Maunu – Maungatapere - Whatitiri Aquifers - Sustainable Yield Assessment

Report Prepared for
NORTHLAND REGIONAL COUNCIL

- Final
- April 2010

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Sinclair Knight Merz
Carlaw Park
12-16 Nicholls Lane
PO Box 9806, Newmarket 1023
Auckland New Zealand
Tel: +64 9 928 5500
Fax: +64 9 928 5501
Web: www.skmconsulting.com

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1. Introduction

In May 2009, the Northland Regional Council (NRC) commissioned Sinclair Knight Merz (SKM) to undertake a hydrogeological review and groundwater numerical modelling assessment of the Maunu-Maungatapere-Whatitiri aquifers, west of Whangarei. These aquifers are classified as “High Actual or Potential Demand” aquifers under the Regional Water and Soil Plan for Northland (2004). The information obtained from this study will assist the NRC to effectively manage allocation and sustainably manage the groundwater resource.

The specific objectives of this project are to:

1) Achieve an understanding of the groundwater system function with respect to groundwater recharge, discharge to streams, storage and flow through the aquifers;
2) Develop a low complexity numerical groundwater model that represents the conceptual hydrodynamic understanding of the system; and
3) Use the modelling tools developed above to determine a high level estimate of sustainable aquifer yield on a sub-catchment basis, focusing on impacts to spring flows.

This report outlines the background information available regarding the hydrogeological and hydrologic system in the area, aquifer conceptualisation with respect to model construction, describes the model configuration and calibration, and provides the results of predictive simulations to determine the aquifers sustainable yield.

2. Background Information

2.1. Site Location

The Maunu-Maungatapere-Whatitiri aquifers are located west of Whangarei (**Figure 1**). The study area comprises of a 62.8 km^2 volcanic plateau and is referred to as the Maunu aquifer within the Regional Soil and Water Plan for Northland (2004). The study area is dominated by the three volcanic cones, Whatitiri (347 m); Maungatapere (375 m); and Maunu (397 m).

- **Figure 1. Location map for Maunu-Maungatapere-Whatitiri aquifers.**
  (See A3 attachment at rear)

2.2. Regional Geology

The geology for this region is outlined on the 1:250,000 scale Geological Map Sheet 2A for Whangarei (Thompson, 1961), which is reproduced in **Figure 2**. The Maunu-Maungatapere-Whatitiri aquifer area comprises a volcanic plateau which overlays a wide range of older, complex folded, weathered and dissected sedimentary rocks (Roke and McLellan, 1983). The relationship of the various rock groups with respect to age is shown in **Table 1**.

- **Figure 2. Regional geology map.**
  (See A3 attachment at rear)

The volcanic plateau consists of basaltic and scoriaceous lava flows which have erupted from the three volcanic cones in the area. The primary source of the basalt flow originated from the Whatitiri cone, located approximately 20 km west of Whangarei, and flows to the west and headwaters of the Whangarei Harbour. The Whatitiri basalt flow covers an area of 26.1 km^2. The eastern boundary of this basalt flow corresponds to the Kauritutahi Stream. This basalt flow comprises of Horeke Basalts which are dated at around 500,000 years old. The thickness of the Horeke Basalt (up to 300 m thick) is greater than those of other basalt flows which indicate that the eruptions from Whatitiri were greater than those from Maunu and Maungatapere (Roke, 1983). The Horeke Basalts are characterised by the absence of scoria. Given the lack of scoria, these basalts are considered to be less permeable than the Taheke Basalts, although groundwater can be obtained from fractures and cracks identified through the basalt.

The Maungatapere and Maunu volcanic zones are smaller secondary vents and consist of Taheke Basalts, which range in age between Pliocene to Recent. The basalt from the Maungatapere cone (area of 21.2 km^2) flows in two lobes to the north, which appear to follow pre-existing valleys, before flowing to the west to reach the Kauritutahi Stream. The basalt flow from the Maungatapere Cone will have flowed over the Horeke Basalt from the Whatitiri Cone, which explains the occurrence of scoria in the north-western section of the aquifer (**Figure 10**). The basalt from the

Maunu cone (area of 15.5 km^2) flows to the east and west, with the southern border determined by the Mokupara and Nihatetea Streams. These basalts are characterised by presence of scoria (up to 68 m thick) and are therefore deemed to be more permeable than the Horeke Basalts. Roke (1983) also states vesicles are common within these basalts, although most are infilled by clay deposited from the groundwater percolating through many of the interconnected pore spaces.

The sedimentary rocks located under and surrounding the basalt flows vary widely in age and have a complex surface distribution. These rocks are described in **Table 1** and discussed below in stratigraphic order from oldest to youngest.

- ***Waipapa Group***– These greywackes and argillites form the Western and Otaika Hills, located in the Maunu area. Generally these basement rocks are characterised by relatively low matrix permeability and are generally low yielding, however where fractured can provide significant groundwater yields.
- ***Mangakahia Group*** –These sediments are part of the Northern Allochthon. The Northland Allochthon represents a series of discrete lithological units that were emplaced as part of a large gravity slide affecting most of Northland. As a results of this mode of deposition, the Northland Allochthon rocks are substantially faulted, fractured and sheared. Claystones or mudstone sediments outcrop to the west of Whatiri, while south of Whatiri Punakitere Sandstone overlays the claystone.
- ***Opahi Group*** – These sediments are also part of the Northland Allochthon. Aponga Shale and Phai Greensand outcrop at the head of the Otaika Valley and north of Maungatapere. A small area of brown shale also occurs north of the Maungatapere cone. An exposure of Ruatangata Sandstone occurs between the Western Hills and the Maunu lava flows.
- ***Onerahi Chaos Breccia***– This formation is found east of Maunu and has been emplaced to overlay the Whangarei Limestone.

Table 1. Regional lithology (from Roke and McLellan, 1983)

Group	Formation	Age (Millions of Years BP)	Content
		Recent (<0.02)	Undifferentiated alluvium
Kerikeri Volcanics	Taheke Basalt	Pliocene – Recent (<13)	Olivine basalts with scoria cones
	Horeke Basalt		Olivine basalts without scoria cones
	Onerahi	Lower Miocene – Pleistocene (25-0.5)	Superimposed, slumped rocks of Cretaceous to lower Tertiary age
Motatau	Whangarei Limestone	Lower to Middle Oligocene (36-30)	Crystalline and Argillaceous limestone
	Pokapu Limestone		Argillaceous limestone
	Ruatangata Sandstone	Upper Eocene (40)	Brown-grey massive glauconitic calcareous sandstone
Opahi	Aponga Shale	Middle Eocene (45)	Shale and argillaceous limestone
	Pahi Greensand		Glauconitic sandstone
Manakahia	Karaka Sandstone	Paleocene (60)	Micaceous sandstone
	Titoki Shale		Calcareous shale and argillaceous limestone
	Punakitere Sandstone	Upper Cretaceous (100)	Micaceous sandstone
	Ngatuturi Claystone		Siliceous claystone
Waipapa		Permian – Jurassic (250-150)	Greywackes and argillites

2.3. Drillers Borelogs

There are 209 bores registered on the NRC bore database for the Maunu-Maungatapere-Whatitiri study area. The location of these bores is shown on **Figure 3**. There are likely to be additional bores in the area that have not been registered with the NRC, so the exact number of bores is unknown.

Figure 3. Location of bores in NRC database.
(See A3 attachment at rear)

A table summarising the bore construction details and geological information is given in **Appendix A**. A bore ranking was assigned to each of the borelogs as part of reconciling the available information, with:

- 0 indicating no borelog available,;
- 1 representing poor geological description; and
- 5 indicating detailed geological information.

Borelogs were available for 154 bores on the NRC bore database. Bore depths range from 6 to 123 m below ground level (mBGL) with an average of 42 mBGL. These bores are generally constructed with casing to the top of the scoria or basalt layers (**Appendix A**) and are open hole (unscreened) thereafter. This suggests the basalt is relatively unfractured and has strength. The base of the aquifer was recorded on 27 borelogs at depths ranging from 10.5 m to 116.7 mBGL. The basement rock identified on the borelogs varied with mudstone, greywacke, sandstone, claystone and limestone located across the study area. The base of the aquifer had previously been identified by the results of the DC-resistivity soundings as outlined in Roke (1983). This information was found in be in general accordance with that defined by drilling.

Yields indicated on the borelogs range from 0.1 to 10 L/s with the greatest yields most likely occurring within the fractured or scoriaceous basalt, although there is insufficient geological information on the majority of borelogs to confirm this. Those logs with more detailed information indicate that the fracture zones and scoriaceous layers are located at variable depths throughout the basalt.

2.4. Rainfall and Evaporation

Rainfall has been recorded at fifteen rainfall stations throughout the area, with locations shown in **Figure 4** and specific site details outlined in **Table 2**. Rainfall isohyets are also shown on **Figure 4** which shows that the greatest rainfall (1600 mm) occurs in the vicinity of Whatitiri volcanic cone and towards Whangarei. The amount of rainfall reduces towards the south and west.

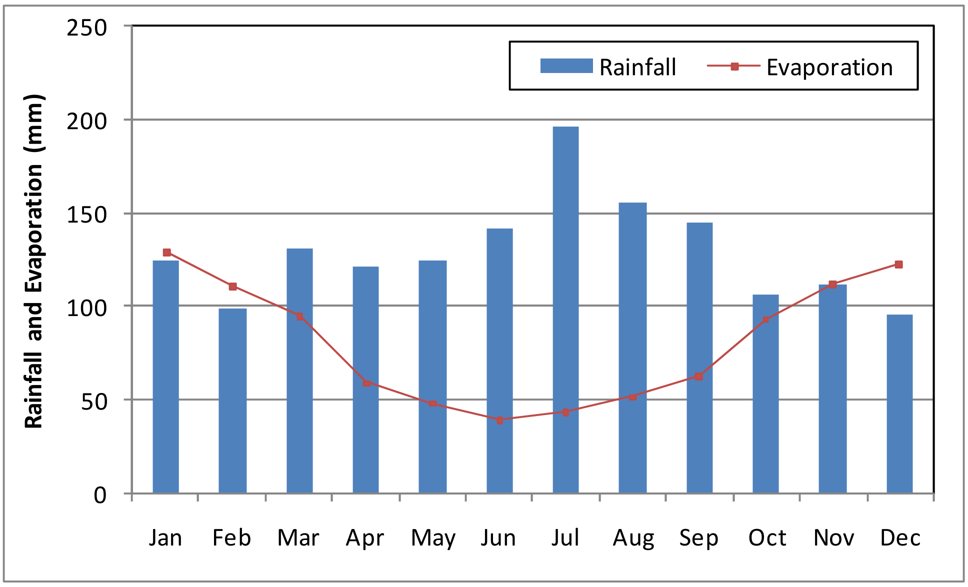
- **Figure 4. Location of rainfall stations.**
  (See A3 attachment at rear)

Figure 5 shows mean monthly rainfall for the area from the Cemetery Road rainfall station which provides the longest rainfall record extending between 1979 to present. Mean monthly Penman Open Water evaporation for the Whangarei Aero AWS (Station A54737) is also shown for 1992 to 2009 (data gap in 1993 and 1994). The rainfall data was obtained from the NRC, whereas the evaporation data was obtained from the National Institute of Water and Atmosphere (NIWA) climate database.

The average annual rainfall for area is 1,516 mm. Monthly rainfall is greater than potential evaporation from March to October, indicating the availability of rainfall for groundwater recharge and surface runoff during these months.

- **Table 2. Rainfall station information**

Rainfall Station	Period of Record	Duration of Record
Cemetery Road at Mokupara	1/09/1979 - 1/05/2009	29 years 12 months
Jongkees at Te Hihi	25/07/1988 – 1/03/2004	15 years 7 months
Kokopu Block Road (Niwa)	8/09/1977 – 5/08/1986	8 years 7 months
Lynwood Farm at Otaika	2/01/1967 – 18/02/1993	26 years 2 months
Maungatapere (Metservice)	3/08/1948 – 31/12/1989	41 years 4 months
Maungatapere (Niwa)	2/01/1976 – 30/11/1986	10 years 10 months
McIntosh at Otaika Valley	2/08/1995 – 1/09/2008	13 years 0 months
Ruamanga at Base Hospital	20/11/1987 – 25/07/1988	0 years 8 months
Redwood Orchard – Maungatapere	2/01/1983 – 1/05/2009	26 years 3 months
Rosehill (Niwa)	2/01/1979 – 31/10/1986	7 years 4 months
Totara Grove (Niwa)	12/04/1973 – 28/05/2005	32 years 1 month
Totara Place (Niwa)	11/01/1978 – 1/06/2009	31 years 4 months
Waipao at Williams	25/09/2007 – 24/02/2009	1 year 4 months
Whangarei Hospital (Metservice)	4/07/1970 – 30/09/1988	18 years 2 months
Whatatiri at Coopers	2/05/1998 – 1/03/2009	10 years 11 months



- **Figure 5. Mean monthly rainfall and evaporation using rainfall from Cemetery Road rainfall station and evaporation data from Whangarei Aero AWS.**

2.5. Hydrology

There are numerous small streams located in the study area which form a radial drainage network around the basalt aquifer (see **Figure 1**). All of the streams originate as springs, either within or on the perimeter of the basalt lava flows (Roke, 1983). Some of the streams, such as Te Hihi and Nihotetea, run along the western border of the study area. The NRC has historically conducted low flow gaugings on 30 of the streams and their tributaries within the study area (**Figure 6**).

The largest surface water features in the area are the Waipao Stream, Poroti Springs and Maunu Springs which are discussed further below.

- ***Waipao Stream*** – this is the largest surface water feature within the area. An automatic water level recording station (site number 46641) was established on this stream at Draffin Road in 1979, located on the northwestern boundary of the study area (**Figure 6**). Flow records indicate the mean flow is 672 L/s, while the mean annual low flow is 239 L/s (NRC, 2007).
- ***Poroti Springs*** – this spring is located to the north of the Whatitiri volcanic cone and ultimately flows into the Waipao Stream. Roke (1983) estimated that almost 80% of groundwater flow within the Whatitiri catchment surfaces at Poroti Springs. Flow records indicate that the flow within the spring range between 180 and 419 L/sec with average flows of 303 L/sec (Roke, 1983).
  In addition, Roke (1983) completed an assessment on the aquifer in the vicinity of Poroti Springs. This assessment indicated that a highly permeable aquifer is located in this area and forms a “channel” approximately 150 to 200 metres wide within the basalt. This channel is likely to be a remnant lava flow from the Whatitiri Cone.
- ***Maunu Springs*** – a series of springs which originate from the southern slopes of the Maunu volcanic cone are collectively known as Maunu Springs and are located in the upper catchment of the Whakapai Stream. The two major springs have been called “Tunnel” and “Chamber”. Roke (1983) provides the weekly flows measured within these two springs, with average flows of 41 L/sec and 9.5 L/sec measured at Tunnel and Chamber springs, respectively.

- **Figure 6. Stream gauging sites.**
  (See A3 attachment at rear)

2.6. Groundwater Quality

Aquifer groundwater quality has been monitored in 11 bores at locations shown in **Figure 7**. Specific details regarding the sampling sites are outlined in **Table 3**. Most sites had monitoring initiated during 2008 except for two sites that have data extending back to 2002 (SIT106742) and 2003 (SIT106740), respectively. The majority of sampling undertaken is for basic parameters such as pH and temperature with the following data collected:

- Chloride – sampled at site 109214 only, ranges from 6.7 – 23.8 g/m^3
- Conductivity – ranges from 11.2 (109655) and 29.6 uS/m (109629)
- Nitrate Nitrogen – ranges from 0.002 (109270) and 15.8 g/m^3-N (109269)
- pH – ranges from 4.9 (109655) to 6.8 (109246 and 109270)
- Temperature – ranges from 12.5 (109246) to 23.1 ^{o}C (109246).

Samples collected from monitoring bores SIT106742 and SIT106740 are analysed for a larger suite of parameters, 38 in total, as part of State of Environment Monitoring Programme undertaken by the Council. This information was used to constructed the diagram in **Figure 8**.

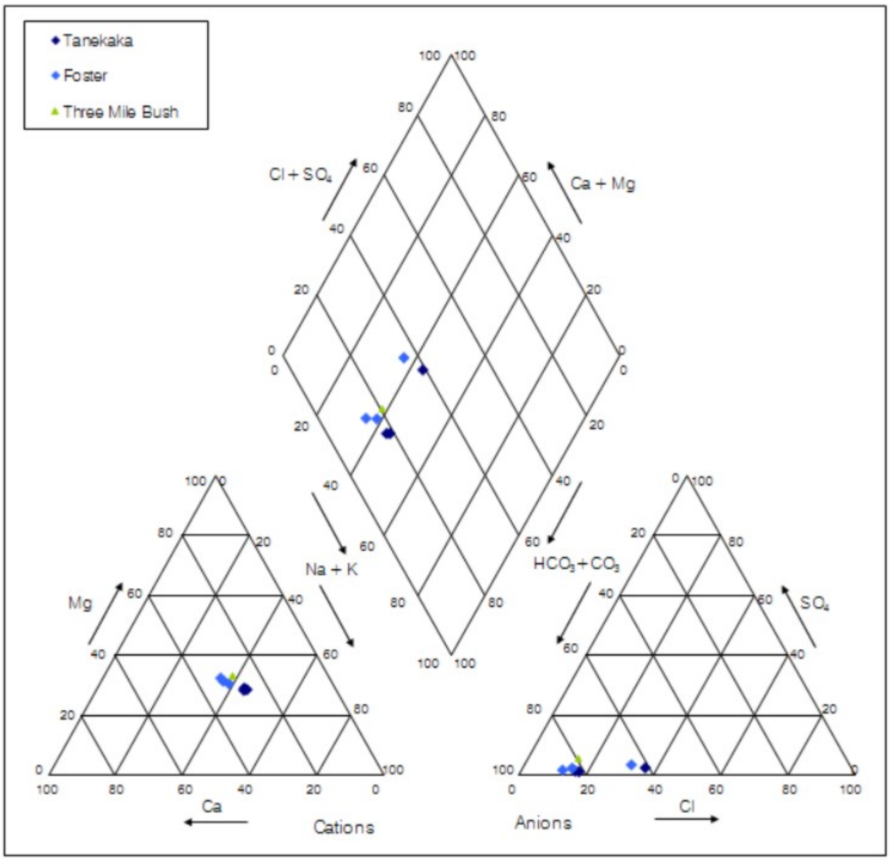
- **Figure 7. Location of NRC groundwater quality monitoring bores.**
  (See A3 attachment at rear)

Figure 8 which is a tri-linear Piper Diagram of the major anions and cations (presented in milli-equivalents) for three monitoring bores: SIT106740 – Tanekaha Partnersip; SIT106742 – Fosters; and SIT106739 205157 – Wises from the neighbouring Three Mile Bush Aquifer. The tri-linear diagram enables the water to be characterised in terms of its major constituents, which are governed by geologic and chemical processes. Three monitoring dates were selected for both bores 106740 and 106742 in order to gain a greater understanding of the water.

The water from all three bores has no dominant cations and is proportionally higher in bio-carbonate than other anions. This type of water is classified as calcium bicarbonate type water. Water of this type is generally recharging water that has not had time to dissolve the surrounding rock minerals or mix with other water types. Groundwater samples from monitoring bores SIT106740 – Tanekaha Partnership and SIT106742 – Fosters, have also been analysed using isotope tracers (CFC, SF6 and Tritium) to estimate the mean resident age for the groundwater at these locations and depths. The initial results indicate a mean resident age of the groundwater delivered from both bores to be around 45 years, however, additional sampling is required to refine these estimates.

- **Table 3. Details of NRC groundwater quality monitoring bores.**

WS Number	Site Name	Record	Sampling Frequency	No. Samples
109269	Maungatapere GW (Clarke)	Jul 08 - Apr 09	Monthly	10
109270	Poroti GW (Hawthorn)	Jul 08 – Aug 08	Monthly	2
109271	Whatitiri GW (Telfer)	Jul 08 – Aug 08	Monthly	2
109214	Poroti GW (Wilson)	Mar 08 – Mar 09	Monthly	13
106742	Whangarei GW (Fosters)	Nov 02 – Dec 08	Quarterly	26
109244	Maungatapere GW (Brown)	May 08 – Apr 09	Monthly	11
109245	Maungatapere GW (Martin)	May 08 – Sep 08	Monthly	4
109246	Whatitiri GW (Chandler)	May 08 – Apr 09	Monthly	11
106713	Whangarei GW (Maunu Mountains)	-	-	-
106740	Whatitiri GW (Tanekaha Partnership)	Jan 03 – Dec 08	Quarterly	24
109655	Mangakahia (Van de Kwaak)	Dec 08 – Mar 09	Monthly	4



- **Figure 8. Piper diagram for bores Tanekaka (106740), Foster (106742) and Wises (205157).**

2.7. Groundwater Abstraction

Table 4 summarises information on consented groundwater takes in the area as of May 2009. There are 32 consented groundwater takes with allocations ranging from 10 to 1,000 m^3/day. The total consented groundwater allocation for the aquifer is 3,385 m^3/day. The locations of the consented groundwater takes are shown in **Figure 9**. The majority of the consented groundwater allocation is for horticultural irrigation with private water supply and water bottling being other uses.

The Regional Water and Soil Plan for Northland states that takes for an individual's reasonable domestic needs and existing lawful takes for animal drinking water purposes are permitted provided that specific criteria are met. Due to the lack of information regarding the exact number and location of permitted takes within the area, this level of allocation was not assessed in this study.

- **Figure 9. Consented groundwater and surface water abstractions.**
  (See A3 attachment at rear)

- **Table 4. Existing groundwater consents**

NRC No.	Name	Allocation (m^3/day)	Bore Depth (mbgl)	Expiry Date	Purpose
19940729701	Pompalier College	50	?	31/05/2011	Private Water Supply
19990231001	D N Routley	60	30	30/06/2010	Horticultural Irrigation
19990420601	Whangarei Catholic Homes Trust	18	68	31/05/2015	Private Water Supply
19990719501	Lynwood Orchards Limited	90	61	31/05/2011	Horticultural Irrigation
19990736901	A J Taylor	150	31	30/06/2010	Horticultural Irrigation
20000231201	Avoglade Ltd	146	27	30/06/2010	Horticultural Irrigation
20000333001	W K and K E Brown Family Trust	12	20	30/06/2010	Horticultural Irrigation
20000439601	Sherwood Park Golf Club	120	69	31/05/2011	Sport and Recreation
20000726301	M J Angelo	500	62	30/06/2010	Horticultural Irrigation
20000746701	Q J Simpson	175	41	30/06/2010	Horticultural Irrigation
20010224601	K J K Mason	26	73	31/05/2011	Horticultural Irrigation
20010269301	The Foster Family Trust	138	60	31/05/2011	Horticultural Irrigation
20010349901	R H K Harding	42	73	31/05/2011	Horticultural Irrigation
20010376401	R S Knightly	60	68	31/05/2011	Horticultural Irrigation
20010914501	G and C Family Trust	72	30	30/06/2010	Horticultural Irrigation
20030177701	K J Chappell	72	17	31/05/2015	Horticultural Irrigation
20030397101	G R Anson	10	11	31/05/2015	Horticultural Irrigation
20031138701	B R Dickens	30	35	31/05/2011	Horticultural Irrigation
20031164301	M A James	15	40	30/06/2010	Horticultural Irrigation
20031170801	S W L Lee	33	17	31/05/2015	Horticultural Irrigation
20040331801	Maunu Mountain Orchids Trust	10	49	31/05/2015	Domestic Water Supply

20040461101	Zodiac Holdings Ltd & R J Nathan	1,000*	to be confirmed	30/06/2035	Private Water Supply
20050320201	R F Donnell	40	57	31/05/2015	Horticultural Irrigation
20050740001	K V Kirkpatrick	30	46	31/05/2015	Horticultural Irrigation
20050866501	B Campbell	32	44	31/05/2015	Horticultural Irrigation
20051327901	G O MacDonald	30	45	31/05/2015	Horticultural Irrigation
20051393401	G E E Ford	20	48	30/06/2020	Horticultural Irrigation
20051514901	J L Hawthorn	38	47	30/06/2010	Horticultural Irrigation
20060715801	M H Hoskings	55	39	31/05/2015	Horticultural Irrigation
20060720701	L Hailes	260	65	31/05/2015	Horticultural Irrigation
20071951701	P M Kalin	35	33	31/05/2025	Horticulture
20071989601	N P James	16	40	30/06/2020	Horticulture
Total Allocated Volume		**3,385**			

Note: * Tied in with surface water consents 2960 and 4607

2.8. Surface Water Abstraction

Table 5 summarises the surface water consents for surrounding streams as of May 2009, with the locations shown on **Figure 9**. Total consented surface water abstraction within the aquifer extent is 28,527 m^3/day. The main purpose for abstraction is for public water supply for the Whangarei Township and horticultural irrigation. The majority of the consented surface water takes are from two sites near the northeastern edge of the aquifer system, i.e. consents 19990296001 and 20000460701. The allocation limits for each of these consents and the groundwater take consent 20040461101 are interlinked, as the maximum of 19,000 m^3/day is the maximum limit for the three takes when used in conjunction.

The Regional Water and Soil Plan for Northland states that the permitted surface water allocation is 30 m^3/day between 1 June and 30 November and 10 m^3/day between 1 December and 31 May provided set criteria are met. As the amount of permitted surface water abstraction is unknown it not been addressed in this study.

The baseflows of the streams within the study area are predominantly groundwater sourced from the basalt aquifer. Any lowering of groundwater levels within the basalt, i.e. via groundwater abstraction or seasonal recharge variation, will adversely affect stream flow and the amount of water available for surface water abstraction.

- **Table 5. Existing surface water consents**

NRC No.	Name	Allocation (m^3/day)	Expiry Date	Purpose
19950096401	Whangarei District Council	4,137	31/05/2011	Public Water Supply
19950096402	Whangarei District Council	2,505	31/05/2011	Public Water Supply
19950096403	Whangarei District Council	1,514	31/05/2011	Public Water Supply
19990296001	Whangarei District Council	15,544	30/06/2010	Public Water Supply
19990717201	Koromiko Nurseries Ltd	25	30/06/2011	Horticultural Irrigation
20000191901	H T Rudolph	100	31/05/2011	Horticultural Irrigation
20000240601	C Stevens	630	31/06/2011	Horticultural Irrigation
20000475501	D G Booth	25	30/06/2016	Horticultural Irrigation
20000460701	Maungatapere Water Co Ltd	2,955	30/06/2010	Horticultural Irrigation
20000741501	J M McGiven	45	30/06/2010	Horticultural Irrigation
20000743201	D L Roke	60	30/05/2011	Horticultural Irrigation
20000744001	G J L Hamilton	60	30/06/2018	Horticultural Irrigation
20010169801	C G Small	60	31/05/2011	Horticultural Irrigation
20014000001	C S Smith	55	31/05/2015	Horticultural Irrigation
20030716301	D W McLennan	190	30/06/2014	Horticulture and Fruit Growing
20031123701	W T Stead	150	30/06/2023	Horticulture and Fruit Growing
20050234301	M A Eagles	15	30/06/2015	Horticultural Irrigation
20050282901	Kiteroa Water Group	300	31/05/2023	Horticultural Irrigation
20050362501	J A Robertson	23	31/05/2015	Horticulture and Fruit Growing
20050716201	L P Acourt	34	31/05/2015	Horticultural Irrigation
20071164101	Williams Family Trust	100	30/06/2027	Horticultural Irrigation
Total Allocated Volume		**28,527**		

3. Aquifer Conceptualisation

This section describes the aquifer conceptualisation for the purpose of the sustainable yield assessment and states how this has been applied to the numerical groundwater model.

3.1. Lithology

Borelogs from the NRC bore database show that although the site geology is highly variable it can be broadly grouped into six units as outlined below in typical stratigraphic order and shown in **Figures 10a** and **b, (cross section lines shown on Figure 3)**:

- Reddish brown or yellow clay between 0.2 m and 27 m thick, with occasional basalt boulders (volcanic soil), with the thickest clay occurring in the vicinity of the Maunu cone;
- Red, soft weathered basalt or scoria up to 29 thick. The majority of scoria is identified around the Maunu cone, with some identified within the Maungatapere basalt flow. The weathered basalt primarily occurs within the Whatitiri basalt flow which is consistent with the age of the basalt.
- Hard, grey vesicular and non-vesicular basalt up to 69 m thick with occasional fractures located at variable depths, with identified fracture zones outlined in **Appendix A**. The thickest basalt was identified in the vicinity of the Maunu cone, with **Figure 10b** showing the location of the vent under this cone.
- In many areas across the aquifer extent, it has been identified that the basalt is underlain by another layer of weathered basalt or scoria with an average thickness of 10 m which is indicative of a succession of basalt flows over the eruptive period.
- A layer up to 21 m thick of hard, grey basalt underlies the second layer of scoria and weathered basalt.
- Sedimentary basement rocks define the base of the aquifer and comprise various lithologies including mudstone, greywacke, sandstone, claystone and limestone. The basement is encountered at depths ranging between 10.5 m (Bore 204045) and 116.7 m (Bore 205122).

- **Figure 10 a and b. Geological cross sections – cross section lines shown on Figure 3.**

This geology is consistent with the regional geology described in **Section 2.2**. All of the units identified above were included within the model except for the sedimentary basement which defined the base of the model.

3.2. Groundwater Levels

Time series groundwater level data has been recorded within 14 bores whose location are shown in **Figure 11**. Specific details of the monitoring bores are summarised in **Table 6** including the respective record periods, with the earliest site (Poroti Springs) was established in 1972.

Groundwater hydrographs for the 14 monitoring bores are shown in **Appendix C**, with these transient records used for model calibration. **Table 6** outlines the bore details for the monitoring bores with interpolated ground levels required for five of the monitoring bores as they had not been surveyed. The depth to groundwater within the monitoring bores ranges from 0 mBGL (5471001) and 40.09 mBGL (5471007). Groundwater fluctuations recorded within the bores ranges from 0.1 m within 5471005 (ignoring the last point which is considered to be an anomaly) to 13.47 m within 5471007.

Depth to groundwater for other bores in the area, assessed from driller's logs, range from 0.5 mBGL to 79.1 mBGL. These water levels were used for the calibration of the steady state model only.

- **Figure 11. Location of groundwater level monitoring bores.**
  (See A3 attachment at rear)

- **Table 6. Groundwater monitoring bore details.**

Site Name	Site No.	Easting NZMG	Northing NZMG	Ground mAMSL	Bore Depth	WelARC ID	Record Length
Poroti Springs	5471001	2613753	6606313	78.1	?	?	1972-87
Poroti Rd	5471003	2614376	6606003	97[1]	23 m	?	1979-88
Cutforths	5471005	2613702	6606843	63.8	?	?	1979
Whatitiri Wines	5471007	2615755	6605190	121.6	?	205852	1980-94
Pororti West	5471009	2612875	6606875	70.9	?	204046	1980-08
Cochcranes	5471011	2615368	6601220	144.9	66 m	?	1987-08
Tanekaha Orchards	5471013	2612866	6603578	132.6	61 m	204052	1987-08
Martins	5471015	2615691	6601166	133.4	13 m	?	1992-08
Angelo	5471017	2613410	6603526	158.3	62 m	205038	2001-07
Pukeatua Road	5471018	2619950	6601631	139.4	17 m	209188	2007-08
Puriri Park	5472001	2627219	6605955	94.5	62 m	205268	1983-08
Atkins	5472005	2622646	6606205	215[1]	?	?	1987-93
Campbell	5472007	2619776	6601792	142	30 m	205775	2002-08
Foster	5472009	2625337	6605452	147.2	60 m	205197	2003-05

[1] Interpolated from 20m contours.

3.3. Piezometric Surface

Figure 12 shows the piezometric surface contour plot for the Maunu-Maungatapere-Whatitiri aquifer, reproduced from Roke (1983). These contours were produced using groundwater levels within existing wells and the results of DC-resistivity soundings (which indicated the surface elevation of the sedimentary basement). Using this data, six individual catchments were identified: i.e. Whatitiri; West Whatitiri; South Whatitiri; Southeast Maungatapere; Maunu West and Maunu East.

As a significant number of bores have been drilled since **Figure 12** was constructed, the piezometric surface contour plot was updated using information obtained from driller's logs, NRC monitoring data and static water levels reported in aquifer test pumping results (**Figure 13**). All bores with static water level measurements have been incorporated in the piezometric correction, excluding bores not screened in the basalt, i.e. screened within sandstone or limestone around the aquifer boundary or with anomalous levels compared to adjacent bores. In addition, the groundwater elevation beneath each volcanic cone was interpolated based on the conceptual understanding of the hydrogeological to aid in contouring of the piezometric surface. These interpolated points are called Dummy Points in **Figure 13**.

Through comparing **Figures 12** and **13** it can be seen that the general trend of groundwater flow across the aquifer has been confirmed by using the updated data. The main difference between the two piezometric surfaces occurs around the Whatitiri Cone, with newer bores indicating higher groundwater levels in this location. The revised piezometric surface will be used during the calibration process in order to assess the accuracy of the groundwater model.

- **Figure 12. Piezometric surface plot reproduced from Roke (1983).**
  (See A3 attachment at rear)
- **Figure 13. Revised piezometric surface plot.**
  (See A3 attachment at rear)

3.4. Aquifer Hydraulic Properties

Aquifer test information was available for 29 bores within the study area. **Table 7** summarises the aquifer test information and resulting hydraulic parameters, with the hydraulic conductivity values shown on **Table 7**.

- **Figure 14. Hydraulic conductivity values within study area.**
  (See A3 attachment at rear)

Transmissivity ranges between 0.8 and 3,278 m^2/day. The lowest transmissivity results are likely to be due to the presence of relatively impermeable non-vesicular basalt which will be relatively unfractured or with low fracture connectivity. The bores with higher transmissivity are considered to have a higher degree of fracturing and connectivity between fractures, although there is a lack of detail on the borelogs to confirm this.

Storativity values were assessed from two pump tests, i.e. those conducted on bores 209471 (0.0048) and 209096 (0.0005). These results indicate that the aquifer is unconfined at the location of 209471 (south of Whatitiri Cone), but confined at the location of 209096 (in the vicinity of Poroti Springs). However, these interpretations are dependent on the accuracy of the aquifer test data.

Hydraulic conductivity was estimated from the transmissivity and the saturated thickness of the aquifer. The hydraulic conductivity from many aquifer tests could not be determined as no borelog information was available to determine saturated thickness. In most cases, the saturated thickness stated within **Table 7** represents the minimum thickness as the base of the basalt was not reached.

The values of hydraulic conductivity range between 0.3 and 1,124 m/day. The largest hydraulic conductivity value of 1,124 m/day appears to be an anomalous high value. The bore for this aquifer test is located next to a stream and could potentially be considered a surface water take. These values are generally within the middle of the range of published hydraulic conductivity values for basalt of 0.009 to 900 m/day (Freeze and Cherry, 1979) and consistent with the values calculated by Roke (1983). The distribution of hydraulic conductivity values shown in **Table 7** provides evidence of the variable nature of the basalt aquifer.

- **Table 7. Summary of aquifer hydraulic parameters**

Bore	Name	Bore Depth (m)	Casing Depth (m)	Saturated Thickness (m)	Pump Rate (m^3/day)	T (m^2/day)	K (m/day)	K (m/sec)
207279	Sherwood Park	68	11.5	47.3	118	59.5	1.25	1.4x10^{-5}
205551	Darligen Orchards	52	18	4	115	40.5	10.1	1.2x10^{-4}
205136	Currin Farms	-	-	5	225	517	103	1.2x10^{-3}
205104	Smith	65.8	19.5	46.3	322	421	9.1	1.1x10^{-4}
205115	Alderton	65	15.2	49.8	200	766	15.4	1.8x10^{-4}
205158	Lynwood Farms	60.3	22.2	38	243	212	5.6	6.5x10^{-5}
205084	Jeeves	-	-	-	26	22.5	-	-
205143	Pattinsen	26.2	11.5	4.8	50	398	82.9	9.6x10^{-4}
205805	Tuakaka Tourist Ltd	-	-	-	164 – 251	139	-	-
205038	Gray	61.5	27	11	72	29.9	2.7	3.1x10^{-5}
-	Puriri Grange Orchard	-	-	-	20	45.9 – 25.5	-	-
205173	Thorn	89.6	18.3	62.2	275	22.6	0.3	3.5x10^{-6}
205197	Hawken	60	18	42	382	493	11.7	1.3x10^{-4}
205190	Brice	40.5	24.4	10.8	Variable	903	83.6	9.7x10^{-4}

Bore	Name	Bore Depth (m)	Casing Depth (m)	Saturated Thickness (m)	Pump Rate (m^3/day)	T (m^2/day)	K (m/day)	K (m/sec)
205198	Kintrae Partnership	66	11.5	52.6	Variable	550	10.5	$1.2x10^{-4}$
205808	Mackay	-	-	-	140	1.8 – 11.6	-	-
205231	Herman	-	-	-	237	132 - 207	-	-
205230	Jeeves	24.4	18.3	6.1	78	109	18	$2.1x10^{-4}$
205047	Clarkson	34	6.5	20.2	267	986	48.8	$5.6x10^{-4}$
207140	Russell	21.3	13.3	8	194	23.6	2.95	$3.4x10^{-5}$
205810	Cochrane	-	-	-	104	11.2 - 173	-	-
-	Leonard	-	-	-	150	18.6	-	-
205811	Croucher	-	-	-	65	3.3	-	-
205812	Maddever Trust	-	-	-	Variable	0.8 – 1.8	-	-
205072	Spratt	37.7	7.9	29.8	60.6	41	1.4	$1.6x10^{-5}$
205813	Cochrane	-	-	-	242	4.5	-	-
204051	Simpson	40.5	22.5	18	Variable	1,785	99	$1.1x10^{-3}$
209471	Ford	48	42	6	55.6	55	9.1	$1.1x10^{-4}$
209096	Whangarei City Council	8.5	5.8	2.7	3,652	3,278	1,214	$1.4x10^{-2}$

3.5. Aquifer Recharge

Aquifer recharge is the flux of rainfall derived water to the groundwater system. Recharge rates vary depending on characteristics such as rainfall, lithology, vegetation and topography.

3.5.1. Background

In the model domain, groundwater recharge forms the major component of the aquifer water balance. Numerous studies (i.e. SKM (2006a), SKM (2006b) and SKM (2007)) have been previously undertaken by SKM to determine the aquifer recharge within basalt aquifers throughout Northland, with results varying between 5 to 49% of annual rainfall for basalt, with estimates for scoria being as high as 60% annual rainfall. The large range in values is a reflection of the variable geology, i.e. weathering basalt thickness and extent of fracturing.

3.5.2. Estimating Recharge

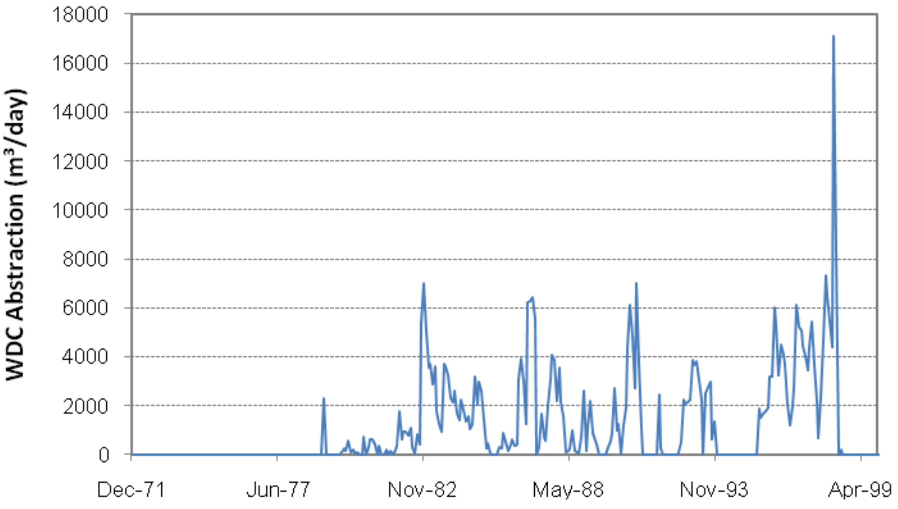
The process of determining recharge to the model was carried out using the Soil Moisture Water Balance Model (SMWBM). Details of the groundwater recharge estimation are included within **Appendix B**, with a discussion on the specific zones of recharge used within the calibrated model outlined **Section 5.3.8**.

3.6. Groundwater Abstraction

Information regarding consented abstraction was obtained from NRC in May 2009 as previously outlined in **Section 2.7**. In addition, historic information was obtained regarding the consented abstraction, i.e. consents which have either expired or been cancelled. This information was available for consents dating back to 1984. Overall, there were 29 additional historic consent abstractions which were included within the model.

Actual water use records for the majority consents were not available and it is considered that using the full allocation would lead to over simulation of pumping impacts on the aquifer. Therefore, a basic relationship between average rainfall deficit (i.e. monthly evaporation minus monthly rainfall) and a percentage of consented abstraction was developed. This relationship was examined during calibration until the drawdown within the monitoring bores, in particular bores 5471011 and 5471017, was accurately simulated. The final relationship was based on a maximum deficit of 220 mm, i.e. if the deficit was 220 mm then 100% of the consented abstraction was simulated. In general, the percentage of consented abstraction used each year ranged between 20 and 50%.

Actual water use records for the Wangarei District Council (WDC) abstraction adjacent to Poroti Springs were obtained from Northland Regional Council. These records documented abstraction between March 1979 and September 1998, with daily abstraction shown in **Figure 15**. Roke (1983) states any water abstraction from the WDC bore reduces the flow at Cutforths monitoring site on the Poroti Spring (adjacent to 5471005) by the equivalent amount implying it intercepts groundwater flow to the spring.



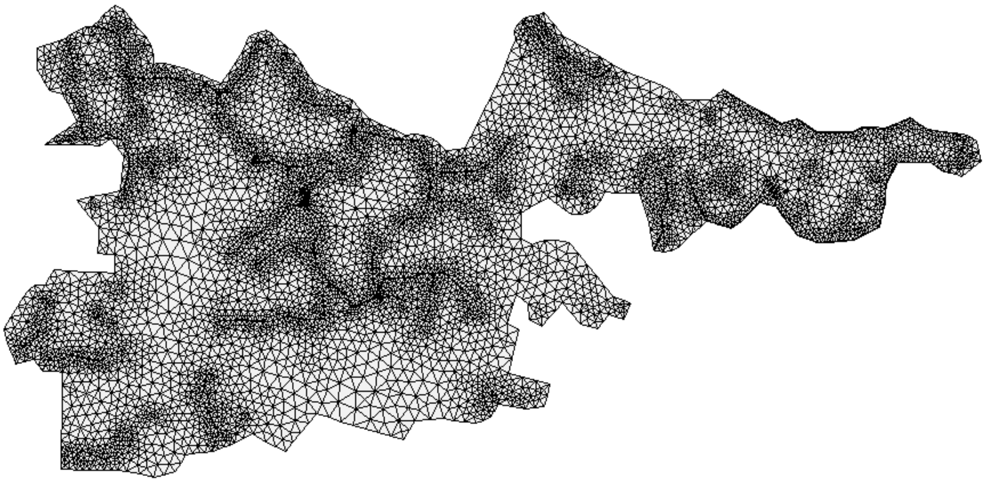
- **Figure 15. Whangarei District Council daily groundwater abstraction.**

4. Model Configuration

FEFLOW numerical simulation code was used within this study to construct the groundwater model and to run the simulations. FEFLOW is a finite element groundwater flow simulation package developed by the WASY Institute in Berlin, Germany.

4.1. Model Domain

A three dimensional groundwater flow was developed in the FEFLOW numerical simulation code. The model was constructed with 5 layers, with the model domain representing an area of approximately 62.8 km^2. The model domain has been discretised into a finite element array of cells (70,970 mesh elements and 43,698 mesh nodes) as shown in **Figure 16**. Grid refinement has been used around the rivers and abstraction bores.



- **Figure 16. Model domain for Maungatapere model (Layer 1).**

4.2. Model Layer Configuration

4.2.1. Layer Geology

The model was constructed with five layers (six slices) which represented the main geological units outlined in **Section 3.1**, i.e. volcanic clay, scoria/weathered basalt, vesicular/non-vesicular basalt, scoria/weathered basalt and vesicular/non-vesicular basalt. Zones of variable hydraulic parameters were used across the layers in order to represent the variable nature of the aquifer system.

4.2.2. Layer Elevations

The vertical boundaries between each model layer were determined using borelog information obtained from NRC and interpolated ground level for each bore location. During the interpolation, rules were applied so that the layer surfaces did not overlap and that adequate representation of unit termination was obtained.

4.3. Boundary Conditions

The boundary conditions used within the model include transfer, wells and no flow boundaries as shown in **Figure 17**. These boundary conditions are discussed in detail below.

4.3.1. Transfer Boundaries

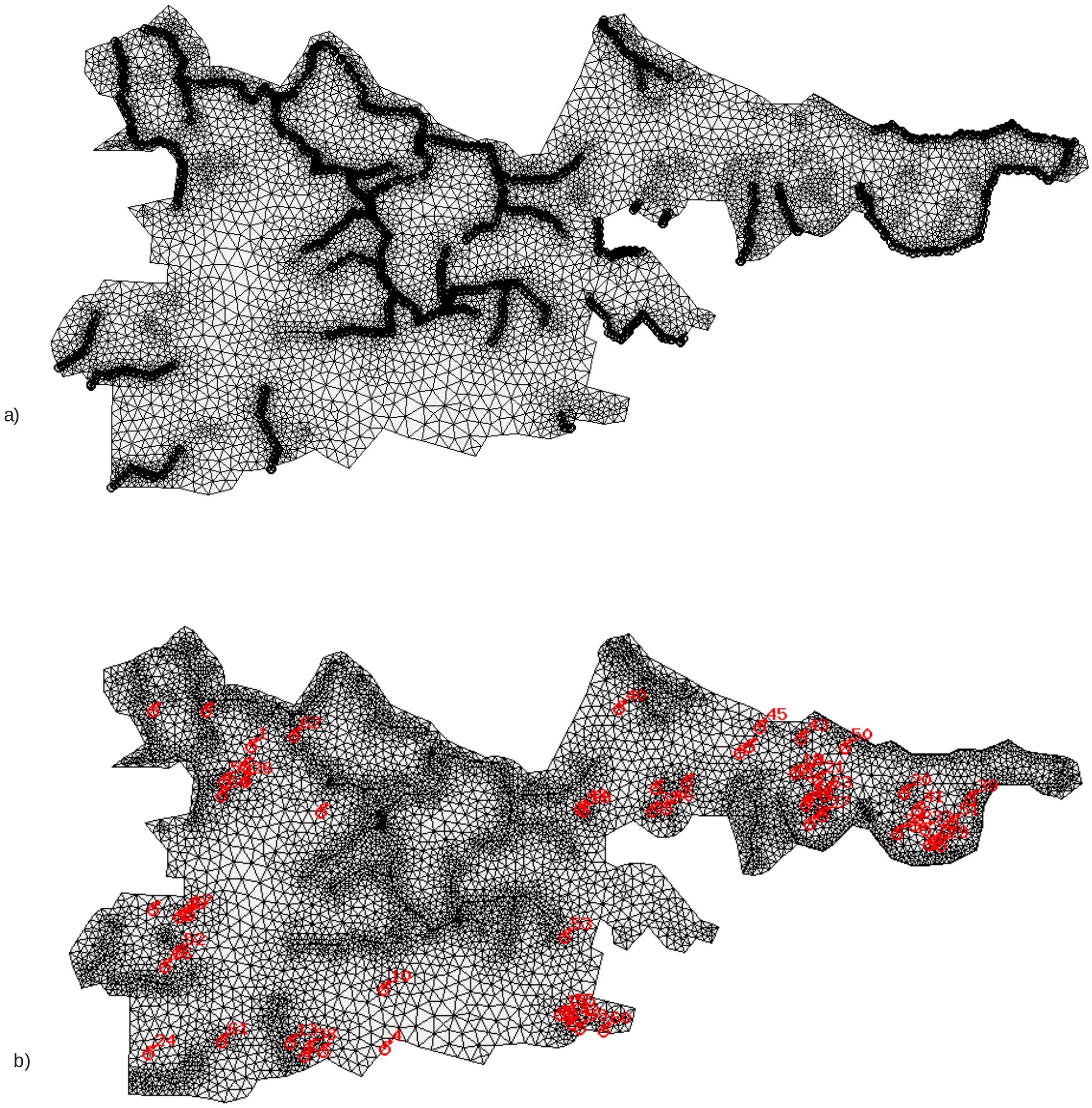
Transfer boundaries are used to define a hydraulic head of a feature within the model domain such as a river. The major streams and rivers within the aquifer extent were included within the model using this boundary condition (**Figure 17a**), with the grid mesh refined around these areas. A transfer rate is akin to the conductance term in MODFLOW and represents a hydraulic restriction to flow or leakage from the boundary, dependent on the model calculated head in the adjoining cells. The transfer rates are unknown parameters within the model and were varied during calibration.

4.3.2. Wells

A total of 61 abstraction bores were included within the model, including 32 currently consented bores (as outlined in **Section 2.8**) and 29 additional consents which have either been expired or cancelled (see **Section 3.7**). These bores were included in the model using the Well boundary condition with the open interval determined through examination of borelogs. It was determined that the majority of bores were open holes abstracting groundwater from Layer 3 of the model, i.e. the first layer of vesicular/non-vesicular basalt. When a borelog was not available for one of the abstraction bores, it was assumed to be screened within Layers 3. The abstraction profile used for the abstraction bore was discussed in detail in **Section 3.6**.

4.3.3. No Flow Boundaries

No flow boundaries were used within the model around the model extent and the base of the model as it is assumed that there will be negligible flow between the basalt and surrounding basement rocks, due to the fact that the permeability of the underlying sediments is orders of magnitude lower than the basalt and the majority of aquifer discharge occurs via springflow along the basalt flow boundaries.



- **Figure 17. Model boundary conditions with river boundaries in Layer 1 shown in a), while b) shows abstraction bores in Layer 3.**

5. Model Calibration

Calibration of the numerical groundwater model was achieved by manual adjustment of model parameters to provide a best fit to nominated calibration targets. The calibration process is outlined in the following sections.

5.1. Steady State Calibration

Steady state calibration was initially undertaken in order to test the validity of the hydrogeological conceptualisation and to obtain approximate model parameters by ensuring the steady state heads are broadly representing field conditions. Observed heads for the steady state model were obtained from the NRC groundwater level monitoring bores as outlined in **Section 3.2**, which represented water levels within the scoria, weathered and fractured basalts throughout the model.

There are many uncertainties associated with these observed heads such as variable reliability of the measurements, the unknown accuracy of the topographic references, and the inconsistent timing of the measurements. For these reasons the steady state calibration was considered appropriate only for the purposes discussed above and hence effort focused on achieving a robust transient calibration.

5.2. Transient Calibration

Transient calibration provides a far more powerful and representative method of model parameterisation and as indicated above was undertaken after the initial steady state calibration was completed. This process involved running the model through iterations of time and comparing the model output with the long-term groundwater level records from the NRC monitoring bores (**Section 3.2**).

5.2.1. Stress Periods and Time Steps

Within FEFLOW the period of simulation is divided into stress periods where the specified model stresses (e.g. recharge) remain constant. Each stress period is then divided into a specified number of time steps. The model calculates the head within each cell at the end of each time step.

The determination of stress periods for the transient model is dependent on the frequency of the transient data points available. Recording of groundwater levels within the NRC monitoring bores started in 1972 with a reliable rainfall record also available over this time. Therefore the model was run over the 27 year period from 1/02/1972 to 1/05/2009. Monthly timesteps were used to enable abstraction for irrigation to be adequately simulated.

5.2.2. Initial Conditions

Starting heads for the transient calibration were initially set to output head values from the steady state model. During the process of transient calibration, heads from discreet time steps of the calibration runs were used to define initial conditions. This was undertaken so that conditions matching the likely climatic situation at the start of the calibration time were used.

5.3. Calibrated Model Outputs

In determining whether or not a model calibration is acceptable, the following factors were considered:

- ***Hydraulic Properties*** **-** The hydraulic parameters used within the model are within the reasonable bounds of known parameters (i.e. from aquifer testing) or typical published values based on the hydrogeology of the aquifer system;
- ***Head Match*** **-** The ability of the model to match groundwater levels within long-term monitoring bores as well as any other groundwater level information available. It is particularly important within transient simulations that the model is simulating the trends and hydrological stresses occurring within the aquifer (e.g. reduction in groundwater levels over time, or the response to abstraction);
- ***Flux Match*** **-** The ability of the model to simulate the various fluxes within the aquifer system, i.e. river leakage or spring discharges; and
- ***Water Balance*** **-** The overall water balance for the model is appropriate with particular importance placed on the percentage of rainfall recharge to the aquifer to ensure that it is within the reasonable bounds based on known rainfall and hydrogeology.

The calibrated model is assessed against these factors as outlined in **Sections 5.3.2** to **5.3.5** below.

5.3.1. Initial Calibration

The geology of the Maunu-Maungatapere-Whatitiri aquifer system is highly variable given the fractured nature of the three primary basalt flows. Adding this level of variability and complexity into a groundwater model from the beginning can lead to issues during calibration. Hence, the first stage of calibration for this project was to obtain a calibration for the bulk aquifer, i.e. using the same hydraulic parameters over large areas of the model to represent the general aquifer conceptualisation.

Specific details regarding these initial calibration test runs are outlined in **Appendix D**. The results of this calibration indicated that although the majority of groundwater levels could be simulated with reasonable accuracy using bulk parameters, some large discrepancies in groundwater levels, lack of observed oscillations in some bores, and a lack of spring flow from Poroti Springs were simulated.

This indicated that areas of highly fractured basalt were required in order for the model to accurately represent the aquifer system.

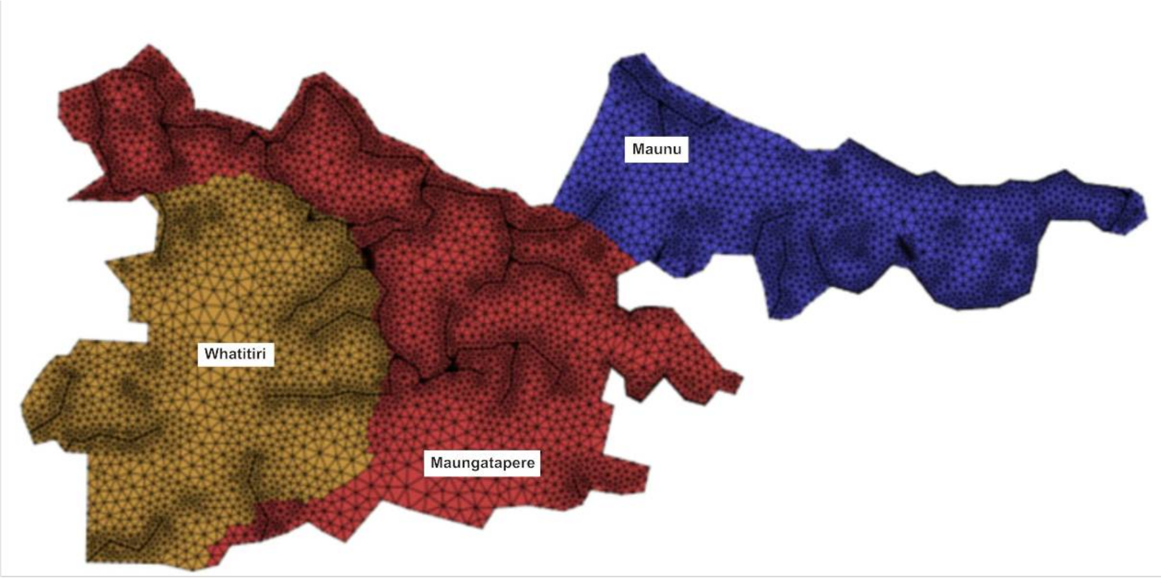
Additional calibration was undertaken on the model through increasing the complexity of the geology through incorporating areas of high permeability and recharge. The results of the calibration are described in the following sections.

5.3.2. Model Parameters

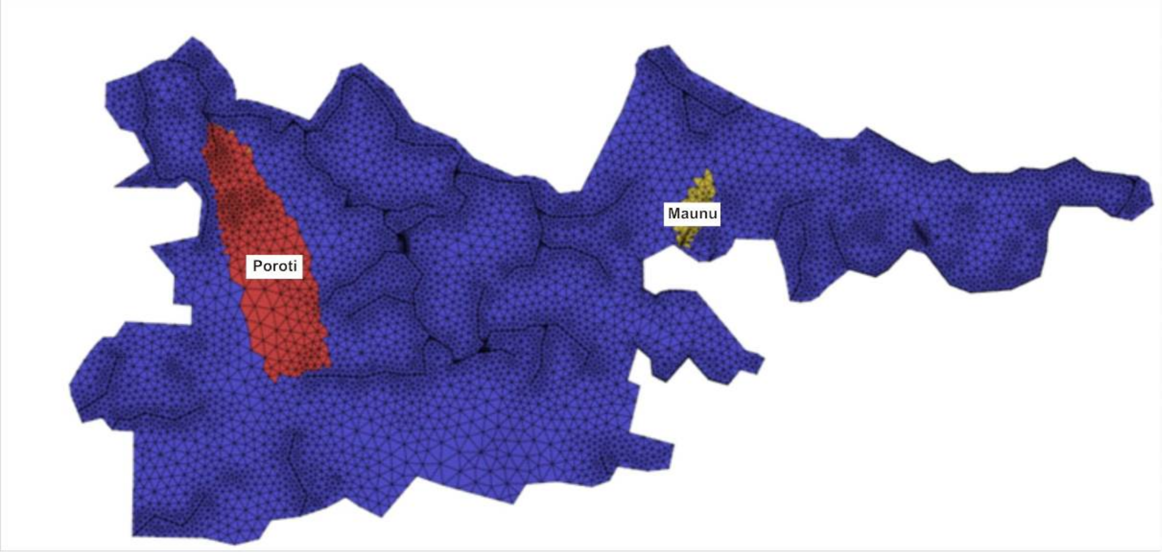
Hydraulic parameters were assigned for the three primary basalt flows in the aquifer, i.e. the Maunu, Maungatapere and Whatitiri basalt flows as shown in **Figure 18**. The location of the primary basalt flows were based on the conceptual understanding of the system, for example the basalt flow from the Maungatapere Cone flowing over the Horeke Basalt from the Whatitiri Cone. The hydraulic parameters were assigned based on the knowledge of the occurrence of scoria, weathering or fractures within the basalt flows. The final hydraulic parameters used for the calibration are outlined in **Table 8**.

Following the analysis of the initial calibration, areas of high permeability were added into the model in the vicinity of Poroti and Maunu Springs as shown in **Figure 19.** The area around Poroti Springs was based on the assessment completed by Roke (1983) which indicated that a highly permeable aquifer is located in this area and forms a “channel”. This channel is considered likely to be a remnant lava flow from the Whatitiri Cone and has been modelled accordingly. Roke (1983) did not provide any information regarding a higher permeability area at Maunu Springs, so for the purposes of this study it is assumed that a similar remnant lava flow occurs at this location.

In general the selected hydraulic conductivities used within the model are within the lower range of those calculated from aquifer testing as outlined in **Table 7**. This is expected as the bores used for aquifer testing were generally production bores and would be abstracting water from site specific permeable regions of the aquifer, i.e. fracture zones. The hydraulic conductivity used to represent the Poroti “Channel” is slight lower than the value calculated during aquifer testing of the Whangarei District Council bore (209096), i.e. a value of 1.4×10^{-2} m/sec.



- **Figure 18. Primary basalt flows defined in calibrated model.**



- **Figure 19. Location of high permeability areas associated with Poroti and Maunu Springs.**

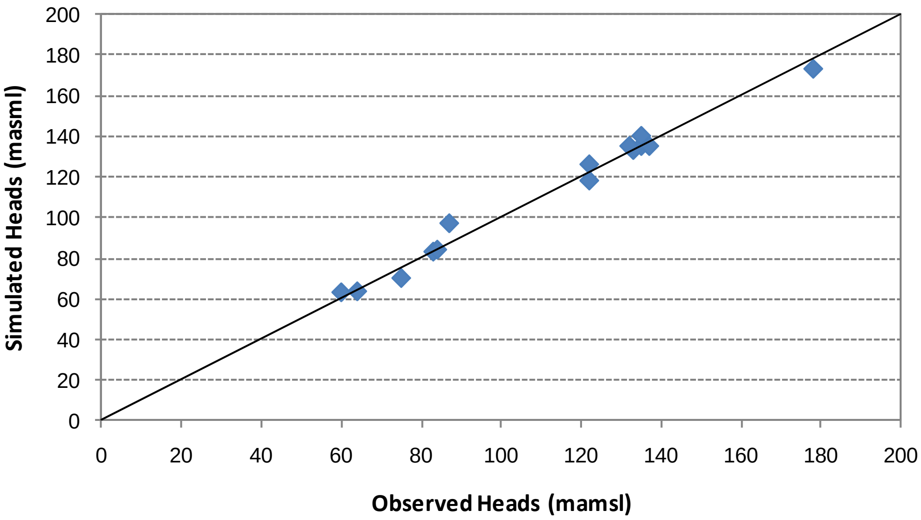
- **Table 8. Calibrated model parameters (based on primary basalt flows)**

Geology	Kx (m/s)	Vertical Anistropy	Sy	Ss
Maunu Flow				
Volcanic Clay	3×10^{-6}	10	0.01	8×10^{-6}
Scoria/Weathered Basalt	1×10^{-5}	3	0.01	8×10^{-6}
Fractured Basalt	1×10^{-6}	10	0.01	8×10^{-6}
“Tunnel” Maunu Springs	6.5×10^{-5}	3	0.01	8×10^{-6}
Maungatapere Flow				
Volcanic Clay	3×10^{-6}	10	0.01	8×10^{-6}
Scoria/Weathered Basalt	1×10^{-5}	3	0.01	8×10^{-6}
Fractured Basalt	9×10^{-6}	10	0.01	8×10^{-6}
Whatitiri Flow				
Volcanic Clay	3×10^{-6}	10	0.01	8×10^{-6}
Weathered Basalt	3×10^{-6}	10	0.01	8×10^{-6}
Fractured Basalt	8×10^{-6}	10	0.01	8×10^{-6}
Poroti “Channel”	8.5×10^{-3}	3	0.01	8×10^{-6}

5.3.3. Calibration to Observed Heads

The groundwater levels simulated by the calibrated model were compared to groundwater levels recorded within the 14 Northland Regional Council monitoring bores outlined in **Section 3.2**. Graphs of the calibrated model results and observed values for all of the bores are shown in **Appendix E** and are discussed in detail below.

An overall assessment of the simulated hydraulic gradient of the model was completed by comparing average simulated and observed groundwater levels for the 14 monitoring bores. This comparison is shown in **Figure 20** which indicates that in general, the model is accurately simulating the hydraulic gradient across the model domain.



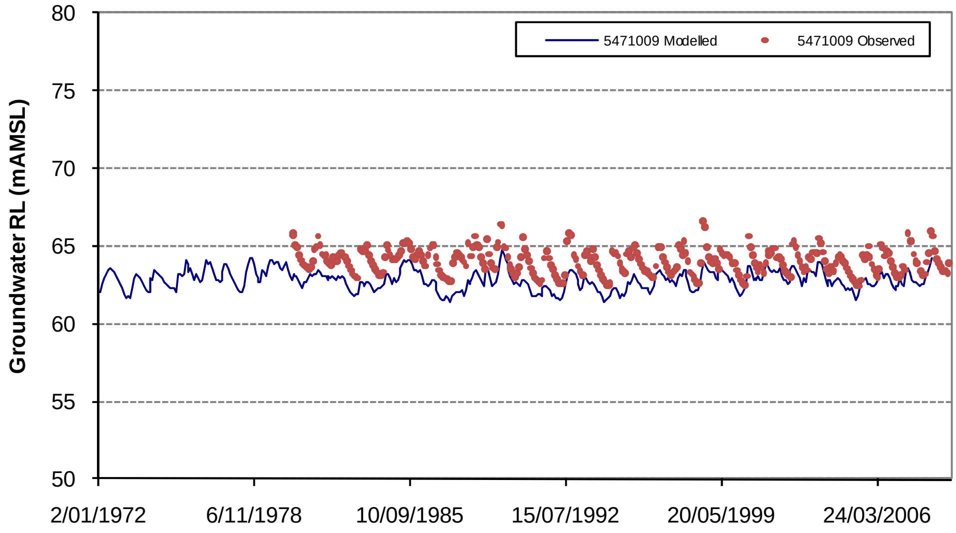
- Figure 20. Average groundwater levels from observation bores in calibrated model

5.3.4. Poroti Springs Area Bores

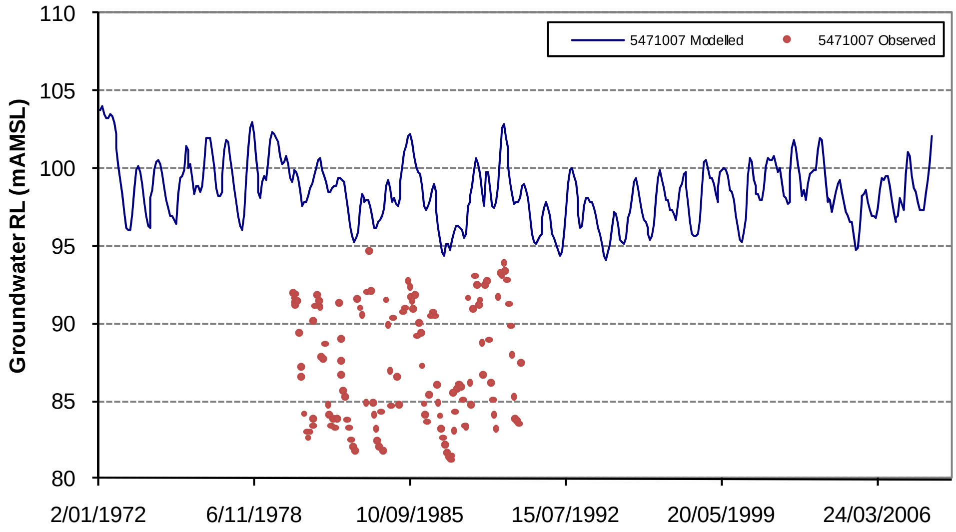
There are five monitoring bores located within the vicinity of Poroti Springs and northern Whatitiri area (5471009, 5471005, 5471001, 5471003 and 5471007). The model simulated the heads in the area of Poroti Springs area with reasonable accuracy as shown in **Appendix E**. In particular, the model simulated the groundwater levels at 5471009 (**Figure 21**) and 5471003 accurately. This is particularly true for 5471009 as this monitoring bore has the longest record and is located at a main discharge area of the aquifer.

Minor discrepancies were simulated for bores 5471005 (groundwater levels modelled approximately 2 m higher than observed) and 5471001 (groundwater levels modelled approximately 4 m lower than observed) (see **Appendix E**). This is likely to be a function of site specific characteristics which cannot be simulated with accuracy in a regional scale model, e.g. spring/stream elevations or location of fractures in the basalt. In addition, bore 5471005 only has three observed groundwater levels which reduces the reliability of using this monitoring bore for calibration.

During the initial calibration it was found that the groundwater levels at 5471007 were simulated approximately 25 metres too high and with minimal oscillations (**Appendix C**). **Figure 22** shows the groundwater levels simulated using the calibrated model. It can be seen that the simulated groundwater levels have reduced by approximately 17 m and the oscillations have increased considerably from the initial calibration. This improvement is the result of including the area of high permeability located around Poroti Springs in the model. The remaining discrepancy between the simulated and observed groundwater levels is likely to be the result of site specific high permeability or fractured zones within the basalt. As no information regarding the extent or location of a high permeability area is available in this specific area, a decision was made not to include an area of high permeability at this stage.



- **Figure 21. Modelled and observed heads for Poroti West (site number 5471009).**

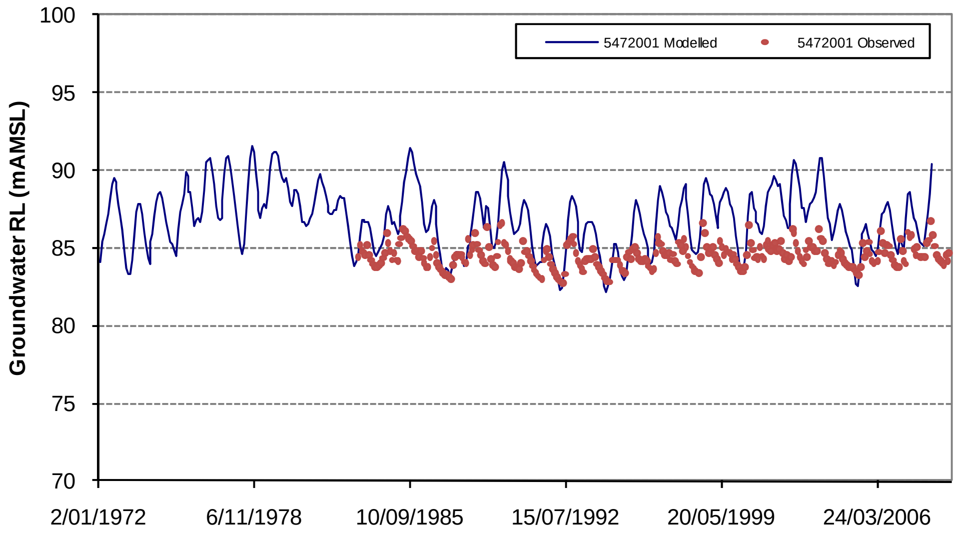


- **Figure 22. Modelled and observed heads for Whatitiri Wines (site number 5471007).**

5.3.5. Maunu Basalt Flow Bores

There are three Northland Regional Council monitoring bores located in the Maunu basalt flow area, i.e. 5472005, 5472009 and 5472001. Groundwater levels at 5472009 and 5472001 were accurately simulated, although some of the oscillations simulated at 5472001 were greater than observed (**Figure 23**).

Groundwater levels at 5472009 were under-simulated by the calibrated model by approximately 5 metres (**Appendix E**). However, this may be a function of an incorrect elevation assumed for the monitoring bore, as the elevation of the bore is unknown.

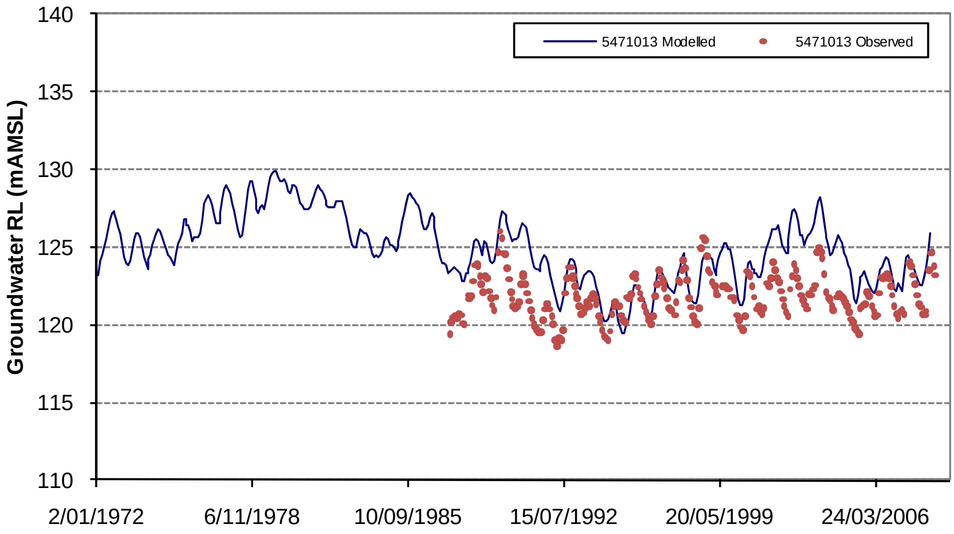


- **Figure 23. Modelled and observed for Puriri Park (site number 5472001).**

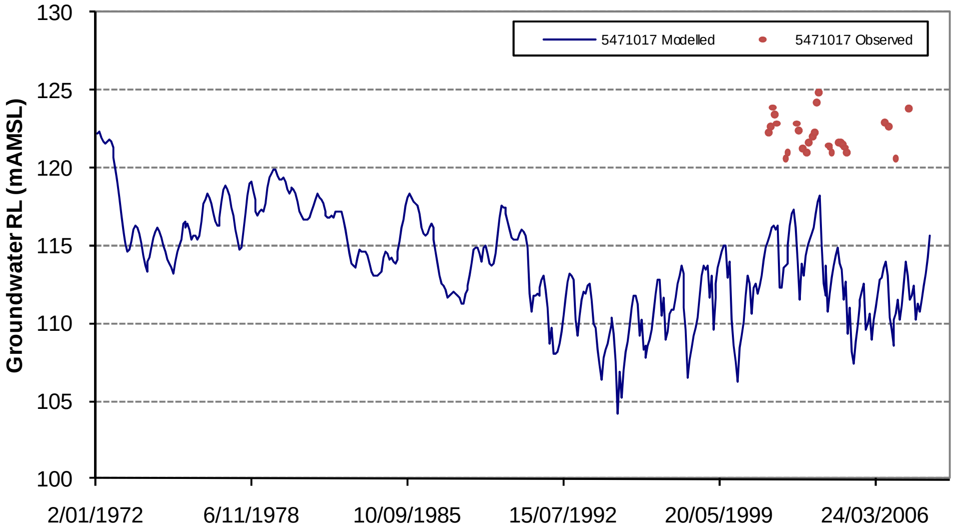
5.3.6. Remaining Monitoring Bores

The remaining six Northland Regional Council monitoring bores are located around the periphery of the Whatitiri and Maungatapere Cones, i.e. 5471013, 5471017, 5471011, 5471015, 5472007 and 5471018. The calibrated model simulated the groundwater levels at 5471013, 5471015 and 5471018 with reasonable accuracy, with the simulated and observed groundwater levels shown in **Figure 24**.

Groundwater levels within 5471011 and 5472007 were also reasonably simulated, although levels were simulated approximately 2 to 3 m lower than the observed. The simulated groundwater levels in 5471017 were approximately 5 m lower than the observed, although the response to abstraction was simulated with reasonable accuracy. The lower groundwater levels in this area are likely due to the location of the high permeability zone associated with Poroti Springs, i.e. in reality the high permeability zone is not as connected to this area of the aquifer as is currently simulated. Lower simulated groundwater levels than measured indicate that the model is conservative for the purposes of the sustainable yield assessment.



- **Figure 24. Modelled and observed heads for Tanekaha Orchards (site number 5471013).**



- **Figure 25. Modelled and observed heads for Angelo (site number 5471017).**

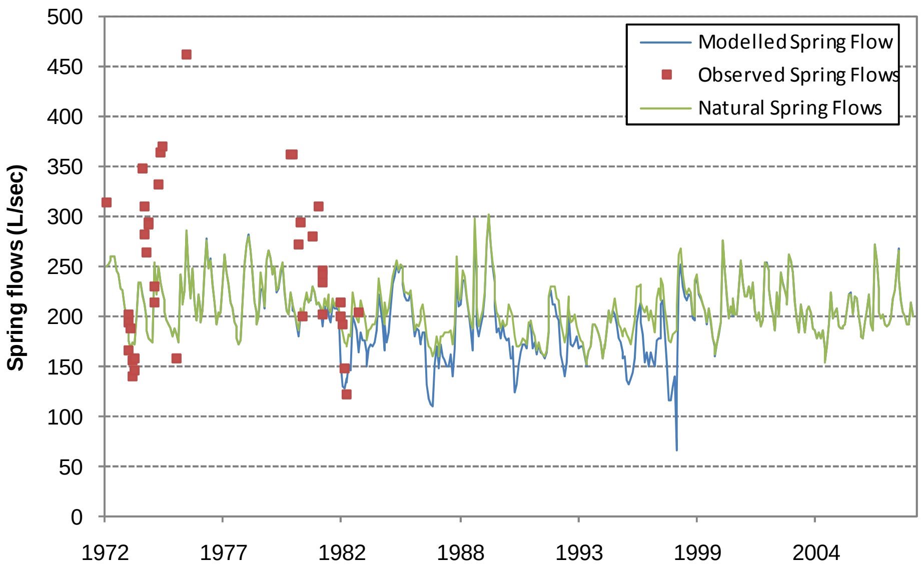
5.3.7. Simulated Spring Flows

An important aspect of determining the level of calibration of the model is its ability to simulate spring flows. As outlined in **Section 2.5**, spring flows have been recorded within Poroti Springs and Maunu Springs and were reported in Roke (1983). A discussion on the simulated spring flows at these locations is outlined below.

5.3.7.1. Poroti Springs

Spot measurements for Poroti Spring flows were available from 1972 and 1982, with flows ranging from 120 to 460 L/sec (**Figure 26**). The model was initially configured without abstraction from WDC (discussed in **Section 3.6**). Simulated spring flows (labelled "Natural Spring Flows" in **Figure 26**) were compared to observed spring flows for the initial calibration. These naturalised flows provided a reasonable match with the observed spring flows, with the exception of the peak flows. However, these peak flows are likely to be the result of direct surface water runoff which is not simulated with the groundwater model, thus the match was considered reasonable.

Following this assessment, the WDC abstraction was activated in the model. The simulated spring flow (with the abstraction activated) is labelled as "Modelled Spring Flow" in **Figure 26**. Roke (1983) stated that the WDC abstraction resulted in a proportional reduction in spring flows. The simulated reduction in spring flow was between 70 and 100% of the abstraction rate. Due to these reasons, the model was considered to be simulating Poroti Spring flows with reasonable accuracy.



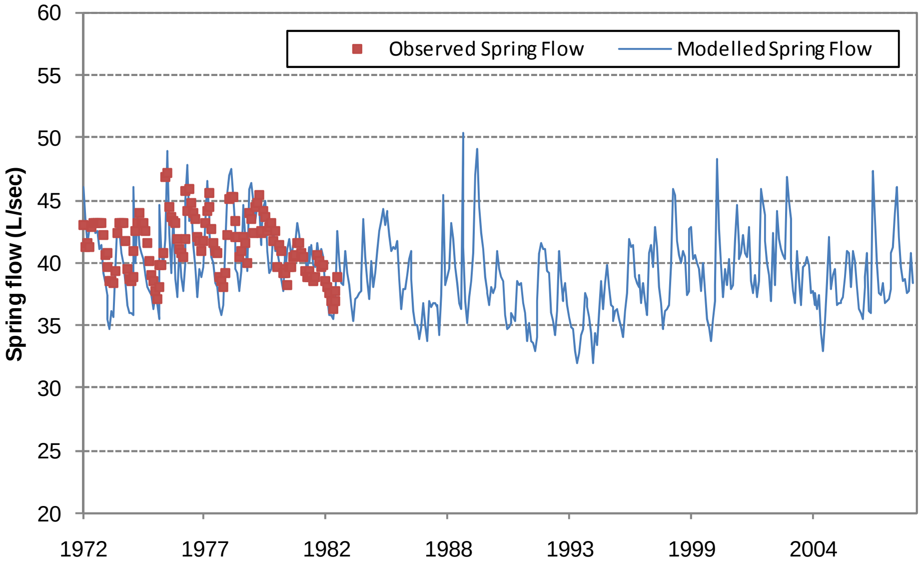
- Figure 26. Modelled, observed and simulated Poroti spring flows

5.3.7.2. Maunu Springs

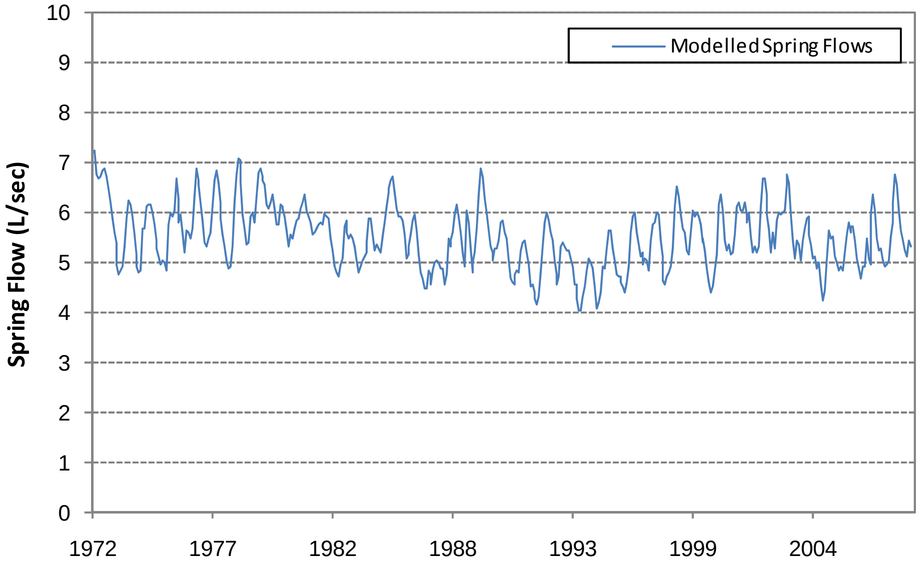
Information on spring flows were outlined in Roke (1983) for the two main springs in the system collectively known as Maunu Springs, i.e. “Tunnel” and “Chamber” (see **Section 3.6**).

A flow record between 1972 and 1982 was available for the ‘Tunnel” spring and is shown in **Figure 27**. In addition, **Figure 27** shows that the model is simulating the spring flows accurately.

A flow record was not available for the ‘Chamber’ spring, however it was stated that the average flow was 9.5 L/sec. **Figure 28** shows that the model simulated an average flow of 6 L/sec. This is lower than the observed although still within the correct range and hence it is considered appropriate.



- Figure 27. Modelled and observed spring flows from Maunu “Tunnel” Springs



- **Figure 28. Modelled and observed spring flows from Maunu "Chamber" Springs**

5.3.8. Model Flow Budget

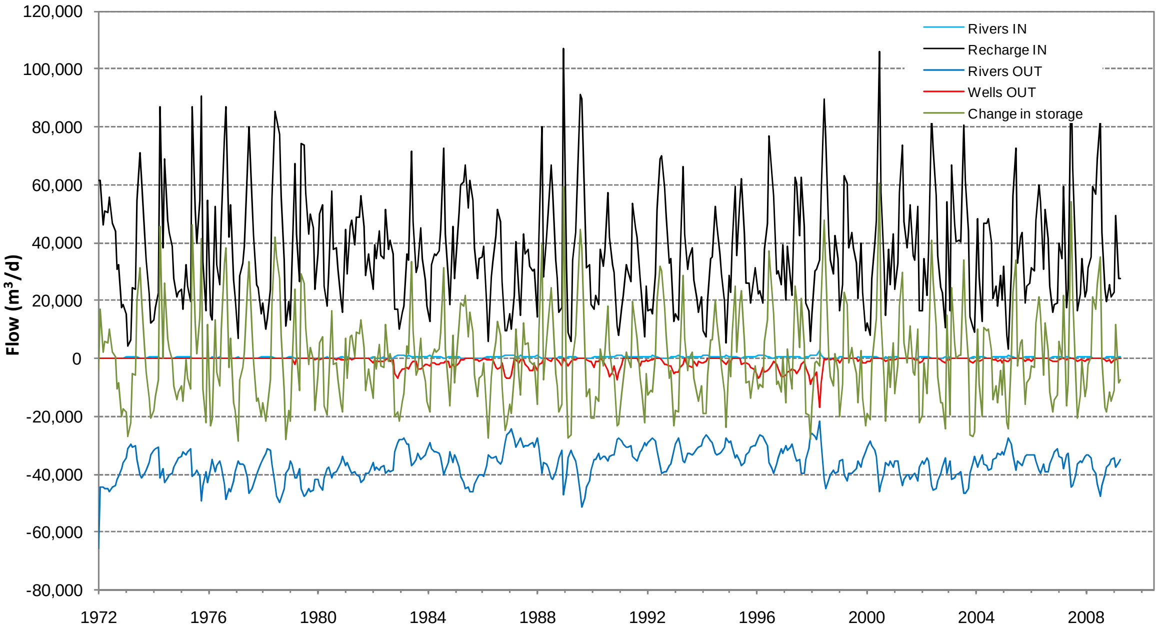
The average flow budget for the calibrated model is outlined in **Table 9**, which provides model domain inflows and outflows as average values over the model run period. The main input into the model is groundwater recharge with 98.9% of the inflow coming from this source. The calibrated model has several different zones of recharge throughout the domain which is discussed in detail in **Appendix B**. There are several output sources for the model, with the majority of groundwater leaving the model via the rivers and springs (96.7%), with the remaining discharge occurring as a result of abstraction.

The average recharge of 37,057 m^3/day over the model domain equates to 17% of the annual average rainfall. The level of recharge applied in the calibrated model is lower than the 29% calculated using the SMWBM as outlined in **Appendix B**. It is possible that an equally well calibrated model could be developed with recharge more closer aligned to the SMWBM results; however the current model calibration represents a conservative simulator for the purposes of sustainable yield and water allocation assessment, following the pre-cautionary principle.

- **Table 9. Average flow budget for calibrated transient model.**

Component	Flow (m^3/day)	Proportion of flow (%)
FLOW IN		
Recharge	37,057	98.9
Rivers	405	1.1
TOTAL IN	**37,462**	**100**
FLOW OUT		
Rivers/Springs	-36,470	96.7
Abstraction	-1,111	2.9
Net Change in Storage	-118	0.3
TOTAL OUT	**-37,698**	**100**

Figure 29 shows a time series plot of the above flow budget components. Inflows to the model cells are plotted as positive values while losses are negative.



- **Figure 29. Time series flow budget for calibrated model.**

5.3.9. RMS calculation

The Root Mean Square Error (RMS) is a frequently used measure of the differences between values predicted by a model and the values actually observed. A small RMS error value indicates low levels of disparity.

RMS error calculations were completed for the simulated and observed groundwater levels in the 14 Northland Regional Council monitoring bores. Two separate calculations were completed for RMS error, one which gives equal weight to the fit of each bore, while the second gives more weight to bores which have a larger number of observation points. The RMS errors are shown in **Table 10** and show that the RMS error is less than 4% disparity in head.

- **Table 10. RMS error calculations**

Calculation	RMS Error (% disparity)
Equally weighted bores	3.65
Equally weighted observations	3.99

6. Sensitivity Analysis

Uncertainty in assigned hydraulic parameters within a groundwater model is an issue for consideration in any model. This is irrespective of the amount of field testing, groundwater or surface water data that is available to calibrate the model and to reduce non-uniqueness within the model parameters. Sensitivity analysis is conducted in order to provide an understanding of the sensitivity of the model to variations in model responses that may be expected due to parameter uncertainty. This typically involves systematically changing the calibrated model parameters and assessing the resulting change in model response.

6.1.1. Scenarios

In this study, a sensitivity analysis was undertaken on the calibrated model in order to demonstrate the effects of higher and lower hydraulic conductivity (K) and recharge on the model hydrographs and spring flows. This analysis was undertaken on these two parameters as these were identified as the most sensitive during the calibration process. Four scenarios were run for the sensitivity analysis:

1) Hydraulic conductivity values being increased by 50%
2) Hydraulic conductivity values being decreased by 50%
3) Recharge increased by 50%
4) Recharge decreased by 50%

The hydraulic conductivity values used within the first two sensitivity analysis scenarios are outlined in **Table 11** while the recharge values used in scenarios 3 and 4 are outlined in **Table 12.**

- **Table 11. Hydraulic conductivity (K) values used in sensitivity analysis**

Geological Unit	Scenario 1 +50% K (m/sec)	Scenario 2 -50% K (m/sec)
Maunu Flow		
Volcanic Clay	4.5×10^{-6}	1.5×10^{-6}
Scoria/Weathered Basalt	1.5×10^{-5}	5×10^{-6}
Fractured Basalt	1.5×10^{-6}	5×10^{-7}
“Tunnel” Maunu Springs	9.75×10^{-5}	3.25×10^{-5}
Maungatapere Flow		
Volcanic Clay	4.5×10^{-6}	1.5×10^{-6}
Scoria/Weathered Basalt	1.5×10^{-5}	5×10^{-6}
Fractured Basalt	1.35×10^{-5}	4.5×10^{-6}
Whatitiri Flow		
Volcanic Clay	4.5×10^{-6}	1.5×10^{-6}
Weathered Basalt	4.5×10^{-6}	1.5×10^{-6}
Fractured Basalt	1.2×10^{-5}	4×10^{-6}

Geological Unit	Scenario 1 +50% K (m/sec)	Scenario 2 -50% K (m/sec)
Poroti “Channel”	1.2×10^{-2}	4.2×10^{-3}

- **Table 12. Percentage of rainfall recharge used in sensitivity analysis**

Recharge Zone	Scenario 3 +50% recharge	Scenario 4 -50% recharge
Bulk Aquifer	9	3
Volcanic Cone	27	9
Poroti/Maunu Springs	93	31

6.2. Results

In order to assess the effects of the sensitivity analysis scenarios on the long term trend of the modelled heads and modelled spring flows, the following analysis was completed:

- Comparison of the root mean square error (**Table 13** and **Figure 30**);
- Comparison of heads in three monitoring bores, 5471003, 5471013 and 5472005 (**Figures 31** to **33**); and
- Comparison of simulated spring flows at Poroti Springs and Maunu “Tunnel” Springs (**Figures 34** and **35**).

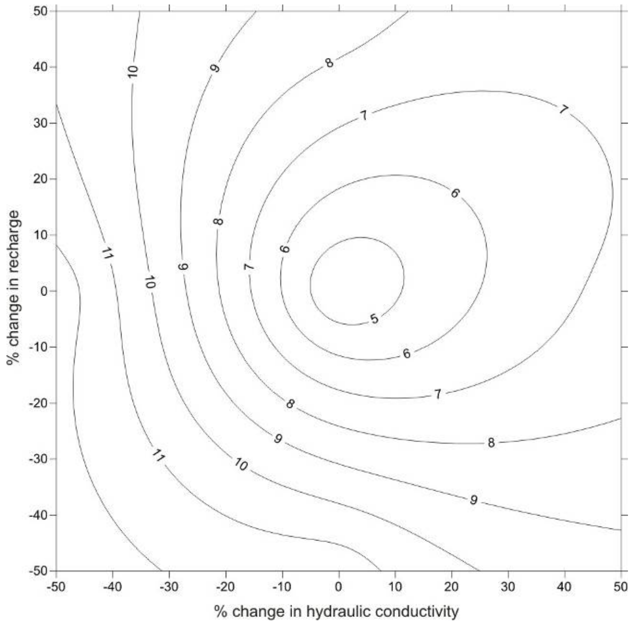
Separately increasing the hydraulic conductivity and decreasing recharge resulted in a reduction in groundwater levels at all locations. This was expected as the increase in hydraulic conductivity results in less hydraulic restriction to groundwater flowing out of the model, while decreasing recharge results in less water entering the aquifer system. This is supported through the comparison of spring flows, which showed with increasing hydraulic conductivity (Scenario 1), spring flows increased (**Figures 34** and **35**). The opposite occurred when the recharge was reduced (Scenario 4).

Separately decreasing the hydraulic conductivity and increasing recharge resulted in an increase in groundwater levels at all locations. This response was again expected and the decreased hydraulic conductivity reduces the model outflow, while the increased recharge results in more water entering the aquifer system. This is supported by the simulated spring flows, with reduced flows occurring when hydraulic conductivities are reduced (Scenario 2) and increased flows occurring when recharge is increased (Scenario 3).

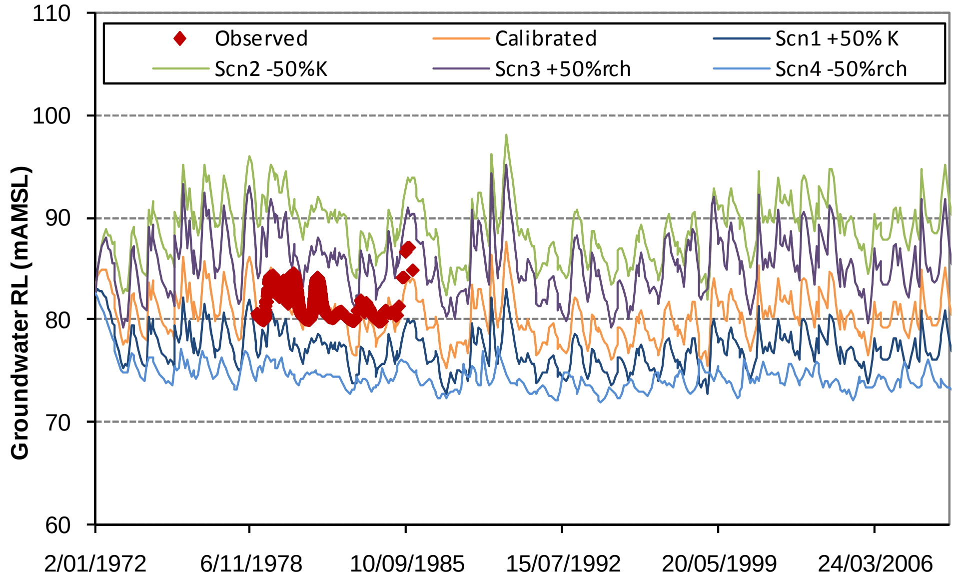
Scenarios 2 and 4 (decreased hydraulic conductivity and decreased recharge, respectively) have the greatest affect on the simulated heads. This is seen by the larger RMS errors calculated for these two scenarios (**Table 13** and **Figure 30**).

- **Table 13. RMS error from sensitivity analysis**

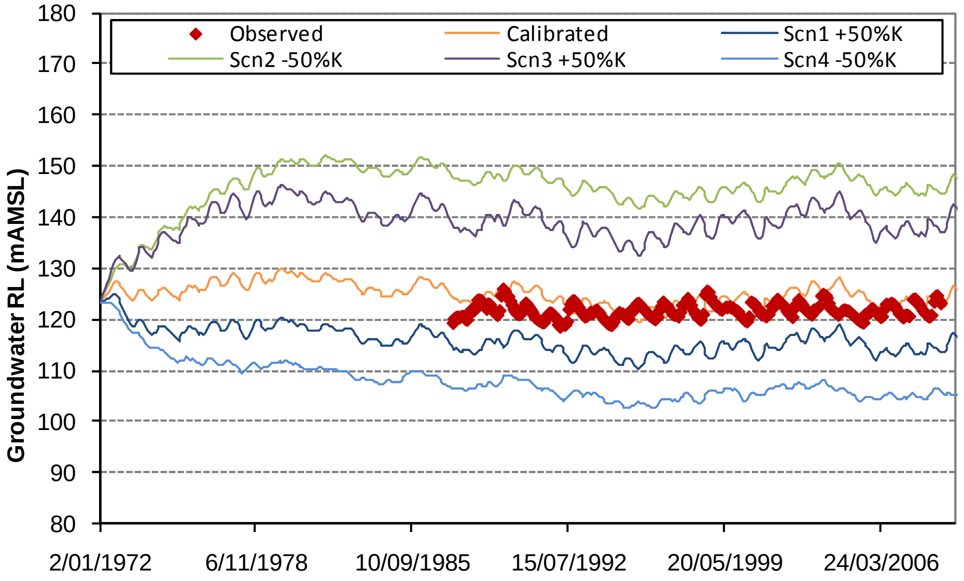
Scenario	RMS Error (%)	RMS Error (% change)
Calibrated model	3.99	
Scenario 1 +50% K	7.31	183
Scenario 2 -50% K	12.61	316
Scenario 3 +50% recharge	8.62	216
Scenario 4 -50% recharge	11.63	291



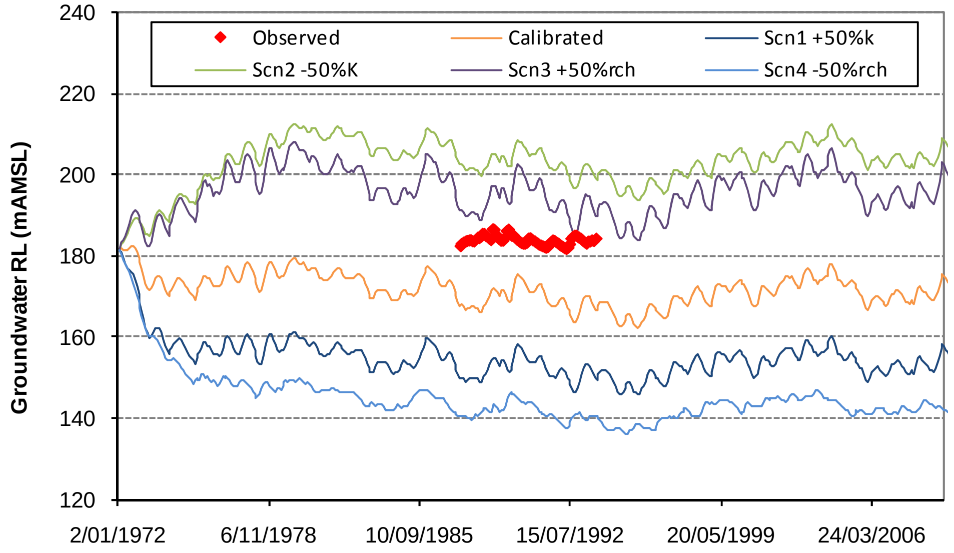
- **Figure 30. RMS error calculated for the four sensitivity analyses.**



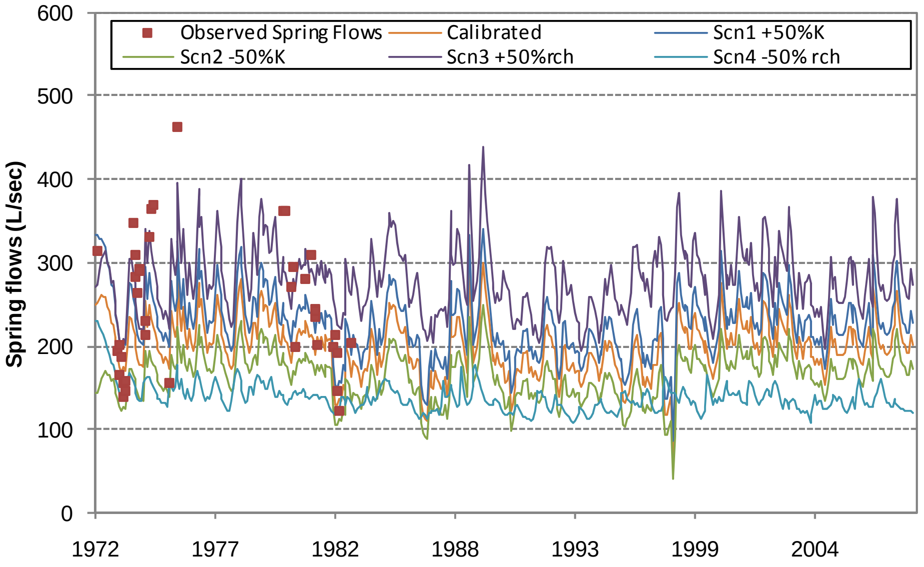
- **Figure 31. Simulated groundwater levels for bore 5471003 for scenarios 1 to 4.**



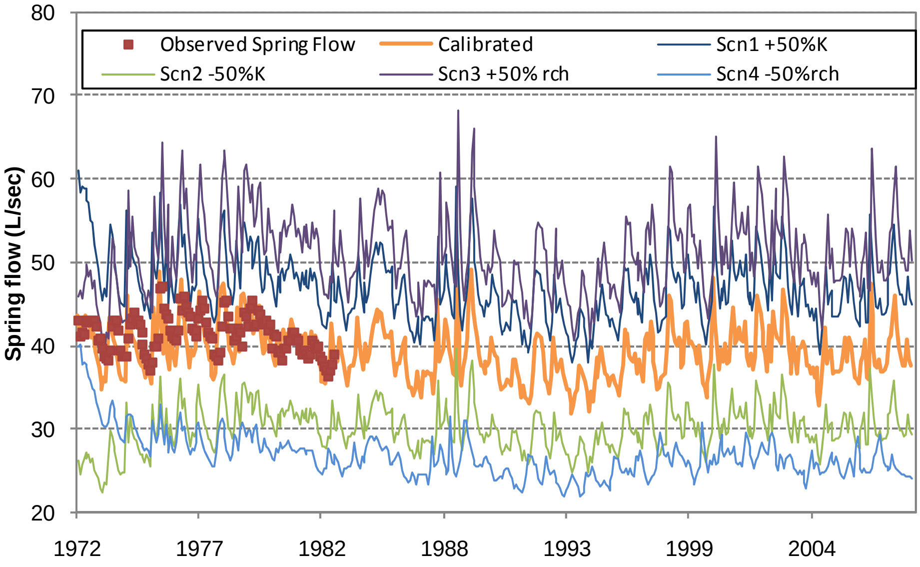
- **Figure 32. Simulated groundwater levels in bore 5471013 for scenarios 1 to 4.**



- **Figure 33. Simulated groundwater levels in bore 5472005 for scenarios 1 to 4.**



- **Figure 34. Poroti Spring Flows simulated for scenarios 1 to 4.**



- **Figure 35. Maunu “Tunnel” Springs simulated for Scenarios 1 to 4.**

6.3. Summary

Overall, the sensitivity analysis shows that the model is sensitive to changes in both hydraulic conductivity and recharge. In terms of hydraulic conductivity, the model is less sensitive to lower values of hydraulic conductivity than higher values. Further, the model is less sensitive to an increase in recharge than a reduction.

7. Predictive Simulations

As previously stated in **Section 1**, the specific objectives of this project are to:

1) Achieve an understanding of the groundwater system function with respect to groundwater recharge, discharge to streams, storage and flow through the aquifers;
2) Develop a low complexity numerical groundwater model that represents the conceptual hydrodynamic understanding of the system; and
3) Use the modelling tools developed above to determine a high level estimate of sustainable aquifer yield on a sub-catchment basis, focusing on impacts to spring flows.

Objectives 1 and 2 have been covered in the preceding sections, while this section discusses the findings of the predictive simulations which aim to develop a high level estimate of sustainable aquifer yield on a sub-catchment basis.

7.1. Setup

The predictive simulation was carried out over a 37 year timeframe from 1 February 1972 to 1 May 2009. This timeframe was selected in order to utilise the long historic rainfall record that captures some extreme weather events that may impinge on aquifer sustainability and results in long term effects on surface waterways, especially spring flows.

Roke (1983) had previously defined six individual sub-catchments for the aquifer system based the contour map of subvolcanic sediments and the developed piezometric surface. These sub-catchments are shown in **Figure 12** and were named:

- Whatitiri
- West Whatitiri
- South Whatitiri
- Southeast Maungatapere
- Maunu West
- Maunu East

It was stated that in most cases, the catchment areas are separated by concealed ridges that have been covered by overlying volcanic, but in some cases (i.e. the separation of Whatitiri and Maunu West catchments) the boundaries are less defined.

For the purposes of this investigation and for simplicity, the aquifer system has been divided into three sub-catchments. These catchments correspond to the primary basalt flows, i.e. Whatitiri, Maungatapere and Maunu. These sub-catchments are consistent with the basalt flows included within the model for the purposes of the assignment of hydraulic parameters. These catchments are also generally consistent with the main surface water catchments, i.e. the Maungatapere catchment covers the majority of the catchment for the Waipao Stream. Further sub-catchment refinement could be completed if required at a later date.

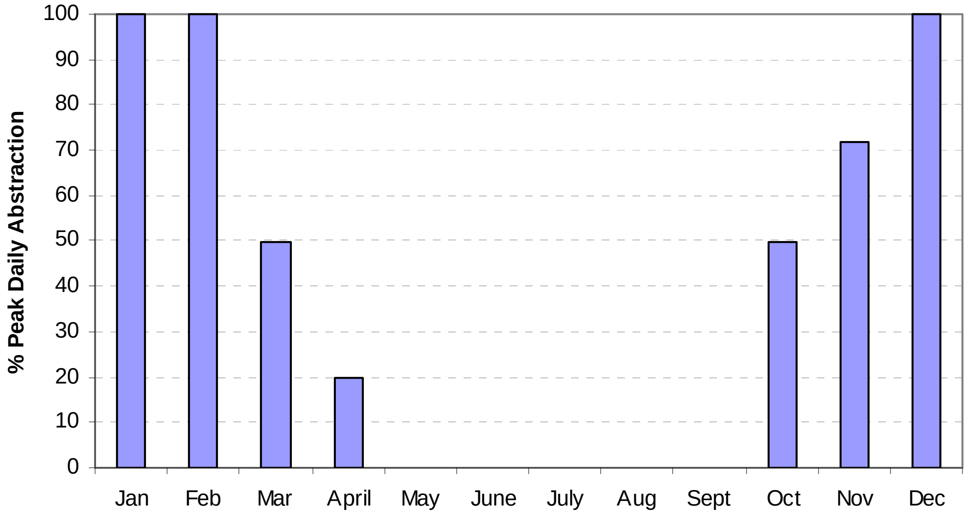
7.2. Scenarios

Three scenarios were run during the predictive simulations. They were as follows:

1) ***No Abstraction*** – this scenario will be used as the base case and to determine the level of affect on spring flows as a result of the two abstraction scenarios.

2) ***Full Consented Abstraction*** – at the time of preparing this report there are 32 groundwater consents granted for the aquifer system as outlined in **Table 4**, with a maximum consented abstraction of 3,385 m^3/day. The full consented allocation for the abstraction bores supplying water for a public water supply was simulated as the maximum consented rate throughout the year. However, the maximum abstraction for use in irrigation was simulated to only occur during the irrigation season (October to April). In addition, abstraction from these bores was based on an irrigation profile as shown in **Figure 36**. Abstraction from consents with annual limits was either scaled up or down until the annual allocation was reached.

   As stated in **Table 4**, groundwater consent 20040461101 is linked with surface water consents 199902960 and 200004607. These consents have a water sharing arrangement which allows them to abstract up to 1,000 m^3/day, while maintaining one third of the mean annual low flow within Poroti Springs (i.e. 50 L/sec). For the purposes of this scenario, the permitted groundwater abstraction of 1,000 m^3/day was abstracted from the bore associated with consent 20040461101.



- **Figure 36. Seasonal Irrigation Demand.**

3) ***Proposed National Environment Standard Allocation* -** The Proposed National Environmental Standard (NES) on Ecological Flows and Water Levels (Ministry for the Environment, 2008) is currently a “discussion document”. However, the Northland Regional Council is keen to maintain consistency with its approaches, and assess the potential water resource management implications. The Interim Limits applicable to this assessment are:

5.1.1 Groundwater Limits for All Other Aquifers

An allocation limit of, whichever is greater of:
- 35% of average annual recharge
- the total allocation from the groundwater resource on the date that the standard comes into force less any resource consents surrendered, lapsed, cancelled or not replaced.

In addition, for groundwater that is shown to be connected to adjacent surface water (as is the case with the spring flows within the aquifer system) the environmental flow or water level set for surface water body will also apply to the management of water takes.

5.1.3 For Rivers or Streams with Mean Flows Less Than or Equal to 5 m^3/sec

A minimum flow of 90% of the mean annual low flow (MALF) and an allocation limit of, whichever is greater:
- 30% of MALF
- the total allocation from the catchment on the date that the national environmental standard

comes into force less any resource consents surrendered, lapsed, cancelled or not replaced.

As previously stated for the purposes of this assessment, the aquifer system has been divided into the three main sub-catchments. **Figure B4** shows that in general each sub-catchment has a specific groundwater recharge, except for the areas of increased recharge in the vicinity of Poroti and Maunu Springs. For the purposes of this assessment, a conservative approach was adopted which was not to calculate potential allocation from these areas of high recharge. This approach is considered appropriate as the exact area and location of these high permeability zones is not accurately known and may lead to a conclusion that additional allocation is available when this is not the case.

The specific abstraction allocation without considering the connection to adjacent surface water for each of the sub-catchments is outlined in **Table 14**.

- **Table 14. Allocation limit for sub-catchments based on National Environmental Standards**

Sub-catchment Zone	Area (ha)	Calibrated Model Average Annual Recharge (m^3/day)	NES Allocation Limit[1] (m^3/day)
Whatitiri Basalt Flow	2,604	16,191 (18% recharge)	5,667
Maungatapere Basalt Flow	2,214	4,442 (6% recharge)	1,554
Maunu Basalt Flow	1,551	9,638 (18% recharge)	3,373

Note: [1] based on the interim limit of 35% of average annual recharge

7.3. Results

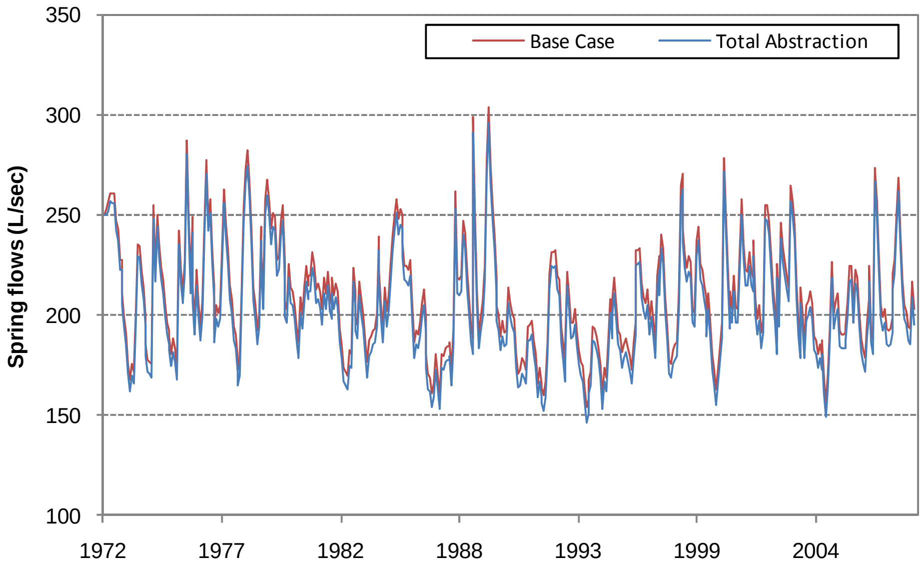
The following section outlined the results of the predictive simulations, specified in the previous sections.

7.3.1. Total Abstraction Assessment

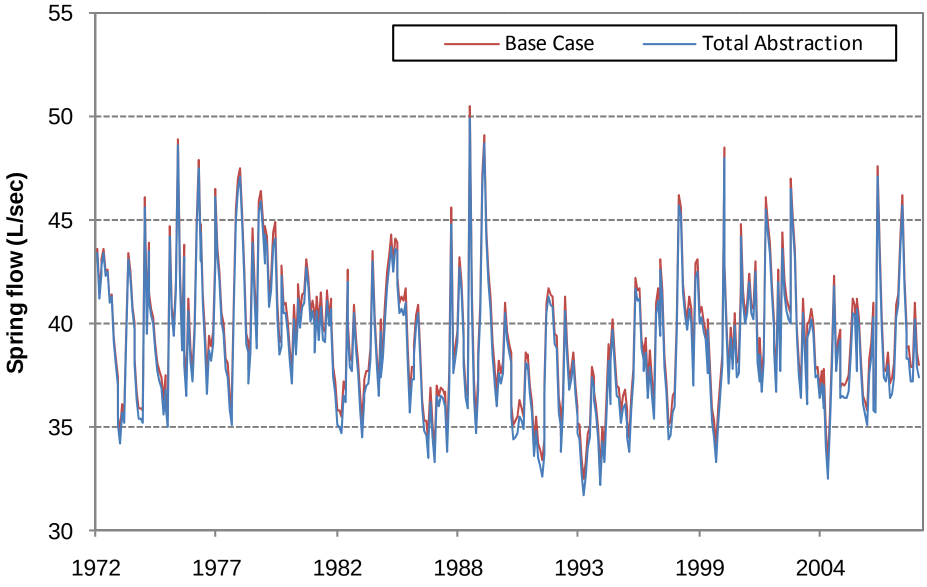
The potential long term effect of total consented abstraction on spring flows and groundwater levels were investigated during this assessment by comparing flows and levels from the Base Case (no abstraction) and Total Abstraction scenarios.

A small reduction in Poroti and Maunu Spring flows occurred as a result of simulating the total consented abstraction throughout the aquifer (**Figures 37** and **38**). The reduction in Poroti Spring flows was approximately 8 L/sec. This 8 L/sec reduction equates to approximately 73% of the consented abstraction from consent 461101 which is to be located next to Poroti Springs (the bore has yet to be drilled). This is consistent with the conceptual understanding of the aquifer system, in which the majority of an abstraction in the vicinity of Poroti Springs will come from spring flows. In essence, this abstraction could be deemed a surface water take.

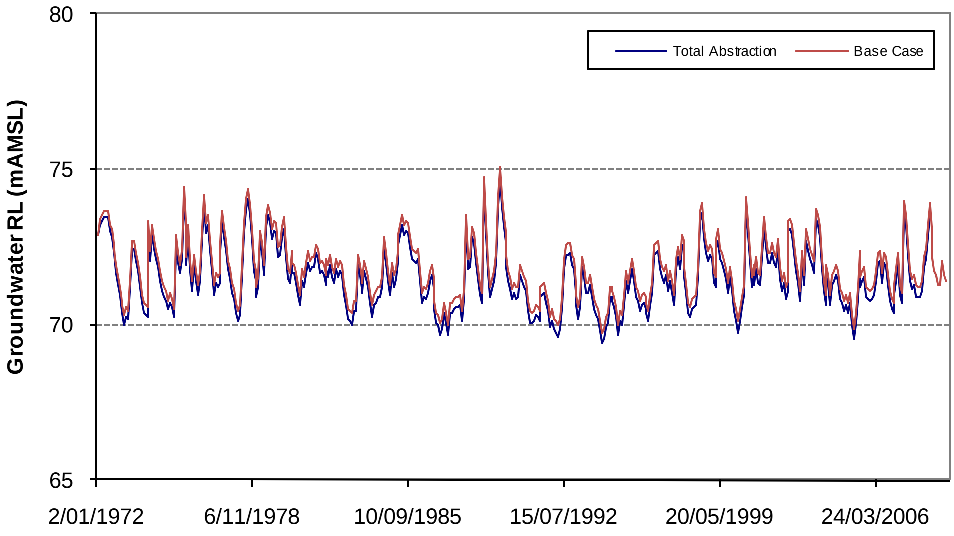
This finding was supported by the simulated groundwater level impact within 5471001 (located close to consented abstraction 461101) were assessed as shown in **Figure 39**. The groundwater levels were only slightly reduced throughout the scenario.



- **Figure 37. Long term modelled Poroti Spring flows.**

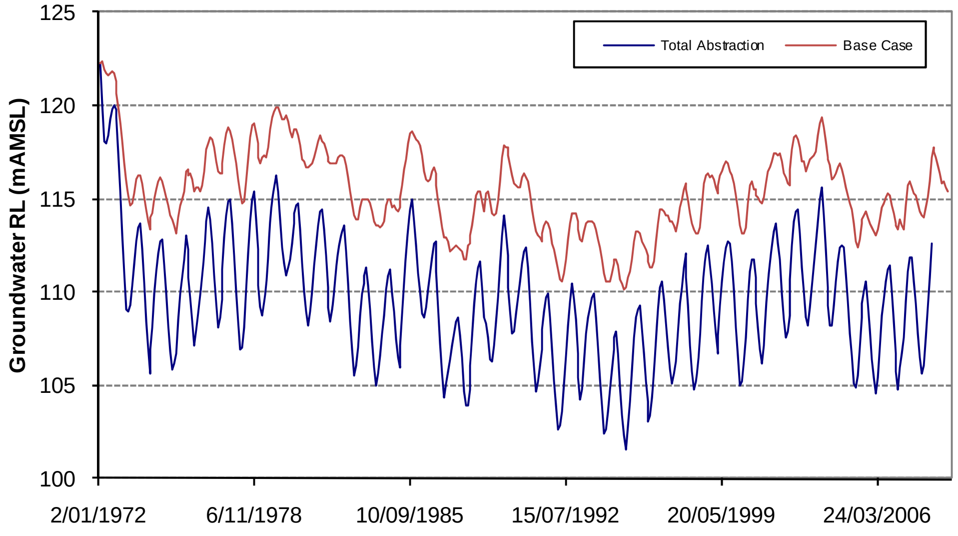


- **Figure 38. Long term modelled Maunu "Tunnel" Spring flows.**



- **Figure 39. Long term modelled groundwater levels in 5471001 monitoring bore.**

The largest affect during the Total Abstraction scenario occurred in the vicinity of bore 5471017 located on the western side of Whatitri Cone, i.e. away from the main discharge areas of the aquifer. Groundwater levels reduced between 2 and 7 m, with the greatest reduction occurring at the end of the irrigation season (**Figure 40**). This reduction is the result of several abstraction bores located in the vicinity of this monitoring bore. This level of drawdown is within the range of drawdown observed within this bore between 2001 and 2007, i.e. up to 5 m of drawdown.



- **Figure 40. Long term groundwater levels in 5471017 monitoring bore.**

7.3.2. National Environmental Standard Assessment

Table 14 outlined the allocation limit calculated for each sub-catchment based on the Proposed National Environmental Standard limit of 35% of average annual recharge. A review of the current consented allocation from each of the sub-catchments was completed with the results shown in **Table 15**. The total abstraction volume for each sub-catchment was then compared to the calculated NES allocation limit.

- **Table 15. Current consented abstraction from sub-catchments.**

Consent Number	Abstraction Volume (m^3/day)
Maunu Sub-Catchment	
224601	26
269301	138
320201	40
331801	10
349901	42
376401	60
397101	10
420601	18

Consent Number	Abstraction Volume (m^3/day)
439601	120
715801	55
719501	90
720701	260
729701	50
1138701	30
1951701	35
Total	**984**
Preliminary NES Allocation	**3,373**
Whatitiri Sub-Catchment	
177701	72
231001	60
231201	147
333001	12
726301	500
736901	150
746701	175
914501	72
1164301	15
1393401	20
1989601	16
Total	**1,239**
Preliminary NES Allocation	**5,667**
Maungatapere Sub-Catchment	
461101	1000
740001	30
866501	32
1170801	33
1327901	30
1514901	38
Total	**1,163**
Preliminary NES Allocation	**1,554**

Table 15 indicates that the current consented allocation does not exceed the calculated NES allocation limits in any of the three sub-catchments. The level of allocation from Maungatapere is close to the allocation limit. However, the abstraction for consent 461101 is included within the sub-

catchment abstraction volume. This bore is located next to Poroti Springs, with the majority of abstraction being sourced from Poroti Springs itself (see **Figure 36**).

The Proposed NES states that "for groundwater that is shown to be connected to adjacent surface water the environmental flow or water level set for surface water body will also apply to the management of water takes". It has been clearly shown through the modelling that the spring flow is connected to groundwater for the Maunu-Maungatapere-Whatitiri aquifer system and hence environmental flows must be considered in groundwater allocation limits to some degree. The timing of impact from groundwater pumping on surface water systems also needs consideration in allocation assessments.

The NES states that a minimum flow of 90% of the mean annual low flow (MALF) is required to be maintained within the streams. This is only applicable where alternative flows have not already been set within a Regional Plan. Northland Regional Council has a policy on maintenance flows for specific rivers (Policy12 in the Regional Water and Soil Plan for Northland) but do not have a policy on allocation limits.

In terms of Poroti Springs, the MALF has been calculated by Northland Regional Council to be 150 L/sec, resulting in a minimum flow of 135 L/sec. During the total abstraction scenario, the spring flow within Poroti Spring did not drop below 135 L/sec at any time, indicating that the current abstraction is not having a significant effect on spring flows. This was not the case when the WDC was previously allowed to abstract up to 23,000 m^3/day from a bore located next to Poroti Springs, as shown during calibration.

A similar assessment could not be undertaken for the Maunu Springs, as the MALF is unknown at this time. However, as only a small reduction in spring flows was observed during the Total Abstraction scenario, it is considered that the current level of groundwater abstraction is not having a significant effect on these spring flows either.

Overall, this assessment shows that using the allocation limit defined by the NES, additional groundwater abstraction could be allocated from the sub-catchments. However such allocation would need to be carefully assessed where it potentially reduces surface flows in surface water catchments where allocation already exceeds the allocation limit and maintenance flow requirements may need to be imposed.

8. Model Limitations

Within the scope of the project, a low complexity groundwater model was developed with a single calibration parameter set. The calibrated model predicts heads and fluxes with reasonably good faithfulness to measured data. The model tends to err on the side of conservatism, with respect to the purpose it was built (i.e. groundwater allocation analysis) - in that the recharge and hydraulic conductivity values applied are both at the lower end of the expected range. Indeed, we have as previously highlighted the overall groundwater model recharge percentage of mean annual rainfall is 17%, while the SMWBM analysis calculated groundwater recharge of 29% (**Table B2**).

Simulations utilising the calibrated model provides one plausible set of responses, however an equally well calibrated model with higher recharge and hydraulic conductivity to compensate, could potentially provide an equally plausible result. Such a model would likely result in sustainable yield values higher than calculated in this study.

To understand the range in potential water allocation outcomes, this model limitation (i.e. recharge assignment potentially at the lower end of the expected range) would need to be considered further. i.e. by undertaking additional calibration runs on the model using higher recharge and hydraulic conductivity values.

9. Conclusions

Northland Regional Council commissioned Sinclair Knight Merz (SKM) to undertake a hydrogeological review and groundwater numerical modelling assessment of the Maunu-Maungatapere-Whatitiri aquifers, west of Whangarei. These aquifers are classified as “High Actual or Potential Demand” aquifers under the Regional Water and Soil Plan for Northland (2004). The information obtained from this study will assist the NRC to effectively manage allocation and sustainably manage the groundwater resource.

Background data on the aquifer system reviewed for this study included regional geology, driller borelogs, rainfall and evaporation, hydrology, groundwater quality, groundwater abstraction and surface water abstractions. This information was used to conceptualise the aquifer system in terms of the lithology, groundwater levels, piezometric surface, aquifer hydraulic properties and aquifer recharge.

Using the aquifer conceptualisation, transient numerical groundwater model was constructed using FEFLOW. The model consisted of five layers which represented the main lithological units identified, i.e. volcanic clay, weathered basalt, scoria, and fractured basalt. This model was set up to run over a 27 year period between 1 February 1972 and 1 May 2009.

The groundwater model was calibrated against groundwater levels within fourteen Northland Regional Council monitoring bores and spring flows from Poroti Springs, Maunu “Tunnel” and “Chamber” Springs. Further the calibration of the model was determined through the assessment of selected hydraulic parameters (i.e. whether they are in the reasonable bounds of known parameters) and the overall model water balance including groundwater recharge.

The calibrated model predicts the groundwater levels and spring flows within the model domain with reasonably good accuracy, although there are some locations within the model that proved difficult to calibrate due to heterogeneities of the system (i.e. fracturing). The model and hence its results are considered conservative as both the hydraulic conductivity and recharge values applied are at the lower end of the expected range. In particular, we have highlighted that the overall groundwater recharge percentage of mean annual rainfall used within the model (17%) is lower than that calculated using the soil moisture water balance approach (29%).

The calibrated model was used to develop a high level sustainable yield of the aquifer system. In particular three scenarios were investigated:

- No abstraction;
- Total Consented Abstraction; and

- Allocation based on the Proposed National Standards on Ecological Flows and Water Levels.

The results of the Total Consented Abstraction Scenario were assessed in terms of potential long term effects on spring flows and groundwater levels. A small reduction in Poroti and Maunu spring flows was simulated. The maximum reduction in Poroti Spring flows was 8 L/sec which is a large proportion of the groundwater take located next to the springs. This is consistent with the conceptual understanding that the majority of groundwater abstraction in the vicinity of the springs will come from spring flows.

A comparison of the current consented abstraction from the three sub-catchments was compared to the allocation limit specified within the Proposed National Environmental Standards. This comparison found that the current consented allocation does not exceed the calculated NES allocation limits in any of the three sub-catchments. Overall, this assessment shows that using the allocation limit defined by the NES, additional groundwater abstraction could be allocated from the sub-catchments. However any future abstraction would need to be carefully assessed where it potentially reduces surface flows and maintence flow requirements may need to be imposed.

The limitations of the calibrated groundwater model are associated with the conservative nature of the modelling, i.e. the fact that the hydraulic conductivity and recharge values are within the lower end of the expected range. Simulations utilising the calibrated model provides one plausible set of responses, however an equally well calibrated model with higher recharge and hydraulic conductivity to compensate, could potentially provide an equally plausible result. Such a model would likely result in sustainable yield values higher than calculated in this study. To understand the range in potential water allocation outcomes, this model limitation (i.e. recharge assignment potentially at the lower end of the expected range) would need to be considered further.

10. References

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