Hydrogeology of the Upper Manawatu and Mangatainoka Catchments, Tararua

June 2014

Horizons Report 2014/EXT/1392

Envirolink 1420-HZLC104

Prepared for:

Abby Matthews
Environmental Scientist - Groundwater
Horizons Regional Council
Palmerston North

June 2014
Report No. 2014/EXT/1392
ISBN 978-1-927250-87-7

Prepared by:

Z Rawlinson and J Begg
GNS Science
P O Box 30-368
Lower Hutt 5040

CONTACT	**24 hr Freephone 0508 800 800**		**help@horizons.govt.nz**		**www.horizons.govt.nz**
SERVICE CENTRES	**Kairanga** Cnr Rongotea and Kairanga-Bunnythorpe Roads Palmerston North **Marton** Hammond Street **Taumarunui** 34 Maata Street	**REGIONAL HOUSES**	**Palmerston** North 11-15 Victoria Avenue **Wanganui** 181 Guyton Street	**DEPOTS**	**Levin** 11 Bruce Road **Taihape** Torere Road Ohotu **Woodville** 116 Vogel Street
POSTAL ADDRESS	Horizons Regional Council, Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442				F 06 9522 929

Hydrogeology of the Upper Manawatu and Mangatainoka catchments, Tararua

Z. J. Rawlinson J. Begg

GNS Science Consultancy Report 2014/127
June 2014

DISCLAIMER

BIBLIOGRAPHIC REFERENCE

Rawlinson, Z.J.; Begg, J. 2014. Hydrogeology of the Upper Manawatu and Mangatainoka catchments, Tararua, *GNS Science Consultancy Report* 2014/127. 48 p

CONTENTS

FIGURES

TABLES

APPENDICES

APPENDIX FIGURES

EXECUTIVE SUMMARY

GNS Science was contracted by Horizons Regional Council (Horizons) to supply a three-layer subsurface hydrogeological conceptual model for the priority catchments within the Tararua Groundwater Management Zone (GWMZ), including the Upper Manawatu and Mangatainoka catchments: with a primary focus on the Mangatainoka catchment. The developed model will form the basis for future nutrient transport studies. A 3D hydrogeological model has been built for the area using LeapFrog Geo software and pre-existing data. Nine new cross-sections for the Mangatainoka catchment area have been created to supply additional modelling constraints. The three modelled layers are as follows:

- 'Quaternary': Holocene to early Pleistocene.
- 'Tertiary': late Early Cretaceous to latest Pliocene.
- 'Basement': Triassic to late Early Cretaceous.

The region is heavily faulted, forming a sequence of basement highs and lows. The thickness of the Quaternary unit reaches a maximum of 227.7 m. Based on the extent of the Quaternary unit, the model boundaries have been adjusted in some areas to simplify future flow modelling with the inclusion of no-flow boundaries.

A potentiometric surface has been created using a combination of static water levels taken during drilling and mean water levels at long-term monitored sites. Spatial sampling limitations of the monitored levels necessitate the inclusion of the static water levels taken during drilling. This results in a surface with high uncertainty due to the temporal disparity of static water level measurements and the resultant use of the monitored sites mean water levels as a more temporal-specific statistic would not be meaningful.

Horizons has been provided with GIS shapefiles of the 3D model volumes and the potentiometric 25 m contours, as well as a Leapfrog viewer file of the 3D model.

Available hydraulic conductivity estimates cluster in the centre of the model, and the large variation of these values suggests a heterogeneous system that is currently insufficiently sampled to be accurately understood.

Recommendations for further work relevant to the groundwater resources in the Tararua GWMZ include:

- Performing a summer and winter potentiometric survey and combining this data with Satellite Equilibrium Water Table measurements in data sparse areas.
- Performing a data collection survey to assess the yield of wells, as well as current and predicted demand for groundwater. Combining this information with a comparison of well screen locations with the lithological units modelled in this report to designate the importance of currently low information areas (the north and east) and hydrogeological units (geological groups in the Tertiary unit).
- Refining the necessary horizontal and vertical groundwater boundaries for flow modelling using the following: the data collection above, constructing a reliable potentiometric map, and analysing a water budget for the area.
- Improving the spatial sampling of the subsurface information through the following options: utilising existing seismic lines, gravity measurements and geological structural information; checking if there is any lithological log information held by drilling

companies that is not currently in the Horizon's database; ensuring all wells drilled in the future have lithological logs obtained.

- Performing a field assessment survey to determine which existing wells would be suitable for performing either single well tests or slug tests, and carrying out such tests to gain better sampling coverage of hydraulic conductivity estimates of the resource.

This data gap identification and work plan only considers the building of the subsurface model component of a hydrogeological conceptual model. For the construction of a full hydrogeological conceptual model other important considerations such as recharge modelling, groundwater–surface water interaction and age dating need to be incorporated.

1.0 INTRODUCTION

Water quality degradation within the Tararua Groundwater Management Zone (GWMZ) has been identified by Horizons Regional Council (Horizons). This degradation is a consequence of nutrient inputs to groundwater and surface water from both historical and current land use. For policy development and implementation to address mitigating this water quality degradation, a better understanding of the fate and transport of these nutrients is required. The focus will initially be on the subcatchments identified by Horizons as high priority Horizons, 2012, which include the Upper Manawatu and Mangatainoka River catchments. To this end, a groundwater nutrient transport flow model for the Mangatainoka catchment will be developed within a Massey University PhD study that is currently in progress.

There has been little previous research on the hydrogeology of the Tararua GWMZ: Zarour (2008) described some of the broad hydrogeological characteristics of the area; Zemansky et al. (2012) delineated the horizontal extent of the Tararua aquifer based primarily on well location data and topography, and provided a single aquifer depth estimate that was described as a conservative estimate.

This current state of knowledge is insufficient to create a useful groundwater nutrient transport flow model for the area. As such, Horizons has commissioned GNS Science to complete a subsurface hydrogeological conceptual model for the priority catchments within the Tararua Groundwater Management Zone (Figure 1.1) that comprises three bulk hydrogeological units and a potentiometric surface. The developed model will form the basis for future nutrient transport studies. Additionally, existing information gaps for model development within the entire Tararua GWMZ are identified and a discussion provided on future work that could address these gaps.

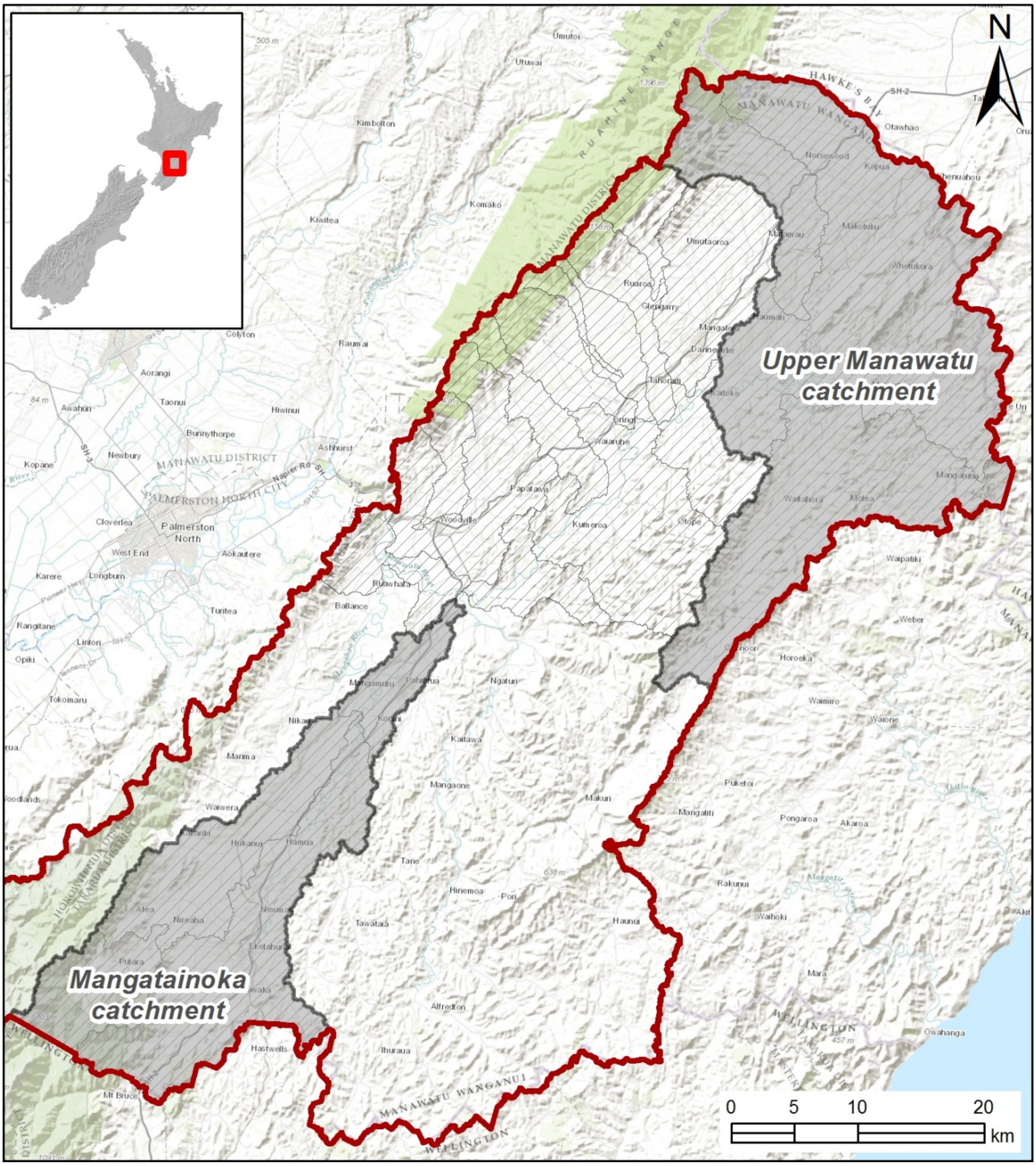

Figure 1.1 Topographic map with boundaries of the study area. The dark red line is the Tararua GWMZ boundary, the grey areas are the Mangatainoka and Upper Manawatu catchments, and the hatched area contains the priority subcatchments that are modelled in this report. The Mangatainoka catchment has the highest priority.

2.0 HYDROGEOLOGICAL MODEL

2.1 OVERVIEW

The study area has recently been geologically mapped as part of two 1:250,000 scale QMAP sheets (Lee and Begg, 2002; Lee et al., 2011). The locality is described by Lee and Begg (2002) as the Pahiatua Basin. The Pahiatua Basin is bounded to the northwest by the active Wellington-Mohaka Fault and the Tararua and Ruahine axial ranges; and to the east by the Waewaepa and Puketoi ranges (Figure 2.1). Alluvial depositional processes in the basin have been occurring for at least the last one million years (Lee and Begg, 2002). During this period, tectonic uplift of the Tararua and Ruahine ranges and the erosion of the Manawatu Gorge have been important depositional driving forces. Immediately prior to this recent alluvial regime, the area was dominated by a marine depositional environment (see Section 2.3.2.5).

GNS Science was contracted to provide a hydrogeological model composed of the three main hydrostratigraphic units in the study area. In the initial contract, these units were described as 'Basement', 'Tertiary' and 'Quaternary'. These three main units have been re-classified, due to the timing of relevant tectonic and depositional environments, as 'Triassic to late Early Cretaceous', 'late Early Cretaceous to latest Pliocene' and 'Early Pleistocene to Holocene', respectively. The original contractual terminology is retained for ease of use. The boundary between Basement and Tertiary lithologies is defined by the termination of the Rangitata Orogeny (Balance, 2009), whilst the boundary between the Tertiary and Quaternary lithologies is defined by the termination of marine deposits associated with the closing of the “Ruataniwha Strait" (Trewick and Bland, 2012). A simplified geological map is displayed in Figure 2.2.

A hydrogeological model of the study area has been developed with the aim of representing the three bulk hydrogeological units as three-dimensional surfaces and volumes.

2.2 MODELLING SPECIFICATIONS

A combination of GIS (ESRI ArcMap 10.0) and 3D modelling software (Leapfrog Geo 1.4.2) has been used to construct the 3D hydrogeological model.

The Mangatainoka/Upper-Manawatu hydrogeological model has been constructed from borehole drill logs, published geological surface maps and cross-sections, published fault information, and newly constructed cross-sections from existing geological structural data. See Appendix 1 for detailed information regarding the input data.

These data are used to create a series of contact points or lines specifying the boundary locations where two different geological units meet. Due to the structural complexity of the fault-riddled area, a large amount of additional modeller input in the form of manually created lines have been used to create a geologically reasonable model. Leapfrog Geo Geological Modelling was then carried out to create contact surfaces. This method uses Radial Basis Functions (RBFs) for interpolation between contact points, which is equivalent to Dual Kriging. User constraint to the interpolation is achieved through stratigraphic sequence definition, deposit type classification, and a surface with directional trends that guide the interpolation. Following contact surface creation, volumes of each geological unit were built.

The horizontal model area of the Mangatainoka/Upper-Manawatu model is displayed in Figure 1.1. In the vertical dimension, the model extends from the topographic surface to 4 km below mean sea level. Model resolution adapts to the density of available data, but is set to not be larger than 250 m in Easting and Northing coordinates.

The Digital Elevation Model (DEM) is gridded with Leapfrog Geo to construct the topographic surface. Data for the DEM is derived from an 8x8 m DEM (Geographx, 2012) and interpolated to a 250x250 m cell grid. The estimated accuracy of this DEM is ±22 m horizontally and ±10 m vertically. Figure 2.1 displays the DEM surface with 15x vertical exaggeration.

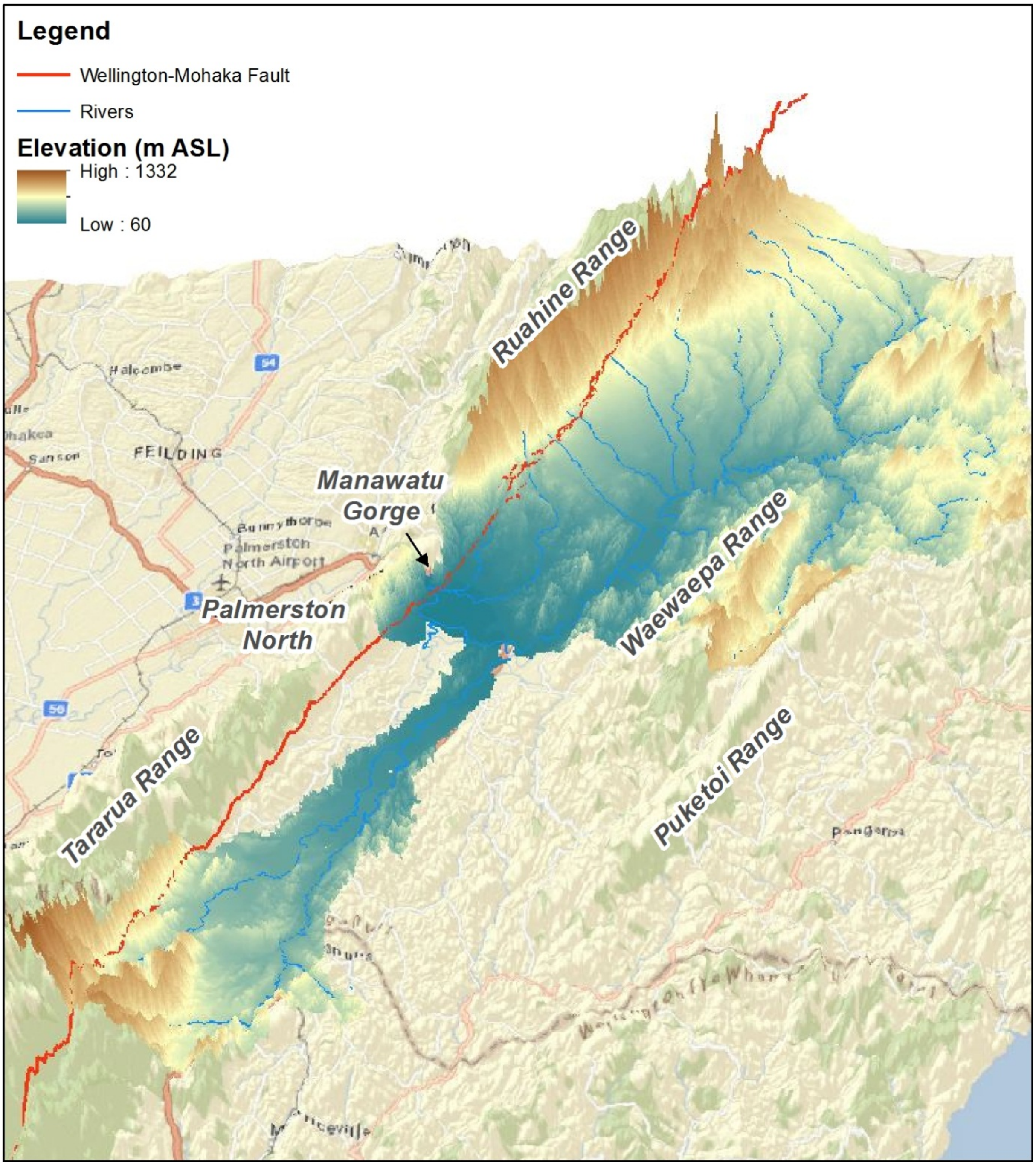

Figure 2.1 Digital Elevation Model of the study area viewed from the southeast with 15x vertical exaggeration. Catchment rivers and an OpenStreetMap base map are displayed for orientation.

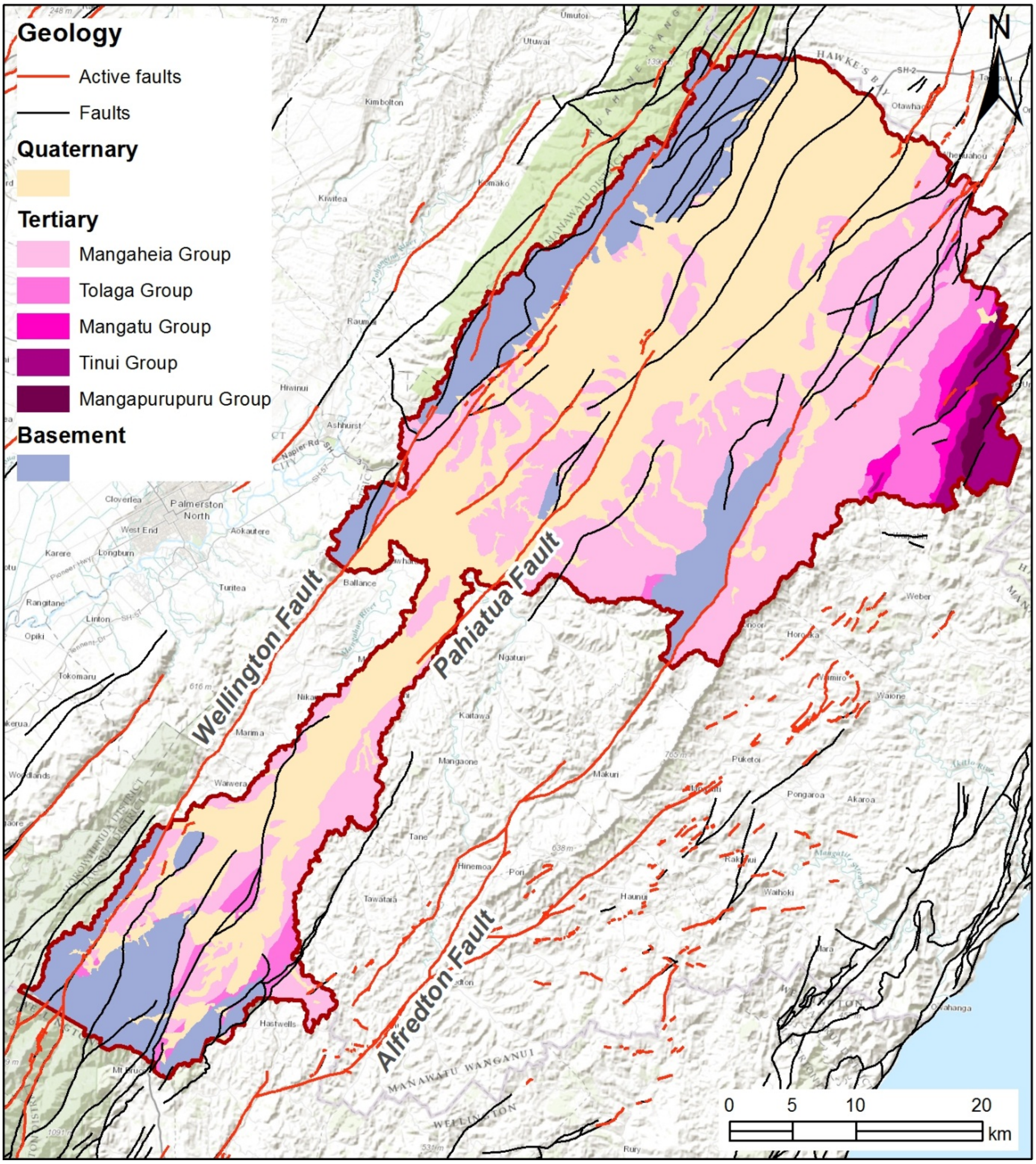

Figure 2.2 A simplified geological map of the study area. See Section 2.3 for the associated rock descriptions.

2.3 BRIEF GEOLOGICAL AND HYDROGEOLOGICAL DESCRIPTION OF GEOLOGICAL UNITS

Brief rock descriptions of the main components of the three modelled hydrogeological units are provided below from oldest to youngest. These descriptions are summarised from Lee and Begg (2002) and Lee et al. (2011).

2.3.1 'Basement': Triassic to late Early Cretaceous

Basement rocks of eastern New Zealand, from Otago to Northland, are dominated by a complex belt of deformed quartzo-feldspathic “greywacke” sandstone and argillite rocks, sometimes regionally metamorphosed: the Torlesse composite terrane. These rocks were deposited as marine sands and muds on the seabed east of the tectonically accreting eastern shoreline of the supercontinental landmass known as Gondwana during the Permian to late Early Cretaceous.

2.3.1.1 Torlesse composite terrane (Esk Head belt, Pohangina melange, Pahau terrane, Waioeka petrofacies)

Within the area of interest, four units of Torlesse composite terrane are found, two of which are dominated by tectonic melange. The two westernmost units, the Esk Head belt and Pohangina Melange, are tectonostratigraphic units and consist dominantly of broken formation and melange.

The Esk Head belt comprises mainly of alternating sandstone and siltstone sequences in varying states of dismemberment, and where heavily sheared, blocks are suspended in a shaley mudstone matrix. Exotic clasts (limestone, chert and volcanics) and component blocks are derived from neighbouring terranes, notably the Rakaia and Pahau terranes. The Esk Head belt lies between Rakaia terrane in the west (outside the study area) and Pahau terrane in the east. Tectonic deposition of Esk Head belt post-dated deposition of these two terranes, probably during or after the Late Jurassic to Early Cretaceous.

The Pohangina Melange comprises a thin belt of melange and only just makes it into the study area in the extreme northwest. It consists mostly of blocks of fine-grained sandstone and packets of thinly bedded sandstone and mudstone within a sheared black mudstone matrix. Pohangina Melange is typically finer grained than Esk Head belt. It has a minor component of exotic clasts such as chert, limestone and volcanics, and it lies between Kaweka terrane in the west and Pahau terrane in the east. Although the age of tectonic deposition is poorly constrained, it was probably during the late Early Cretaceous.

Pahau terrane lies to the east of the Esk Head and Pohangina melanges in the study area. These rocks are mostly thin-bedded, alternating sandstone and mudstone. Sandstones are quartzo-feldspathic and commonly carbonaceous. Limited palyontological evidence from outside the area suggests an Early Cretaceous age for Pahau terrane.

Waioeka petrofacies rocks are found to the east of the Pahau terrane rocks. They are similar in sedimentary style to Pahau terrane, typically comprising cm-dm thick bedded sandstone and mudstone, although thick-bedded sandstone is more common. They differ from Pahau terrane rocks in having lower quartzo-feldspathic composition than Pahau terrane and a higher volcanoclastic component. Broken formation is present only locally. Microfossils (dinoflagellates) from outside the area indicate an Early Cretaceous deposition.

Bedding is commonly steep to subvertical within Torlesse composite terrane, but thickness is irresolvable due to a lack of marker horizons, tectonic accretion and subsequent deformation.

Deposits of subsequent groups (with the exception of Mangapurupuru, Tinui and Mangatu groups) may locally overlie Torlesse composite terrane with an angular unconformably. This unconformity marks a major geological transition, and also separates highly jointed and sheared rocks from those significantly less sheared and jointed.

Hydrogeology

Mineralised intergranular cement results in very low values of porosity and permeability, such that intergranular fluid storage is typically non-existent. Jointing and shearing provide discrete locations of high secondary permeability, with associated water storage capacities. The typically limited extents and discrete nature of these resources, however, result in restricted productive groundwater storage volumes. Within the well information provided (Appendix 1), only two wells (0.2%) are located on surficial basement lithology (Figure 2.3). However, the location of these wells on basement lithology is suspect, as they lie close to contacts with other lithologies and the locations have been estimated rather than obtained via GPS (there are no associated lithological logs to verify these locations).

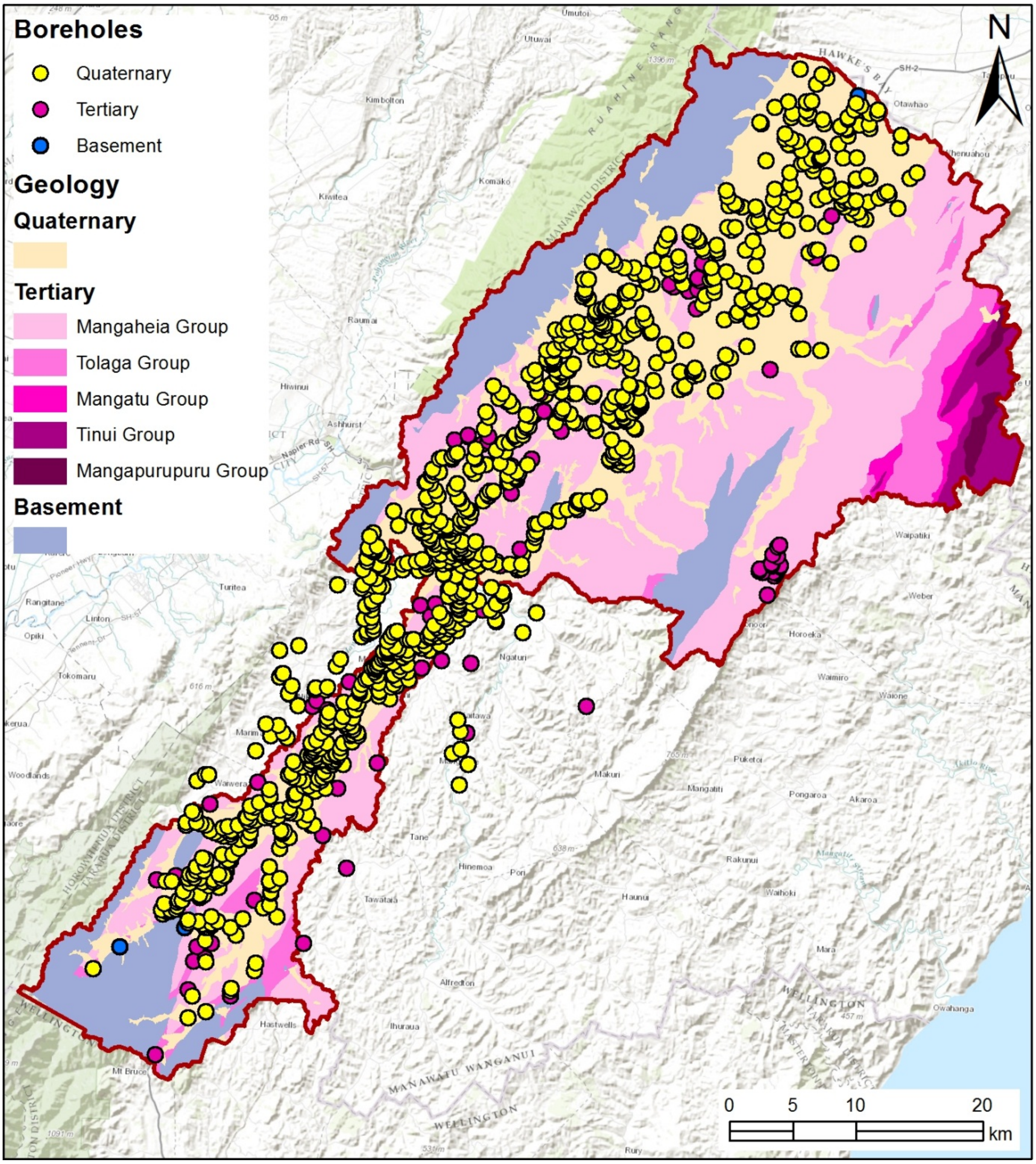

Figure 2.3 Wells in the Tararua GWMZ coloured by the surficial lithology at their emplacement.

2.3.2 'Tertiary': late Early Cretaceous to latest Pliocene

The second major unit in this report represents deposits that post-date the major tectonic event that terminated deposition of basement rocks. They are characterised by their comparative softness, their lack of pervasive bedding, plane shear and relative structural simplicity. Below, this unit is described within five different geological groupings. The older three groups have limited to no water storage potential, with thick subunits that can be characterised as aquicludes, and some structural complexity. The youngest two groups have aquifer potential and existing wells (Figure 2.3). Due to the geological complexity of the area and a current lack of information, the separation of these groups within the modelling presented in this report has not been possible.

2.3.2.1 Mangapurupuru Group (Springhill Fm.)

Springhill Formation crops out only in the extreme northeast of the area of interest, in the core of a series of faulted anticlines east of Dannevirke. These consist of massive mudstone, alternating sandstone and mudstone, minor pebble conglomerate and sparse limestone beds. The relationship with underlying basement rocks is thought to be unconformable where exposed to the south, outside the study area, and thickness is thought to be c. 750 m (Lee et al., 2011). Fossils, where present, indicate a late Early Cretaceous to early Late Cretaceous age. They are now generally interpreted as a submarine landslide deposit.

Hydrogeology

Within the study area, Springhill Formation is dominated by Cretaceous mudstone and is likely to have low permeability and act as an aquitard. Of the wells provided, none are located on areas geologically mapped as this group.

2.3.2.2 Tinui Group (Whangai Fm., Tangaruhe Fm.)

Tinui Group sediments unconformably overlie Mangapurupuru Group only in the northeast of the map area and consist of two formations, the Tangaruhe and overlying Whangai formations. The basal Tangaruhe Formation consists of c. 280 m of pebbly sandstone and mudstone, with minor greensand. This is overlain conformably by up to 500 m of Whangai Formation comprising well-indurated, poorly bedded siliceous mudstone, commonly weathered with powdery jarositic (yellow) and iron (rusty brown) staining. Tinui Group deposits are marine in origin and are thought to have been deposited in an anoxic oceanic basin.

Hydrogeology

Within the study area, the Tinui Group sediments are dominated by glauconitic sandstone and siliceous mudstone and are unlikely to represent a significant reservoir lithology. Of the wells provided, none are located on areas geologically mapped as this group.

2.3.2.3 Mangatu Group (Wanstead Fm.)

Wanstead Formation (up to 300 m thick) and the overlying Weber Formation (c. 200–300 m thick) are constituents of Mangatu Group, and they flank folds in the extreme northeast of the map area. The Wanstead Formation probably conformably overlies Tinui Group and consists predominantly of soft, smectitic mudstone (sometimes sandy) and greensand. The Weber Formation conformably overlies Wanstead Formation and consists of hard, sandy brown and grey usually calcareous mudstone.

Hydrogeology

The low porosity of the mudstone-rich Mangatu Group comprises an aquitard. Of the wells provided, none are located on areas geologically mapped as this group.

2.3.2.4 Tolaga Group (undifferentiated Early to Middle Miocene, Mangaoranga Fm., undifferentiated Late Miocene, Waikopiro and Whetukura limestones)

Tolaga Group is a name that has been adopted for Miocene marine sedimentary rocks of the eastern North Island from Raukumara to Wairarapa. Miocene rocks are found in the east and south of the area of interest and probably lie unconformably on Mangatu Group rocks in the east and are certainly unconformable on basement in the south.

Early Miocene rocks are present in the northeast, consist of calcareous, sometimes glauconitic sandstone and are 400–500 m thick.

Middle Miocene sediments are present only in the northeast where they consist of calcareous silty fine sand and sandy silt. Late Miocene marine sediments are found in the northeast and south of the area.

Immediately east of Dannevirke, and west of the Oruawharo Fault, a Late Miocene sequence including pebbly mudstone, sandstone, sandy mudstone and limestone (Waikopiro Limestone) overlies basement rocks, attesting to the presence of intra-Miocene local unconformities. In the south, Late Miocene rocks typically comprise calcareous sandstone and mudstone, but locally (in the south) a basal conglomerate and a bioclastic limestone (Kaipororo Limestone) are present.

In the northeast, laterally equivalent rocks are dominantly sandy silt and silty sand, but include the bioclastic limestone bands of the Waikopiro and Whetukura limestones.

Hydrogeology

Sandstones within the Miocene rocks may store groundwater, although in most places the silty rock component probably restricts hydraulic conductivity. Within the wells provided, 6 wells (0.5%) are drilled into surficial Tolaga Group geology (Figure 2.3). As we do not have logs for all wells, it is unclear if all of these wells draw from the Tolaga Group or the underlying geological units. Specifically, these wells are situated exclusively in the south on the Mangaoranga and Kaiparoro Formation conglomerate.

2.3.2.5 Mangaheia Group (undifferentiated Early Pliocene, undifferentiated Late Pliocene, Kaipororo, Kumeroa, Tourere, Whetukura, Waitahora, Rongomai, and Te Onepu limestones)

The Mangaheia Group comprises Pliocene marine deposits that record the closing of the “Ruataniwha Strait”, an arm of the South Pacific Ocean that lay between the emerging Tararua/Ruahine ranges and shallow or emergent land where the eastern Wairarapa ranges are now located. The strait lay across the Tararua/Ruahine ranges near the Manawatu Gorge and near Kuripapango (north of the area of interest).

Mangaheia Group sediments are dominated by sandstone, siltstone, mudstone and limestone, but include minor conglomerate and rhyolitic tephra. In particular, the lower units, which are Early Pliocene in age are dominated by sandstone and mudstone with bioclastic limestone (including the Whetukura Limestone) and minor conglomerate. These Early Pliocene rocks rest unconformably on basement rocks in places, but on Late Miocene marine sediments elsewhere, indicating the presence of one or more unconformities, and/or local erosion.

Late Pliocene Mangaheia Group rocks are dominated by siltstone, mudstone and bioclastic limestone with locally significant sandstone. A minor lithology, particularly in the south and west, is conglomerate. The youngest Pliocene rocks, dominated by limestone, sandstone and siltstone, are found in the east of the area, close to the eastern Wairarapa ranges.

Hydrogeology

Limestones and to a lesser degree, late Neogene (Pliocene) sandstones potentially store significant volumes of groundwater. Within the wells provided, 91 wells (7.3%) are drilled into surficial Mangaheia group geology (Figure 2.3). As we do not have logs for all wells, it is unclear if all of these wells draw from the Mangaheia group or the underlying geological units.

2.3.3 'Quaternary': Holocene to early Pleistocene

Early Quaternary deposits of the Kidnappers Group are found at the surface mostly north and northeast of Dannevirke and comprise gravel, sand, silt, and carbonaceous beds, including lignite, but also commonly include rhyolitic tephra. Deposits of the lowermost part of the Quaternary are commonly estuarine in origin: these materials being overlain by lake and fluvial materials and tephra. Middle and Late Quaternary deposits, including Holocene materials, are present in the Mangatainoka and upper Manawatu catchments and dominated by alluvial gravel and sand. Middle Quaternary deposits are present in surface exposure less than either the Early Quaternary or the Late Quaternary/Holocene.

Hydrogeology

In general, Quaternary deposits are more important than underlying units for groundwater bearing potential as they are close to the surface, commonly coarse grained, higher porosity and have limited structural complexity. Within the wells provided, 1148 wells (92%) are drilled into surficial Quaternary lithology (Figure 2.3). As we do not have logs for all wells, it is unclear if all of these wells draw from the Quaternary geology or the underlying geological units. Gravel and sand of the Kidnappers Group potentially comprise groundwater reservoirs, although gravels are likely to be clay-bound. Older middle Quaternary gravels may be more or less clay-bound, but Holocene gravel is likely to represent good groundwater potential.

2.4 GEOLOGICAL STRUCTURE

The area of interest is dissected by a number of active and older inactive faults (Figure 2.2). Many of these faults dip westward and are associated with folds in Neogene and Quaternary deposits. Inactive faults are thought to be late Neogene to early Quaternary in age and are dominantly reverse faults. Active faults are part of the North Island Fault System (also known as the North Island Dextral Fault Belt) and are strike-slip type with varying vertical components of slip. The strike-slip faults are commonly believed to represent re-activated reverse faults.

The most active of the faults is the Wellington Fault that commonly lies at the base of the Tararua and Ruahine ranges, although basement extends east of the fault to the west of Norsewood. To the east of the Wellington Fault, two further active faults extend the length of the area, the middle of which is collectively called the Pahiatua Fault, and the eastern one, the Alfredton Fault. Both these faults are depicted in the model with steep westward dips (c. 60° and 65° respectively, see Appendix 1). Basement rocks lie intermittently at the surface on the western side of these faults along their length.

No basement rocks are found at the surface to the east of the Alfredton Fault (east of the area of interest), where the oldest exposed rocks are of marine origin and belong to Late Cretaceous Glenburn Formation. Within the area of interest, the oldest rocks east of the Alfredton Fault are within the cores of two anticlines and comprise Late Cretaceous Springhill Formation.

The Wellington Fault is largely responsible for upthrow of the Tararua and Ruahine ranges, where geomorphic and geological indications of uplift are available. Downcutting of the Manawatu Gorge is a record of uplift of the ranges, and the continuous presence of a westward flowing river that goes back in time to the initiation of vertical displacement on the Wellington Fault. The presence of Nukumaruan (2.4 to 1.63 Ma) marine and marginal marine sediments in road cuttings is a clear indication that a seaway existed through the gorge at that time. Deformed lacustrine deposits close to the Wellington Fault near the eastern entrance to the Manawatu Gorge contain abundant rhyolitic tephra beds and are interpreted to be of early Castlecliffian age (1.63 to 1 Ma). This age indicates that displacement on the Wellington Fault had commenced by then. Early and middle Quaternary rocks are clearly involved in folding defined by underlying Nukumaruan limestone near the Wellington Fault on the southeastern side of the Manawatu Gorge. The depth of Quaternary deposits is generally poorly constrained from available borehole logs, but there are constraints imposed on their thickness by the structure of the rocks they rest upon.

The elevation of the Manawatu River at the entrance to the gorge is c. 60 m, and the top of a prominent erosion surface in basement rocks above the gorge is c. 360 m. Subsurface and surficial bedrock at the eastern end of the gorge forms a “groundwater dam” creating a base level below which, the river cannot erode. While basement is buried by Quaternary and late Pliocene deposits near the entrance to the gorge, there are other indicators that suggest that subsidence on the eastern side of the Wellington Fault is limited. The widespread surficial presence of late Pliocene marine deposits (as young as Nukumaruan) as an elevated eroded topography across a wide area east of the ranges (locally to elevations exceeding 300 m) also indicates that there has been limited tectonic subsidence on the eastern side of the Wellington Fault. The depth therefore of Quaternary deposits in the upper Manawatu and Mangatainoka catchments is limited by geological constraints and unlikely to exceed 150 m.

2.5 3D MODEL

Hydrogeological volumes created in the 3D Leapfrog model are displayed below. Both the study area previously discussed and an extended study area are presented.

2.5.1 Initial study area

The basement is heavily faulted (Figure 2.4), forming a series of ridges and depressions. The depth to basement is unknown to the east as the base of the Tertiary sediments has not been found: QMAP cross-sections extend to a depth of 5 km and specify the lowest Tertiary deposit as having an unknown thickness (Lee and Begg, 2002). The known basement depths vary between surface outcrop and 2.2 km below ground level.

Tertiary sediments in-fill the ridges and troughs formed by the basement (Figure 2.5). The thickness of the unit varies between 0.03 m and 2.2 km below ground level. To the east of the model, the base of the Tertiary has not been found, and the thickness of the unit is at least 2.2–4.7 km.

Quaternary sediments fill the remainder of the model (Figure 2.6). The thickness of the unit varies between 0.01 m and 227.7 m below ground level.

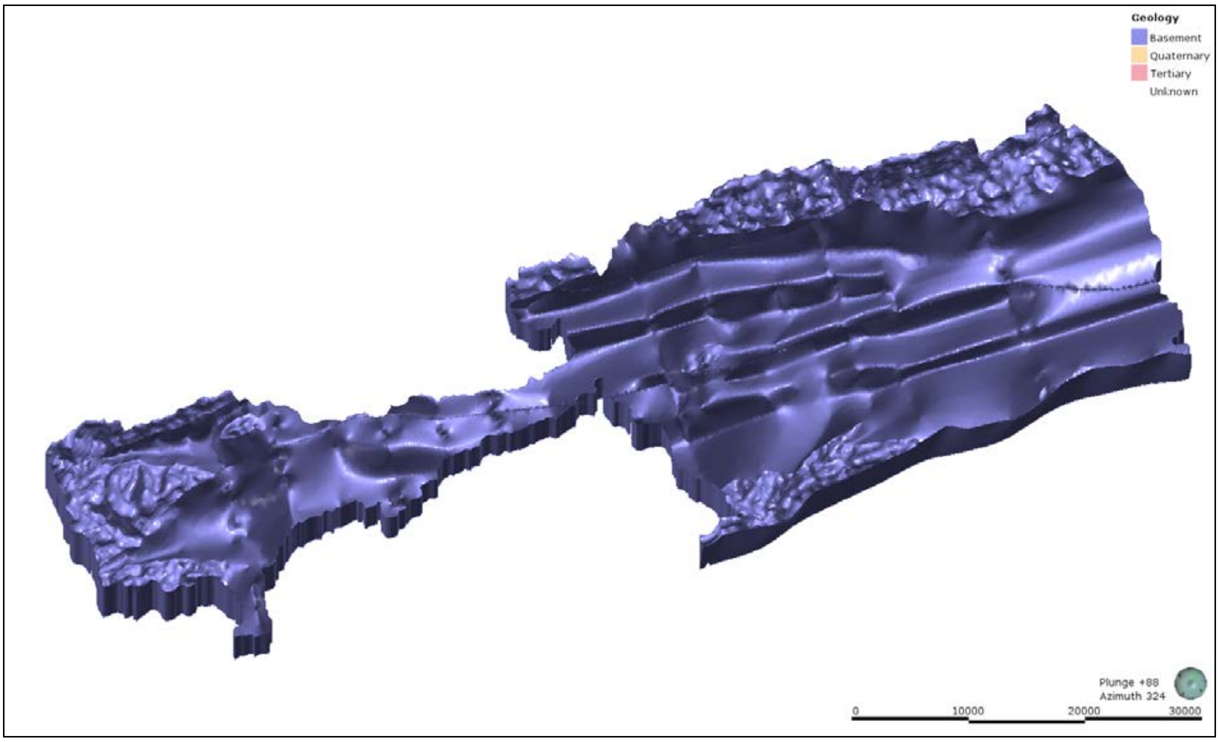

Figure 2.4 Basement volume in the 3D model.

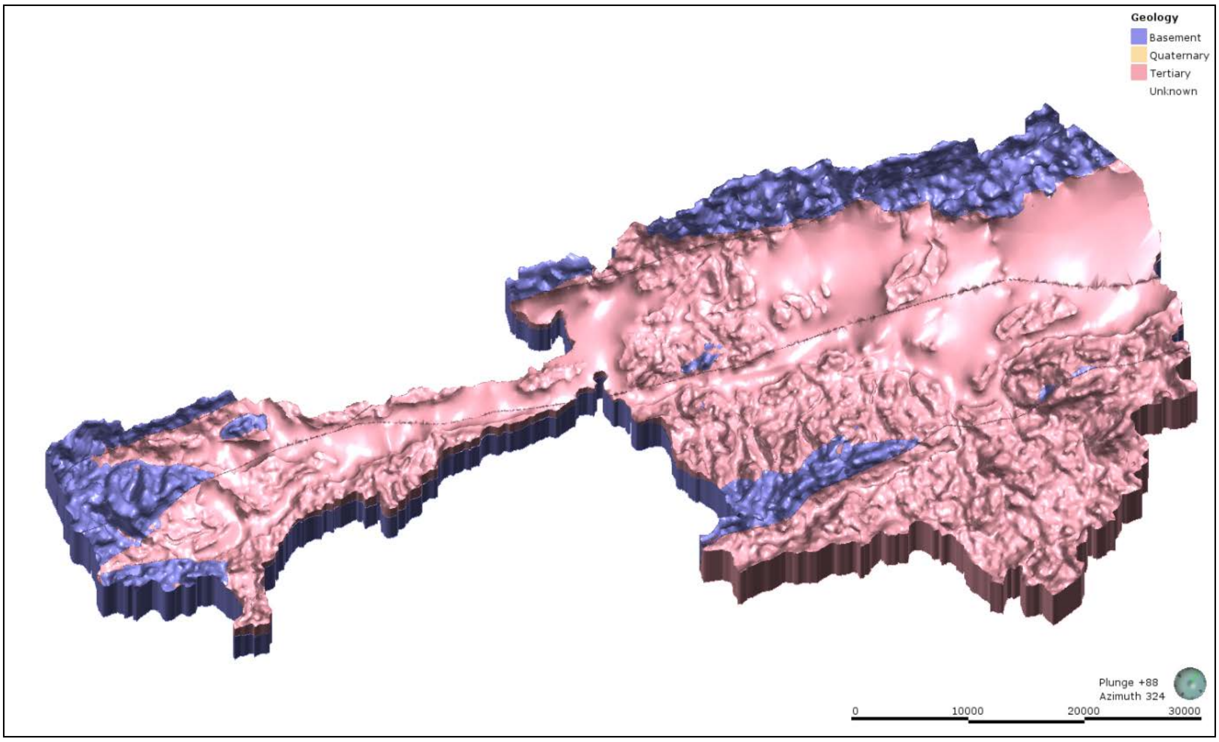

Figure 2.5 Tertiary and basement volumes in the 3D model.

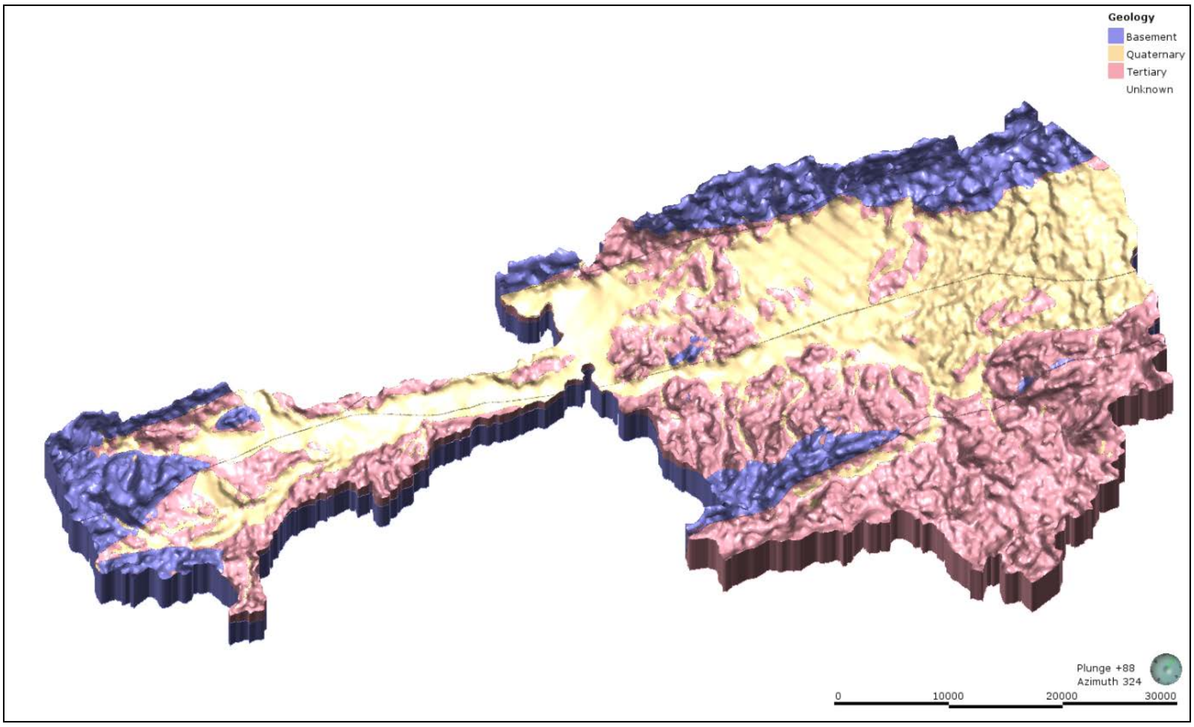

Figure 2.6 All Quaternary, Tertiary and Basement volumes in the 3D model.

2.5.1.1 Discussion

It is apparent from Figure 2.5 that the high priority subcatchment boundaries are not suitable for no-flow boundaries in groundwater flow modelling of the main Quaternary aquifer. Figure 2.7 identifies zones on the model boundary that could not be considered as no-flow boundaries for groundwater flow modelling. Due to the geometry of the 3D model boundary and input data, Zones 1–3 can be addressed by simply extending the model boundaries slightly (Figure 2.8). However, better characterisation of Zone 4 is beyond the scope of this study; as it is associated with a northeast–southwest trending depression that extends approximately another 50 km northeast into Hawke's Bay.

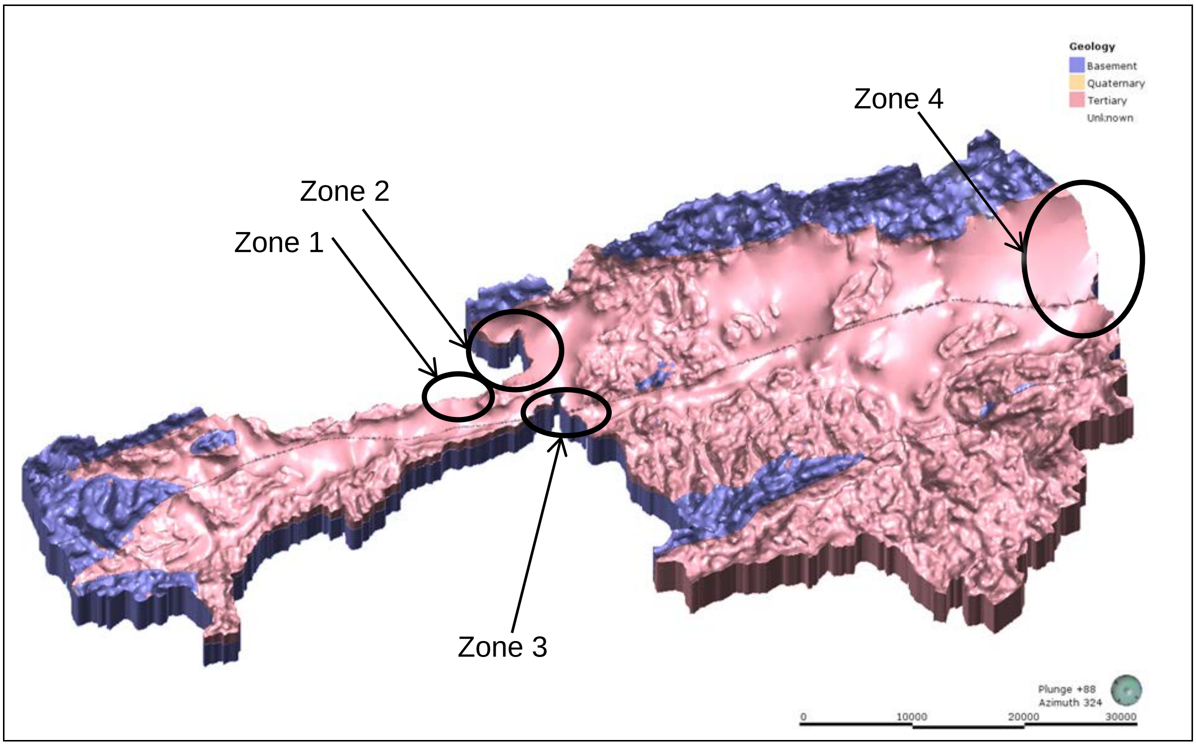

Figure 2.7 Zones on the model boundary that could not be considered as no-flow boundaries for groundwater modelling.

2.5.2 Extended study area

The model layers and thicknesses for the extended study area are shown in Figure 2.8–Figure 2.13. The Quaternary layer (from the extended model) has a total volume of 41,273 km^3 and covers an area of 1,666 km^2. The mean depth is 49.5 m with a standard deviation of 46.5 m, and a maximum depth of 227.7 m. The deepest lithological log (well id 338031) describing Quaternary sediments reaches a depth of 179.2 m. This is consistent with the aquifer depth estimate of 150 m by Zemansky et al. (2012) (rounded down to the nearest 25 m) and estimated from the local tectonic history (Section 2.4). This well, however, ends in Quaternary sediments. Therefore, it is possible that Quaternary sediments extend below this depth. There are only three small areas where the 3D model has Quaternary sediments deeper than this: near the northern boundary, near the centre of the model directly alongside the Pahiatua Fault and near the Manawatu Gorge. The area near the northern boundary has poor input data constraint, therefore this is possibly a depth exaggeration. Near the Manawatu Gorge is the location of the 178.2 m deep well, and a deep trough in the basement running alongside the Wellington Fault, therefore it is likely that this is a good indication of Quaternary sediment thickness. The accuracy of the central deep area is unclear; it is possibly an exaggeration due to its proximity to the fault line.

Each unit's volume is constructed with a mesh, and for each mesh the vertices have been extracted and their x, y, z coordinates stored in a GIS shapefile provided to Horizons. For each volume, Quaternary, Tertiary and Basement, these files are named *Quaternary_vertices_extended.shp*, *Tertiary_vertices_extended.shp* and *Basement_vertices_extended.shp,* respectively. Additionally, a Leapfrog viewer file has been created and provided to Horizons for easy visualisation of the 3D model.

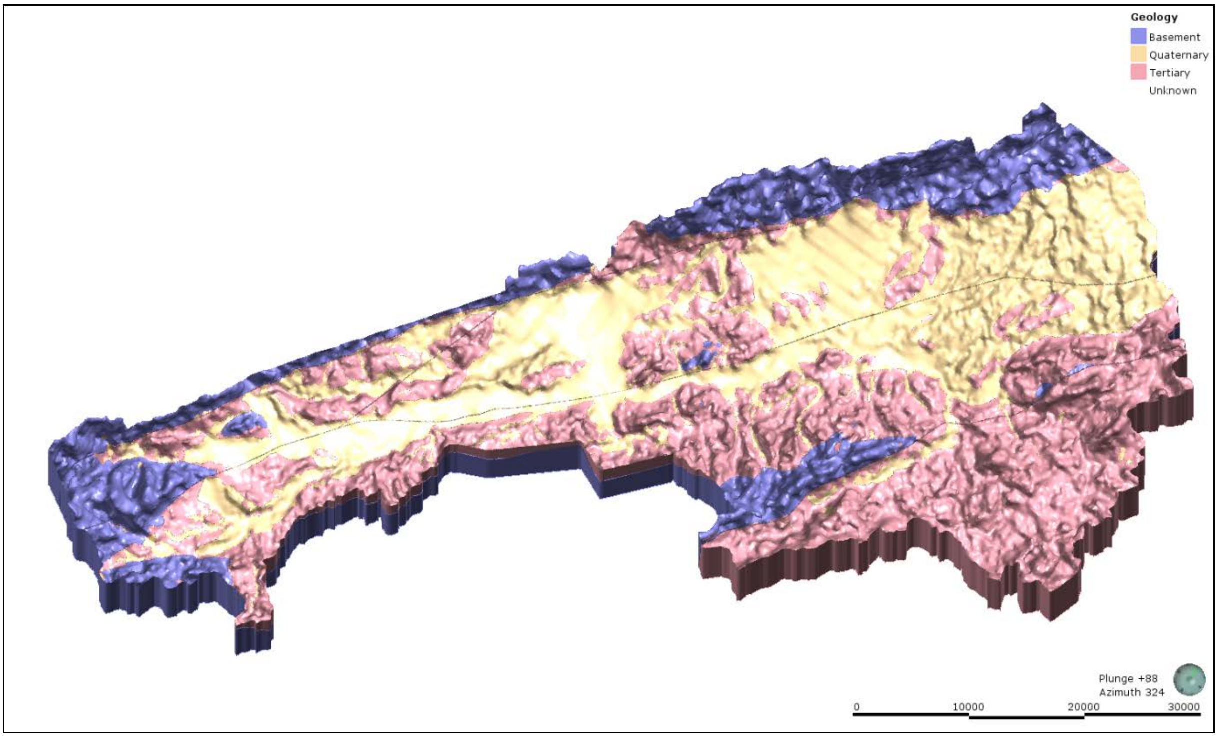

Figure 2.8 All Quaternary, Tertiary and Basement volumes in the extended 3D model. The extended model boundary should remove expected groundwater flow modelling boundary issues associated with Zones 1–3 identified in Figure 2.7.

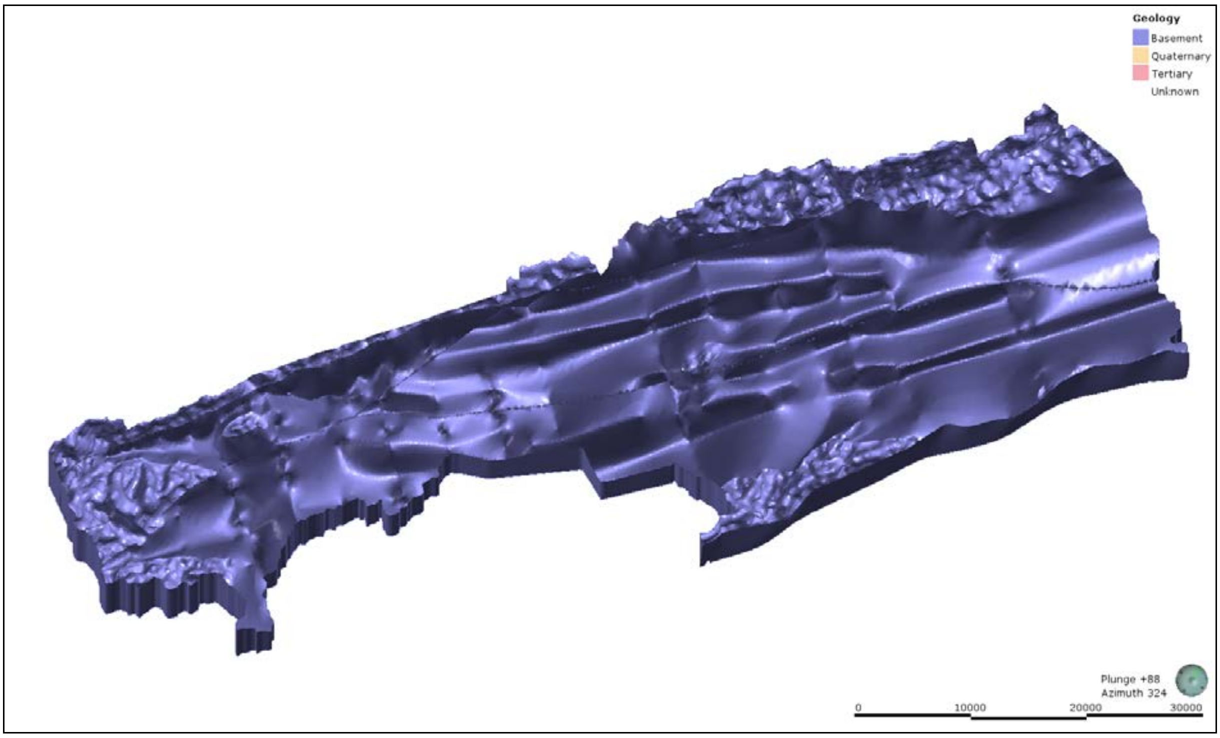

Figure 2.9 Basement volume in the extended 3D geological model.

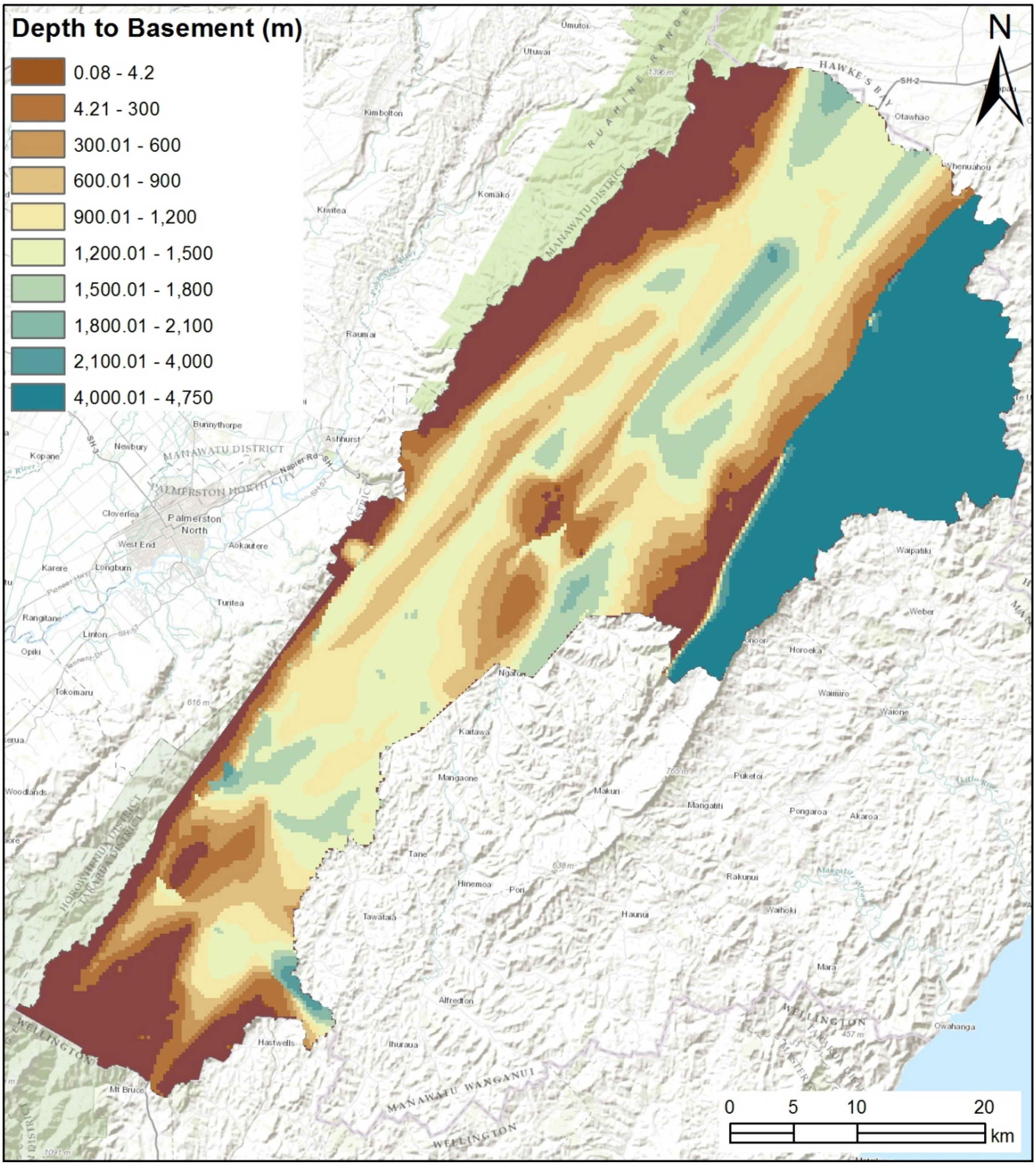

Figure 2.10 Depth to Basement from the extended 3D model. Note that in the area to the east with thicknesses >4 km these are minimum thicknesses.

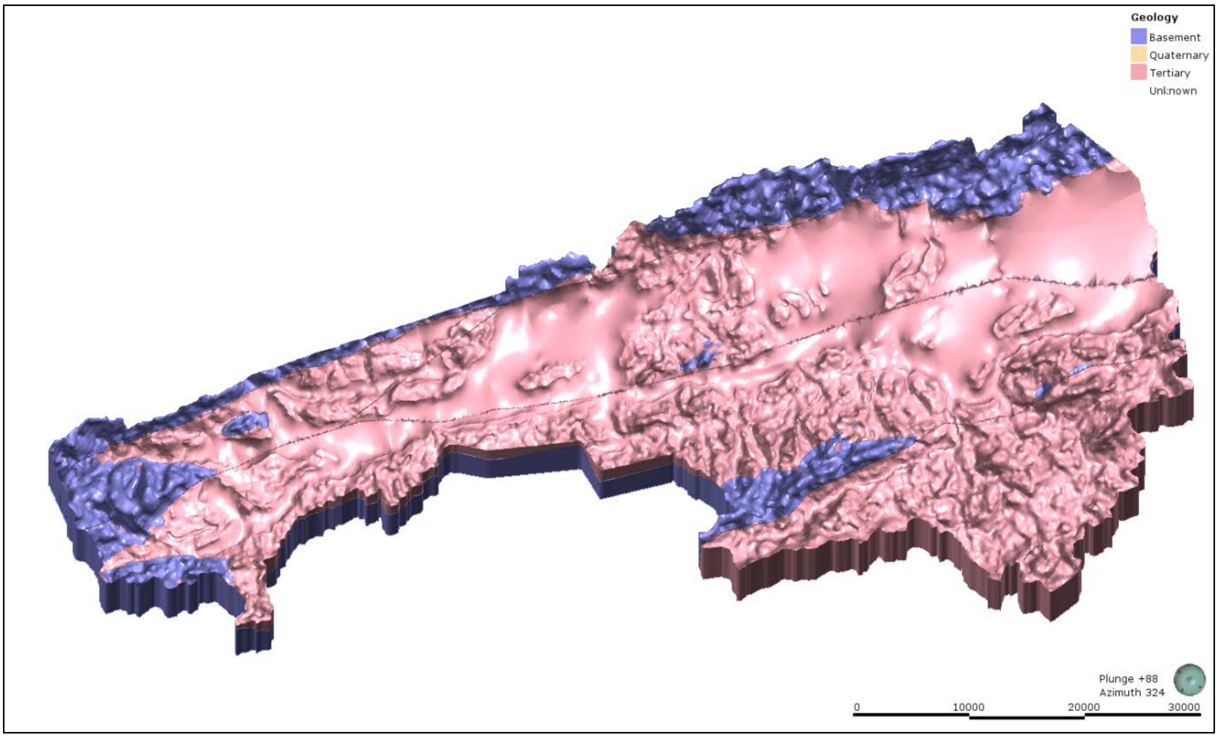

Figure 2.11 Tertiary and Basement volumes in the extended 3D model.

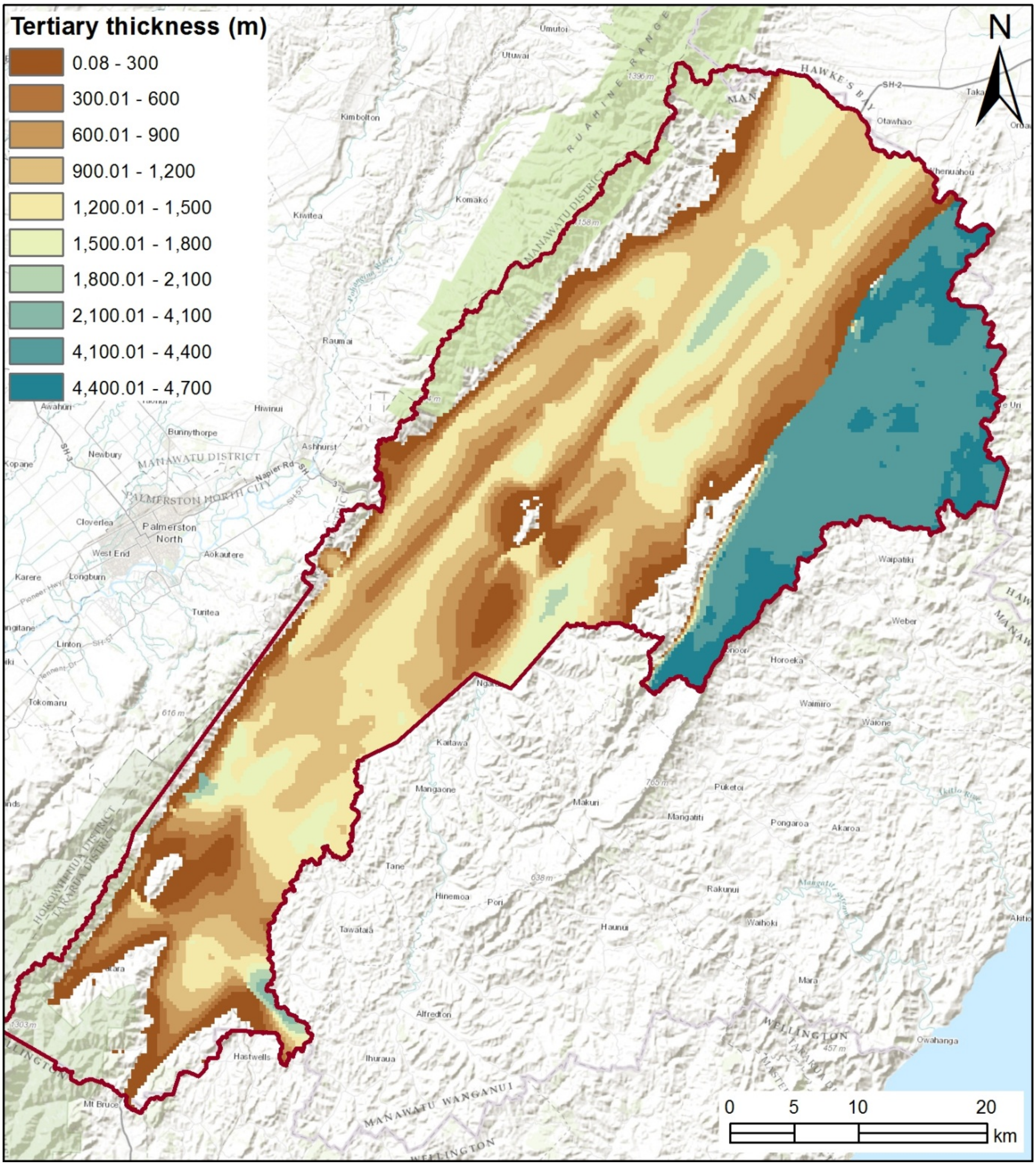

Figure 2.12 Tertiary layer thickness in the extended 3D model.

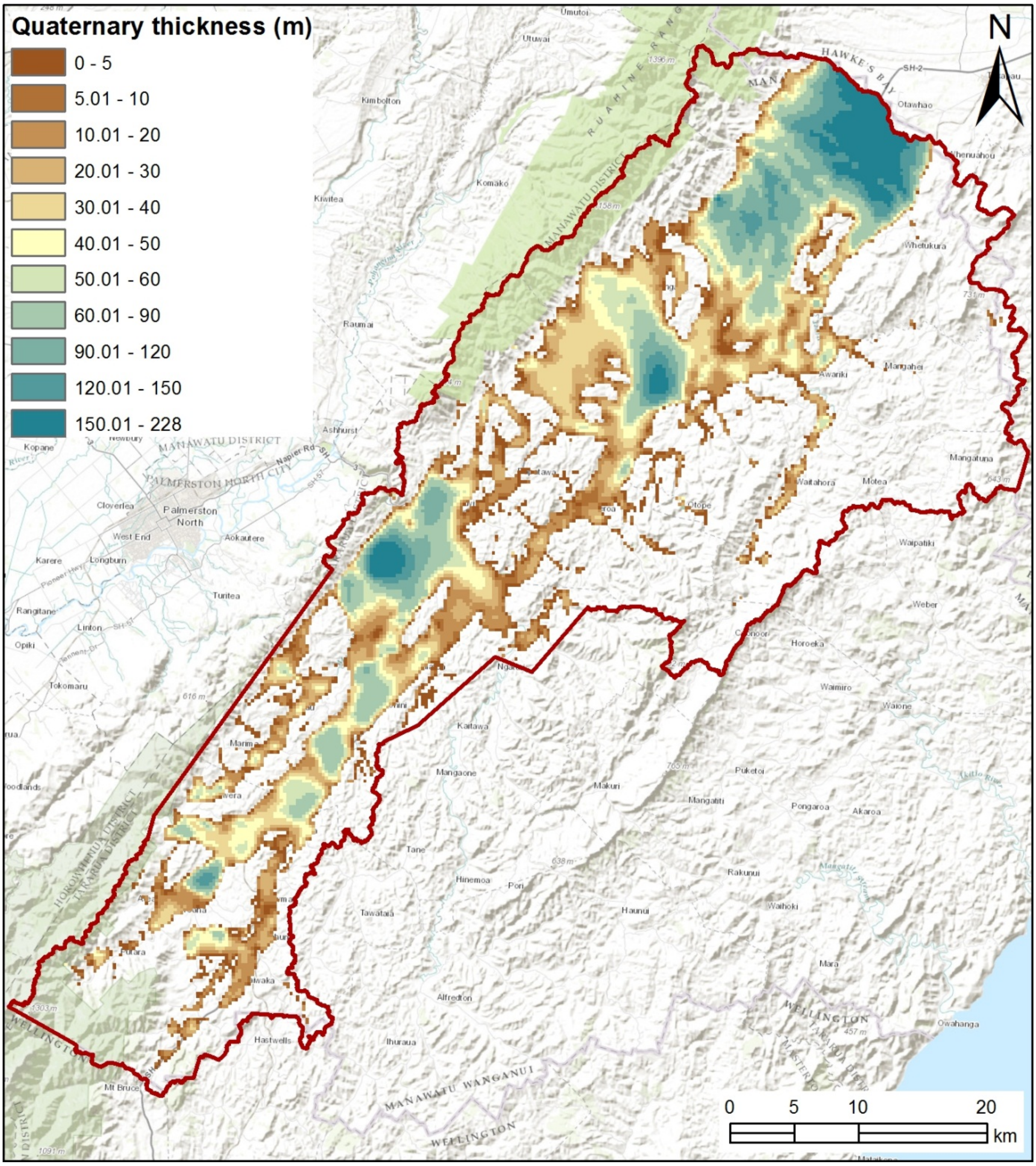

Figure 2.13 Thickness of the Quaternary unit from the extended 3D model.

3.0 HYDRAULIC PARAMETERS

3.1 POTENTIOMETRIC MAP

There are 447 wells in the Tararua GWMZ with available static water level data collected during drilling. There also 13 long term monitoring wells that are part of Horizon's Manual Monthly Water Level Monitoring Programme and have measurements dating back to 1992 (Table 3.1). A potentiometric surface has been created using a combination of 422 static water levels and the mean of the long term monitoring wells (Figure 3.1). Twenty five of the static water levels have not been used as they are located at distances from the main data and beyond topographic and geological changes and that are insufficiently sampled to produce any meaningful inter-sample interpolation. Due to the expected geological conditions and to simplify interpretation, it has been assumed that all water levels are measured from an unconfined aquifer. Adjustment to metres above sea level has been made using the available DEM (Figure 2.1). Interpolation between these data has been performed using Surfer 11.0 software. The interpolation was undertaken using the Local Polynomial method (due to the high uncertainty of the static water level data), 100x100 m grid cells and a 10 km search radius. The resultant contours of the potentiometric surface are displayed in Figure 3.2. The spatial extents of the contours are limited by the distribution of the available data.

Table 3.1 Bores in Tararua GWMZ in the Manual Monthly Water Level Monitoring Programme.

Bore ID	Easting (NZMG)	Northing (NZMG)	Height of measurement point (Metres Above Ground Level)	Mean (Metres Below Ground Level)	Start Date	End Date
338005	2753312.87	6088925.82	0.24	5.12	12/05/1992	14/08/2013
338011	2754300.00	6093800.00	0.08	4.74	12/05/1992	3/11/1994
338051	2753538.79	6090428.92	0.27	4.67	12/05/1992	14/08/2013
338061	2754662.00	6088708.00	0.64	10.91	12/05/1992	14/08/2013
339001	2763981.81	6092199.56	0.42	3.53	1/07/1994	14/08/2013
348003	2754559.58	6084513.93	0.1	5.75	12/05/1992	14/08/2013
348005	2748581.00	6079493.00	0.22	2.20	12/05/1992	14/08/2013
348007	2748621.00	6079529.00	0.5	2.59	12/05/1992	14/08/2013
348009	2753421.00	6083113.00	0.35	2.71	12/05/1992	14/08/2013
348021	2748852.82	6080633.10	1.38	2.03	12/05/1992	14/08/2013
348061	2753442.00	6083110.00	0.1	1.20	12/05/1992	14/08/2013
420075	2766498.17	6100097.42	0.3	3.37	1/07/1994	14/08/2013
430005	2767644.55	6096315.09	0	3.89	1/07/1994	14/08/2013

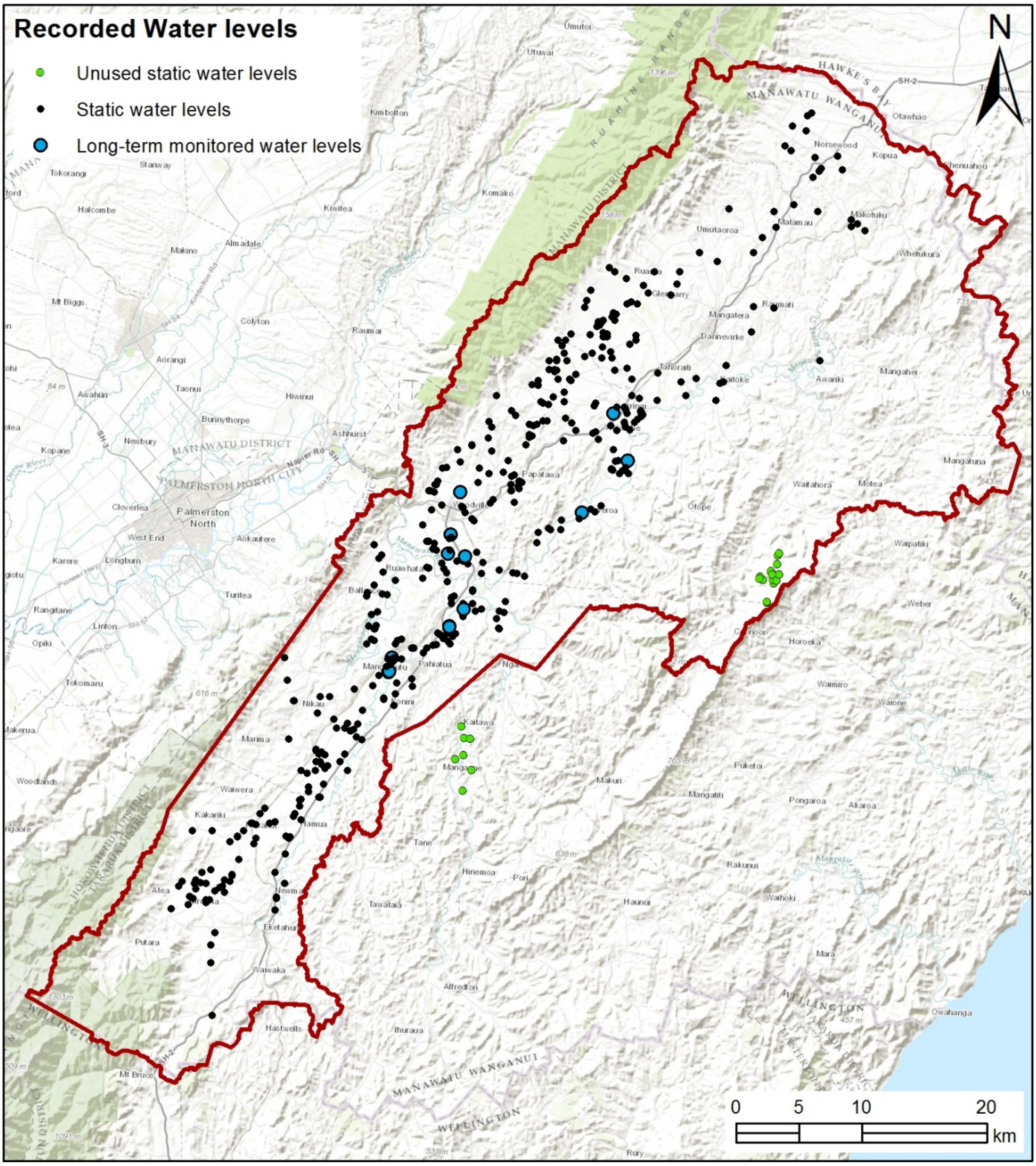

Figure 3.1 Long term monitoring and static water level measurements in the Tararua GWMZ. All locations except for the green circles are used in the development of a potentiometric surface for the extended study area (red line).

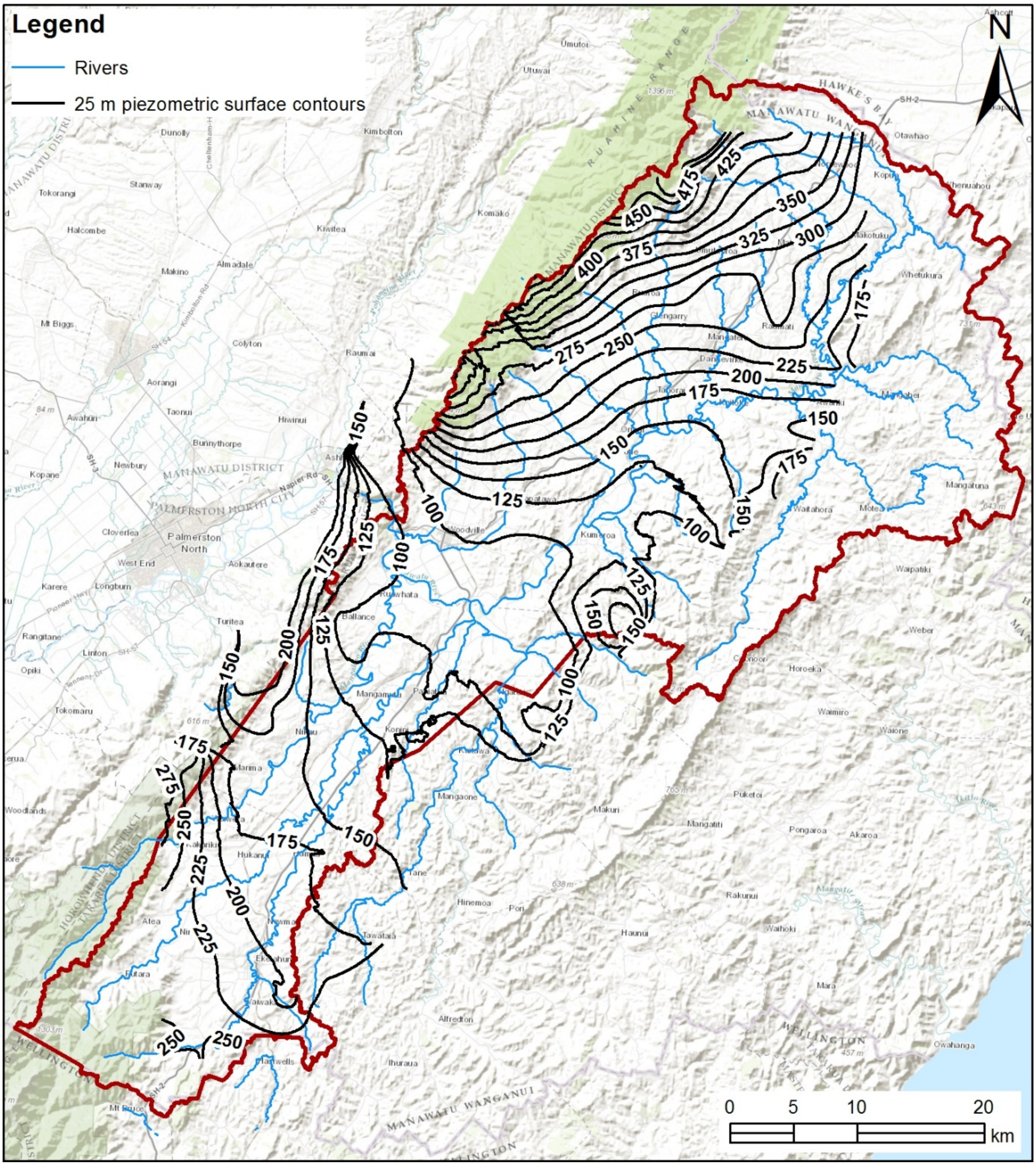

Figure 3.2 Potentiometric surface 25 m contours. Rivers are also shown for reference. The extended study area is shown by the red line.

Groundwater elevation contours in Figure 3.2 suggest that the direction of groundwater flow generally mirrors that of the coincident surficial rivers: with the upper catchment groundwater flowing to the south and the Mangatainoka groundwater flowing to the northeast. An area of groundwater ponding appears to occur within the area where the Mangahao River and Mangatainoka River meet the Manawatu River. The accuracy of the potentiometric map is obviously compromised due to insufficient spatial and temporal sampling. However, we have not used additional manual methods for refinement of the potentiometric surface as this surface will soon be superseded with superior data to be collected during summer and winter potentiometric surveys in 2014 (Matthews, 2014). A GIS shapefile of the contours shown in Figure 3.2 (*Potentiometric_contours.shp*) has been provided to Horizons.

The data used for the development of the potentiometric surface provides a good overview of the general trends in flow for the area; however, it is insufficient to create meaningful flow vectors for any high resolution modelling. As water levels fluctuate both seasonally and yearly, an ideal potentiometric surface is created from spatially-dense water level measurements taken concurrently. The magnitude of seasonal fluctuations can exhibit local variations; therefore, both a summer (low water level) and a winter (high water level) potentiometric surface should be created. Additionally, if a multilayered aquifer system exists then data must be able to be assigned to each aquifer. Using static water levels to supplement long term monitored water levels greatly increases the uncertainty of the surface due to the need to ignore the impacts of yearly and seasonal fluctuations. Additionally, static water levels may be incorrectly measured before water levels have returned to equilibrium following drilling. Such errors can only be manually checked by discarding glaring outliers. Additionally, only 71 of the sites have had their locations surveyed with GPS, the rest are map estimated locations only.

3.2 AQUIFER HYDRAULIC PROPERTIES

There are 16 aquifer tests with transmissivity estimates available in the Tararua GWMZ. These were compiled by Zemansky et al. (2012) and converted to hydraulic conductivity estimates using the screened well length. All measurements sample from the Quaternary volume only, and only a small area of this volume is sampled. Figure 3.3 shows that there are large variations in hydraulic conductivity estimates over short spatial scales in the area that is highly sampled. This suggests a complicated spatial distribution of hydraulic conductivites that is insufficiently sampled throughout most of the volume. That the hydraulic conductivity estimates vary over three orders of magnitude with 5 km is important for the development of a valid flow model. A geological unit with a hydraulic conductivity value two orders of magnitude lower than the aquifer is sometimes classed as an aquiclude and set as a no-flow boundary within flow modelling (Anderson and Woessner, 2002). Clearly, more information is needed on the hydraulic properties and distribution within the aquifer.

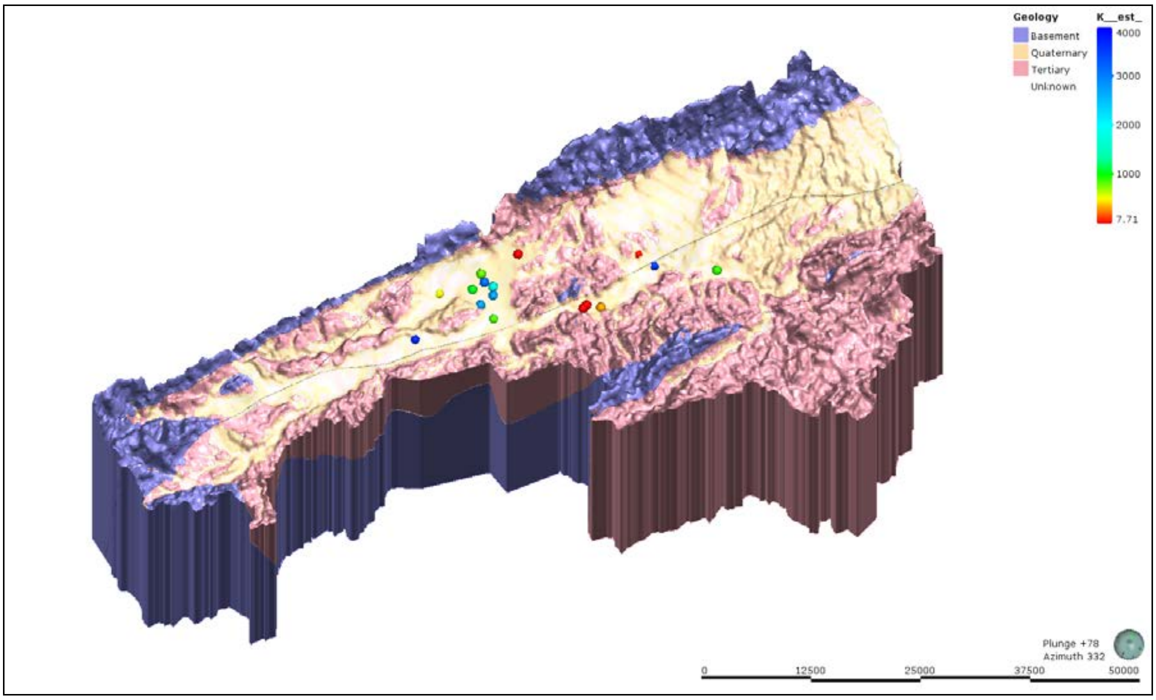

Figure 3.3 Wells with available aquifer test data coloured based on their associated hydraulic conductivity estimates: K_est_ (m/day).

4.0 TARARUA GWMZ DATA REVIEW AND RECOMMENDED WORK PLAN

4.1 DATA REVIEW

The available data within the Tararua GWMZ is discussed below. Figure 4.1 shows the distribution of wells with and without lithological logs within the GWMZ. There are large gaps in lithological information, particularly north of Dannevirke and the eastern half of the entire Tararua GWMZ. Figure 4.2 again highlights the lack of subsurface information particularly within the north and east of the area. Additionally, only 13 lithological logs extend deeper than 100 m (Figure A 1.2). Figure 4.3 shows that the area falls into three different QMAP regions (Begg and Johnston, 2000; Lee and Begg, 2002; Lee et al., 2011), and that both hydraulic conductivity estimates and monitored water levels are very spatially limited (confined mostly to a small central area). Figure 4.4–Figure 4.6 display some additional data in the area that could be used to contribute subsurface information.

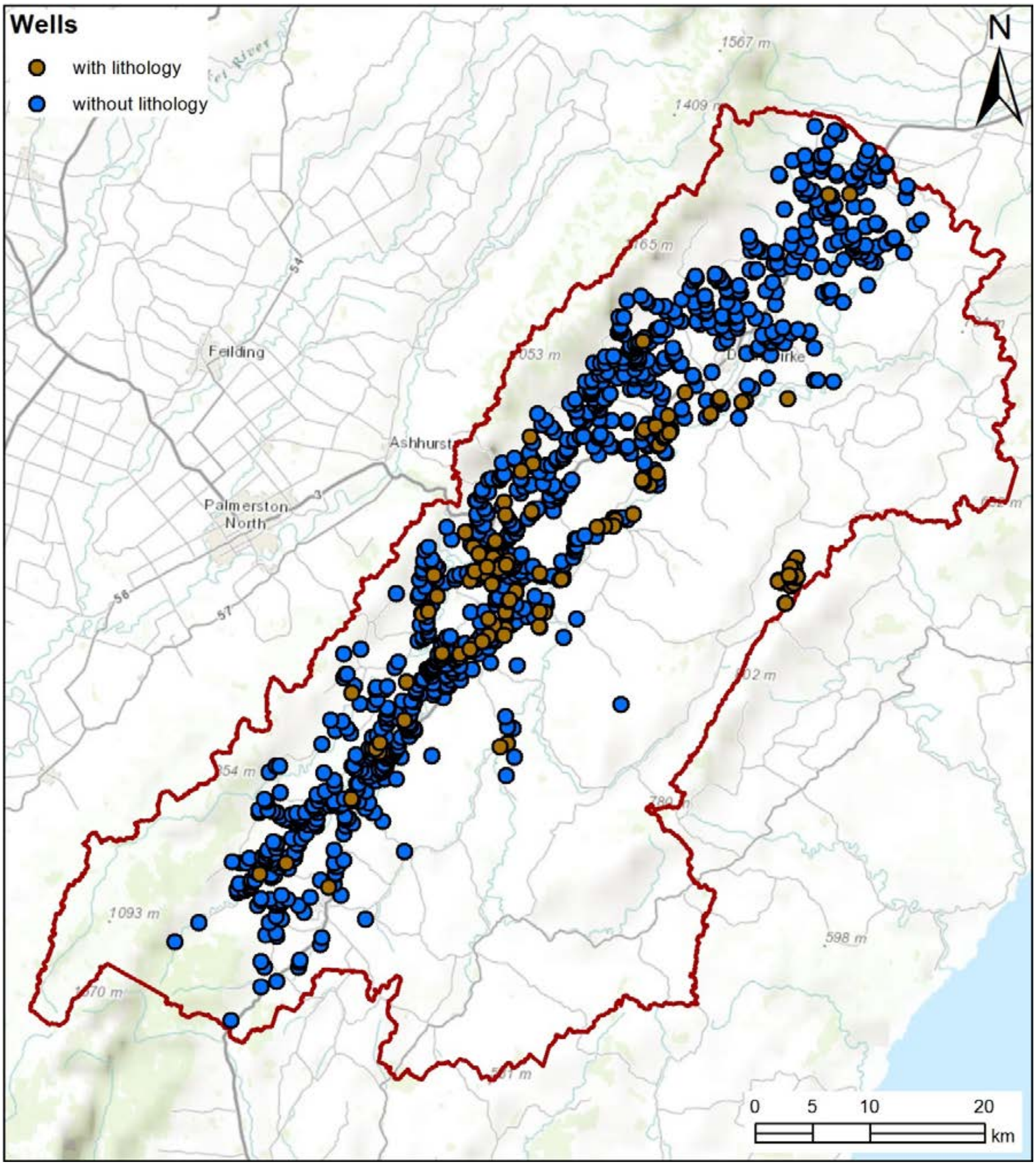

Figure 4.1 All wells in the Tararua GWMZ. The red line shows the Tararua GWMZ boundary.

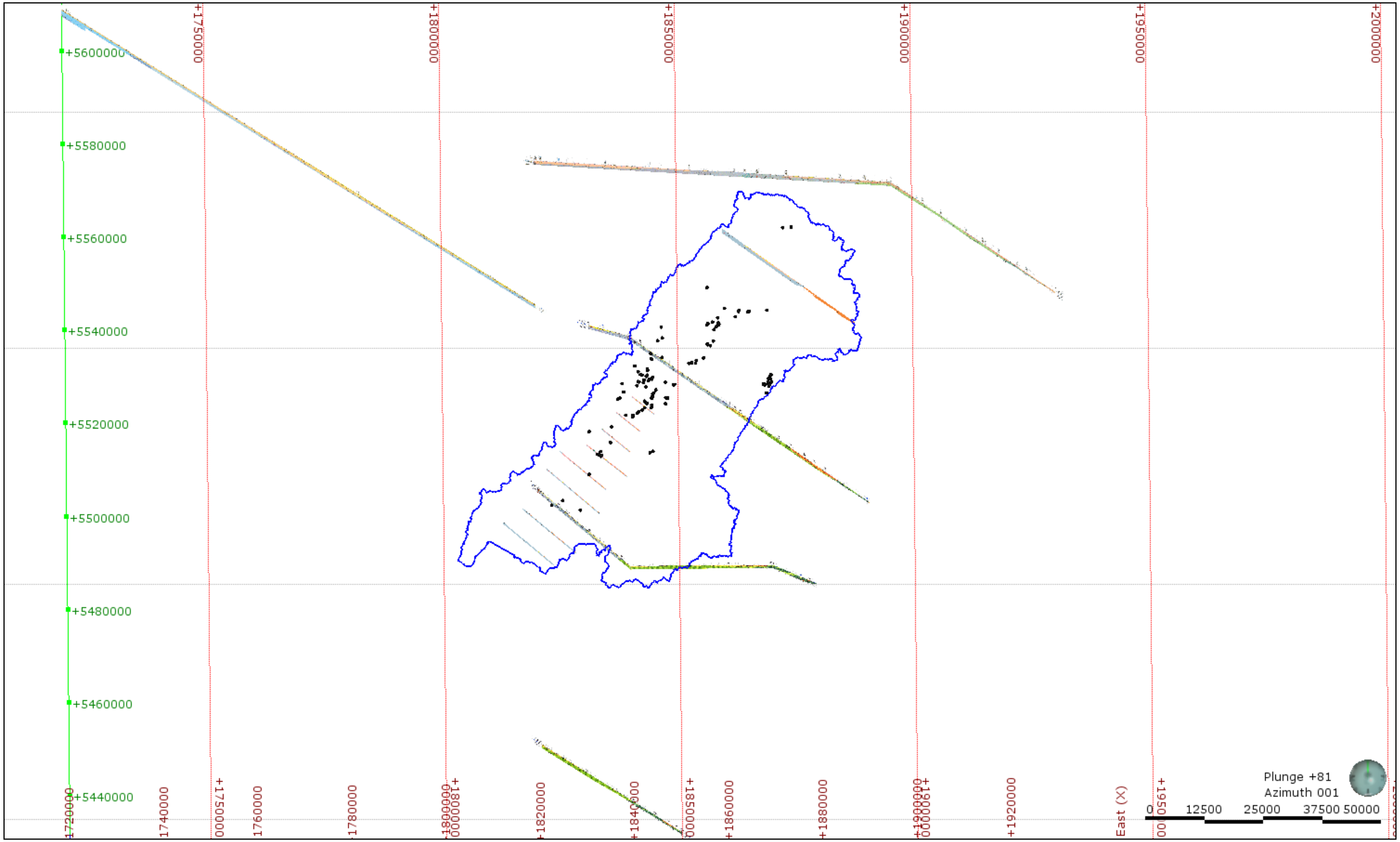

Figure 4.2 Map view of available subsurface data for developing a 3D model of the Tararua GWMZ. Coloured lines display the locations of the georeferenced QMAP cross-sections and the nine newly created cross-sections. Black circles show the locations of the available lithological logs. The blue line is the Tararua GWMZ boundary.

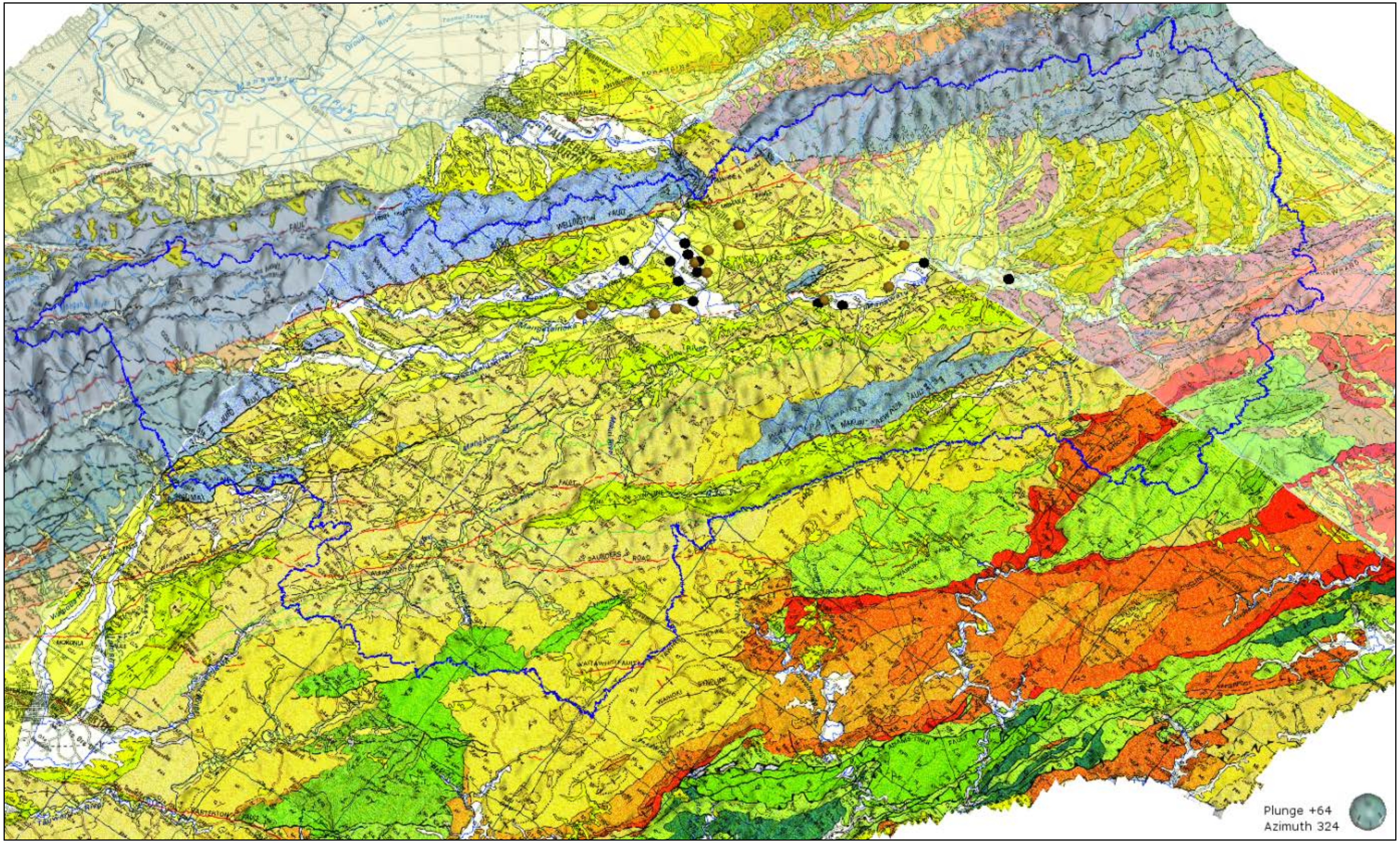

Figure 4.3 QMAP with 5x vertical exaggeration (Begg and Johnston, 2000; Lee and Begg, 2002; Lee et al., 2011; Townsend et al., 2008). The blue line is the Tararua GWMZ boundary. Black circles are locations with hydraulic conductivity estimates from pump tests. Brown circles are wells with monitored water levels.

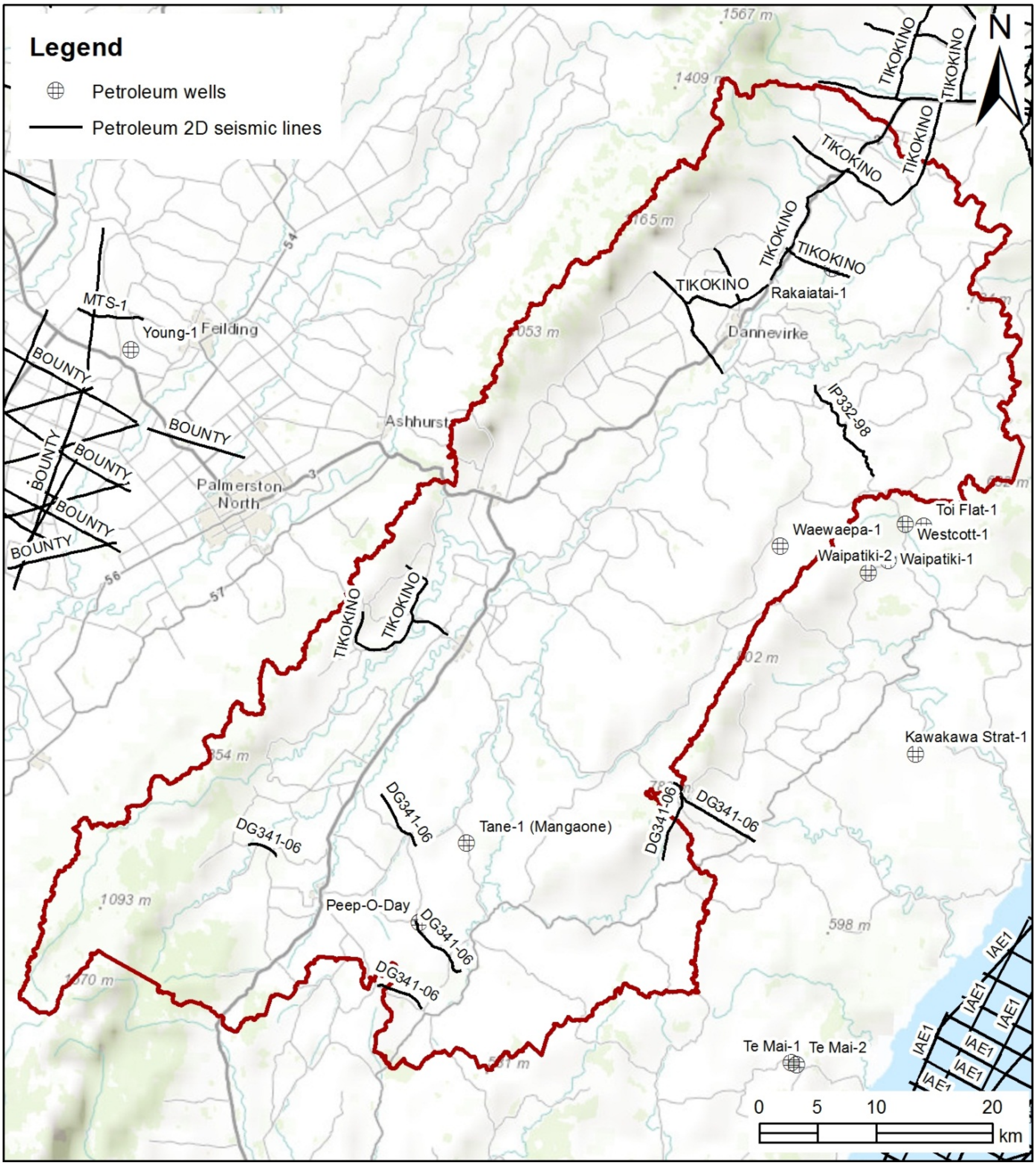

Figure 4.4 Petroleum 2D seismic and well data in the area (Ministry Of Economic Development, 2014). The red line is the Tararua GWMZ boundary.

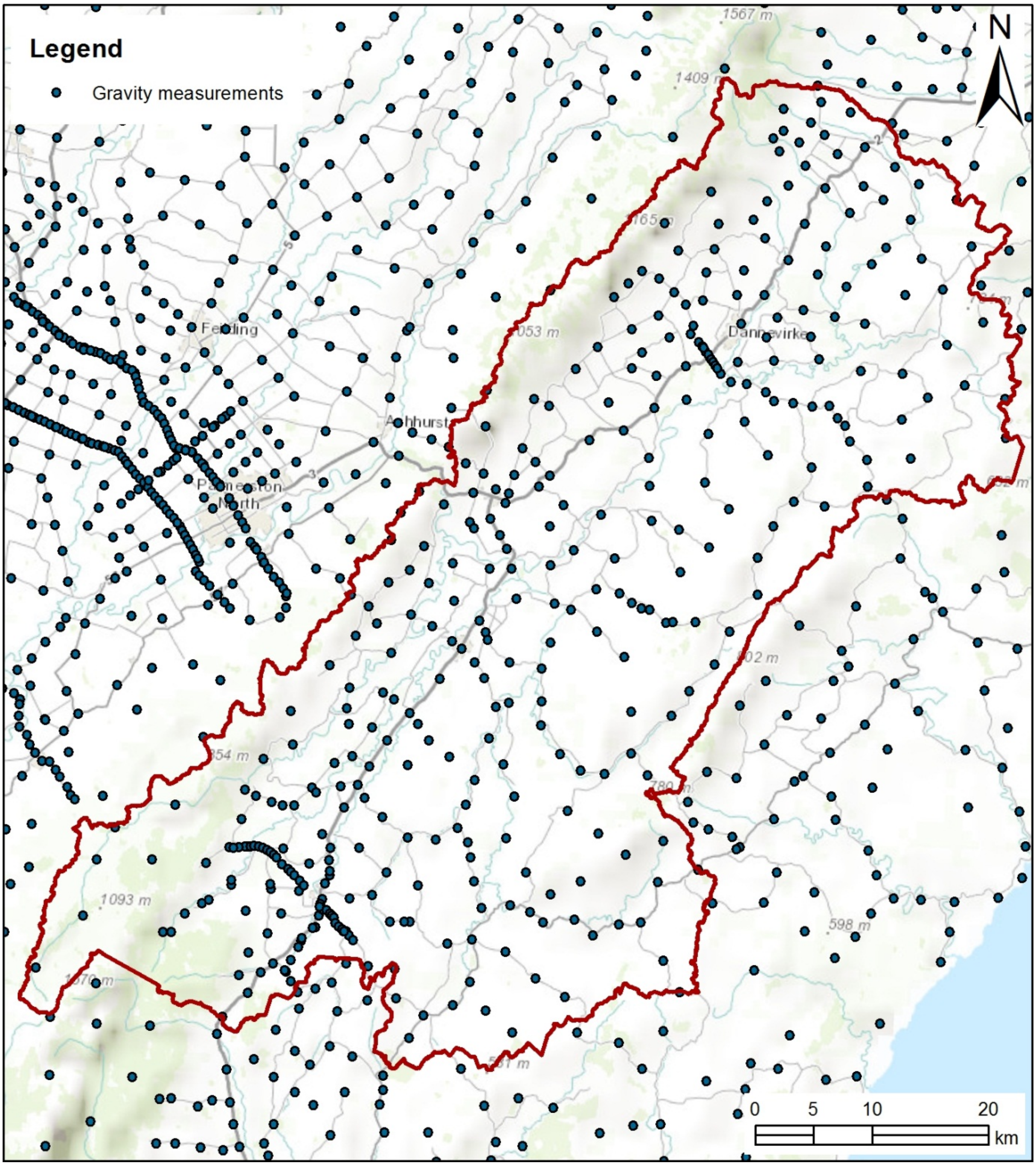

Figure 4.5 Gravity measurements from the New Zealand Gravity Stations Network (GNS Science, 2013). The red line is the Tararua GWMZ boundary.

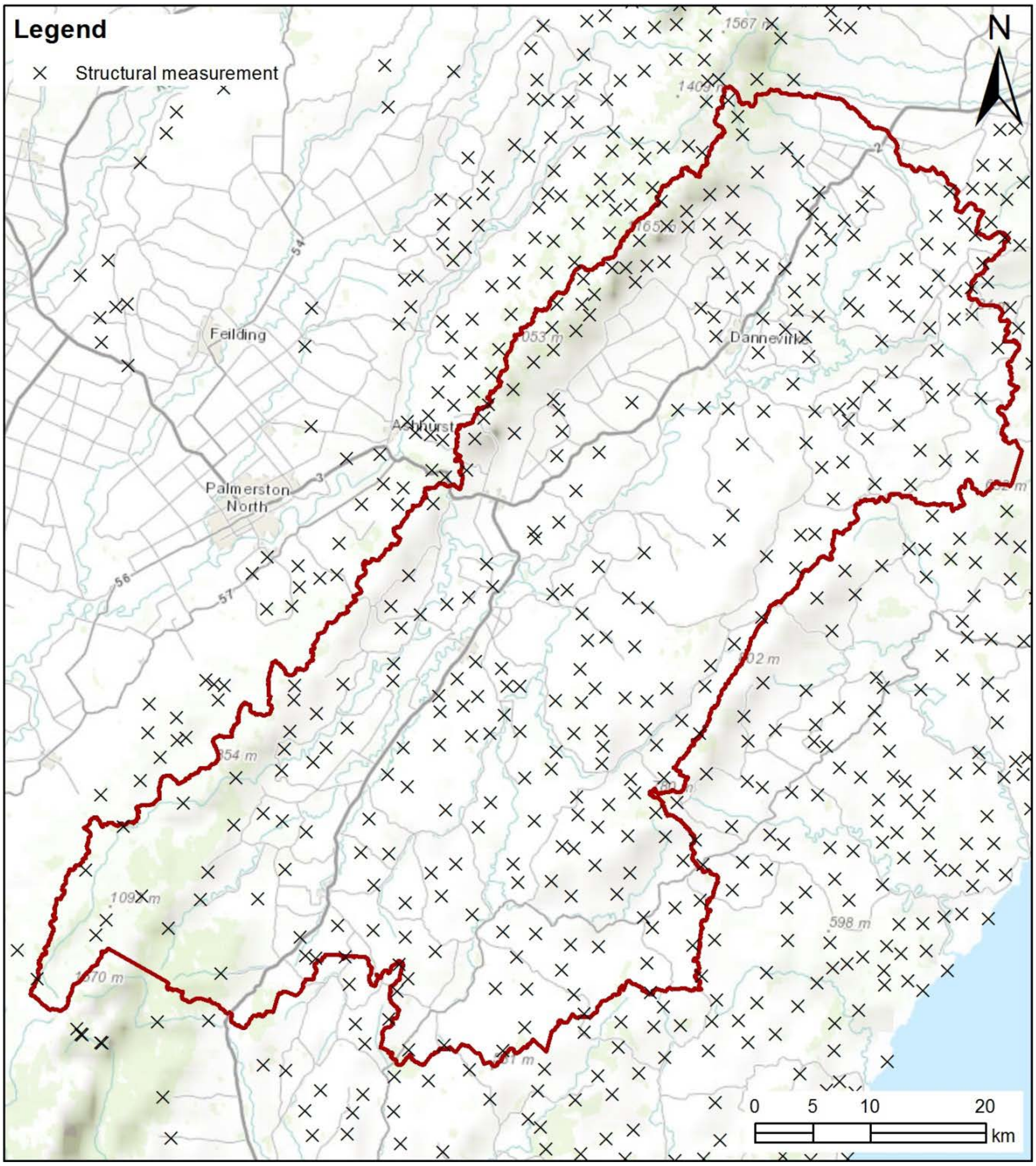

Figure 4.6 Available QMAP geological structural measurements (Begg and Johnston, 2000; Lee and Begg, 2002; Lee et al., 2011; Townsend et al., 2008). The red line is the Tararua GWMZ boundary.

4.2 INFORMATION GAPS AND POTENTIAL FUTURE WORK

There are a number of information gaps relating to building a subsurface model suitable for groundwater flow modelling within the Tararua GWMZ. As these knowledge gaps are very large in some areas within the Tararua GWMZ, the first step in any new data collection plan needs to be on designating the relative importance of select regions and targets. A data collection survey should be performed to assess the yield of wells and a collation of current and predicted demand for groundwater. This should focus on three aspects:

- Defining the importance of groundwater in the north (from just south of Dannevirke to the northern boundary).
- Defining the importance of groundwater from Tertiary sources.
- Deciding if wells are likely to be drilled in the southeast in the future.

The information gaps are presented and recommendations for further work are identified below depending on the results of the three aspects outlined above.

4.2.1 Model boundaries

The Tararua GWMZ should be refined to delineate the area that is relevant for groundwater flow modelling. There are a number of aspects that come into this refinement:

- Locations with demand for water: as shown in Figure 4.1, the distribution of existing wells suggests that there are likely to be some areas that are unnecessary to model, for instance the south- and north-east. A decision needs to be made as to whether the modelling of these areas is necessary.
- Horizontal geological no-flow boundaries: as discussed in Section 2.5.1.1, based on the geological model it is possible that there is in-flow from the north. However, this northern boundary abuts onto the southern boundary of Hawke's Bay's Ruataniwha Plains groundwater model, where Baalousha (2010) has placed a no-flow boundary condition. As the contour lines of the potentiometric map in this report are approximately perpendicular to the northern boundary (Figure 3.2), it is possible that it is suitable to set a no-flow boundary condition here. A more reliable potentiometric map should be developed for assessment of this (see Section 4.2.4).
- Vertical geological no-flow boundaries: as discussed in Section 2.3.2, the youngest two Tertiary units are likely sources of groundwater, whereas the oldest three units are unlikely to contain groundwater. In the collection of well yield and groundwater demand data discussed above, the quantity and quality of water obtained from Tertiary sources should be defined to determine whether hydraulic basement should be defined at the base of the Tolaga Group or the base of the Quaternary sediments. If hydraulic basement should be defined at the base of the Tolaga Group, then further modelling will be required to split the Tertiary unit presented in this report into two different units.
- Recharge sources: it should be checked whether the defined groundwater no-flow boundaries balance a water budget for the area. A water budget approach using precipitation, actual evapotranspiration, and surface water gauging measurements can be used to verify the groundwater flow model boundary (e.g., White and Tschritter, 2014).

4.2.2 Hydrogeological unit mapping

As discussed above, a work plan for improved hydrogeological unit mapping relies on first determining the importance of the areas that currently have large data gaps. In conjunction with the well yield and demand data collection, a comparison of all well screens with the modelled lithologies should be used for determining the production importance of Tertiary units. The extent of further work will depend on whether the base of the Quaternary or the base of the Tolaga Group should be considered as the hydraulic basement. If the Tolaga Group base should be considered as the hydraulic basement then additional work will be required to determine methods of differentiating this group from the other Tertiary groups that are currently considered as one unit.

The existing data sets shown in Figure 4.4–Figure 4.6 could be interpreted to provide additional subsurface constraints. The existing seismic lines shown in Figure 4.4 could be accessed and reinterpreted to determine if lithological thicknesses can be further constrained, particularly in the northern area where data is sparse. Additionally in this area, as it joins to an area that has been extensively studied by Hawke's Bay, liaising with Hawke's

Bay Regional Council could provide additional information. As performed for the Mangatainoka catchment in this study, existing structural information (Figure 4.6) could be used for creating additional cross-sections throughout the GWMZ. Gravity data (Figure 4.5) could be used for providing lithological unit thickness constraints throughout the GWMZ (this will be investigated within the Smart Aquifer Characterisation Research programme (Rawlinson, 2013)).

Figure 4.1 highlights the disparity between the numbers of existing wells versus those with available lithological logs. A data gathering process should be performed to determine if Horizons holds data on all existing lithological logs, or if there is some missing information that is potentially being held by drilling companies. As drilling is an expensive process, lithological logs should be obtained from any future drilled wells.

4.2.3 Hydraulic properties

There is an insufficient distribution of hydraulic conductivity estimates to meaningfully inform spatial heterogeneity of hydraulic properties for sub units within the Quaternary sediments for groundwater flow modelling. Ideally, a number of aquifer pumping tests with observation wells should be performed to provide estimates of storativity and hydraulic conductivity. To get larger coverage of hydraulic conductivity estimates, it would be useful to perform a field assessment survey to determine which existing wells would be suitable for single well or slug testing. Suitability would depend on the well size, construction and sufficient available details on well construction. To minimise costs for single well tests, wells with an existing pump installed should be selected, otherwise a drilling or pump contractor would be required to install a temporary pump. Following this data collection, a plan should be created and carried out regarding which suitable wells should be tested given the existing data distribution. A comparison of aquifer lithological properties and aquifer hydraulic properties within existing Hawke's Bay Ruataniwha Plains information could also yield useful information on likely hydraulic properties.

If it is determined that the Tertiary unit is productively important, then aquifer testing will need to be performed in this unit as there are currently no hydraulic conductivity estimates for the Tertiary unit.

4.2.4 Flow vectors

Both a summer (low water level) and a winter (high water level) potentiometric surface should be created, with measurement locations obtained using GPS. These surveys will be carried out in 2014 (Matthews, 2014). Additionally, if a multilayered aquifer system exists then data must be able to be assigned to each aquifer.

A Satellite Equilibrium Water Table, currently being created as part of the Smart Aquifer Characterisation programme (Westerhoff and White, 2014), should be considered to supplement these surveys in data sparse areas.

4.2.5 Other Information

This data gap identification and work plan only considers the building of the subsurface model component of a hydrogeological conceptual model. For the construction of a full hydrogeological conceptual model, other important considerations such as recharge modelling, groundwater–surface water interaction, and age dating need to be assessed.

5.0 CONCLUSIONS

A 3D hydrogeological model has been built for the priority catchments within the Tararua Groundwater Management Zone (GWMZ) using LeapFrog Geo software and pre-existing data. The three layers used for modelling are as follows:

- 'Quaternary': Holocene to early Pleistocene.
- 'Tertiary': late Early Cretaceous to latest Pliocene.
- 'Basement': Triassic to late Early Cretaceous.
- The region is heavily faulted, forming a sequence of basement highs and lows. The thickness of the Quaternary unit reaches a maximum of 227.7 m. Based on the extent of the Quaternary unit, the model boundaries have been adjusted in some areas to simplify future flow modelling with the inclusion of no-flow boundaries.

A potentiometric surface has been created using a combination of static water levels taken during drilling and mean water levels at long-term monitored sites. Spatial sampling limitations necessitate the inclusion of static water levels and results in a surface with a high uncertainty.

Horizons has been provided with GIS shapefiles of the 3D model volumes and the potentiometric 25 m contours, as well as a Leapfrog viewer file of the 3D model.

Recommendations for further work relevant to the groundwater resource in the Tararua GWMZ include:

- Performing a summer and winter potentiometric survey and combining this data with Satellite Equilibrium Water Table measurements in data sparse areas.
- Performing a data collection survey to assess the yield of wells, as well as current and predicted demand for groundwater. Combining this information with a comparison of well screen locations with the lithological units modelled in this report to designate the importance of areas and hydrogeological units.
- Refining the necessary horizontal and vertical groundwater boundaries for flow modelling using the following: the data collection above, constructing a reliable potentiometric map, and analysing a water budget for the area.
- Improving the spatial sampling of the subsurface information through the following options: utilising existing seismic lines, gravity measurements and geological structural information; checking if there is any lithological log information held by drilling companies that is not currently in the Horizon's database; ensuring all wells drilled in the future have lithological logs obtained.
- Performing a field assessment survey to determine which existing wells would be suitable for performing either single well tests or slug tests, and carrying out such tests to gain better sampling coverage of hydraulic conductivity estimates of the resource.

This data gap identification and work plan only considers the building of the subsurface model component of a hydrogeological conceptual model. For the construction of a full hydrogeological conceptual model other important considerations such as recharge modelling, groundwater–surface water interaction and age dating need to be incorporated.

6.0 REFERENCES

Anderson, M. P.; Woessner, W. W. 2002. *Applied Groundwater Modeling* (p. 381). Elsevier, Oxford.

Baalousha, H. 2010. Ruataniwha Basin transient groundwater-surface water flow model. *Hawke's Bay Regional Council, EMT 10/30, HNRC Plan No. 4234*, 103.

Balance, P. F. 2009. *Sedimentation in Oblique-slip Mobile Zones: Special Publication 4 of the IAS (Google eBook)* (p. 368). John Wiley & Sons.

Begg, J. G.; Johnston, M. R. 2000. *Geology of the Wellington Area*. *Institute of Geological and Nuclear Sciences 1:250 000 geological map 10* (p. 1 sheet + 64). Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited.

Geographx, (2012), http://geographx.co.nz/_wp/wp-content/uploads/2012/12/GX-Terrain-Metadata.pdf, last accessed March 2014.

GNS Science 2013. New Zealand Gravity Station Network, http://maps.gns.cri.nz/website/gravity/, last accessed 3rd May 2013.

GNS Science 2014. New Zealand Active Faults Database, http://data.gns.cri.nz/af/, last accessed May 2014.

Horizons 2012. http://www.horizons.govt.nz/assets/one-plan-publications-and-reports/factsheets/Map20120911Target-CatchmentsCourt-Decision1.pdf, last accessed May 2014.

Lee, J.; Begg, J. 2002. *Geology of the Wairarapa area*. *Institute of Geological and Nuclear Sciences 1:250 000 geological map 11* (p. 1 sheet + 66). Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited.

Lee, J.; Bland, K.; Townsend, D.; Kamp, P. 2011. *Geology of the Hawke's Bay area*. *Institute of Geological and Nuclear Sciences 1:250 000 geological map 8* (p. 1 sheet + 93). Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited.

Matthews, A. 2014. Abby.Matthews@horizons.govt.nz, Horizons Regional Council, pers. comm., 28th January 2014.

Ministry Of Economic Development 2014. New Zealand Petroleum and Minerals online exploration database, https://data.nzpam.govt.nz/GOLD/system/mainframe.asp, last accessed May 2014.

Rawlinson, Z. J. 2013. A review of the most effectual and economical geophysical techniques for characterising groundwater within New Zealand. *GNS Science Report 2013/38*, 96.

Townsend, D.; Vonk, A.; Kamp, P. J. J. 2008. *Geology of the Taranaki Area*. *Institute of Geological and Nuclear Sciences 1:250 000 geological map 7* (p. 1 sheet + 77). Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited.

Trewick, S.; Bland, K. 2012. Fire and slice: palaeogeography for biogeography at New Zealand's North Island/South Island juncture. *Journal of the Royal Society of New Zealand*, *42*(3), 153–183.

Westerhoff, R. S.; White, P. A. 2014. Application of equilibrium water table estimates using satellite measurements to the Canterbury Region, New Zealand. *GNS Science Report 2013/43*, 30.

White, P. A.; Tschritter, C. 2014. Groundwater-surface water interaction in the Torepatutahi Stream catchment. *GNS Science Letter Report No. CR 2014/110 LR*, 12.

Zarour, H. 2008. Groundwater Resources in the Manawatu–Wanganui Region: Technical Report to Support Policy Development. *Horizons Regional Council*, 262.

Zemansky, G.; Tschritter, C.; Lovett, A. 2012. The Extent and Depth of Known East Coast Aquifers, North Island, New Zealand. *GNS Science Consultancy Report 2012/273*, 35.

APPENDICES

APPENDIX 1: 3D MODEL INPUT DATA

The Mangatainoka/Upper Manawatu hydrogeological model has been constructed from borehole logs, published geological surface maps and cross-sections, published fault information, and newly constructed cross-sections from existing geological structural data. Below, these data inputs are discussed.

A1.1 BOREHOLE LOGS

Horizons hold a database containing 1247 groundwater wells within the Tararua GWMZ. Of these, 126 have available driller's log records (Figure A 1.1). The logs have a maximum depth penetration of 255 m, with a median depth penetration of 12.2 m, and 13 wells that have been drilled deeper than 100 m (Figure A 1.2). No wells penetrate through to basement. These logs have been analysed to obtain constraints on locations of Quaternary and Tertiary sediment surfaces (Figure A 1.3). There is some difficulty in ensuring the accuracy of the split between these two units, both in that the division is not simple and that the logs are not of the highest accuracy as they have been recorded by drillers rather than geologists. Techniques used for distinguishing the Tertiary sediments from Quaternary have been to mainly use the existence of the descriptive terms "shell", "rock", "papa", "cemented", "hard", "firm" and "claybound". Such terms were not always available, and some less obvious decisions have had to be made. Some wells have a higher uncertainty than others depending on the available descriptions. John Begg is an author on the QMAP of this region (Lee and Begg, 2002) and is thus experienced with interpreting the lithological logs of local boreholes. Therefore, we are satisfied that the split has been made as accurately as possible given the available data.

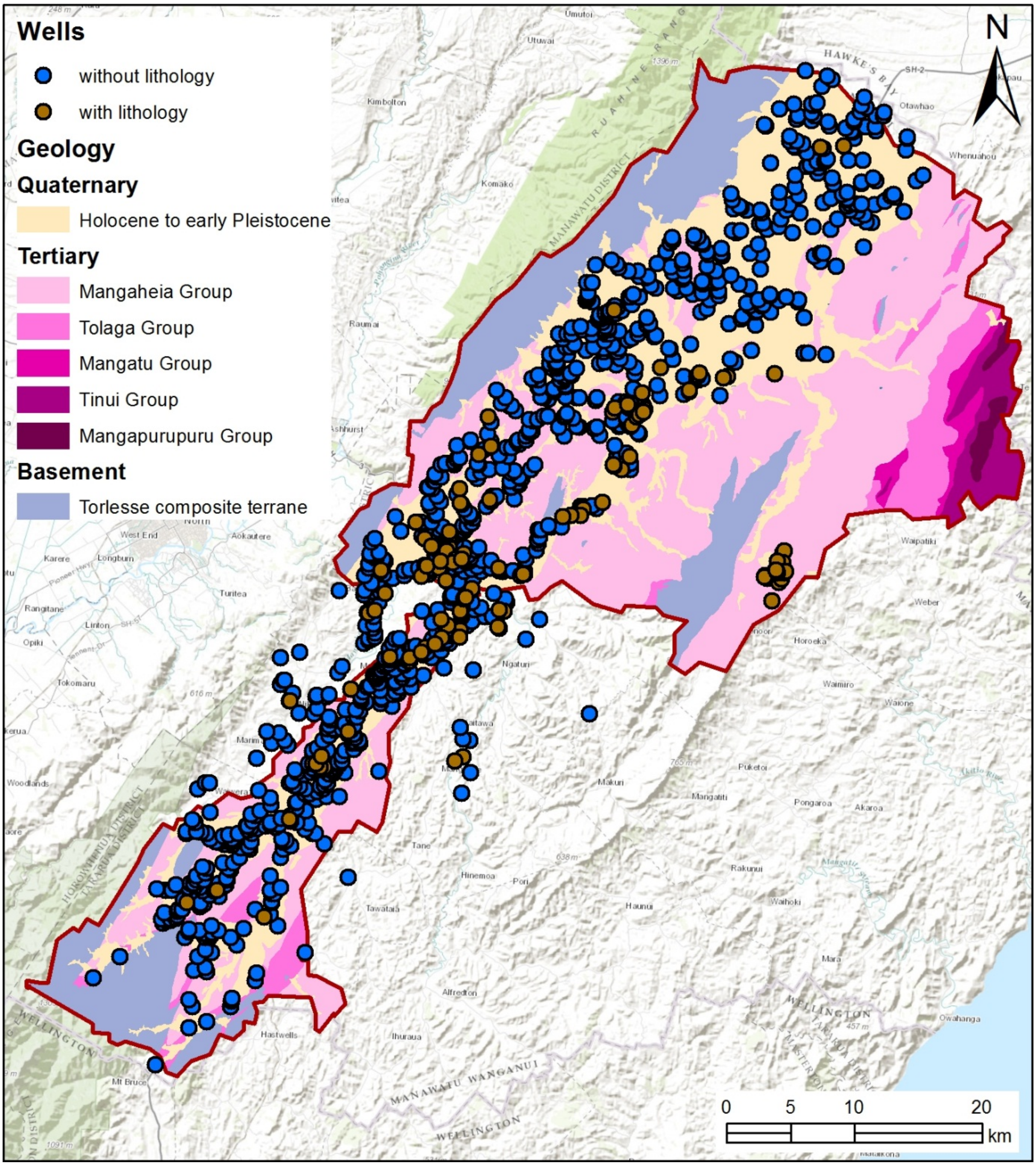

Figure A 1.1 All wells in the Tararua GWMZ.

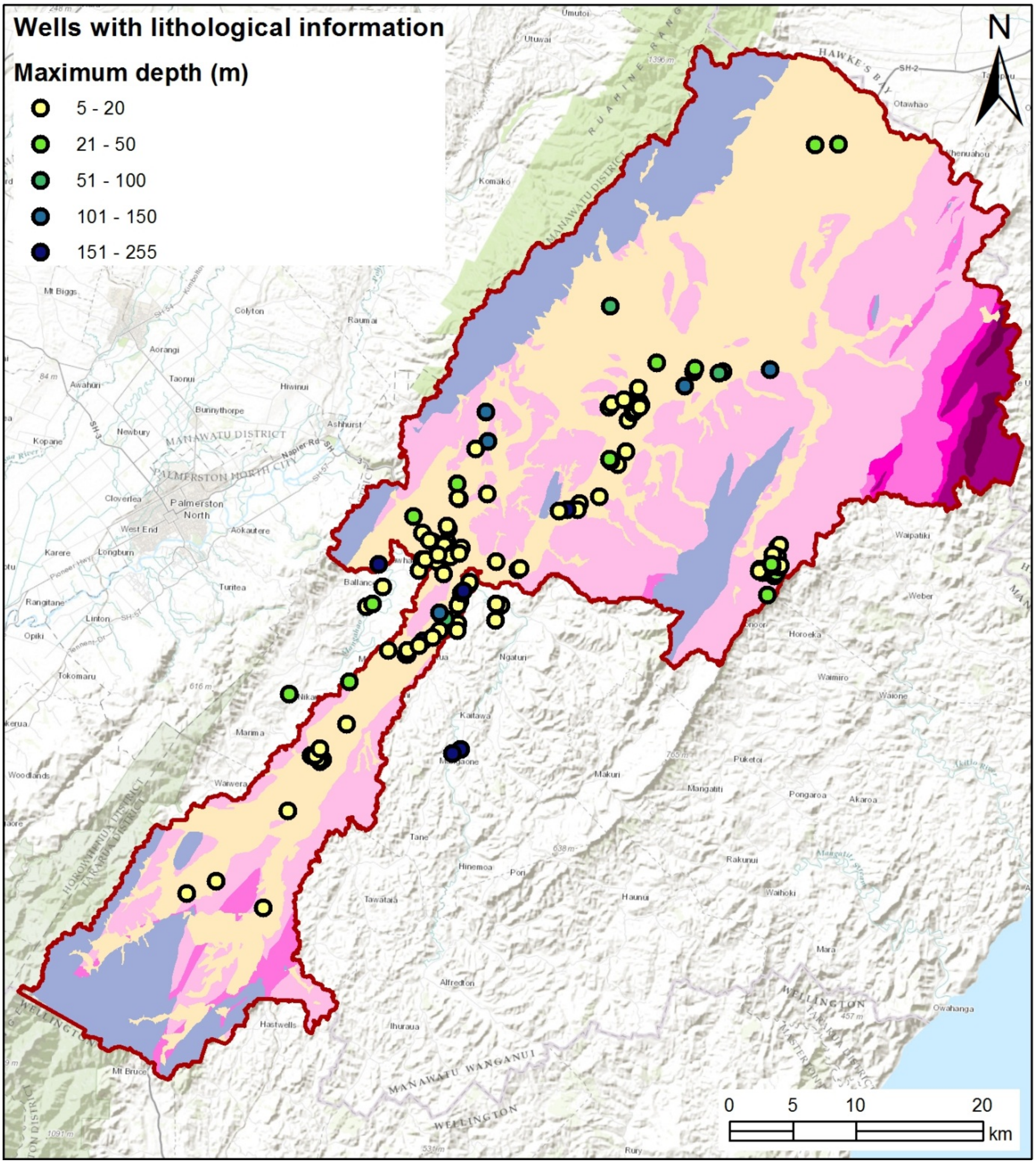

Figure A 1.2 Depths of wells in the Tararua GWMZ with lithological information.

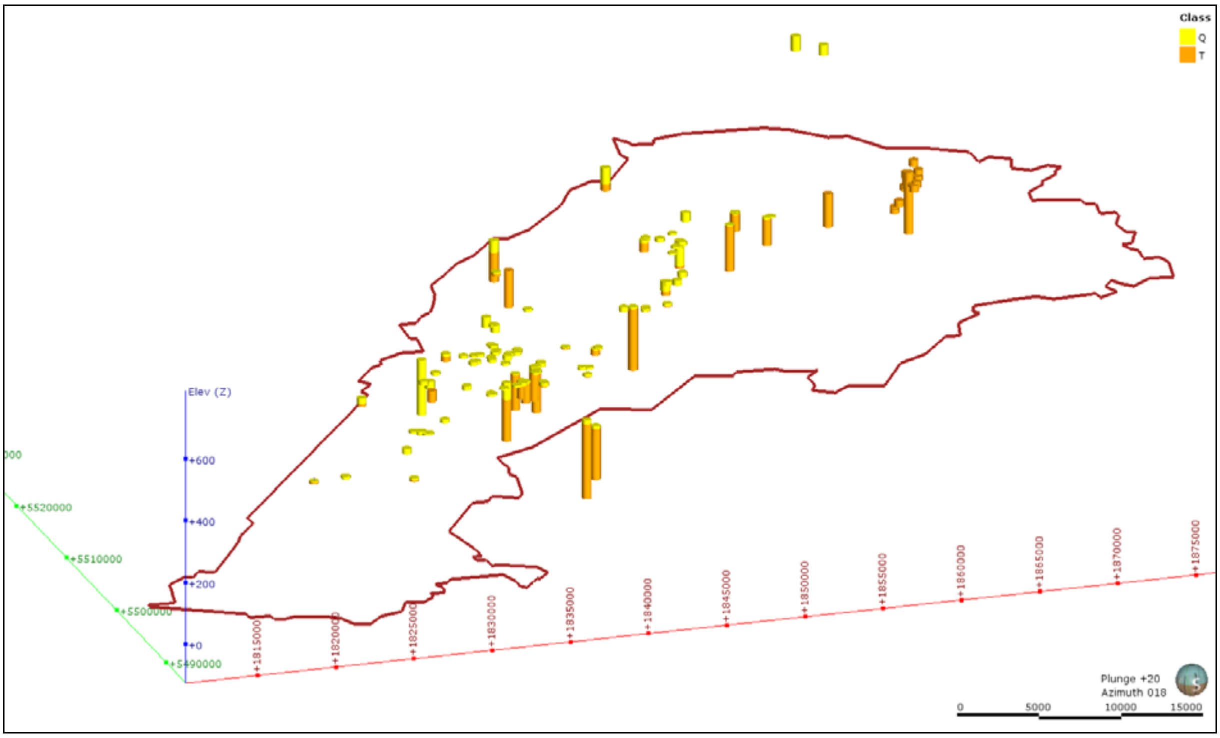

Figure A 1.3 Interpretation of borehole logs used for modelling (Q=Quaternary, T=Tertiary). Note that the top of the boreholes coincide with topography and a 20x vertical exaggeration has been applied. The dark red line is the extended boundary used for the final model (see Section 2.5.1.1).

A1.2 CROSS-SECTIONS AND FAULTS

The published QMAP geological maps include subsurface geological cross-sections. Cross-sections that lie within or near to the model boundary have been georeferenced and used as guidelines for boundaries between the modelled hydrogeological units (Figure A 1.4). An additional nine cross-sections have been created from existing QMAP structural data (Figure A 1.5 and Figure A 1.6) and used in the same manner. These have been created focussing on the Mangatainoka catchment, which was specified as the priority catchment for this study. The region is riddled with faults (Figure 2.2). Of these faults, four that have active sections have been included (Figure A 1.4–Figure A 1.6). These are the Alfredton Fault, the Huru Fault, the Pahitua Fault and the Wellington Fault. Their surfaces have been constructed from simplifications of the GNS Science Active Faults Database (GNS Science, 2014).

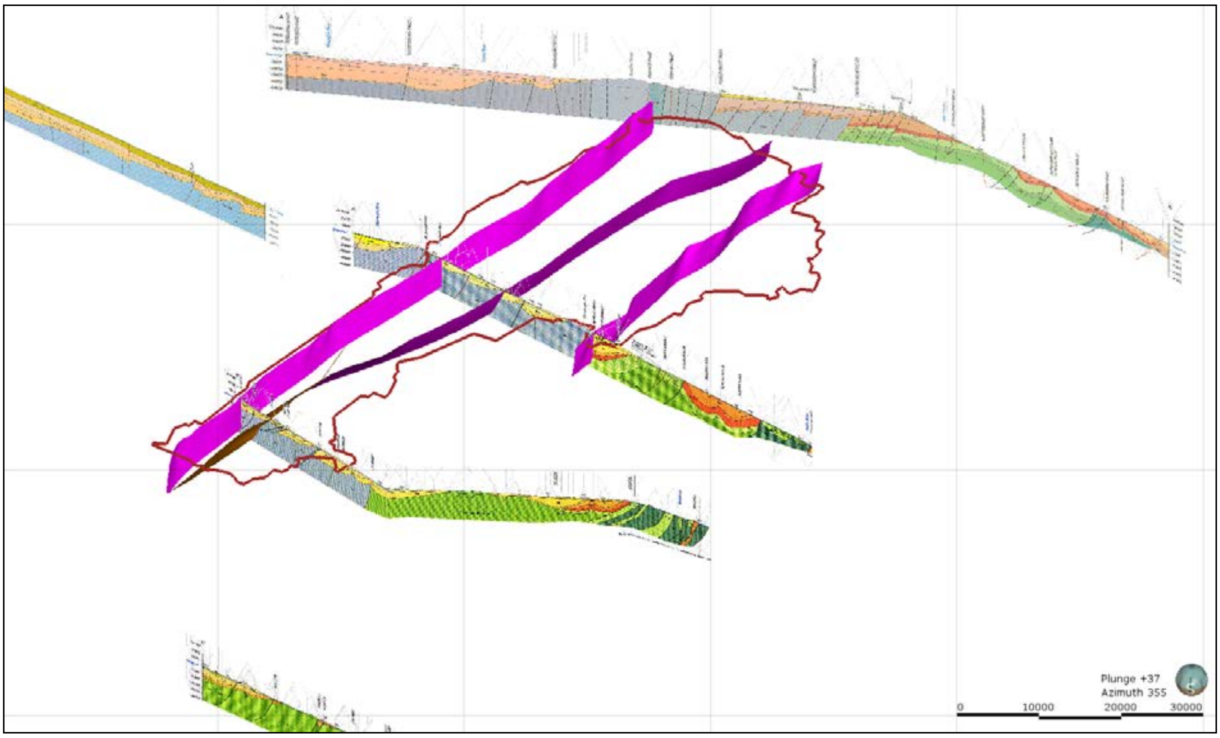

Figure A 1.4 Coloured images of the georeferenced QMAP cross-sections used as input data. Purple surfaces are the faults used as input data. The dark red line is the extended boundary used for the final model (see Section 2.5.1.1).

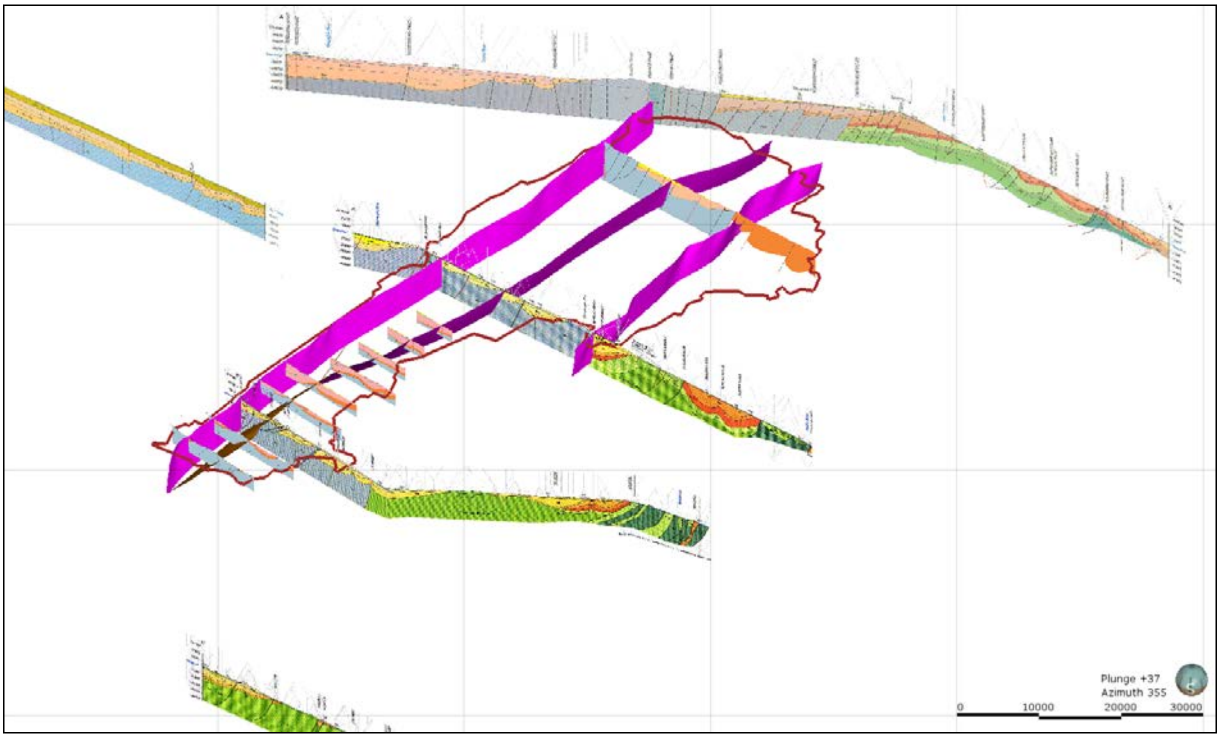

Figure A 1.5 Coloured images of the georeferenced QMAP cross-sections and the nine newly created cross-sections used as input data. Purple surfaces are the faults used as input data. The dark red line is the extended boundary used for the final model (see Section 2.5.1.1).

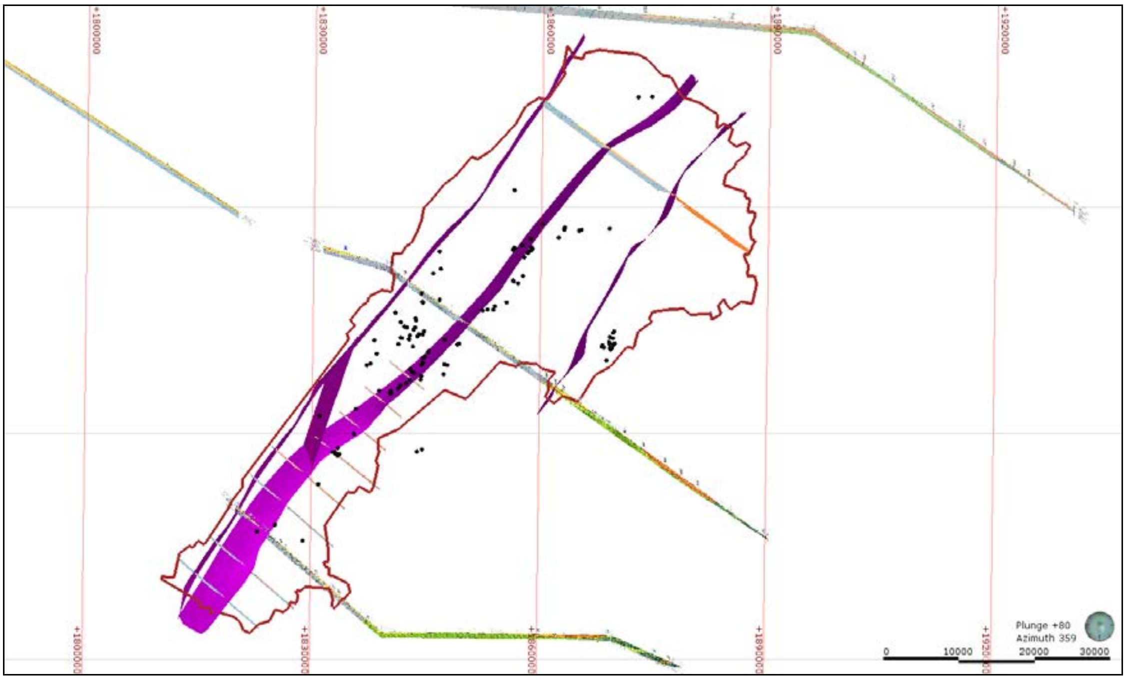

Figure A 1.6 Map view of the input data. Coloured images of the georeferenced QMAP cross-sections and the nine newly created cross-sections used as input data. Purple surfaces are the faults used as input data. Black circles are the lithological logs. The dark red line is the extended boundary used for the final model (see Section 2.5.1.1).

A1.3 GEOLOGICAL SURFACE MAP

QMAP data has been simplified into the geological map shown in Figure 2.2. This simplified map has then been used to extract the surficial boundaries between the modelled hydrogeological units (Figure A 1.7).

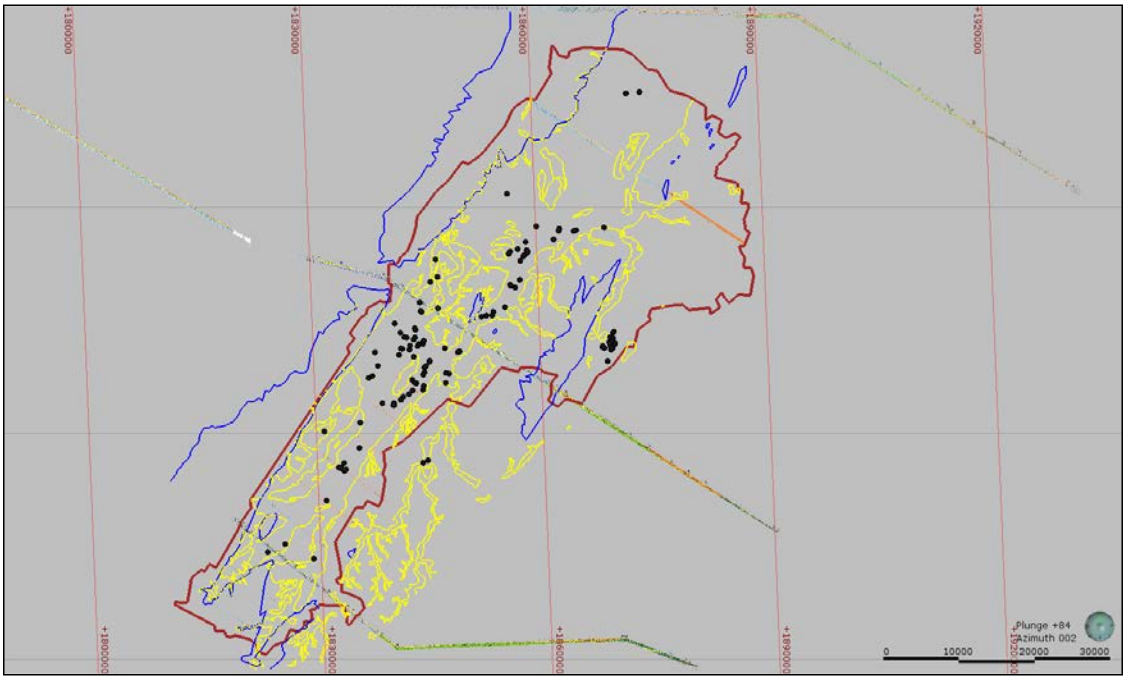

Figure A 1.7 Map view of the input data. Surficial geological boundaries are extracted from QMAP: yellow lines display the surficial boundary between Quaternary and Tertiary sediments; blue lines display the boundary between Tertiary sediments and basement. Also shown are coloured lines of the georeferenced QMAP cross-sections and the nine newly created cross-sections used as input data. Black circles are the lithological logs. The dark red line is the extended boundary used for the final model (see Section 2.4.4).

www.gns.cri.nz

Principal Location

1 Fairway Drive
Avalon
PO Box 30368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600

Other Locations

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
T +64-3-477 4050
F +64-3-477 5232

Wairakei Research Centre
114 Karetoto Road
Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

National Isotope Centre
30 Gracefield Road
PO Box 31312
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4657

horizons
regional council

11-15 Victoria Avenue
Private Bag 11 025
Manawatu Mail Centre
Palmerston North 4442

T 0508 800 800
F 06 952 2929
help@horizons.govt.nz
www.horizons.govt.nz