Preliminary Hydrogeological Investigations - Four Northland Aquifers

KAIKOHE GROUNDWATER RESOURCE

- Report prepared for Northland Regional Council
- Final
- 2 February 2007

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Sinclair Knight Merz
25 Teed Street, Newmarket
Auckland
New Zealand
Tel: +64 9 913 8900
Fax: +64 9 913 8901
Web: www.skmconsulting.com

Contents

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1. Introduction

Sinclair Knight Merz was commissioned by Northland Regional Council (NRC) to provide preliminary hydrogeological assessments of the Three Mile Bush, Maungakaramea, Kaikohe and Matapouri Bay aquifers. These aquifers are recognised in the Northland Regional Water and Soil Plan as being “at risk” aquifers due to high actual or potential demand for groundwater or potential for saltwater intrusion (NRC, 2004). The information obtained from each study will assist the NRC to effectively manage the groundwater resource.

This report focuses on the hydrogeology of the Kaikohe basalt aquifer, which is classified as an “at risk” aquifer based on the high demand for groundwater for horticultural and domestic supply. Contrary to the other three aquifers, the NRC has already conducted a preliminary assessment of the water resources associated with the Kaikohe basalt aquifers. This was completed in 1992 (NRC, 1992).

This report investigates the current state of the groundwater resource in terms of groundwater quantity and provides a reassessment of sustainable yield. Additional data collected since the 1992 assessment includes:

- Extended groundwater level monitoring records;
- Extended rainfall record;
- Additional low flow stream measurements;
- Borelogs for six new bores;
- Updated groundwater and surface water consent details.

2. Background Information

2.1 Site Description and Location

The Kaikohe Aquifer is defined as comprising the Kaikohe volcanic centre located at Memorial Hill, the lava flows that are sourced from this centre, and the underlying older basaltic lava flows with no definable centre. The aquifer is bounded by the Mangamutu and Wairoro Streams to the north and east, Mataraua Road to the west and the Punakitere River to the south. The total aquifer area is 27 km^2. Figure 1 shows the boundary of the Kaikohe Aquifer.

The Kaikohe volcanic centre is marked by a scoria cone at Memorial Hill that reaches an elevation of 282 m above mean sea level (mAMSL) and is approximately 1 km in diameter. The basalt flows associated with the Kaikohe volcanic centre, defined as the Kaikohe Basalt, extend to the south and south-east of the cone splitting into two main lobes. One lobe extends south-west along State Highway 12 and the other extends south along Mangakahia Road to the Punakitere River. These lobes appear to follow pre-existing valleys. The Kaikohe Basalt slopes from north to south, falling from an elevation of approximately 200 mAMSL near the base of the scoria cone to 160 mAMSL near the southern limit of the basalt. Most of the Kaikohe Basalt ranges between 180 mAMSL and 160 mAMSL with steeply sloping edges.

The underlying older basalt flows are exposed in the southern part of the study area and as outcrops along the Wairoro Stream. These flows have been termed the South Omapere Basalt after mapping work in the wider area (Mulheim, 1973). The South Omapere Basalt is located at elevations between 160 and 120 mAMSL with steeply sloping edges along the southern boundary down to the surrounding Cretaceous siltstones.

The Kaikohe Aquifer was initially investigated by the NRC in 1992 (NRC, 1992). The purpose of this investigation was to improve knowledge of the groundwater and stream flow resource, quantify existing demand and assess groundwater availability. The study was initiated in response to increased and competing demand on the resource, after applications for water rights for public water supply from the aquifer were approved. The Kaikohe Borough Council required this water to replace the supply previously abstracted from Lake Omapere, which became unsuitable for public water supply after severe blue-green algal blooms in 1983.

The NRC commissioned SKM in 2005 to review existing information on the aquifer in response to two main events, including 1) recent requests for resource consent to drill bores and abstract groundwater for horticultural irrigation, and 2) higher than normal groundwater level decline in monitoring bores during 2005.

- **Figure 1. Site location plan.**

  (see A3 attachment at rear).

2.2 Regional Geology

Geology for the Northland region is outlined on the 1:250,000 scale Geological Map Sheet 1 for North Cape (Kear and Hay, 1961). This map shows broad geological units for the region. More detailed mapping of the study area is provided in Reedy (1992). This map is reproduced in Figure 2.

The basalt flows in the study area are part of the Kaikohe-Bay of Islands basalt field, which extends from Kaikohe north-east to the coast approximately 50 km away. The study area comprises a small proportion of the Kaikohe-Bay of Islands basalt field, covering an area of 27 km^2. The Kaikohe-Bay of Islands basalt field belongs to the wider Kerikeri Volcanic Group, which incorporates all geologically young, volcanic rocks deposited in Northland and as far south as Raglan Harbour.

The basalts in the Kerikeri Volcanic Group have been classified as either Horeke or younger Taheke flows, and are differentiated based on the topographic form, presence or absence of a scoria cone, the degree of erosion and weathering, and the resultant soil type. Taheke basalt in the study area is labelled as Kaikohe Basalt, with an estimated age of approximately 0.2 million years. Horeke basalt is labelled as South Omapere Basalt in the study area and has been dated at 1.27 (±0.02) million years (Reedy, 1992). This nomenclature is based on previous work in the area and is used by Reedy (1992) and NRC (1992), as shown on Figure 2. The same terms are used in this study to differentiate the two basalt flows in the study area.

South Omapere basalt appears denser and less permeable than the Kaikohe basalt, based on visual descriptions of outcrops in the study area (Reedy, 1992).

The Kaikohe Aquifer is bounded on the western side by mid to upper Cretaceous Kaikohe Formation, which consists of sandstones and siltstones (Skinner, 1981). The Kaikohe Formation forms ridges up to 320 m elevation north-west of the study area.

The basalt is bounded on the eastern side by ridges of upper-Cretaceous Mangakahia Group calcareous shale, limestone, sandstone and siliceous mudstone up to 320 m elevation. Both the Kaikohe Formation and Mangakahia Group are part of the Northland Allochthon, which represents a series of discrete lithological units that were emplaced as part of a large gravity slide affecting most of Northland (Skinner, 1981).

In the southern half of the study area the basalt overlies the Mangakahia Group sandstone. The basalt boundary stands approximately 20 m above the surrounding topography in this location.

Undifferentiated Quaternary sediments are present in the stream valleys along the interface between the basalt and Cretaceous sandstones.

- **Figure 2. Geological map of the Kaikohe Basalt Aquifer. Reproduced from Reedy (1992).**

  (see A3 attachment at rear).

2.3 Geological Structure

Minor north-east trending faults within the Kaikohe Formation and Mangakahia Group sediments. The alignment of several volcanic centres to the north of the study area can be related to these minor faults (Skinner, 1981). The faults are overlain by, and therefore predate, South Omapere and Kaikohe basalt.

2.4 Main Findings from NRC 1992 Study

The following information is a summary of the main findings contained in the NRC 1992 report:

Aquifer Description

- The Kaikohe basalt forms the main aquifer in the study area. The underlying South Omapere basalt is considered to be less permeable than the Kaikohe basalt, based on visual descriptions of the basalt and the low proportion of spring flows sourced from the South Omapere basalt.
- The extent of South Omapere basalt beneath, and in contact with, Kaikohe basalt is not well understood. In some areas the Kaikohe basalt is separated from the South Omapere basalt by an ash and tuff layer, which would act as an aquiclude. There is no available aquifer test pumping information to show the magnitude of hydraulic interaction between the two aquifers.
- Aquifer storage capacity for the Kaikohe basalt estimated from test pumping data and groundwater level records varies widely, from 0.00058 to 0.025. This indicates considerable variability in aquifer characteristics. The data indicates that the Kaikohe basalt is generally unconfined, but also has locally semi-confined conditions.
- The shape of the aquifer suggests that it can be managed in terms of small groundwater catchments rather than a single aquifer body. A bore abstracting from the western lobe for example would experience significant boundary effects before inducing drawdown in the southern lobe.

Groundwater and Stream Flow Resources

- Groundwater is recharged by rainfall which in turn discharges to springs and streams. Spring discharges occur around much of the aquifer's margin, but particularly along the southern edge of the western and southern lobe. This suggests some structural control of groundwater flows may occur in these areas, such as the presence of major fractures within the basalt mass.
- Rapid falls in groundwater levels following recharge events indicates that much of the recharge flows quickly out of the aquifer. The critical factor affecting late summer

groundwater levels and spring flows is therefore the length of time since the last significant recharge event.

- Groundwater and stream flow should be considered as a single interdependent resource and any management strategy should reflect this. In general terms, spring flow is directly dependent on groundwater levels. The taking of groundwater will reduce spring flows.
- The aquifer is variable in nature and the effects of pumping at one location on adjacent spring flows cannot be accurately predicted without site specific investigations (i.e. concurrent groundwater level and spring flow measurements, and knowledge of aquifer hydraulic properties).

Resource use

- Spring and stream flow use is close to, or exceeds the limits of available flow over significant areas of the Kaikohe basalt, in particular the upper Otangaroa and Waikaka Stream catchments.
- The Far North District Council (FNDC) has access to adequate water resources to meet the current town supply usage (comment refers to 1992 usage). Any increased demand would require the development of new supply sources.

Habitat and ecological values of streams

- General instream ecological values are low, largely due to agricultural activities.

Water quality

- Stream low flow quality is typical of small streams draining farmland.
- Groundwater quality is good, however it is vulnerable to contamination from the overlying urban and farm landuses.

Water availability for future developments

- Groundwater and stream flow can only provide for relatively small increases in demand for groundwater. Other sources will need to be developed for large water requirements.
- Other options for increased water yields that could be investigated include storage dams, abstraction from more distant rivers and artificial recharge of the aquifer using summer storm runoff.

3. Update of Existing Information

3.1 Rainfall and Evaporation

Daily rainfall data is available for six stations around Kaikohe, as summarised in Table 1 and shown on Figure 3. Two sites have rainfall records extending beyond 1992 (Site **534725** and Site **534807**). Average annual rainfall varies between the sites, ranging from 1,358 mm to 1,612 mm. The lowest annual rainfall was 813 mm in 1986, recorded at Station 534803.

- **Table 1. Rainfall monitoring stations.**

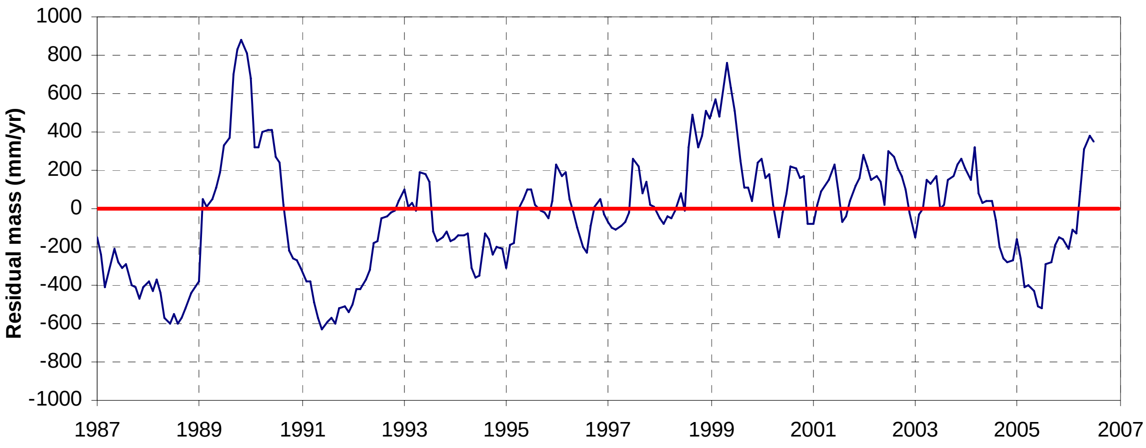
Site	Station name	Altitude (mAMSL)	Period of record	Annual average (mm)	Annual minimum (year) (mm)	Annual maximum (year) (mm)
534701	Kaikohe Orr	162	Jun 1922 – Jun 1971	1,612*	1,249 (1931)	2,459 (1956)
534725	Kaikohe Woolshed	160	Apr 1989 – May 1999	1,358	1,116 (1991)	1,703 (1998)
534801	Kaikohe Aero	170	Jul 1956 – Jul 1978	1,507*	1,217 (1973)	2,054 (1962)
534802	Kaikohe DSIR	185	Jan 1973 – Feb 1986	1,594*	1,137 (1983)	1,995 (1985)
534803	Kaikohe MWD	201	Mar 1979 – Dec 1989	1,478**	813 (1986)	2,258 (1989)
534807	Kaikohe DSIR EDR	204	Nov 1985 – open	1,425	927 (1991)	2,101 (1989)
	AVERAGE			1,496		

Note: *Statistics from NRC (1992); **Recalculated statistics.

- **Figure 3. Monitoring and consent locations.**

  (see A3 attachment at rear).

Figure 4 shows residual mass rainfall for site 534807 with the longest rainfall record. The plot shows that total rainfall for the year up to 31 May 1992 was significantly below the long-term average annual rainfall of 1,425 mm. Annual rainfall statistics for 1992 to 2004 were above or roughly similar to the long-term average, however rainfall for the year up to 30 June 2005 is again significantly below average conditions similar to the drought conditions experienced in 1992.



Note: Red baseline indicates position of long-term annual average rainfall of 1,425 mm.

- **Figure 4. Residual mass rainfall for site 534807.**

3.2 Stream Flows

Surface runoff and spring flows from the Kaikohe basalt discharge to subcatchments of the Punakitere River, which ultimately flows west towards the Hokianga Harbour. The Kaikohe basalt is bordered on the east by the Wairoro Stream, northwest by tributaries of the Otangaroa Stream, and to the south by the Punakitere River as shown on Figure 3. There are also a number of smaller streams draining the centre of the basalt. The streams have developed along the Cretaceous siltstone/basalt interface or between basalt flow sequences.

The NRC has conducted low flow monitoring (spot measurements) at a number of spring and stream locations between 1973 and 2005. Low flow monitoring results provide estimates of groundwater baseflow, as the gaugings are conducted during extended dry periods. Consideration needs to be given to the level of surface water abstraction occurring upstream however, as this will reduce estimates of naturalised baseflow. Table 2 summarises the monitoring data and Figure 3 shows the low flow monitoring locations.

Low flow measurements range between 0 and 435 L/s. The lowest values were recorded in the summer of 1987 and 1991-94, when the summer and preceding winter rainfall was significantly below average. The greatest stream flow measurement of 435 L/s was recorded at site 47588 on the Punakitere River during November 1991.

Only three sites were monitored during 2005 including:

- ***Wairoro Stream – DSIR (Cumbers Rd):*** Stream flow was 34.1 L/s during April 2005. The estimated extreme low flow for this site is reported to be 35 L/s (NRC, 1992), which indicates that April 2005 was a dry summer. However, there may have also been a number of abstractions further upstream reducing the flow at the gauging site.
- ***Wairoro Stream (Kopuru Stream) – SH12 (FNDC take):*** Stream flow was measured on three occasions during March and April 2005, and ranged from 18.9 L/s to 32.1 L/s. The estimated extreme low flow for this site has been previously reported at 25 L/s (NRC, 1992). Similar to above, the low stream flow measurements during April 2005 indicate a very dry summer.
- ***Wairoro Stream – FNDC weir:*** Stream flow was measured on three occasions during March and April 2005, and ranged from 26.3 to 32.1 L/s. There are no previous measurements for comparison.

Flow measurements from the DSIR and FNDC take monitoring sites during April 2005 are below the extreme low flows for each site estimated by the NRC in 1992. The extreme low flows can be equated to a 1 in 10 year return period low flow, implying that April 2005 has a similar recurrence interval, however as previously stated the flows measured in 2005 may have been influenced by abstractions upstream.

Table 2. Low flow monitoring details.

Site ID	Site	Location	Period of monitoring	Low flow (L/s)
47563	Korowhata Stream	H Clarks	1991	3.7 - 11
47578	Omaumu Stream	Slyfield's (Kaikohe)	1981 - 1983	0.6 – 9.1
47579	Omaumu Stream		1973 - 1974	0.1 – 5.3
47544	Omaumu tributary	Guest upper springs	1988	0.4 – 3.0
47545	Omaumu tributary	u/s Spring Guest pump	1988 - 1990	0.0 – 4.1
47546	Omaumu tributary	Above confluence	1990	1.2
47554	Otangaroa Stream	Barneys Crossing	1982 -1994	0.3 - 16
47501	Otangaroa Stream	Squires Spring	1973-1974	0.1 – 3.8
47529	Otangaroa Stream	Squires Spring - FNDC Weir	2000 - 2003	1.0 – 5.7
47552	Otangaroa Stream	u/s Johnsons Dam	1989 - 1993	0.3 – 5.2
47553	Otangaroa Stream	d/s Johnsons dam	1977 - 1993	0.0 - 20
47570	Otangaroa Stream	Rock Outcrop	1973 - 1992	0.1 - 19
47581	Otangaroa Stream		1972 - 1973	3.0 - 224
47582	Otangaroa Stream	Jordan Rd	1985 - 1986	24 - 45
47580	Otangaroa Stream	W Daltons property	1983	0.3
47548	Papahawaiki Stream	Tauri property	1988 - 1991	6.0 – 15
47583	Papahawaiki Stream	Rangihamama Rd	1988	7.8 – 8.7
47558	Punakitere River	Ngapipito Rd /Mangakahia Rd intersection	1990 - 1994	84 - 435
47559	Punakitere River	Mangakahia Rd above falls	1990 - 1994	48 - 179
47567	Punakitere tributary	O'Conners culvert	1989 - 1991	1.1 – 5.9
47539	Te Tunaotemuka tributary	Rock weir	1989 - 1995	0.6 – 9.4
47543	Te Tunaotemuka tributary	M/A windmill spring	1988 - 1992	0.9 – 4.3
47562	Te Tunaotemuka tributary	Smith w/r	1991 - 1993	0.2 – 2.2
47585	Tokakopura Stream	Maori Affairs dam	1981 - 1989	4.7 - 15
47586	Tokakopura Stream	Edwards Rd	1989	5.1 – 8.9
47587	Tokakopura Stream	Wooden Crossing	1981 - 1989	14 - 70
47588	Tokakopura Stream	Waimatenui Rd	1983	30
47550	Tokakopura tributary	New M/A dam outfall	1989 - 1991	0.6 – 6.7
47551	Tokakopura tributary	LH trib Browns Rd & picket fence	1981 - 1994	5.9 - 70
47549	Tokakopura tributary	RH trib Browns Rd	1981 - 1994	3.4 – 76
47572	Waikaka Stream	Bernora Produce	1991 - 1994	0.9 – 4.0
47512	Wairoro Stream	DSIR (Cumbers Rd KKE)	1981-2005	15 - 382
47541	Wairoro Stream	Quarry	1981 - 1991	45 - 417
47598	Wairoro Stream	US FNDC weir (at old concrete weir)	2005	26 - 32
47537	Wairoro (Kopuni Stream)	SH 12 (FNDC take)	1986 - 2005	10 - 173
47564	Wairoro Stream	Northland College Grounds	1974 - 1991	11 - 199

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3.3 Groundwater and Surface Water Abstraction

Table 3 and Table 4 summarise information on groundwater and surface water consent and permitted allocations active in 1992 (NRC, 1992). Farm and domestic water supply requirements, which are a permitted activity, were estimated from stock and house numbers. Total groundwater allocation for the Kaikohe basalt was 1,429 m^3/day and total surface water allocation was 2,652 m^3/day.

Table 5 and Table 6 summarise the total consented groundwater and surface water abstraction from the study area as at June 2005. Consented groundwater and surface water abstraction is 819 m^3/day and 1,969 m^3/day, respectively.

The taking of 1 m^3/day of groundwater for reasonable stock and domestic needs is a permitted activity under the Regional Water and Soil Plan for Northland (NRC, 2004). This volume applies to new abstractions only, with existing permitted takes allowed 30 m^3/day for stock use and 2 m^3/day for domestic use. Due to uncertainty over the exact number and use of permitted takes in the study area, permitted takes at the time of this study are assumed to be similar to the 1992 estimate. A bore and water use survey is required to more accurately assess permitted use. Assuming that farm and domestic supply is similar to the 1992 estimate, total groundwater allocation is estimated as 870 m^3/day and total surface water allocation is 2,502 m^3/day.

Current consented allocation from both groundwater and surface water are less than the total allocation in 1992. This is primarily due to the cancellation of the unexercised Far North District Council (FNDC) Rangihamama bore consent, and expiry of some small horticultural irrigation surface water takes.

- **Table 3. Consented and permitted groundwater allocation as at 1992.**

Consent No.	Name	Use	Volume (m^3/day)
1862	Far North District Council – Memorial Hill	Public water supply	493[1]
1865	Johnsons Plants Limited	Horticultural irrigation	38
2006	Kairangi Orchard	Horticultural irrigation	50
3875	Johnsons Plants Limited	Horticultural irrigation	100
4026	Johnsons Plants Limited	Horticultural irrigation	100
4393	Far North District Council - Rangihama	Public water supply	597[2]
	Total consented takes		**1,378**
	Total permitted takes		**51**
	Total takes		**1,429**

Notes: [1]Consent allows 180,000 m^3/yr to be taken from bores; [2]Consent allows 218,000 m^3/yr.

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Table 4. Consented and permitted surface water allocation as at 1992.

Consent No.	Name	Use	Volume (m^3/day)
1862	Far North District Council – Squires Spring	Public water supply	289[1]
1659	B H Thom	Horticultural irrigation	100
4732	WD Smith	Horticultural irrigation	45
4109	Far North District Council – Wairoro Stream	Public water supply	1,300[2]
3672	Grasslands Division DSIR	Horticultural irrigation	20
4826	Benora Produce Ltd	Horticultural irrigation	150
2939	N H Munford	Horticultural irrigation	90
3707	Northland College Board of Trustees	Horticultural irrigation	25
2172	Levondale Farms Ltd	Horticultural irrigation	100
	Total consented takes		**2,119**
	Total permitted takes		**533**
	Total takes		**2,652**

Notes: [1]Total consent allocation is 288,000 m^3/yr, but 180,000 m^3/yr can be abstracted from Memorial Hill bore; [2]Consented allocation over November-April

Table 5. Consented and permitted groundwater allocation as at June 2005.

Consent No.	Name	Use	Volume (m^3/day)
19960387501	Horizon2 Limited	Horticultural irrigation	160
19980495001	Far North Apparel Master Limited	Manufacturing	30
20010757701	Johnsons Plants Limited	Horticultural irrigation	75
20040186201	Far North District Council – Memorial Hill	Public water supply	493
20041132002	Holcim NZ Limited	Manufacturing	18
20041246801	R B Scott	Livestock farming	43
	Total consented takes		**819**
	Total permitted takes		**51**
	Total takes		**870**

Table 6. Consented and permitted surface water allocation as at June 2005.

Consent No.	Name	Use	Volume (m^3/day)
19920410901	Far North District Council – Wairoro Stream	Public water supply	1,300
20000473201	Smith Calla Trust	Horticultural irrigation	90
20000749601	N H Munford	Horticultural irrigation	90
20000750401	Levondale Orchard	Horticultural irrigation	100
20000752201	B H Thom	Horticultural irrigation	100
20040186201	Far North District Council – Squires Spring	Public water supply	289
	Total consented takes		**1,969**
	Total permitted takes		**533**
	Total takes		**2,502**

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3.4 Drillers Borelogs

There are forty-one bores registered on the NRC bore database for the Kaikohe aquifer. Six bores have been drilled since August 1992, and have therefore not been incorporated into the NRC 1992 report. The bore details are summarised in Table 7. Appendix A contains details for the full list of bores in the study area.

The six borelog descriptions generally show soft, weathered basalt at the ground surface followed by hard basalt, occasionally fractured and interlayered with scoria, ash and clay. The interlayering indicates a number of basalt flows in the area rather than a single flow deposit. The descriptions are consistent with other borelogs in the area.

- **Table 7. Bore details for bores drilled after August 1992.**

Bore	Owner	Drilled date	Depth (m)	Cased depth (m)	Static water level (mBGL)	Yield (L/s)	Base of basalt (mBGL)
203270	Kaikohe Laundry	8/10/1992	60	12.0	8	-	54
203323	Shell Depot	22/07/1999	8	6.0	3	-	-
204068	Hedge Family	14/02/1998	31	3.5	10	1.7	-
209165	Holcim Ltd	10/09/2003	53	6.0	3	0.2	50
209194	Associated Auctioneers	22/01/2004	101	12.7	9	0.5	38
209466	Northland Forestry Nursery Ltd	15/07/2005	67	22.9	6	1.0	-

3.4.1 Basalt Thickness

The extent and depth of Kaikohe Basalt across most of the study area has been confirmed from drilling and geophysical investigations completed for the NRC 1992 report. The 1992 Kaikohe basalt thickness plot has been reproduced in Figure 5.

The thickness of the basalt is greatest on the western lobe near Rangihamama Road and on the southern lobe immediately south of Browns Road, where the basalt has infilled a paleovalley.

The NRC 1992 report indicated that there was some ambiguity in the geophysical interpretations across the southern parts of the basalt, where there are no bores drilled for ground-truthing. The new bores drilled since 1992 are located in areas where the basalt depth is relatively certain, and have depths generally consistent with previous interpretations (see Figure 5). The small differences that do occur are mainly due to insufficient detail on the borelogs to assess the change from Kaikohe basalt to South Omapere basalt. The borelogs for bore 209165 and 209194 indicate alternating layers of basalt with ash, where the separation between Kaikohe basalt and South Omapere basalt is not certain.

- **Figure 5. Kaikohe basalt thickness.**

(see A3 attachment at rear).

3.5 Groundwater Levels

The NRC has monitored groundwater levels in eight bores from 1987. Table 8 summarises the period and frequency of monitoring for these sites and Figure 3 shows the locations.

- **Table 8. Groundwater level monitoring sites.**

Site	Name	Bore	Period of monitoring	Frequency of monitoring
5347001	Rangihamama at Kaikohe	203196	Sep 1987 – May 1999	Variable (15 min – 3 hourly)
5347002	Town Bore at Kaikohe	203195	Oct 1987 - present	Monthly
5347003	Woolshed at Kaikohe	203199	May 1988 – Jul 1998	Variable (15 min – monthly)
5347005	Woolshed Piezo at Kaikohe	-	May 1988 – Jul 1998	Monthly
5347007	S.H.12 at Kaikohe	203198	May 1988 – Sep 2003	Variable (15 min – daily)
5347011	Roadside at Kaikohe	203200	Jun 1988 - present	Variable (15 min – monthly)
5347012	Roadside Piezo at Kaikohe	203197	Oct 1987 - present	Monthly
5347013	Kaikohe Hill at Kaikohe	203057	Mar 1989 - present	Monthly

Figure 6 and Figure 7 show the groundwater hydrographs for each of these bores. Groundwater levels for the majority of monitoring bores fluctuate over a 2 to 4 m range, with maximum elevation occurring between July and September. The Memorial Hill bore (203057) has a greater range of fluctuation due to pumping of this bore for public water supply.

The lowest groundwater levels in the monitoring bores, excluding the Memorial Hill bore, occurred in June 1991. This corresponds with an extended period of below average rainfall, as shown on the residual mass rainfall plot in Figure 8. The rainfall data is from the Kaikohe DSIR EDR station (534807).

Low groundwater levels in the Memorial Hill bore occurred in March 1991, June 1999 and September 2005. The low groundwater levels recorded in June 1999 do not correspond with an extended period of below average rainfall, suggesting that the low groundwater levels at this time were a result of increased groundwater abstraction compared to previous years. The residual mass rainfall plot for June 2005 indicates an extended period of below average rainfall similar to May 1991. This is reflected in the low groundwater levels in the Memorial Hill bore, with levels at the end of February 2005 being fairly similar to February 1991 groundwater levels. However, contrary to 1991 where groundwater levels recovered after summer, groundwater levels from March to September 2005 were still declining, only starting to recover in October. This indicates that water usage over March to September 2005 is greater compared to previous years under similar climatic conditions.

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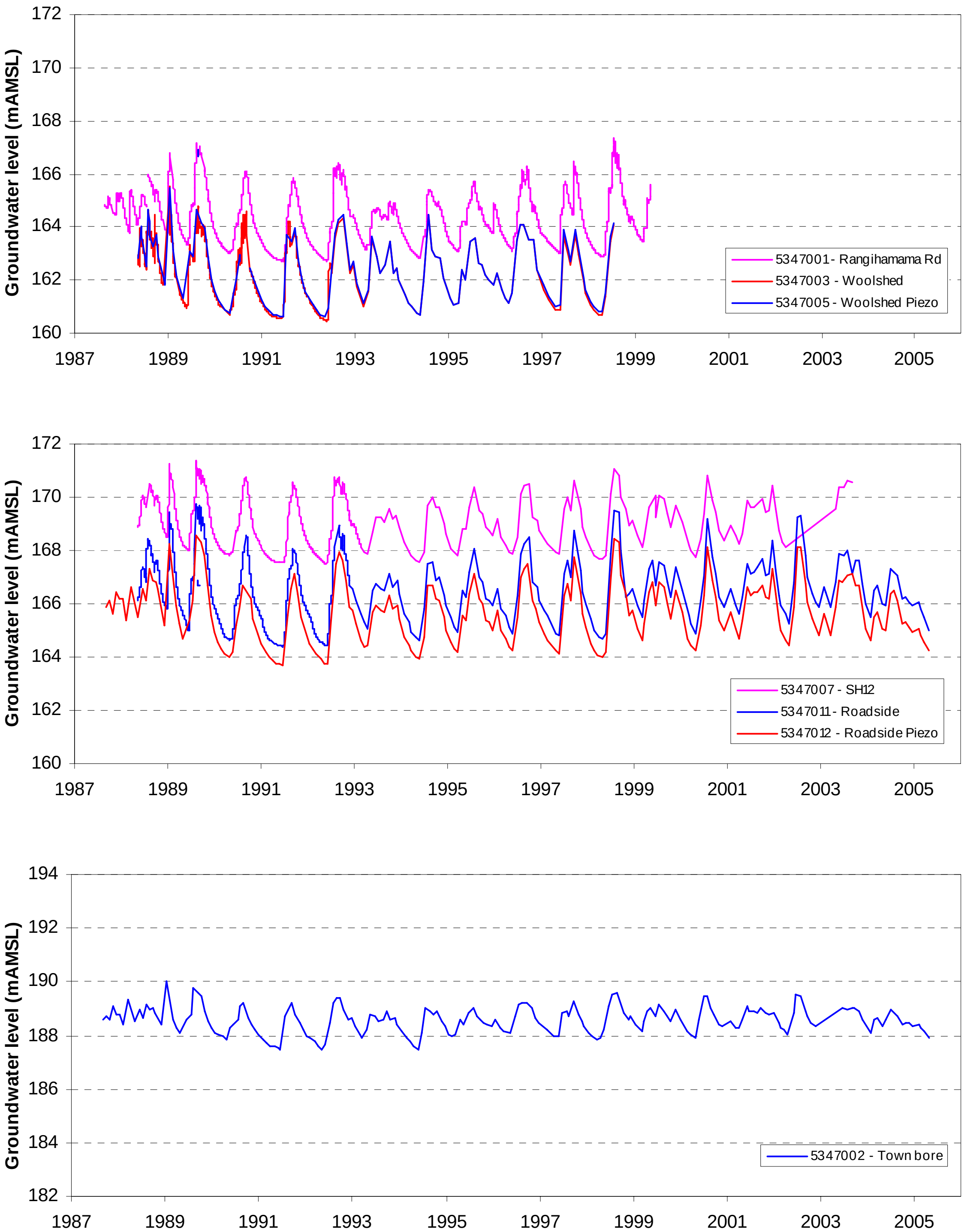

▪ **Figure 6. Groundwater hydrographs.**

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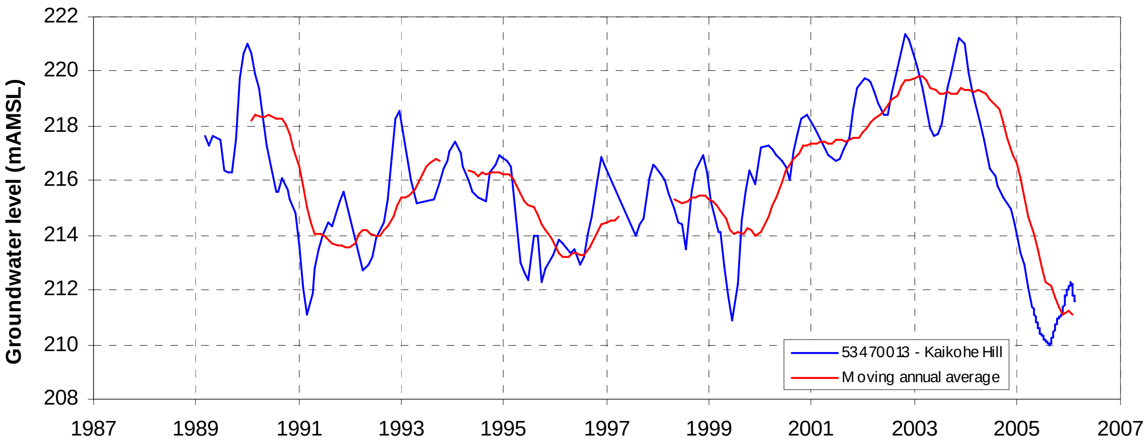
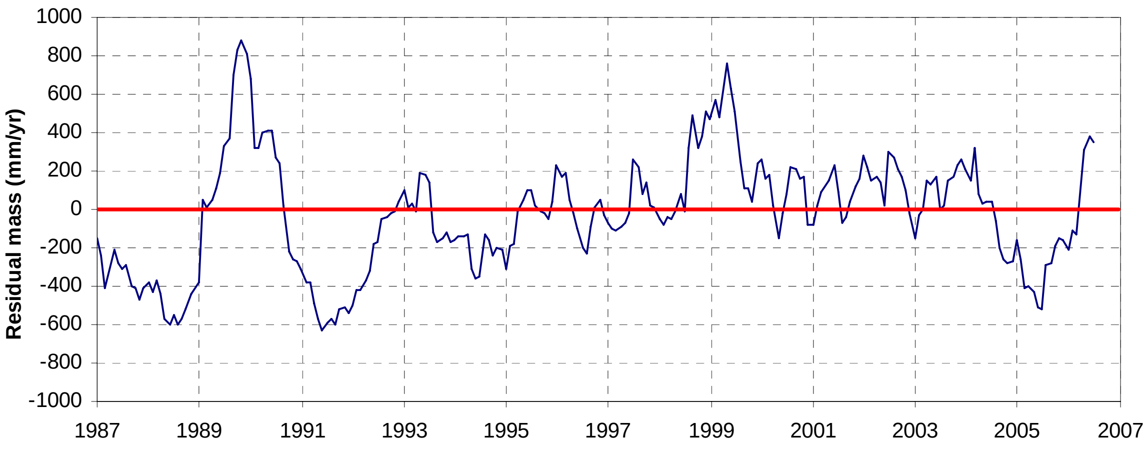


▪ **Figure 7. Memorial Hill bore groundwater hydrograph.**



Note: Red baseline indicates position of long-term annual average rainfall of 1,425 mm.

▪ **Figure 8. Residual mass rainfall.**

3.5.1 Groundwater Level - Spring Flow Relationship

Heavy pumping from the FNDC Memorial Hill bore over the 1990/91 summer resulted in the flow from Squires Spring almost stopping, and the neighbouring spring drying up (NRC, 1992). As spring flow is influenced by groundwater levels, flow from Squires Spring (located at approximately 220 mAMSL) is likely to have been similarly affected during the 2004/05 summer.

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3.6 Piezometric Surface

Figure 9 shows the piezometric surface contour plot for the Kaikohe basalt aquifer, reproduced from NRC (1992). The figure also shows the locations and groundwater level elevations of the six new bores. Table 9 summarises the groundwater level elevations for these bores.

The new bores have groundwater level elevations generally consistent with the 1992 piezometric contour interpretation. Bore 203323 has the greatest variation from the nearest contour, at 15 m. The differences that occur in the bore groundwater elevations are likely to be due to incorrect estimation of the ground level elevation, and/or use of static water levels from driller's logs that may not be fully recovered after drilling, or have been recorded from different seasonal periods.

The predominant groundwater flow direction is from northeast to southwest, with radial flow outwards from the Memorial Hill scoria cone. Spring discharges occur around most of the aquifer margin, in particular along the southern boundary of the western and southern lobe.

- **Table 9. Groundwater level elevations for new bores.**

Bore	Name	Static water level (mBGL)	Approximate ground elevation (mAMSL)	Groundwater elevation (mAMSL)
203270	Kaikohe Laundry	8	210	202
203323	Shell Depot	3	198	195
204068	Hedge Family*	10	115	105
209165	Holcim Ltd	3	190	187
209194	Associated Auctioneers	9	185	176
209466	Northland Forestry Nursery Ltd	6	178	172

Notes: *Bore 204068 located outside of Kaikohe basalt boundary.

- **Figure 9. Piezometric surface plot.**

(see A3 attachment at rear).

3.7 Aquifer Hydraulic Properties

Aquifer test pumping exercises have been conducted on three bores within the Kaikohe basalt. Table 10 summarises the hydraulic properties for two of these bores. One pump test has been excluded as the bore location and details are unknown. The information has been extracted from the NRC 1992 report, with no further test pumping exercises conducted since this date.

Transmissivities range from 50 to 174.9 m^2/day, with hydraulic conductivities in the range of 1 to 3.2 m/day.

Specific capacity ranges from 0.00058 to 0.025. The higher storage value was obtained from water balance modelling. The higher values are considered to be representative of the wider aquifer, while the lower storativity values obtained from aquifer test pumping exercises are considered to reflect localised conditions only. The available data suggests that much of the Kaikohe Basalt comprises an unconfined aquifer, but is confined or semi-confined in some places by lower permeability ash or other aquitards (NRC, 1992).

Table 10. Summary of aquifer hydraulic properties.

Bore ID	Name	Bore depth (m)	Casing depth (m)	Saturated thickness (m)	Q (m^3/day)	T (m^2/day)	S (-)	K (m/day)
203196	Frazer Thomas Partners[1]	80.7	20	54.9	400	69.2 – 174.9	0.00058 – 0.00072	1.2 – 3.2
203176	Mahi Kia Mohia Trust	34	-	-	18	50	-	-
203176	Mahi Kia Mohia Trust	34	-	-	64	87 - 130	-	-
	Average					98.2	0.00065	

Notes: Leakage observed in all tests; [1]Alternative analysis of a single test.

3.8 Water Quality

Groundwater quality information has been collected from Johnsons Plant bore (bore 203172) from February 1991 as part of New Zealand's National Groundwater Monitoring Program (NGMP). The NGMP program aims to provide a national perspective on groundwater quality and to identify spatial and temporal trends in groundwater chemistry.

Appendix B summarises the groundwater quality results from this bore. The results have been compared to the Australian and New Zealand Environment and Conservation Council (ANZECC, 2000) guidelines which apply to the protection of aquatic ecosystems, and the Drinking Water Standards for New Zealand (DWSNZ, 2005). Exceedances of the relevant guideline value are discussed below:

- The groundwater is near neutral to slightly acidic (pH 6.2 to 7.4).
- Nitrate-N values range from 2.2 to 3.4 mg/L. These concentrations exceed the ANZECC (2000) aquatic ecosystems guideline of 0.158 mg/L for surface water. This is likely to be due to nitrate leaching on nearby farmland or from possible fertiliser use at the plant nursery where the bore is located.

Groundwater quality results contained in NRC (1992) were generally good, with the groundwater suitable for most uses. One bore sample had high iron, which is not uncommon in basalt aquifers.

3.8.1 Age Dating

Age dating analyses have been undertaken from a number of bores in the Northland region as part of the NGMP Program. Preliminary age estimates from tritium, CFC and SF6 analyses for the Kaikohe Johnsons Plant bore (bore 203172) indicate that the groundwater is approximately 60 years old (NRC, 2005). This bore is screened from 61 to 88 mBGL within South Omapere Basalt.

The relatively old age of the groundwater suggests slow groundwater flow through the surrounding rocks at this location and depth. The South Omapere Basalt is generally considered to be denser and less vesicular than the overlying Kaikohe Basalt, based on the limited geological information available (NRC, 1992). It is likely that the Kaikohe Basalt has a younger mean residence time in the surficial layers, particularly where fractures occur. The groundwater response following recharge events suggests that much of the recharge quickly flows out of the aquifer (see Section 2.4).

The majority of groundwater recharge to the South Omapere Basalt is likely to come from the Kaikohe Basalt, as the exposed surface area of South Omapere Basalt is relatively small and infiltration from the surrounding and underlying low-permeability Cretaceous siltstone is likely to be minimal. Hydraulic interactions between the South Omapere Basalt and Kaikohe Basalt have not been investigated, however it is considered likely that some interaction does occur (NRC, 1992).

Age distribution analysis is required to understand the extent of possible mixing of young and old groundwater within the aquifer,

3.9 Groundwater Recharge

Groundwater recharge has been estimated in the NRC (1992) report using an infiltration-soil moisture budget model. The estimated average annual recharge rate was 500 mm, which equates to 27,397 m^3/day over a 20 km^2 Kaikohe Basalt outcrop recharge area.

A soil moisture water balance model is an appropriate method to estimate recharge provided one or more of the model outputs is calibrated against local field data (e.g. stream flow records). This does not appear to have been done for the infiltration soil moisture budget model, with the quickflow loss calculated from rainfall and stream records for the Waipao Stream west of Whangarei.

Groundwater recharge was also estimated in the NRC (1992) report from groundwater level rise during rainfall events, resulting in a groundwater recharge estimate of 2.3 mm/yr to 87.5 mm/yr (i.e. 126 m^3/day to 4,794 m^3/day). The range in values is due to the range in storage coefficient of 0.00065 to 0.025. The lower storage coefficient is considered to reflect localised conditions only (NRC, 1992).

The large range in recharge estimates (126 to 27,397 m^3/day) demonstrates the high degree of uncertainty associated with analytical calculation of rainfall recharge. The lower end of the range is considered to reflect localised conditions only, with average recharge estimates more towards the middle of the range. The largest value calculated from the infiltration-soil moisture budget model equates to approximately 33% of rainfall, which is considered near the upper end of rainfall recharge for basalt.

Groundwater recharge has been assessed in this study using a soil moisture water balance model (SMWBM) calibrated to low flow monitoring records for Squires Spring and Tokakopura Tributary. The model has been separately calibrated to account for the anticipated higher groundwater recharge component from the Monument Hill scoria cone compared to Kaikohe basalt.

The SMWBM utilises daily rainfall data and mean-monthly evaporation totals to calculate soil moisture conditions, percolation to the groundwater table, surface runoff and interception storage. A detailed description of the model and parameter values utilised is given in Appendix C.

Daily rainfall from five Kaikohe stations (534701, 534801, 534802, 534807 and 534725) were combined to create a continuous record from 1922 to 2005, and evaporation was obtained for climate station A53487 (2 km south-east of Kaikohe).

Groundwater recharge for Monument Hill and the Kaikohe basalt was estimated from the 83 year simulation of the SMWBM at 16.5% and 13.2% of rainfall, respectively. This equates to 802 m^3/day over a 1.135 km^2 for Monument Hill and 11,299 m^3/day over 20.0 km^2 for Kaikohe basalt. Combined, total groundwater recharge is therefore estimated at 12,101 m^3/day, which is within the range of values presented in NRC (1992).

The SMWBM outputs could be further refined in the future with additional stream flow monitoring data, including higher flows.

3.10 Summary of Updated Information

The main points obtained from analysis of additional data for the study area includes:

- Rainfall for the year ending 30 June 2005 was significantly below long-term average annual rainfall. Similar rainfall conditions were last experienced in 1992.
- Stream flow measurements during April 2005 were below estimated extreme low flow values at the DSIR (Cumber Rd) site and SH12 FNDC site on the Wairoro Stream, which indicates that April 2005 was a dry summer and may also be a reflection of pumping further upstream. These sites are two of three stream gauging sites that were monitored during 2005. The other site (FNDC weir) does not have an extreme low flow value as the period of monitoring is short.
- Groundwater consented abstraction is less than the 1992 level, at 819 m^3/day (559 m^3/day difference). Likewise, surface water abstraction is less at 1,969 m^3/day (150 m^3/day difference).

- Six additional bores have been drilled in the area since 1992. The geology, basalt thickness and groundwater elevations are fairly consistent with other bores in the area. Differences may be due to uncertainty in interpretation of basalt flow boundaries, estimation of groundwater elevation without the use of survey data and/or variable seasonal conditions at the time of groundwater level measurement.
- Low groundwater levels in the Memorial Hill bore occurred in March 1991, June 1999 and September 2005. The low levels experienced in June 1999 are likely to be a reflection of high abstraction from the bore compared to previous years, as the date does not correspond to a period of below average rainfall. Rainfall was below average in the year ending May 1991 and June 2005, however contrary to 1991 where groundwater levels began to recover after summer, groundwater levels in 2005 did not recover until October 2005. This indicates high water usage in 2005.
- There is no additional aquifer hydraulic property information since the NRC (1992) study.
- Groundwater quality data for Kaikohe Johnsons Plant bore (bore 203172) indicate high nitrate-N levels, which is likely to be due to nutrient inputs from surrounding farmland or the nursery.
- Age dating data for Kaikohe Johnsons Plant bore indicate that the groundwater is approximately 60 years old. This bore is screened through the underlying, less permeable South Omapere basalt. The relatively old age is a reflection of the slow groundwater flow at this depth and location.
- Refinement of the groundwater recharge and discharge estimates has been undertaken by calibrating a SMWBM to low flow monitoring records. The results are consistent with upper estimates of groundwater recharge estimated previously.

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4. Assessment of Sustainable Yield

This section provides an assessment of sustainable yield for the Kaikohe Basalt. Sustainable yield has not been assessed for the South Omapere Basalt as the Kaikohe Basalt is the primary aquifer system in the study area. The South Omapere Basalt is considered to be low yielding.

On an individual bore basis, restrictions to abstraction may still apply regardless of the total amount of groundwater potentially available for allocation from the aquifer. This is because drawdown from bores located near aquifer boundaries, springs or other bores may have adverse effects despite the relatively small volume being abstracted. This needs to be assessed on an individual basis.

Rainfall recharge assessed in the NRC 1992 study ranged from 126 to 27,397 m^3/day for the Kaikohe Basalt. The lower limit is a reflection of localised conditions, with average conditions considered to be more in the range of 12,101 to 27,397 m^3/day. Rainfall recharge can be considered to equate to the maximum volume of water available for abstraction from the Kaikohe Basalt. A proportion of this water needs to be set aside to maintain environmental flows in streams for aquatic ecosystems and downstream users.

The SMWBM has been used to assess sustainable yield from the volume available for allocation from stream flow. Policy 9.05.07 of the Regional Water & Soil Plan (NRC, 2004) states that the Design Minimum Flow (i.e. 1 in 5 year 7-day low flow) represents the flow required to maintain environmental flows. Flows above the Design Minimum Flow (DMF) are potentially available for allocation.

The SMWBM was calibrated to available low-flow gauging data for Squires Spring (gauging site 47529) and Tokakopura Tributary (gauging site 47551). The calibrated hydrographs and description of parameters used in the model is summarised in Appendix C. The flow statistics for each site were scaled up from their respective catchment areas to provide estimates of discharge for the wider Monument Hill (1.135 km^2) and Kaikohe basalt (20.0 km^2), and the DMF values were assessed from this data.

The DMF values (i.e. 1 in 5 year 7 day low flows) assessed from the long-term record were 441 m^3/day and 6,287 m^3/day for Monument Hill and Kaikohe basalt, respectively. These values represent the environmental flows that must be maintained from Monument Hill and the Kaikohe basalt.

Monument Hill

From the SMWBM, annual average groundwater percolation accounted for 16.5% of rainfall for Monument Hill. As rainfall over the period of record was 4.28 mm/day on average, groundwater

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recharge equates to 802 m^3/day over the 1.135 km^2 Monument Hill catchment area. Therefore, the sustainable yield, or available flow, for Monument Hill is 361 m^3/day (Table 11).

The current estimate of sustainable yield for Monument Hill is less than the 800 m^3/day that can be abstracted under consent 20040186201 (Far North District Council). The DMF analysis has been assessed using a catchment area corresponding to the elevation of Squires Spring, which is approximately 220 mAMSL. However, the bore is screened from approximately 20.2 to 86.2 mBGL (exact bore construction details unknown from borelog 203057), with the base of the bore intake located 26 m below Squires Spring elevation at approximately 194 mAMSL. This suggests that the bore may actually draw water from a larger groundwater catchment area than was used in the DMF analysis. A more definitive assessment of sustainable yield of the Monument Hill bore will require integration of this DMF analysis with various bore construction and groundwater monitoring data.

Kaikohe Basalt

Groundwater percolation for the Kaikohe basalt is 13.2 % of rainfall, based on calibration of the SMWBM. This equates to groundwater recharge over a catchment area of 20.0 km^2 of 11,299 m^3/day. The sustainable yield (groundwater recharge minus DMF) for the Kaikohe Basalt is 5,012 m^3/day (see Table 11 for calculation summary).

▪ **Table 11. Summary of sustainable yield calculations.**

	Monument Hill	Kaikohe Basalt
Rainfall recharge (% of annual average rainfall)	16.5	13.2
Rainfall recharge (m^3/day)	802	11,299
Design Minimum Flow (m^3/day)	441	6,287
Sustainable Yield (m^3/day)	361	5,012
(% of annual average rainfall)	7.4	5.9
(% of annual average recharge)	45.0	44.4

Combined, the total sustainable yield for the aquifer is approximately 5,373 m^3/day. This is based on average rainfall recharge inputs, which will reduce during a prolonged dry period.

Total groundwater allocation for the aquifer is 870 m^3/day, and total surface water abstraction is 1,202 m^3/day excluding the FNDC take from Wairoro Stream upstream of the Kaikohe Basalt (see Section 3.3,). This is below the average sustainable yield estimate of 5,373 m^3/day, but may become stressed during prolonged dry periods. It is known that abstraction from particular bores affect nearby spring flows, so although the total allocation for the aquifer is within the maximum sustainable yield the individual consented allocation needs to be assessed on a site-specific basis, as alluded to above (e.g., Monument Hill).

5. Conclusions and Recommendations

This study provides an update to the Kaikohe Water Resources Assessment report completed in 1992 (NRC, 1992). The majority of additional information collected since 1992 is generally consistent with previous information, in terms of spring flows, basalt thickness and groundwater levels. Groundwater level monitoring data from March to September 2005 for the Memorial Hill bore shows levels lower than previous monitoring records. Rainfall records for this period are similar to the below average conditions experienced in June 1991, suggesting that water usage in 2005 was greater. Groundwater and surface water consented abstraction is less than 1992 totals.

The recommendations for further investigations contained in the 1992 report include:

- Longer, higher rate pump testing than previously carried out to establish the nature and extent of the aquifer system, effects on spring and stream flows, and interaction with other aquifers (eg. South Omapere basalt).
- Mapping and gauging of springs and stream flows, and concurrent groundwater level monitoring, to allow estimation of abstraction related impacts.
- Development of a groundwater model based on this data, which would enable quantitative prediction of abstraction impacts on surface water resources.

These investigations have not been implemented and are still applicable for better understanding of the Kaikohe basalt aquifer. In addition to the NRC recommendations the following is suggested:

- Major abstractions, if they are to avoid adverse effects on spring flows, should be spread over a number of locations rather than one part of the aquifer. Groundwater subcatchments could be delineated within the aquifer for management purposes.
- Gauging of stream and spring flows during periods of higher flows will allow the stream design minimum flow to be determined and hence sustainable abstraction rates to be defined. This information can be used to refine the SMWBM assessment, which may remove the requirement for a groundwater model to be developed.
- Conduct a bore and water use survey to assess the volume of groundwater and surface water abstracted under permitted activity status. This will enable sustainable yield to be refined.
- Age distribution analysis of groundwater to determine the extent of mixing of young and old groundwater and aid in interpreting the results of water quality monitoring.
- Strategies to take advantage of seasonal resource availability, such as storage of water during winter, should be implemented where required.

6. References

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Appendix A Bore Details

- **Table A1. Summary of bore details.**

Bore ID	Name	Bore depth (m)	Cased depth (m)	Static water level (m)	Yield (L/s)
203019	R Jordan	10.6	7.6	6.6	
203020	P Edmonds	10.6	2.4		0.1
203021	S Edmonds	22	13	9.7	0.4
203022	Stevens	20	18	6	0.5
203025	E O'Halloran	17		7	0.4
203028	F Goodhue	22.8		No water	
203029	Te Iringa Marae	14.6		6.4	0.4
203031	P Williams	27.7		13.7	0.1
203032	Johnsons Plants Ltd	50		6	2.6
203033	Strong	14	5.8	7	0.7
203036	L Jerkovich	19			
203037	Rowsell and Rowsell Sawmills		9.7		
203038	Kaikohe Marae	22.2	2.1		0.2
203040	Prichards	25.6	24.3	4.8	1.3
203041	M Johnson	16.7	11.5	4.8	0.1
203046	B Gillis	12.8		2.7	0.3
203048	H Crump	11.6	5.5	5.8	0.3
203049	R Manus				
203050	Nicholas				
203051	Northland College	22.2	12.8	16.1	
203057	Frazer Thomas Partners	86.2		55.9	
203159	Johnsons Plants Ltd	99	6	8	2.5
203172	Johnsons Plants Homestead Nursery	88		22	1.6
203176	Mahi Kia Mohia Trust	33.5	17		0.5
203186	L Maddox	46	12.8		0.6
203195	Frazer Thomas Partners	57.7			
203196	Frazer Thomas Partners	80.7	20	8.5	
203197	Frazer Thomas Partners	61.4			
203198	Kaikohe Borough Council	48.9			
203199	Kaikohe Borough Council	38	27.3		
203200	Kaikohe Borough Council	12			
203206	G McGregor	23	3	1	
203209	J Pilcher	26.8	23.8	4.9	
203211	B Smith	33	3	3	
203220	A Dadson	23	5	6	
203270	Kaikohe Laundry	60	12	8	
203323	pdp - shell depo - Kaikohe	8	6	2.8	
203327	Mackie - Pump test				
204068	Hedge Family - Te Iringa, Kaikohe	31	3.5	10	1.7

Bore ID	Name	Bore depth (m)	Cased depth (m)	Static water level (m)	Yield (L/s)
209165	Holcim Ltd, Kaikohe	53	6	2.5	0.2
209194	Associated Auctioneers, Mangakahia Rd	101	12.7	9.3	0.5
209466	Northland Forestry Nursery Ltd	67	22.9	6	1.0

Appendix B Groundwater Quality

- **Table B1. Groundwater quality results from Johnson No.1 bore (Sampling site 101920).**

Date	Bicarbonate	Carbonate	Total Alkalinity	Bromide	Calcium	Chloride	Electrical Conductivity	Dissolved Oxygen	Dissolved Reactive Phosphorus	Fluoride	Dissolved Iron	Total Iron
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/m	mg/L	mg/L	mg/L	mg/L	mg/L
21/02/91	73		60		12.6	11	18					0.07
30/08/00			66	0.07	10.5	10.8	17			< 0.05		0.03
29/11/00			72	0.09	10.6	10.7	18			< 0.05		< 0.02
5/03/01			64	0.07	10.6	10.6	18			< 0.05		< 0.02
6/06/01			65	0.05	11.8	10.8	19			< 0.05		< 0.02
7/08/01			65	< 0.03	11.4	10.6	19			< 0.05		< 0.02
7/12/01			66	0.03	10.9	10.7	16			0.02		< 0.02
6/03/02			69	< 0.1	11	10.8	19			< 0.03		< 0.02
17/06/02			63	< 0.1	10.3	10.6	17		< 0.1	< 0.03	< 0.02*	
2/09/02			69	< 0.1	10.9	10.7			< 0.1	< 0.03	0.03*	
22/11/02	77			< 0.1	9.8*	11	21		0.08	0.03	< 0.02	
4/03/03	63			< 0.1	10.7*	10.8	18.1		< 0.05	0.05	< 0.02	
28/05/03		62		< 0.1	11*	10.6	16.6		< 0.05	0.03	< 0.02	
3/09/03	65			< 0.1	12*	10.6	17.1	6.7	< 0.05	< 0.03	< 0.02	
28/11/03	64			< 0.1	10.8*	10.5	16.7	5.6		< 0.03	< 0.02	
25/02/04	76			< 0.1	10.8*	11				0.03	< 0.02	
18/05/04	66			< 0.01	11.6*	10.6	18.2			0.03	< 0.02	
24/08/04		59		< 0.1	6*	10.1	16.4			0.03	< 0.02	
22/11/04		75		< 0.1	9.9*	10.7	17.7			0.04	< 0.02	
3/03/05		74		< 0.04	10.3*	10.7	17.7		0.082	0.029	< 0.02	
18/04/05							16.8					
23/05/05		61		< 0.04	10.5*	10.2	15.1			0.024	< 0.02*	
Average	**69**	**66**	**66**	**<0.1**	**10.7**	**10.7**	**17.6**	**6.15**	**<0.1**	**<0.05**	**<0.002**	**<0.02**
ANZECC**											0.3	0.3
DWSNZ						250				1.5	0.2	0.2

Notes: *Acid soluble; **Protection of 95% of species.

Date	Potassium	Magnesium	Dissolved Manganese	Total Manganese	Sodium	Ammoniacal Nitrogen	Nitrate nitrogen	pH	Silica	Reactive Silica	Sulphate	Temperature
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	pH units	mg/L	mg/L	mg/L	°C
21/02/91	1.53	6.1		< 0.02	14.6			7.2			2	18.5
30/08/00	1.3	6.1		< 0.01	12.3	< 0.01	3.3	7.2	37		2.9	
29/11/00	1.3	6.2		< 0.005	14.7	< 0.01	2.7	6.7	41		3	
5/03/01	1.3	6		< 0.005	12.2	0.01	3.1	6.3	38		3.1	17.8
6/06/01	1.3	6.6		< 0.005	12.4	< 0.01	3.4	6.6	43		2.9	17.6
7/08/01	1.6	6.5		< 0.005	12.6	< 0.01	3.1	6.4	41		3	17.7
7/12/01	1.9	6.1		< 0.005	11.7	< 0.01	3.1	6.2	39		3	18.1
6/03/02	1.5	6.1	< 0.005*	< 0.005	13	< 0.01	3.4	6.4	41		2.6	19
17/06/02	1.3	6	< 0.005*		11.2	< 0.01	3.1	6.8	37		3	17
2/09/02	1.6	6.3	< 0.005*		11.7	0.01	2.8	6.6	41		3.6	
22/11/02	1.8	6	< 0.005		15.7	< 0.01	2.7	6.8		41	2.5	19.3
4/03/03	1.5	6	< 0.005		11.1	< 0.01	3	6.7		41	2.8	
28/05/03	1.7	6.6	< 0.005		11.2	< 0.01	3.1	6.4		40	2.9	17.6
3/09/03	1.3	6.7	< 0.005		11.5	< 0.01	3	6.6		42	2.8	17.8
28/11/03	1.3	6.3	< 0.005		11.5	< 0.01	2.9	6.3		39	2.8	18.1
25/02/04	1.6	6.3	< 0.005		15	< 0.01	2.7	7.2		41	2.5	18.2
18/05/04	1.4	6.5	< 0.005		11.4	< 0.01	3.1	6.6		40	2.8	17.7
24/08/04	0.75	3.5	< 0.005		6.7	< 0.01	2.7			24	3.5	17.4
22/11/04	1.8	6	< 0.005		14.6	0.01	2.5			38	2.5	18.4
3/03/05	1.9	6.2	< 0.005		15.1	< 0.01	2.2	7.4		43	2.9	18.5
18/04/05								6.6				17.9
23/05/05	1.2	6	< 0.005		11.3	< 0.01	2.8	6.7		38	2.7	18.3
Average	**1.47**	**6.1**	**<0.005**	**<0.005**	**12.45**	**<0.01**	**2.94**	**6.7**	**40**	**39**	**2.8**	**18.1**
ANZECC**			1.9	1.9		0.01^{+}	0.158	7.3-8.0^{+}				
DWSNZ			0.05*	0.05*	200		11.3	7-8.5			250	

Notes: *Acid soluble; **Protection of 95% of species; $^{+}$Upland river default trigger value.

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Appendix C SMWBM Description

C.1 Operation of the SMWBM

The soil moisture water balance model (SMWBM) is a deterministic lumped parameter model originally developed by Pitman (1976) to simulate river flows in South Africa. Modification of these algorithms and reworking of the code into a Windows environment now permits soil moisture accounting and assessment of the various components of the catchment water balance. In this study the SMWBM is employed as a tool for assessing long-term surface runoff, infiltration and groundwater recharge characteristics for the project area.

The model utilises daily rainfall and mean-monthly evaporation data to calculate soil moisture conditions and rainfall percolation to the aquifer. The model incorporates parameters that characterise the catchment in terms of:

- interception storage,
- evaporation losses,
- soil moisture storage capacity,
- soil moisture infiltration,
- surface runoff (quickflow);
- stream baseflows (groundwater contribution); and
- parameters that govern the recession and/or attenuation of groundwater and surface water flow components, respectively.

The fundamental operation of the model is as follows:

Daily rainfall is disaggregated into hourly intervals when a rainday occurs to allow refined accounting of soil infiltration and evaporation losses. Rainfall received must first fill a nominal interception storage (PI – see below) before reaching the soil zone, where the net rainfall is assessed as part of the runoff/infiltration calculation.

Water that penetrates the soil fills a nominal soil moisture storage zone (ST). This zone is subject to evapotranspiration via root uptake and direct evaporation (R) according to the mean monthly evaporation rate and current soil moisture deficits. The soil moisture zone provides a source of water for deeper percolation to the underlying aquifer, which is governed by the parameters FT and POW.

If disaggregated hourly rainfall is of greater intensity than the calculated hourly infiltration rate (ZMAX, ZMIN) surface runoff occurs. Surface runoff is also governed by two other factors, which are the prevailing soil moisture deficit and the proportion of impervious portions of the catchment directly linked to drainage pathways (AI).

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Rainfall of sufficient intensity and duration to fill the soil moisture storage results in excess rainfall that is allocated to either surface runoff or groundwater percolation depending on the soakage and slope characteristics of the catchment (DIV).

Finally, the model produces daily summaries of the various components of the catchment water balance and calculates the combined surface runoff/percolation to groundwater to form a total catchment runoff discharge.

C.2 Model Parameters

The most significant parameters used in the soil moisture accounting model are described below.

ST: Maximum soil moisture capacity

The parameter ST is of major importance in that it is the most significant factor governing the ability of the catchment to regulate runoff for a given rainfall event. The higher the value of ST, potentially the greater the amount of rainfall absorbed during wet periods, and results in more sustained baseflow during dry periods. The depth of the ST zone basically prescribes an active zone above the water table (vadose zone) within which plant root uptake can occur.

SL: Soil moisture storage capacity below which percolation ceases

There is a definable soil moisture state below which percolation ceases due to soil moisture retention.

ZMAX & ZMIN: Maximum and minimum soil infiltration rate

ZMAX and ZMIN are nominal maximum and minimum infiltration rates in mm/hr used by the model to calculate the actual infiltration rate ZACT. ZMAX and ZMIN regulate the volume of water entering soil moisture storage and the resulting surface runoff. ZACT is usually nearest to ZMAX when soil moisture is nearing maximum capacity. ZMIN is usually assigned zero.

FT: Percolation rate from soil moisture storage at full capacity

Together with POW, FT (mm/day) controls the rate of percolation to the underlying aquifer system from the soil moisture storage zone. FT is the maximum rate of percolation through the soil zone.

POW: Power of the soil moisture-percolation equation

The parameter POW determines the rate at which percolation diminishes as the soil moisture content is decreased. POW therefore has significant effect on the seasonal distribution and reliability of percolation, as well as the total yield from a catchment.

AI: Impervious portion of catchment

This parameter represents the proportion of impervious zones of the catchment directly linked to drainage pathways (AI).

R: Evaporation-soil moisture relationship

Together with the soil moisture storage parameters ST and SL, R governs the evaporative process within the model. The rate of evapotranspiration is estimated using a linear relationship relating evaporation to the soil moisture status of the soil. As the soil moisture capacity approaches full, evaporation occurs at a near maximum rate based on the mean monthly pan evaporation rate, and as the soil moisture capacity decreases, evaporation decreases linearly according to the predefined function.

DIV: Fraction of excess rainfall allocated directly to groundwater.

TL: Routing coefficient for surface runoff.

TL defines whether excess rainfall that does not infiltrate directly will flow overland to a surface water course or pond *in situ* and remain for later infiltration to groundwater.

GL: Groundwater recession parameter.

GL defines whether water within the vadose zone discharges to surface water bodies prior to later infiltration to groundwater.

C.3 Application of the SMWBM

A preliminary assessment of the Design Minimum Flow (DMF) for Squires Spring and Tokakopura Tributary was undertaken for this study using long-term continuous stream flow records generated from the SMWBM. The SMWBM was calibrated to available low-flow gauging data for Squires Spring (gauging site 47529) and Tokakopura Tributary (gauging site 47551). These sites were chosen for the following reasons:

1) The Squires Spring flow record is considered representative of groundwater discharge from the Monument Hill scoria cone. Groundwater recharge to scoria is typically higher than basalt due to its higher permeability.
2) Stream flow from the Tokakopura Stream and tributaries is derived mainly from groundwater and surface water runoff from the basalt aquifer. The groundwater baseflow component is assumed to be representative of discharge rates from the Kaikohe basalt.
3) Gauging site 47551 on the Tokakopura Tributary has no known upstream consented surface water abstractions and has a relatively large number of spot flow measurements.
4) Combined, the two simulated flow records for Squires Spring and Tokakopura Tributary roughly encompasses the entire study area.

The simulated stream flow record for each site was estimated on a daily basis using the SMWBM for the period 1973 to 2005, which corresponds to an overlapping period of monitoring at rainfall stations 534701, 534801, 534802, 534807 and 534725. Monthly evaporation totals were calculated for climate station A53487 (2 km south-east of Kaikohe).

The simulated stream flow record for Squires Spring is a combination of two separate SMWBM runs representing the scoria dome and surrounding basalt. The scoria has higher permeability, hence a lower surface runoff and higher groundwater percolation component than the basalt. Table C1 summarises those values that are necessarily different in order to simulate expected conditions under scoria and basalt.

- **Table C1. SMWBM parameters used for catchment modelling**

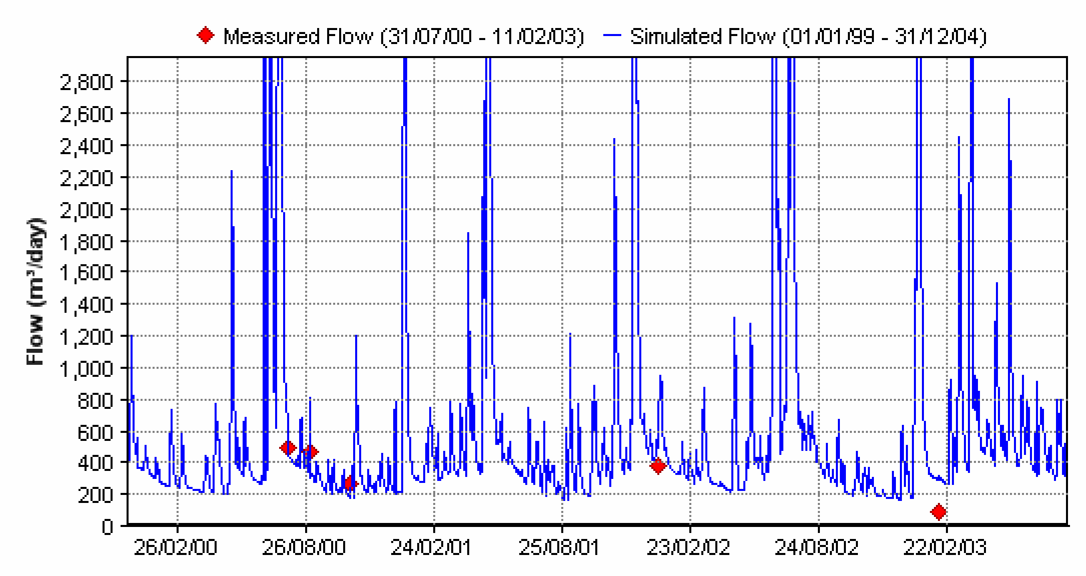
Model Parameter	Simulation	
	Scoria	Basalt
POW	2	2
ST	400	200
FT	5	1
AI	0	0.1
ZMAX	50	15
DIV	0.2	0.1
R	1	1

The groundwater hydrographs for the two lithologies were combined, weighted by catchment area, to produce one flow record for calibration. Figure C1 shows the flow hydrograph for Squires Spring.

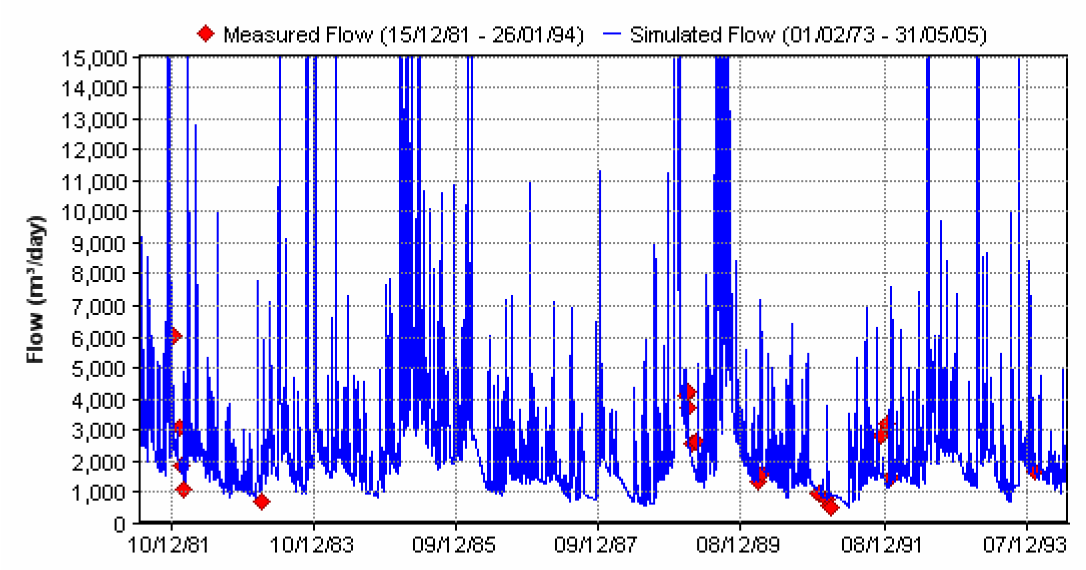
The hydrograph for the basalt flow component used in the Squires Spring record was based on the Tokakopura Tributary calibrated flow record, scaled to the Squires Spring basalt catchment area. Figure C2 shows the calibrated flow hydrograph for Tokakopura Tributary. As can be seen on both hydrographs, the accuracy of the simulation is limited by the minimal number and timing of spot measurements. The focus of the calibration was on the low-flow measurements used for the DMF analysis rather than the higher flows.

The flow record for each site was scaled up to provide estimates of discharge for Monument Hill (1.135 km^2) and Kaikohe basalt (20.0 km^2), and the DMF values were assessed from this data. The 7 day annual maxima Average Recurrence Interval (ARI) curve for Monument Hill and the Kaikohe Basalt are presented in Figure C3 and C4.

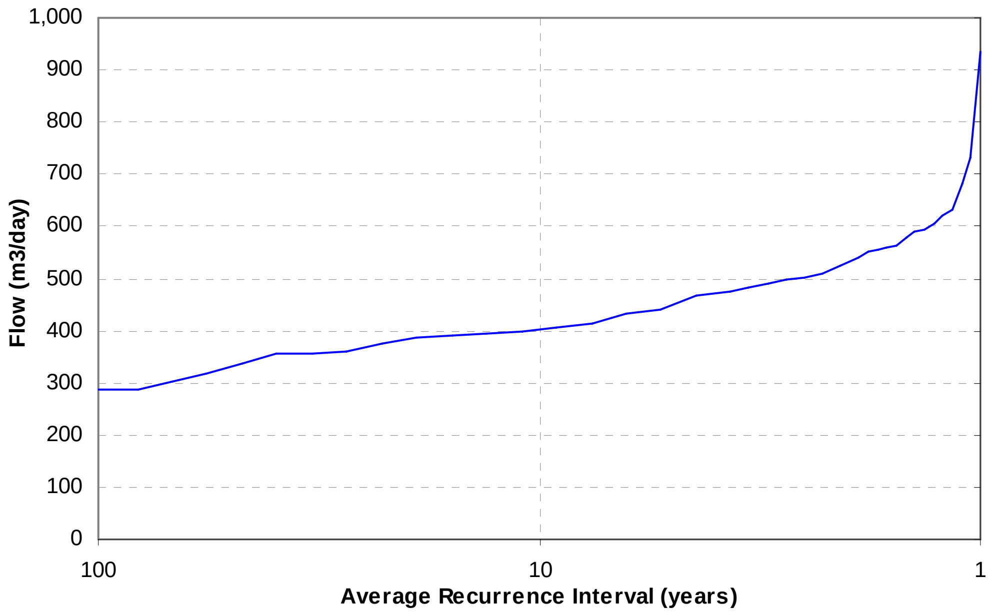
The DMF values (i.e. 1 in 5 year 7 day low flows) assessed from the long-term record were 441 m^3/day and 6,287 m^3/day for Monument Hill and Kaikohe Basalt, respectively. These values represent the environmental flows that must be maintained, according to Policy 9.05.07 in the Northland Regional Plan, from Monument Hill and the Kaikohe Basalt.



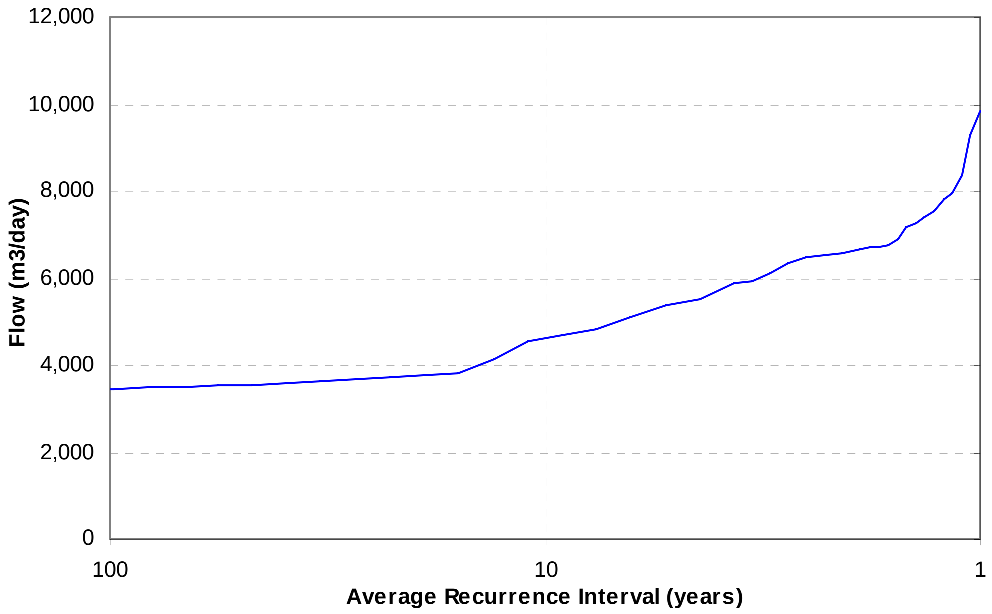
■ **Figure C1. Calibration hydrograph for Squires Spring.**



■ **Figure C2. Calibration hydrograph for Tokakopura Tributary.**



- **Figure C3. Average Recurrence Interval for Monument Hill.**



- **Figure C4. Average Recurrence Interval for Kaikohe Basalt.**