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Preliminary Hydrogeological Investigations - Four Northland Aquifers

MANGAWHAI GROUNDWATER RESOURCE

- Report prepared for Northland Regional Council
- Final
- August 2005

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1. Introduction

Sinclair Knight Merz was commissioned by Northland Regional Council to provide preliminary hydrogeological assessments for four Northland aquifers – Mangawhai, Coopers Beach, Three Mile Bush and Glenbervie. These aquifers are recognised in the Northland Regional Water and Soil Plan (NRC, 2004) as being “at-risk” aquifers with respect to groundwater demand and water quality issues.

The information obtained from this preliminary hydrogeological study will assist the Northland Regional Council (NRC) to effectively manage allocation of the groundwater resource.

The specific objectives of the study include the following:

- Develop an understanding of the aquifer hydrogeology (groundwater recharge, hydraulic characteristics and discharge dynamics)
- Provide a preliminary estimation of the sustainable yield
- Identify information gaps and recommend future actions to enable the sustainable management of the groundwater resource.

This report provides an assessment of the Mangawhai groundwater resource. The Northland Regional Water and Soil Plan has classified the Mangawhai aquifer as being “at-risk” based on the potential for saltwater intrusion. In addition, the area is experiencing significant subdivision expansion, placing further pressure on the groundwater resource from additional groundwater abstractions and land use change.

2. Background Information

2.1 Site Location and Description

Mangawhai Village and Mangawhai Heads are coastal resort towns located approximately 100 km north of Auckland. The towns, in particular Mangawhai Heads, are currently experiencing subdivision, which is increasing the demand on groundwater. Groundwater in the area is used mainly as a supplementary domestic supply for many of the residences, and to a lesser extent for horticultural irrigation and stock drinking water. A number of bores have poor water quality, believed to be due to seawater intrusion, hence the classification of the area as being an "at-risk" aquifer.

The total study area is 14 km^2 encompassing Mangawhai Village, Mangawhai Heads and the sandspit bordering the estuary to the east (see Figure 1). Most of the study area is low-lying around the estuary, extending to 53 m above mean sea level (mAMSL) at Mangawhai Heads and approximately 100 mAMSL in the rolling hills behind Mangawhai Village. A volcanic intrusion just to the north of the Mangawhai Heads peninsula reaches 107 mAMSL.

Figure 1 shows the main points of interest of the study area, including the aquifer boundary. The aquifer boundary has been delineated based on the lithological change from coastal sands to consolidated hardrock of various types, and is as defined in the Northland Regional Water & Soil Plan (NRC, 2004). The NRC holds borelogs, hydraulic information, groundwater quality and groundwater level data for bores located outside of, but in close proximity to the aquifer boundary. Information from these bores has been included and discussed in this report for comprehensiveness. The bores are also included on Figure 1.

- **Figure 1. Locality Plan.**

(see A3 attachment at rear).

2.2 Regional Geology

The geology of the Mangawhai Area is described on the 1:250,000 Geological Map Sheet 2A for Whangarei, and is reproduced in Figure 2.

Greywacke and argillite basement rocks of Permian to Jurassic age (295 to 145 million years before present) underlie the study area at depths of between 100 and 690 m below mean sea level (Massey, 1987). The rocks are dark grey or green, intensely deformed, jointed or sheared with secondary silica or calcite along the joint planes (Thompson, 1961). They are upfaulted to the north of the study area along the E-NE trending Waipu Fault.

Overlying the downfaulted basement rocks within the study area are Cretaceous to Oligocene age (145 to 25 million years) Northland Allochthon sediments. 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 result of this mode of deposition, the Northland Allochthon rocks have been substantially faulted, fractured and sheared, and rocks of differing age are commonly found together or within close proximity to each other. The rocks that outcrop within the study area include Mangakahia Group sandstones of Cretaceous age, and Opahi Formation greensands, argillaceous limestone and shale of Eocene age. The Mangakahia Group sediments outcrop in the centre of the study area near Tara Creek, and are grey, sulphurous and micaceous. The Opahi Formation sediments outcrop to the north of the study area, with closely fractured grey-white argillaceous limestone being most commonly exposed.

Overlying the Northland Allochthon sediments are Waitemata Group sandstones and mudstone of Miocene age (25 to 6 million years old). The Waitemata sediments are widespread beneath and around the study area and comprise dark grey non-calcareous sandstones thinly or thickly bedded with mudstone. There are occasional thin coal seams, fossils (shell fragments, limestone) and volcanic breccia beds (Thompson, 1961). The rocks are moderately hard and can be weakly to moderately fractured. They typically weather to soft yellow brown silty clays to depths of 30 m (NRC, 1989).

There are intrusions of Late Miocene age Parahaki Volcanics (dacite lava and tuff) on the northern headland near Mangawhai Heads and to the west of the study area. The dacites are light grey, and weather to soft white or brown clays (NRC, 1989).

There are small isolated outcrops of Pliocene age (6 to 2 million years) Ti Point olivine basalts near the centre of the study area (Thompson, 1961).

The predominant surface geology of the study area is Pleistocene to Recent (up to 2 million years old) coastal sand dunes and alluvium, located at low elevations around the estuary and in the stream valleys. The sands form active dunes around the ocean beach and fixed dunes and terraces further inland (ie. Mangawhai Heads). The Pleistocene terrace deposits are poorly consolidated silty sands, muds and gravels with minor vegetative remains (plant fragments and peat). A hard iron pan often caps these deposits (Massey, 1987). In some locations where the deposits are exposed at the surface the sediments have weathered to brown stained, soft clayey sand to depths of 15 m (NRC, 1989). Overlying the Pleistocene terraces are Recent fixed and active dunes, which thicken around the estuary and coastline. These sediments are unconsolidated and unweathered sands. The alluvium within the stream valleys is comprised of sands, muds, and gravels with minor peat.

- **Figure 2. Regional Geology.**

(see A3 attachment at rear).

2.3 Geological Structure

The greywacke basement rocks that outcrop to the north of the study site are upfaulted along the E-NE trending Waipu Fault. Gravity data provided in Massey (1987) shows that the fault dips very steeply on the down-thrown side reaching a maximum depth of 690 m just south of Sentinel Rock. The greywacke basement gradually becomes shallower to the south, outcropping again near Te Arai Point.

The fault abruptly terminates Northland Allochthon and Waitemata sediments, but is overlain with Parahaki Volcanics. This indicates that the fault movement postdates Waitemata Group deposition but predates Parahaki Volcanic emplacement.

The outcrop of Northland Allochthon (Mangakahia Group) sediments to the west of the estuary, which is surrounded by approximately 200 m of Waitemata sediments (see log of bore 208246), suggests that further faulting (block faulting) has occurred within the greywacke basement after deposition of the Waitemata sediments.

2.4 Drillers Borelogs

There are 80 boreholes registered on the NRC bore database for Mangawhai. A summary of the relevant bore construction and hydraulic test details are included in Appendix A, and Figure 1 shows the approximate location of the bores.

Eighteen bores are screened within the coastal dune sands to depths of between 4.5 and 33.5 m, with diameters of 38 to 150 mm. The aquifer has yields ranging from 12 to 409 m^3/day. The limited extent and depth of the sand aquifer beneath the water table and the presence of intercalated silts, clays and thin iron pans restricts the volume of water that can be abstracted, as indicated by the low number and distribution of bores drilled into the sand. Some logs have brief comments relating to poor water quality (high iron, sulphur odours), which is typical of decomposition of vegetative remains in recent alluvial sediments.

The majority of the bores tap into the Waitemata sediments. The bores are between 12.6 and 210 m depth, with an average depth of 65 m. The bores are 64 to 100 mm in diameter and are generally open (unscreened) through the sandstone. Yields range from 9 to 454 m^3/day, with the greatest yields from fractured zones with the sandstone. The fracture zones appear to be located at greater depths. Artesian flows are reported in four bores (208249, 208276, 208344 and 208376), which are relatively deep (>55 m) and situated at low elevations around the estuary and in the stream valleys. Some bore logs have brief water quality comments relating to saltwater contamination, sulphur odours and slight iron discolouration.

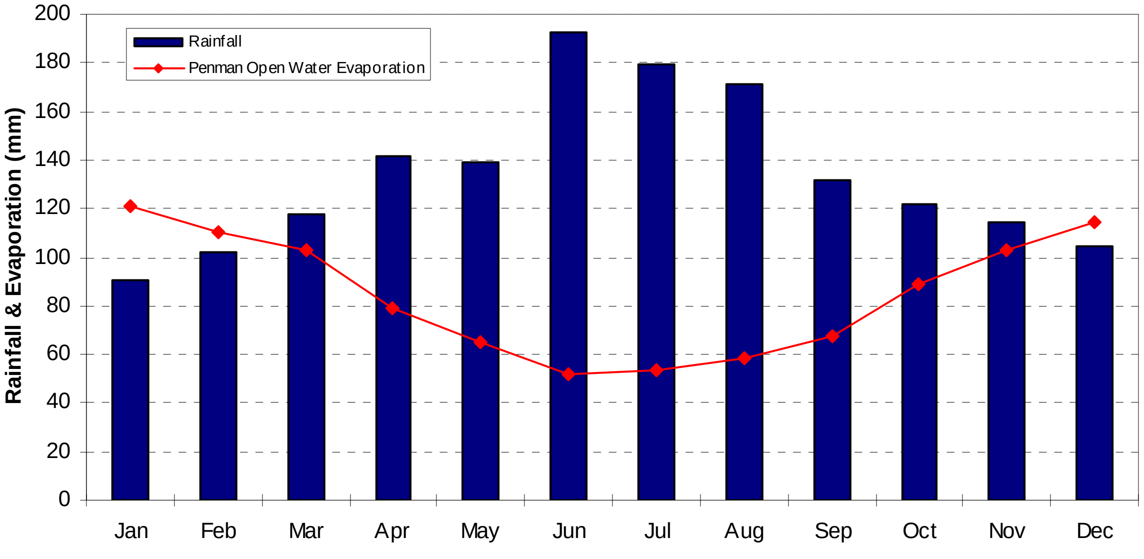
It should be noted that there may be inaccuracies in the drillers' logs, in terms of approximate bore locations, lithology and yield. This has implications on the conceptualisation of the aquifer discussed later in this report, including aquifer lithology, aquifer properties and piezometric surface distribution.

2.5 Hydrology

There are two main streams in the area, including Tara Creek that drains the Tara volcanic area west of the study area and Bob Creek that drains the Waitemata sediments. Tara Creek is partly spring fed from springs emerging from the basalt. No information is available on stream flows, however monitoring of one spring flow near Tara indicates flow of up to 311 m^3/day (NRC, unknown date). The stream flows are likely to be higher than this, due to the discharge of a number of spring flows into the stream, and surface and groundwater inputs further down the catchment.

2.6 Rainfall and Evaporation

Figure 3 shows mean monthly rainfall for Tara (Station A641511) for the period 1946 to 2004 (missing data between 1983 to 1989), and mean monthly evaporation for Leigh (Station A64282) for the period 1972 to 2004. The annual average rainfall is 1,600 mm. Rainfall exceeds evaporation for all but the summer months, indicating the availability of water for groundwater and surface water recharge for most of the year.



- **Figure 3. Mean Monthly Rainfall and Evaporation.**

2.7 Groundwater Abstraction

The current allocation for groundwater is summarised in Table 1. There are 12 consented groundwater takes ranging from 10 m^3/day to 250 m^3/day, resulting in a total allocation of 815 m^3/day. Figure 4 shows the location of the consented groundwater takes. Three of the consented takes are from the sand aquifer at Mangawhai Heads.

Groundwater takes of less than 1 m^3/day within an "at-risk" aquifer do not require a resource consent (NRC, 2004). Assuming that the remaining 78 bores on the NRC database[1] that do not have consented allocations use their permitted water right during peak periods, the total groundwater allocation for Mangawhai would be 893 m^3/day.

The total groundwater allocation for the aquifer does not reflect actual groundwater use. In addition, there are likely to be additional bores in the study area that have not been identified and registered on the NRC bore database. A survey to identify all existing bores in the study area, as well as a review of water use records is required before total groundwater use can be determined.

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[1] Includes 3 bores not on NRC bore database (ie. bores with drillers logs) but for which the NRC have water quality or aquifer test information.

- **Table 1. Existing Groundwater Consents.**

NRC No.	Name	Allocation (m^3/day)	Bore depth (m)	Expiry date	Purpose
Sand					
20010481901	Hakaru Bowling Club Inc	15	10	31/05/2012	Horticultural irrigation
20010803201	Kaipara District Council	136	10	Suspended	Public water supply
20010234401	Mangawhai Golf Club Inc	250	10	31/05/2012	Sport and recreation
Waitemata					
20030446601	GE McConachy	10	40	31/05/2020	Private water supply
20031093201	GA Crosbie	50	48.8	31/05/2008	Horticultural irrigation
19960197801	B Smith	25	19	31/05/2007	Accommodation
19970350802	Riverside Motorcamp	20	40	31/05/2007	Accommodation
19970254901	Mangawhai Estates	200	100	31/05/2007	Horticultural irrigation
19970395002	Three G Orchard Ltd	50	106.7	31/05/2007	Horticultural irrigation
20010424801	J Spyksma	35	54	31/05/2020	Horticultural irrigation
20010808702	Moirs Point Christian Camp	10	140	30/09/2016	Accommodation
19980438701	Hideaway Holiday Park	14	38	31/05/2008	Accommodation
TOTAL		**815**			
Sand	17 additional bores	17			
Waitemata	68 additional bores	61			
TOTAL		**893**			

- **Figure 4. Existing Consents.**

(see A3 attachment at rear).

3. Aquifer Conceptualisation

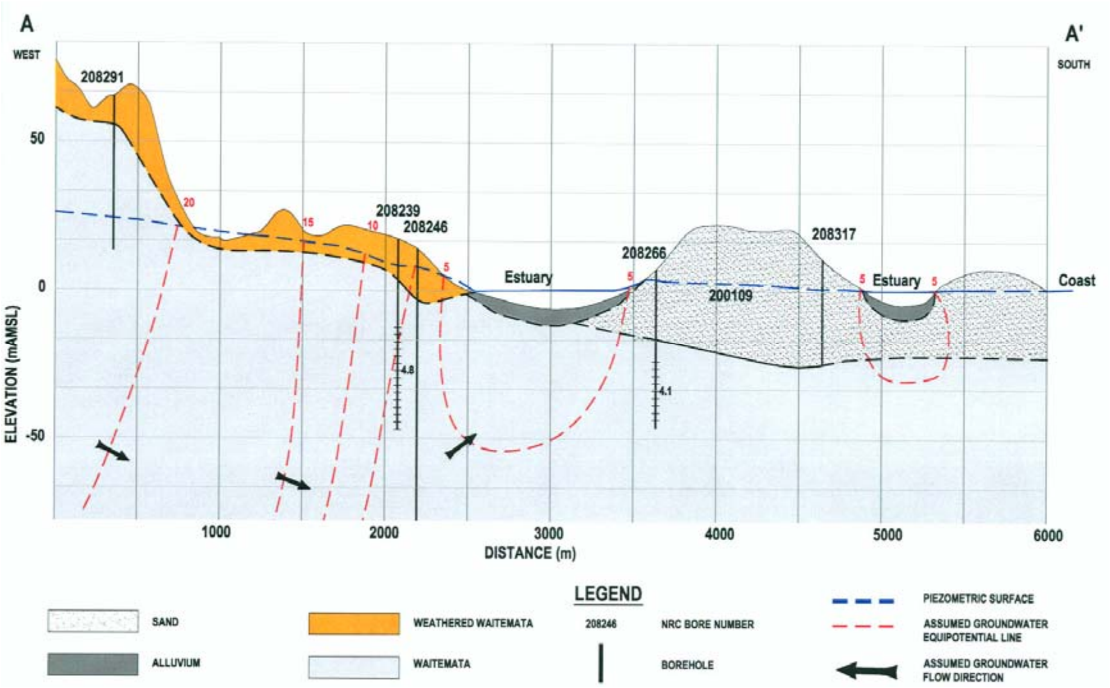
3.1 Aquifer Lithology

Borelogs from the NRC database within the study area show the site geology to consist of the following:

- Loose to consolidated brown sand (active and fixed dunes) up to 34 m thick.
- Grey sand to silty sand interspersed with layers of gravel, peat, iron pans and shells (older fixed dune and terrace deposits). These sediments are up to 18 m thick and are generally overlain with younger brown dune sand.
- Alluvial clays and gravels up to 11 m thick.
- Sticky yellow and blue clays up to 22 m thick (weathered Waitemata rock).
- Soft to hard, grey to blue-grey Waitemata sandstone and mudstone with traces of coal and limestone. The rock is fractured in some places, generally at deeper depths. The Waitemata sediments are overlain with one or more of the above deposits depending on bore location.
- Opahi Formation grey-white argillaceous limestone (ie. Northland Allochthon rocks) is logged in bore 208246 at 195 m depth.

These geological descriptions are consistent with the regional geology described in Section 2.2.

A hydrogeological cross-section (A-A') oriented north to south through the study area has been compiled from drillers logs. The section position is indicated on Figure 4 and the cross-section is shown in Figure 5.



- **Figure 5. Hydrogeological Cross-Section.**

3.2 Groundwater Levels

Depth to groundwater for the sand aquifer, obtained from drillers' logs, ranges from above ground level (artesian conditions) to 19.0 mBGL. The artesian conditions occur in bore 208344, located at a low topographic elevation near the estuary. The bore is screened through the Waitemata sediments to 54.9 m depth, but the artesian conditions were encountered at 9 m depth during drilling. The artesian conditions may be due to some sort of confining layer within the sands, although the drillers log is insufficiently detailed to be certain. The deepest groundwater level occurs in the deepest bore screened through the sand (bore 208317).

Depth to groundwater for the Waitemata aquifer ranges from above ground level (artesian conditions) to 45 mBGL. The artesian conditions occur in three bores (208249, 208276, and 208376), located at low topographic elevations around the estuary and within the stream valleys. The bores are all deep bores (ie. greater than 83.2 m depth), indicating that groundwater pressures increase with depth to the point that artesian conditions occur. Groundwater upwelling (discharge) occurs at these locations.

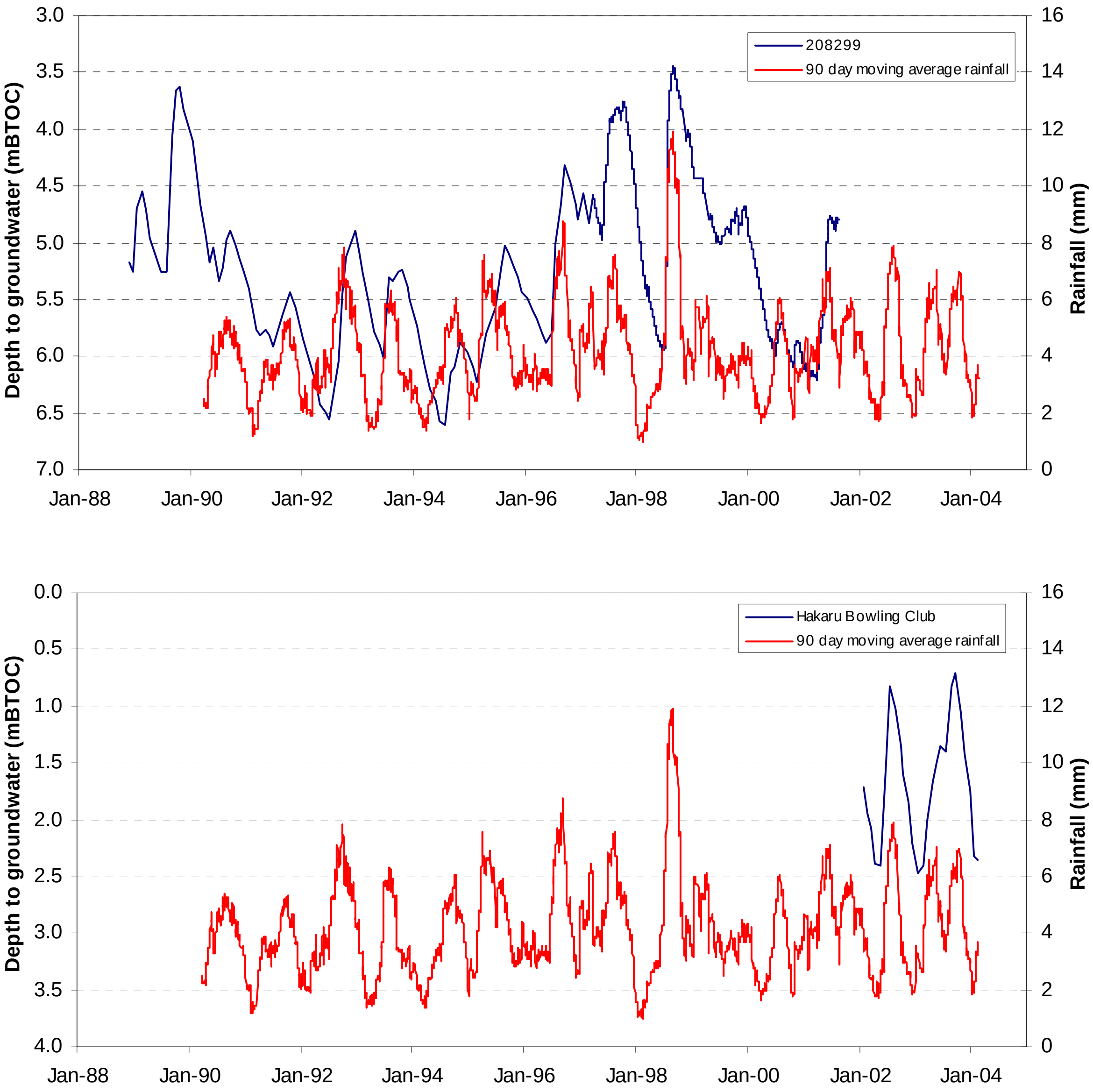
Groundwater levels have been monitored by the NRC in seven bores since 1986. Table 2 summarises the bore details and water level monitoring frequency and Appendix B includes the groundwater hydrographs for each bore. Figure 4 shows the locations of the monitoring bores.

- **Table 2. Groundwater Level Monitoring Bore Details.**

Bore	Owner	Bore depth (m)	Period of record	Type of measurement	Frequency of measurement
208234	H Marshall	96	1986 - 1989	Manual	Monthly
208243	Mangawhai Estates	100	1987 - 1988	Automatic	15 minutes
208246	Bower 3	210	1987 - 1988	Automatic	15 minutes
208269	J Coats (Alamar Rd)	27.4	1986 - 1989	Manual	Monthly
208299	Medical Centre	11	1988 – 1997 1997 - 2001	Manual Automatic	Monthly 15 minutes
-	Hakaru Bowling Club	10	2002 - 2004	Manual	Monthly
-	Domain	128	1987 - 1988	Automatic	4 hourly

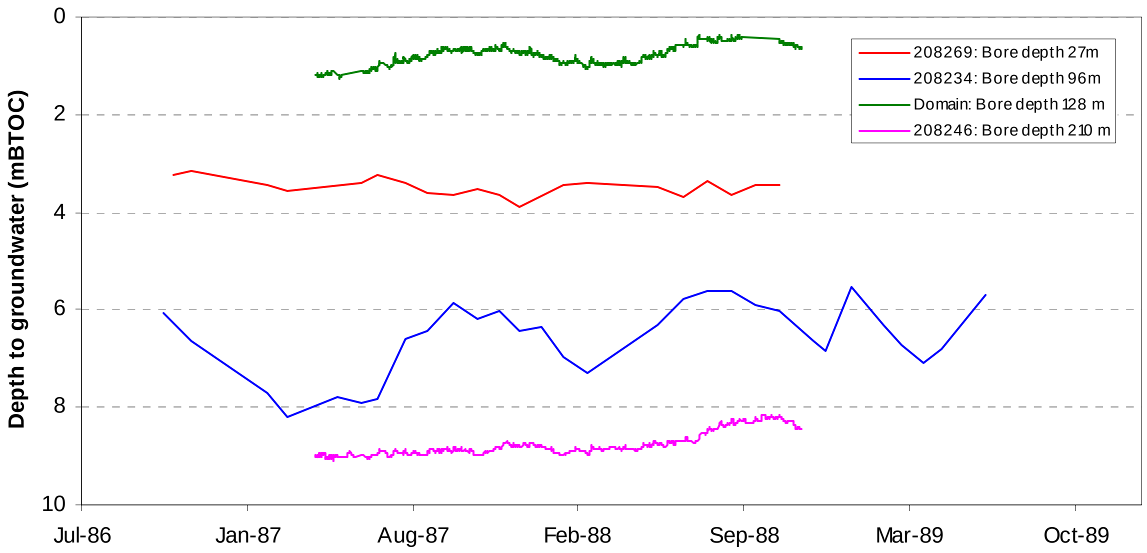
Figure 6 shows the groundwater hydrograph for bore 208299 and Hakaru Bowling Club, along with the 90-day moving average rainfall in order to compare groundwater responses to climatic conditions. Both bores are screened within the sand aquifer. No bores screened within the Waitemata aquifer have been compared to rainfall as the Tara rainfall station record has missing data corresponding to the period of groundwater level monitoring.

Groundwater levels within the sand aquifer oscillate seasonally, with maximum elevations occurring during spring and minimum elevations towards the end of the autumn months. The groundwater response in bore 208299 lags between one month and three months behind the rainfall response, whereas the lag in the Hakaru Bowling Club bore is approximately 1 week. Both bores are shallow (ie. approximately 10 m depth) and are located within 200 m of each other. The slower response in bore 208299 may be due to the presence of silts and clays acting as a confining layer within the sand, although there is insufficient detail on the borelog to be certain of this.



- **Figure 6. Hydrographs for Bore 208299 and Hakaru Bowling Club with Moving Average Rainfall.**

Groundwater levels for four bores screened through the Waitemata sediments are shown on Figure 7. The groundwater levels for bore 208243 have not been included on Figure 7, as pumping of the bore or a nearby bore has influenced the measurements. Both the Domain bore and bore 208269 are located at lower topographic elevations than bore 208234 and 208246, and have shallower depth to groundwater levels.



- Figure 7. Groundwater Hydrographs for Waitemata Bores.

3.3 Piezometric Surface Distribution

Figure 8 and Figure 9 are plots showing the piezometric surface geometry for the sand aquifer at Mangawhai Heads and the Waitemata aquifer, respectively. The piezometric surface was constructed from depth to groundwater information from the drillers' logs and NRC monitoring data, and estimated ground level elevations. Bores screened at depths greater than 90 m were not included in the Waitemata aquifer piezometric surface, as the groundwater levels were inconsistent with levels from shallower bores (ie. artesian heads).

Groundwater pressures within the sand aquifer display a similar geometry to topography, albeit at a shallower gradient. Groundwater pressures range from approximately 0 mAMSL along the estuary to 25 mAMSL near the centre ridgeline of the peninsula.

Groundwater pressures within shallow bores in the Waitemata aquifer are also similar to topographic contours, with pressures ranging from 0 mAMSL around the estuary to 25 mAMSL in the hill area behind Mangawhai. The regional groundwater flow direction is from high hydraulic head in the hill area to low hydraulic head at the estuary. The groundwater pressures in the Waitemata aquifer are generally lower than groundwater pressures in the sand aquifer, except where artesian pressures are encountered. This suggests that the sand aquifer can potentially recharge the underlying Waitemata aquifer.

Although not included on the piezometric surface plot, the artesian heads in deep bores at low elevations around the estuary indicate upward groundwater flows at these locations.

- **Figure 8. Piezometric Surface – Sand aquifer.**

(see A3 attachment at rear).

- **Figure 9. Piezometric Surface – Waitemata Group.**

(see A3 attachment at rear).

3.4 Aquifer Hydraulic Properties

Information on hydraulic properties is available from aquifer test pumping exercises conducted on nine bores within the study area. Most of the test pumping exercises were conducted to obtain information for water right applications, however some of the tests were conducted as part of a 1987 investigation into the Mangawhai water resource undertaken by the Northland Catchment Commission (NCC). Drawdown data for two bores was analysed during this study. The analysis results are included in Appendix C.

The hydraulic properties are summarised in Table 3. Only one test pumping exercise has been conducted within the sand aquifer. Transmissivity for the sand ranged from 440 to 700 m^2/day and specific yield was estimated at 0.04. The specific yield is within the expected range (0.01 - 0.30) for an unconfined aquifer (Freeze & Cherry, 1979). Hydraulic conductivity was estimated from the saturated thickness of the aquifer and the transmissivity, and ranged from 47 to 75 m/day. This is within the range of reported values for silty to clean sand (Freeze & Cherry, 1979).

Transmissivity for the Waitemata aquifer ranges between 1 and 20 m^2/day, and hydraulic conductivity ranges from 0.01 to 2 m/day. The hydraulic conductivity values are at the upper end of literature values for sandstone, which are reported to range between 10^{-6} and 10^{-2} m/day (Freeze & Cherry, 1979). This is most likely due to the presence of fractures within the sandstone. Storativity ranges between 0.002 and 0.0002, and is indicative of a confined aquifer.

- **Table 3. Summary of Aquifer Hydraulic Properties.**

Bore	Owner	Bore depth (m)	Casing depth (m)	Saturated thickness (m)	Q (m^3/day)	T (m^2/day)	S (-)	K (m/day)
	Waitemata							
208232	S Wright	21	12	10	164	20	-	2
208240	M Bower	64	24.4	42.1	103	2.9 – 5.7	-	0.07 – 0.14
208243	Mangawhai Estates	100	11.4	92	157	14.3	-	0.16
208243	Mangawhai Estates	100	11.4	92	135	7.5	1.6×10^{-3}	0.08
208244	Mangawhai Estates	104.2	19.2	99.3	65	7.6	-	0.08
208249	McCabe	83.2	25.6	79.2	5	1	-	0.01
-	Becroft Orchards Ltd	106.7	48.8	58	137	15 - 27	-	0.26 – 0.47
-	Russell	27	18	9	280	8.3	1.5×10^{-4}	0.92
-	Mang. Farm Partnership	54.9	36.6	18	285	14	-	0.78
	AVERAGE					11.7	8.8×10^{4}	0.50
	Sand							
208287	Mangawhai Golf Club	10.7	7.5	9.3	340	440 - 700	4×10^{-2}	47 - 75

Notes: Q = discharge, T = transmissivity, S = storativity, K = hydraulic conductivity; Drawdown data for Becroft Orchards Ltd and 208244 was analysed during this study.

3.5 Groundwater Quality

The NRC routinely monitors groundwater quality in two bores located beside Mangawhai Harbour (Hideaway Holiday Park and Riverside Motor Camp). In addition, groundwater quality information is available for 12 bores sampled by the NCC (now NRC) in 1987. The NCC sampling was conducted as part of an investigation into the origin and composition of high salinity waters in some bores, which was suspected to be indicative of seawater intrusion. Table 4 summarises the sampling results for these bores. The bore locations are shown on Figure 4.

Values in Table 4 that exceed the Drinking Water Standards for New Zealand (DWSNZ) published by the Ministry of Health (2000) are highlighted in red. Exceedances occur for the following list of parameters (guideline value in brackets):

- Boron (1.4 mg/L)
- Aluminium (0.15 mg/L)
- Chloride (250 mg/L)
- Hardness (200 mg/L)
- Iron (0.2 mg/L)
- Manganese (0.05 mg/L)
- pH (7.0 – 8.5)

- Sodium (200 mg/L)

Boron exceeds the Maximum Acceptable Value (MAV) for inorganic determinands of health significance in the majority of bores located close to the estuary. Natural sources of elevated boron include water in contact with volcanic rocks and within geothermal areas. The elevated boron at Mangawhai is consistently found in bores that also have elevated chloride and sodium concentrations.

Chloride and sodium exceeds the aesthetic Guideline Value (GV) under the DWSNZ. Exceedance of the GV's for aesthetic determinands indicates that the groundwater has an unpleasant taste and appearance. The high chloride and sodium concentrations could have several origins including seawater intrusion, connate seawater and marine evaporites trapped in sedimentary rocks, or geothermally heated water. The source of the high chloride, sodium and boron concentrations at Mangawhai is discussed further later in this chapter.

The remaining parameters are all aesthetic determinands under the DWSNZ. Elevated iron and manganese has the potential to cause "rusting" of bore and plumbing fixtures, and are common in alluvial aquifers where reducing conditions may be present. The low pH (less than 7) measured in four bores is potentially corrosive, while the high pH (8.8) measured in the Domain bore may give a soapy taste.

High hardness values, indicative of high calcium and magnesium concentrations, occur in four bores located at low elevations near the estuary. High hardness has the potential to cause scale deposition and corrosion. Calcium and magnesium are common constituents of sedimentary rocks.

Aluminium concentrations have only been measured in the Riverside Motorcamp bore. The elevated concentrations have the potential to discolour the water and cause deposition of aluminium hydroxides. Although aluminium is an abundant element in many rocks and soils, it rarely occurs in solution unless the pH of the water is very low or there are high concentrations of complexing agents such as fluoride, sulphate or humic substances (USGS, 1985). As the water in the Riverside Motorcamp bore has near-neutral to high pH and the fluoride and sulphate concentrations are not unusually high, the high dissolved aluminium concentrations may be due to the presence of humic acids in the water (ie. from peat).

- **Table 4. Summary of Groundwater Quality Results.**

Parameter (mg/L)	Hideaway	Riverside	208234	208235	208240	208243	208244	208244(2)	208246	208246(2)	208247	208276	208284	Domain	Wood	MFP
Date sampled	20 May 04	20 May 04	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987
Alkalinity	129	231	173	23	62	217	46	36	94	161	39	356	257	28	51	164
Aluminium		0.31														
Ammoniacal-N	0.08															
Bicarbonate	157	276	211	28	75	264	56	20	115	196	48	434	313	0	62	200
Boron			0.09	0.05	8.6	0.08	5.4	14	0.1	7.6	9.4	31	0.08	18	13.1	0.09
Bromide	0.18	0.54														
Calcium	14.2	18.5	50	7	35	37	52	0.9	25	32	110	70	61	89	75	34
Chloride	45.7	189	39	27	566	57	740	1160	39	430	1115	865	25	1195	1080	29
Conductivity (mS/m)	39.4	83.8	44	18	178	57	248	366	31	165	350	322	50	375	339	37
Dissolved oxygen	5.6	3.4														
DRP	0.062	0.163														
E. coli (MPN/100mL)	<1	<1														
Total coliforms (cfu/100mL)	2	<1														
Fluoride	0.1	0.24	0.02	0.03	0.46	0.1	0.05	0.07	0.09	0.48	0.29	0.63	0.11	0.48	0.48	0.09
Hardness	67	65	163	41	96	123	140	139	81	84	307	274	197	223	202	121
Iron	1.08		2.5		0.13	0.17							0.86		0.1	1.1
Lithium			0.02	0	0.04	0.02	0.08	0.11	0.01	0.05	0.08	0.44	0.02	0.06	0.09	0.01
Magnesium	7.72	4.48	9.2	5.6	2.1	7.4	2.8	0.9	4.4	1	7.8	24.5	10.8	0.3	3.6	8.8
Manganese	0.159	0.0238														
Nitrate-N	<0.002	<0.002														
Nitrite-N	<0.002	<0.002														
pH	7.1	7.9	6.8	6.4	8.1	7.6	8.2	8.4	6.6	7.7	8	7.4	7.5	8.8	7.4	6.9
Potassium	2.77	1.68	1.7	1	1.5	1.5	1.6	1.6	1	1	1.9	5.2	1.7	0.038	1.7	1.4
Silica (soluble)	77.7	21.1														
Sodium	60.8	207	30	17	336	81	404	588	38	324	648	488	38	500	623	38
Sulphate	6.1	10.7	5	3.8	1	1	<0.5	<0.5	10	0.9	<0.5	<0.5	4	<0.5	<1	3
Temperature (°C)	16.9	17.6	19	11.5	18.5	19	16	17.5	18	18	17.5	16.5	18	18	18.5	19
Total organic carbon	1															
Water type	$NaHCO_3$	NaCl	$Ca(HCO_3)_2$	$CaCl_2$	NaCl	$NaHCO_3$	NaCl	NaCl	$NaHCO_3$	NaCl	NaCl	NaCl	$Ca(HCO_s)_2$	NaCl	NaCl	$Ca(HCO_s)_2$
Chloride/Boron ratio			433	540	66	713	137	83	390	57	119	28	313	66	82	322

Notes: Metal concentrations are for dissolved metals; Only the latest sampling round for Hideaway Holiday Park and Riverside Motorcamp has been presented; Bore 208244 (2), 208246 (2) and Domain are sampled at 100 m depth; Bore 208244 is sampled at 50 m depth; Bore 208246 is sampled at 16 m depth; MFP = Mangawhai Farm Partnership.

Figure 10 is a Piper Diagram of the major anions and cations (presented in milli-equivalents) for all bores for which data is available. The tri-linear diagram enables the water to be characterised in terms of its major constituents, which are governed by geologic and chemical processes. The bore data is grouped according to water type, and includes data for seawater, geothermal water (Parakai) and mixed cooled geothermal water from Parakai (Aspden), which were sampled concurrently with the groundwater bores in 1987 by the NCC.

Groundwater that has no dominant cations and is proportionally higher in bicarbonate is classified as Ca-HCO_3 type water. This type of water is relatively young recharging water that has not had time to dissolve rock minerals or mix with other water types. Bores with Ca-HCO_3 type water include 208234, 208284 and Mangawhai Farms Partnership. These bores are located furthermost away from the estuary within the Waitemata sediments (see Figure 4).

Na-HCO_3 type water occurs in bores 208243, 208246 (sampled at 16 m depth), and Hideaway Holiday Park. These bores are also screened within the Waitemata sediments but are situated close to the estuary. Na-HCO_3 type water is indicative of ionic exchange of calcium and sodium cations on clay lattices and occurs at deeper depths in the Waitemata rocks.

There was one bore sampled (bore 208235) that had CaCl type water, which is probably indicative of mixed Ca-HCO_3 and NaCl type water. This bore is relatively shallow at 32 m depth.

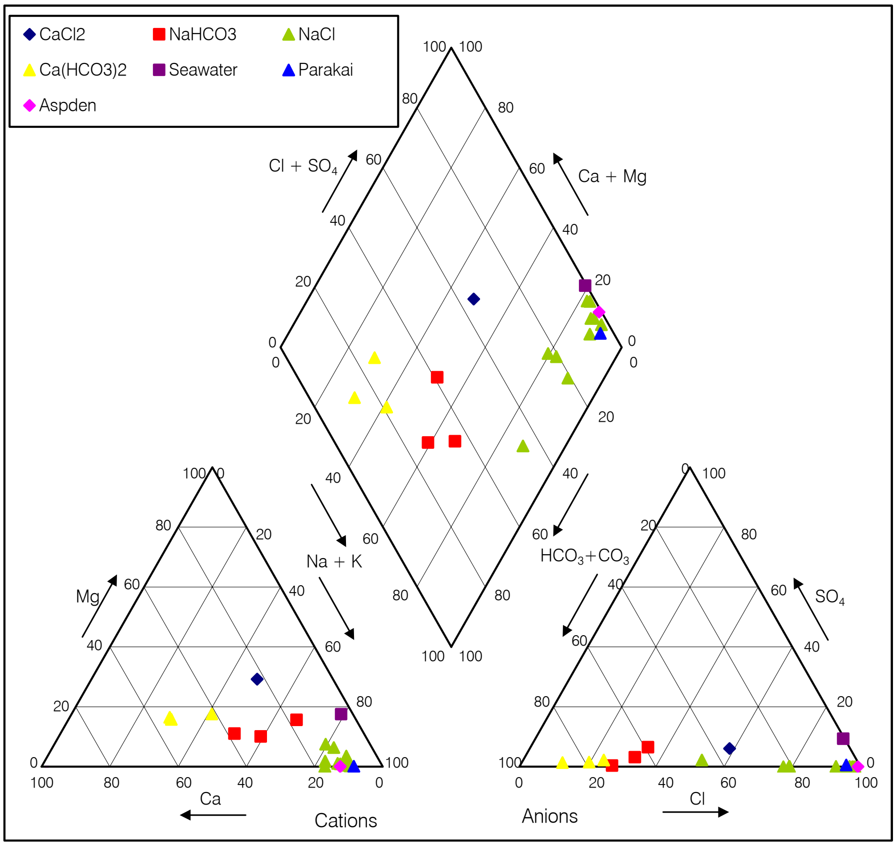
The majority of bores sampled at Mangawhai have NaCl type water, indicative of a saline water influence. All NaCl bores sampled were located close to the estuary, and ranged in depth from 30 to 212 m. With the exception of bores 208246 (sampled at 100 m depth), 208276 and Riverside Motorcamp, the NaCl type waters are similar to geothermal waters (see Parakai and Aspden samples on Figure 10). Water from bores 208246, 208276 and Riverside Motorcamp have a greater proportion of bicarbonate and less chloride than the geothermal samples.

The high chloride concentrations in bores with NaCl type water could have a number of different origins including:

- active and relic seawater intrusion;
- connate seawater or evaporites trapped in marine sediments;
- geothermally heated water; or
- a mixture of the above.

Geothermally heated water generally has high concentrations of boron, fluoride and lithium (KRTA, 1986). As the high chloride concentrations found in the NaCl type bores are correlated with elevated boron, fluoride and lithium, the source of the saline water is considered to be due predominantly to thermal water recharge. There is also considered to be a secondary indirect contribution from connate water high in chlorides, as indicated from magnesium concentrations that are higher than expected from thermal water only but less than expected from active seawater intrusion. A more detailed discussion of the chemistry of the NaCl type waters is given in Appendix D.

A conceptual model for thermal water intrusion at Mangawhai has been proposed by the NRC (1989) based on a model developed by KRTA (1986) for waters at Franklin-Clevedon. The model involves the circulation of groundwater through the greywacke basement rocks at depths of 1 km or greater. Waters at these depths are heated by the regional thermal gradient and mobilise chloride, boron, lithium and fluoride from the greywacke. The mineralised water subsequently ascends into the Northland Allochthon and Waitemata rocks where permeability permits, most probably along the Waipu Fault and through block fracture systems.



■ **Figure 10. Groundwater Chemical Characterisation Plot (Piper Diagram).**

3.6 Surface Water Quality

Surface water monitoring conducted by the NRC at Mangawhai since 1989 has shown variable, but often high faecal coliform concentrations in drains and streams. The faecal contamination has been attributed to catchment runoff and seepage from on-site sewage treatment and disposal systems, with the latter considered to be the main cause for contamination around Mangawhai Heads - a predominantly residential area. The NRC conducted an investigation into the source of the contamination in 1997, which involved a comprehensive water quality survey of streams and drains around Mangawhai Heads and Mangawhai Village, and the collection of shellfish samples at the stream and drain outlets. The purpose of the survey was to demonstrate that Mangawhai would benefit from a community sewerage scheme or upgraded on-site treatment and disposal systems.

Faecal coliform bacteria were detected in 81 and enterococci in 82 of the 83 water samples collected during the survey. Median concentrations of faecal coliforms at all sites ranged from 10 to 13,400 cfu/100 mL, taken over 3 sampling occasions. Only 3 out of the 30 sampling sites had median concentrations less than 126 cfu/100 mL, which is the median guideline limit for *E.coli* for the purpose of contact recreation as specified in the Northland Regional Water & Soil Plan (NRC, 2004). The results of the survey were consistent with historical monitoring data. Enterrococci were detected in all but one of the 100 shellfish samples collected.

Overall, the results indicate that faecal coliform contamination arising from seepage from on-site sewage treatment and disposal systems is a problem in most parts of Mangawhai Heads and Mangawhai Village. The faecal contamination of drains and streams is having adverse effects on shellfish quality in Mangawhai Harbour (NRC, 1997). These results are not reflected in bacterial analyses from Hideaway Holiday Park or Riverside Motorcamp.

3.7 Groundwater Recharge

There are likely to be two main mechanisms for groundwater recharge of the Waitemata rocks, including:

- Rainfall recharge directly onto the surface of the rocks. This mechanism gives rise to the calcium bicarbonate type waters.
- Upward leakage from the underlying greywacke basement rocks. This mechanism gives rise to the sodium chloride type waters experienced in some bores near the harbour.

Only the rainfall recharge component for the Waitemata aquifer has been estimated during this study. An analytical approach to estimate the volume of groundwater upwelling is not feasible at this stage, due to a number of unknown variables including fracture flow, extent of upwelling, and variability over time.

Groundwater recharge to the sand aquifer includes the following components:

- Rainfall recharge directly onto the ground surface.
- Surface runoff from the adjacent Parahaki Volcanics

Similarly to the Waitemata aquifer, only rainfall recharge has been estimated for the sand aquifer at Mangawhai Heads in this study. Rainfall recharge has not been assessed for the sand aquifer around the southern part of the study area (ie. Tern Point) due to the limited number of bores screened within the sand in this area.

3.7.1 Rainfall recharge

Annual average rainfall recharge to the Waitemata aquifer has been estimated as 180 m^3/day to 1,840 m^3/day, based on an area of 4.2 km^2, average annual rainfall of 1,600 mm, and an average annual recharge coefficient of 1% to 10%.

The recharge coefficient for the Waitemata aquifer takes into account the low permeability of the weathered sandstone (ie. clays) at the ground surface. Most of the infiltrating rainwater will be removed via soil evaporation and plant uptake, limiting the amount of water reaching the sandstone. In comparison, the sand aquifer would have a higher range of recharge coefficients due to higher permeability.

The range in values (ie. 1% to 10%) accounts for the uncertainty involved in estimation of the recharge coefficient.

Annual average rainfall recharge to the sand aquifer has been estimated as 1,960 m^3/day to 3,110 m^3/day, based on an area of 4.4 km^2 (Mangawhai Heads only) and an average annual recharge coefficient of 10.2% to 16.1%. The recharge coefficient was estimated from the magnitude of watertable rise during various long-term rainfall events. Appendix E summarises the analysis and results from each rainfall event and shows the groundwater hydrographs for the two sand monitoring bores. The groundwater recharge from a range of rainfall events was assessed to account for antecedent soil moisture conditions.

The recharge coefficient for the sand aquifer takes into account the low permeability of interlayered clays, peat and thin iron pans.

Table 5 summarises the parameters used in the assessment of rainfall recharge.

- **Table 5. Estimated Daily Rainfall Recharge.**

	Recharge area (m^2)	Average annual rainfall (mm)	Rainfall recharge (m/yr)	Average daily recharge (m^3/day)
Waitemata aquifer	4.2×10^6	1,600	0.016 – 0.16	184 – 1,841
Sand aquifer (Mangawhai Heads)	4.4×10^6	1,600	0.163 – 0.258	1,965 – 3,110

Notes: Sand area excludes Tern Point.

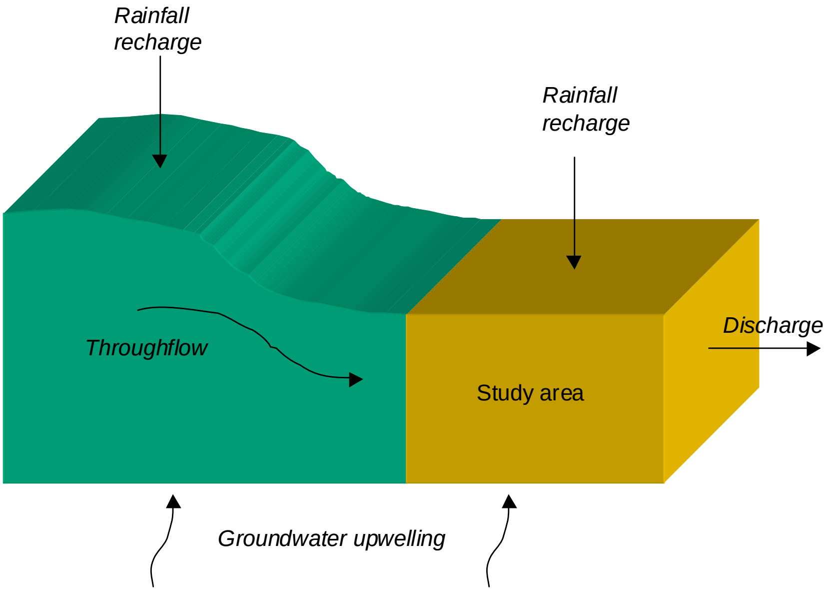
3.8 Groundwater Discharge

An assessment of groundwater discharge for the Waitemata aquifer has been calculated from the average hydraulic parameters shown in Table 3 and from the piezometric surface plots shown on Figure 8 and Figure 9. Table 6 summarises the data that has been used in the discharge calculation.

The hydraulic gradient for the Waitemata aquifer within the aquifer boundary is 0.009 m/m. Due to the limited extent of the aquifer boundary defined in this study (ie. the boundary does not encompass the entire catchment), there are uncertainties associated with the accuracy of the hydraulic gradient. A conservative value for hydraulic gradient has been taken.

Discharge from the Waitemata aquifer to the estuary has been estimated at 548 m^3/day. This is within the range of the rainfall recharge estimation of 184 m^3/day to 1,841 m^3/day assessed in Section 3.7.1. In reality, groundwater recharge to the study area would be comprised of direct rainfall recharge within the study area, rainfall recharge from the upgradient Waitemata rocks, and a component of groundwater recharge sourced from the underlying greywacke aquifer (deep groundwater upwelling). This is diagrammatically shown on Figure 11.

It should also be noted that the groundwater discharge assessment contains a number of uncertainties, increasing the error associated with the analytical calculation. In particular, the average transmissivity adopted for this discharge calculation may not represent the true value for the fractured Waitemata aquifer, as fractures impart a large anisotropy to the permeability and transmissivity field.



- **Figure 11. Conceptual Diagram of Groundwater Recharge and Discharge to the Waitemata Aquifer.**

- **Table 6. Summary of Aquifer Discharge Calculation Parameters.**

	Average hydraulic gradient (m/m)	**Average transmissivity (m/day)**	**Discharge boundary length (m)**	**Discharge volume (m^3/day)**
Waitemata	0.009	11.7	5,200	548

Groundwater discharge from the sand aquifer at Mangawhai Heads has been assessed from the groundwater hydrographs in Figure 6 and the specific yield shown in Table 3. The net annual discharge was determined from the average total annual decline in the watertable. Appendix E summarises the analysis methodology and results.

Discharge from the sand aquifer has been estimated as 420 m^3/day to 1,130 m^3/day. This is less than the lower recharge limit of 3,110 m^3/day assessed in Section 3.7.1. The discharge calculations comprise significant uncertainty due to the complex aquifer geology and areal extent.

3.9 Summary of Conceptual Aquifer Understanding

The conceptual understanding of aquifers in the study area is as follows:

- Two aquifers are represented in the study area, namely a sand aquifer consisting of unconsolidated to consolidated dune sand with intercalated silt, clay and peat sequences, and a sandstone aquifer (Waitemata Group sediments). The Waitemata aquifer is underlain with Northland Allochthon limestones and mudstones at approximately 195 m depth, followed by greywacke basement rocks located at depths of up to 700 m. No bores intercept these deeper layers within the study area.
- Bore yields range from 12 to 409 m^3/day within the sand aquifer and 9 to 454 m^3/day within the Waitemata aquifer. Although average yields are greatest in the sand aquifer, long-term yield is constrained by the occurrence of silt and clay lenses and thin iron pans, the limited extent and relatively shallow depth (up to 34 m) of the aquifer. The greatest yields within the Waitemata aquifer occur within the fractured sandstone. The extent of fracturing increases with depth.
- Areal groundwater recharge (downward movement) occurs over most of the study area, which is sourced from rainfall infiltration. Groundwater discharge (upwelling) occurs at low topographic elevations around the estuary, as indicated from groundwater quality information and artesian pressures in deep bores.
- High chloride, boron, fluoride and lithium concentrations are common in bores located near the estuary around Mangawhai Village. The concentrations are higher than would be expected from seawater intrusion and are similar to concentrations found in thermal groundwaters. Seawater intrusion is therefore not considered to be the direct source of the poor water quality. The cooled thermal water is likely to originate from the underlying greywacke basement rocks. Connate water from the underlying Northland Allocthon rocks may also be a secondary indirect source of the high chlorides.
- Groundwater quality in bores located further away from the estuary and within the sand aquifer is indicative of relatively young recharging waters (ie. rainfall recharge).

4. Assessment of Sustainable Yield

The sustainable yield is defined in this study as the volume of groundwater available for abstraction without compromising the performance of environmental systems, such as stream flow, and without inducing saline intrusion at the coast. The volume of groundwater recharge to the aquifers represents the upper limit of groundwater availability, without considering the potential adverse effects from excessive abstraction.

There are a large number of uncertainties associated with the groundwater recharge and discharge calculations, as discussed in the previous sections. Due to these uncertainties the sustainable yield for the Waitemata and sand aquifers have not been assessed at this stage. It is recommended that a groundwater model based on dynamic estimates of groundwater recharge be developed to refine the recharge and discharge estimates, and thus enable the assessment of sustainable yield.

5. Summary & Conclusions

This study provides a preliminary hydrogeological assessment of the Mangawhai groundwater resource. The assessment is based on information from borelogs, aquifer test pumping exercises conducted for water right applications, routine NRC monitoring, and results from a Mangawhai groundwater investigation conducted by the NCC in 1987.

The predominant surface geology of the study area is Waitemata sandstones and mudstones, overlain with clays (weathered Waitemata), sands or alluvium. The sands are located on the peninsula at Mangawhai Heads and around the sandspit, while the alluvium is located with the stream valleys. The Waitemata rocks are underlain with Northland Allochthon limestones and mudstones at approximately 195 m depth. Greywacke basement rocks underlie the Northland Allochthon sediments at a maximum depth of approximately 700 m.

Groundwater is abstracted from both the Waitemata and sand aquifers. Groundwater yields in the sand aquifer range from 12 to 409 m^3/day, while yields from the Waitemata aquifer range from 9 to 454 m^3/day. The majority of bores are screened through the Waitemata sediments due to the limited extent and depth (up to 34 m) of the sand and the presence of intercalated silts, clays and thin iron pans. Groundwater yields are greatest in the Waitemata sediments where fractures are encountered. The extent of fracturing increases with depth.

Groundwater quality data shows high chloride, boron, fluoride and lithium concentrations in bores located near the estuary around Mangawhai Village. Groundwater quality in these bores is closer in composition to geothermal waters than seawater intrusion, suggesting that groundwater upwelling (discharge) of deep greywacke water is occurring at this location. There may be a secondary indirect source of the high chlorides from connate water in the underlying Northland Allochthon rocks. Groundwater quality data from other bores in the study area is indicative of relatively young recharging water (ie. calcium bicarbonate and sodium bicarbonate type waters). High iron is common in some bores, which is most likely a function of the geology (ie. presence of peat and iron pans). Elevated bacteria concentrations have been found in drains and streams around Mangawhai Heads.

Areal groundwater recharge (downward movement) occurs over most of the study area, with groundwater discharge (thermal upwelling) occurring around the estuary. The upward groundwater movement is indicated from artesian pressures occurring in deeper bores at low elevations near the estuary, and from the groundwater quality information. The upwelling is occurring through discrete fractures within the Northland Allochthon and Waitemata sediments. It is possible that the thermal groundwater is upwelling beneath the entire study area, but the discharge is restricted to the estuary by downward rainfall recharge. There are no deep bores located at higher topographic elevations to confirm this.

The main issues affecting the quality and quantity of groundwater in the study area include the following:

- ***Elevated chlorides, boron, fluoride and lithium*** – elevated concentrations occur in some bores located at low elevations near Mangawhai Village and along the southern end of the estuary. It is likely that the bores intercept discrete fractures within the Northland Allochthon and Waitemata rocks, through which thermal upwelling can occur. It is possible that elevated concentrations occur in other bores throughout the study area that encounter these persistent fractures or high permeability zones, in particular near the Waipu Fault or around igneous intrusions. However, there is currently no groundwater quality data to verify this.
- ***Iron and manganese*** – elevated concentrations occur in some bores, which is most likely a function of the geology.
- ***Bacteria*** – concentrations that exceed the Regional Water & Soil Plan has been detected in drains and streams around Mangawhai Heads. The faecal contamination has been attributed to catchment runoff and seepage from on-site sewage treatment and disposal systems.

6. Recommendations

Based on the preliminary findings from this report and without knowledge of NRC's research priorities, SKM recommend the following activities and studies be undertaken:

- Given the uncertainties associated with the analytical calculations of groundwater recharge and discharge, a refinement of the estimates for both the sand and Waitemata aquifer is recommended. This will provide a more accurate assessment of sustainable yield in order to assess the volume of groundwater available for allocation. A model based on dynamic estimates of groundwater recharge is recommended.
- The available allocation for the Waitemata aquifer will be affected by abstraction upgradient of the study boundary. The estimate of total groundwater use for the Waitemata aquifer and the estimate of groundwater recharge and discharge can be refined by using information from bores located within the Waitemata aquifer but outside of the study boundary. This would involve extending the management boundary for the Waitemata aquifer back towards Tara.
- It is considered that the two existing NRC groundwater quality monitoring sites are sited correctly for saltwater intrusion monitoring in the Waitemata aquifer, being located close to the estuary and away from Mangawhai township where the likelihood of encountering high chloride concentrations associated with a geothermal influence is high. The Riverside Motorcamp already has NaCl type water, although current chloride concentrations are below the DWSNZ aesthetic guideline value. A monitoring round in the Riverside Motorcamp bore that includes boron, fluoride and lithium is recommended to assess the source of the NaCl type water
- It is recommended that a saltwater intrusion and groundwater level monitoring bore be established in the sand aquifer. Besides providing an early warning system for saltwater intrusion, the groundwater level information can be used as calibration data for a groundwater model and to refine the piezometric surface. There is an existing NRC groundwater level monitoring bore in the sand aquifer (Hakaru Bowling Club) near the northern end of Mangawhai peninsula. It is recommended that a new saltwater intrusion/groundwater level monitoring bore be installed near the southern end of Mangawhai peninsula. This is an area where there is currently no groundwater level information.
- Any new bores drilled that have high chloride levels should also be sampled for boron, fluoride and lithium. This would assist in confirmation of the conceptual geothermal model and would enable the extent of the high chloride zone to be further refined.
- A review of the NRC database for bores drilled into the greywacke near Mangawhai (ie. upthrown side of Waipu Fault) and an assessment of any groundwater quality data from these bores, may assist in confirmation of the conceptual geothermal model.

7. References

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Appendix A Bore Details

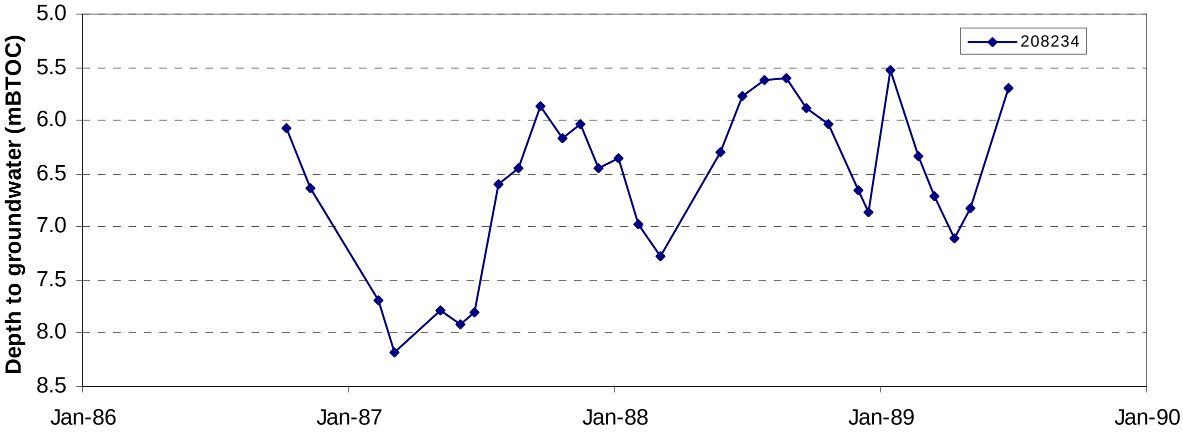
- **Table A-1. Summary of Bore Details and Aquifer Test Pumping.**

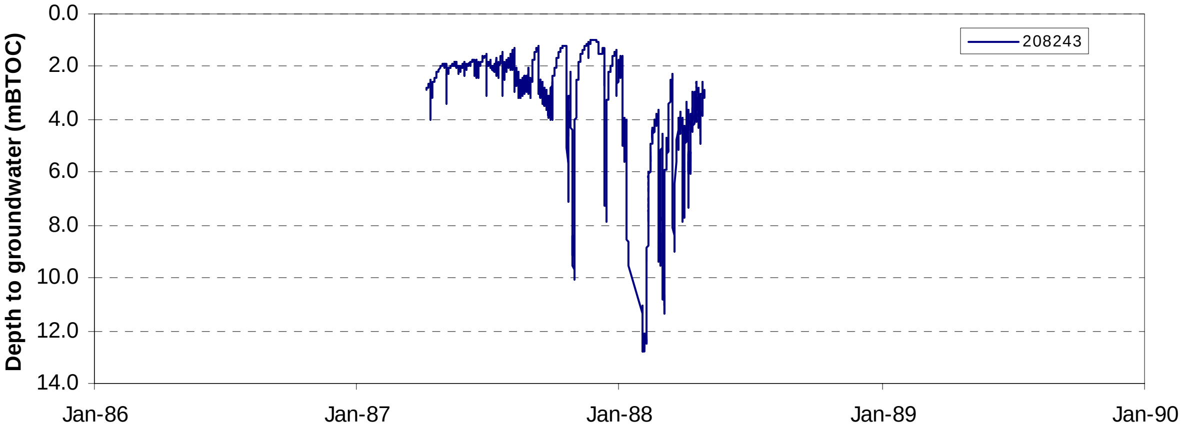
Bore	Owner	Drilled date	Depth (m)	Cased depth (m)	Yield (m^3/hr)	Drawdown (m)
208231	R Denize	6/12/1972	26.2	8.5	1	-
208232	S Wright	2/04/1981	21	12	2	8.3
208234	H Marshall	20/06/1980	96	17.7	-	-
208235	E Carter	23/10/1979	32	18.3	2	2.2
208236	J McLaclan	17/10/1979	57.6	19.2	2	5.2
208237	Blissland Stud Ltd	15/07/1968	79.3	10	-	-
208238	Cullen Bros	24/11/1972	9.4	6.4	-	-
208239	C Bower	5/10/1982	64	24.4	-	-
208240	M Bower	20/10/1982	64	24.4	-	-
208241	Skate Bros	24/11/1972	44.2	-	-	-
208242	V Fiske	26/02/1982	7.2	6.5	2	6
208243	Mangawhai Estates	5/10/1983	100	11.4	11	46
208244	Mangawhai Estates	12/10/1982	104.2	19.2	2	-
208245	B Clarke	6/12/1972	58.5	10.7	1	-
208246	Bower 3		210	-	-	-
208247	Mangawhai Hotel	7/03/1966	45.7	26	-	-
208248	Auckland Education Board	2/05/1983	62	32	2	2.7
208249	McCabe	15/01/1981	83.2	25.6	2	-
208253	Mangawhai Golf Club	28/04/1981	9	6	11	5
208254	L Wharf	6/10/1982	36.9	-	-	-
208255	M Daniel	-	10.4	9.8	2	0.9
208258	J Jessop	23/11/1973	-	27.4	2	-
208259	H Mathews	20/01/1973	14.6	2.7	1	-
208260	Terris Village Motor Camp	20/01/1973	27.4	19.8	-	-
208262	A Markwick	1/03/1968	33.5	26	-	-
208266	L Smith	7/11/1979	51.2	25.6	3	0.6
208267	M Braddock	8/10/1982	58	26.4	-	-
208268	McCaughey	2/04/1981	9	8.5	1	3.5
208269	J Coats	22/04/1975	27.4	19.2	4	-
208270	R Bull	28/01/1978	45.7	-	2	-
208271	R Bull	7/03/1973	28	6.5	-	-
208272	Denize Bros	28/01/1978	12.6	1.6	1	-
208273	L Bull	20/04/1964	90	25	-	-
208274	F McCaugham	26/02/1982	49	-	1	-
208275	J Spyksma	12/02/1982	54	21.5	4	-
208276	E Willis	20/04/1977	167.6	42.7	-	-

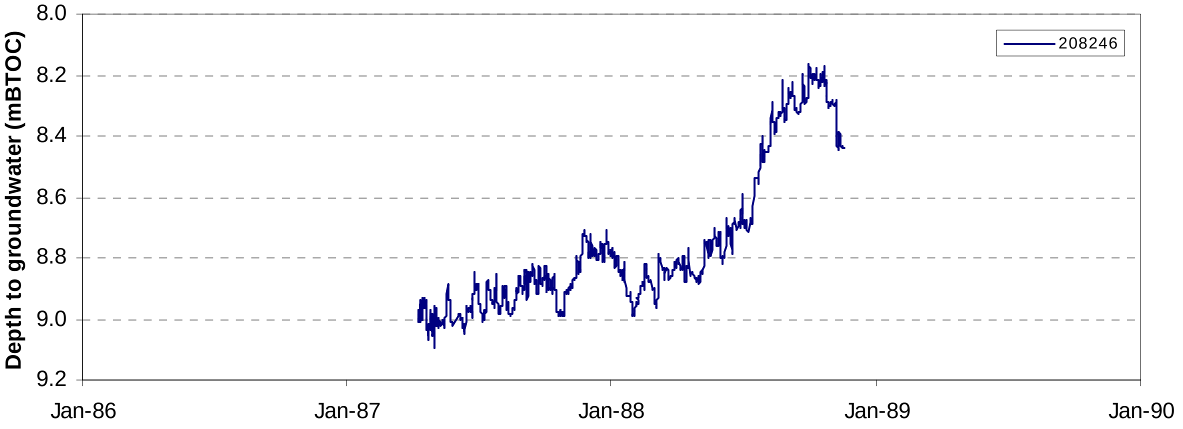
208277	J Allen	24/01/1976	-	-	-	-
208278	W Phillips	6/03/1971	30	11	-	-
208283	Smith	25/07/1984	66	20	3	6
208284	H Denize	31/07/1984	64.4	31	-	-
208285	R Huddart	20/09/1984	8.8	7.5	1	4.4
208287	Mangawhai Golf Club	-	10.7	7.5	17	2.8
208291	S Kok	17/06/1985	51	-	11	6
208296	Gerken	4/12/1975	44.8	38.4	2	9.1
208299	Medical Centre	24/11/1988	11	5	-	-
208314	P Cockayne	9/01/1996	46	42	19	-
208317	Jopson - Dave	27/01/1997	33.5	31.5	1	4.4
208320	J Milestone	4/11/1987	40	30	6	3
208341	P Cockayne	9/01/1996	46	42	19	-
208342	J Young	10/11/1997	50.3	30.8	3	18
208343	D Baird	10/03/1998	100.6	56.4	3	-
208344	B Imrie	6/10/1998	54.9	35	7	15.9
208348	Flavell	9/06/1999	51.5	21	2	1.8
208361	G I Olsen	26/11/1999	70.5	35.9	10	12.7
208364	I Shirmski	17/06/2000	62.2	48.8	2	4.3
208365	E Mc Intyre	2/12/1999	4.5	3.5	1	1.8
208366	A Smart	4/07/2000	68.2	54.9	9	13.8
208367	J Russel	20/05/2000	62.2	53.9	1	2.1
208369	A Smart	16/03/2000	54.9	41.8	4	13.8
208370	Tern Point Company	29/05/2000	74.4	53	2	3.1
208371	B Robbin	12/04/2000	91.4	52.4	1	17.4
208373	ES & DA Hoverd	27/03/1998	20.5	17.5	3	-
208374	Waters	28/07/2000	62.2	42.7	1	-
208375	L & P Renner	29/08/2000	7	6	2	2.9
208376	M Davies	19/12/2000	121	48	2	-
208381	Crosbie	17/04/2001	48.8	32.6	2	2.8
208382	B Buchanan	19/10/2000	23.8	18.3	2	-
208383	J & P Hendrikson	13/10/2001	37.8	34.7	2	9.1
208384	C Carter	17/09/2000	84	47.2	5	-
208386	Hakaru Bowling Club	-	69	23	3	-
208387	M & J Van Kan	30/10/2001	24	19	2	-
208388	J W Rous	11/05/2001	37.5	7.3	2	-
208423	A Smart	21/03/2002	18.5	14.5	5	-
208425	WFF Ward	12/03/2001	10	9	2	8
208436	H.G & F.A Brien	6/11/2002	191	61.5	-	-
208439	R & S Paine	21/01/2003	30.4	26.5	1	-
208440	C W Linnell	24/01/2003	205	46.5	3	-

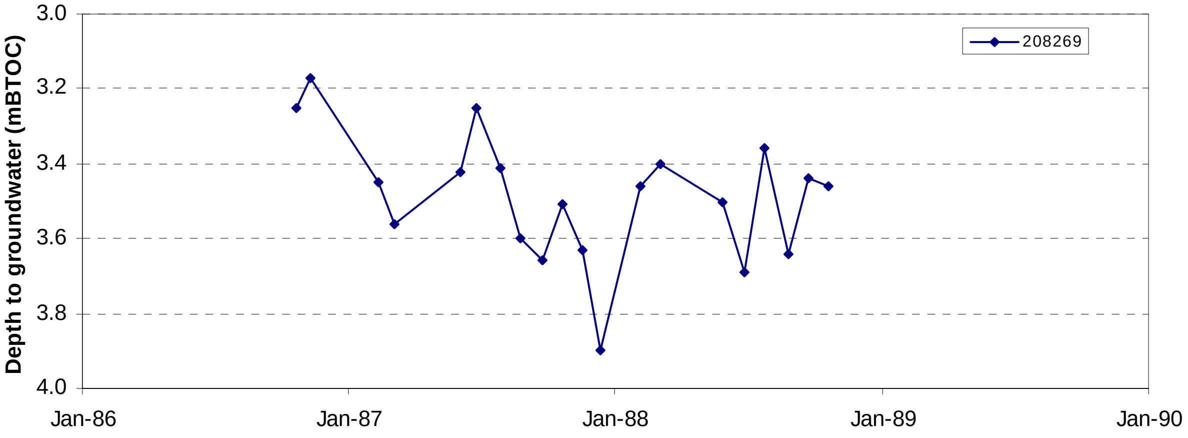
209139	Meritec Ltd	7/02/2002	15	-	-	-
209140	Meritec Ltd	7/02/2002	22.5	-	-	-
209151	J Milestone	4/11/1987	40	30	6	3
-	Kaipara District Council	-	10	-		
-	Hakaru Bowling Club	-	10	-		
-	Domain	-	128	-		
-	Becroft Orchards Ltd	-	107	48.8		
-	B Smith	-	19	-		
-	Mangawhai Farm Partnerships	-	55	36.6		
-	Moirs Point Christian Camp	-	140	-		
-	Russell	-	27	18		
-	Hideaway Holiday Park	-	38	-		
-	Riverside Motorcamp	-	40	-		

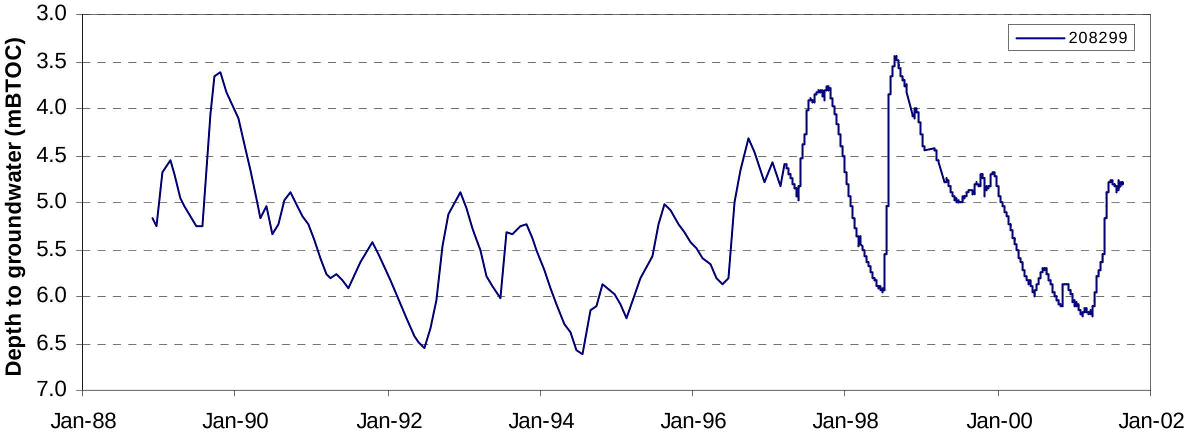
Appendix B Groundwater Hydrographs

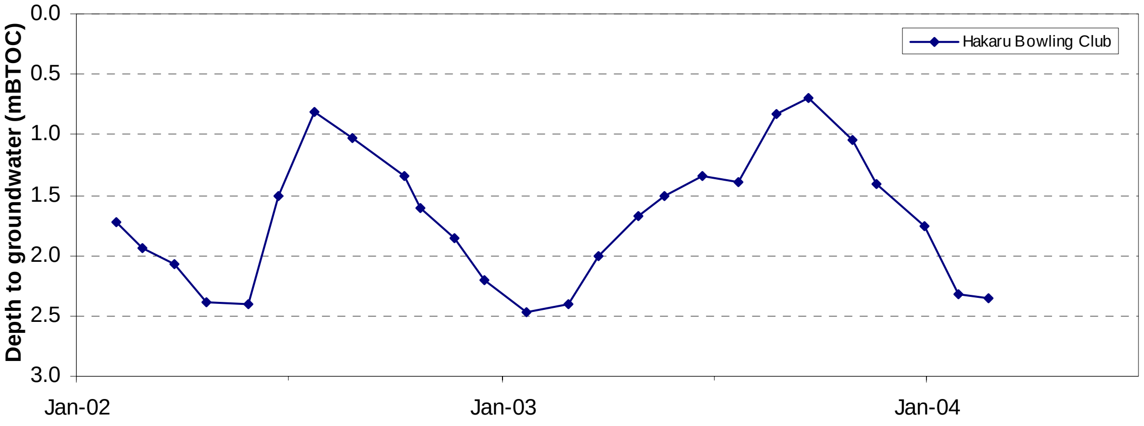


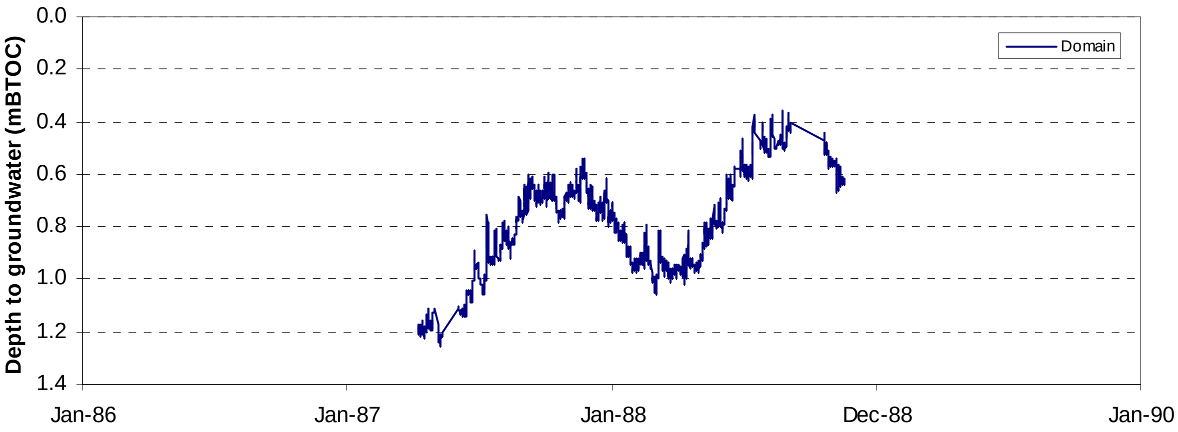





Depth to groundwater (mBTOC)
3.0
3.2
3.4
3.6
3.8
4.0
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
208269


Depth to groundwater (mBTOC)
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
208299


Depth to groundwater (mBTOC)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Jan-02
Jan-03
Jan-04
Hakaru Bowling Club


Depth to groundwater (mBTOC)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Jan-86
Jan-87
Jan-88
Dec-88
Jan-90
Domain

Appendix C Aquifer Test Results

Appendix D Groundwater Chemistry Discussion

There are a number of indications from the groundwater sampling that the high salinities found in the NaCl type bores are due predominantly to thermal activity rather than active seawater intrusion, including:

- The high chloride concentrations are accompanied by high boron, lithium and fluoride concentrations (see Table 4), which are typical of geothermal waters (KRTA, 1986).
- Boron is a conservative element that is generally unaffected by chemical processes. Once in solution the concentration is indicative of the waters of origin or has changed as a result of mixing of different waters only. The typical concentration of boron in seawater is 4.5 mg/L (Richter and Kreitler, 1993) but can exceed this value in thermal waters (KRTA, 1986). Table includes sampling results for groundwater from the Parakai geothermal area and for mixed cooled Parakai fluid (Aspden). The NaCl type waters at Mangawhai all have boron concentrations exceeding 4.5 mg/L, with concentrations similar to thermal water from Parakai.
- Chloride is also considered to be conservative once in solution. Given that both chloride and boron are relatively unreactive once in solution, the chloride and boron concentrations should be in proportion to their ratio in seawater if seawater was the origin of the waters. Seawater has typical chloride concentrations of 19,000 mg/L (Richter and Kreitler, 1993), giving a chloride/boron ratio of 4,222 (Table D-1). The chloride/boron ratios for Mangawhai NaCl type water range between 28 and 137, which are similar to the ratios found in samples from the Parakai geothermal area (72 and 144) (Table 4 and Table D-1).
- If the source of the chlorides in the groundwater was seawater then the groundwater would be comprised of only 6% seawater, based on the maximum chloride concentration of 1,196 mg/L sampled in the Domain bore. This would provide 0.3 mg/L of boron. In a similar manner, the concentrations of fluoride (at greater than 0.08 mg/L) and lithium (at greater than 0.01 mg/L) in the NaCl bores are higher than can be attributed to seawater (except for fluoride concentrations in bore 208244).

- **Table D-1. Composition of Seawater and Geothermal Sampling Results.**

Parameter (mg/L)	Seawater	Parakai	Aspden
Chloride	19,000	1,006	964
Sodium	10,500	625	548
Sulphate	2,700	8.8	0.1
Magnesium	1,350	0.7	0.2
Calcium	410	51	68
Potassium	390	19.6	1.6
Bicarbonate	142	71	12
Boron	4.5	14	6.7
Fluoride	1.3	2.16	1.9
Lithium	0.18	0.84	0.19
Ratio:			
Chloride / Boron	4,222	72	144

A conceptual model for thermal water intrusion at Mangawhai has been proposed by the NRC (1989) based on a model developed by KRTA (1986) for waters at Franklin-Clevedon. The model describes the circulation of groundwater through the greywacke basement rocks at depths of 1 km or greater. Waters at these depths are heated by the regional thermal gradient and mobilise chloride, boron, lithium and fluoride from the greywacke. The mineralised water then ascends into the Northland Allochthon and Waitemata rocks where permeability permits, most probably along the Waipu Fault and through basement fracture systems.

Water from the greywacke formation at Franklin-Clevedon are sodium bicarbonate type, with or without elevated boron, fluoride and lithium depending on whether the water has been heated at depth (KRTA, 1986). It is likely that the deep greywacke waters at Mangawhai are also of sodium bicarbonate type, which has been recharged from rainfall on the upthrown side of the Waipu Fault. The bores with high boron, fluoride and lithium concentrations are indicative of a deep groundwater source, as high temperatures are required to mobilise these elements. However, as these bores have NaCl type waters rather than Na-HCO_3 type waters, this suggests that the extra chloride required to change the water from Na-HCO_3 to NaCl type is incorporated into the groundwater as it moves along its flow path. The source of the extra chlorides is most likely to be from connate water high in chlorides, based on the following information:

- The magnesium concentrations measured in the NaCl waters are less than a 6% seawater solution (80 mg/L) but higher than concentrations in thermal waters from Parakai.
- The sulphate concentrations are also lower than expected from a 6% seawater solution (167 mg/L) but are similar to mixed cooled waters from Aspden. It is likely that the sulphate (and magnesium) has reduced over time, under the anaerobic conditions that will persist in a deep

groundwater system. This suggests that the secondary source of the high chloride water is very old.

- The bore with the highest chloride concentration (Domain bore) does not have the highest concentration of boron, lithium and fluoride.
- Groundwater from bores 208246 (sampled at 100 m depth), 208276 and Riverside Motorcamp may be most indicative of the deep greywacke water, which has high concentrations of boron, lithium and fluoride but more bicarbonate than the other NaCl type waters.

This data supports the idea of a secondary indirect contribution of saline water. The most likely source of this chloride is the Northland Allochthon rocks. As these rocks are marine sediments (limestone and mudstones), they are likely to contain connate seawater. Sufficient time has elapsed since the Northland Allochthon sediments were emplaced for sulphate and magnesium reduction to occur (NRC, 1989).

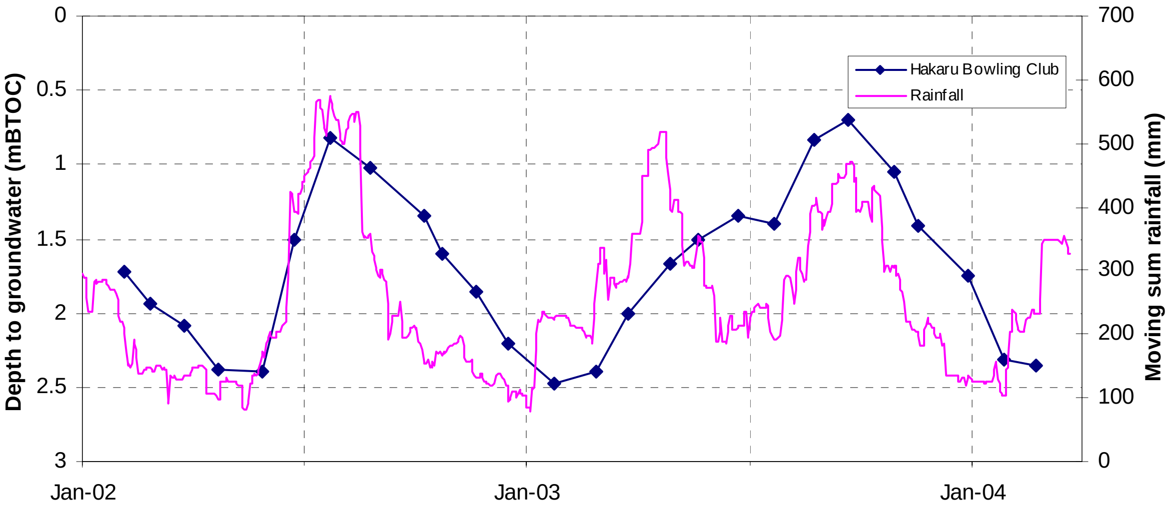
Resistivity surveys conducted by Massey (1987) indicate that the saline water body occurs along the northern and southern side of the Harbour near Mangawhai Village only. The saline body is wedge-shaped and of considerable lateral and depth extent. Seismic refraction data from the same area shows that the saline boundary does not coincide with geological boundaries, with saline water occurring in both the sand and Waitemata aquifers.

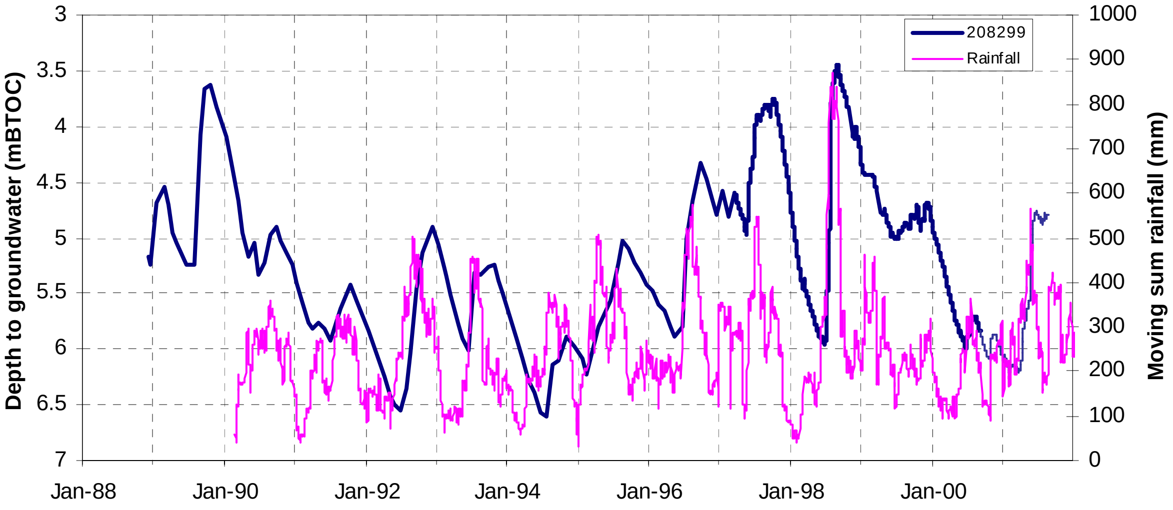
The presence of the NaCl type water around Mangawhai Village and south of the estuary may be due to a thinner sequence of Northland Allochthon and Waitemata sediments in that region (Massey, 1987). The artesian flow at three bores located around the estuary, and the general increase in groundwater pressures with depth, is indicative of groundwater upwelling (discharge) at that location. In addition, the Waipu Fault and igneous intrusions (ie. Ti Point basalts) through the Northland Allochthon and Waitemata sediments would provide leakage paths for deep greywacke waters.

The existing groundwater data shows that the groundwaters derived from the deep greywacke source do not mix with the calcium bicarbonate waters of shallow origin (ie. rainfall recharged). It is therefore probable that downward rainfall recharge restricts upward movement from the deeper groundwater and limits the discharge of the deep greywacke waters to around the harbour. This is diagrammatically shown on the hydrogeological cross-section in Figure 5.

The variation in levels of saline contamination between bores located at similar depths within close proximity to each other (eg. bore 208243 and 208244), may be explained through the presence of persistent fracture systems intersecting the Waitemata rocks. Bore 208243 and 208244 are 100 and 104 m deep respectively, and are located within 20 m of each other.

Appendix E Recharge & Discharge Calculations





- **Figure E-1. Groundwater Hydrographs Used To Assess Rainfall Recharge & Discharge.**

- ### Table E-1. Estimate of Rainfall Recharge to the Sand Aquifer.

Date of event	Change in water level (m)	Specific yield	Recharge (m)	Size of rainfall event (m)	Recharge coefficient (%)
Hakaru Bowling Club					
May 02 – July 02	1.58	0.04	0.0632	0.462	13.7
Jan 03 – Jun 03	1.12	0.04	0.0448	0.438	10.2
Bore 208299					
May 92 – Dec 92	1.65	0.04	0.0660	0.411	16.1
May 96 – Sep 96	1.56	0.04	0.0624	0.407	15.3
May 97 – Oct 97	1.16	0.04	0.0464	0.425	10.9
Jun 98 – Sep 98	2.394	0.04	0.0958	0.814	11.8

- ### Table E-2. Estimate of Discharge from the Sand Aquifer.

Year	Annual change in water level[1] (m)	Specific yield	Discharge per unit area (m^3/yr)	Discharge volume[2] (m^3/yr)	Discharge volume (m^3/day)
Hakaru Bowling Club					
2002	2.33	0.04	0.0932	410,080	1,124
2003	1.67	0.04	0.067	293,920	805
Bore 208299					
1989	1.18	0.04	0.047	207,680	569
1990	1.70	0.04	0.068	299,200	820
1991	1.14	0.04	0.046	200,640	550
1992	0.88	0.04	0.035	154,880	424
1998	2.096	0.04	0.084	368,896	1,011
2000	1.745	0.04	0.070	307,120	841

Notes: [1]Cumulative annual watertable decline from hydrograph; [2]Catchment area is 4.4 km^2.