SINCLAIR KNIGHT MERZ

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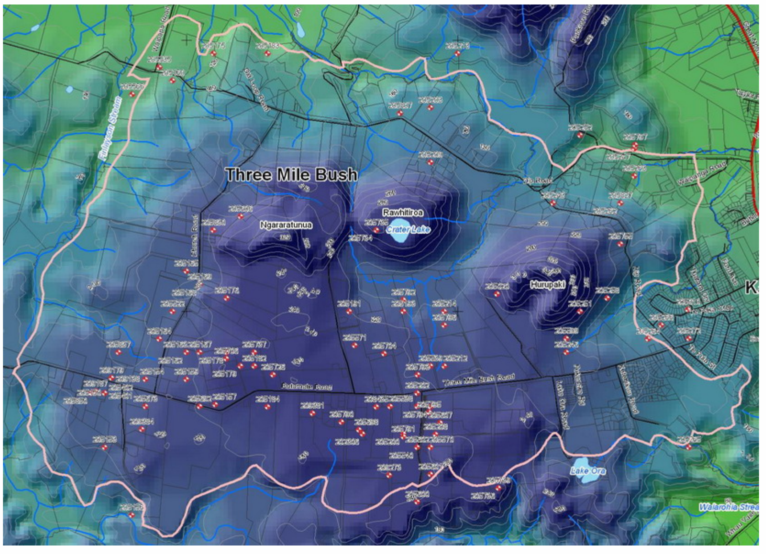
NORTHLAND REGIONAL COUNCIL

Preliminary Hydrogeological Investigations - Four Northland Aquifers

THREE MILE BUSH GROUNDWATER RESOURCE

- Report prepared for Northland Regional Council
- Final
- 28 March 2006



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1 Introduction

Sinclair Knight Merz was commissioned by Northland Regional Council (NRC) to undertake a preliminary hydrogeological investigation of the Three Mile Bush, Maungakaramea, Kaikohe and Matapouri Bay aquifers. These aquifers are classified as “at-risk” aquifers under the Regional Water and Soil Plan for Northland (NRC, 2004), and as such abstraction is restricted under specific rules in the Plan.

The information obtained from this study will assist the NRC to effectively manage allocation of the groundwater resource.

The specific objectives of the preliminary hydrogeological investigations include the following:

- Achieve an understanding of the groundwater recharge and discharge dynamics;
- Estimate future sustainable yields for each resource; and
- Identify information gaps and recommend future actions required to enable the sustainable management of these resources.

This report summarises the hydrogeology of the Three Mile Bush basalt aquifer. The aquifer is classified as “at-risk” under the Regional Water and Soil Plan for Northland (NRC, 2004) due to the high actual groundwater demand and potential future demand.

2 Background Information

2.1 Site Location and Description

The Three Mile Bush aquifer is located adjacent to and west of Kamo township. The study area comprises a 13.2 km^2 basalt plateau at an elevation of approximately 230 m above mean sea level (mAMSL). There are four scoria cones reaching up to 360 mAMSL. The three largest cones are named, from west to east, Ngararatunua, Rawhitiroa, and Hurupaki. A small additional vent to the east of Hurupaki is unnamed. Hurupaki has an operational scoria quarry on the western side, and Rawhitiroa has an unbreached crater on its summit that forms a small lake.

Figure 1 shows the location of the Three Mile Bush aquifer. Figure 2 is a photograph of the two western scoria cones, taken from the scoria quarry on Hurupaki. Rawhitiroa is in the foreground and the peak of Ngararatunua can be seen in the left background.

Groundwater from the Three Mile Bush aquifer is currently used for irrigation, stock water and domestic water supply. High actual and potential demand for further water takes for horticultural irrigation forms the basis of this aquifer being classified as “at-risk”.

- **Figure 1. Locality plan.**

  (see A3 attachment at rear).

- **Figure 2. Photograph from Hurupaki scoria quarry, looking towards Rawhitiroa and Ngararatunua.**

2.2 Regional Geology

Geology for this region is outlined on the 1:250,000 scale Geological Map Sheet 2A for Whangarei (Thompson, 1961), which is reproduced in Figure 3. Further information is available on the 1:25,000 scale Geological Map Sheet 26 for the Whangarei Urban Area (White and Perrin, 2003), however the limits of this map do not cover the entire study area.

The Three Mile Bush aquifer comprises Taheke basalt, a Late Miocene-Late Pleistocene age (11 to 0.3 million years before present) formation of scoria cones and lava flows belonging to the Kerikeri Volcanic Group. Lava in the Three Mile Bush area came from four eruptive vents, each marked by a well-preserved scoria cone. These cones include those discussed in the previous section. The lava erupted along the east-west oriented Ngunguru fault and the resulting flows were constrained within pre-existing valleys. Hurupaki scoria has been radiometrically dated at 0.31 ± 0.15 million years, and exhibits a range of compositions including transitional basalt, tholeiitic basalt and quartz tholeiite (White and Perrin, 2003).

Lava flows extend continuously from the Three Mile Bush aquifer study area south towards Whangarei City, although it is uncertain whether they originate from the Hurupaki volcanic centre (White and Perrin, 2003). The demand for groundwater in the lava flows south of the Three Mile Bush study area is not considered to be high, and have therefore not been incorporated into the NRC “at risk” aquifer boundary that is the basis for this study. As the lava flows are located downgradient of general groundwater flow direction for the Three Mile Bush aquifer (see Section 3.3 later in this report), the impact of these basalt flows on recharge and discharge dynamics is negligible.

The Three Mile Bush basalt is flanked to the north by Pleistocene age (0.8 ± 0.1 million years before present) Maungarei Dacite, consisting of massive to flow-banded dacite with widespread alteration to halloysitic clay (White and Perrin, 2003). There are also pockets of reworked alluvium occupying some surrounding valley floors (Thompson, 1961; White and Perrin, 2003).

There are small zones of Whangarei Limestone (flaggy, white to cream limestone, locally pebbly), Ruatangata Sandstone (blue to green-grey glauconitic, calcareous muddy sandstone) and Kamo Coal Measures (conglomerate, sandstone, mudstone and coal) bordering the basalt on the west and north-eastern side, and to the south near Lake Ora. These materials are part of the Te Kuiti Group and are of Late Eocene to Oligocene age (37 to 23.8 million years before present) (White and Perrin, 2003).

Underlying the aquifer and outcropping to the south are Waipapa Terrane basement rocks consisting of massive, indurated sandstone (“greywacke”) and interbedded sandstone and argillite. The Waipapa Terrane is of Permian to Late Jurassic age (295 to 142 million years before present).

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- **Figure 3. Regional geology.**

  (see A3 attachment at rear).

2.3 Drillers Borelogs

There are 95 bores registered on the NRC bore database for the Three Mile Bush study area[1]. The locations of these bores are shown on Figure 1. There are likely to be additional bores in the area that have not been registered with the NRC, however the exact numbers are unknown. A table summarising the bore construction details is given in Appendix A.

Drillers' borelogs are available for 91 bores on the NRC bore database. Bore depths range from 8 to 94 m below ground level (mBGL) with an average of 37 mBGL. The bores are 75 to 203 mm in diameter and are generally open (unscreened) through the basalt, which suggests the basalt is relatively unfractured and has strength. The base of the basalt was recorded on 27 borelogs at depths ranging from 8.5 m to greater than 77 m. Yields range from 0.3 to 1.9 L/s with the greatest yields most likely occurring within the fractured or scoriaceous basalt, although there is insufficient information on the borelogs to confirm this. The fracture zones and scoriaceous layers are located at variable depths throughout the basalt.

Bores that have penetrated the base of the basalt often have brief drillers' comments indicating elevated iron concentrations in the groundwater. Bores with comments indicating "very good to excellent" water quality are those screened within the basalt.

2.4 Hydrology

The Three Mile Bush aquifer has a number of small bordering streams with tributary headwaters beginning along the edge of the basalt. These include tributaries of Finlayson Stream, Waikoropupu Stream, Waitaua Stream, Waiarohia Stream, and Mangere Stream.

The NRC has conducted low flow monitoring on some of these streams. The Big Dam, Crane Road and Lockwood House monitoring locations are situated close to the basalt boundary and thus the low flow measurements will be indicative of flow sourced mainly from the basalt (i.e. groundwater flow). Low flow measurements from these sites range from 2.7 to 83.8 L/s.

Table 1 summarises the stream low flow monitoring information, while Figure 4 shows the stream flow monitoring locations.

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[1] Bores 205139-42 (Portland Cement), 205745 (Thomas) and 205754 (Millington) have been removed from the database list provided by the NRC as the bores are outside the basalt boundary. Four pump tests allocated bore IDs on the NRC database have been matched to different bores.

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A small lake occupies the crater of the central scoria cone (Rawhitiroa) while another small lake (Lake Ora) lies along the south-eastern corner of the aquifer boundary. These lakes have formed on impeding sediments, which in the case of Rawhitiroa is a clay plug or relatively impermeable lava flow (Rollin, 1991).

- **Table 1. Stream low flow monitoring.**

Stream	Site	Period of monitoring	Low flow (L/s)
Waiarohia tributary	5556 (Big Dam)	Sept 84 – Dec 91	2.7 – 17.3
Waikoropupu Stream	1046675 (Crane Rd)	Dec 68 – Apr 05	14.9 – 83.8
Waitaua Stream	5546 (Lockwood House)	Dec 81 – Jan 92	15.6 – 44.2
Waitaua tributary	5569 (Budds)	Feb 95	4.6

Notes: Flow measurements from September 1984 have been removed from the data at each site. These values are significantly greater than other low-flow measurements.

- **Figure 4. Existing consents and monitoring locations.**

  (see A3 attachment at rear)

2.5 Rainfall and Evaporation

Figure 5 shows mean monthly rainfall data for Wairua (Station 546103 at Ruatangata) for the period between 1905 and present, and mean monthly Penman Open Water evaporation for Whangarei Aero AWS (Station A54737) for 1992 to 2005 (data gap in 1993 and 1994). The rainfall data was obtained from the NRC, whereas the evaporation data was obtained from the National Institute of Water and Atmosphere (NIWA) climate database.

Monthly rainfall is greater than potential evaporation from March to October, indicating the availability of rainfall for groundwater recharge and surface runoff during these months. Average annual rainfall is 1,591 mm.

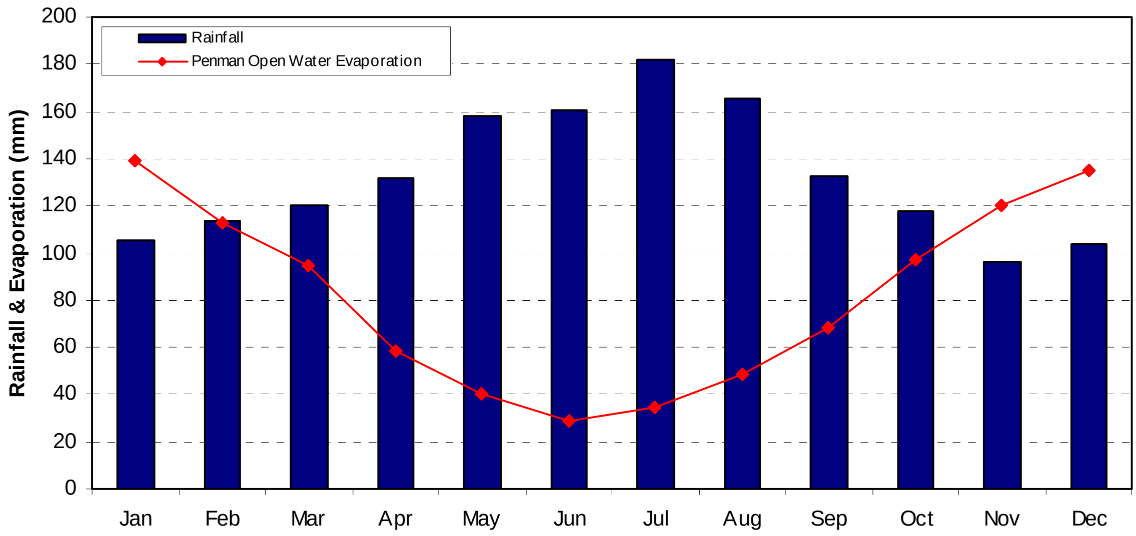

Figure 5. Mean monthly rainfall and evaporation.

2.6 Groundwater Abstraction

Error! Reference source not found. summarises information on existing consented groundwater takes in the area. There are currently 12 consented groundwater takes with allocations ranging from 10 to 180 m^3/day. The total consented groundwater allocation is 1,050 m^3/day. The locations of the consented groundwater takes are shown in Figure 4.

The permitted water allocation for reasonable stock and domestic use is 30 m^3/day and 2 m^3/day, respectively, for existing bores. New abstractions are permitted to take 1 m^3/day from an "at-risk" aquifer (NRC, 2004). Due to the high level of uncertainty over the exact number and use of permitted takes in the area, permitted activity use has not assessed in this study. A bore and water use survey is required to address this.

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- **Table 2. Existing groundwater consents.**

NRC No.	Name	Allocation (m^3/day)	Bore depth (m)	Expiry date	Purpose
19950211401	Mr D V Rowe	150	50.0	30/06/2005	Horticultural Irrigation
19960187201	C J Claridge	10	57.0	30/11/2010	Horticultural Irrigation
19960251602	Wajim Properties	100	57.0	31/05/2008	Horticultural Irrigation
19990222701	Mr R H Blank	55	-	30/06/2010	Horticultural Irrigation
19990254801	Mr W J Evans	60	27.0	30/11/2010	Horticultural Irrigation
19990723301	J P Griggs	35	50.6	30/06/2010	Horticultural Irrigation
20000267101	Red Cone Orchard	180	36.5	30/06/2010	Horticultural Irrigation
20000448001	J C McIntosh	90	56.6	30/06/2010	Horticultural Irrigation
20000449901	Parkgard Growers Limited	100	77.0	30/06/2010	Horticultural Irrigation
20000717801	Kerreton Orchard Limited	50	46.0	30/06/2010	Horticultural Irrigation
20000742901	Mr R F Barber	180	36.5	30/06/2010	Horticultural Irrigation
20040480701	Mr I B Olsen	40	-	30/06/2011	Horticultural Irrigation
	Total consented allocation	**1,050**			

2.7 Surface Water Abstraction

Table 3 summarises the existing surface water consents for surrounding streams. Total consented surface water allocation, including one dam take, is 3,160 m^3/day. Stream baseflow at these take points (see Figure 4) is likely to be groundwater sourced from the basalt aquifer. Any lowering of groundwater levels within the basalt, via groundwater abstraction or seasonal recharge variation, will adversely impact upon stream flow and the amount of water available for surface water abstraction.

Similar to groundwater abstraction, permitted surface water abstraction is unknown and has not been addressed in this study.

- **Table 3. Existing surface water consents.**

NRC No.	Name	Allocation (m^3/day)	Expiry date	Purpose
19940732201	R J McGregor	2,450[1]	30/06/2005	Pasture/Crop Irrigation
19950744401	Northland Christian Fellow	13	31/05/2005	Accommodation
19960251601	Wajim Properties	510	31/05/2008	Horticultural Irrigation
19970346401	Regent Training Centre Lim	50	31/05/2005	Horticultural Irrigation
19990197701	J D Currie	70	30/06/2011	Crop Irrigation
20000359301	G Abercrombie	37	30/06/2011	Crop Irrigation
20000762401	P R Morgan	30	31/05/2015	Horticultural Irrigation
	Total consented allocation	**3,160**		

Note: [1]Dam water take.

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3 Aquifer Conceptualisation

3.1 Aquifer Lithology

Borelogs from the NRC bore database show the site geology to generally consist of the following:

- Reddish brown or yellow clay between 2 and 9 m thick, with occasional basalt boulders (volcanic soil).
- Red, soft weathered basalt or scoria up to 21 m thick.
- Hard, grey vesicular and non-vesicular basalt up to 73 m thick with occasional fractures located at variable depths. The hard basalt is interlayered with soft, red basalt rubble or scoria up to 5 m thick and/or ash layers up to 1.8 m thick. This is indicative of a succession of basalt flows over the eruptive period (Rollin, 1991).
- The basalt is underlain with baked red and/or white clay up to 7 m thick (alluvium or weathered sandstone). A thin layer (2.8 m) of coal is present beneath the basalt in one bore (Kamo Coal Measure), and limestone up to 15 m thick is present in three bores (Whangarei Limestone).
- Beneath the clay, coal or limestone is grey or brown sandstone (weathered Waipapa Terrane).

The borehole geology is consistent with the regional geology described in Section 2.2.

The depth to the base of the aquifer varies from 8.5 m to greater than 77 m below ground. The thickest parts of the basalt are in the general proximity of the scoria cones and along the centre of the lava flow (Rollin, 1991).

3.2 Groundwater Levels

Depth to groundwater has been monitored by the NRC since 1988 in four bores within the study area. Table 4 summarises the monitoring frequency and period of monitoring for each bore. Figure 6 shows the groundwater hydrographs for each monitoring bore and Figure 4 shows the bore locations.

Depth to groundwater ranges from 0.5 to 8.7 mBGL. Groundwater fluctuates from 0.5 to 6.4 mBGL in the Wise monitoring bores, and 0.4 to 3.4 mBGL in the Subdivision monitoring bore. The monitoring period of the Flower bore (bore 209179) is not long enough to determine the range in fluctuation.

Depth to groundwater for other bores in the area, assessed from drillers logs, range from 0.5 to 40 mBGL. At the time of measurement, these levels may not have fully recovered from the drilling phase and therefore may not be truly representative of the stabilised water table position.

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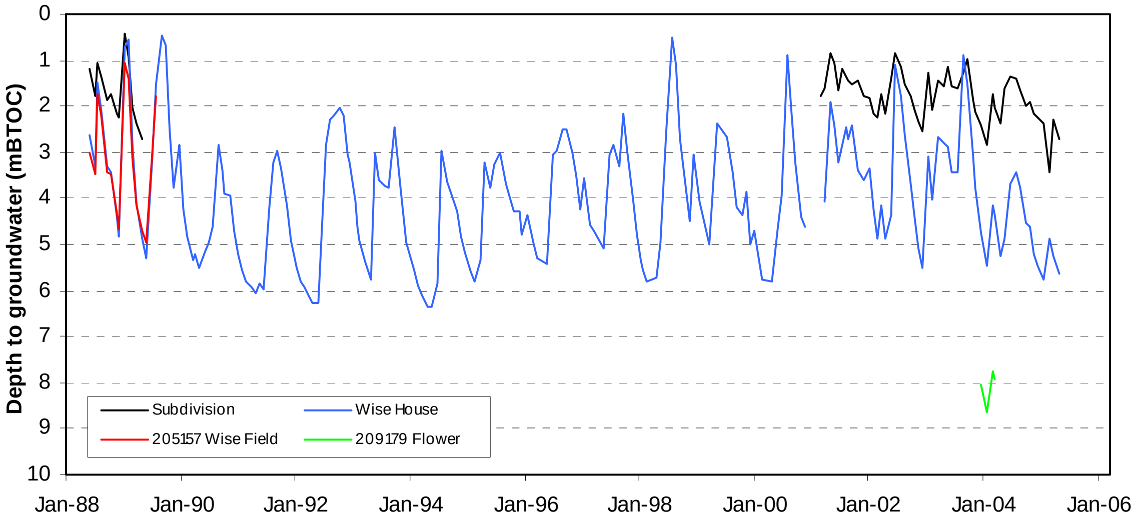
■ **Table 4. Groundwater level monitoring bore details.**

Bore	Name	Bore depth (m)	Period of record	Frequency of monitoring
205157	Wise Field	18	14 months	Monthly
-	Wise House	> 6.5	17 years	Monthly
-	Subdivision	> 3.5	6 years	Monthly
209179	Flower	41	4 months	Monthly



■ **Figure 6. Groundwater hydrographs.**

3.3 Piezometric Surface

Figure 7 shows the piezometric surface for the basalt aquifer, which was constructed from depth to groundwater information and estimated ground level elevations. The depth to groundwater information was obtained from drillers' logs, NRC monitoring data and aquifer test pumping results. All bores with static water level measurements were used, excluding bores not screened in the basalt or with anomalous levels compared to adjacent bores.

Groundwater elevations along the streams were assigned ground level elevations to represent the assumed locations of springs (not identified but assumed to exist). In addition, the groundwater elevation beneath each scoria cone was estimated to aid in contouring of the piezometric surface. The degree of certainty of the piezometric contours is subjective because of this manipulation, however a degree of interpolation was necessary due to the lack of groundwater level data in some parts of the aquifer.

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Groundwater piezometric pressures across the aquifer range from 100 to 220 mAMSL. The direction of the groundwater flow generally radiates outwards to the edge of the basalt from the three main scoria cones. Flow is towards the Waikoropupu Stream tributary in the centre of the study area.

- **Figure 7. Piezometric surface.**

(see A3 attachment at rear).

3.4 Aquifer Hydraulic Properties

Information on aquifer hydraulic properties is available for eight bores within the study area. Table 5 summarises the hydraulic properties.

Transmissivity ranges between 2.4 and 3,660 m^2/day. The lowest transmissivity results obtained are from bores 205208, 205153 and 205797. This is likely to be due to the presence of relatively impermeable non-vesicular basalt that is likely to be relatively unfractured or with low fracture connectivity. The bores with higher transmissivity are considered to have a higher degree of fracturing and connectivity between fractures, although there is a lack of detail on the borelogs to confirm this.

Storativity has been assessed for one pump test at 0.038. This indicates that the aquifer is unconfined at this location.

Hydraulic conductivity was estimated from the transmissivity and the saturated thickness of the aquifer, and ranges between 0.17 and 310 m/day. These values are within the typical range of published hydraulic conductivity values for basalt of 0.009 to 900 m/day (Freeze and Cherry, 1979).

- **Table 5. Summary of aquifer hydraulic properties.**

Bore	Name	Bore depth (m)	Casing depth (m)	Saturated thickness (m)	Q (m^3/day)	T (m^2/day)	S (-)	K (m/day)
205208	R Blank	45	7	14.5	30	2.4 – 3.3	-	0.17 – 0.23
				14.5	45	13 - 26	-	0.90 – 1.79
205214	C Keyte	39	11	30.5[1]	220	36 - 43	-	1.18 – 1.41
205793	Abbot	-	-	-	60	35 - 73	-	-
205199	Reid	58	13	12.3	21 - 75	52 - 489	0.038	4.23 – 39.8
				12.3	43	37 - 60	-	3.01 – 4.88
205792	Finlayson	50	8.5	46.0[1]	192 - 245	15 - 20	-	0.33 – 0.44
205153	McIntosh	57	-	-	89	5.6	-	-
205091	King	14	8.5	11.8[1]	200 - 270	2,148 – 3,660	-	182 - 310
205797	Kamo Service Station	-	37	-	42	2.9	-	-
	Average			**23**		**373**		**39.4**

Notes: [1]Minimum saturated thickness, as the base of the basalt was not reached.

3.5 Groundwater Quality

Groundwater quality has been sampled in bore 205157 (Wise) on ten occasions since 2003. The sampling was conducted by the NRC. Table 6 summarises the groundwater quality monitoring results for this bore.

Values that exceed the Ministry of Health Drinking Water Standards for New Zealand (DWSNZ) are highlighted in Table 6 (Ministry of Health, 2005). These parameters include the following (guideline value in brackets):

- *Escherichia coli* (less than 1 in 100 mL sample)
- pH (7.0 – 8.5)

Escherichia coli exceeds the microbiological Maximum Acceptable Value (MAV) for health on three occasions. Total coliform bacteria, which includes faecal and environmental coliform bacteria, have also been elevated during seven sampling rounds in 2003-05. These results indicate that the aquifer at this location may be at risk from surface contamination. Water quality sampling from other bores would be required to confirm whether the contamination is more widespread.

pH exceeds the inorganic Guideline Value (GV) for aesthetic determinants on seven of the ten monitoring occasions. Exceedance of aesthetic GV's indicates that the groundwater has an unpleasant taste or appearance. The low pH indicates that the groundwater is potentially corrosive.

Nitrate-nitrogen levels are slightly higher than generally accepted natural levels in groundwater of 1 mg/L (Close et al., 2001). This may be due to surface contamination such as fertiliser application or animal wastes. Overall however, groundwater quality is good when compared against drinking water guidelines.

Figure 8 is a Piper Diagram of the major anions and cations (presented in milli-equivalents) in the Wise bore for November 2003. 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 data for other monitoring dates is not included on the Piper Diagram as the anion/cation ratios do not balance which is suggestive of some inaccuracy in the analytical results. Water quality data from the Glenbervie basalt aquifer, located to the east of Kamo, is included on Figure 8 for comparison.

The water from the Wise bore has no dominant cations and is proportionally higher in bicarbonate than other anions. This type of water is classified as calcium bicarbonate-type water. Water of this type is generally recharging water that has not had time to dissolve the surrounding rock minerals

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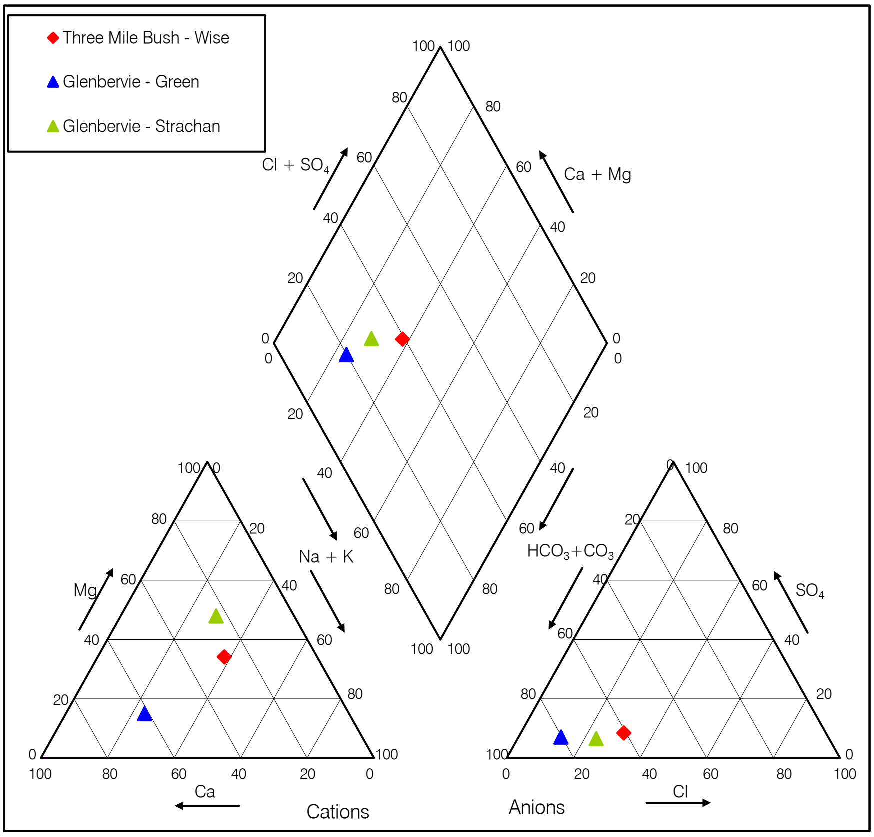
or mix with other water types. This suggests that the age of the groundwater in the aquifer at this location and depth is relatively young.

The major anion/cation composition from the Wise bore is similar to the Strachan bore (205322) from the Glenbervie aquifer. The Green bore (205594) is also calcium bicarbonate-type water, however the calcium content is slightly higher. This bore is screened through the basalt and into the underlying sandstone.



■ **Figure 8. Piper diagram of Wise bore water (bore 205157).**

- **Table 6. Groundwater quality sampling results for bore 205157.**

Parameters (mg/L)	17-Feb-03	26-May-03	18-Aug-03	25-Nov-03	24-Feb-04	20-May-04	24-Aug-04	29-Nov-04	21-Feb-05	23-May-05
Bicarbonate		63	51	47	39	40			44	
Carbonate		52	42			33	34		36	
Total alkalinity				38	32					
Bromide	0.05	< 0.05		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	
Calcium	8.77	9.73	7.55	7.61	7.42	7.23	7.51	7.2	8.03	
Chloride	12.2	15.6	16.1	13.9	13.3	13.3	14.1	12.1	12.9	
Total coliforms (n/100mL)	1	2	< 1		< 1	613	< 10	> 2419	1	17329
Conductivity (mS/m)	7.4	18.4	18.9	15.9	16.1	12	14.2	13.2	16	14.7
Dissolved oxygen (%)			90							
Dissolved oxygen			8.8			6.1				
Dissolved reactive phosphorus	< 0.05	0.053	0.016	0.023	0.018	0.018	0.015	0.019	0.019	
Escherichia coli	< 1	< 1	< 1	< 1	< 1	< 1	< 10	3	< 1	< 10
Fluoride	< 0.05	< 0.05		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	
Dissolved iron	< 0.02	< 0.02		< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	
Total hardness		56	40	42	39	41				
Potassium	0.63	0.66	0.58	0.55	0.55	0.55	0.55	0.52	0.59	
Magnesium		7.65	5.14	5.67	5.31	5.54	5.47	5.02	5.7	
Dissolved manganese	0.0009	0.0006		< 0.0005	0.0006	0.001	0.0008	< 0.0005	0.001	
Sodium	12.9	13	11.5	11.6	11.9	11.8	12	10.6	12.1	
Ammoniacal nitrogen	< 0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	
Nitrite/nitrate nitrogen		2.28	2.85	2.89	2.91	2.97				
Nitrite nitrogen		< 0.002	< 0.002	< 0.002	0.018	< 0.002				
Nitrate nitrogen	2.43	2.28	2.84	2.89	2.91	2.97	2.86	2.7	2.84	
pH	6.4	6.9	6.1	6.4	6.4	7.2	6.2	6.2	7.8	
Dissolved reactive silica	31.3	31.1		29.7	29.6	29.5	28.9	13.5	26.6	
Sulphate	6.2	5.4	7	5.2	5.7	5.6	6	6.1	6.6	
Total dissolved solids								108	113	
Temperature (deg C)	17.2	17.6	16.8	17.3	18.2	16.6	16.7	17.6	18.3	17.5
Total organic carbon						< 0.5	< 1		< 0.5	

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3.6 Groundwater Recharge

Rainfall is considered to be the main source for groundwater recharge to the Three Mile Bush aquifer. The rate of rainfall infiltration on the scoria cones is anticipated to be greater than that infiltrating the basalt surface, due to the relatively thick layer of clay (volcanic soil) above the fresh basalt. Hence, rainfall recharge in this study is assessed separately for scoria and basalt.

Rainfall recharge is assessed using the following parameters:

- Surface area contributing in the recharge;
- Average annual rainfall; and
- Recharge coefficients for basalt and scoria.

The total recharge area of the Three Mile Bush aquifer is approximately 13.2 km^2. The area of the scoria cones is estimated to be 1.4 km^2 and the basalt area approximately 11.8 km^2.

Annual average rainfall is estimated to be 1,591 mm using long term data from Station 546103 at Ruatangata (see Section 2.5).

The average annual recharge coefficient for the basalt area is estimated to be 28% to 49% of rainfall. This range in recharge coefficient was estimated from the magnitude of water table rise for the Wise long-term monitoring bore during various rainfall events. Appendix B summarises the analysis and results from each long-term rainfall event. The recharge coefficients are similar to those assessed for the basalt aquifers at Kaikohe and Pukekohe from soil moisture water balance modelling (i.e. 22% to 44%) (NRC, 1992).

The recharge coefficient for the scoria cones is estimated to be within the range of 55% to 65%. The lower range for the basalt (i.e. 28% to 49%) takes into account the lower permeability of the overlying soils and the proportion of rainfall recharge lost through soil evaporation and plant uptake before reaching the basalt. The wide range for both recharge coefficients is a reflection of the level of uncertainty involved in estimation of the recharge coefficient.

The parameters used in the assessment of groundwater recharge are summarised in Table 7. Combined daily average recharge to the aquifer ranges from 17,740 m^3/day to 29,180 m^3/day.

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- **Table 7. Parameters used in estimation of rainfall recharge.**

	Recharge area (m^2)	Average annual rainfall (mm)	Rainfall recharge (m/yr)	Average daily recharge (m^3/day)
Scoria cones	1.4×10^6	1,591	0.875-1.034	3,354 – 3,963
Basalt	11.8×10^6	1,591	0.445-0.780	14,386 – 25,216
TOTAL	**13.2×10^6**			**17,740 – 29,179**

3.7 Groundwater Discharge

Groundwater discharge has been estimated from the aquifer hydraulic properties shown in Table 5 and the piezometric surface shown in Figure 7. Table 8 summarises the parameters used in this assessment.

The saturated thickness of the aquifer was assumed to be the average saturated thickness determined for five of the bores in Table 5. The average hydraulic conductivity was assumed to be 0.8 m/day using the hydraulic property data in Table 5 but excluding very high values (i.e. King and Reid bores) that are considered to be localised values.

Average daily discharge from the aquifer is estimated at 13,910 m^3/day. This figure is below the estimated rainfall recharge of 17,740 to 29,180 m^3/day discussed in Section 3.7, and is a reflection of the level of uncertainty associated with the analytical calculation of aquifer recharge and discharge. For example, should the average hydraulic conductivity used in the calculation be increased to include bores with higher values then the discharge estimation would also increase.

The measured low flow discharge from local streams is 233 to 7,240 m^3/day (see Section 2.4), which is below the average daily estimated discharge.

- **Table 8. Parameters used in estimation of groundwater discharge.**

Average hydraulic gradient (m/m)	Average hydraulic conductivity (m/day)	Discharge area (m^2)	Discharge volume (m^3/day)
0.04	0.8	18,900 m $\times$ 23 m	13,910

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3.8 Summary of Conceptual Aquifer Understanding

The conceptual understanding of the Three Mile Bush aquifer is as follows:

- The aquifer is comprised of basalt and scoria deposits sourced from four volcanic vents. The geometry of the aquifer is confined by the topography that existed at the time of basalt eruptions (i.e. former valleys), and overlies less permeable basement greywacke. Pleistocene-age Maungarei Dacite and alluvium, and Tertiary-age coal, limestone and sandstone sediments surround the basalt on the western, northern and eastern sides.
- Aquifer hydraulic properties for the basalt are highly variable between each bore but still within typical transmissivity and hydraulic conductivity values for basalt. This variability is a result of the high heterogeneous character of such aquifers. Extreme values are likely to be localised and related to scoria layers or highly fractured zones.
- Groundwater quality, as measured in one monitoring bore, is generally good, with the exception of high bacterial counts on occasion, and a slightly low pH.
- Rainfall is identified as the only source of aquifer recharge based on groundwater contours and outwards radial groundwater flow. Recharge rates most likely differ across the scoria cones and basalt plateau due to the heterogeneity of the aquifer lithology and the occurrence of a low permeability clay weathering layer above the basalt. Infiltration rate to the scoria cones is estimated to be 55% to 60 % of annual rainfall, and 28% to 49% for the basalt taking into consideration the lower permeability of overlying volcanic soils.

4 Assessment of Sustainable Yield

The sustainable yield is defined in this study as the volume of groundwater available for abstraction without compromising the functioning of connected ecosystems, for example stream flow.

Rainfall recharge of the groundwater system represents the upper limit of the water potentially available for abstraction, and ranges between 17,740 m^3/day and 29,180 m^3/day. In the absence of detailed groundwater recharge investigations, 30% of rainfall recharge is allowed for maintaining environmental flows and an additional 30% allocated for conservatism and to maintain stream water takes (which are partly groundwater fed). The remaining 40% of rainfall recharge is in this study considered to be the limit for groundwater abstraction. Sustainable yield is thus estimated as between 7,090 and 11,680 m^3/day.

Total groundwater allocation for the aquifer is approximately 1,050 m^3/day (see Section 2.6), and surface water allocation excluding the dam take is 710 m^3/day (Section 2.7). The total allocation of 1,760 m^3/day is roughly one-third of the most conservative estimate of sustainable yield (7,090 m^3/day). This suggests that there is potential for additional allocation from the aquifer.

Although there appears to be room for additional allocation of the groundwater resource, due to the high degree of uncertainty in the estimation of rainfall recharge and sustainable yield it is considered important to be conservative when allocating more groundwater. The recharge and discharge estimates would need to be refined to increase the level of certainty, via the collection of additional monitoring data (e.g. bore and water use survey, infiltration rates) and groundwater recharge modelling. In addition, there is a high level of uncertainty associated with the total allocation volume for the aquifer, especially as permitted activity use has not been included. A bore and water use survey is required to refine this value.

5 Limitations

There are a number of limitations identified in the available data for this study that affects the interpretation of groundwater recharge and discharge dynamics and estimation of sustainable yield. These limitations relate to information gaps and the use of analytical calculations rather than dynamic methods. The information gaps include the following:

- ***Bore position and elevation*** – The top of casing elevation for the bores used to create the piezometric surface were estimated from 20 m topographic contours. Potential inaccuracy in the top of casing elevation data and bore position affects the piezometric surface contouring.
- ***Limited spatial distribution of bores*** – The absence of bores from some parts of the aquifer results in less certainty in piezometric surface contouring in those areas. In this study, groundwater elevations along the streams were estimated to aid in the piezometric contouring.
- ***Soil infiltration properties*** – The rainfall recharge coefficients were estimated in the absence of exact values for the site, which influences the results of the analytical calculation of groundwater recharge.
- ***Aquifer hydraulic properties*** **–** The wide range of transmissivity values assessed from the small number of aquifer hydraulic test exercises has resulted in uncertainty over the average hydraulic conductivity used in the assessment of groundwater discharge. The average saturated thickness of the aquifer was also estimated as most bores have not reached the base of the basalt. Some uncertainty also exists with regard to the depth to groundwater measurements since these were taken immediately after drilling, where the groundwater levels may not have stabilised to their true position.
- ***Actual groundwater use*** **–** It was assumed that all consented bores on the NRC bore database were being utilised for their full water right. However, actual water use may vary considerably from this estimate, affecting the comparison with the estimate of sustainable yield. In addition, permitted activity use has not been assessed.

6 Summary & Conclusions

This study represents a preliminary hydrogeological assessment of the groundwater resource for the Three Mile Bush basalt aquifer. The assessment is based on information contained in borelogs, aquifer test pumping exercises and long-term monitoring data provided by the NRC.

The basalt aquifer formed as a result of volcanic activity from four volcanic centres, marked by well-preserved scoria cones within the study area. The lava and scoria infilled pre-existing valleys on greywacke basement rock (Waipapa Terrane). Maungarei Dacite, coal, limestone, sandstone and alluvium surround the basalt on the western, northern and eastern sides.

The thickness of the basalt varies between 2 m and approximately 80 m, as determined from existing bore information and resistivity sounding (Rollin, 1991). Groundwater yields vary between 0.3 L/s and 1.9 L/s and groundwater levels vary between 1 and 40 meters below ground level based on information from the drillers logs.

Aquifer test pumping exercises conducted on eight bores indicates yields of up to 3.1 L/s (270 m^3/day) are sustainable, although there is large variation in hydraulic properties across the aquifer. This is related to the degree of fracturing encountered in each bore.

Groundwater quality has been monitored in one bore, and is generally good except for elevated bacterial counts on occasion. This indicates that the aquifer at this location is potentially not secure from surficial contamination, although bore construction (e.g. depth and effectiveness of casing) may be an issue.

Rainfall recharge is considered to be the only significant source of recharge to the aquifer. The recharge rates are expected to differ across the scoria cones and basalt plateau, due to the presence of low permeability volcanic soils above the basalt.

A preliminary assessment of sustainable yield suggests that the aquifer is not fully allocated. However, there is a high degree of uncertainty associated with the analytical calculation of rainfall recharge and estimated groundwater use. Refinement of these parameters is required to increase the level of certainty surrounding available groundwater for additional allocation.

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

- ***Bacteria*** – concentrations that exceed the NZ drinking water guidelines were detected in the NRC water quality monitoring bore. This suggests that groundwater may not be secure from surface contamination at this location. The extent of the problem is unknown due to monitoring of only one bore in the aquifer.

- ***Basalt permeability*** –highly variable basalt permeability influences the rate of groundwater that can be abstracted in a particular area.
- ***Abstraction*** – the preliminary assessment of sustainable yield compared to current groundwater allocation indicates that the basalt aquifer is not fully allocated. However, a refinement of the sustainable yield is recommended in order to provide a more accurate assessment of the volume of groundwater available for allocation. More detailed analysis is likely to indicate more water is available for allocation, and should be considered if demand continues to increase.

7 Recommendations

Based on the preliminary findings contained in this report, SKM recommends the following:

- Refinement of the sustainable yield to provide a more accurate assessment of the groundwater available for allocation. This may only be required should demand continue to increase markedly.
- Groundwater level measurements in a number of bores across the aquifer will refine the piezometric surface and enable future transient calibration of a groundwater model. The identification and monitoring of bores in those areas where data is scarce (i.e. on the northern side of the aquifer) would be invaluable. It would also be beneficial to undertake concurrent monitoring of spring and stream flow at various locations.
- Soil infiltration tests are recommended as they will assist in refinement of the understanding of groundwater recharge dynamics, in particular on the scoria cones where it is considered that rainfall recharge is higher.
- Groundwater quality monitoring in other bores across the aquifer (i.e. consented groundwater take bores) will enable the extent of bacterial contamination to be determined and provide an indication of other potential groundwater quality issues.

8 References

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Appendix A Bore Details

Bore ID	Name	Drilled date	Depth (m)	Cased depth (m)	Yield (m^3/hr)	Depth to basalt base (m)
202306	V Houba	9/12/2000	35	14.42	3	not reached
205010	Allison		18	8.83	1	16
205020	James		30	24.3		not reached
205091	King		14	2		not reached
205149	G Wilson	11/11/1981	45	6.25		41.5
205150	G Wilson	2/09/1983	49	6.5		44.5
205153	McIntosh	4/05/1983	57			
205154	J Smith	25/01/1974	15	6.4		
205156	K Scott	10/05/1984	36	8.7		36.3
205157	K Wise	6/05/1983	18	9		not reached
205159	Elliot	27/10/1983	44	13		not reached
205160	M McGregor	10/11/1983	59			
205162	K King	22/01/1974	21	6		
205163	K King	7/07/1982	13	12		12.5
205164	D Baker	6/08/1982	31	7.7		not reached
205165	G Puriri	27/09/1979		4		
205167	K King		13			not reached
205168	H Rodgers	11/05/1967	18	3.2		
205169	G Puriri	17/05/1983	21	13		not reached
205175	Finlayson		61	17.6		27.4
205176	K King		37	11		not reached
205177	Beasley	13/05/1983	51	11		51
205178	Lilley		15	9.1		not reached
205179	Lilley		27	6.7		not reached
205182	Beasley	15/08/1983	63	6.5		62
205183	Finlayson		23	7.3		not reached
205184	Howie		19			not reached
205191	Campbell		36	8.8		not reached
205193	D and B Rowe	18/10/1982	51	8.5		not reached
205199	B Reid	23/09/1983	58	13		27
205200	B Reid	6/02/1982	15	9.4		not reached
205202	D Hewih		27	6.6		not reached
205203	G Fenwick	17/12/1974	14	7.6		
205207	G Chisnall	2/03/1983	21	9.3		not reached
205208	R Blank		45	7		20
205209	I Irvine		23	12		not reached
205212		17/11/1982	78	8.2		67
205213	Attwood		30			not reached
205214	C Keyte	27/07/1979	39	11		not reached
205243	W Pamplin	5/10/1962		9		

Bore ID	Name	Drilled date	Depth (m)	Cased depth (m)	Yield (m^3/hr)	Depth to basalt base (m)
205246	J James	11/05/1967	21	8.6		
205247	R Chamberlain	7/10/1981	49	37		8.5
205251	James		30	12.4		not reached
205252	G Morris	15/05/1975		18.5		
205258	Hurapak Berry Farm	17/01/1983	21	17		not reached
205262			30			not reached
205263	D Gates	27/11/1975	28	22.2		
205264	P James	21/10/1983	35	32		not reached
205265	Wajim Properties	17/10/1984	57	12		not reached
205266		20/03/1984	31	10		24
205272	Wakelin		38	3.9		not reached
205401	G Wilson	3/12/1978	61.8?			36.6
205402	G Wilson	3/12/1978	17			
205522	N McLean	27/01/1983	46			46
205535	G Yallot	5/05/1986	45	18.4		12.2
205538	R Smith	8/04/1986	94	23.5		70
205539	R Smith		9	4		not reached
205540	R Smith	13/03/1986	23	23		not reached
205566	J Hall	8/07/1987	41	5.5		40.5
205570	Mills	22/12/1988	44	33.7		not basalt
205571	J Warotsworth	10/06/1988	77	8.5		not reached
205599	T Doidge	4/06/1992	42	16		32
205600	T Doidge	24/03/1992	52	27		10
205601	Going	26/03/1992	44	15		18.5
205602	G McPherson	18/05/1994	58	39		9
205606	G Stebbings	24/03/1995	44	24		not reached
205607	R Blank	6/06/1995	57	32		11
205673	Carl Hansen	3/10/1997	40	11		35
205692	Rod McGregor	4/12/1992	42	14		not reached
205698	V Houba	28/11/1996	20	5.6		not reached
205704	L and M Martin		34	15		not reached
205706	John Robinson	18/12/1996	50	18.5	50	not reached
205726	D Crocott	18/08/1994	22	7		not reached
205734	Paddy McDonnell	17/10/1991	58	23		not reached
205735	J Kerr	4/10/1991	23	22		not reached
205736	Dave Letcher	21/02/1991	8	5.5		not reached
205737	Rod Hooker	2/11/1989	39	35.5		not reached
205739	Grant Webster	5/02/1992	30	15		not reached
205755	J Foote		74	37		not reached
205790	Harore Holdings					
205792	Finlayson - Pump test		51	8.5	8	not reached
205793	Abbot - Pump test					
205797	Kamo Service Station					

Bore ID	Name	Drilled date	Depth (m)	Cased depth (m)	Yield (m^3/hr)	Depth to basalt base (m)
205807	Puriri Grange Orchard					
205827	P K Gaulden	22/02/1998	72	72	1	not reached
205830	S & K Currie	14/05/1997	23	23	3	not reached
205837	G M Moore	19/11/2000	14	14	2	13
205850	Billington Retiremen	6/04/1995	25			
208435	GO and A M King	20/01/2003	34	14	5	not reached
209138	BC Flower	11/08/2003	41	7.5	3	40
209179	B Flower	11/08/2003	41	7.5	3	40
209187	AR & DA Billington	18/12/2003	44		2	
209273	N Walker	13/07/2004	22	12.3	6	not reached
209381	Murry & Fay Durroch	19/04/2005	35	9.6	7	not reached
209384	E & R Davis	26/04/2005	30	8.2	3	27

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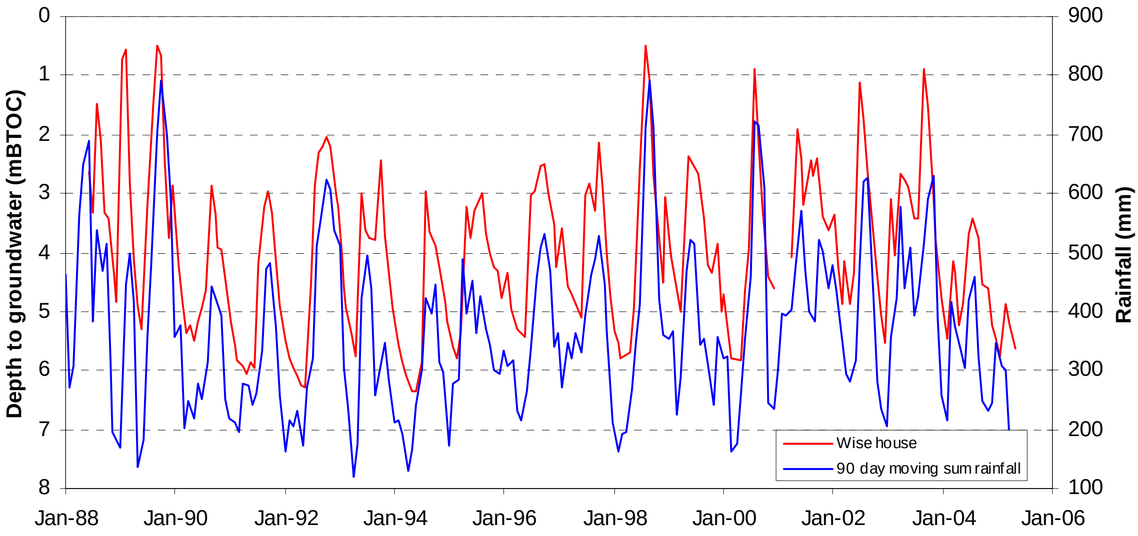
Appendix B Recharge Calculations



- **Figure B-1. Groundwater hydrograph used to assess rainfall recharge.**

- **Table B-1. Estimate of rainfall recharge.**

Date of event	Change in water level (m)	Specific yield (-)	Recharge (m)	Size of rainfall event (m)	Recharge coefficient (%)
Dec 88 – Jan 87	4.28	0.038	0.1626	0.329	49
May 89 – Aug 89	4.83	0.038	0.1835	0.655	28
May 90 – Aug 90	2.64	0.038	0.1003	0.225	45
Jul 91 – Sep 91	3.01	0.038	0.1144	0.240	48
May 92 – Oct 92	4.24	0.038	0.1611	0.436	37
Apr 93 – May 93	2.74	0.038	0.1041	0.374	28
Apr 94 – Jul 94	3.39	0.038	0.1288	0.295	44
Feb 95 – Apr 95	2.56	0.038	0.0973	0.317	31
May 96 – Sep 96	2.92	0.038	0.1110	0.316	35
Feb 98 – Jul 98	5.30	0.038	0.2014	0.631	32
Mar 99 – May 99	2.63	0.038	0.0999	0.291	34
Apr 00 – Aug 00	4.92	0.038	0.1870	0.539	35
Apr 02 – Jun 02	3.76	0.038	0.1429	0.346	41
Jul 03 – Aug 03	2.54	0.038	0.0965	0.236	41