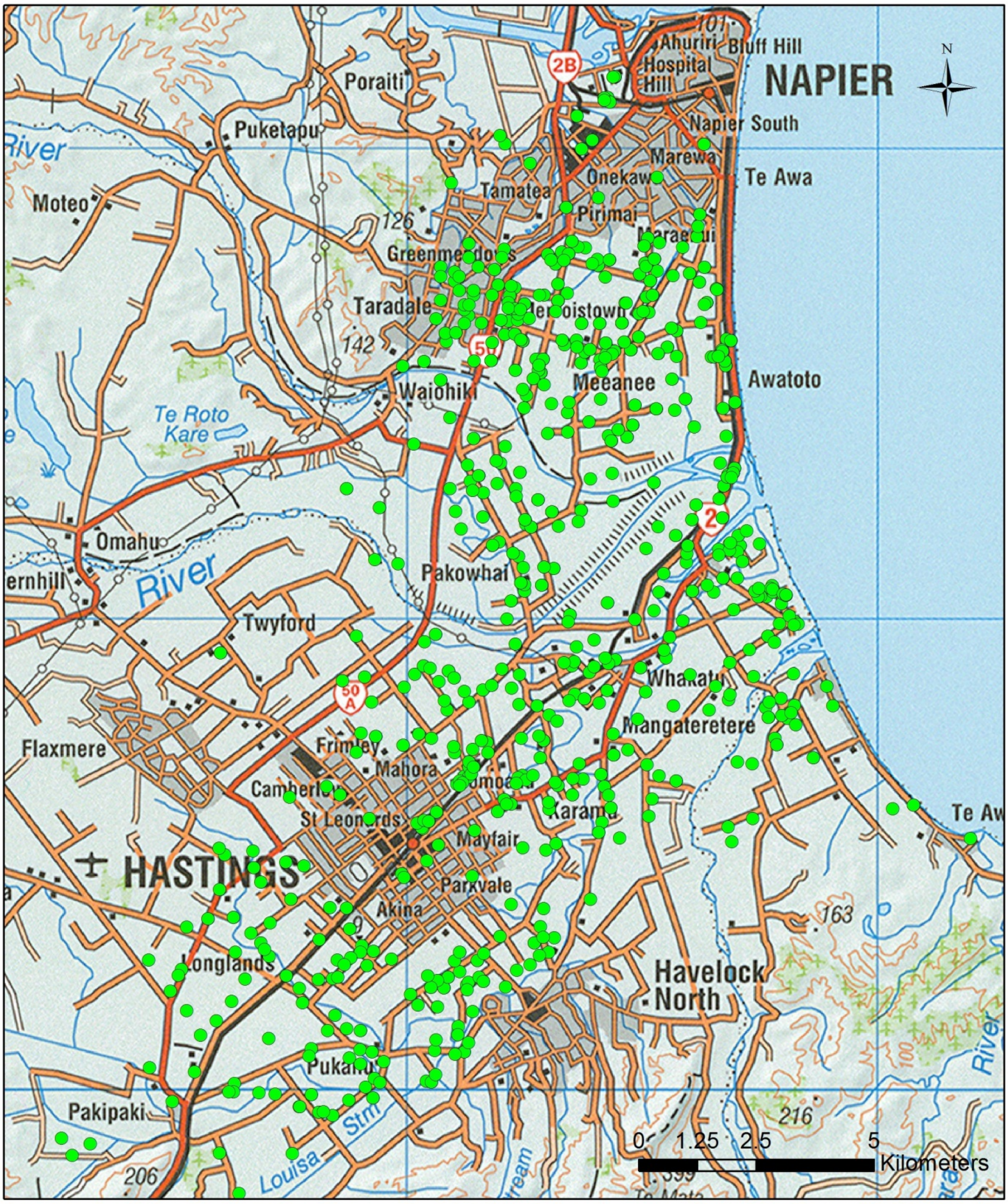


**Figure 4** The distribution of shells (green dots) from borelog data that lie above the base of the Holocene surface, showing the maximum inland extent of sea level 7000 years' ago. The topographic map is from the LINZ 1:250 000 Topo50 map series.

Ongoing deposition from the rivers has subsequently infilled the estuary and built up the plains. Beach gravels, dune sands and swamps were deposited inland from the coastline at each stage of this evolution.

Holocene estuarine deposits are found within the former Ahuriri Lagoon that stretched from Napier to Bay View. In the 1870s, the mud flats and shallow lagoons around Bluff and Hospital hills were drained and reclaimed by the settlers. Much of the estuary was uplifted 1 m above sea level as a result of the 1931 Napier Earthquake. Clay, silt and sand deposits are c. 30–40 m thick in this area; in the Bay View area they lie directly upon the last glacial gravels, probably derived from the Esk River.

## 2.5 HOLOCENE ALLUVIAL FAN DEPOSITS

Since sea level stabilised 7000 years ago, the Tutaekuri and Ngaruroro rivers have deposited sand and gravel into the former estuary, building up gravel-dominated sediment in the form of alluvial fan deltas (Figure 5).

A thick layer of Ngaruroro fan gravels was identified from borelogs in the Roys Hill area. This Holocene fan has a downstream dip of around 0.24° and rests directly upon last glacial gravels; thus the lower contact of these Holocene gravels is not well defined. The fan gravel is up to 30 m thick in places and is overlain mainly by thin layers of pumice-rich alluvium or silts that are less than 10 m thick. In the Hastings area, the deeper part of the basin, the gravel fan is directly overlain by clay, thin gravels and pumiceous alluvium.

A further fan deposited by the Tukituki River extends from Havelock North downstream to Whakatu. The head of the fan lies close to surface exposures of last glacial gravels and dips around 0.09° downstream. The fan gravel interfingers with and is overlain by Holocene marine sediments. A small lens of gravel east of the Tukituki River connects the larger Tukituki fan with beach gravels at Haumoana (Tukituki River mouth gravels).

The LiDAR topographic model shows that the rivers have changed course frequently, creating and abandoning numerous channels across the plains. Pumice-rich alluvium in the top 10–15 m of borelogs around and southwest of Hastings was deposited by the Ngaruroro River following the Taupo eruption 1800 years ago.

Swamp deposits are found in low-lying areas of the plains, particularly drainages that have been isolated by subsequent deposition of overbank silt and/or through tectonic activity.

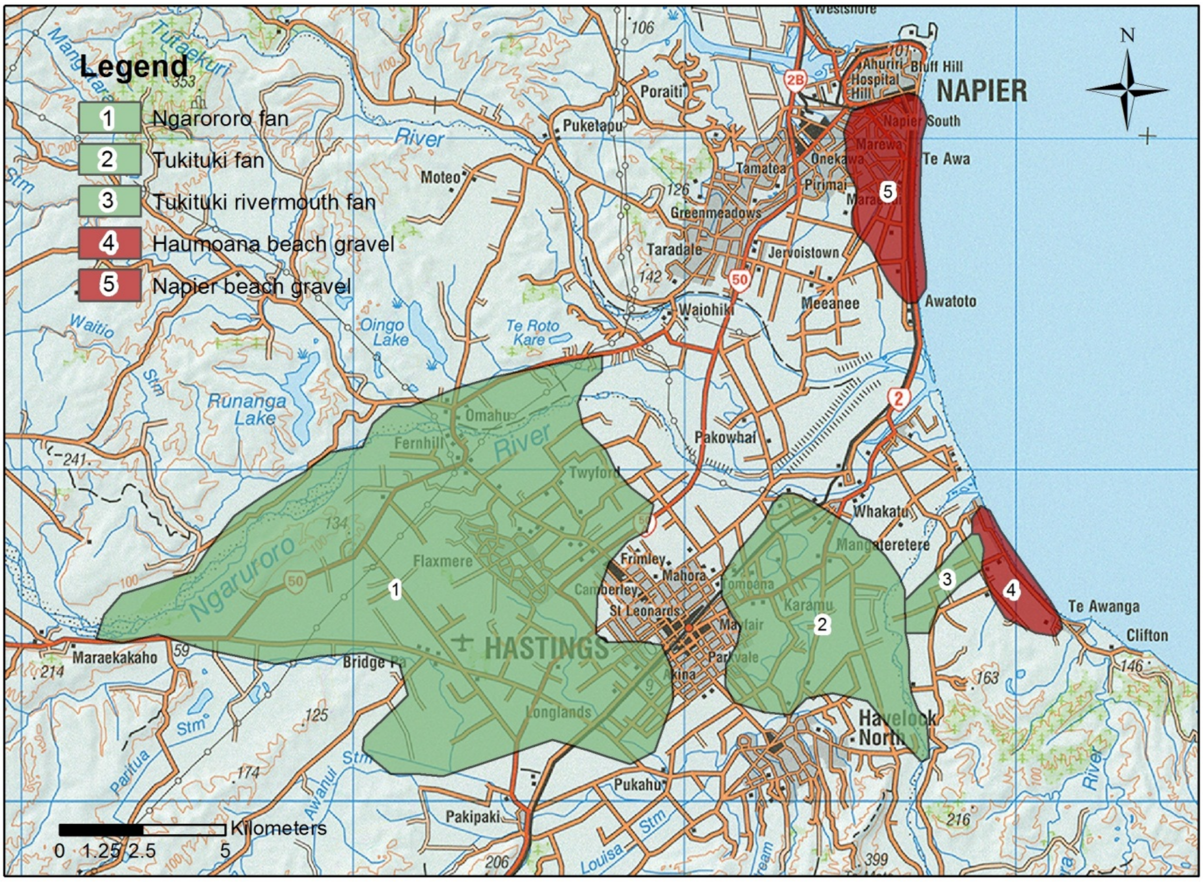


**Figure 5** A map view of the surface and subsurface distribution of Holocene gravels identified from the borelogs. Beach gravels south of Napier and at Haumoana (reddish brown) and inland alluvial fan deltas (green) were deposited by the Ngaruroro and Tukituki rivers.

## 2.6 HOLOCENE BEACH GRAVELS

Holocene beach gravels developed through redeposition of river gravels by longshore drift currents and in places form a barrier bar separating sea from land. Borelogs show the presence of a lens of such Holocene barrier bar gravels about 10 m thick along the coastline south of Napier Hill to Awatoto at around 10 m below the ground surface. These barrier bar gravels are underlain and overlain by Holocene marine silt and clay.

Beach gravels at Haumoana lie just beneath the ground surface and are 5–10 m thick. The southern end of this gravel unit overlies last glacial gravels but interfingers with marine sediments towards the Tukituki River.

## 2.7 UNDIFFERENTIATED QUATERNARY DEPOSITS

QMAP geology (Figure 2) shows areas of undifferentiated Quaternary alluvium and fan deposits around the margins and outside of the Heretaunga Plains. They represent grouped areas of late Quaternary deposits aged from Holocene to 186 000 years. These areas were grouped because of scale or the ages of the deposits were not well constrained.

# 3.0 METHODOLOGY

A 3D geological model generally consists of a series of 3D geological unit volumes organised according to their age and structural relationships. The volumes are defined either as intrusive bodies or by their bottom surfaces. Generally it is only necessary to delineate the lower surface of a unit, as the top of that unit volume is defined automatically by the base the overlying unit (when volumes are generated). The 3D geological model is built from its component unit basal surfaces as dictated by their stratigraphic relationships.

The geological model of the greater Heretaunga/Ahuriri area was developed using the 3D modelling software Leapfrog Geo 1.4.2 (ARANZ Geo Ltd 2014). The following data sources were used in the development of the model surfaces:

- Topographic data (combined DEM consisting of HBRC LiDAR data, 8x8m Geographx DEM, and NIWA offshore DTM)
- 1:250,000 Geological map of Hawke's Bay (QMAP) (Lee et al., 2011)
- Land Information New Zealand 1: 250 000 scale Topo50 map
- Radiocarbon age data (Dravid & Brown 1997)
- Borelogs provided by HBRC.

As required by HBRC, the model was developed at a horizontal resolution of 100 by 100 m using the New Zealand Transverse Mercator (NZTM2000) projection.

The last glacial gravels (Q2-Q4) and Holocene alluvial fans and beach gravels described below, form important hydraulic conductivity zones in the Heretaunga Plains.

## 3.1 DELINEATING THE LAST GLACIAL GRAVELS

The surface extent of this unit was identified in ArcGIS using digital vector data from the Hawke's Bay QMAP. The subsurface extent was determined using borelogs provided by HBRC and using the radiocarbon age data from Dravid & Brown (1997). The basal surface of the overlying fine-grained Holocene unit was defined in Leapfrog Geo as a depositional surface.

Additionally, where Holocene gravel lies upon Last Glacial gravel, where it is not possible to accurately define using borelogs, polylines were drawn on the scattered radiocarbon age data to define the top of the unit.

## 3.2 DELINEATING HOLOCENE ALLUVIAL FANS AND BEACH GRAVELS

Holocene alluvial fans were identified from the HBRC borelog database using Leapfrog. They appear as lenses of gravels that lie above the last glacial surface. Dips of the gravel fans were estimated by slicing the model down the dip of the fan and drawing a plane down the top of the gravels. The slicer was used to view the fans at different angles to get a better understanding of their extent and thickness. Polylines were drawn around logs recording gravel using the slicer oriented at the dip angle with the slice width set to 0.5 m and step size to 0.5 m. Polylines were digitised around large patches of gravel that best represent the distribution of the fan. The volumes defined in the model do not fully honour the borelog data because the digitised shape of the fan was simplified and because complex shapes are unusable in the numerical flow modelling software. Polylines were digitised at 2–5 m intervals, using the slicer to step down through the fan to increasing depth. The bottom of the fan was recognised either where it could no longer be distinguished from last glacial gravels or where gravels terminated. Surfaces were generated from the polylines; the surfaces were then adjusted by varying the Along Pitch and Out of Plane values until there was a satisfactory representation of the fan. Sometimes, polylines were re-digitised or simplified when surfaces poorly represented the shape of the fan. Beach gravels were digitised using the same method as described above, but digitised with zero dip angles. Three dimensional volumes were built for each of the fan or beach gravel packages.

## 3.3 DELINEATING UNITS BELOW LAST GLACIAL GRAVELS

All geological units older than the last glacial gravels have been defined crudely, as a more detailed modelling is not supported by available borelog data. However, to provide a base for the model, approximated surfaces were drawn using interpretations from the three deep borelogs, Flaxmere (ID 3698), Tollemache (ID 3697) and Awatoto (ID3699) of Dravid & Brown (1997). Polylines were drawn between unit boundaries in each borelog, and between unit boundaries and the edge of the Holocene deposits. All polylines were then modified to conform to the general morphology of the modelled top surface of the last glacial gravel. Surfaces were forced over the top of surrounding hills underlain by older materials using external buffers generated in ArcGIS at various distances from the QMAP line depicting the edge of the Holocene deposits. These were given interpolated multipliers of 3D elevations from an imported version of the Leapfrog DEM; these lines were then imported back into the Leapfrog model. The subsurface extents were estimated.

The “basement” surface, representing the base of the Heretaunga basin (i.e., the base of the Kidnappers Group) was based on the form of horizons in published seismic lines (Ozolins & Francis 2000; Beanland et al., 1998) and on the depths represented in the deep borelogs of Dravid & Brown (1997).

# 4.0 UNCERTAINTIES

By definition, models are simplifications of the reality. As such, this 3D geological model of the Heretaunga Plains should not be considered a true life replica, but should instead be treated as the best estimate currently available. The form of the model is a function of the input topographic, geologic, stratigraphic data and correlation; expert judgement by modelling geologists; and interpolation methods provided by the 3D modelling software. Model uncertainty arises due to both absence of data or lack of knowledge, as it is not possible to fully see or investigate the subsurface geology and relationships, and necessary modelling restrictions such as gridding algorithms.

Four main sources of 3D model uncertainty can be distinguished: the distribution and uncertainty of the input data used, the geological complexity of the model area, modeller scientific knowledge and experience, and modelling software algorithms and restrictions. Many of these uncertainties can only be expressed in a descriptive manner, e.g., borelog data uncertainty, as there is not enough information to enable any kind of ground-truthing of the model surfaces. Other uncertainties may be quantified approximately if they include numerical information. Examples of these are the QMAP input dataset that has a set numerical resolution of the geological surface data, or the model resolution (grid size) that is set by the modeller and enforced by the 3D modelling software.

The uncertainties and limitations associated with the Heretaunga Plains geological model are described below.

## 4.1 INPUT DATA

The elevation model used for generating topography in Leapfrog is a combined model incorporating LiDAR, an 8 m resolution elevation model, and offshore bathymetric data from the National Institute of Water and Atmospheric Research (NIWA). The methodology of how this data was stitched together is described below, as each processing stage introduces uncertainties and the final model may not reflect the original values of each DEM. The elevation model is reprocessed to a lower resolution when it is imported into Leapfrog. It is not possible to import LiDAR data with large file sizes (e.g., the LiDAR data for the study area was 715 MB) at high resolutions (such as 2 m), as the software is unable to process this data efficiently.

LiDAR sourced from HBRC, was flown in 2003 and 2006. It covers most of the study area except for the upper reaches of the Ngaruroro River, the western side of Lake Poukawa and the offshore area (Figure 6). The original data had a 10 m offset, with sea level set at 10 m. Cell values were recalculated by subtracting 10 from each cell to normalise sea level to zero. An elevation model of the LiDAR data with a 1 m resolution built by William Ries at GNS Science was down-sampled to 8 m resolution.

The 2003 metadata sheet for this LiDAR data states that the horizontal accuracy of each laser strike was <0.55 m and the vertical accuracy was around 0.15 m. Ground elevations beneath trees may be less accurate, although no uncertainty estimate is supplied. Field checks of the LiDAR survey showed there is less accuracy in the Te Aute area, with a standard deviation of 0.509 m and no test points were surveyed in some areas. Horizontal accuracy of the 2006 laser strikes have a horizontal accuracy of <0.4 m and a vertical accuracy of 0.15 m. Again, ground elevations beneath trees may be less accurate. The 2003 and 2006 LiDAR data were merged and there are height variations in places such as riverbeds and agricultural crops. The LiDAR files were delivered as xyz point data and processed to create gridded elevation models at 2 m resolution. However, due to the low density of the data, actual resolution is more likely to be accurate to 5 m. An 8 m resolution DEM (created by Geographx; [www.geographx.co.nz](www.geographx.co.nz)) was mosaicked with the 8 m LiDAR to create a complete 8 m onshore elevation model of the study area. The DEM has a 22 m horizontal accuracy and 10 m vertical accuracy.

NIWA offshore bathymetry was stitched to the onshore elevation model and contains information licensed under the NIWA Open Data Licence v1.0. The offshore elevation model grid was created by GNS Science and was based on NIWA bathymetric contours for New Zealand (available from [https://koordinates.com/layer/1541-new-zealand-region-bathymetry/](https://koordinates.com/layer/1541-new-zealand-region-bathymetry/)). The offshore model had an original cellsize of 250 m and was reprocessed to 8 m and mosaicked with the onshore elevation model; however, the accuracy of the elevation model offshore will retain the 250 m uncertainty.

The combined onshore-offshore elevation model has an 8 m resolution. After being further down-sampled to a resolution of 100 m using ArcGIS 10, this was imported into Leapfrog.

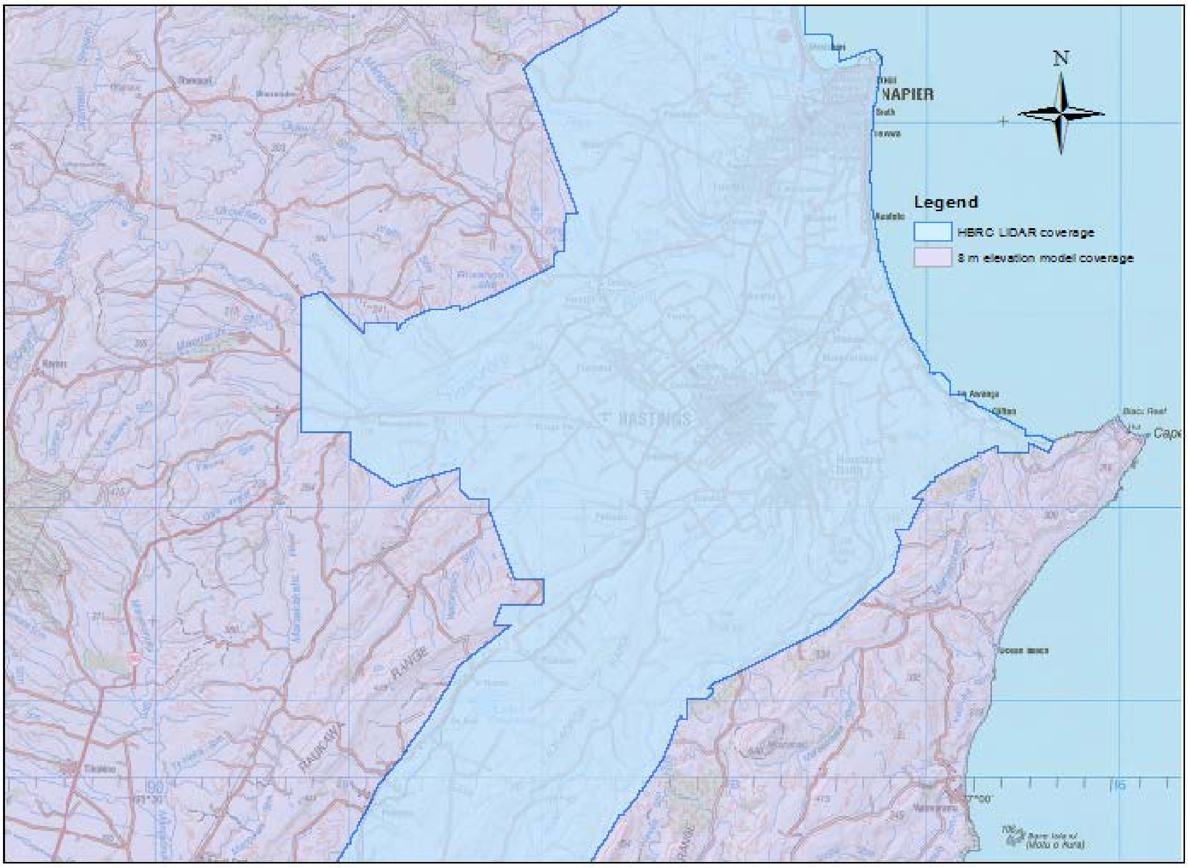


**Figure 6** Map showing the different sources that were used to create the elevation model for this study area. LiDAR (blue polygon) data was used where available. Outside of the LiDAR area, an 8 m elevation model filled in the remaining onshore land area (pink polygon). NIWA bathymetry was used for the area offshore.

### 4.1.1 QMAP

The digital surface geological data was sourced from the GNS Science QMAP Seamless database that is accurate at 1:250 000 scale. The spatial accuracy of the data is estimated to be no better than +/- 100 m for accurately located geological features and in some places may exceed 250 m. Geological data attributed as approximately located will have a spatial accuracy no better than 250 m and in some places is expected to be significantly worse. Geological information comes from the QMAP publication “Geology of the Hawke’s Bay area” by Lee et al. (2011). The geology provided by QMAP is derived from map compilation of information from published and unpublished reports, theses and papers, and field work designed to fill knowledge gaps; linework is simplified for publication at 1:250 000 scale.

For the Hawke’s Bay QMAP, pre-Quaternary geology was mapped in detail by Bland (2006) and Kelsey et al. (1993). Quaternary geology was mapped using aerial photograph interpretation, published maps (including Dravid & Brown 1997) and information from Litchfield (2003). Many Quaternary deposits in the study area are undifferentiated or grouped, as ages of Quaternary units in Hawke’s Bay are generally not well constrained and because of restrictions of map scale.

Active faults mapped in the area were simplified from the GNS Science Active Faults Database and mapping by Bland (2006). Inactive faults were simplified from mapping by Kelsey et al. (1993), Pettinga (1980) and Bland (2006). Concealed faults beneath the Heretaunga Plains were inferred from petroleum report seismic interpretations; the faults mapped at depth have been projected to the surface by the geologist. The accuracy of their positions at the surface may be 250 m to 500 m. To simplify the Leapfrog model, the Tukituki Fault has been extended northeast to connect to with the fault adjacent to the Whakatu-1 petroleum well (see Fig. 2), and the active fault lying between the Napier and Awanui faults has been connected with the Awanui Fault

### 4.1.2 Borelogs

Borelogs provided by HBRC constitute the main source of subsurface data for the construction of the 3D geological model. Information included within the log data that is used for the modelling is: ‘well ID’, ‘well location’ (NZTM Easting, Northing), ‘Top’ and ‘Bottom’ of the logged interval as depth from ground level, ‘primary strata’ and ‘full strata’. Generally, the description of the strata is lithological not geological, i.e., no actual geological formations are defined in the log file. ‘Full strata’ contains the entire lithological description, whereas ‘primary strata’ provides only the main lithology, e.g., gravel. In general, these well logs were prepared by commercial drillers (rather than trained geologists) during or after drilling of the well.

As these well logs play an essential part in model development, uncertainties arising from this input dataset can have a major effect on the geological model. As well as accuracy of well locations, of lithological descriptions and depths recorded in the log, other potential sources of uncertainty are inherent in the spatial collar density, the spatial distribution and in the depth of the borelogs. The following section will discuss these sources of uncertainty in more detail.

**Borelog density, distribution and depth**

In general, the denser the population of borelogs within a part of the model area, the greater the certainty in model development for this area. Distribution of borelogs throughout the model area is another important factor, as areas without any or with very few borelogs have a far higher uncertainty than areas with evenly distributed or clustered borelogs. However, a high density and even distribution of borelogs will not increase model certainties for boundaries deeper than the bulk of the borelogs.

There are 4051 borelogs located within the 828 $km^2$ model area which corresponds to approximately 5 borelogs per $km^2$ (Figure 7). The highest densities of these borelogs are within the Heretaunga Plains and the Tutaekuri River valley. However, there is a lower density of borelogs in the Ngaruroro River valley and the Poukawa Basin, and no borelogs exist in the offshore area of the model. About 84% of all borelogs with lithology provided by HBRC are less than 50 m deep and more than half of all borelogs are in the depth range between 20 to 50 m (Figure 8). Therefore the number of borelogs deeper than 50 m is very limited and uncertainty in the model increases considerably below this depth. Borelogs with depths less than 20 m are mainly found in the north-western part of the model area (Figure 9). The central part, mainly the Heretaunga Plains, is dominated by borelogs between 20 and 50 m depth. Borelogs deeper than 50 m are mainly located in the eastern and south-eastern areas of the model.

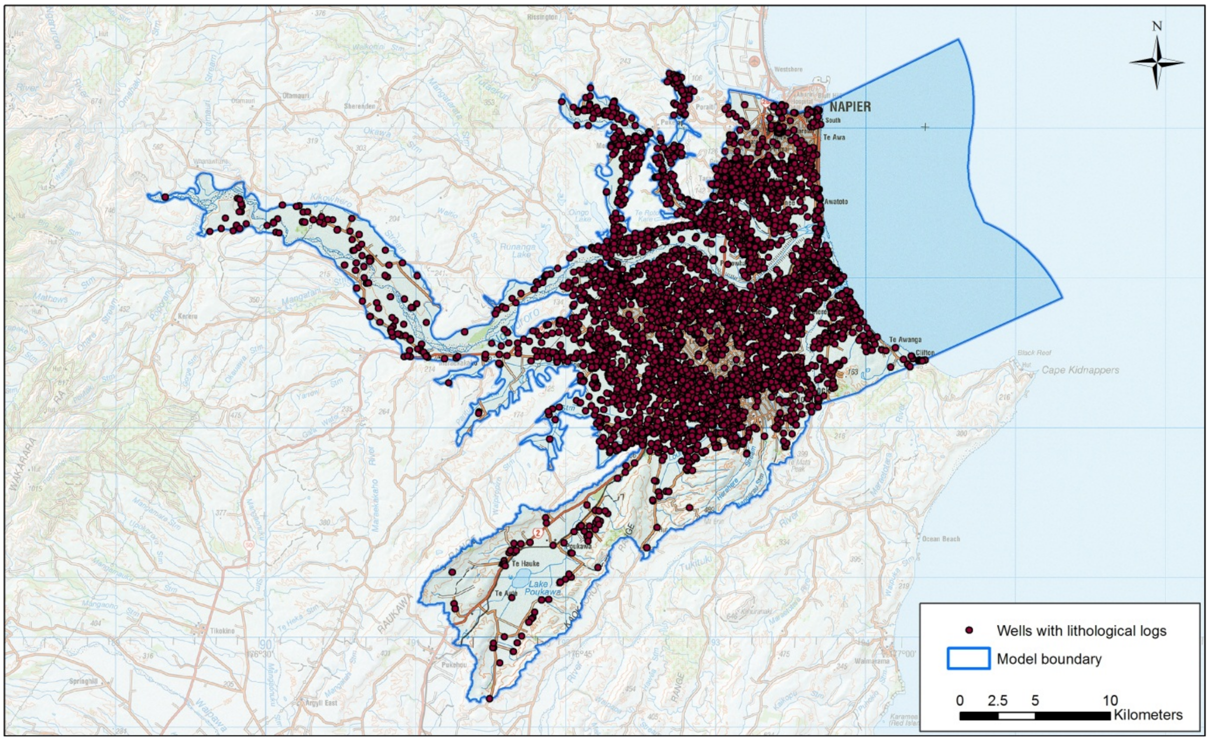


**Figure 7** Location of borelogs within the model area.

In general, the density and distribution of borelogs throughout the study area is adequate for geological modelling up to a depth of 50 m. However, the accuracy of the model is significantly constrained by the depths of the borelogs. Potentially, an adequate accuracy for modelling in the Heretaunga Plains can be achieved down to a depth of 100 m, but the uncertainty will be higher outside of the Plains and in areas with limited borelog frequency and depth.

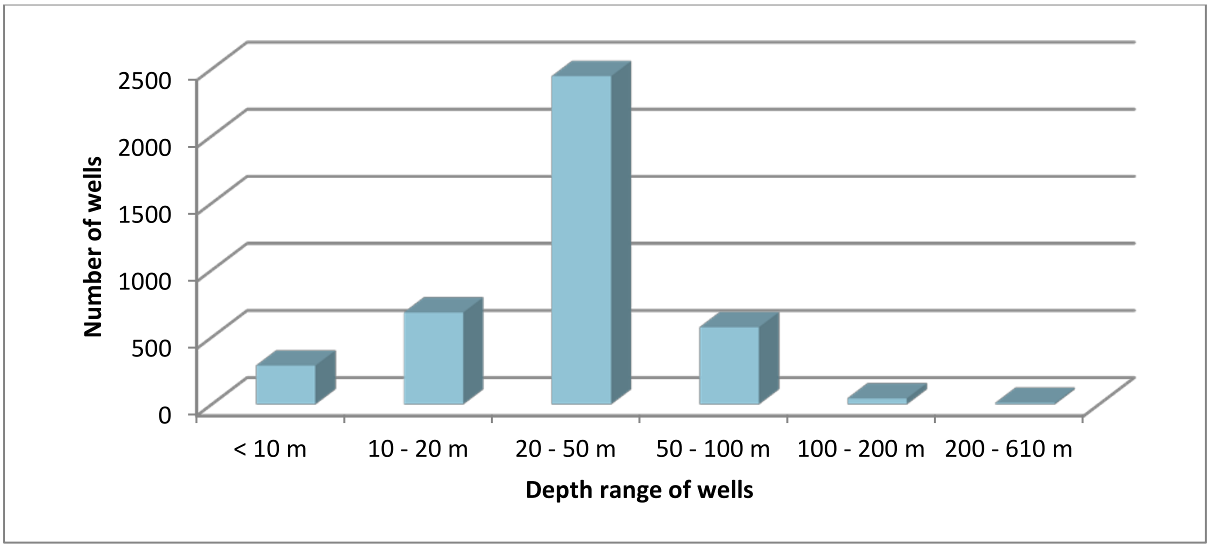


**Figure 8** Frequency distribution of borelogs in the model area, at different well depth ranges.

## Borelog quality

Quality of the borelogs is strongly influenced by correct or incorrect borelog data acquisition, description and input into the database. For example, the borelog locations could have been incorrectly surveyed or may have been calculated from map reference coordinates with an accuracy of less than 100 m.

The influence of the borelog description on the model uncertainty is two-fold. Most of the borelogs in the model area have been drilled and described by commercial drillers rather than experienced geologists. Drillers usually use a more basic lithological description of the changes in subsurface rocks and sediments they encounter during drilling and they do not use standard definitions of materials, so descriptions of materials may be inaccurate; for example, ignimbrites are often described as rhyolites and vice versa, or depending on the drilling method and the degree of welding, may be described as sand or gravel. In addition, the logs do not describe actual geological units used in the 3D modelling.

All borelog data has been entered manually and may be subject to mistakes in data entry. One example is borelog 2803, a 9 m deep borelog in the Heretaunga Plains. One entry in the interval table for this borelog lists gravel from a depth of 7.3 m to a depth of 929 m. This interval table is directly loaded into Leapfrog Geo and used as the basis for the 3D modelling. Unfortunately, the entry is incorrect and could have resulted in future modelling errors for deeper formations if it had remained undetected. This entry error was discovered because it is so conspicuous, but less significant errors may be present that have not been noticed.

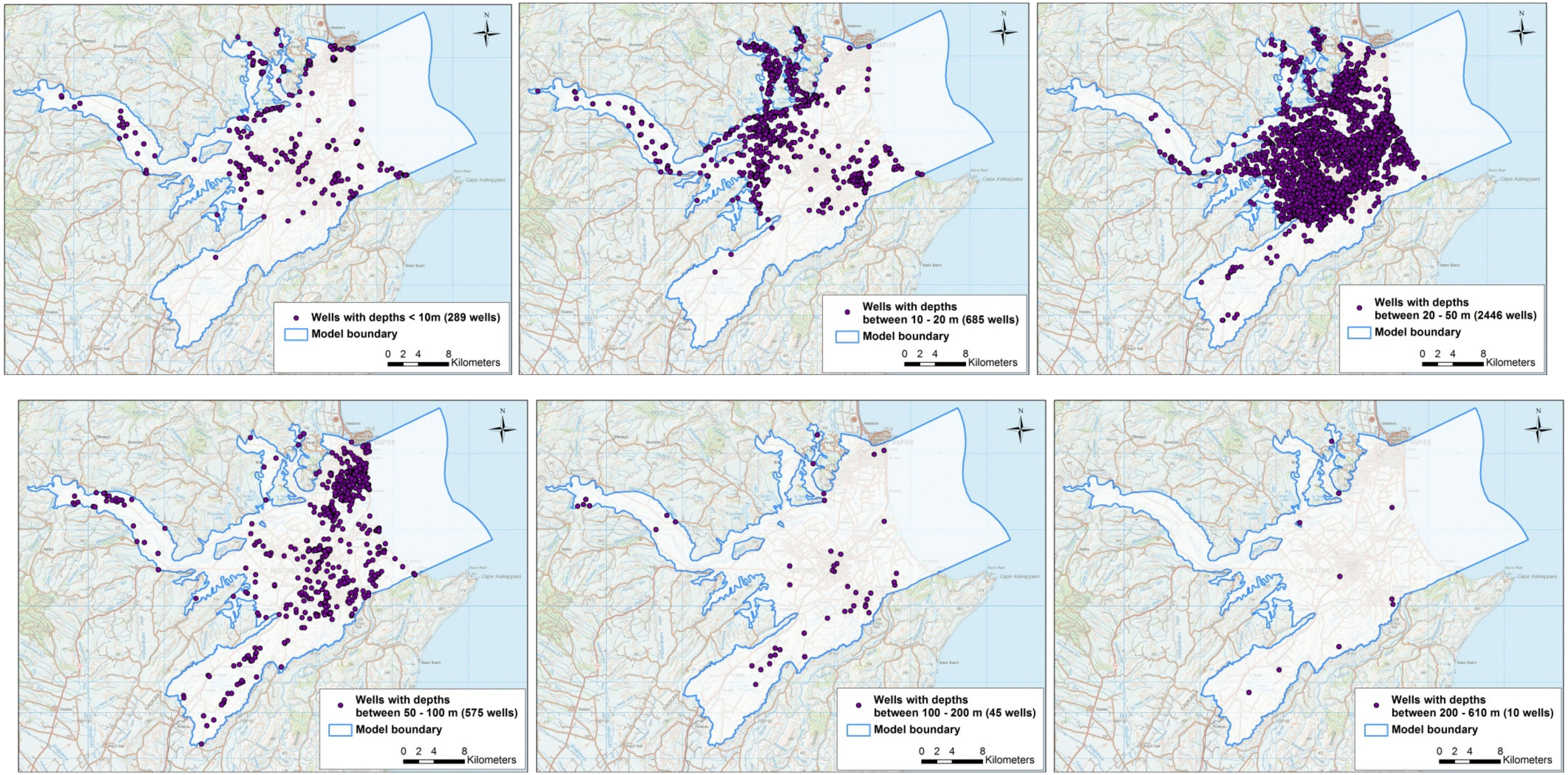


**Figure 9** Spatial distribution of borelogs in the model area, at different borelog depth range.

### 4.1.3 Radiocarbon ages

Radiocarbon age data, published by Dravid & Brown (1997), are the most accurate information available regarding the age of Holocene subsurface materials in the HBRC model area. However, the sample distribution in the study area is very sporadic (Figure 10) and only two samples are dated older than 10,000 years. The model uncertainty increases with lateral and vertical distance from these samples.

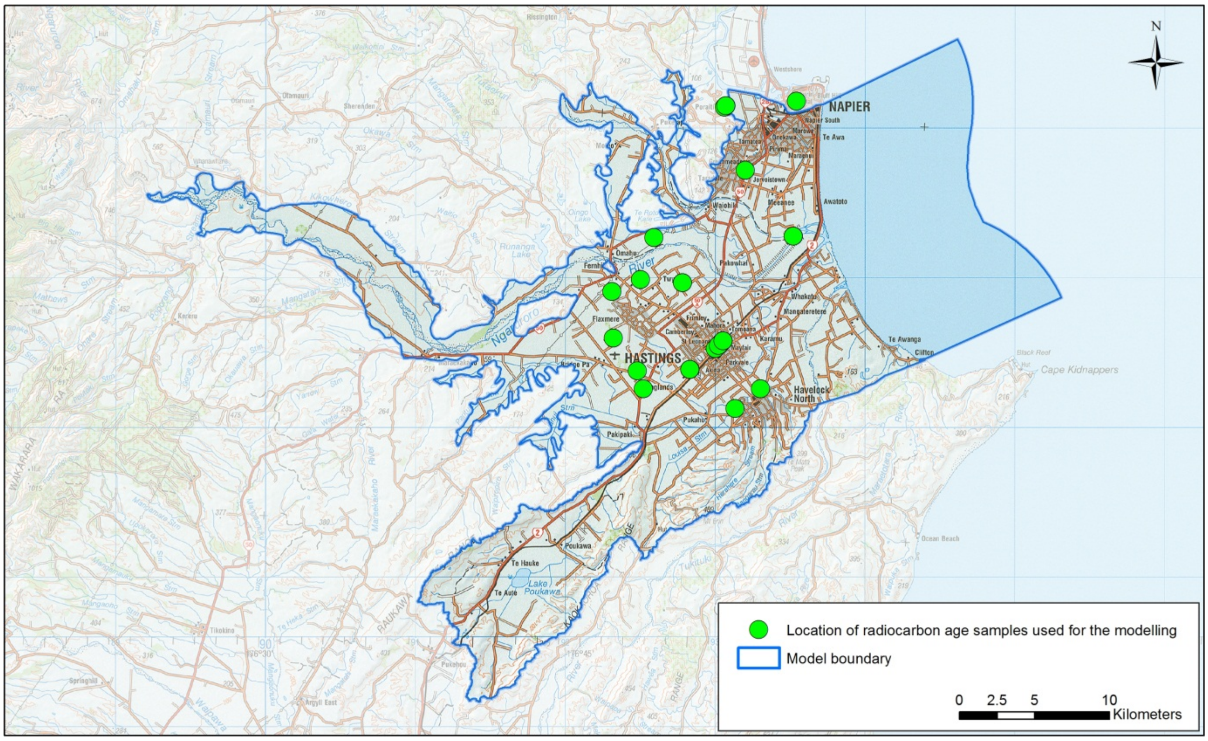


**Figure 10** Location of radiocarbon samples used for age dating within the model area.

### 4.1.4 Correlation

Borelogs have been interpreted using a specific geological model involving sea level change, correlation with the international sea level curve and an assumption that in most cases within the Heretaunga Plains subsurface, erosion during low sea level stands failed to remove materials deposited during the previous high stand. That is, that each of the major climatic changes is represented by deposits that are stacked in stratigraphic order from oldest to youngest. This is certainly not the case in the hill country surrounding the Heretaunga Plains, where erosion has been a significant factor for much or most of the Quaternary. We interpret coarse, thick, laterally persistent gravels as representing cold climatic conditions, and fine (sand, silt, “clay” and peat), sometimes shelly, laterally persistent units as warm climatic deposits.

This model has been used elsewhere in a number of New Zealand’s active depositional basins and results have been consistent and useful. There is, however, a possibility that differential tectonic deformation in the Heretaunga Plains area may have resulted in non-deposition or erosion that could corrupt the inherent correlation principals.

## 4.2 GEOLOGICAL COMPLEXITY

The geology in the Hawke's Bay area is complex. Compression between the Australian and Pacific plates have faulted and buckled the land and episodic uplift and subsidence generated by active faulting has influenced development of the Heretaunga basin (e.g., 1931 Napier Earthquake). The geology is most complex on the southeast side of the basin where numerous active and inactive faults cut the geology into complex fault-bounded slivers. The active faults in the Poukawa area may continue northeast into the Heretaunga basin, where they may displace Quaternary deposits, although subsurface geology is not well enough known to be sure; seismic surveys across the plains mostly fail to image Quaternary deposits because they were designed for understanding deeper units and structures. Two seismic lines, one associated with the Whakatu-1 petroleum borelog (Ozolins & Francis 2000), the other between Bridge Pa and Pakipaki, published by Beanland et al. (1998), have been used to help constrain the depth and geometry of the base of the Heretaunga basin. However, the depth of the Quaternary deposits in the Heretaunga basin is still uncertain due to uncertainty in seismic velocity. Dravid & Brown (1997) estimated the basin is deepest near the Tollemache borelog (ID 3697) and from seismic profile interpretation, is probably around 900 m deep. The interpreted seismic lines mentioned above suggest a somewhat deeper basin (1600 m quoted in Beanland et al., 1998), and we have adopted an intermediate depth, with a maximum depth of c. 1270 m.

The pattern of gravel distribution beneath the Heretaunga Plains is not simple; the Ngaruroro, Tutaekuri and Tukituki rivers have frequently changed their courses throughout the Holocene due to flooding, tectonic movement or human intervention. Complex patterns of abandoned channels crosscutting the plains and isolated occurrences of gravel in borelog data indicate that these rivers have dropped their bedload in different areas through time. Episodic sea-level change during the Quaternary shifted the position of the shoreline and influenced where rivers deposited gravels.

## 4.3 MODELLER

The modellers are responsible for the geological interpretation of the input data and the development of the 3D geological model. The uncertainty of the model decreases with more knowledgeable and experienced modellers, both in terms of the geology in the model area and the actual modelling process. The modelling team consists of experienced regional geologists and 3D modellers.

## 4.4 MODELLING AND MODELLING SOFTWARE RESTRICTIONS

The modelling software used is Leapfrog Geo 1.4.2. (ARANZ Geo Ltd 2014). Leapfrog Geo is the newest product of the Leapfrog 3D modelling suite and it is using the same surface interpolation algorithm as the other products (e.g., Leapfrog Geothermal): the Fast Radial Basic Function (FastRBF™) (ARANZ Geo Ltd 2014). Radial Basic Functions (RBF) is used to develop smooth 3D surfaces. In general, RBFs are exact interpolation methods, i.e., the surface must pass through each data point. However, Leapfrog allows the modeller to disable this constraint if the data is too complex, too uncertain, or large changes in elevation occur within short distances. As a result of the gridding and the snapping algorithms, artefacts and irregularities might be introduced into the modelled surfaces.

HBRC require model surfaces to be provided at a horizontal resolution of 100 by 100 m, to be used for groundwater flow modelling. Therefore, the 3D geological model of the Heretaunga Basin was developed using this resolution with the point snapping function activated. Due to the uncertainty in the input data, a snapping distance 50 m has been specified.

An additional uncertainty may be introduced during the exporting process that will convert the geological model surfaces to MODFLOW grids using the Hydro Module for Leapfrog Geo. The Leapfrog Geo model uses an adaptive mesh for the geological model surfaces; therefore, although the resolution of the MODFLOW grid will be specified at 100 by 100 m, some simplification will occur during the conversion of this mesh into a regular grid as used by MODFLOW.

## 4.5 SIMPLIFICATION

As mentioned above, models are inherently simplifications of reality and therefore imperfect. However, there are also practical reasons, such as model purpose, resources and efficiency, which may result in additional simplifications of the model.

The main reason for simplification of the Heretaunga Plains geological model is the limited availability of certain geological input data. It is primarily based on already simplified lithological logs (‘Primary Strata’) of limited (and poorly defined) quality (see Section 4.1.2). However, as the purpose of this model is for the foundation of a groundwater flow model, the main interest is identification of permeable and less permeable units which can be approximated using lithological descriptions. However, it should be kept in mind that without further data (e.g., radiocarbon age data), it is difficult to distinguish between, for example, Holocene gravels and directly underlying gravels of the last glacial stage.

It is also important to recognise that there is variation in the hydrogeological properties of the “aquicludes” (aquitards), as these are complex combinations of sand, silt and clay. Since there is no identifiable, consistent mappable variation in these materials “aquicludes” are an undifferentiated combination of all.

## 4.6 IMPROVING UNCERTAINTIES IN THE MODEL

The uncertainties in the geological model increase at depth. As mentioned above, most borelogs have a depth range of 20–50 m, coinciding with the top of the last glacial gravels. At least two deeper borelogs, one located near Clive and one near Hastings, would complement the Awatoto borelog and provide better constraint on the deeper Quaternary geological units, ideally drilled to the base of Q7. Careful logging by a geologist or trained technician would ensure more accurate interpolation between the borelogs. Ages obtained from samples from the borelogs would further constrain and refine interpretation between the geological units.

Interpretation of existing seismic data in the Heretaunga Plains area may also improve correlation of the older Quaternary units.

## 5.0 CONCLUSION

This report accompanies a 3D geological model of the Heretaunga/Ahuriri Groundwater Management Zone and is designed to explain the spatial geological distribution of gross geological units within the basin for hydrogeological purposes.

A summary of the geographic features of the area and an overview of the geological setting is presented. The model is based on correlations expected using a climate-based chronology for deposits of the basin interpreted from borelogs held by HBRC. A general description of materials within each of the modelled geological units is provided.

A summary of methods used in building the model and uncertainties inherent in the model completes the report.

## 6.0 ACKNOWLEDGEMENTS

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# APPENDICES

# APPENDIX 1: DATA DICTIONARY FOR LEAPFROG VIEWER PROJECT

This appendix describes the file names within the model produced for the project.

## TOPOGRAPHY

**Onshore_offshore_dem**: Elevation model used for generating topography. It is a combination of LiDAR, an 8 m resolution elevation model and NIWA bathymetry. Detailed information is in the report. A summary is provided in the Leapfrog file – Right Mouse Button click on Topography, go to Properties and go to the Comments tab.

## GIS DATA, MAPS AND PHOTOS

*Shapefiles*

**hbrc_groundwater_aoi** – GIS shapefile of area of interest for Hawke's Bay groundwater project

**Hawke's_Bay_trimmed** – Georeferenced raster geological map of QMAP Hawke's Bay

**Heretaunga_plains_clip_topo** – LINZ 1:50 000 Topo50 map of Napier-Hastings

## BORELOG DATA

**hb_intervals_march14_clipped** – lithology information from borelog intervals in area of interest only

## MESHES

**Onshore_offshore_dem** – duplicate of elevation model of same name in Topography; this inserted here by default

## GEOLOGICAL MODELS

*Fault System*

**Awanui Fault; Awanui Fault segment; Tukituki Fault** – 3D surfaces of significant faults simplified from QMAP geology

*Lithologies*

List of stratigraphic units defining surfaces and volumes. See further explanation below in Surface Chronology

*Surface Chronology*

**Napier beach gravel contacts** – surface for a lens of beach gravels just south of Napier

**Tukituki beach gravel contacts** – surface for a lens of beach gravels near the mouth of the Tukituki River

**Tukituki rivermouth gravel contacts** – surface for a lens of gravels near the mouth of the Tukituki River

**Tukituki fan gravel contacts** – surface for a gravel fan formed by the Tukituki River

**Ngaruroro fan gravel contacts** – surface for a gravel fan formed by the Ngaruroro River

**Base Holocene contacts** – surface defining the base of Holocene deposits

**Base Q4 glacial contacts** – surface defining the base of Last Glacial deposits

**Base Q5 interglacial contacts** – surface defining the base of Last Interglacial deposits

**Base Q6 glacial contacts** – surface defining the base of Penultimate Glacial deposits

**Base Q7 interglacial contacts** – surface defining the base of Penultimate Interglacial deposits

**Basement contacts** – surface representing the base of the Heretaunga basin

*Output volumes*

**Napier beach gravels** – volume for a lens of beach gravel at Napier

**Tukituki beach gravels** – volume for a lens of beach gravel near the Tukituki River mouth

**Tukituki rivermouth gravels** – volume for a lens of gravel near the Tukituki River mouth

**Tukituki fan gravels** – volume for the Tukituki River gravel fan

**Ngaruroro fan gravels** – volume for the Ngaruroro River gravel fan

**Holocene** – volume for Holocene deposits

**Q4 Last Glacial** – volume for Last Glacial deposits

**Q5 interglacial** – volume for Last Interglacial deposits

**Q6 Glacial** – volume for Q6 deposits

**Q7 interglacial** – volume for Q7 interglacial deposits

**Basement** – volume for deposits older than Quaternary to the base of the Heretaunga basin

## APPENDIX 2: GENERATION OF MODFLOW FILES

Geological layers from the Leapfrog Geo model were exported and an identical model was rebuilt in Leapfrog Hydro. Because the area of interest was large, the rebuilt Hydro model was sent to ARANZ so that the MODFLOW model could be processed to 100 m cellsize then exported as a Groundwater Vista *.nam file. When building the MODFLOW model, the minimum thickness was set to 10 m – thin enough to capture the resolution of the geological layers and also to preserve the horizontal and vertical aspect ratios. The layer guides were set to the units defined in the Geological Model. The number of layers within each unit for the MODFLOW model was set to accommodate the complexity within the Geological Model. More layers were set within the Holocene volumes since the volume directly below the ground surface is assumed to have the greatest influence on ground water flow. To keep the total number of layers at a manageable limit the older units had their layering defined by the range in thickness of the geological layers throughout the model.
The layering was set as follows:

- Five layers between the ground surface down to the base of the Holocene;
- Two layers from the base of the Holocene down to the base of Q2-4;
- One layer from the base of Q2-4 to the base of Q5;
- One layer from the base of Q5 to the base of Q6;
- One layer from the base of Q6 to the base of Q7;
- Two layers from the base of Q7 to the base of the early-middle Quaternary;
- Two layers from the base of the early-middle Quaternary to the base of the model.

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