Lake Rotorua Shallow Groundwater Assessment

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GLOSSARY

Caldera – A large, roughly circular crater left after a volcanic explosion or the collapse of a volcanic cone. Calderas are typically much wider in diameter than the openings of the vents from which they were formed.

Downgradient groundwater – The hydraulic gradient is a measure of the rate of change of hydraulic head with distance as a fluid moves. Downgradient groundwater is groundwater that has moved past a given location.

Hydraulic – Of or pertaining to water or other fluids in motion.

Head loss – A measure of the energy of a fluid lost as the fluid moves from one location to another. Groundwater in an aquifer is a fluid.

Hydraulic head – Hydraulic head is the total head or energy of a fluid at a given location. It includes elevation, pressure, and velocity head components. Groundwater typically flows so slowly that its velocity head is negligible. For groundwater in an unconfined aquifer, the total head is approximately given by the elevation of the water table above the standard datum of mean sea level.

Springs and seeps – An issue of water from the earth. There are various kinds of springs, depending on the specific geology by which they are formed. For example, “contact” springs are commonly found near the base of hills when a low permeability layer prevents groundwater from further vertically downward movement.

Wetlands – Wetlands are areas where water either covers the soil or is present at or very near the surface for a substantial portion of the year including the growing season. Their wet nature results in characteristic vegetation. Swamps, bogs, and marshes are typical wetland areas.

Finite element – The two most commonly used mathematical procedures for making a groundwater flow model are know as finite difference and finite element models. Finite difference models utilize a rectangular grid system. Finite element models utilize a mesh formed by polygonal cells. In practice, these are typically triangular in shape.

Head boundary – Numerical models must be bounded on all sides to allow calculations of groundwater flow to be made. A commonly used boundary is known as a specified or constant head or Dirichlet boundary. This is when the hydraulic head is specified at a constant value for that location or boundary of the model at all times.

Shallow groundwater – Groundwater found at relatively shallow vertical distance below ground level. “Shallow” is a relative term that means not deep. In the case of groundwater, it generally refers to the first saturated zone below ground and within a few meters to less than 50 meters depth. Shallow groundwater may also be referred to as a high groundwater table.

DTM – Digital terrain model. A digital representation of the earth’s surface or terrain excluding vegetation and artificial structures. In the past, DTM’s have commonly been produced by photogrammetric methods. Photogrammetric methods are generally being replaced by LIDAR (light detection and ranging). LIDAR is similar in concept to radar, but uses much shorter wavelengths of the electromagnetic spectrum.

LIST OF ABBREVIATIONS

RDC – Rotorua District Council

GNS – Institute of Geological and Nuclear Sciences

DTM – Digital terrain model.

GPS – Global positioning system

EBOP – Environment Bay of Plenty Regional Council

GIS – Geographical information system

3D – Three dimensional

DHI WASY GmbH – WASY is the German company that developed the Feflow groundwater model. DHI is the Danish company that recently purchased WASY GmbH to form DHI WASY GmbH currently marketing and supporting Feflow.

Feflow – Finite element groundwater flow

MSL – Mean sea level.

BGL - Below ground level

ENSO – El Nino Southern Oscillation

GHG – Greenhouse gasses

NIWA – National Institute for Water and Atmospheric Sciences

NERMN - Natural Environment Regional Monitoring System

GCM – Global climate model

EXECUTIVE SUMMARY

Rotorua District Council (RDC) requested that GNS Science provide an assessment of locations in the vicinity of Lake Rotorua where very shallow groundwater exists (i.e., high groundwater table).

Zones of shallow groundwater were identified and mapped as follows:

1. Development of depth to groundwater using the existing GNS Science groundwater flow model of the Rotorua catchment.
2. Development of depth to groundwater using available contoured groundwater level data.
3. Plotting known features including seeps, springs, swamps, wetlands, and geotechnical boreholes.
4. Development from catchment topography of a plot of low lying ground.

In addition, data gaps on the location of shallow groundwater were discussed in general and the potential impact of climate change on groundwater in the Lake Rotorua catchment was assessed.

This report provides four figures identifying shallow groundwater locations and additional details in Appendix figures. GIS shape/raster files of these have been separately provided to RDC.

Lake Rotorua is located in a part of New Zealand which is expected to be only minimally impacted by climate change. Therefore, it is not expected that it will substantially affect groundwater levels.

Recommendations for further work to refine the identification of shallow groundwater locations made in this report are as follows:

1. Re-run the GNS Science groundwater flow model of the Rotorua catchment re-setting the Lake Rotorua constant head boundary to reflect updated information provided by RDC.
2. Re-contour the groundwater potentiometric surface using the new Lake Rotorua level information for shoreline control points.
3. Utilize the more precise digital elevation model (DEM) provided by RDC to develop better information for contouring the potentiometric surface.
4. Obtain additional groundwater monitoring information from RDC files and incorporate this information into potentiomtric surface contouring and plots of shallow groundwater features.
5. Develop long-term groundwater level monitoring that can be used to assess the impact of climate change on groundwater levels in the future.

1.0 INTRODUCTION

Rotorua District Council (RDC) requested that GNS Science review various hazards. The review included the following specific tasks with regard to the relatively high groundwater table (shallow depth to groundwater) that exists in parts of the Lake Rotorua catchment, particularly in close proximity to the lake:

1. Using the existing GNS Science groundwater model of the Lake Rotorua catchment and information in available databases, assess the nature of the groundwater table in the Rotorua Caldera;
2. Review topographic maps to identify low lying ground around the circumference of Lake Rotorua that might have potential shallow groundwater problems;
3. Identify knowledge gaps and locations where further field research is required; and
4. Assess the potential impacts of climate change on groundwater levels in the Rotorua District.

RDC requested that a separate report be prepared for each part of the project. This report has been prepared to document only the groundwater part of the overall project.

The occurrence of a high groundwater table in the vicinity of a lake is not an unusual situation. The surface of the lake acts as a surface expression of the maximum elevation of associated groundwater and, because of the relationship between groundwater and associated surface waters, it is normal that groundwater will either be flowing downgradient into a lake or that water from the lake will be flowing into downgradient groundwater. Because of this close hydraulic relationship, the depth to groundwater in the immediate vicinity of the edge of a lake will be only marginally different than the surface of the lake (the difference in elevation being a result of head loss experienced by groundwater entering the lake or lake water leaving it) and above the lake surface where groundwater is flowing into the lake.

2.0 GNS SCIENCE GROUNDWATER MODEL AND AVAILABLE DATABASE INFORMATION

Information on groundwater elevations is available from two sources: (1) the GNS Science groundwater model of the Rotorua catchment; and (2) measurements of groundwater levels below ground in wells within the Rotorua catchment. With regard to the latter, groundwater elevations may be calculated from levels where the top of well casing or ground elevation measurement datum is known from either GPS or survey measurements or can be picked off of topographic maps or digital terrain models (DTMs).

In addition to groundwater elevation data, surveys have been conducted for springs, seeps, and wetlands both around the edge of Lake Rotorua and within the general Lake Rotorua catchment. Information of this kind was also relied on by Environment Bay of Plenty (EBOP) in producing a GIS map of wetland locations in the Lake Rotorua catchment. Finally, there is limited information primarily from geotechnical boreholes at two locations around the lake on the occurrence of shallow groundwater.

2.1 GNS Science Groundwater Model

White, et al. (2007) assessed the groundwater hydrology of the Lake Rotorua catchment for EBOP. As part of this study, GNS Science developed a three-dimensional (3D) geological model and used it in constructing a 3D groundwater flow model. The groundwater flow model was implemented in the Feflow computer software package developed by WASY and now owned by DHI Group. Feflow is a 3D, finite element, groundwater flow model. This work incorporated earlier field work on the groundwater hydrology of the Lake Rotorua catchment by Reeves, et al. (2005), discussed in more detail below, which was, in part, used in the calibration of the 3D groundwater flow model. Ground elevations in the model were based on a 20 m contour interval DTM and Lake Rotorua was used as a constant head boundary at an elevation of 281 m above mean sea level (MSL) datum.

Groundwater and ground elevation contours were extracted from the 3D Feflow groundwater flow model. Groundwater elevation contours at contour intervals of 5 m and 1 m are shown in Appendix Figures A-1 and A-2, respectively. These contours indicate that the direction of groundwater flow is generally radially inward toward the lake. Because these contours were generated on a catchment scale from limited data, there may be a relatively high level of uncertainty about them in locations for which there was limited data to produce them. For example, there is a relatively high level of uncertainty with regard to the groundwater elevation contours under the northwestern boundary of the Rotorua catchment and under that portion of the City of Rotorua extending to the southwest because of the limited data from those areas used in producing the model and, with regard to the northwestern boundary, because of the major changes in topography involved. The accuracy of these contours is also limited by the precision of the DTM utilized for ground elevations and the use of a constant head boundary of 281 m for Lake Rotorua. This boundary may have been higher than actual. Information on the location of the weather station at Rotorua indicates the original one was at a height of 281 m above MSL and that the current one is at a height of 283 m above MSL. These locations on the airport are several hundred metres from the lake edge and are certainly above the water surface of Lake Rotorua, except possibly under conditions of extreme flooding. The topographic map also shows a point on the airport between the weather stations and the lake edge at an elevation of 280 m above MSL. Therefore, appears likely that a more representative elevation for the lake surface would be something less than 280 m above MSL.

To assess depth of groundwater from these model data, groundwater elevation was subtracted from the corresponding ground elevation to yield depth below ground to groundwater. The resulting information is presented in Figure 2-1, using color-coded depth intervals in metres below ground level (BGL). The shallowest zones are designated by a red band (indicated to be up to 2 m above ground). With the exception of where wetlands might be involved, it’s not likely groundwater elevation is really aboveground. This is probably more a function of the imprecision of the model (see above discussion of lake surface constant head boundary above) and the DTM as well as the assumed constant head level for Lake Rotorua. The next shallowest zones are three 1 m bands from 0 to 3 m below ground indicated by dark orange, light orange, and yellow, respectively. The indicated depth to groundwater within the next green band is 3 to 5 m and the two shades of blue indicate the depth to groundwater is in excess of 5 m. Areas shown as gray represent zones for which groundwater elevations were considered inaccurate because of the lack of underlying data to support them given the nature of the contouring algorithm (i.e., its ability to interpolate but not extrapolate).

2.2 Groundwater Level Data

Groundwater level measurements were obtained by GNS Science for various wells in the Lake Rotorua catchment as a part of field work to assess the groundwater hydrology of that catchment for EBOP. These data, presented in Reeves, et al. (2005), were used with information on the measurement datum elevation from GPS or survey measurements, the topographic map, or the 20 m DTM to calculate groundwater elevations. EBOP also undertook a survey of spring and seep locations and elevations in the Lake Rotorua Catchment. The locations of the features were recorded using GPS while the elevations were estimated by using a 50 m by 50 m grid. These data, presented in White, et al. (2007), were used with Reeves, et al. (2005) groundwater level data to calculate groundwater elevations near Lake Rotorua. Groundwater elevations from wells, springs, and seeps were then contoured. Locations of these wells, springs, and seeps and resulting contours are shown in Appendix Figure A-3 at a 1 m contour interval. In addition, the elevation of the water level of Lake Rotorua was used as 281 m above MSL to provide contouring control points. Comments above about this elevation, with regard to the groundwater model, apply here also. The direction of groundwater flow indicated by these contours is generally radially inward toward the lake.

To assess depth of groundwater from these field data, groundwater elevation was subtracted from the corresponding ground elevation to yield depth below ground to groundwater. The resulting information is presented in Figure 2-2, using the same color-coded depth intervals as were used in Figure 2-1 for similar groundwater model information.

2.3 Database and Other Available Information

Sources of information to identify locations of shallow groundwater, springs, seeps, and wetlands are individually discussed below and such locations are shown in figures presented in Appendix A. Figure 2-3 is a composite presentation of the locations of all of these features.

2.3.1 Lake-Edge Springs, Seeps, and Wetlands Survey

A lake-edge survey of springs, seeps, and wetlands was reported by Reeves, et al. (2005). Seventy-five such features were located, described, and photographed as a part of this effort. GPS coordinates were recorded using a handheld Garmin GPS unit with a precision of plus or minus 20 m. Locations of these features are shown in Appendix Figure A-4. Water level information was not provided as a part of this survey. Flows were also measured in December 2004 and February 2005 for 185 surface water features near Lake Rotorua including these springs, seeps, and wetlands and, in addition, streams, drains, culverts, and ponds. The range of flows found was from 0 to 2,543 L/s with the largest such feature being Hamurana Springs.

2.3.2 Other Catchment Springs and Seeps

In addition to the lake-edge survey noted above, 193 other springs and seeps identified by EBOP survey work were presented by White, et al. (2007). Locations were identified using the same handheld GPS unit. Elevations were estimated from the 20 m DTM on a 50 m by 50 m grid. Locations of these features are shown in Appendix Figure A-5.

2.3.3 EBOP Wetlands Vegetation Mapping

EBOP produced a GIS map of wetlands vegetation in the Lake Rotorua catchment. The information base for doing so included data from the above two surveys. EBOP provided a GIS shape file of this map for this project. These wetlands locations are shown in Appendix Figure A-6.

2.3.4 Geotechnical Boreholes

The RDC provided GNS Science with geotechnical reports which identified shallow groundwater levels at two sites on the west side of Lake Roturua: (1) Western Road, Ngongotaha; and (2) Tipu Ora Medical Centre, Ohinemutu. The locations of these sites are also shown in Appendix Figure A-6.

The Western Road, Ngongotaha site is a proposed residential development located in the Ngongotaha Stream valley. Lake Rotorua is located approximately 1.5 km to the east of the proposed development. Three reports relating to this site were supplied to GNS Science by RDC including; MTEC Consultants (2009), and Tonkin and Taylor Ltd (2009a and 2009b). The reports indicate the site is subject to high groundwater levels and soft ground. Monthly groundwater level monitoring was undertaken at seven locations across the site from July 2008 to January 2009 and sixteen additional sites were added in December 2008. Groundwater level measurements were taken from different types of features including; boreholes (~ 15 m depth), cone penetration test holes (7 – 15 m depth), and open standpipes (3 m deep). Tonkin and Taylor Ltd (2009a) concluded that the data indicate seasonally high groundwater levels that are likely to rise within 1 m of the ground surface, and possibly to ground level during winter months.

Tipu Ora Medical Centre is located at 16/20 Houkotuku Street, Ohinemutu which is approximately 0.15 from the south-western side of Lake Rotorua. There are proposed plans to extend the medical centre building. The RDC supplied GNS Science with Terrane Consultants Ltd (2010) preliminary geotechnical report. As part of the geotechnical investigation, groundwater was recorded in three of the five test borings on the site at depths less than 1 m. In one test hole the groundwater rose above ground and eventually stabilised at 0.05 m BGL. The water temperature in the boreholes ranged from 35 – 53°C and gas was noted to be venting from two of the holes. This groundwater information is likely related to a geothermal feature rather than the area-wide shallow groundwater table.

3.0 LOW LYING GROUND

The topographic map was reviewed with respect to the presence of low lying ground around the circumference of Lake Rotorua. Areas around the circumference of the lake with ground elevations near that of the surface of Lake Rotorua have high potential for shallow groundwater.

The topographic map was reviewed. However, the contour interval of 20 m does not provide much detail around the circumference of the lake. Therefore, contours were prepared from a recent DTM with a contour interval of 1 m. The resulting information is presented in Figure 3-1, using colour-coded elevation bands in metres above MSL. The lowest elevation zones are designated by a red band. Progressively higher dark and light orange bands are also lower than the 281 m above MSL lake surface elevation used for modelling and contouring. The yellow band indicates ground elevations that are within 2 m above that level.

4.0 DATA GAPS

The currently available data provides reasonable delineation of areas in proximity to Lake Rotorua of potentially shallow groundwater. However, his delineation cannot be considered to be comprehensively definitive. This information could be improved by a program of drilling in other areas to provide more complete data. Such a program would be expensive and may not be justified. While the available information identifies those areas where shallow groundwater is known to exist or has a high likelihood of occurrence, shallow groundwater may also be found, if looked for, in other areas close to the circumference of Lake Rotorua. The only conclusive way to be absolutely sure is to require the performance of borings and measurement of depth to water prior to final consent for construction.

5.0 POTENTIAL CLIMATE CHANGE IMPACT ON GROUNDWATER LEVELS

5.1 Introduction

Attempts to consider the potential impact of climate change (i.e., global warming) on groundwater resources in general are fraught with uncertainty because, as has been noted, "How climate change will affect groundwater is not well known" (Karl et al., 2009). Furthermore, changes in atmospheric temperature and resulting changes in precipitation "may have long-term effects on aquifers that are relatively subtle and difficult to identify" (Jacobs et al., 2001), particularly against "The observed irregular variations in hydrologic time series [such as... groundwater levels]" which "reflect a range of natural and human climate stresses" as well as "other anthropogenic factors" (USGS, 2009).

Natural climate variability has always been with us and impacts all parts of the hydrologic cycle including groundwater. With specific regard to New Zealand, "New Zealand's climate varies with fluctuations in the prevailing westerlies, and in the strength of the subtropical high-pressure belt. Many of these [variations] are short-lived or random. Others are linked to general variations over the southern hemisphere or Pacific Ocean. These are persistent and predictable to some degree" (Mullan et al., 2009). They include the Antarctic Oscillation, a trend over the last 30 years towards stronger westerly winds at latitude 50o south that has been attributed to a combination of global warming and stratospheric ozone depletion, and the El Nino-Southern Oscillation (ENSO) phenomena. ENSO is a two-phase pattern (El Nino and La Nina) "that affects air pressure, winds, sea temperature, and rainfall" and "follows an irregular three to seven years cycle" (Mullan et al., 2009). ENSO is considered "the leading cause of interannual climate variability" and the cause of "significant climate anomalies" in New Zealand (Mullan et al., 2002).

In contrast with natural climate variability, climate change from anthropogenic emissions of greenhouse gasses (GHGs) and aerosols is a relatively recent circumstance. Various studies of long-term hydrologic data have found impacts from global warming (e.g., temperature increases and both increases and decreases in surface stream flow and changes to water chemistry) during the latter half of the 20th century. In some cases, such changes have accelerated in the last 20 to 30 years of that century (e.g., Raymond et al., 2008 and Rood et al, 2005).

A number of potential impacts of climate change on levels of water resources in New Zealand have been identified. These have been summarised in Table 4-1. The considerable uncertainty inherent in climate change scenarios and models is evident in Table 4-1. Table 4-1 addresses streams and lakes as well as groundwater. Streams and lakes have been included because groundwater relationships with these surface waters will likely influence groundwater levels to some degree.

Table 5-1 Potential impacts of climate change on levels of New Zealand water resources (from Mullen et al., 2008).

Resource	Potential Impact	Present Sensitivity to Climate
Streams	Streamflows likely to increase, on average, in the west and decrease in the east of New Zealand. More intense precipitation events would increase flooding (by 2070 this could be from no change, up to a fourfold increase in the frequency of heavy rainfall events).	Strong seasonal, interannual and interdacadanal fluctuations.
Lakes	Lake levels likely to increase, on average, in western and central parts of New Zealand, and possibly to decrease in some eastern areas. Higher temperatures and changes in rainfall, particularly in areas such as the Rotorua Lakes, could result in a range of effects including alteration of lake margin habitats.	Seasonal and interannual fluctuations.
Groundwater	Little change to groundwater recharge is expected in eastern New Zealand, but increased demand for water is likely. Some localized aquifers in northern and eastern regions could experience reduced recharge. For example, small coastal aquifers in Northland would be under threat from reduced rainfall.	Seasonal fluctuations; but at present, generally stable over the longer term.

5.2 Observations for the Lake Rotorua Catchment

Although other effects may have occurred, the major direct line of evidence regarding climate change in New Zealand is atmospheric temperature. In its review of temperature data for New Zealand, NIWA concluded that there was a warming trend of about 1 ^{o}C during the 1931-2008 period (NIWA, 2008). This was based on atmospheric temperatures taken at ground-based stations with long records located around New Zealand. Similar but marginally smaller magnitude temperature increases were reported for night time minimum air temperatures taken from ships at sea around New Zealand (i.e., 0.7 ^{o}C) and sea surface temperatures measured from the same ships (i.e., 0.6 ^{o}C) over the 1900-1993 period (NIWA, 2008).

Data on temperature specific to the Lake Rotorua catchment are more equivocal. Trend analysis of annual mean temperature data, using the Mann-Kendall test, from the two stations that have been located at the Rotorua airport over the period 1964 through 2009 indicate considerable variation without any statistically significant trend (Sen slope of zero). In contrast, again with considerable variation, there is a reasonably strong indication of decline in rainfall for the same period at the Rotorua airport at a rate of 4.68 mm/year (p value = 0.0766). This would be a total decline of 215 mm/year over the 46 year period involved or about 15 percent of the median for the period of 1,408 mm/year. Temperature and rainfall data for this analysis were obtained from the national climate database (NIWA, 2010).

Water level data from the EBOP's Natural Environment Regional Monitoring System (NERMS) are available for seven wells in the Rotorua catchment (three in the Ngongotaha area). These data, with gaps in the record of two to three years each, were previously analyzed for trend over the 1996-2006 period. Small trends that were not considered significant were found in each case with increasing depth to groundwater for five of the seven wells and decreasing depth for the other two wells. The magnitude of these trends was generally on the order of several centimetres/year. The visual nature of the trends for all wells were described as "horizontal" (Zemansky, 2006). Small increasing depth to groundwater trends would be consistent with the declining rainfall trend noted.

5.3 Potential Groundwater Level Changes Related to Climate Change

Global climate models (GCMs) for various scenarios (taking into account such things as economic growth, population change, and energy usage) have been used to estimate potential anthropogenic temperature changes over the next century. Using the A1B scenario (considered a "middle of the road" or "average" case scenario) and average downscaled results from 12 GCMs, NIWA concluded that a best estimate for temperature increases in New Zealand from 1990 were 0.9 °C and 2.1 °C for 2040 and 2090, respectively (Mullan et al., 2008).

GCMs produce global projections on a fairly coarse scale (on the order of degrees latitude and longitude). NIWA downscaled these projections to produce a regional model on a roughly 5 km grid for New Zealand. Averaging for 12 GCMs and six illustrative emissions scenarios, warming for New Zealand was projected to be about 1 °C by 2040 and 2 °C by 2090 compared to 1990. Results vary somewhat by season and for different locations within New Zealand and are marginally less than projected global average changes for the same scenarios. For the EBOP region, increases in annual mean temperatures and lower and upper limits for them were estimated to be (Mullan et al., 2008):

1. 2040 – 0.9 °C (0.2 °C lower and 2.4 °C upper limits); and

2. 2090 – 2.1 °C (0.6 °C lower and 5.5 °C upper limits).

These temperature changes are projected to produce changes in seasonal and annual rainfall that are location-specific throughout New Zealand. In the case of the EBOP region, rainfall is projected to marginally decrease over most of the region during the 50 to 100 years after 1990 but could marginally increase over parts of it (including Rotorua during the latter 50 years). Marginal in this case means less than 2.5% of annual rainfall. Examples of the magnitude of projected changes and seasonal variation (in % change from 1990 annual rainfall) for the vicinity of Tauranga are (Mullan, et al, 2008):

1. 2040 -
    a. Summer 2 (-16 lower and 25 upper limits);
    b. Autumn 3 (-12 lower and 25 upper limits);
    c. Winter -4 (-16 lower and 2 upper limits);
    d. Spring -5 (-18 lower and 7 upper limits); and
    e. Annual -1 (-10 lower and 18 upper limits).

2. 2090 –

   a. Summer 2 (-20 lower and 23 upper limits);
   b. Autumn 5 (-15 lower and 16 upper limits);
   c. Winter -3 (-16 lower and 8 upper limits);
   d. Spring -9 (-32 lower and 12 upper limits); and
   e. Annual -2 (-12 lower and 5 upper limits).

It is clear that there is a large degree of uncertainty associated with these projections. For example, the estimated 1% decrease in annual rainfall by 2040 falls within lower and upper limits spanning a range of 28%. Therefore, an increase in annual rainfall is about as likely as a decrease. Climate change rainfall projections presented by Mullan (2008) as maps indicate a decrease in the Rotorua area of less than 2.5% for the 1990-2040 period and an increase of less than 2.5% for the 2040-2090 period.

6.0 CONCLUSIONS

6.1 Locations of Shallow Groundwater

Four maps were prepared to assess where those areas are that have shallow groundwater (shallow groundwater depths below ground or a high groundwater table). They indicate, the depth to groundwater based on groundwater model and field data contours (Figures 2-1 and 2-2, respectively), identified springs, seeps, wetlands, and geotechnical borings where shallow groundwater is known to exist within 1 m of ground level (Figure 2-3), and low lying ground (Figure 3-1).

These maps indicate areas of particular concern as follows:

1. Figure 2-1 –

   a. Generally on the west side of the lake to the north of Kawaha Point between Waikuta and Ngongotaha to a distance on the order of 1 Km from the lake.

   b. On the southwest side of the lake within the major urban area of Rotorua (with the exception of an area in the vicinity of Kuirau Park). This includes

      1) A zone to the south of Kawaha Point generally along the lake edge east of Koutu Road to Ohinemutu within several hundred metres of the lake.

      2) Downtown Rotorua up to 2 Km from the lake.

      3) Much of the residential area either side of SH5 about 1 Km wide.

      4) Two areas between SH30 and the lake within 1 km of the lake, one to the east of Puarenga Park and one centred on Holden's Bay and the airport.

   c. Several small areas on the lake edge scattered around the west, north and east side of the lake within 100 metres of the lake.

2. Figure 2-2 –

   a. The same areas identified from Figure 2-1 in points 1.a and 1.b above except possibly somewhat larger distance from the lake edge.

   b. The northwest side of the lake from approximately Awahou through Hamurana and within about 1 Km of the lake.

   c. The area between at the outlet channel of Lake Rotorua leading to Lake Rotoiti at Mourea.

3. Figure 2-3 –

   Many of the same areas identified from Figures 2-1 and 2-2 with additional detail from specific features and new locations of wetlands and seeps along the east side of the lake within several hundred m of the lake.

4. Figure 3-1 –

   Similar areas identified from Figures 2-1 and 2-2. The primary area is point 1.a from Figure 2-1 (between Waikuta and Ngongotaha). The southwest part of this area is also shown to extend about 2 Km inland to the vicinity of Rainbow Springs and Selwyn Heights. Points 1.b.4), 2.b, and 2.c are also delineated.

6.2 Potential Impact of Climate Change on Groundwater Levels

Increased atmospheric temperatures are expected to, in general, increase precipitation worldwide; but, the distribution would not be uniform and decreased rainfall is expected in some regions. All other factors being equal, increased rainfall might logically be expected to increase groundwater levels. However, how much rainfall becomes groundwater recharge depends on a balance of other factors in the overall water budget including surface runoff, evapotranspiration, and the nature of stream-groundwater interactions. For example, increased temperatures due to climate change will result in increased evapotranspiration (which may also be increased by increases in photosynthesis caused by higher atmospheric CO_2 levels) and the predicted increase in extreme events such as rainfall intensity, flooding, and droughts may increase both surface runoff and evapotranspiration while also reducing rainfall infiltration during critical times. All of these factors could negatively influence groundwater rainfall recharge and, thereby, reduce groundwater levels.

The Lake Rotorua catchment is located in a part of New Zealand which, from the standpoint of rainfall, is expected to be minimally impacted by climate change. Current NIWA simulations indicate a small declining trend in rainfall over the 1990-2040 period and a small increasing trend over the 2040-2090 period. The declining trend in rainfall and marginal declining trends for five of seven monitoring wells in groundwater levels from real world data are consistent with the NIWA projection for the 1990-2040 period. However, trends on the order of centimetres/year even for periods as long as periods of 50 years may only produce changes in water levels that are comparable with seasonal variations and could be reversed over the next 50 years. Taking the information currently available into account, it is not expected that the impact of climate change on groundwater levels in the Lake Rotorua catchment will result in substantial changes. Long-term monitoring is necessary to confirm how accurate that conclusion is and provide data to evaluate it.

7.0 RECOMMENDATIONS

7.1 Locations of Shallow Groundwater

The work reported on herein to identify shallow groundwater locations in the Lake Rotorua area can be refined with additional work. The following additional work is recommended to accomplish such refinement:

1. RDC has provided GNS Science with new information on the level of Lake Rotorua. This information could be used to re-set the constant head boundary used to represent Lake Rotorua in the GNS groundwater flow model of the Lake Rotorua catchment. Doing so and re-running the model will provide more accurate groundwater elevation contours.
2. Lake Rotorua shoreline points were also used as control points in the contouring of water level data. These control points can be re-set using the new information on the level of Lake Rotorua to develop a more accurate groundwater potentiometric surface.
3. RDC has provided GNS Science with a new DEM (digital elevation model). This DEM could be used in developing better information to be used in contouring water elevation data to develop a more accurate groundwater potentiometric surface.
4. RDC has indicated that it has additional groundwater monitoring data in its files. This information can also be added to existing information used for contouring to produce a more accurate groundwater potentiometric surface.

7.2 Potential Impacts of Climate Change on Groundwater Levels

Rotorua is in a part of New Zealand that is not expected to be highly impacted by climate change. Continued groundwater level monitoring is recommended to develop long-term data that can be used to assess climate change impacts, if any, in the future. Long-term trend monitoring is most effective if it is regularly and proficiently done. The basic data required is groundwater level measurements on at least a quarterly basis. Any such monitoring program should include an accurate survey of the well reference point for water level measurements to determine coordinates and elevation and quality assurance procedures to ensure the accuracy of measurements. Monitoring should be conducted routinely at roughly the same frequency without data gaps.

8.0 ACKNOWLEGEMENTS

Thank you to the Environment Bay of Plenty for allowing the use of the data collected and results from the groundwater field investigation and groundwater model.

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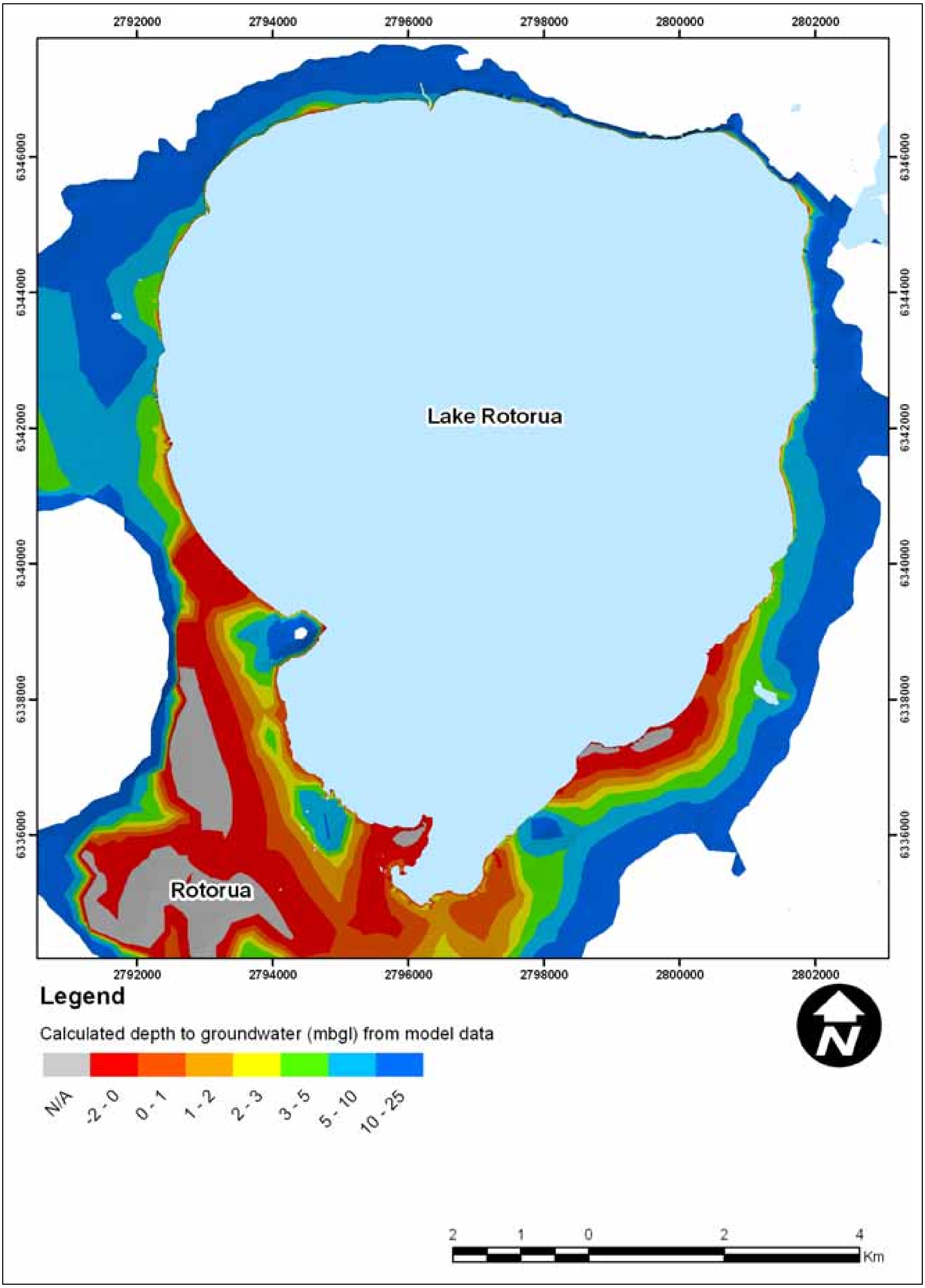

Figure 2-1 Groundwater model depth to groundwater.

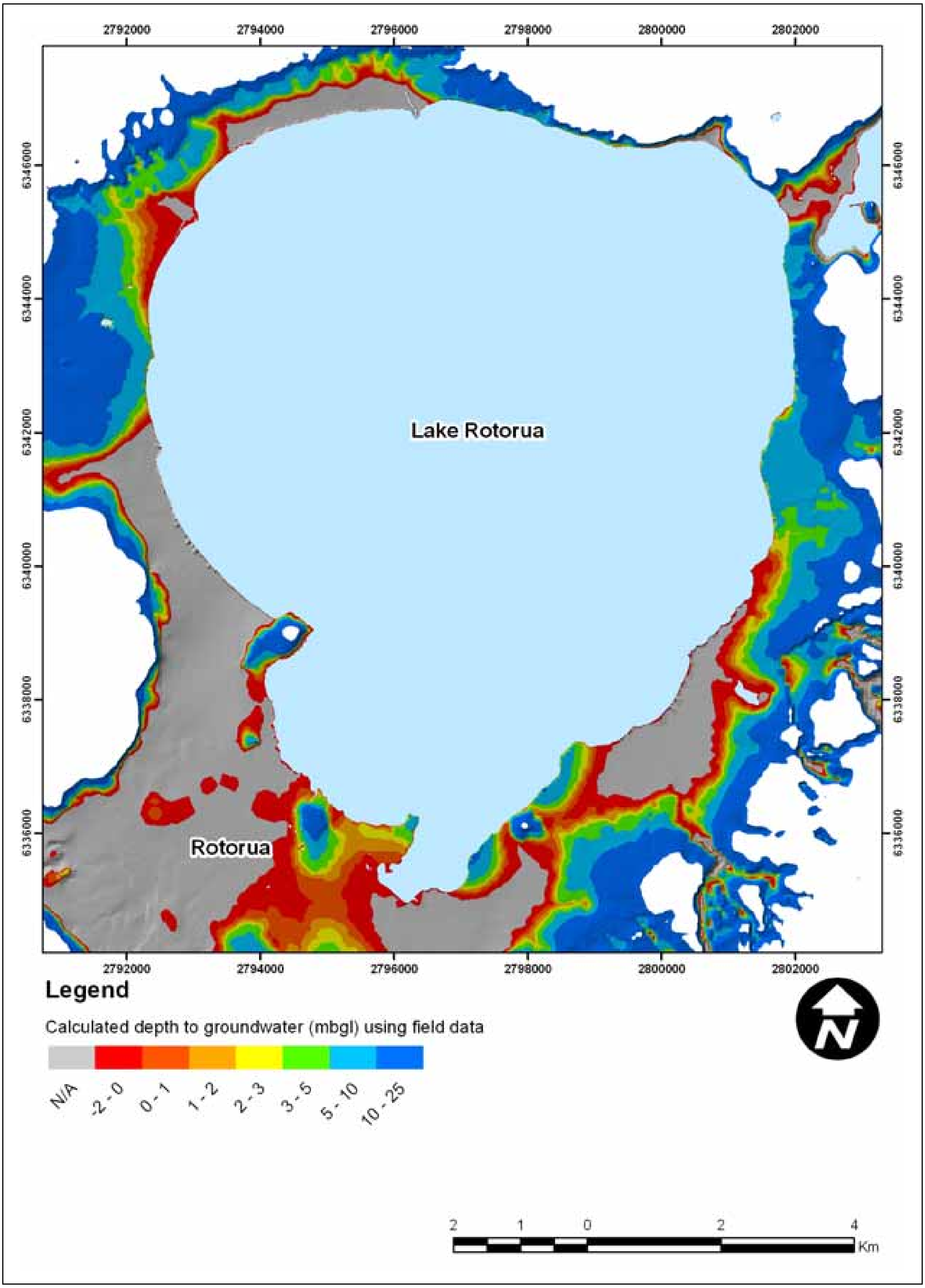

Figure 2-2 Groundwater field data depth to groundwater.

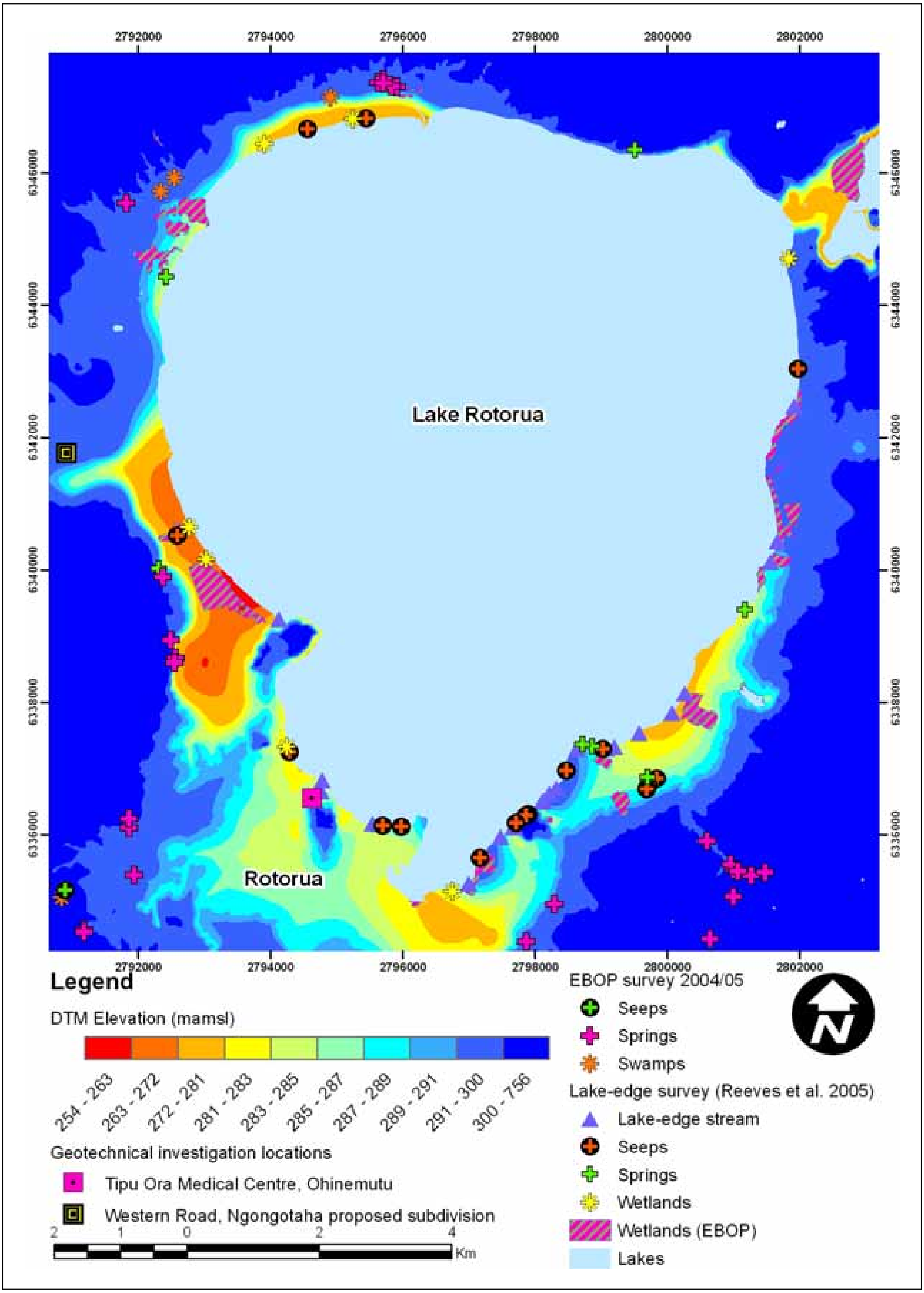

Figure 2-3 Shallow groundwater features.

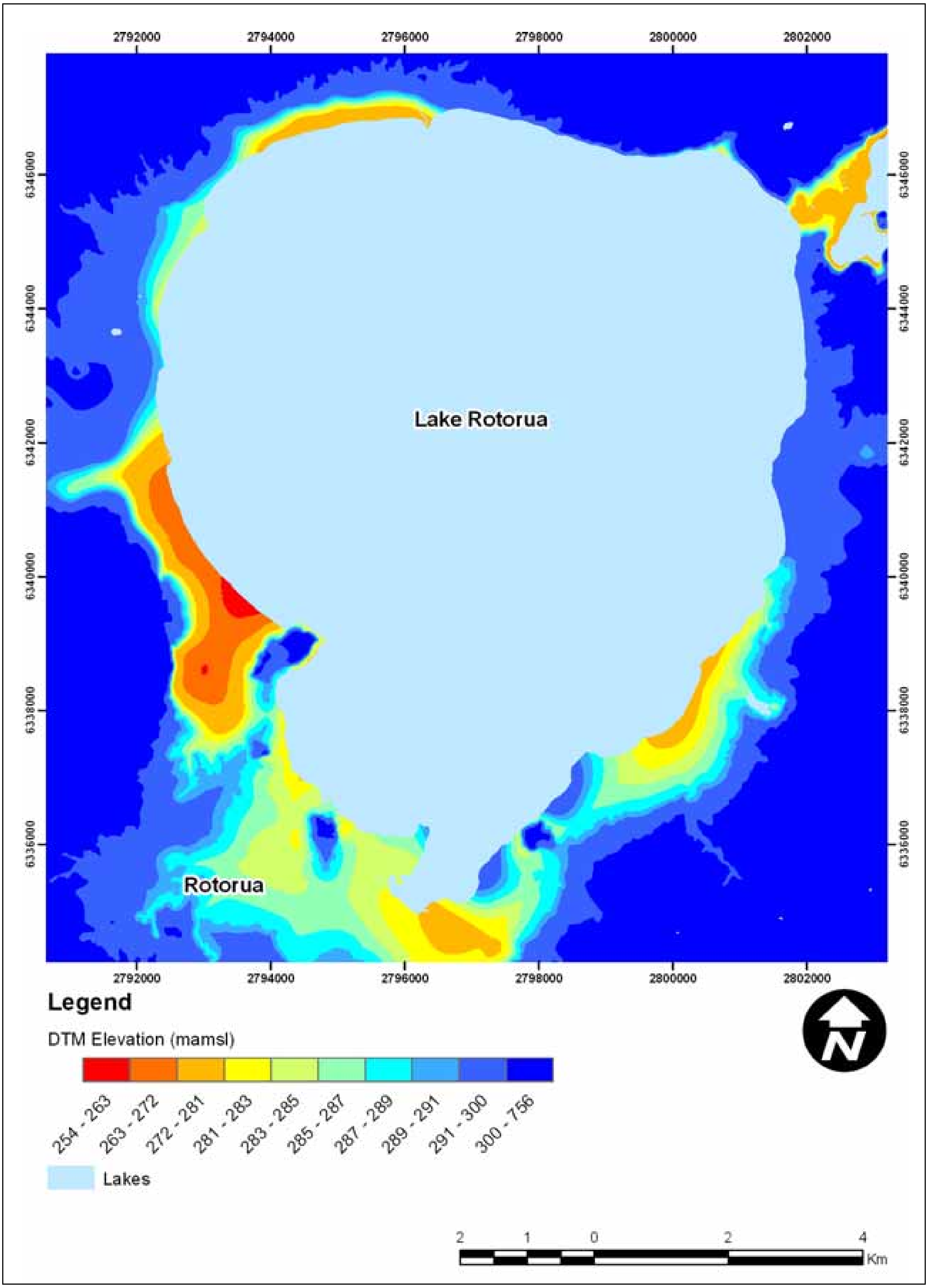

Figure 3-1 Low lying ground.

APPENDIX A FIGURES RELATED TO HIGH GROUNDWATER TABLE

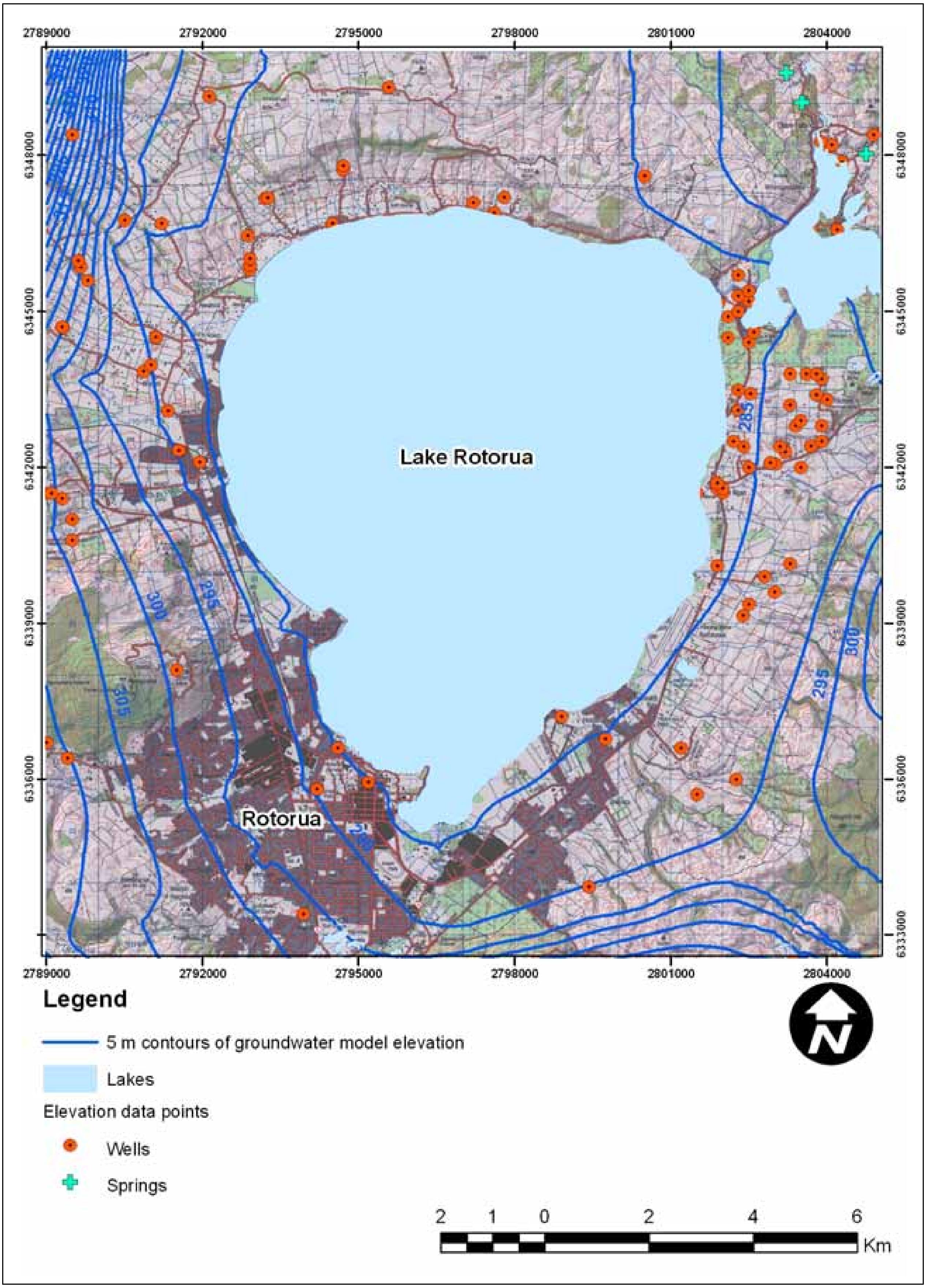

Figure A-1 Groundwater model elevation 5 m interval contours.

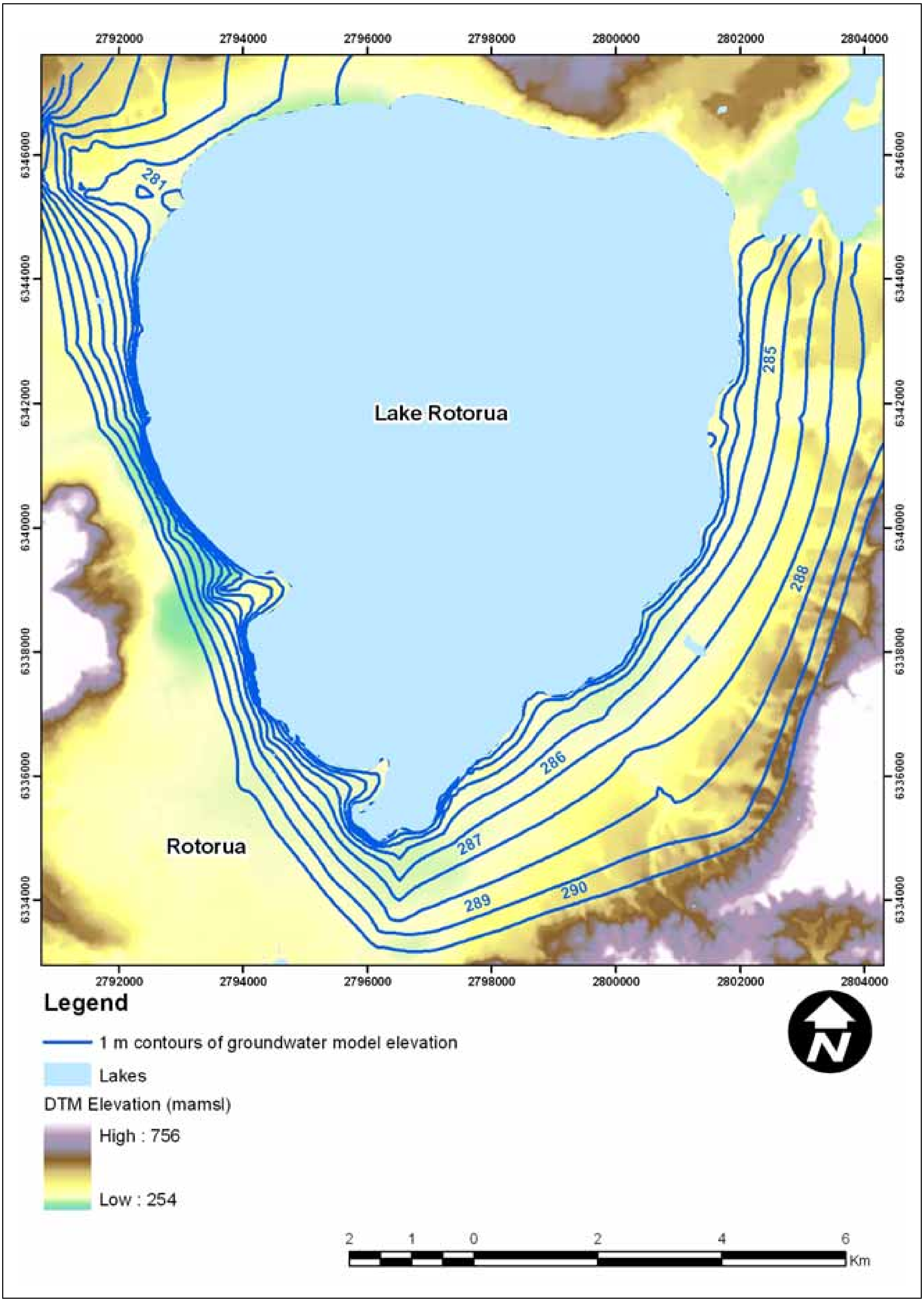

Figure A-2 Groundwater model elevation 1m interval contours.

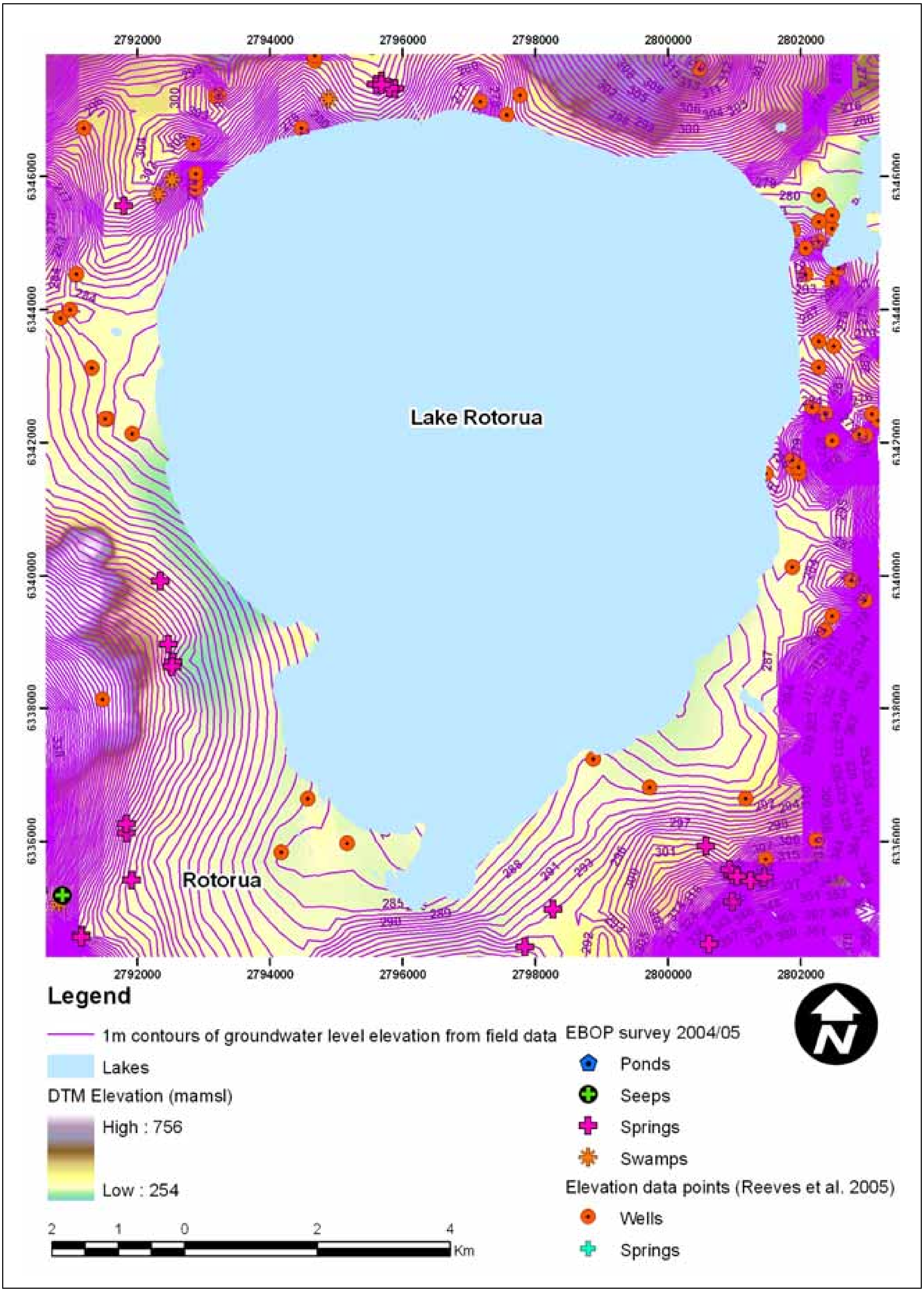

Figure A-3 Groundwater field data elevation 1 m interval contours.

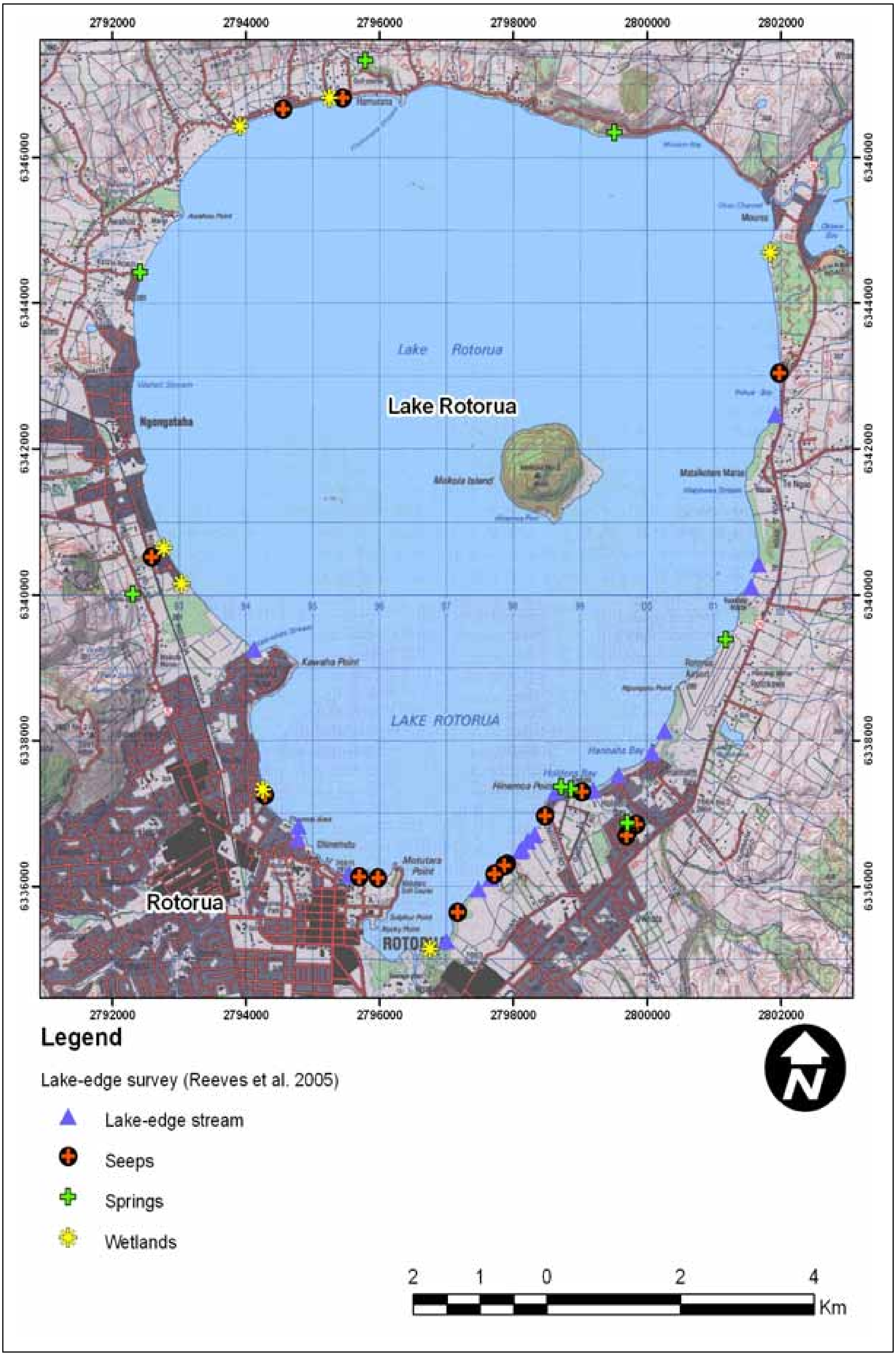

Figure A-4 Location of lake edge features.

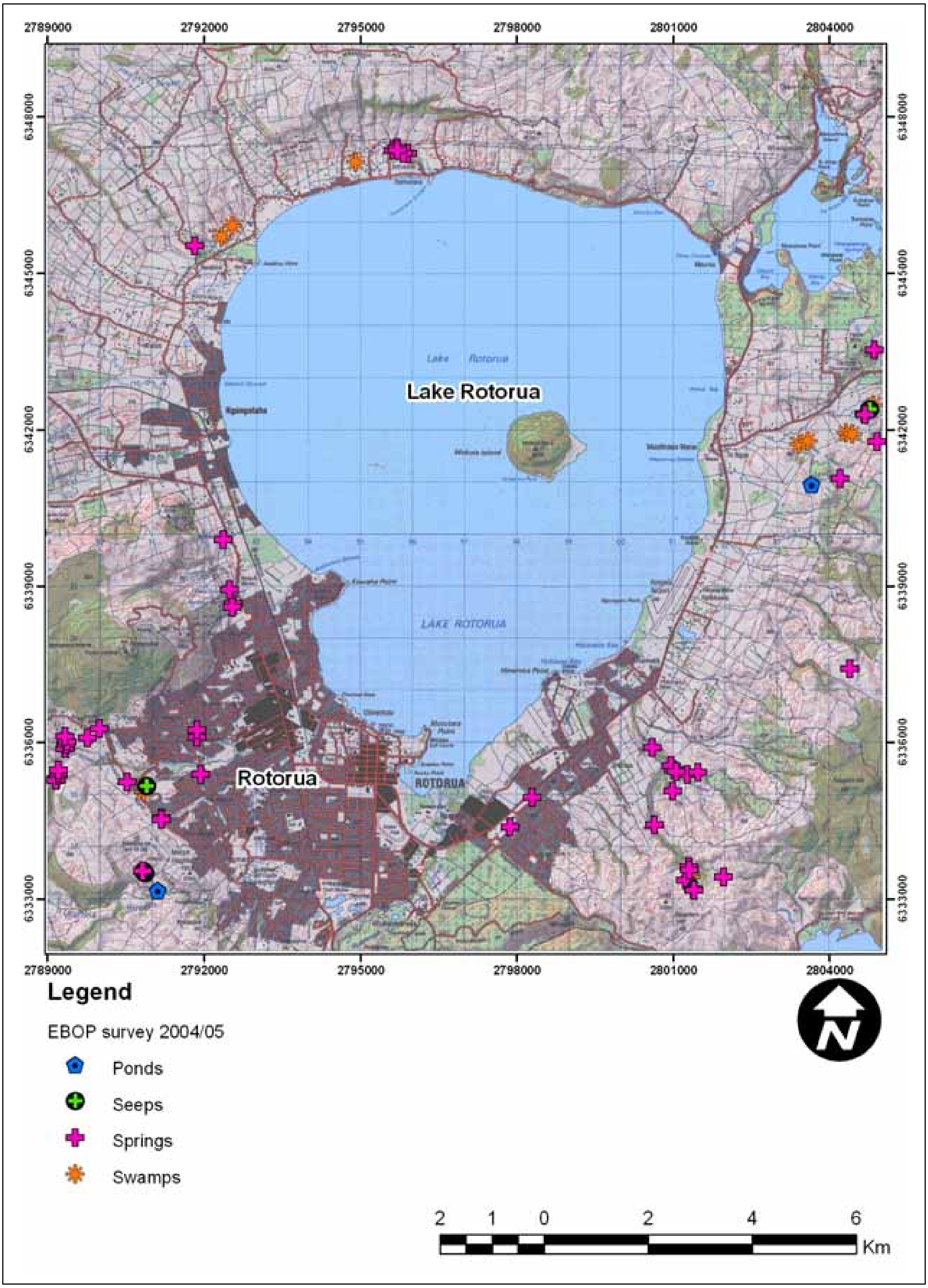

Figure A-5 Location of springs and seeps mapped by EBOP in 2004/05.

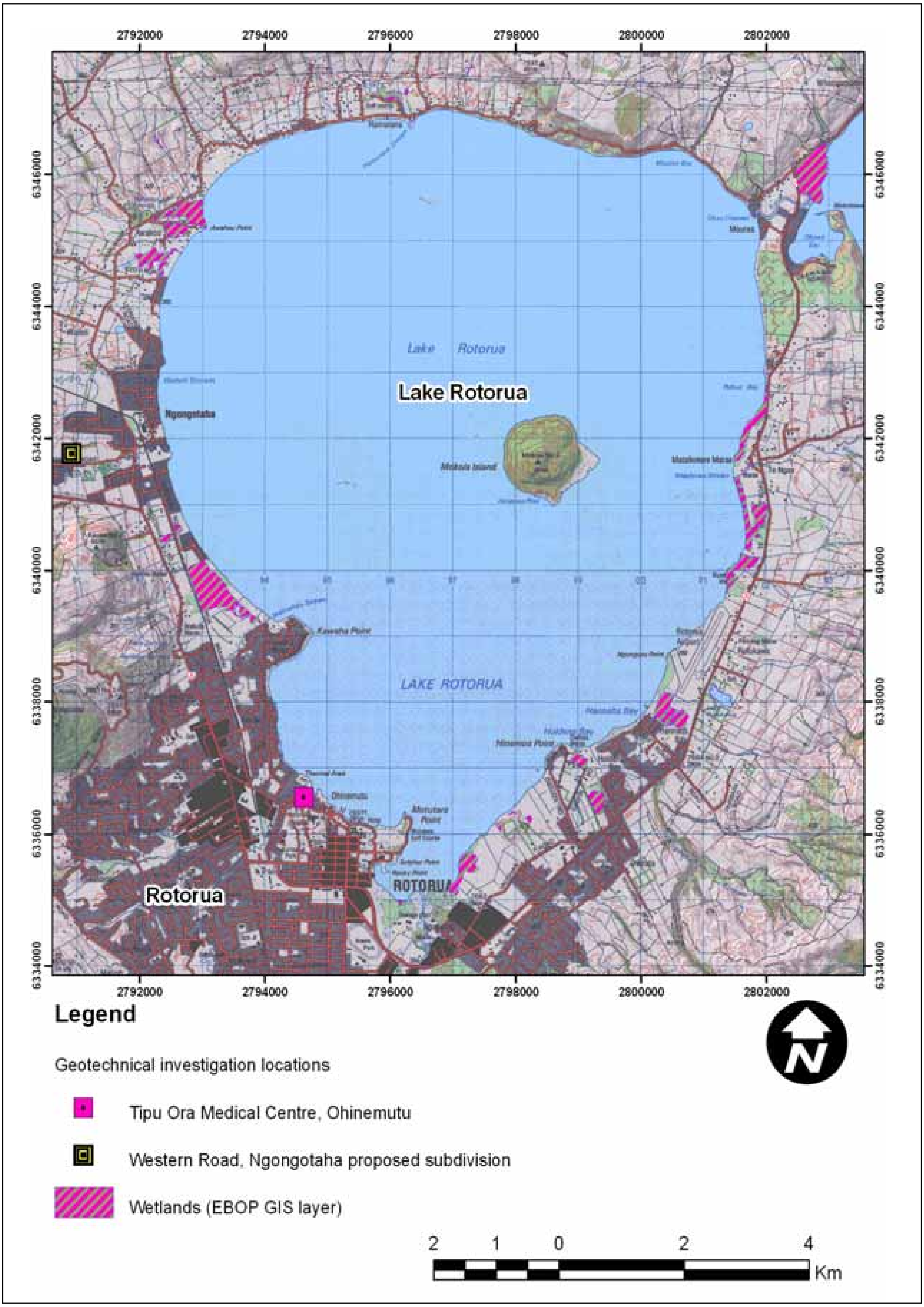

Figure A-6 Location of wetlands and geotechnical boreholes near Lake Rotorua.

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