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Dear Susie,

NRC Coastal Aquifers – Kerikeri

Introduction

Sinclair Knight Merz (SKM) was commissioned by Northland Regional Council (NRC) to undertake hydrogeological reviews of ten coastal aquifers in the Northland region, with particular emphasis on determining likely groundwater recharge rates and reviewing aquifer management boundaries. The work was commissioned to partially fulfil NRC's knowledge requirements following the release of a discussion document by the Ministry for the Environment's (MfE) in March 2008 on Proposed National Environmental Standard (NES) on Ecological Flows and Water Levels.

The Proposed NES sets interim default allocation limits for shallow coastal aquifers of whichever is the greater of,

- *15% of the average annual recharge as calculated by the regional council; or*
- *The total allocation from the groundwater resource on the date that the standard comes into force less any resource consents surrendered, lapsed, cancelled or not replaced.*

This report presents the results of the hydrogeological review undertaken for the **Kerikeri basalt aquifer**.

Methodology

The review of the aquifer management area and determination of the recharge rate was achieved through compilation and review of various data sources, primarily provided by NRC. These datasets are summarised as follows:

- Geological borelogs;
- Geological maps;

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- Legal property boundaries (cadastral);
- Topographical contours;
- Rivers; and
- Meteorological data.

In addition to these site specific datasets, a compilation of recharge estimates from previous coastal aquifer studies in the Northland region has been undertaken to categorise the range in likely recharge rates by aquifer type. This data is presented in **Appendix A** and has been used to compare recharge calculations within the current study.

For the purpose of this study, aquifer management boundaries have been refined where appropriate to coincide with cadastral boundaries. This was implemented to avoid potential conflict with and between landowners resulting from future management decisions based on these extents.

Aquifer Description

Kerikeri is located approximately 10 km north east of Kaikohe. The geology for the area is shown on **Figure 1** and is described by the 1:250,000 Geological Map Sheet 1 for North Cape (Kear and Hay, 1961). The local geology predominantly comprises Horeke basalt flows which overlie Waipapa Group greywacke and argillite basement rocks. The Horeke basalt appears to be the result of several overlapping lava flows with a number of discrete ash and basalt layers. A Parahaki rhyolitic dome is located in the centre of the basalt flow adjacent to an area of thin alluvium in the low lying river valley region.

- **Figure 1. Kerikeri Regional Geology Map**
  (See A3 attachment at rear)

NRC records indicate initial drilling at Kerikeri occurred in 1960 with records for 164 bores in the area to date. Due to the number of bores located within the study area, geological and hydraulic testing information from bores drilled after 1990 have been used. A further 13 borelogs (pre 1990) have been used in areas where the recent drilling and associated aquifer information was not as prevalent. The approximate locations of the boreholes are shown in **Figure 1** and **Figure 2.** The bores in the Kerikeri area range in depth from 11.0 to 181 mBGL with the majority abstracting from the basalt aquifer. Summary geological, bore construction and aquifer testing information for the borelogs considered as part of this review is provided in **Appendix B**.

- **Figure 2. Kerikeri Basalt Aquifer Management Map**
  (See A3 attachment at rear)

In general, bore geology correlates with the regional geological map excluding an area in the west of the catchment. This area has been mapped as greywacke, as described by the

1:250,000 Geological Map Sheet, however borelogs define the geology as basalt. In this instance, the geology as defined by drilling has been used.

The majority of bores encounter clay (weathered material) overlying the basalt flow. The basalt is generally encountered close to the ground surface although competent hard rock material is typically overlain by clay and ash, which commonly exceeds 20 metres in thickness.

An isopach map showing the thickness of the solid basalt (i.e. excluding surficial clay cover) is presented in **Figure 3**. The map shows that the thickest basalt is encountered in the west with general thinning toward Kerikeri Inlet (east).

- **Figure 3. Kerikeri Basalt Thickness Map**
  (See A3 attachment at rear)

The typical nature of the basalt is summarised as follows:

- Up to 110 metres in total thickness (bore 209238);
- At least 3 discrete flow members separated by ash layers;
- Generally reported as grey or brown, occasionally red, green or black; and
- Often described as 'hard' or 'very hard' with fractures between 15 and 30 mBGL.

Static groundwater levels for the basalt aquifer range between 2.3 mBGL (bore 203317) and 57 mBGL (bore 203314). This shows large variation in the thickness of the unsaturated zone which is likely to be controlled by topography across the study area.

Figure 4 shows the piezometric surface contour plot for the Kerikeri basalt aquifer. The regional groundwater flow is from west to east, with groundwater elevations in excess of 280 mAMSL in the upper part of the catchment and decreasing to sea level at Kerikeri Inlet.

- **Figure 4. Kerikeri Basalt Piezometric Surface Map**
  (See A3 attachment at rear)

The available test pumping information indicates that the bores abstracting from the Kerikeri basalt aquifer have the following hydraulic characteristics:

- Twenty nine bores have test pumping results and indicate highly variable yields ranging from 4.5 m^3/day (0.05 L/s), to 288 m^3/day (3.3 L/s);
- Maximum drawdown measurements recorded during the test pumping exercises indicate that bore specific capacities are similarly variable, ranging between 0.14 m^3/day/m and 26.2 m^3/day/m (32 tests);
- Results indicate that high yields are predominant where bores are screened between 20 and 30 mBGL. A layer of ash occurs in this interval although the high yields are

considered due to the brecciated margin of the basalt flow units adjacent to this ash layer. It also appears that high yields are associated with a discrete zone of rock fracturing at approximately 90 mBGL in a small number of bores, particularly bore 202300 and 209195.

Aquifer Extent

Review of borelogs and the regional geological map has enabled delineation of the anticipated groundwater recharge area for the basalt aquifer. The extent of the groundwater recharge area typically coincides with the mapped extent of the Horeke basalt in the Kerikeri area. The southern area of Horeke basalt (near Lake Omapere) has been excluded from the groundwater recharge area due to topographical divide (and subsequent surface water catchment divisions). The resultant groundwater recharge area covers 183.2 km^2 and is shown in **Figure 2** (red dashed line).

The management area for the basalt aquifer is also shown in **Figure 2** and is approximately 179.4 km^2. The extent of the management area is based on the groundwater recharge area but modified to match the nearest cadastral boundaries.

The physical groundwater recharge area of 183.2 km^2 has been used in the recharge estimates.

Recharge Estimate

Groundwater recharge is a function of the rainfall and evapotranspiration regimes, as well as geomorphological characteristics of a catchment (e.g. slope, soil and land cover characteristics, etc.).

Long-term local rainfall data was obtained from a rainfall station (station 1056, Kerikeri Ews) located within the study area, approximately 5 km north west of Kerikeri Inlet (**Figure 2**). The data is for the period between 1982 and 2008, and indicates the following annual rainfall statistics:

- Minimum: 1,152 mm (1994)
- Maximum: 2,516 mm (1989)
- **Average: 1,710 mm**

Potential monthly evaporation data were sourced from the nearest NIWA weather station holding this information (Kaikohe Aws, 1134), which is located approximately 30 km south west of the rainfall station.

Streamflow data from two gauging sites on the Rangitane Stream have been used to calibrate a Soil Moisture Water Balance Model (SMWBM) for Kerikeri. The flow gauging data available

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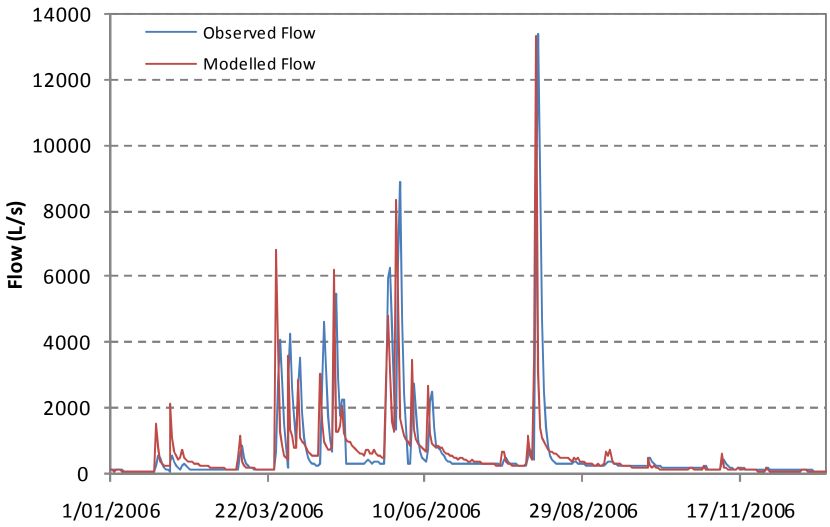
for this study was collected between 1977 - 2001 (Tubbs), and 2001 - 2008 (Stirling). Both flow gauging site locations are shown on **Figure 2.**

Basalt Recharge Estimate

Groundwater recharge was estimated using a SMWBM which is essentially a rainfall-runoff model. Details of model functioning and parameters used are described in **Appendix C**.

Rainfall, mean monthly evaporation and streamflow (described in previous section) were used to calibrate the model for the period between 1982 and 2008. As shown by the match between measured and modelled flow in the hydrograph, for the selected 12 month period (2006), in **Figure 5** and the flow duration curve **Figure 6**, a good level of calibration was achieved.

The focus of the calibration was on low flow conditions, in particular, base flow recession which influences groundwater recharge. We have not focussed on the higher flow (mismatch observed at the 50^{th} percentile, **Figure 6**) as this is controlled by surface water processes.



- **Figure 5. Hydrograph of rainfall-runoff model calibration**

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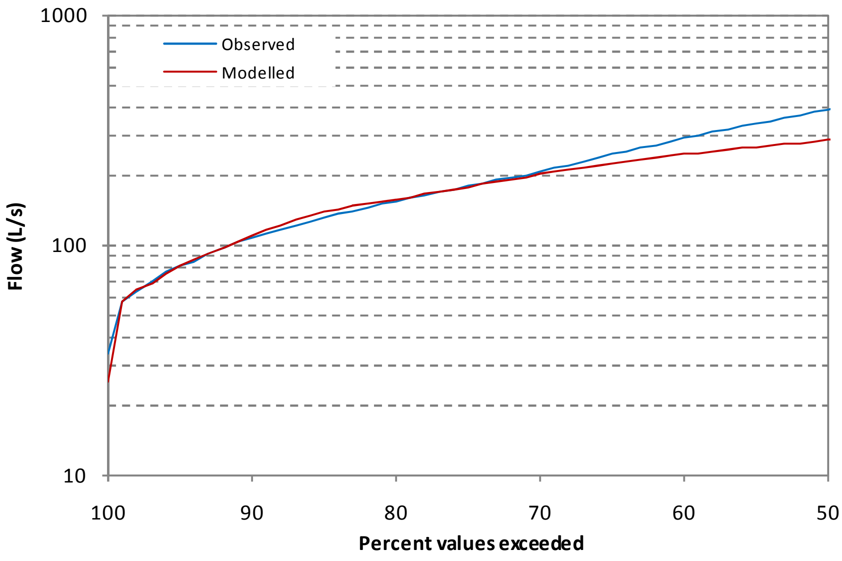

■ **Figure 6. Flow duration curve of rainfall-runoff model calibration**

Values calculated for the key water balance components of the SMWBM are provided in **Table 1.**

■ **Table 1. Estimated catchment water balance**

Water balance component	Proportion of mean annual rainfall
Interception loss	15.6 %
Soil Evaporation	25.8 %
Surface runoff	40.8 %
Groundwater recharge	**17.5 %**
Change in storage	0.04 %
Total	**99.7 %**

Recharge to groundwater estimated for Kerikeri from the model calibration is 17.5 % of mean annual rainfall. This recharge estimate is consistent with previous calibration studies undertaken in Horeke basalt in the Northland region (**Appendix A**), which range between 13.2 % (Kaikohe basalt) and 16.5 % (Monument Hill). Both previous studies also utilised a SMWBM which was calibrated with streamflow records.

Based on the groundwater recharge estimate obtained from the SMWBM calibration and to maintain consistency with previous studies undertaken for NRC, a range of **15 – 20 % of annual average rainfall** has been used to estimate the most likely rainfall recharge for Kerikeri.

The likely range of annual groundwater recharge to the Kerikeri Basalt aquifer based on the local rainfall record and physical aquifer extent, as a percentage of annual rainfall is given in **Table 2**.

▪ **Table 2. Kerikeri basalt annual groundwater recharge volume**

Average Annual Rainfall (mm/yr)	Aquifer Extent (km^2)	Total Recharge Volume (m^3/yr)	% GW Recharge	GW Recharge Volume (m^3/yr)
1,710	183.2	313,272,000	15% (min.)	46,990,800
1,710	183.2	313,272,000	20% (max.)	62,654,400

The groundwater recharge assessment for the Kerikeri basalt aquifer indicates that annual recharge is likely to be between 46,990,800 and 62,654,400 m^3/year for the 15% and 20% recharge proportions, respectively. Accordingly, the interim default allocation limit under the NES (15% of groundwater recharge) would be between **7,048,620** and **9,398,160 m^3/year.**

Yours sincerely

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Appendix A. Summary of recharge rates by aquifer type

Aquifer	Type	Recharge estimate	Recharge Method	Reliability	Source
Glenbervie	Weathered Taheke Basalt	5 - 15%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2005a)
Coopers Beach	Tangihua Basalts	5 - 15%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2005c)
Tara	Parahaki Volcanics?	7 - 10%	Estimate		NRC Report
Kaikohe	Horeke or Taheke Basalt	13.2%	SMWBM	HIGH Calibrated to stream flow.	SKM (2007a)
Monument Hill	Horeke or Taheke Basalt	16.5%	SMWBM	HIGH Calibrated to stream flow.	SKM (2007a)
Maungakaramea	Taheke Basalt	22 - 44%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2006a)
Three Mile Bush	Taheke Basalt	28 - 49%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2006b)
Maungakaramea	Scoria Cone	55 - 65%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2006a)
Ruawai	Alluvium	30%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2003)

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Aquifer	Type	Recharge estimate	Recharge Method	Reliability	Source
Awanui	Alluvium	4.2%	SMWBM	MODERATE Calculated indirectly during calibration of a groundwater model.	SKM (2007b)
Awanui	Dune Sands	43.7%	SMWBM	MODERATE Calculated indirectly during calibration of a groundwater model.	SKM (2007b)
Mangawhai	Sand	10.2 - 16%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2005b)
Russell	Gravel	26 - 52%	SMWBM	MODERATE Calculated indirectly during calibration of a groundwater model.	SKM (2001)
Mangawhai	Sandstone	1 - 10%	Estimate	LOW Calculated using annual average rainfall and recharge coefficient estimates from previous experience pro-rated by area.	SKM (2005b)
Russell	Greywacke	1 - 5%	SMWBM	MODERATE Calculated indirectly during calibration of a groundwater model.	SKM (2001)

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Appendix B. Summary of geological borelogs

Bore #	Location**	Geology		Total Depth	Casing / Screen Details	Screened Geology	Additional Testing Information
		Depth (m)	Lithology				
201120	P4 951-702	0.0 – 36.6 36.6 – 64.0 64.0 – 67.0 67.0 – 70.0	Soft volcanic clay Yellow clay and grit Blue clay Blue shale	70.0 m	*Abandoned*	*Abandoned*	N/A
201122	P4 951-702	0.0 – 31.0 31.0 – 50.0 50.0 – 55.5	Hard rock Softer rock Hard greywacke	55.5 m	Casing (0 – 5.4 m) Open hole (5.4 – 55.5 m)	Greywacke	Q = 65.5 m^3/day
201123	P4 951-702	0.0 – 11.0 11.0 – 25.0	Soft clay and sand Rock	25.0 m	*Unknown*	*Unknown*	
201124	P4 951-702	0.0 – 7.6 7.6 – 28.9	Boulders Weathered rock	28.9 m	Galvanised steel (0 – 19.8 m) Open hole (19.8 – 28.9 m)	*Unknown*	SWL = 3.6 mBGL Q = 38.2 m^3/day
201129	P4 955-714	0.0 – 9.0 9.0 – 19.5	Soft clay and sand Hard sandstone	19.5 m	Casing (0 – 10.4 m) Open hole (10.4 – 19.5 m)	Sandstone	Q = 21.9 m^3/day
201140	P4 967-675	0.0 – 12.2 12.2 – 16.7 16.7 – 21.3	Clay Brown greywacke Hard blue greywacke	21.3 m	PVC casing (0 – 12.2 m) Open hole (12.2 – 21.3 m)	Greywacke	SWL = 9.1 mBGL Q = 33.1 m^3/day
201141	P5 969-685	0.0 – 0.6 0.6 – 11.6 11.6 – 38.0 38.0 – 39.0	Clay Soft shale and sandstone Firm to hard sandstone Hard blue greywacke	39.0 m	*Abandoned*	*Abandoned*	N/A
201142	P5 969-687	0.0 – 15.0 15.0 – 26.0 26.0 – 27.5 27.5 – 55.0 55.0 – 64.0 64.0 – 70.0	Volcanic clay and rock Basalt Blue clay Basalt Clay and weathered greywacke Greywacke	70.0 m	*Unknown*	*Unknown*	
201150	P5 973-695	0.0 – 2.4 2.4 – 11	Clay Rock	11.0 m	Galvanised steel (0 – 4.8 m) Open hole (4.8 – 11.0 m)	*Unknown*	Q = 65.5 m^3/day
201152	P5 976-694	0.0 – 56.0 56.0 – 70.0	Soft clay and sand Brown and blue greywacke	70.0 m	Casing (0 – 55.0 m) Open hole (55.0 – 70.0 m)	Greywacke	Q = 32.7 m^3/day

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Bore #	Location**	Geology		Total Depth	Casing / Screen Details	Screened Geology	Additional Testing Information
		Depth (m)	Lithology				
201153	P5 978-692	0.0 – 25.0	Soft material	25.0 m	Galvanised steel (0 – 17.3 m) Open hole (17.3 – 25.0 m)	Unknown	SWL = 6.1 mBGL Q = 38.2 m^3/day
201154	P5 978-697	0.0 – 42.7 42.7 – 55.8	Clay Brown and blue greywacke	55.8 m	Casing (0 – 34.7 m) Open hole (34.7 – 55.8 m)	Greywacke	Q = 21.8 m^3/day
201157	P5 979-699	0.0 – 18.3 18.3 – 22.8	Soft clay and sand Rock	22.8 m	Casing (0 – 20.7 m) Open hole (20.7 – 22.8 m)	Unknown	
201492	Q4 913-607	0.0 – 27.0 27.0 – 30.0 30.0 – 43.0	Orange-brown clay Brown-grey weathered basalt Grey-green very hard coarse basalt	43.0 m	Casing (0 – 27.0 m) Open hole (27.0 – 43.0 m)	Basalt	SWL = 9.0 mBGL Q = 288 m^3/day Sc = 26.2 m^3/day/m
202300	P5 832-606	0.0 – 31.0 31.0 – 32.5 32.5 – 64.5 64.5 – 71.6 71.6 – 96.5	Clay with large ash layers Broken weathered basalt Hard black basalt Light grey and black ash Fractured blue-black basalt	96.5 m	Casing (0 – 45.5 m) Open hole (45.5 – 96.5 m)	Basalt (some fracturing)	SWL = 23.8 m Q = 66.5 m^3/day Sc = 2.1 m^3/day/m
203212	P5 910-622	0.0 – 33.0 33.0 – 41.0 41.0 – 53.0 53.0 – 73.0	Clay Boulders White-grey silt Dark grey basalt	73.0 m	Casing (0 – 41.0 m) Open hole (41.0 – 73.0 m)	Basalt	SWL = 8.0 m Q = 96.0 m^3/day Sc = 5.6 m^3/day/m
203216	P5 002-650	0.0 – 13.0 13.0 – 45.0 45.0 – 62.0	Clay and sand Hard basalt with fractures Siltstone and brown greywacke	62.0 m	Casing (0 – 15.0 m) Open hole (15.0 – 62.0 m)	Basalt	SWL = 12.0 mBGL Q = 4.5 m^3/day Sc = 0.1 m^3/day/m
203218	P5 001-650	0.0 – 12.0 12.0 – 32.0 32.0 – 38.0	Clay and sand Hard basalt Siltstone and brown greywacke	38.0 m	Casing (0 – 15.0 m) Open hole (15.0 – 32.0 m)	Basalt	SWL = 23.0 mBGL Q = 36.3 m^3/day Sc = 7.3 m^3/day/m
203224	P5 885-596	0.0 – 46.0 46.0 – 72.0 72.0 – 74.0 74.0 – 90.0 90.0 – 97.0	Clay Grey basalt White silt Firm basalt Siltstone	97.0 m	Casing (0 – 48.0 m) Open hole (48.0 – 97.0 m)	Basalt	SWL = 9.5 mBGL Q = 36.3 m^3/day
203240	P5 979-643	0.0 – 45.0 45.0 – 50.0 50.0 – 80.0	Brown and orange clay Green-grey weathered greywacke Very hard greywacke	80.0 m	Casing (0 – 50.0 m) Open hole (50.0 – 80.0 m)	Greywacke	SWL = 9.0 mBGL Q = 72.0 m^3/day Sc = 2.0 m^3/day/m

Bore #	Location**	Geology		Total Depth	Casing / Screen Details	Screened Geology	Additional Testing Information
		Depth (m)	Lithology				
203243	P5 938-661	0.0 – 35.0 35.0 – 45.0 45.0 – 53.0 53.0 – 57.0	Brown clay Very hard grey basalt Brown to red basalt Grey clay and ash	57.0 m	Casing (0 – 35.0 m) Open hole (35.0 – 57.0 m)	Basalt	SWL = 13.5 mBGL Q = 240.0 m^3/day Sc = 9.8 m^3/day/m
203249	P5 861-628	0.0 – 24.0 24.0 – 30.0 30.0 – 45.0	Brown to yellow clay Very hard grey basalt Siltstone	45.0 m	Casing (0 – 13.0 m) Open hole (13.0 – 45.0 m)	Basalt / Siltstone	SWL = 12.0 mBGL Q = 7.3 m^3/day Sc = 0.6 m^3/day/m
203253	P5 003-651	0.0 – 14.0 14.0 – 42.0	Clay and weathered greywacke Very hard greywacke	42.0 m	Casing (0 – 12.0 m) Open hole (12.0 – 42.0 m)	Greywacke	SWL = 7.0 mBGL Q = 9.6 m^3/day Sc = 0.4 m^3/day/m
203258	P5 867-633	0.0 – 11.0 11.0 – 31.0	Soft clay and ash Hard grey basalt	31.0 m	Casing (0 – 11.0 m) Open hole (11.0 – 31.0 m)	Basalt	SWL = 5.0 mBGL Q = 72.0 m^3/day Sc = 3.3 m^3/day/m
203272	P5 967-649	0.0 – 19.0 19.0 – 31.0 31.0 – 40.0 40.0 – 42.0	Soft clay Hard grey basalt Hard grey/blue/green/white basalt Soft grey ash	42.0 m	Casing (0 – 20.0 m) Open hole (20.0 – 42.0 m)	Basalt	SWL = 8.0 mBGL Q = 27.3 m^3/day Sc = 1.0 m^3/day/m
203274	P5 967-649	0.0 – 8.0 8.0 – 19.0	Soft clay Brown volcanic clay	19.0 m	Casing (0 – 8.0 m) Screen (8.0 – 18.0 m)	Clay	SWL = 3.4 mBGL Q = 36.0 m^3/day Sc = 1.4 m^3/day/m (previous bore had large volumes of gas)
203291	P5 967-647	0.0 – 5.5 5.5 – 15.0 15.0 – 39.0 39.0 – 50.0 50.0 – 60.0	Clay and ash Basalt Chaos and thin layers of basalt Hard grey basalt Brown clay	60.0 m	Casing (0 – 40.0 m) Screen (40.0 – 52.0 m)	Basalt	SWL = 8.4 mBGL Q = 11.7 m^3/day Sc = 0.4 m^3/day/m
203299	P5 848-576	0.0 – 52.0 52.0 – 92.0 92.0 – 105	Dark red-brown soil, clay and ash Very hard grey basalt Soft grey siltstone and ash	105 m	Casing (0 – 52.0 m) Open hole (52.0 – 105 m)	Basalt	SWL = 18.4 mBGL Q = 240 m^3/day Sc = 9.0 m^3/day/m

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Bore #	Location**	Geology		Total Depth	Casing / Screen Details	Screened Geology	Additional Testing Information
		Depth (m)	Lithology				
203301	P5 019-653	0.0 – 16.0 16.0 – 22.0 22.0 – 110	Yellow-brown clay Hard greywacke Dark brown greywacke with quartz	110 m	Casing (0 – 21.0 m) Open hole (21.0 – 47.0 m) Cement grout plug (47.0 – 51.0 m)	Greywacke	SWL = 16.5 mBGL Q = 19.2 m^3/day Sc = 0.9 m^3/day/m (test had inflow of saltwater 60 mBGL)
203309	P5 014-665	0.0 – 14.5 14.5 – 34.0 34.0 – 37.0 37.0 – 45.0	Red-brown clay Grey-brown basalt Ash Brown-green basalt	45.0 m	Casing (0 – 16.0 m) Open hole (16.0 – 45.0 m)	Basalt	SWL = 16.0 mBGL Q = 62.4 m^3/day Sc = 4.5 m^3/day/m
203312	P5 016-669	0.0 – 40.0 40.0 – 60.0	Soil, clay and weathered greywacke Blue greywacke	60.0 m	Casing (0 – 45.0 m) Screen (39.0 – 60.0 m)	Greywacke	SWL = 9.0 mBGL Q = 54.0 m^3/day Sc = 2.0 m^3/day/m
203314	P5 977-587	0.0 – 50.0 50.0 – 79.0 79.0 – 91.0 91.0 – 104 104 – 107	Clay Weathered red basalt Red basalt Very hard blue basalt Red basalt	107 m	Casing (0 – 80.0 m) Open hole (80.0 -107 m)	Basalt	SWL = 57 mBGL Q = 45.4 m^3/day Sc = 3.5 m^3/day/m
203317	P5 910-622	0.0 – 48.8 48.8 – 78.0 78.0 – 91.0 91.0 – 118 118 – 181	Multi-coloured volcanic clay and ash Green and grey basalt and light grey silt Dark grey-green basalt White clay and brown shale (unstable) Hard dark grey 'ash stone'	181 m	Casing (0 – 130 m) Open hole (130 – 181 m)	Basalt	SWL = 2.3 mBGL Q = 24.0 m^3/day
203328	P5 858-583	0.0 – 38.0 38.0 – 65.0 65.0 – 81.0 81.0 – 82.0	Soft clay and ash Brown to grey basalt Very hard grey basalt Soft grey mudstone	82.0 m	Casing (0 – 38.0 m) Open hole (38.0 – 82.0 m)	Basalt	SWL = 16.0 mBGL Q = 72.0 m^3/day Sc = 3.6 m^3/day/m
203335	P5 865-578	0.0 – 18.0 18.0 – 33.0 33.0 – 60.0 60.0 – 79.0 79.0 – 81.0	Clay and ash Hard basalt, fractured Ash Very hard basalt Mudstone	81.0 m	Casing (0 – 34.0 m) Screen (34.0 – 52.0 m)	Ash	SWL = 10.5 mBGL Q = 48 m^3/day Sc = 1.4 m^3/day/m

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Bore #	Location**	Geology		Total Depth	Casing / Screen Details	Screened Geology	Additional Testing Information
		Depth (m)	Lithology				
203339	P5 792-598	0.0 – 34.0 34.0 – 73.0	Clay and ash Basalt with ash layers (merging into mudstone)	73.0 m	Casing (0 – 35.0 m) Open hole (35.0 – 78.0 m)	Basalt	SWL = 22.7 mBGL Q = 28.8 m^3/day Sc = 0.8 m^3/day/m
203346	P5 864-584	0.0 – 40.0 40.0 – 64.5 64.5 – 67.0	Soil, fill, clay and ash Black and blue basalt Blue-green clay	67.0 m	Casing (0 – 40.5 m) Open hole (40.5 – 67.0 m)	Basalt	SWL = 13.0 mBGL Q = 216 m^3/day Sc = 8.6 m^3/day/m
203347	P5 867-615	0.0 – 28.0 28.0 – 49.0 49.0 – 52.0	Soil and some boulders Basalt Carbonaceous siltstone	52.0 m	Casing (0 – 34.5 m) Open hole (34.5 – 52.0 m)	Basalt	SWL = 11.0 mBGL Q = 120 m^3/day Sc = 24.0 m^3/day/m
205788	P5 945-643	0.0 – 40.0 40.0 – 42.0 42.0 – 44.0 44.0 – 60.0	Clay and ash Very hard grey basalt Brown clay Very hard basalt	60.0 m	Casing (0 – 30.0 m) Open hole (30.0 – 60.0 m)	Basalt	SWL = 4.0 mBGL Q = 24 m^3/day Sc = 1.3 m^3/day/m
209147	P5 816-537	0.0 – 11.8 11.8 – 34.0 34.0 – 38.0	Clay, ash and some boulders Basalt with ash layers Green silt	38.0 m	Casing (0 – 18.0 m) Open hole (18.0 – 38.0 m)	Basalt	SWL = 25.3 mBGL
209195	P5 845-673	0.0 – 39.0 39.0 – 90.0	Clay and some boulders Basalt (with fractures from 82m)	90.0 m	Casing (0 – 40.25 m) Open hole (40.25 – 90.0 m)	Basalt	SWL = 45.6 mBGL Q = 129.6 m^3/day Sc = 5.8 m^3/day/m
209202	P5 938-589	0.0 – 3.1 3.1 – 21.1 21.1 – 28.0	Soil and some boulders Basalt with ash layers Soft siltstone	28.0 m	Casing (0 – 6.2 m) Open hole (6.2 – 28.0 m)	Basalt / Siltstone	SWL = 2.3 mBGL Q = 23.0 m^3/day Sc = 1.8 m^3/day/m
209238	P5 833-630	0.0 – 39.0 39.0 – 149	Clay Basalt	149 m	Casing (0 – 41.3 m) Open hole (41.3 – 149 m)	Basalt	SWL= 11.6 mBGL Q = 61.9 m^3/day Sc = 2.0 m^3/day/m
209468	P5 923-591	0.0 – 23.0 23.0 – 29.6 29.6 – 36.5 36.5 – 39.0	Clay and ash Basalt with ash layers Hard black basalt (fractured) Soft green siltstone	39.0 m	Casing (0 – 32.3 m) Open hole (32.3 – 39.0 m)	Basalt	SWL = 2.9 mBGL Q = 48.0 m^3/day Sc = 2.5 m^3/day/m
209590	P5 945-643	0.0 – 20.0 20.0 – 25.0 25.0 – 29.0	Clay and ash Ash and basalt layers Hard basalt	29.0 m	PVC casing (0 – 21.5 m) Open hole (21.5 – 29.0 m)	Basalt	SWL = 1.5 mBGL Q = 28.8 m^3/day Sc = 3.8 m^3/day/m

Bore #	Location**	Geology		Total Depth	Casing / Screen Details	Screened Geology	Additional Testing Information
		Depth (m)	Lithology				
209634	P5 916-622	0.0 – 29.0 29.0 – 84.2 84.2 – 122 122 – 123	Soil and ash Clay and weathered rock Basalt Soft grey rock	123 m	Galvanised steel (0 – 85.4 m) Open hole (85.4 – 123 m)	Basalt	SWL = 21.1 mBGL Q = 57.6 m^3/day
209713	P5 014-665	0.0 – 19.5 19.5 – 22.0 22.0 – 25.0	Clay with some boulders Basalt (fractured) Grey clay	25.0 m	Casing (0 – 20.0 m) Open hole (20.0 – 25.0 m)	Basalt	SWL = 9.2 mBGL Q = 36.0 m^3/day Sc = 1.8 m^3/day/m
209773	P5 979-643	0.0 – 25.5 25.5 – 127	Clay and silt Greywacke	127 m	Casing (0 – 26 m) Open hole (26 – 127 m)	Greywacke	SWL = 2.5 mBGL Q = 24 m^3/day Sc = 0.5 m^3/day/m

Notes: * *Locations are approximate only. **SWL** is static water level measured in metres below ground level. **Q** is discharge rate measured during test pumping. **Sc** is specific capacity.
Borelogs that did not contain geological information have not been included in this table, or labelled with NRC reference in Figure 1 and Figure 2.

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Appendix C. Estimation of groundwater recharge with Soil Moisture Water Balance Modelling (SMWBM)

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 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 infiltration rates,
- soil moisture percolation rates;
- 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 rain day 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).

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.

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. Depending on the vegetative and lithological characteristics of the catchment, this may coincide with the soil zone or may be deeper.

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. For practical purposes this has been assigned zero.

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.

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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.

Table C1 summarises the parameter values applied for the simulation.

- **Table C1. Model input parameters.**

Parameter	Primary model parameters					Secondary model parameters									
	Area	ST	FT	Z_{max}	PI	AI	Z_{min}	R	DIV	TL	GL	LAG	O_{obs}	POW	SL
Units	km^2	mm	mm/d	mm/h	mm	%	mm/h		%	d	d	d	m^3/day		mm
Model	23.4	250	1.2	15	2	0	0	0	0	1.5	7	0	70,000	2	0

Estimation of Groundwater Recharge

The model was run using the rainfall record and calibrated model parameters and the groundwater percolation component of the output was used to represent groundwater recharge.

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