South Auckland Groundwater, Kaawa Aquifer Recharge Study And Management Of The Volcanic And Kaawa Aquifers

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1. INTRODUCTION

1.1. General

The aim of this report is to provide guidelines for the management of aquifers in the northern part of Franklin District. Aquifers studied include Bombay, Pukekohe and Glenbrook volcanics, and the Kaawa Formation.

The primary focus of this study was to review the mechanism of groundwater flow within and between the aquifers underlying the Manukau Lowlands and Pukekohe Hill, establish the recharge mechanism, and prepare a model of the recharge. A major component of the work was to estimate the volume of water that can be safely allocated for use (water availability) from the Kaawa aquifer and determine its relationship with other aquifers. The last comprehensive review of the management of these aquifers was completed in 1989 (ARWB, 1989, TP85).

Water demand has increased since the late 1980's to an extent where some resources were considered fully allocated, based on water availability figures from previous studies. The need for accurate information on water availability from aquifers to satisfy demand led to the review of water management in the area.

A major outcome of this work was to provide the technical basis for water availability figures and policy for water management set out in the Proposed Auckland Regional Plan: Air, Land and Water, which was notified in October 2001.

This investigation was focussed on:

(1) The interaction between volcanic aquifers (Pukekohe, Drury-Bombay and Glenbrook) and underlying Kaawa Formation aquifer,

(2) The relationship of the aquifers with stream and spring discharge, and discharge to the sea

(3) The significance of the rainfall/infiltration ratio in the recharge pattern.

(4) The best management approach.

This required a reassessment of geology, hydrogeology and aquifer hydrological parameters. The results of the investigations lead to the management approach as outlined in the Proposed Auckland Regional Plan: Air, Land and Water, 2001 .

1.2. Background

This investigation and report is a continuation of previous work from 1996 undertaken to estimate recharge and review management of the Pukekohe Volcanic Aquifer (ARC, 1996). Recommendations in that report outlined the need for a better understanding of interaction between the Pukekohe Volcanic Aquifer and Kaawa Aquifer.

In the last two decades, numerous investigations from a geological, geophysical and hydrogeological prospective have been carried out across the Franklin district.

Work by Rafferty (1977) and Jukic (1995) provided valuable information about geology of the area. Allen (1996) and Greenwood (2000) also contributed towards better understanding of the geological relations.

The Institute of Geological and Nuclear Sciences (1995) and Hadfield (1988) used computer modelling to evaluate hydrology of the Pukekohe Volcanic aquifer and Kaawa Formation providing valuable information and background for the groundwater modelling and the conceptual model of recharge in this report.

The most comprehensive and complete work on the Kaawa aquifer was the report produced by Auckland Regional Water Board (ARWB,1989). This report included management proposals and water availability for the aquifer. The report outlined the importance of the Pukekohe Volcanic Aquifer as a potential source of recharge for the Kaawa Aquifer.

Rosen et al (2000) provided fundamental information on infiltration and infiltration rates in the Pukekohe Volcanic Aquifer, which was the basis for the recharge and water availability estimation in this study.

1.3. Location

The study area covers nearly 350 square kilometres and is situated approximately 50 kilometres south of the Auckland City, bordering the Waikato Region (Environment Waikato).

The study area encompasses a part of the Franklin District between Awhitu Peninsula, the Manukau Harbour, Bombay - Drury and the Waikato River (Figure 1.1)

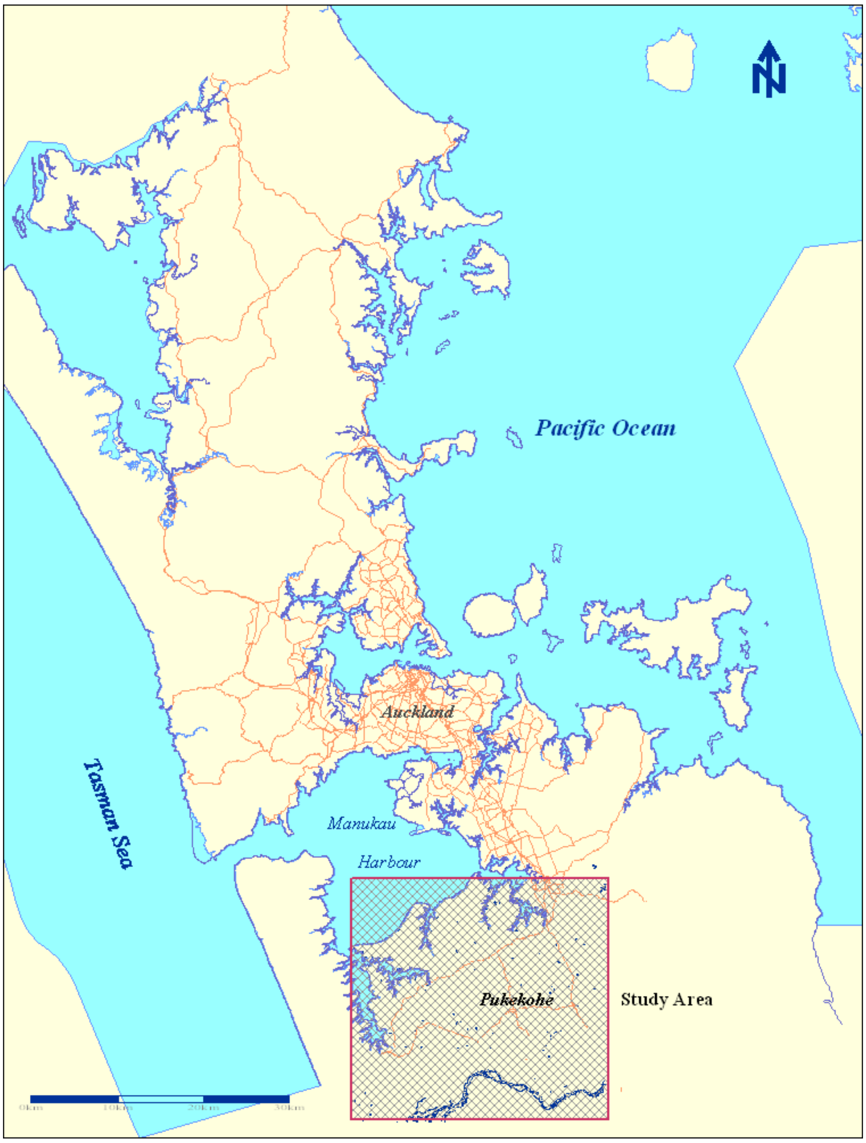


Figure 1.1 Study area location map

The area includes features such as the Manukau Lowlands adjacent to the Manukau Harbour, and the Bombay, Pukekohe and Glenbrook uplands. The topographically dominating forms are the volcanic cones, with the maximum elevation of over 200 meters (Pukekohe Hill) and areas covered by volcanic deposits with an average elevation of 80 to 100 meters above sea level.

From the central elevated zone (Bombay - Pukekohe – Glenbrook), the terrain moderately slopes towards the Manukau Harbour to the north and the Waiuku River to the west. To the south, the terrain slopes steeply from the central area towards the Aka Aka plain and Waikato River, (Figure 1.2), all of which is in the Waikato Region. The Regional boundary is shown on Figure 1.2.

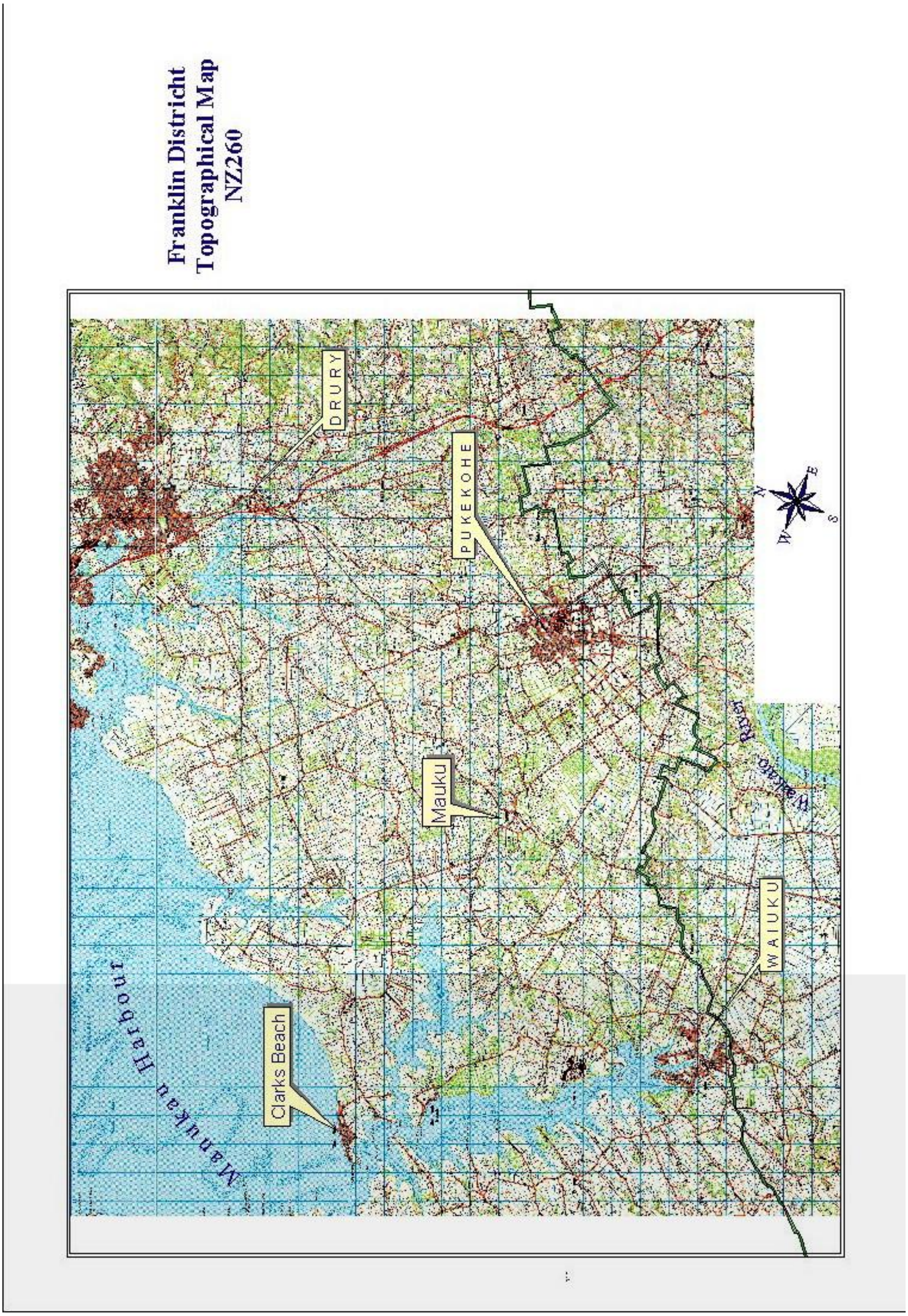


Figure 1.2 Topographic map of the Franklin area

1.4. Data Collection and Reliability

1.4.1. Introduction

This section outlines the source of data used in the South Auckland Groundwater Investigations and makes comments on its reliability. It does not present results of analysis or assumptions made in the use of the data. A lot of information has been gained from reports, maps, and other literature. Where data is presented in other reports it is not reproduced here, although relevant references to this information are given. A list of these documents and maps is provided in Chapter 10 References.

1.4.2. Geology

Geological information has been obtained from two main sources; the “Pukekohe - Provisional Map Compilation”, Geological Map of New Zealand 1: 50,000 (IGNS, July 1995) compiled by S.W.Edbrooke (Sheet R 12, 1:50,000) and “Auckland Map sheet R 12" in digital form by F.Brook and S.W.Edbrooke (Auckland Region, 1:250,000, 1999).

Data quality of these maps is acceptable although there are minor discrepancies between them. Some outcrops presented on the Provisional map are not shown on the digital map. Similarly, some geological boundaries differ. Structural data (faults and folds) are not shown on these maps.

Structural information came from the several sources. Digital data for faults from 1995 contained the location of a number of faults. Further digital were obtained in 1997 which contained only the locations of a few major faults such as Bombay -Drury, Waikato and Glenbrook Fault.

Other geological information was obtained from; “Volcanic Geology and Petrology of South Auckland” by Rafferty (1977),

Geological information from the maps has been used to create surface distribution of lithological units, delineate aquifers and help to determine recharge and discharge zones. Rafferty's geological map has been used to identify volcanic centres within the Franklin Volcanic field.

1.4.3. Aquifer Parameters

The Auckland Regional Council (ARC) has a broad range of reports on aquifer tests carried out on groundwater bores in the study area. These range from airline tests carried out on completion of bore construction to well designed and implemented tests carried out to determine aquifer parameters, optimal bore yields and pump sizing.

While airline tests may be used as a very crude indication of bore yield they do not give any reliable hydrogeological value for resource assessment. A number of step drawdown and constant discharge tests has been carried out in South Auckland over the last 30 years. Few of these have been carried out for a sufficient length of time to give more accurate value to the data being collected. However, some information can be gleaned from these tests and in areas of poor hydrogeological definition, some data is certainly better than no data. The test data is used to estimate aquifer parameters such as transmissivity, storativity and hydraulic conductivity.

Analysis of this information shows that it is characterised by a very wide range of aquifer parameters and irregular spatial distribution of the aquifer tests. As a consequence estimation, interpolation and averaging of the parameters across the aquifers is necessary.

It was difficult to calculate hydraulic conductivity (K) because of difficulty to determine the thickness of some aquifers. The thickness was very often interpolated and estimated. The computer modelling process is particularly sensitive to these parameters.

1.4.4. Bore Logs

The ARC holds bore records for most bores drilled in the Auckland Region since October 1987 when a bore permit requirement was introduced. These bore records include, amongst other information, a lithological log, bore construction, static water level, location (generally to the nearest 100m), drilling contractor and bore owner.

The ARC records of bores drilled prior to 1987 are incomplete. The location of many pre-1987 bores is known as a consequence of land use surveys carried out by the ARC and through resource consent processing.

The ARC holds a record of about 1200 bores in the study area. These records, together with geological reports and maps have been used to define hydrogeological boundaries, especially the aquifer boundaries. Not all bore logs were used for this work. This was primarily because of the poor quality of some records.

All bores were mapped on the basis of total drilled depth so that the deeper bores, with generally more information, could be preferentially selected. In areas such as Karaka, where the stratigraphy is comparatively less complex, few bore logs were required. A total of 100 bores were selected for use in defining boundaries for numerical modelling purposes. These bores give a fairly good coverage of the area although some gaps remain primarily due to relatively shallow bores in parts of the study area or very poor quality of information (e.g.. some parts of the Glenbrook Volcanics).

Approximately 20 bore records from Environment Waikato were used to determine hydrogeological boundaries in the southern part of the study area.
These bore records were simplified into seven main units: Franklin basalt, Pleistocene sands, Kaawa sands and sandstone, Kaawa shell bed, Waitemata sandstone and Greywacke for the construction of the geological model (Chapter 2) and numerical modelling (Chapter 8).

The following problems were encountered with bore log information:

- A very large number of bores drilled for water abstraction purposes do not have adequate (or any) lithological or geological descriptions. The use of these bores in the geological reconstruction was not possible.

- A number of bores partially penetrate the aquifer(s). These have been partially used to reconstruct the extent or presence of the aquifer(s). The consequence of this was inaccurate, and interpolated thickness in some areas of the aquifers (Kaawa and Volcanic).

- Despite a considerable number of bores within the area, some parts are still lacking in information. In areas such as Pukekohe Hill, Bald Hill or Bombay Hill the Kaawa Formation is deep below the surface (at places more than 150m) therefore drilling into this aquifer to utilise ground water was too expensive. Consequently the extent, thickness and geological description of the aquifers in such areas was not known.

1.4.5. Infiltration Investigations

The ARC in conjunction with the Institute of Geological and Nuclear Sciences (GNS), Lincoln Ventures Ltd. and Crop and Food Research initiated an investigation of the groundwater recharge rates into the Pukekohe Volcanic Aquifer. In the period from July 1997 to May 1998 GNS established a monitoring site as a part of an overall assessment to examine changes in soil moisture and hence rainfall recharge around Pukekohe. Later, several further sites were established (P.White, 2002) and the result of the investigation supported the result from the first site.

The first site is located within the NIWA (National Institute of Water and Atmospheric Research) climate station compound at the Crop and Food Research station, Cronin Road, Pukekohe.

A second research site (Lim site) has been installed at the edge of a market garden on the property of Mr Lim on the eastern side of Pukekohe Hill in the same soil type as the Crop and Food research site. The instrumentation at the Lim site is the same as at the Crop and Food site.

Both sites include:

- A soil moisture pressure-vacuum lysimeter installed at depth of 2.8 m below the ground.

- A soil moisture pressure-vacuum lysimeter installed to sample at 1 m below the ground surface.

- A Campbell Scientific CS615 Water Content Reflectometer (TDR) connected to a Campbell Scientific CR10 data logger (solar powered). Reflectometers were installed at depths of 10 cm, 40 cm and 70 cm below ground surface. The data logger was set to record soil moisture (% soil moisture content) values every 10 minutes. A rain gauge was also connected to the data logger.

- A Streat Aquaflex Soil Moisture Meter with soil moisture and temperature sensors at depths of 10 cm, 40 cm, 70 cm and 1 m. This unit (uncalibrated) was set to take soil moisture and temperature readings every 1.5 hours and store these readings in it's own Data Storage Unit.

- A rainwater collector consisting of a 5 L plastic water container with an on-off tap at the bottom and a funnel in the top, all on a stand. Approximately 500 ml of oil is poured into the collector to prevent any rainwater collected from being exposed to the atmosphere (essential for ^{18}O isotope analysis).

Monthly sampling of the lysimeters, boreholes, rainwater collectors and downloading of data from the TDR and Aquaflex units commenced on 20 January 1997.
The results of the research are given in two reports, Rosen & all (2000) and White & all (2002).

1.4.6. Rainfall

Rainfall data has been obtained for a period of 20 years (1978 – 1998) for 11 sites in the Pukekohe area and for the Auckland Airport. The Airport site was selected because it is the nearest long-term rainfall record to the study area. A table of site details and data length and quality is given in the Chapter 4.

The rainfall record for the area is generally good. The only problem was in the inconsistency in recording periods across the region and missing records as a consequence of closing down or opening the monitoring sites. The missing record was substituted by interpolating data using records from neighbouring sites.

1.4.7. Evapotranspiration

Evaporation data were obtained for the Pukekohe DSIR station for the period of 17 years (1972 – 1989) and for the Auckland Airport for the period of 20 years (1978 –

1998). Data from the Auckland Airport were used to synthesize the missing data from the Pukekohe site.

Evapotranspiration values were estimated across the area based on a comparison between the Auckland Airport site and historic Pukekohe (DSIR) information. Because of a lack of information, the differentiation in evapotranspiration values between different land use and (micro) climate conditions was very difficult to achieve. As a consequence it was assumed that evapotranspiration is uniform across the area.

1.4.8. Surface Water Flow Data

The purpose of this information is to provide surface water discharge data for the groundwater availability calculation and inclusion in the groundwater modelling.

The ARC regularly monitors water levels in a number of streams within the region with the purpose to calculate stream discharge values. There are also a large number of sites gauged manually as a part of the ARC's Low Flow Gauging Programme, and for the surface water management purposes.

Three automated water level recorder sites are located in the study area, in the Ngakaroa, Whangamaire and Waitangi Catchments. The records from January 1st 1980 to December 1998 were used for simulating flows at selected gauging sites. Each site has operated for different lengths of time and all are currently operating today. The ARC operates two sites and the Waitangi site is operated by the NIWA.
The quality of the water level data from each of the automatic recorder sites is an important factor because this information was used to simulate flow records at gauging sites where little or no information is available.

Flow record for three sites in the Waikato region (Parker Lane and two at Whakapipi Stream) is obtained from Environment Waikato.
The stream flow information, where it exists, is of good quality but there are a few gaps. Missing data was substituted with synthesised information using long term monitoring stations.

1.4.9. Groundwater Levels

Groundwater level fluctuation has been monitored in the area for 25 to 30 years (some records dating from the early 1970's). Apart from a large number of private bores, a number of monitoring bores were drilled and equipped especially for the purpose of observing groundwater levels in different aquifers.

There are two main groups of monitoring bores; baseline monitoring bores and management monitoring bores. The baseline monitoring sites are designed for the analysis of long term groundwater trends.

The management monitoring network is designed to monitor direct effects of groundwater abstraction.

Figure 1.3 Shows location of the ARC groundwater monitoring bores and the list of sites is given in Chapter 3.

Site No	Bore ID	Site Name	Aquifer
7419007	343	*Fielding Rd (sand)*	Sand
7419009	344	*Fielding Rd (volcanic)*	Volcanic
7419011	479	*Cooper Rd*	Sand
7510005	791	*Wootten Rd*	Volcanic
7417001	3199	*Glenbrook Hall*	Kaawa
7427003	3215	*Divers Rd*	Kaawa
7428049	3371	*Mauku bore No2*	Kaawa
7428043	3553	*Pukekohe DSIR Northern*	Volcanic
7428001	3545	*Pukekohe DSIR No2*	Volcanic
7429017	3614	*Douglas Rd shell bed*	Kaawa
7429013	3614	*Douglas Rd lower volcanic*	Volcanic
7419003	3770	*Tuhimata*	Kaawa
7419005	4128	*Ingram Rd*	Kaawa
7429019	5009	*Pukekohe Borough Council*	Kaawa
7417017	20789	*Glenbrook Peninsula*	Kaawa
7427005	20807	*Maraeorahia production*	Kaawa
7418003	20810	*Waiau Pa No2c*	Kaawa
7418029	20811	*Ryan Rd Production*	Kaawa
7428047	20812	*Mauku main prod bore No1*	Kaawa
7418013	20813	*Batty Rd production*	Kaawa
7418023	20814	*Ostrich Farm #2 recorded*	Kaawa
7418021	20815	*Ostrich Farm product*	Kaawa
7429011	20816	*Ravell Court*	Volcanic
7428051	33772	*Mauku bore No3*	Kawa

Figure 1.3 ARC groundwater monitoring locations

1.4.10. Groundwater Use

All current water permit holders, that are exercising their permits, are required to fit water flow meters and record readings on at least a weekly basis. Water meter readings are forwarded to the Auckland Regional Council quarterly. Data quality varies considerably with missing data and inaccuracy in reading meters being the main problems.

Bores used for stock watering and domestic use are not required to fit and read water meters. Total water use for these users can only be estimated. Calculations have been based on historical data collected by the ARC, such as land use surveys, and resource consent application information. In this report domestic water supply is based on household and stock water consumption of maximum 10 m^3/day.

In some locations it was difficult to separate the use from different aquifers through which the bore was drilled. Old bores can be poorly constructed (tapping multiple aquifers) or have poor lithological records.

1.5. Data reliability

Data quality and reliability was assessed using a simple method of ranking information (out of 10) in several categories (Table 1.1).

Table 1.1 Data reliability assessment

	rainfall	evaporation	aquifer parameters	stream discharge	groundwater levels	bore logs	water use	
Initial data quality	8	7	7	7	8	6	5	out of 10
Missing data	8	1	5	7	5	5	7	out of 10
Data coverage	8	1	5	6	4	7	8	out of 10
Interpolation	y	y	y	y	y	y		
Quality of used data	9	6	6	7	7	8		out of 10
Data reliability	**83**	**38**	**58**	**68**	**60**	**65**	**65**	%

Note: 1 = poor, 10 = the best

Figure 1.4 shows estimated cumulative assessment expressed as a percentage.

This estimation was used to generally assess confidence in the results.

Overall data confidence is between 60% and 80% which is relatively good taking into account the size of the area, number of parameters and amount of data required for the project. Final data used in the project are of good to very good quality but the main problem is in data coverage.

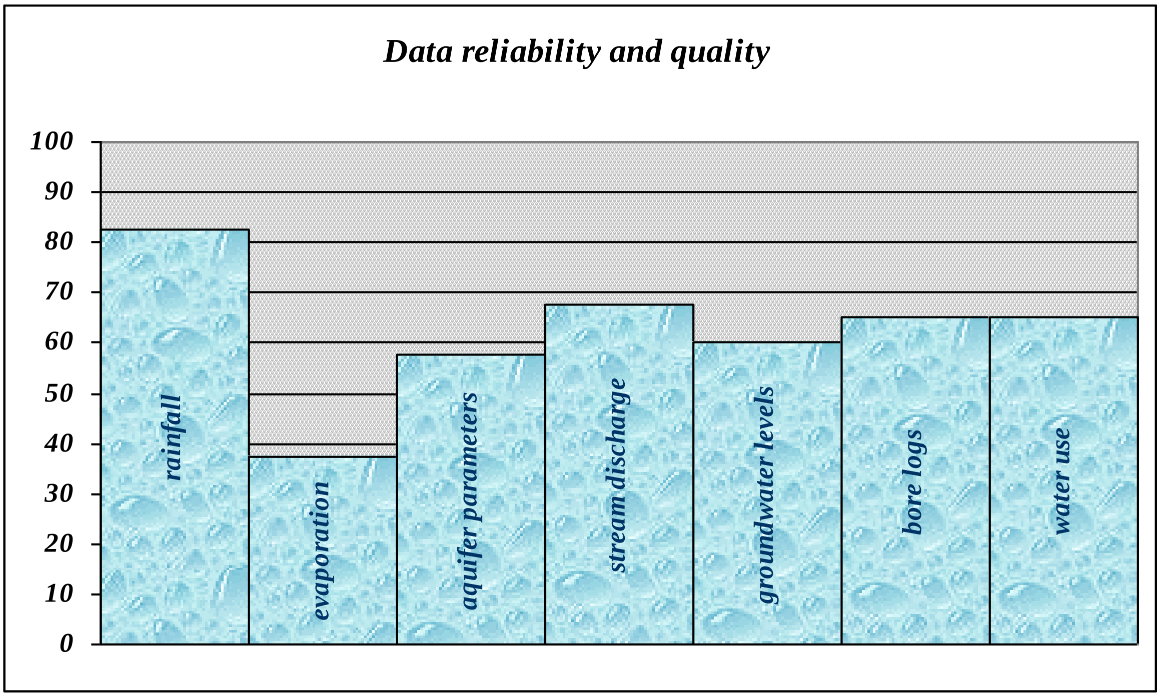


Figure 1.4 Overall data quality and reliability

2. GEOLOGY

2.1. Introduction

The study area is bounded by the Manukau Harbour in the north, by the Drury Fault to the east, by the Waikato River and Waikato Fault to the south and to the west by the Awhitu Peninsula. The area is partially flat lying with incised river valleys trending north south in the northern part, and hilly in the south with a number of volcanic hills up to 222 metres of elevation, see Figure 1.2.
The map on figure 2.1 shows surface geology compiled from the data from several different sources.

The central Pukekohe area is covered by volcanic material, mainly basalt and tuff. The Manukau Lowlands to the north and the Awhitu Peninsula to the west are covered by Pleistocene and Quaternary fluviatile and coastal sands.

The basement comprises Waipapa – Murihuku Group greywacke, unconformably overlain by Waitemata Group sandstone and mudstone sequences. The Pliocene Kaihu Group unconformably overlies the Waitemata Group. The Kaawa Formation forms the basal sequence of the Kaihu Group. The Waitemata Group and Kaawa Formation only outcrop in limited northern coastal areas and in the northeast.
No new field research has been undertaken for this study. The lithology and structural interpretation have been derived using data from a number of earlier studies, reports and technical publications.

Approximately 120 of the 1200 bore logs from the South Auckland area in the ARC bore log database have been used as the data source for the geological description of the subterrain geology.

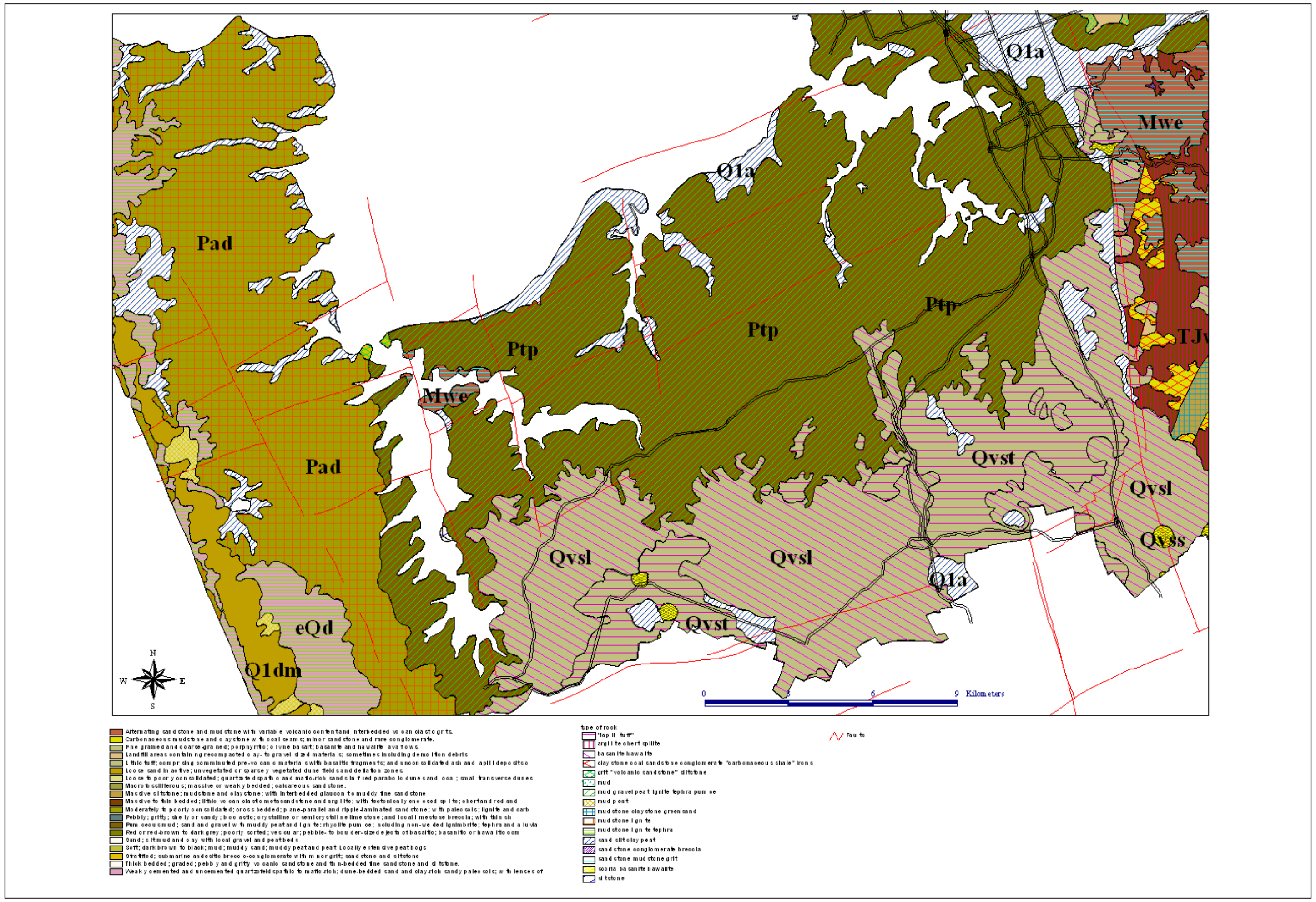


Figure 2.1 Compiled Geological Map (Edbrooke1995, 2001, Rafferty, 1977)

2.2. Stratigraphy

A simplified stratigraphic column (Figure 2.2) graphically shows the relationship between lithological and stratigraphic units.

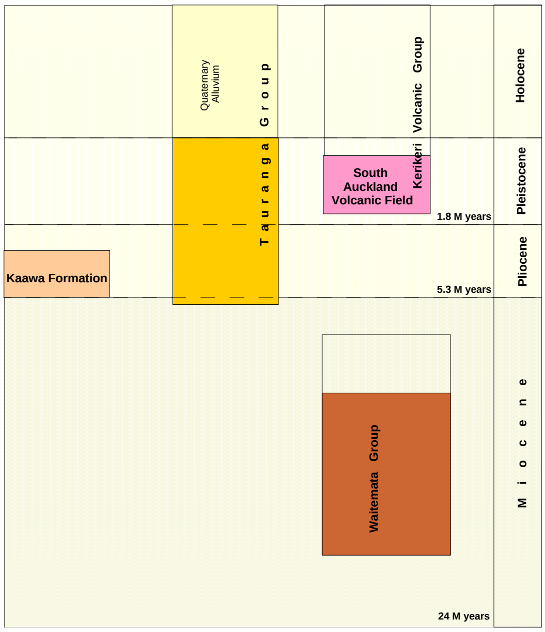


Figure 2.2: Simplified stratigraphic column for the South Auckland Area (after Edbrooke 1995)

2.2.1. Mesozoic - basement

The basement rocks of the area are Mesozoic Waipapa Group and/or the Murihiku Supergroup, indurated sandstones and mudstones, commonly known as greywacke. They do not outcrop in the study area but are uplifted in the Hunua Ranges east of the Drury Fault (Figures 2.1 and 2.7).

2.2.2. Miocene - Waitemata Group

The basement is unconformably overlain by Miocene Waitemata Group rocks, which consists of inter-bedded, graded sandstone and mudstone, of marine origin. Waitemata Group is exposed at the surface with a few outcrops located along the

Manukau Harbour coastline particularly on the north of the Glenbrook peninsula and in the Waiau Pa and Te Hihi area (Berry, 1986).

2.2.3. Pliocene to Quaternary - Kaihu Group

The Kaihu Group unconformably overlies the Waitemata Group and includes Pliocene marine sediments, the basal member of which is the Kaawa Formation.

The type-section for the Kaawa Formation is located south of the study area at Kaawa Creek, south of Port Waikato, however there are several coastal exposures within the study area around Pahurehure Inlet (Berry, 1986).

The Kaawa Formation consists of shell beds and dark blue (and green) fine to medium grained sandstone (ARWB, 1989). The Kaawa Shellbed is the basal unit of the Formation and comprises shell beds up to 3m in thickness (Berry, 1986). The overlying sands are subdivided into two units; the lower consists mostly shelly medium grained sand the upper is volcanogenic with no macrofossils. The Kaawa Formation is accumulated in shallow marine and estuarine environments (Edbrooke, 2001).

The thickness of the Kaawa Formation varies, depending on the paleotopography of the Waitemata Group, tectonic movements and local depositional environment.

The isopach map in Appendix 2.1 generated using bore log analysis, shows a spatial distribution of the thickness of the Kaawa deposits across the South Auckland area.

The map shows a generally thin Kaawa layer in the northern part of the area with considerable thickening towards the south. In the south, Kaawa is up to 250 metres thick aligned nearly East – West and approximately following St Stephens and Waiuku Faults. The maximum thickness of the Kaawa Formation can be up to 250 m. In the north the thickness of Kaawa Formation is small varying from a few metres to 50 and is generally absent in the Karaka and Drury area.

An isopach map produced in 1989 (ARWB) shows a thin horizon of Kaawa deposits aligned approximately ENE – WSW, south of the Glenbrook Fault, thickening to the south. This horizon generally corresponds with Allen's (1995) model of a paleo topographic ridge in the Waitemata surface.

2.2.4. Quaternary Deposits

Quaternary deposits can be divided into two groups., Tauranga Group sediments and the volcanic rock of the South Auckland Volcanic Field.

<u>Tauranga Group</u>

The majority of the study area to the north is shown on the geological map as Puketoka Formation, of the Tauranga Group, a Late Pliocene to Early Pleistocene non marine sediment (Edbrooke, 2001). These sediments are often referred as a Pleistocene sands. Total thickness of the Tauranga Group is up to 80 m. Beds of Tauranga Group act as an aquitard in relation to the basalt rocks (see Chapter 3).

<u>South Auckland Volcanic Field</u>

Volcanic rocks, mainly basalt and tuff, are the most common lithographic unit in the Pukekohe area. The South Auckland Volcanic Field results from between 70 (Rafferty, 1977) and 97 (Edbrooke, 2001) subaerial volcanic centres. Surface distribution of the volcanic rocks within the study area is shown in Figure 2.1. Volcanic materials include coarse and fine-grained basaltic lava, scoria, and pyroclastic material. The variation in lava ranges from hard dense rock with various degrees of fracturing, to the highly vesicular and scoraceous material.

Fresh exposure of the volcanic rocks is very rare and most of information is gained from numerous bore logs (ARC, 1996). The degree of weathering depends of the nature of rock and associated sedimentation episodes following eruption.

Volcanic activities are dated as Pliocene to Pleistocene events (0.5 to 1.6 Ma) (Edbrooke, 2001). Two series are identified in the study area: Bombay Basalt is older, Late Pliocene to the early Pleistocene; the Pukekohe Basalt is slightly younger, mid Pleistocene (ARWB, 1989). Bombay and Pukekohe Basalt are not very clearly distinguished by chemical and mineralogical differences.

Bombay Basalt is mainly located in the east and originates from approximately 10 eruptive centres around Bombay Hill which has an elevation of 320 metres (Figure 2.1).

The cone north of St. Stephens fault (Rutherford Road) with elevation of 171 metres above mean sea level (m amsl) and cone at Harrisville Road with elevation of about 160 m amsl were used in the Kaawa recharge calculation (Chapter 7).

Basalt of the Pukekohe plateau is the thickest accumulation of basalt within the area and varies from extremely dense fractured lava flows to the coarse to fine scoria cones and beds. Pukekohe Basalt consists of a large number of lava flows, interbedded with tuff, lapilli and scoria, interfingering sedimentary layers of Tauranga group. The structure of the basalt body is very heterogeneous with considerable lateral and vertical variations in lithology, thickness and number of fractures and joints. Bore logs suggest thickness of basalt in areas such as Pukekohe Hill as greater than 100m and reaching more than 100 metres below sea level. In the Pukekohe Volcanic area there are 5 clearly identified volcanic centres: Pukekohe Hill with elevation of 222 m amsl and cones at Blake Road (120 m amsl), Pollock Road (120 m amsl), Patumahoe Road (87 m amsl), and Day Road (89 m amsl).

Glenbrook volcanics are the most westerly located deposits covering the area between Mauku Stream and Waiuku River, and is sourced mainly from Bald Hill (Bald Hill - South with elevation of 147 m amsl and Bald Hill North with elevation of 109 m amsl) and volcanic centres at Sommerville Road (100 m amsl) and Masters Road (111 m amsl).

The sediments overlying basalt deposits in the southern part of the area are rare and most surficial exposures are heavily weathered volcanics, providing good quality soil.

2.2.5. Soil

The dominant soil type in the Pukekohe area is Brown Granular Loam, which is derived mostly from andesitic tuff or basalt and rhyolitic ash from the Taupo Volcanic Zone. This type of soil covers more than 80% of the area (Rosen & all, 2000). A second soil type is Yellow-Brown Loam also of volcanic origin from Ruapehu/Bay of Plenty and Taranaki (ARWB, 1989). Thickness is very inconsistent and varies between a few centimetres to up to 20 metres. However soil thickness is generally more than a few metres.

Thickness of the soil layers and the soil porosity are significant in the recharge process.

Soil provides a buffer zone between surface water and groundwater, enabling longer and consistent recharge by slow release of water into the volcanic aquifer.

2.3. Cross sections

In the construction of preliminary geological columns and cross sections data from a number of other studies, reports and technical publications ["Study of the Kaawa Formation aquifer system in the Manukau Lowlands" (Technical Publication ARC, No 85, 1989), "Volcanic Geology and Petrology of South Auckland" (W.J. Rafferty, 1977), "A model of recharge to Pukekohe volcanic aquifers" 1996 (ARC Technical Publication, No 77) and "Drury - Bombay, groundwater investigation and interim management plan" (ARC Technical Publication No 105, 1991)] are used. It is assumed that the geological data referred to in these reports are accurate. Approximately 120 bores with the best geological description were selected from approximately 1200 bore logs (from the South Auckland Area) in the ARC bores database for the interpretation of the subterrain geological structure and lithological relations. Figure 2.2 shows the location of bores and cross sections.

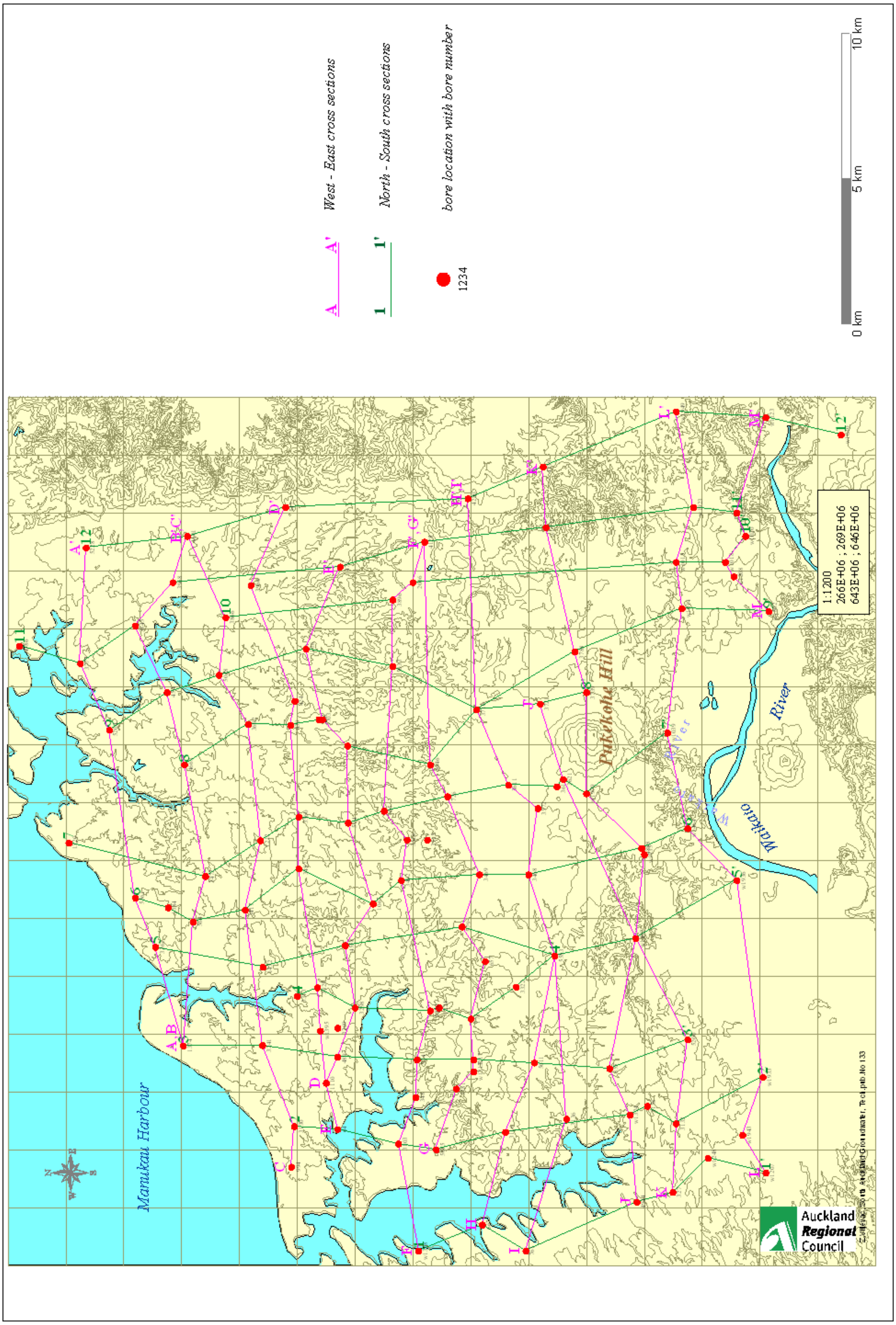


Figure 2.2 Bores and cross sections location

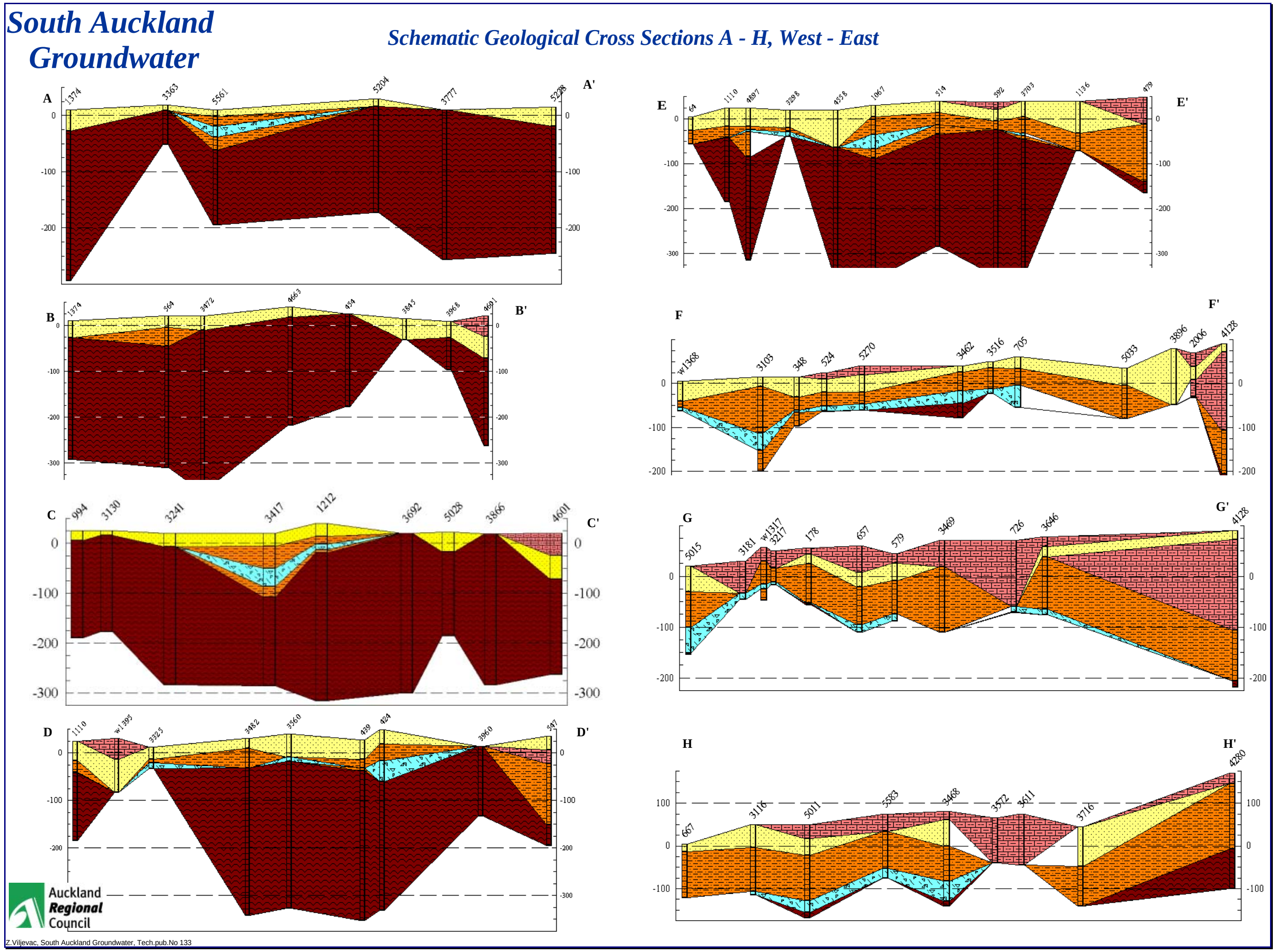


Figure 2.3 Cross sections A – H, west - east

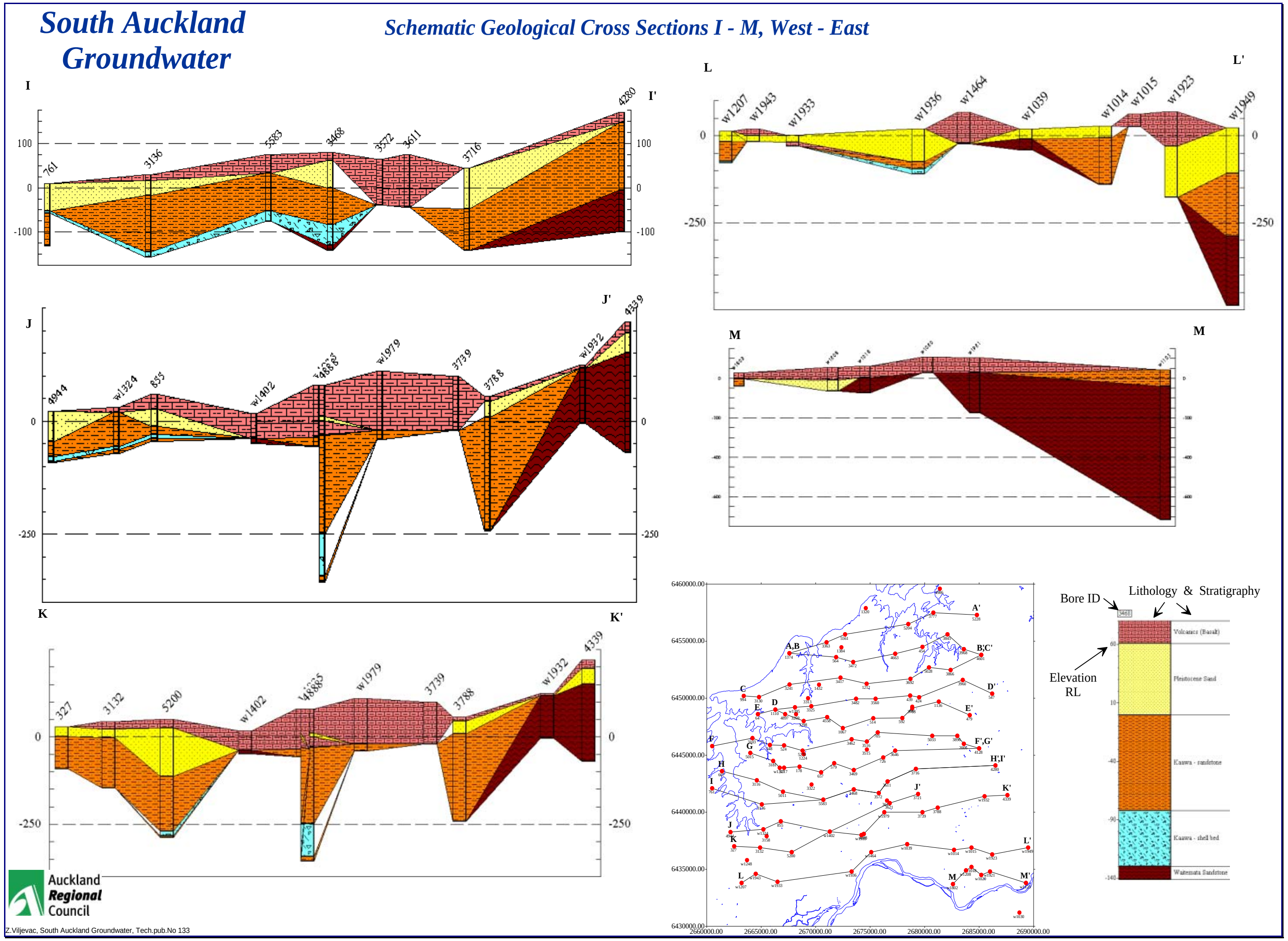


Figure 2.4 Cross sections I – M, west - east

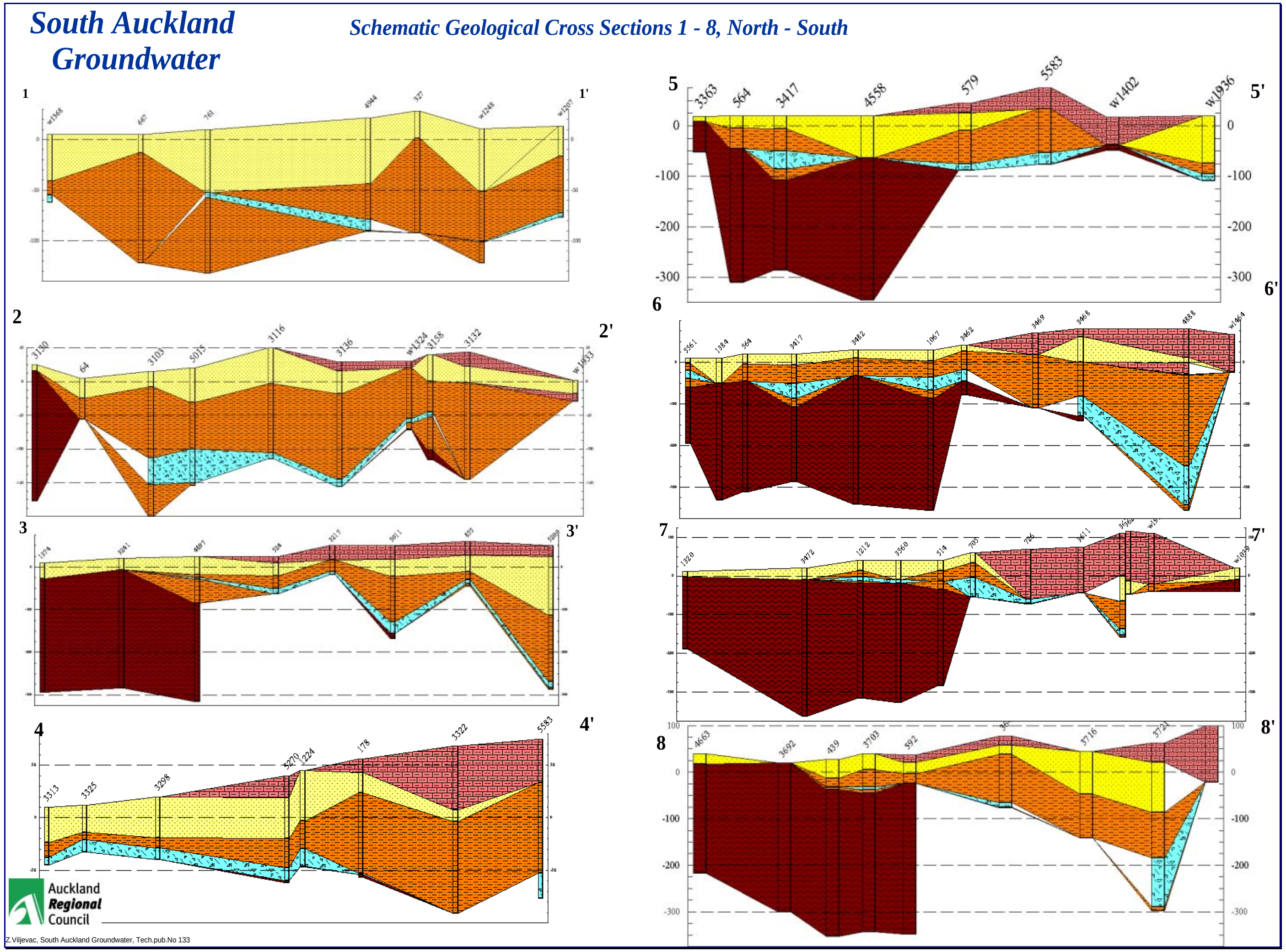


Figure 2.5 Cross sections 1- 8, north - south

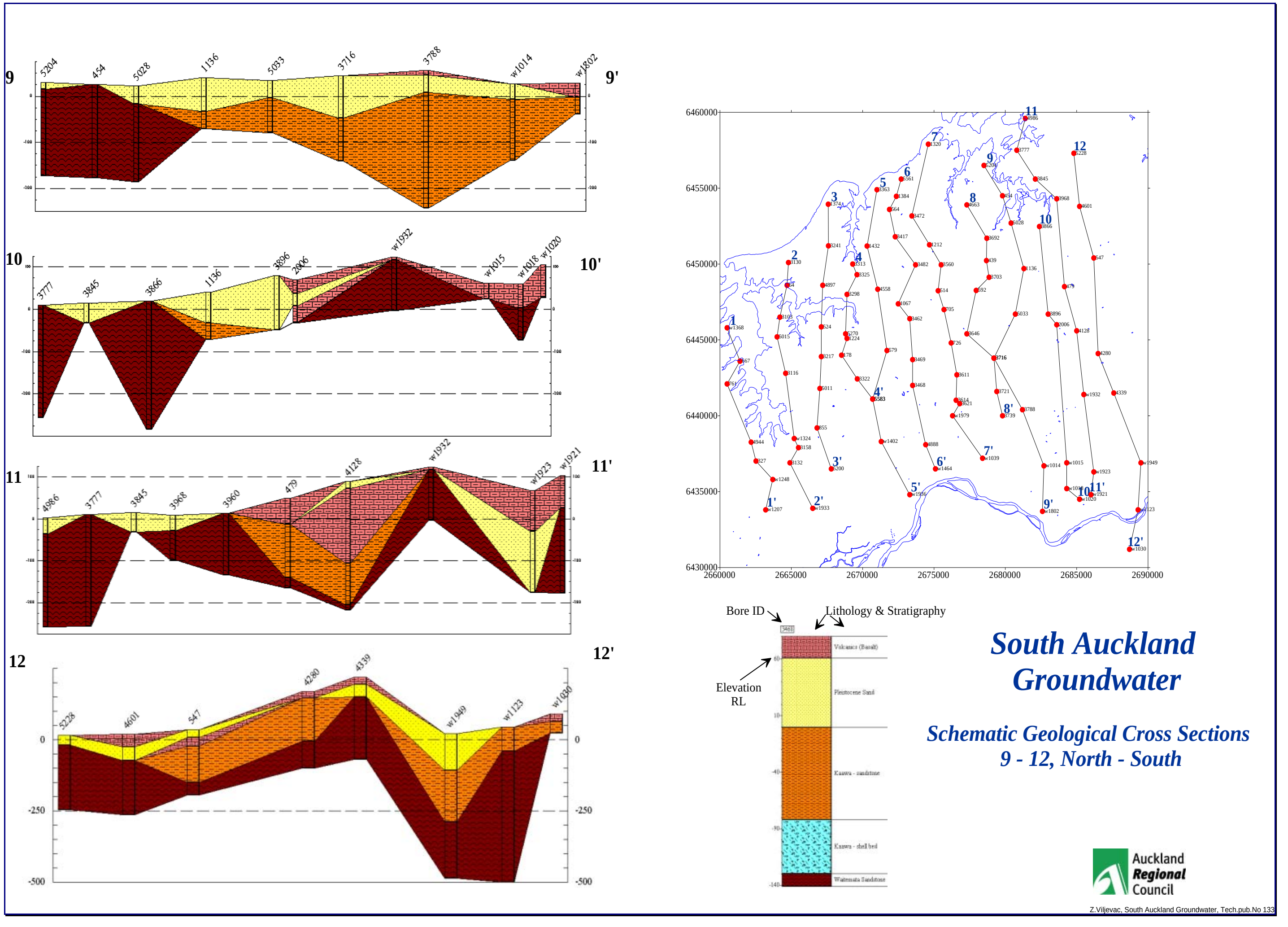


Figure 2.6 Cross sections 9 – 12 , north – south

The cross sections (Figures 2.3 to 2.6) are largely simplified, although the aim was to delineate the Waitemata sandstone, as a bedrock, from the Kaawa Formation and obtain thickness and relative position of all deposits.

Cross sections A to E (Figures 2.5 and 2.6) positioned in the Manukau Lowlands in an west-east direction show relatively thin Kaawa deposits covered by thin Pleistocene sand deposits overlying relatively uplifted Waitemata sandstone.

The elevation of the upper Waitemata surface is from 50 metres below sea level to up to 10 to 20 metres above sea level. Further south, cross sections from F to L show very thick Kaawa deposits with Waitemata bedrock at a depth of up to 300 metres below sea level. Pleistocene and Kaawa deposits are in this area generally covered by very thick volcanic deposits.

Cross sections J, K and M (Figure 2.4) indicate that the Waitemata rocks are uplifted to elevations of up to 100 metres above sea level at the eastern side of the area.

Figures 2.5 and 2.6 illustrate cross sections in North – South direction numbered from 1 to 12 starting from Awhitu Peninsula. These cross sections show very thick Kaawa deposits in the west of the area (cross sections 1 and 2) with approximate thickness of over 50 metres and elevation of the lower surface of more than 100 metres below sea level. In the central part of the area (cross sections 3 to 9) there is an apparent thickening and dipping of the Kaawa deposits towards south, with very deep Waitemata bedrock (up to 300 metres below sea level). At the surface this area is covered by thick basalt and tuff deposits. The Eastern part of the area is characterised by very variable Waitemata topography. Elevation of the Waitemata upper surface varies from 250 metres below sea level to the more than 100 metres above sea level in the south.

This schematic geological construction was the base for further tectonical and structural analysis and interpretation of geological and hydrogeological relations. This geological interpretation becomes the basis for the conceptual model of the recharge to the Kaawa Aquifer.

2.4. Tectonic and Structural Setting

2.4.1. Faults

By the end of the Early Miocene, approximately 17 million years ago, there was uplift of the Waitemata Basin. The Miocene tectonic activity formed a large number of faults and blocks (Balance, 1995). The post Miocene phase was a period of tectonic quiescence with erosion of the Waitemata followed by terrestrial and shallow marine sediment deposition (Pliocene) in areas of local subsidence.

The study area is bounded by several structural forms, which control the geology and hydrogeology of the region (Figure 2.7).

At the eastern side of the region the major Drury Fault elevated the Mesozoic rocks (mainly Greywacke) of the Hunua Ranges and defines the eastern boundary of the Kaawa aquifer. This fault is followed by a number of parallel faults (B. Alloway, 1998).

In the north, the study area is delineated by the Glenbrook Fault, which uplifted the underlying Waitemata Group rock.

The Waikato Fault forms the southern boundary of the area also uplifting the large complex of the Waitemata sediments and older rocks south of the fault. This fault is followed by several parallel faults (north of the Waikato fault) which created a very deep depression in the Waitemata topography (Figure 2.9).

The Waiuku River Fault forms the western boundary of the study area. This boundary is interpreted to be a no flow boundary, based on hydrogeological conditions of the Kaawa aquifer.

He topography of the Waitemata Group (upper Waitemata surface) was constructed based on geological and bore log data, and is used as the bottom boundary for the recharge model.

This surface is a combination of the palaeo topography (erosion) and ongoing tectonical movements and shows significant differences in topography.

This indicates the likelihood of a number of faults across the area. The general fault trends are in the north – south and west – east direction, similar to the pattern in northern part of the area (Figure 2.7). This creates a typical block tectonic environment across the region.

The distinctive tectonics form a number of tectonic depressions (grabens) such as Seagrove, Glenbrook and Aka Aka Graben and elevated areas (horsts) such as Waiau Horst (ARC 1979).

A conceptual block tectonic map (Figure 2.8) was created to show a possible fault - block distribution, based on the described methodology and the fault location provided by IGNS.

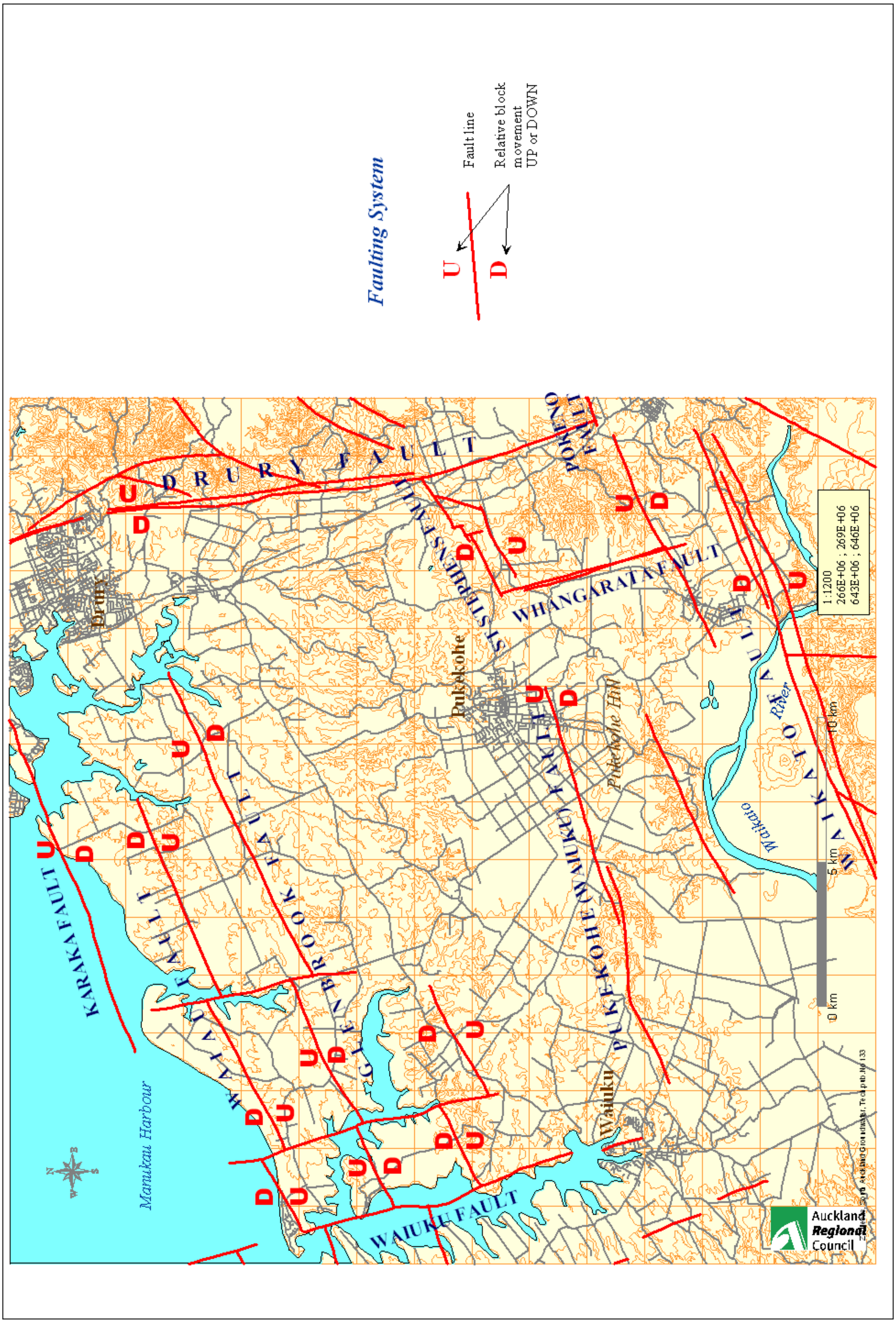


Figure 2.7 South Auckland faults

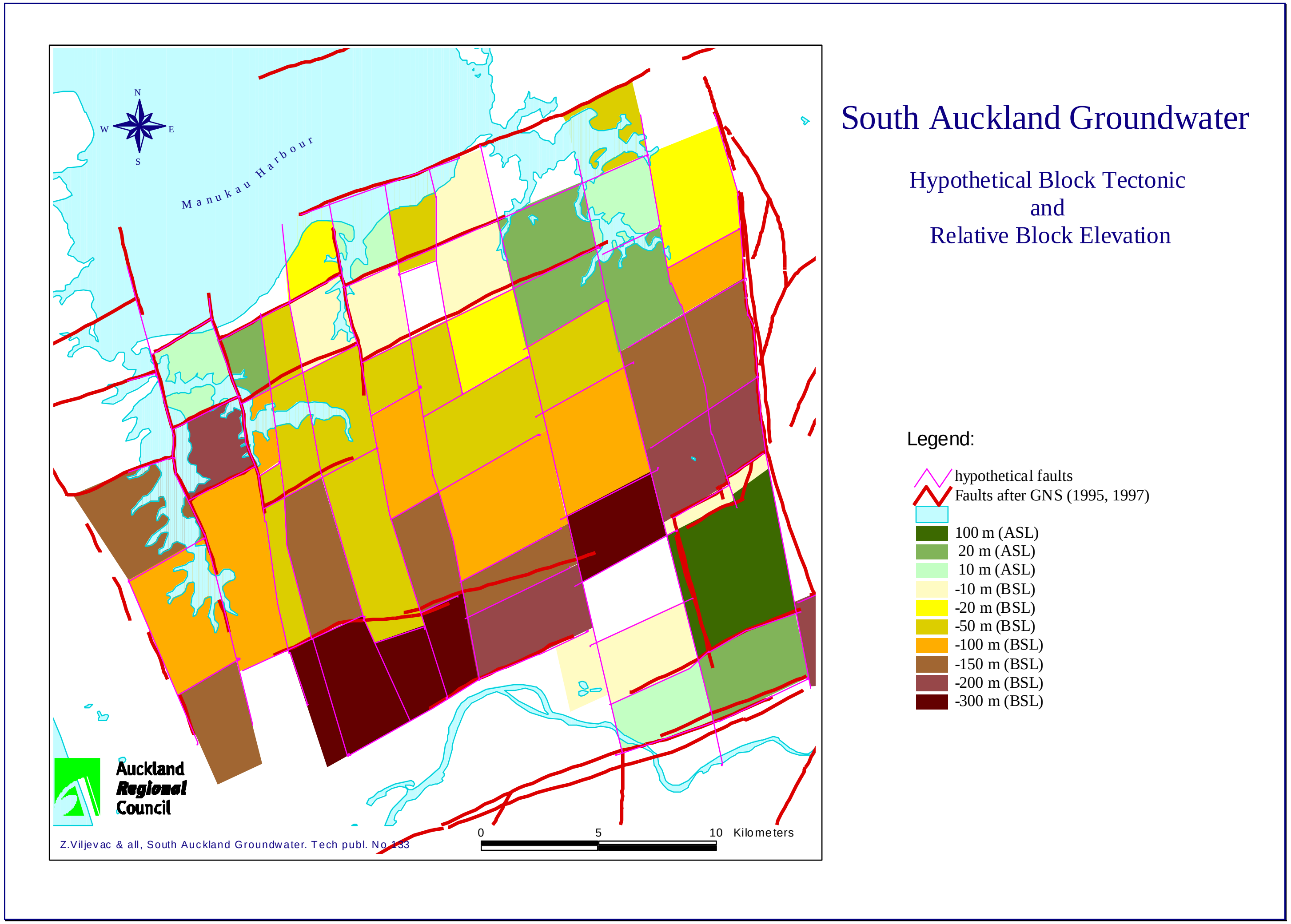


Figure 2.8 Hypothetical block tectonic and relative block elevation

Despite massive variability in elevations in the Waitemata upper surface, it is possible to distinguish three comparable areas. The first one is the northern area (close to the Manukau Harbour) with elevations of the Waitemata blocks around or above sea level. The second area, which is close to the Waikato River, with Waitemata blocks descended to approximately 200 to 300 metres below sea level. The third area is the wide band along the Waiuku River with elevations of 100 to 150 metres below sea level.

In the southeastern part of the study area, is an area with an elevated Waitemata block bounded by the Drury, Waikato and St. Stephens faults. The elevation of the block is over 100 metres above sea level, which creates a difference of over 400 metres in comparison to adjacent blocks (Figure 2.8).

The surface of the Waitemata deposits was exposed to erosion before and during the deposition of the Kaawa Formation. This accentuates some of paleo-topographic features. Paleo-topography has been vital in the subsequent deposition of the Kaawa Formation.

More recent work including geophysical exploration, combined with analysis of boreholes did not confirm the existence of some earlier described features (Allen, 1995 and Greenwood, 2001). Allen (1995) models the Glenbrook Fault, like the Drury Fault, as a scissor type structure, with the throw increasing from east to west over 10km from 0 to 200+m. The absence of such a pattern in the Kaawa Formation indicates the Glenbrook Fault is largely pre Pliocene in the Manukau lowlands.

The “high” ridge of Waitemata Formation is bordered by depressions to the north and south where the surface of the Waitemata Formation is 40 – 60m below sea level (Figure 2.8), and was identified by gravity surveys, resistivity surveys and bore hole analysis (ARC, 1989, Allen, 1995, Greenwood, 2001).

2.4.2. Waitemata surface

The Waitemata Group is considered to be the basal lithological unit within the Manukau Lowland. It consists mainly of inter-bedded, graded sandstone and mudstone of marine origin. The Waitemata Group is exposed at the surface at the few outcrops located along the Manukau Harbour coastline (Waiau Pa and Te Hihi area).

In other areas of the Franklin District, the Waitemata rocks are buried relatively deeply under the younger deposits.

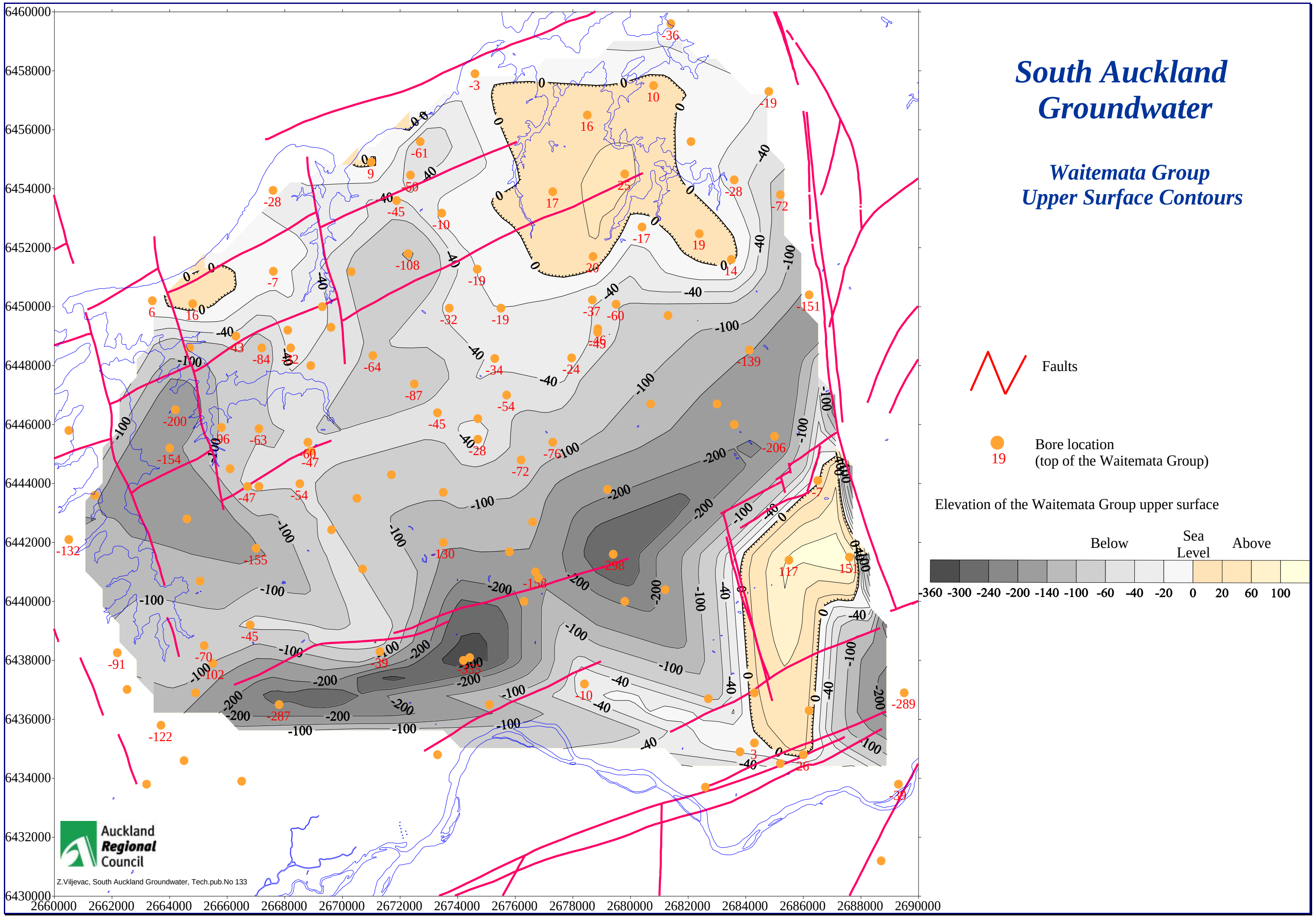


Figure 2.9 Topography of the upper surface of the Waitemata Group

A southern massive “trench” feature, in the Bombay – Pukekohe – Waiuku area (dark gray in Figure 2.9) has a depth of up to 300 m below sea level. In the north, a “plateau” sloping south (Drury – Karaka – Waiau Pa area) has elevations around or slightly below the sea level. The thickness of the Waitemata Group is considerable and in places is thought to be more than 300 metres (Figures 2.3 to 2.6). In the east, the Waitemata Group is separated from the Mesosoic greywacke by the Drury Fault and in the south by the Waikato and Pokeno Faults (Figure 2.7).

2.4.3. Kaawa Surface

The Kaawa Formation thins in the northern part of the Manukau Lowlands (Karaka) but rapid thickening (particularly in the sand sequence) occurs towards the east (Drury Fault), south (Pukekohe and Buckland) and southwest (Glenbrook - Waiuku) shown in (Figure 2.10).

Figure 2.10 shows the spatial distribution and thickness of the Kaawa Formation. It shows very thick Kaawa deposits of more than 250 m in the southern and western part of the area and a reduction in thickness towards the north.

The upper surface of the Kaawa Formation or its upper surface (Figure 2.11) is relatively “flat” compared with lower surface (top of the Waitemata Group). The upper surface, in the area between Waiuku and Karaka has elevations mainly above sea level while in other areas the elevations are on average 40 to 50 metres below sea level. Only a few places with elevations for the top of the Kaawa Formation around 100 metres below sea level are identified in southern and eastern part of the region.

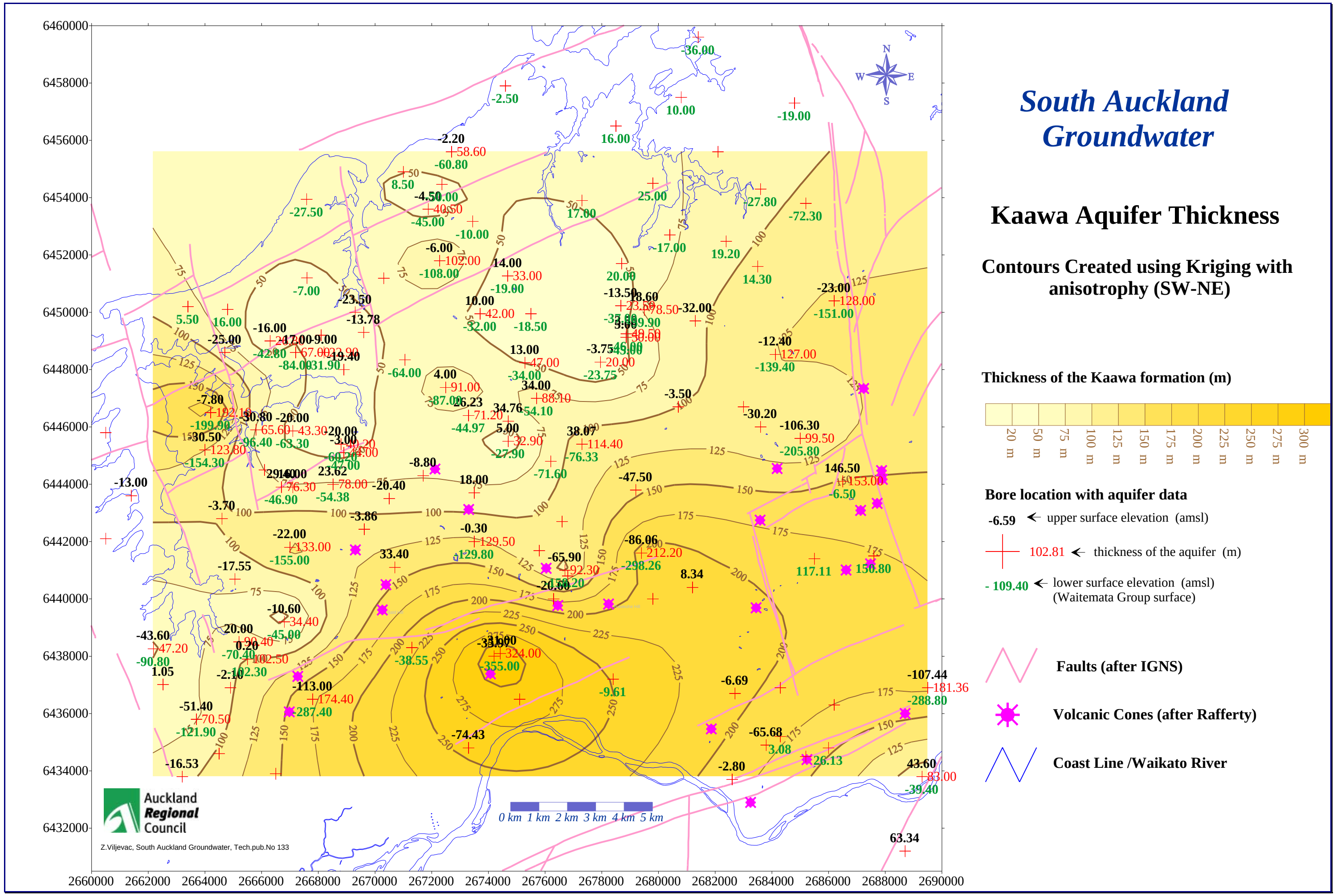


Figure 2.10 Kaawa Formation thickness

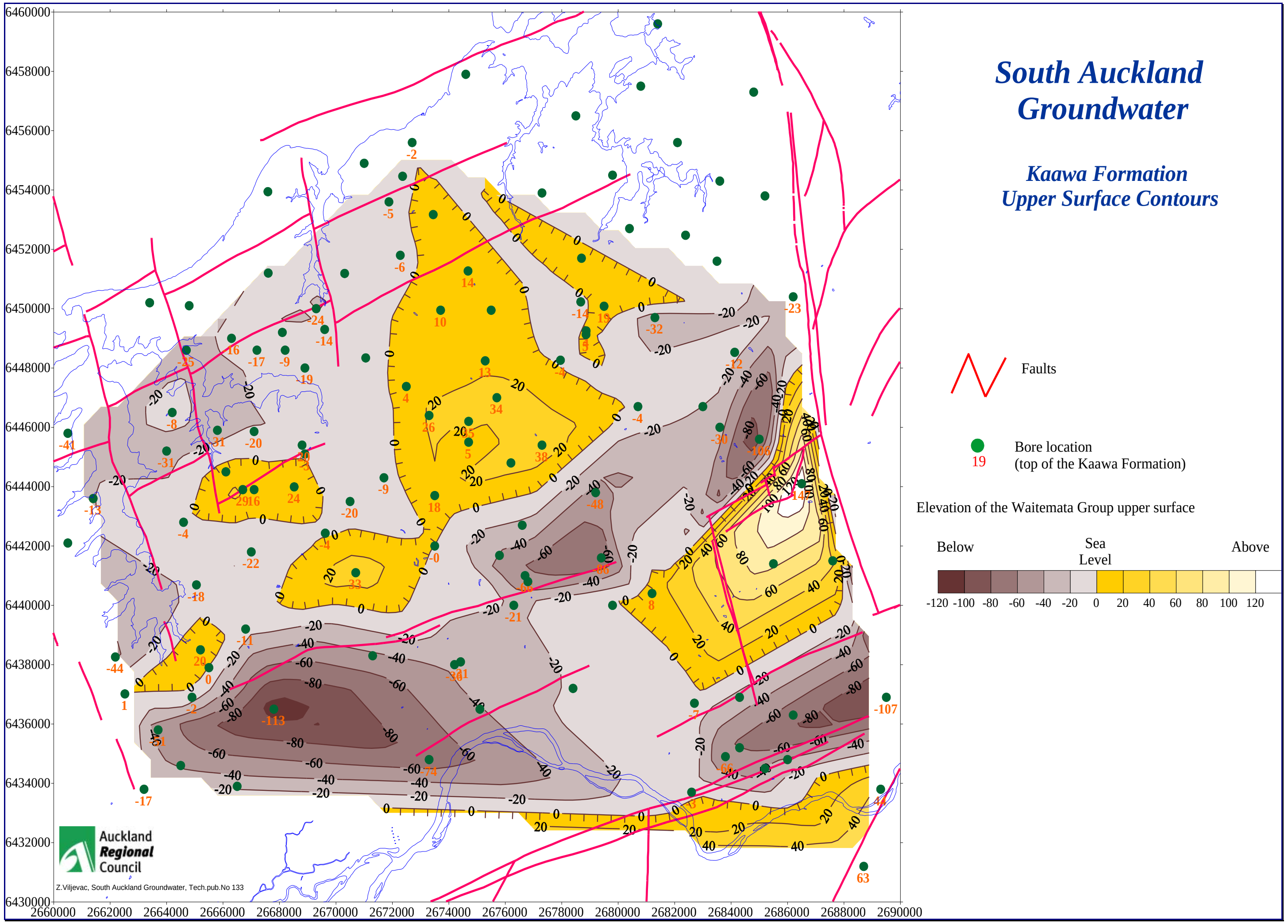


Figure 2.11 Topography of the upper surface of the Kaawa Formation

3. HYDROGEOLOGY

3.1. Introduction

The hydrogeological characteristics of rocks are described by three main hydrogeological parameters;

Transmissivity (T)- as the volume of water transmitted through a unit of width of an aquifer under a unit of gradient (IS units: m^2/day),

Storage coefficient (s)- the amount of water released from the storage per unit area and per unit of change in head (dimensionless value),

Hydraulic conductivity (k) - as transmissivity divided by saturated thickness (IS units: m/day).

These parameters vary often with very wide spatial irregularity in both the lateral and vertical direction. The irregularity directly corresponds to isotropy or homogeneity of the rock or group of rocks. A number of other parameters, such as **porosity**, **specific yield** and **specific retention** are also important to understand hydrogeological properties of the rock.

The key factor in the hydrogeology within the study area is a relatively complex geological and tectonical setting (chapter 2). As well as heterogeneous lithological composition of sediments and volcanic rocks, the heterogeneous hydrogeological properties such as transmissivity and conductivity affect groundwater levels, groundwater flows and aquifers recharge patterns. For the purpose of this report the aquifer test results were, when appropriate, averaged across each of the aquifers.

Figure 3.1 shows the location of aquifer tests used in this study. A full list of aquifer tests and results is shown in Appendix 3.1)

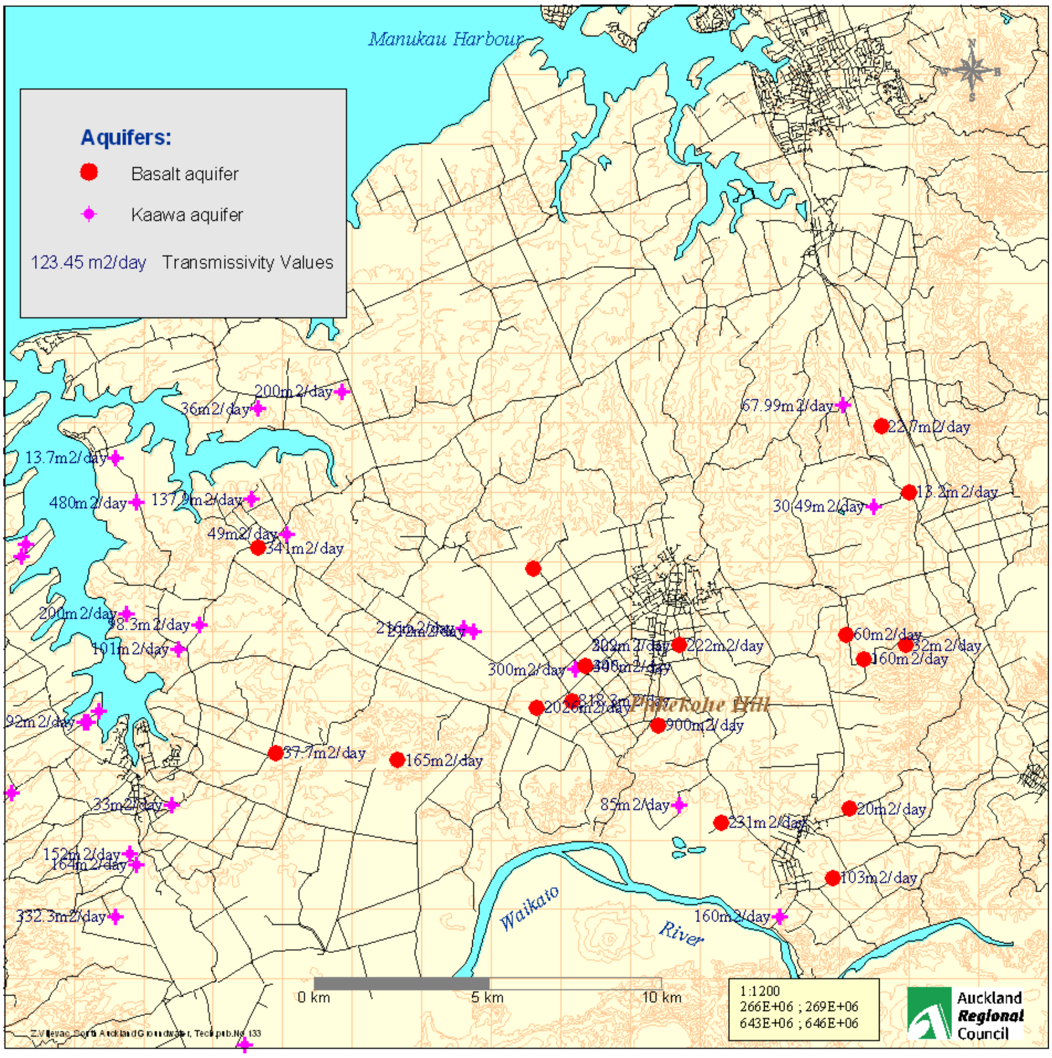


Figure 3.1 Aquifer tests location

The range and the average aquifer parameters for the lithological units included in the recharge model are discussed in the section 3.2. Delineation of the hydrogeological properties between the units was the major influence on the configuration of the conceptual model of the recharge. The analysis of over 60 aquifer tests demonstrates the large variation in hydrogeological parameters within and amongst the aquifers. Generally, variations in values are more common in fractured media such as basalt or sandstone, than in porous media like sand or clay.

3.2. Aquifers and aquifer parameters

3.2.1. Basalt

The extent of the basalt aquifers is limited by the spatial distribution of the basalt flows. This is shown on the geological map Figure 2.1, Chapter 2. Basalt is often described as a shallow unconfined fractured aquifer. Some parts of the aquifer appear to be semi - confined or perched depending on the existence of inter-bedded tuff or clay deposits, but most of the aquifer remains as an unconfined aquifer.

Major characteristics of the shallow basalt aquifer is the surface or near surface setting, relatively small thickness and water table that is close to the surface (Russell, 1977; P White, 1995). Previously, the basalt aquifer is divided into two “aquifers”, shallow and deep aquifer based on groundwater levels (ARC, 1996). It is more likely that the difference in water levels is a consequence of the degree of the confinement of some parts of the volcanic aquifer than a result of separate aquifers.

Basalt deposits are the result of a series of eruptions from a number of volcanic centres. Composition varies from massive thick lava flows to multiple deposits of scoria, lava and ash. Scoriaceous material has been deposited as an air fall deposit or fountaining lava forming massive scoria cones (e.g. Pukekohe Hill). All this creates what is considered have to be a single anisotropic and heterogeneous aquifer with considerable vertical and horizontal variation in hydrogeological properties. Spatial heterogeneity in basalt is considerable both in the horizontal and vertical direction. Basalt rocks have relatively high permeability, but the porosity is relatively low. Porosity of the basalt rock can be described as a dual porosity or a combination of primary vesicular porosity and secondary fractured porosity. Primary porosity is generally low (up to 10%) but the actual porosity is higher and can be more than 25%

(Chapter 7). Transmissivity values for the basalt aquifer vary widely ranging from 13 to over 2000 m^2/day (Table 3.1). Experience in other areas such as the Auckland Isthmus show these values can be over 4000 m^2/day (Viljevac, 1998).

Table 3.1 Basalt Aquifer average and median aquifer parameters

	T (m2/day)	S
No of tests	**20**	
MAXIMUM VALUE	2026	4.84*10-4
MINIMUM VALUE	13.2	2*10-4
AVERAGE	344.145	
MEDIAN	226.5	

The basalt aquifer in the Franklin area is generally covered by the thick soil, originating from the weathering process of the basalt and combined with tuff and volcanic ash fall. Soil moisture has an important role in the recharge of basalt (M.Rosen, 2000; P.White 2002). Slow release of water from the soil and residence time of approximately four months enables a more steady and sustainable recharge of the basalt aquifer (Rosen & all, 2000).

3.2.2. Tuff

Tuff (ash and lapilli) is usually unconsolidated and well sorted with the coarse fragments close to the vent and finer distal deposits. Vertical and lateral exchange of differently graded beds is very frequent. Tuff deposits have a rather low permeability but moderate to high porosity and as a result tuff is able to store a greater quantity of water per unit of volume than basalt. At the same time water is released much slower from the tuff than from the basalt rocks (ARC, 1996; Viljevac, 1998). Porosity of the tuff deposits is directly related to the size of particles, sorting and the degree of cementation and ranges from 14% for welded tuff to 40% for pumiceous bedded tuff (Viljevac, 1998). The surface extent of tuff deposits in the Franklin area is shown on the geological map in Figure 2.1.

3.2.3. Pliocene - Pleistocene sediments

Hydraulic properties of sedimentary rocks are very variable across layers often with heterogeneity in both the horizontal and vertical direction.

Pleistocene sediments of the Tauranga group are composed of complex layers of sands, silts, clays, gravel and peat. Heterogeneity is often more significant in vertical than in horizontal direction and the Tauranga group forms a “Regional Aquitard”

(P.White, 1996) confining the underlying Kaawa sediments. Hadfield (1988) also assumed that lower part of the Tauranga Group (Pleistocene sediments) creates a confining layer for the Kaawa Formation.

3.2.4. Kaawa Formation

The Kaawa Formation in the Franklin area is bounded in the south and the east by the major regional faults, Waikato and Drury (Figure 2.6). The northern boundary is formed by a line of faults such as Glenbrook, Waiau and Karaka with a west – east trend. In the North Kaawa deposits are relatively thin and partially fade out towards the Manukau Harbour. The Formation consists of a number of porous shell bed layers, sand deposits and weakly cemented fractured sandstone. The layered structure, with it's rather variable lithological composition, has an impact on its hydrogeological properties, namely a large variation in horizontal and vertical transmissivity).

Hydrogeological properties of the Kaawa Formation show a large variety across the area. This is the result of internal lithological differences which are evident in the results of aquifer tests conducted in this area.

The local aquifer characteristics are used in the calculation of the aquifer's recharge and groundwater availability. Calculated values of the aquifer parameters are shown in Appendix 3.1 and the spatial distribution of the aquifer tests in Figure 3.1. Tabulated statistics representing the major aquifer parameters are shown in Table 3.2. Kaawa deposits are generally more permeable than Pleistocene sands and the Waitemata Group sandstone aquifers and they provide good groundwater storage. As a result of heterogeneity of the aquifer, groundwater flows are likely to be related to the preferred groundwater flow paths presented by the shell beds.

Table 3.2 Kaawa Aquifer average and mean aquifer parameters

	T (m2/day)	**S**
No of tests	**28**	
MAXIMUM VALUE	500	3.3*10-3
MINIMUM VALUE	13.7	2.15*10-5
AVERAGE (SHELL)	163.1118	
AVERAGE (KAAWA)	179.46	
MEDIAN (SHELL)	140.95	

3.2.5. Waitemata Group

The Waitemata Group forms the hydrogeological basement formation in the area. Its hydrogeological properties are significant for the recharge/discharge pattern, influencing general groundwater flows in the Kaawa Formation and construction of the conceptual model. The Waitemata Group is generally described as a group of rocks with low to very low permeability (average $2.7*10^{-2}$ m/day) and an average infiltration rate of 2 to 2.5 mm/m^2 (Pattle Delamore, 1991, P. White, 1995). Because of low permeability it is assumed that none or very limited flow exchange exists between Kaawa aquifer and Waitemata sediments. This was the principle used in classifying the Waitemata Formation as the underlying confining layer. Main groundwater movement occurs either through the more permeable beds or a distinctive fractured system. Vertical heterogeneity is generally higher than horizontal, which is significant regarding possible interaction with volcanic conduits and the overlying Kaawa aquifer.

The main aquifer horizons within the Waitemata sediments are captured in layers with higher porosity (thick, fractured sandstone) and occur in a number of perched and confined aquifers. In the northern part of the Manukau Lowlands (Karaka, Glenbrook) the Waitemata aquifer has reasonable yield and relatively large number of groundwater users.

Table 3.3 shows statistical information on the Waitemata aquifer parameters.

Table 3.3 Waitemata Aquifer average and mean aquifer parameters

Waitemata	**T (m2/day)**	**S**
No of tests	**5**	
MAXIMUM VALUE	205.2	
MINIMUM VALUE	1.17	
AVERAGE	84.242	6.9*10-5
MEDIAN	48.871	

3.3. Groundwater levels and groundwater flow

Groundwater level fluctuations have been monitored in the area for at least 25 to 30 years (some records are dating from the early 1970s).

Apart from a large number of private bores, a number of monitoring bores were purposely constructed and equipped for the observation of groundwater levels in different aquifers. There are two main groups of monitoring bores; baseline monitoring bores and management monitoring bores. The baseline monitoring sites have a role to provide information on long term groundwater trend monitoring. The management monitoring network provides hydrological information for day to day aquifer management. Groundwater level observation bores monitor groundwater level changes in the Volcanic aquifer, the Kaawa aquifer and the Waitemata Aquifer. Figure 1.3 in Chapter 1 shows the location of the ARC bores within the study area.

In this report, groundwater level fluctuation is analysed from the recharge and groundwater interaction perspective.

Groundwater contours have been developed from groundwater level analysis in the Volcanic and Kaawa aquifer. The analysis is based on the information gathered from groundwater level surveys of private bores between 1994 and 1996 (ARC, 1996) and data from the ARC monitoring sites. The list of the ARC monitoring bores used in this report is shown in table 3.4.

Table 3.4 List of observation bores

Site No	Bore ID	Site Name	Aquifer
7419007	343	*Fielding Rd (sand)*	Sand
7419009	344	*Fielding Rd (volcanic)*	Volcanic
7419011	479	*Cooper Rd*	Sand
7510005	791	*Wootten Rd*	Volcanic
7417001	3199	*Glenbrook Hall*	Kaawa
7427003	3215	*Divers Rd*	Kaawa
7428049	3371	*Mauku bore No2*	Kaawa
7428043	3553	*Pukekohe DSIR Northern*	Volcanic
7428001	3545	*Pukekohe DSIR No2*	Volcanic
7429017	3614	*Douglas Rd shell bed*	Kaawa
7429013	3614	*Douglas Rd lower volcanic*	Volcanic
7419003	3770	*Tuhimata*	Kaawa
7419005	4128	*Ingram Rd*	Kaawa
7429019	5009	*Pukekohe Borough Council*	Kaawa
7417017	20789	*Glenbrook Peninsula*	Kaawa
7427005	20807	*Maraeorahia production*	Kaawa
7418003	20810	*Waiau Pa No2c*	Kaawa
7418029	20811	*Ryan Rd Production*	Kaawa
7428047	20812	*Mauku main prod bore No1*	Kaawa
7418013	20813	*Batty Rd production*	Kaawa
7418023	20814	*Ostrich Farm #2 recorded*	Kaawa
7418021	20815	*Ostrich Farm product*	Kaawa
7429011	20816	*Revell Court*	Volcanic
7428051	33772	*Mauku bore No3*	Kawa

The spatial distribution of groundwater levels and seasonal fluctuations in the water table in both aquifers has been determined. Using this information recharge areas are distinguished from discharge areas and groundwater divides are identified. Apart from rainfall the major influencing factors on groundwater levels and their fluctuation are the location in recharge and discharge areas, aquifer characteristics and water abstraction from the aquifer. The aquifers are mostly interconnected and water levels may be influenced by conditions in other aquifers. For example, Pukekohe Volcanic Aquifer is the major recharge area for the Kaawa Aquifer and groundwater levels within this basalt aquifer are influencing water levels within Kaawa Aquifer.

Figure 3.2 shows groundwater level contours for three major aquifers in Franklin District. Blue contours represent average low (summer) groundwater levels within the Pukekohe Volcanic Aquifer. Groundwater levels range between 50 and 100 metres above mean sea level, and the extend of the groundwater body is restricted by the hydrogeological properties and the shape of the aquifer. Green contours in Figure 3.2 show average groundwater levels for the Kaawa Aquifer in the 1993/1994 summer when the groundwater levels were at the it's lowest point. It is evident from the contour configuration that the highest groundwater level occurs in Pukekohe Hill area.

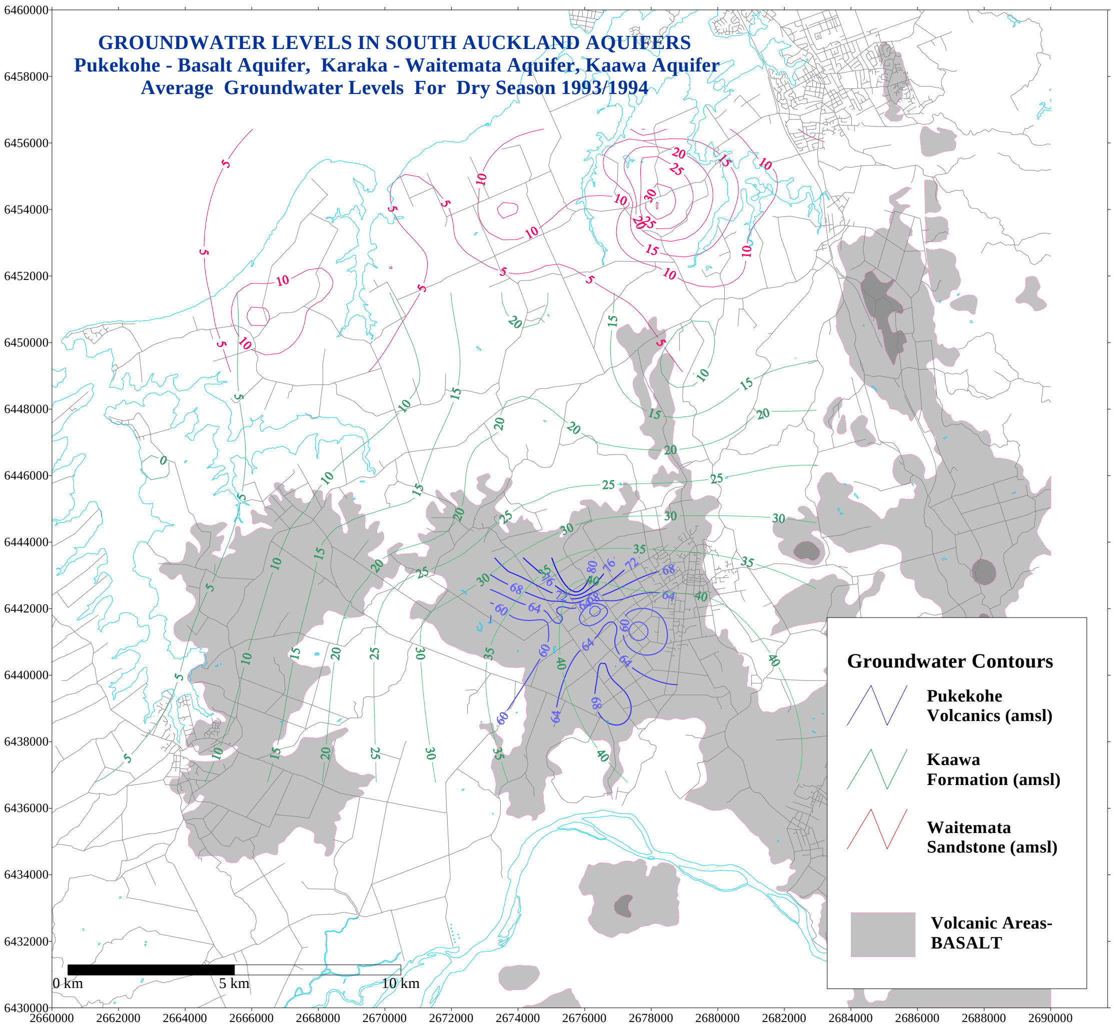


Figure 3.2 Groundwater levels in Pukekohe Volcanic, Kaawa and Waitemata aquifer

The Kaawa Aquifer is a confined, relatively deep, aquifer where the groundwater is under pressure and contours represent pressure heads. Some of groundwater levels exceed the ground elevation (artesian conditions). The third of the aquifers is the Waitemata aquifer. This aquifer is closest to the surface in the northern part of the area. The Waitemata aquifer shows some characteristics of confinement with the water levels are in some areas above the top of the aquifer. Three highs in groundwater levels are apparent but there is no evidence of a connection between this aquifer and other aquifers.

3.3.1. Volcanic Aquifer

A relatively limited amount of groundwater information and high variability in groundwater levels required manual construction of contour lines in the volcanic aquifer as shown in Figure 3.3. The major groundwater divides in the volcanic aquifer are also shown in the Figure 3.3. The contours indicate several areas of elevated groundwater levels of approximately 80 to 100m amsl (Figure 3.3). The first group is located to the south in the Pukekohe Hill - Puni Spring area and the second in the northern part of the volcanic aquifer (Pukekohe – Patumahoe Spring area).

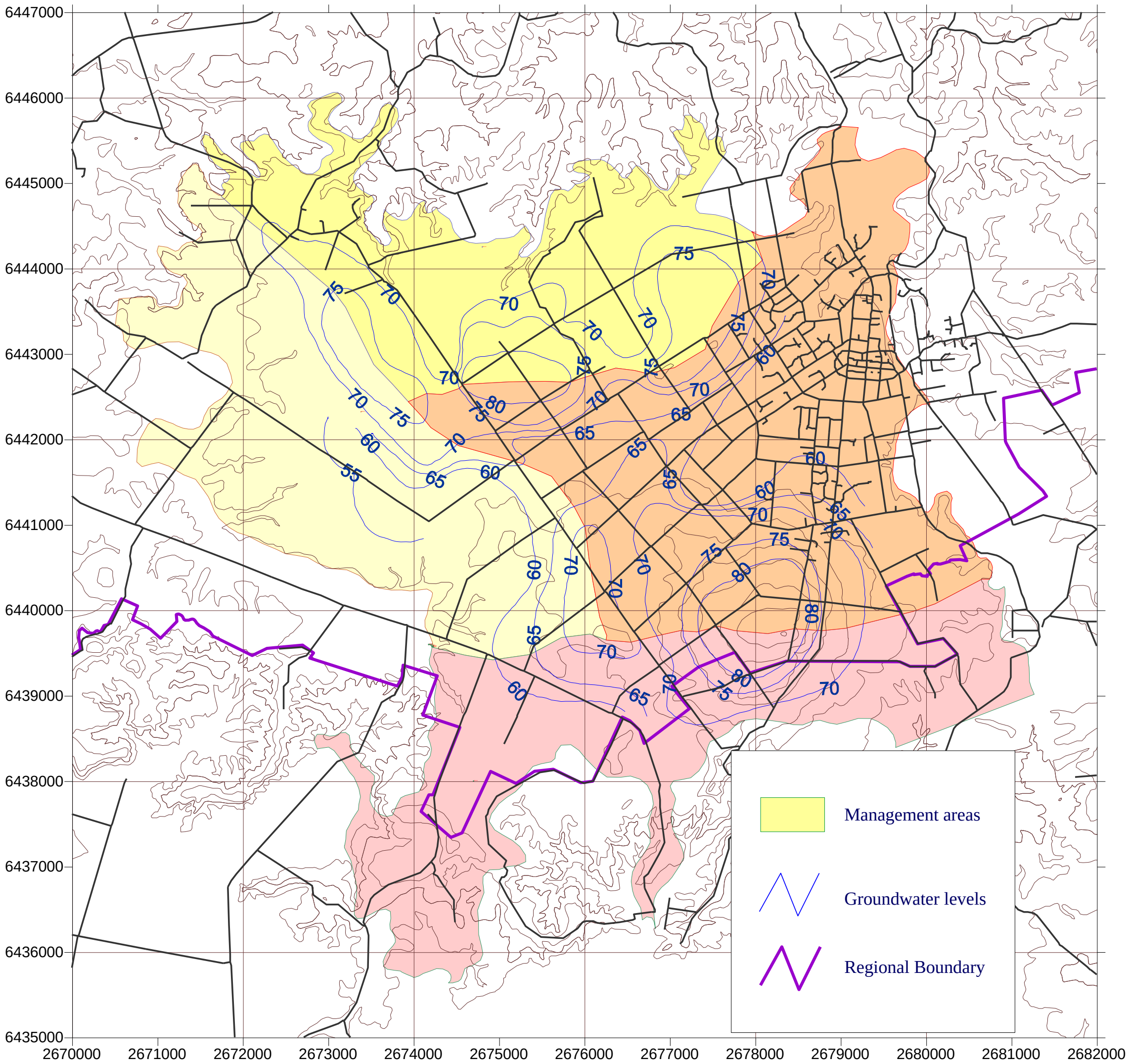


Figure 3.3 Pukekohe Volcanic Aquifer groundwater contours

A steeper groundwater level gradient suggests discharge areas (discharge to the streams) and higher groundwater velocities, however a smoother and flatter gradient indicates recharge zones with rather slower groundwater movement. A water level depression between these two groups is relatively wide and flat and is caused by discharge of the groundwater into the Whangapouri, Tutaenui and Mauku streams. This area represents a large discharge zone. Groundwater flow is generally radial with flow direction towards the edge of the basalt body (Figure 3.3). The contours indicate a relatively steep gradient towards the south and the west, particularly in the Pukekohe Hill area.

Figure 3.4 illustrates a 3D morphology of the Pukekohe Volcanic aquifer groundwater level showing a several recharge areas (elevated parts). This is the winter water elevation of the shallow (upper) groundwater horizon.

In the central Pukekohe area groundwater flow is encountered from the south and the north towards the central part of the aquifer with discharge paths towards north - east. Several deeper depressions in the central area are possibly produced by intensive water extraction from the aquifer.

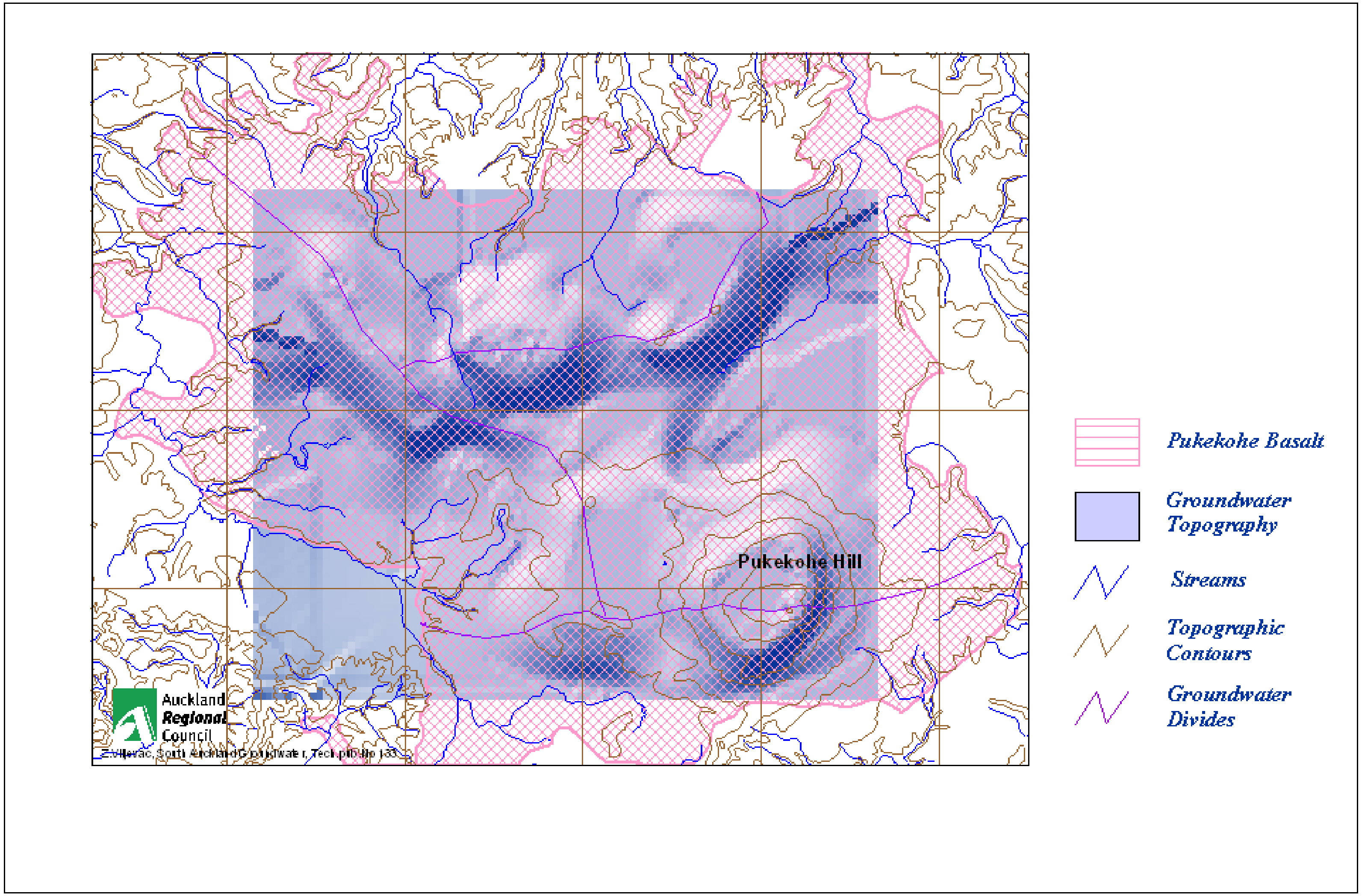


Figure 3.4 Pukekohe volcanic three-dimensional groundwater surface

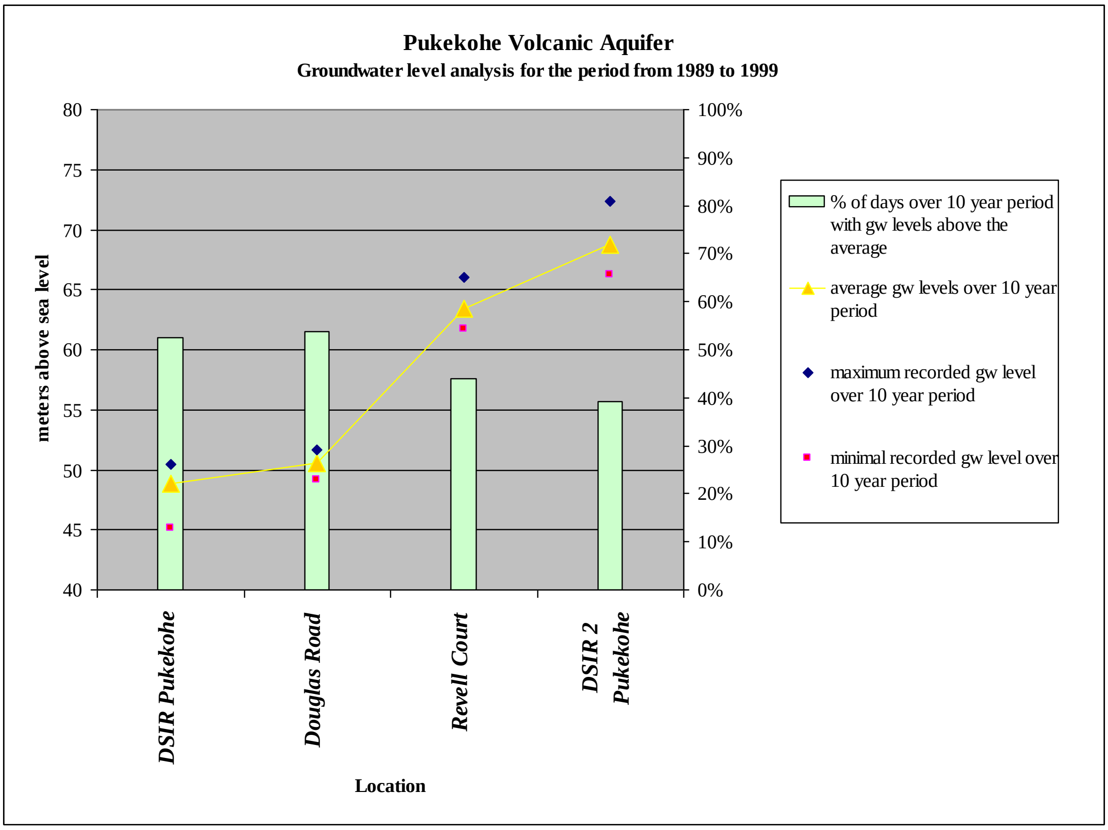


Figure 3.5 Pukekohe Volcanic aquifer, 10 year groundwater level analysis

Ten year groundwater analysis from the volcanic aquifer presented in Figure 3.5 shows two groups of monitoring bores. The first group (Revell Court and DSIR2 bores) are located in an area with higher groundwater levels, and the second group (Douglas Road and DSIR bores) in the area with lower groundwater levels.

The first group of bores show a slightly bigger difference between recorded maximum and minimum water levels than the second group. The period during which groundwater levels are above the average is significantly lower (40% to 45%) in this first elevated water level group compared with 50% to 55% in the lower group. That could be related to the location of bores in relation to zones of recharge and discharge, and also to associated groundwater flow and shifting groundwater masses down the gradient.

Water levels in Glenbrook volcanics are in majority between 50 m amsl (Glenbrook Road) and 65 m amsl (in vicinity of Bald Hill) reducing towards the coastal area. In the Bombay–Drury volcanic area groundwater levels reduce from about 170 m amsl at Bombay Hill to approximately 15 m amsl at Drury.

3.3.2. Kaawa Aquifer

The Kaawa aquifer has a number of monitoring sites which, in combination with the groundwater level survey (ARC, 1996), enable construction of groundwater contours which indicate groundwater table and groundwater flow directions.

Groundwater contours on Figure 3.6 show a distinct zone of high elevation (40 to 45 metres above sea level) in the Pukekohe Hill area and two areas with groundwater contours only 2.5 to 5 metres above sea level. Two major groundwater divides are distinguished: a divide between Manukau Harbour and Waikato River catchments and one between the eastern and western part of the Kaawa aquifer using the groundwater contour pattern and implied groundwater flow direction. The aquifer functions relatively autonomously on either side of the groundwater divides.

The Pukekohe Hill area is identified as a major recharge area and Waiuku – Glenbrook and Karaka – Drury as potential discharge areas (Chapter 6). Groundwater flow is generally in a north-west and north-east direction.

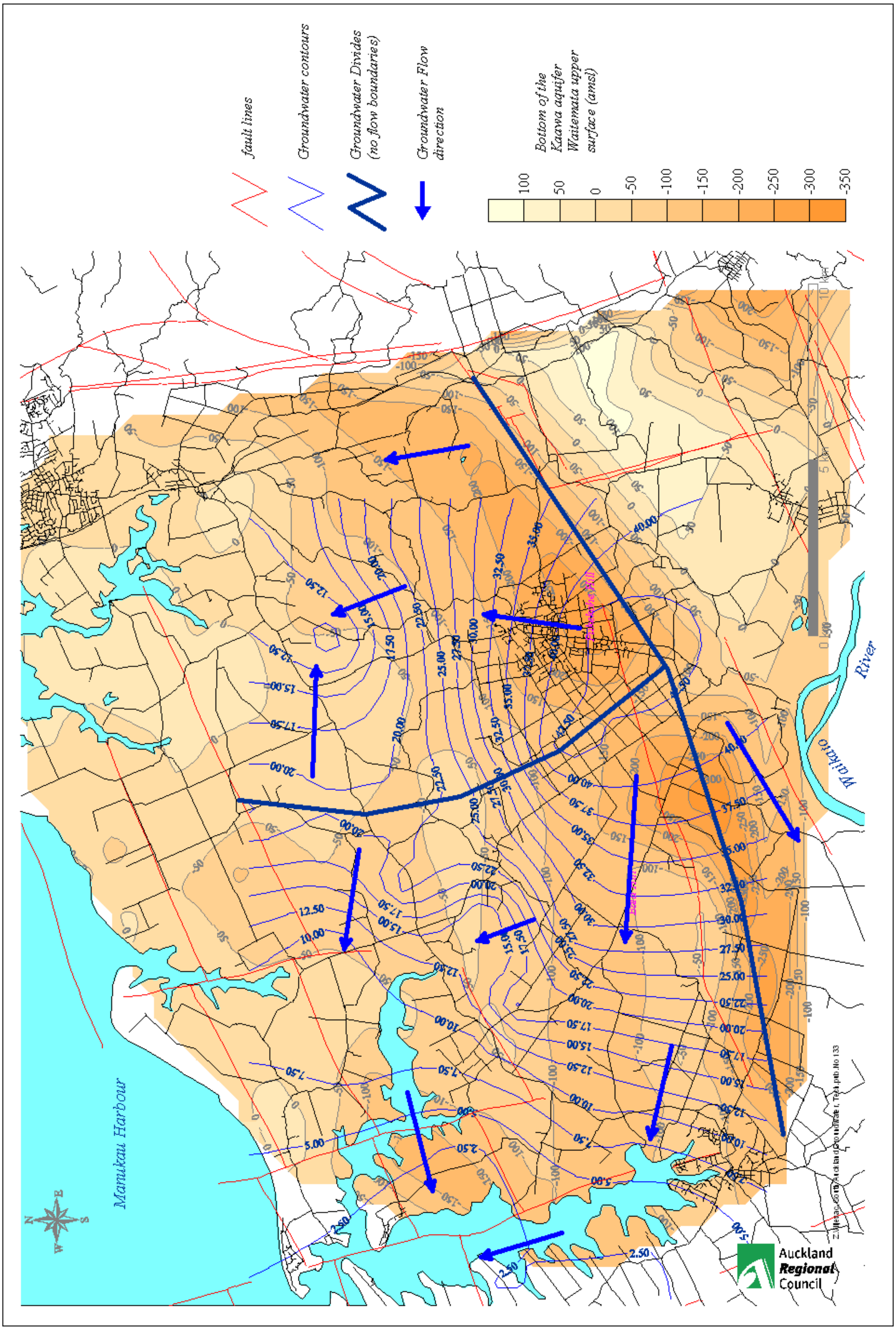


Figure 3.6 Kaawa aquifer groundwater levels

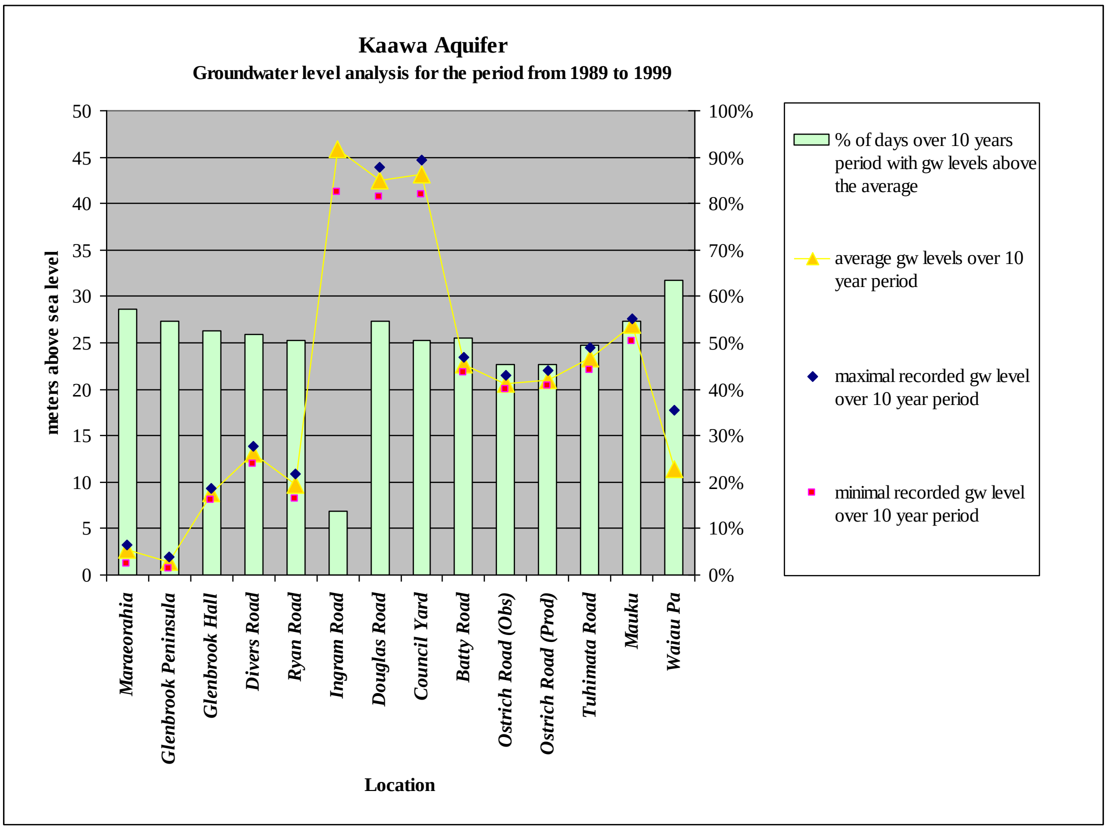


Figure 3.7 Kaawa aquifer, 10 year groundwater level analysis

Figure 3.7 shows ARC monitoring bores and analysis of a 10 year monitoring record. Bores can be arranged in three groups: bores with average groundwater levels of about 45 metres above sea level, bores with water levels of about 20 to 25 metres above sea level and a third group of bores with water levels between 1 and 15 metres above sea level. The majority of bores have a relatively small and uniform difference between minimum and maximum measured level. Almost all water levels are above the average levels for the site (around 50% of time).

3.3.3. Seasonal groundwater fluctuation

Volcanic aquifers are very sensitive to variation in rainfall because of their topographic location, and consequently influence springs and stream discharge. The aquifer's recharge occurs through a relatively thick layer of the residual soil. That enables a more consistent and steady recharge (GNS, 2000). Seasonal groundwater fluctuation was analysed from several ARC monitoring bores and a typical record is shown in Figure 3.8 for the Revell Court bore which is relatively unaffected by the groundwater abstraction. The Revell Court bore is located in a high-elevated part of Pukekohe Volcanic aquifer where groundwater levels are measured at elevations between 60 to 66 meters above sea level.

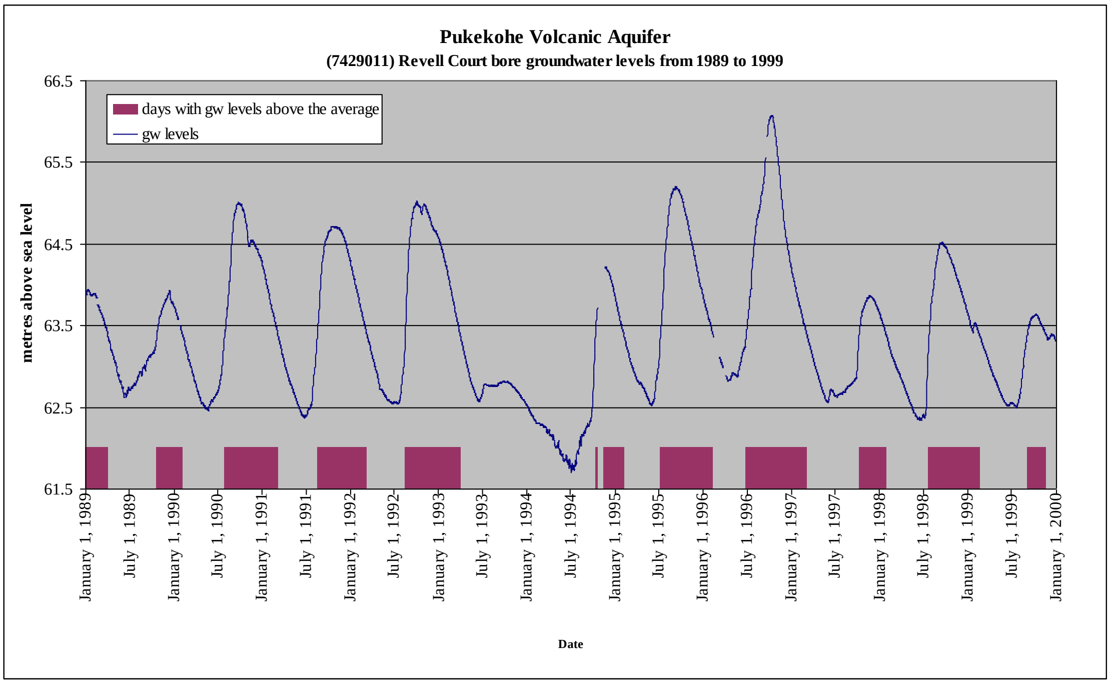


Figure 3.8 Revell Court, seasonal groundwater fluctuation

Analysis for the 11 year period (1/1/1989 to 1/1/2000) shows that the groundwater levels are regularly above the average between August and March and below average between March and July/August. This corresponds to the rainfall cycle (Chapter 4). The beginning and end of the recharge to the aquifer shows an offset to the rainfall season of approximately 3 – 4 months.

That offset is considered to be due to a lag time produced by the soil retention (GNS, 2000).

The drought in 1993/94 (Chapter 4) had a large effect on groundwater levels when the levels were significantly below average for more than one and a half year (the lowest point in July 1994). The groundwater level was only 61.75 m amsl or almost 3 metres below average.

The highest water level was recorded in September/October 1996 (66 m amsl). 1996 was a very wet year (Chapter 4) with more than 1600 mm/year of rainfall. This is evidence of the close association and vulnerability of groundwater levels in volcanic aquifer to rainfall. Rainfall effects are thought to have been the major cause of water level declines in the early 1980's which lead to water allocation restriction being put in place (see section 3.3.5). Other bores showed a very similar pattern in groundwater level fluctuation.

Most of the Kaawa bores show a relatively regular seasonal groundwater level fluctuation which corresponds well to the seasonal fluctuation in the volcanic aquifer. An example is the Divers Road bore shown on Figure 3.9. The groundwater oscillation shows a similar pattern to the volcanic aquifer but without the extreme low in 1993/94 and high in 1996. The reason is probably due to the indirect recharge from the volcanic aquifer which provided a buffer and smoothed the extreme events.

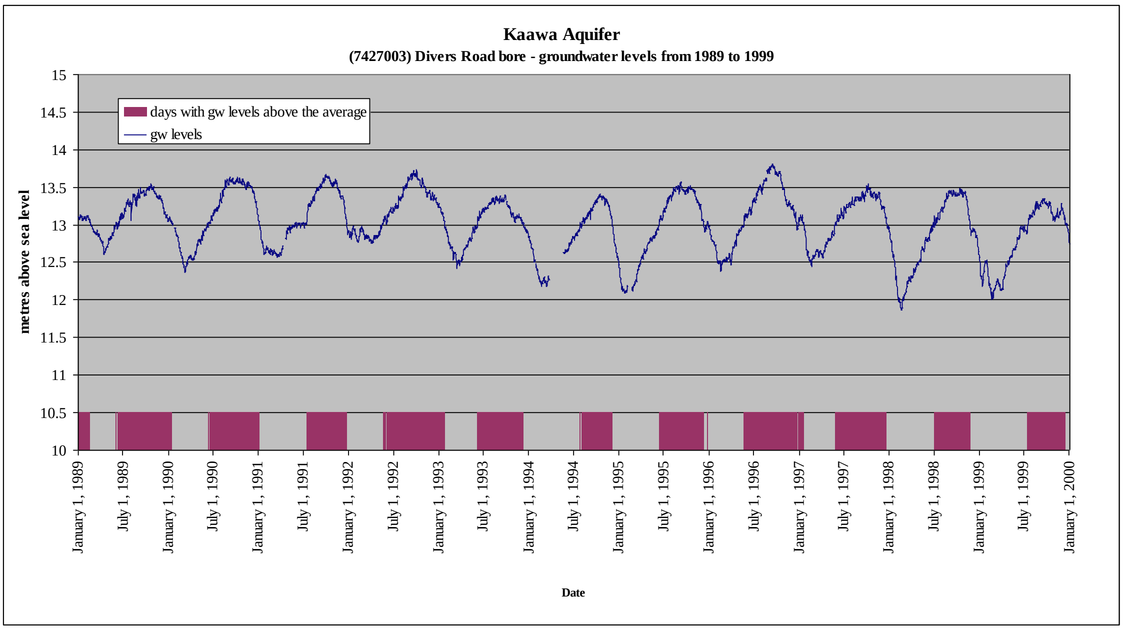


Figure 3.9 Kaawa aquifer seasonal groundwater level fluctuation at Divers Road

When the hydraulic pressure through the volcanic conduits is high the water levels in Kaawa aquifer are high and when pressure is low the water level is lower. It is concluded that the oscillation in groundwater levels in the Kaawa aquifer is a function of recharge and pressure head differences in volcanic aquifer.

3.3.4. Groundwater abstraction effect

A large number of groundwater users (Chapter 5) withdraw water from the aquifer, influencing groundwater level spatial distribution and seasonal fluctuation.

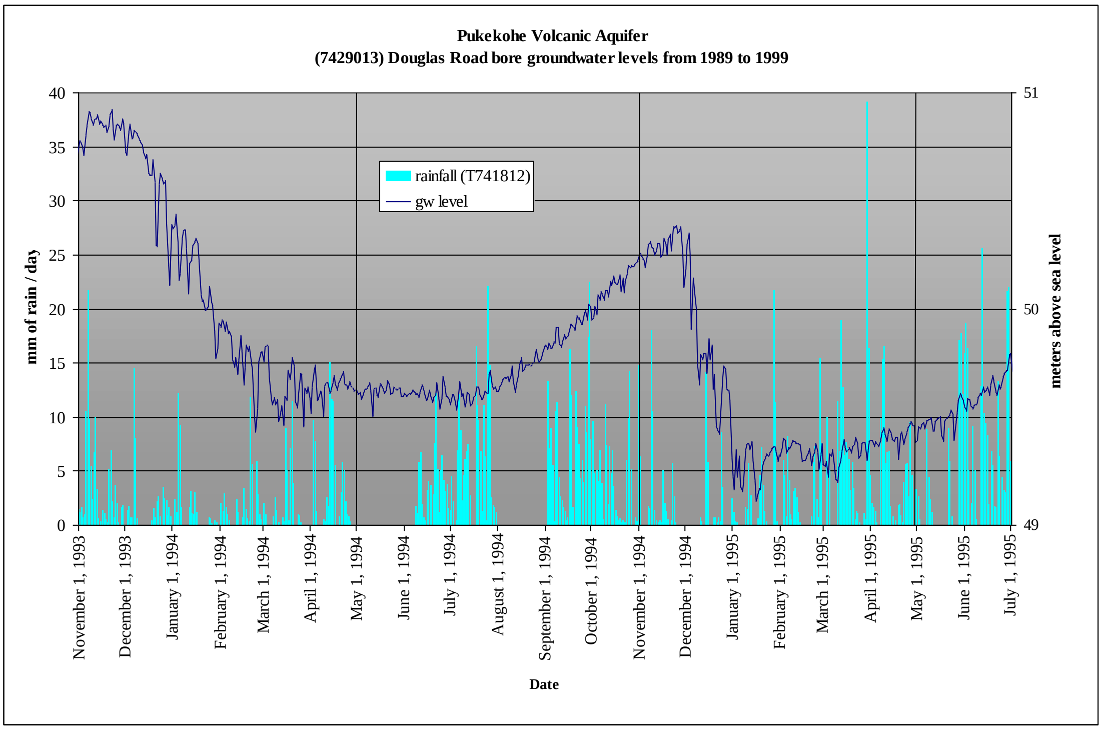


Figure 3.10 Pukekohe volcanic aquifer, Douglas Road bore, groundwater take effect

Two bores, one from the volcanic and another from the Kaawa aquifer were selected to illustrate effect of groundwater use on groundwater levels. Figure 3.10 shows water levels for period from 1993 to 1995 and Figure 3.11 for the period from 1992 to 1994 when the water levels were generally very low. Both examples show a decline in groundwater levels at the beginning of January with a continuation of low water levels through the summer and the autumn period (until April/May).

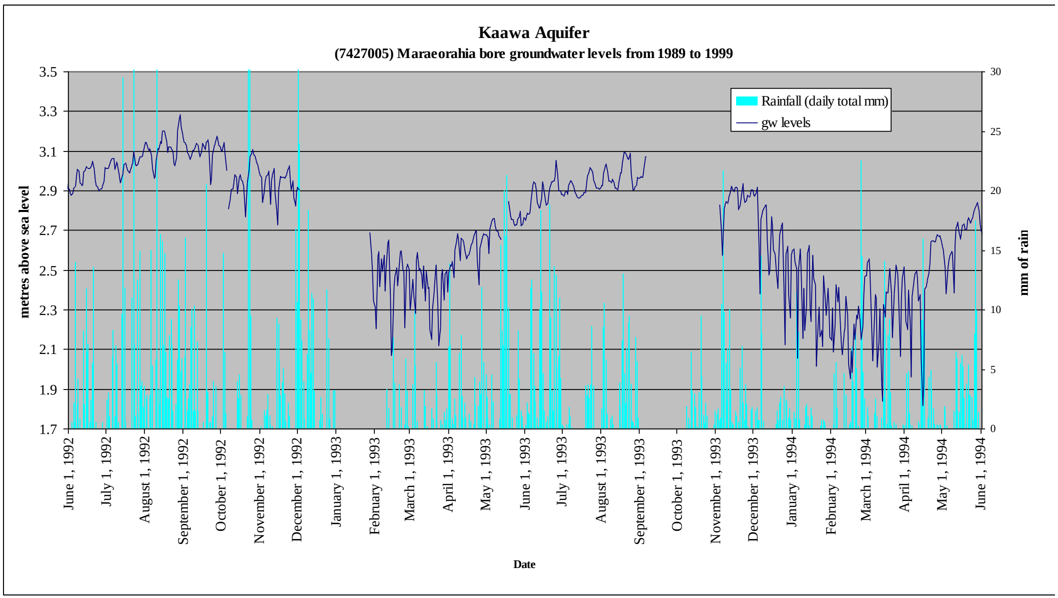


Figure 3.11 Kaawa aquifer, Maraeorahia bore, groundwater take effect

Groundwater abstraction was, as measured by consent holders (Chapter 5), intensive during the summer period and Figure 3.10 shows several sharp drops in water levels during January to March in 1993 and 1994. Water level records from the Kaawa aquifer in figure 3.11 show the effect of a longer period of intensive use and sharp drops are recorded in period from January to April or May. Rainfall information is added to the diagram to illustrate its effect on water use and water levels. It is noticed that rainfall events have an effect on water level recovery in the basalt aquifer (Figure 3.10) and in the Kaawa aquifer (Figure 3.10).

A period of rainfall events terminates the need for additional groundwater abstraction which results in groundwater level rise.

3.3.5. Long term trends

The long term groundwater analysis (20 year record) shows a declining trend in groundwater levels until the beginning of the 1990s. Since approximately 1993/94 groundwater levels in most of the aquifers in Franklin area have an upward trend. This trend for the Volcanic aquifer is shown on Figure 3.12. The trend is equally common in deep and shallow parts of the aquifer.

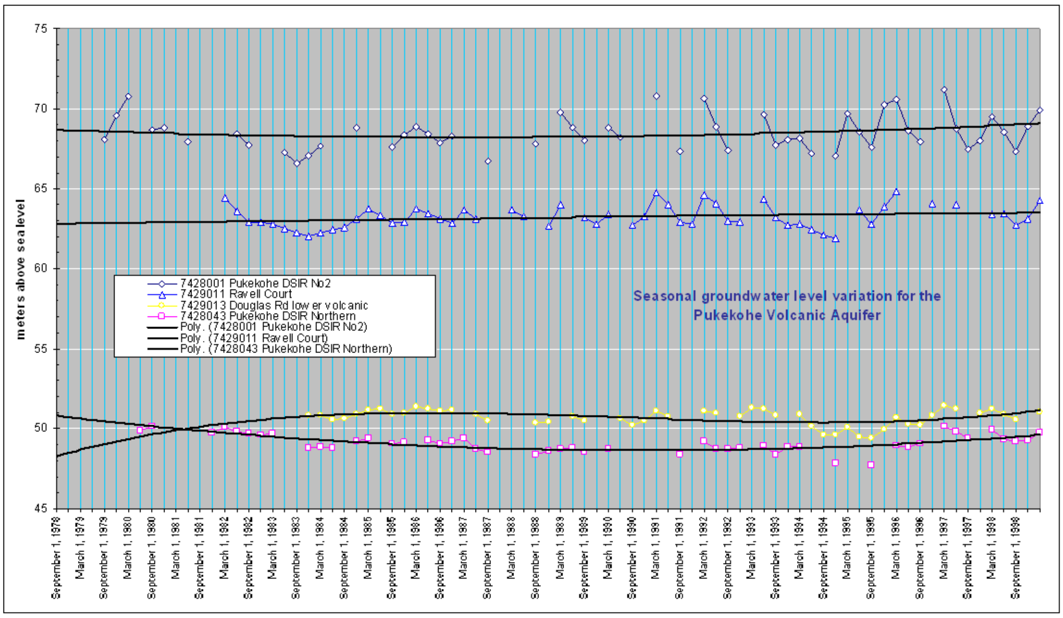


Figure 3.12 Long term trend in groundwater levels in the Pukekohe volcanic aquifer

Figure 3.13 shows a long term trend for groundwater levels in the Kaawa Aquifer which are similar to those in volcanic aquifer.

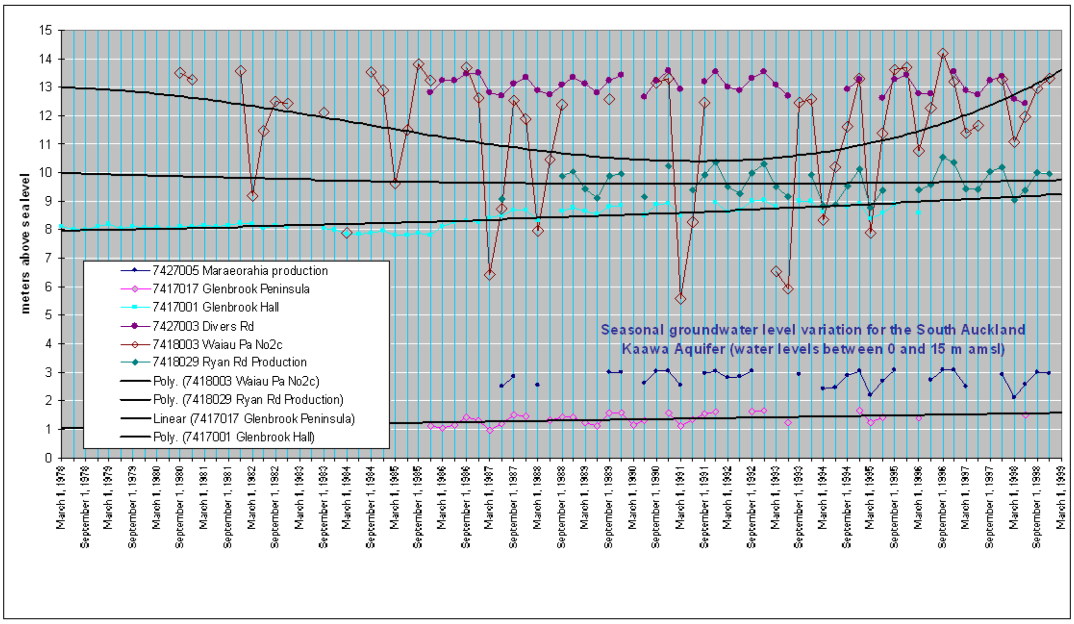


Figure 3.13 Long term trend in groundwater level in the Kaawa aquifer

The reason for the increase in the groundwater levels is the increase in annual precipitation within the area over the last since 1995 (see the rainfall analysis in the Chapter 4).
A negative effect on the long term trend was caused by a dry period in 1992/93 which resulted in the trend line declining for a short time.

3.4. Groundwater Surface Water Interaction

While the groundwater - surface water interaction in the volcanic areas is reasonably well known, the Kaawa aquifer interference with the surface water remains largely unknown.
Kaawa aquifer, because of its geological and tectonic setting does not have surface exposure within the area. Therefore the groundwater discharge through springs is not encountered. However, in the areas such as the Waikato River Valley, Waiuku River and Drury Creek the discharge into the sea is possible along the fault lines. There is no physical evidence and appearance of the sea bed springs but according to groundwater contour lines, and groundwater flow direction, this is considered to be likely (Chapter 6). Contribution or potential discharge (seepage) through the river floor is estimated using a flow net model (Chapter 7).

The volcanic aquifer has a significant role in the stream - spring discharge. Most of the streams draining the volcanic aquifer have very high groundwater component. In Chapter 4 the groundwater component in the base flow was calculated for the Whangapouri, Whangamaire, Mauku, Waitangi, Ngakaroa, Tutaenui and Parker Lane streams.

4. HYDROLOGY

4.1. Rainfall and Evapotranspiration

Approximately 640 sites are operating or once operated to collect rainfall information within the Auckland region. The majority of those sites have records shorter than 10 years. A total of 64 sites have a record greater than 10 years.

The sites are operated or were operated either by the New Zealand Meteorological Service (NZMS), the National Institute for Water and Atmospheric Research (NIWA) or by the Auckland Regional Council. Twenty-one rainfall sites are identified within the Franklin area, and sixteen of them no longer operate. The majority of records are shorter than 10 years. Data sources and data quality is described in the Chapter 1.

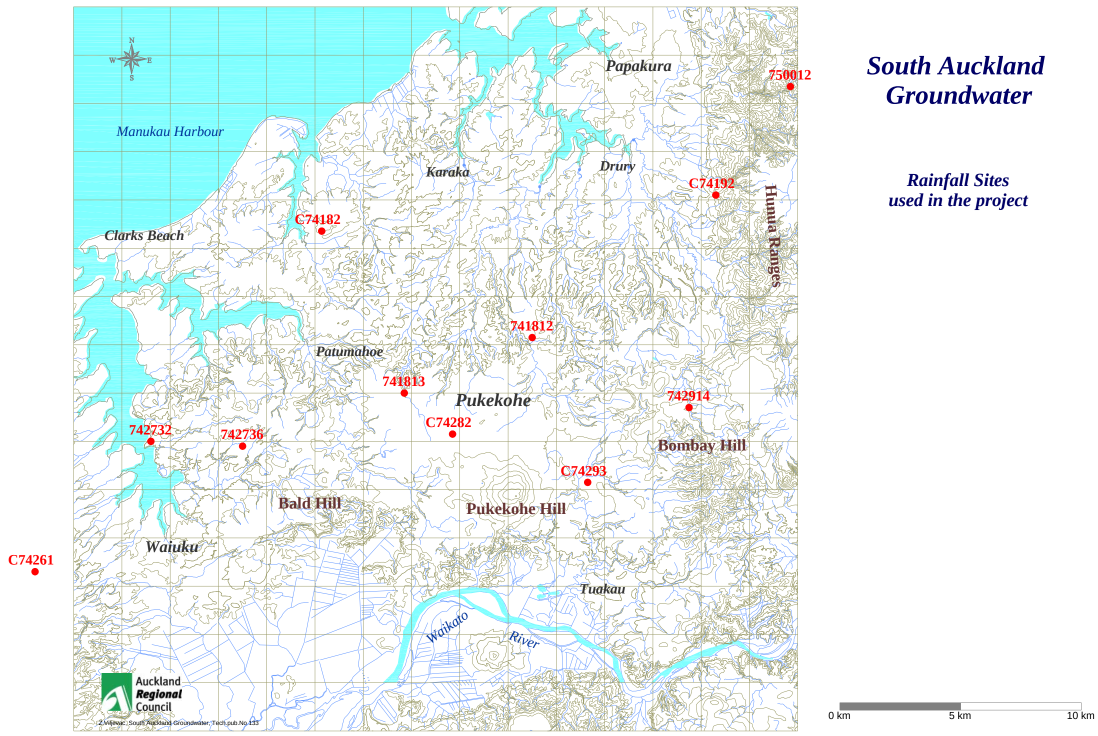


Figure 4.1 Rainfall sites location map

Eleven rainfall sites within the area shown on Figure 4.1 were used for the rainfall analysis. The Auckland Airport and Ardmore stations were added to the list of sites because of their long and consistent record and were used in the simulation process to reconstruct missing record for the other sites. Rainfall is the ultimate source of water for the recharge of the aquifers, as well as ultimate source of water for most of the stream flows.

The list of all sites with their approximate location is given in the Table 4.1.

Table 4.1 Rainfall sites used in the study

site number	*site name*	*cachment*	*elevation*	*easting*	*northing*
741812	***Paerata Dairy Co***	Whangapouri	150	2679000	6446300
741813	***Patumahoe weir***	Whangapouri	70	2673700	6444000
742732	***Glenbrook***	North Side	100	2663700	6427000
742736	***Waitangi***	Drivers Road		2667000	6441800
742914	***Donovans (weir)***	Ngakaroa	160	2685500	6443400
750012	***Water Treatment***	Hunua	180	2689700	6456700
C74182	***Kingseat***			2670279	6450709
C74192	***Drury***	Hingaia		2686609	6452203
C74261	***Waiuku***			2658146	6436153
C74282	***Pukekohe EWS***	Whangamaire	84	2675700	6442300
C74293	***Pukekohe FDC***	Tutaenui		2681300	6440300
C74082	***Auckland Airport***		4	2670549	6463654
C74091	***Ardmore***			2685200	6461400

The spatial distribution of rainfall intensity across South Auckland is variable. An example is shown in Figure 4.2. Elevated regions such as Awhitu Peninsula and Pukekohe plateau (with Pukekohe Hill as the highest point) shape the rainfall pattern (Chapter 1, Figure 1.2). As a consequence a rainfall gradient exists between the Manukau Harbour (Karaka) and Pukekohe Volcanic Plateau (Figure 4.2).

The difference between Kingseat (C74182) at 9 m amsl elevation, Pukekohe DSIR (C74293) at 50 m amsl or Pukekohe EWS site (C74282) at 84 m amsl corresponds with a 100 mm difference in rainfall. A similar rainfall gradient occurs east of the Awhitu Peninsula and west of Hunua Ranges.

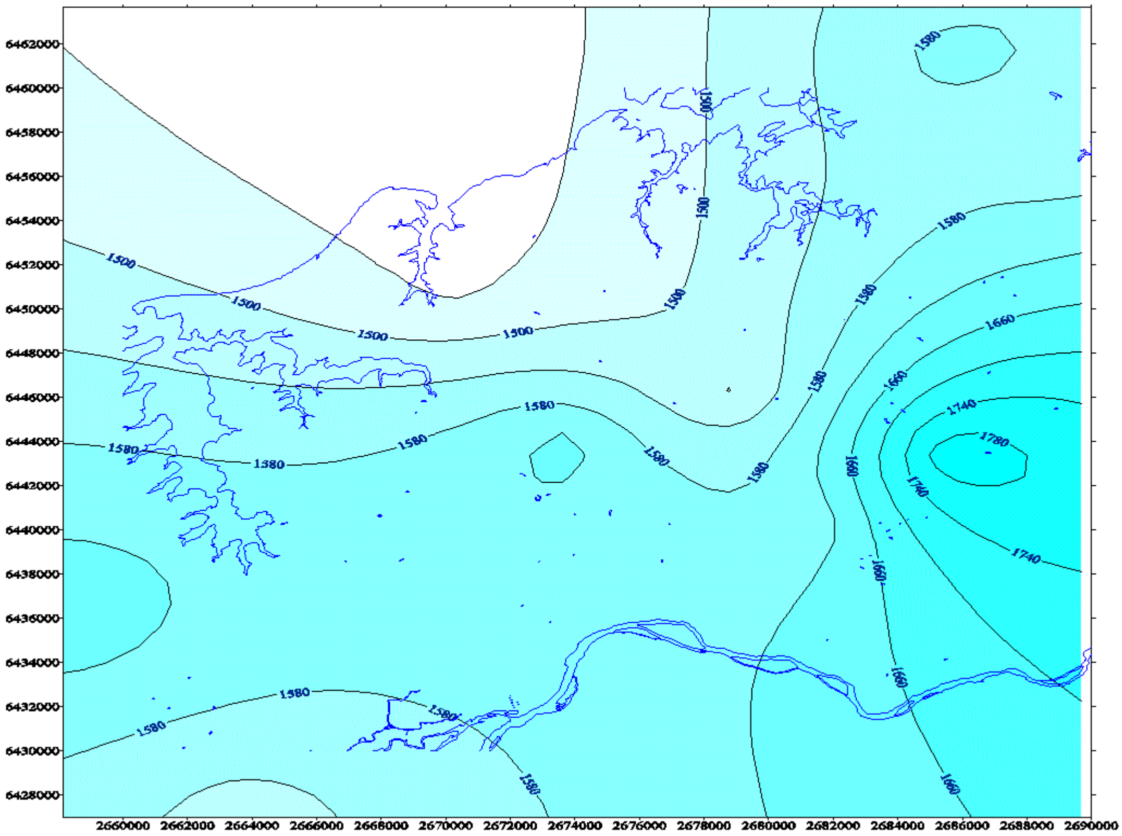


Figure 4.2 Rainfall Gradient, average annual rainfall (20 year record)

The length of record available for the analysis is an important factor that influences the seasonal pattern. The longer the record, the more distinct the pattern is. Such a distinct seasonal pattern can be noticed at Kingseat (C74182) and Pukekohe (C74293) where records extend for more than 30 years. A diverse seasonal pattern, in contrast can be seen at Diver Road (742736). This is a reflection of the averaging of two years of record.

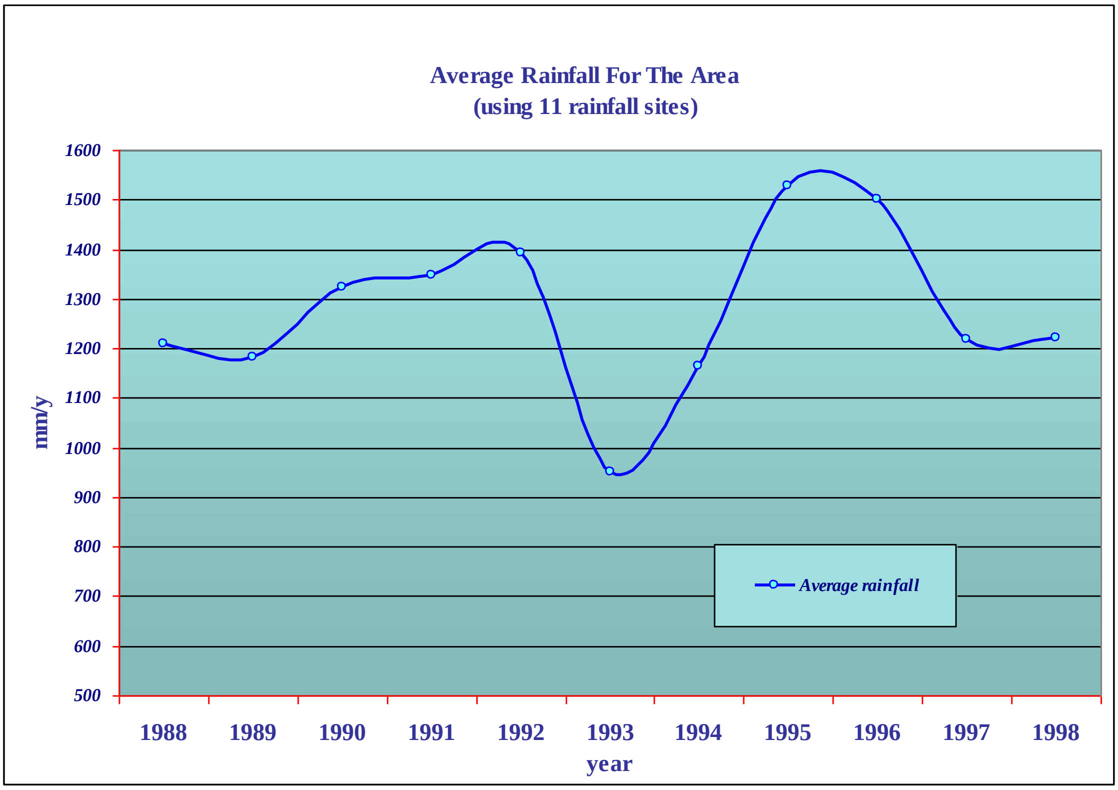


Figure 4.3 Annual rainfall fluctuation (10 year record)

Another significant factor is variation in total annual rainfall. This, as well as seasonal variation, considerably affects recharge – increasing or decreasing available water for the recharge on an annual basis. Figure 4.3 shows 10 year averaged total annual rainfall for the 11 South Auckland stations. There is clearly a low in 1993/4 rainfall, which was almost 350 mm lower than average rainfall for the area. A very high total annual rainfall, some 350 mm above the average, is recorded in 1995/1996. This shows that total oscillation in rainfall between years can be up to 700 mm which is almost 65% of the average rainfall for the area. The effect of differences in rainfall between dry and wet years and spatial distribution is shown on Figure 4.4. There is a similar pattern for years of low and high rainfall, but the difference in annual total rainfall is significant.

Figures 4.5 and 4.6 are comparing differences in spatial distribution of rainfall using data from the database with simulated data replacing all gaps and missing records. Spatial distribution using simulated "complete" data shows more realistic and smooth spatial distribution. The maps are presented in the same scale for easy comparison.

The variation in annual total rainfall between sites is shown on the Figure 4.7. The difference between some locations can be more than 400 mm.

The seasonal rainfall pattern varies from year to year. A clear pattern appears when monthly totals are averaged over several years. As shown in Figure 4.8, June and July are the wettest months as opposed to January, February, November and December. There is a distinct seasonal pattern at Kingseat (C74182).

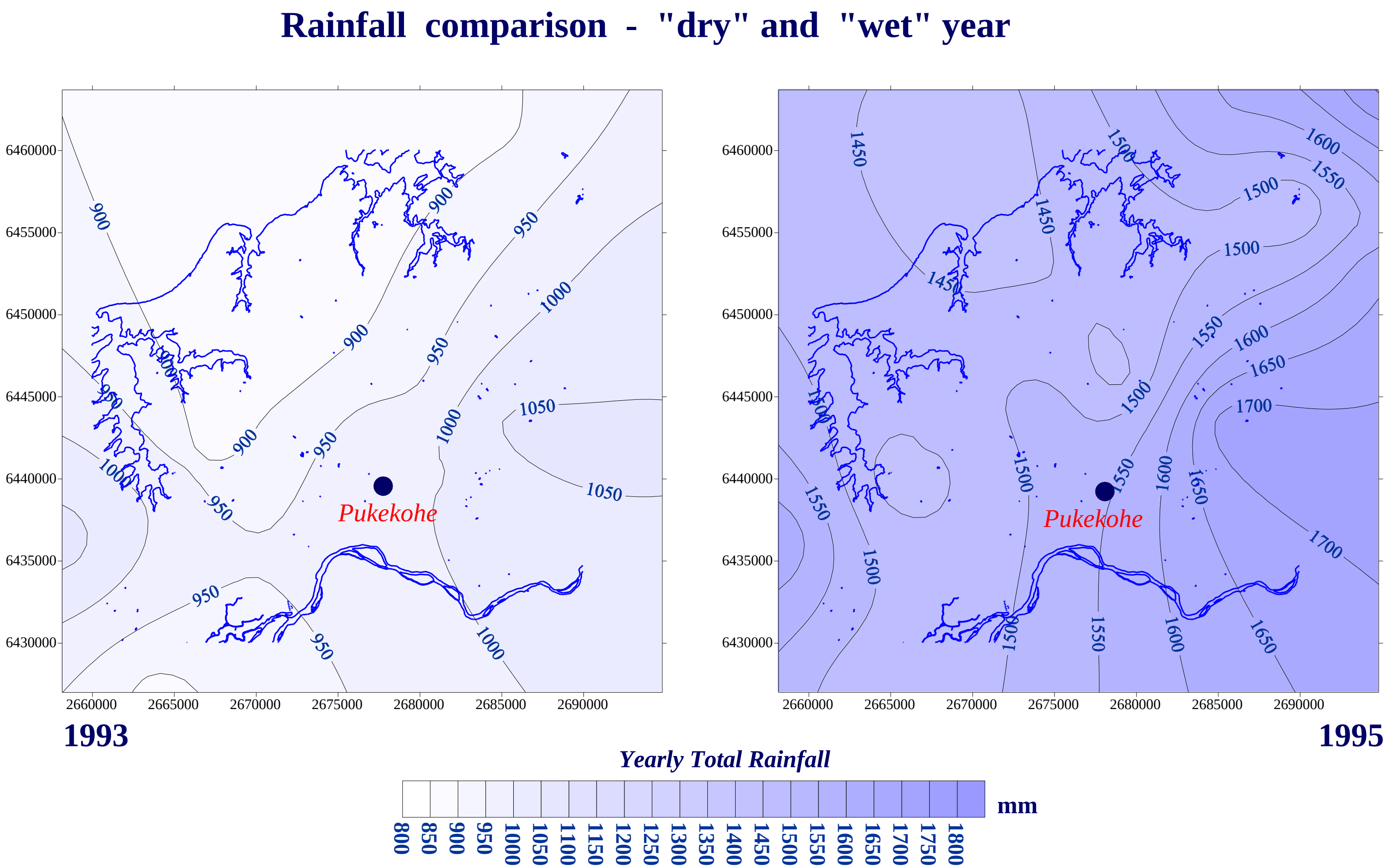


Figure 4.4 Rainfall distribution difference between dry and wet years

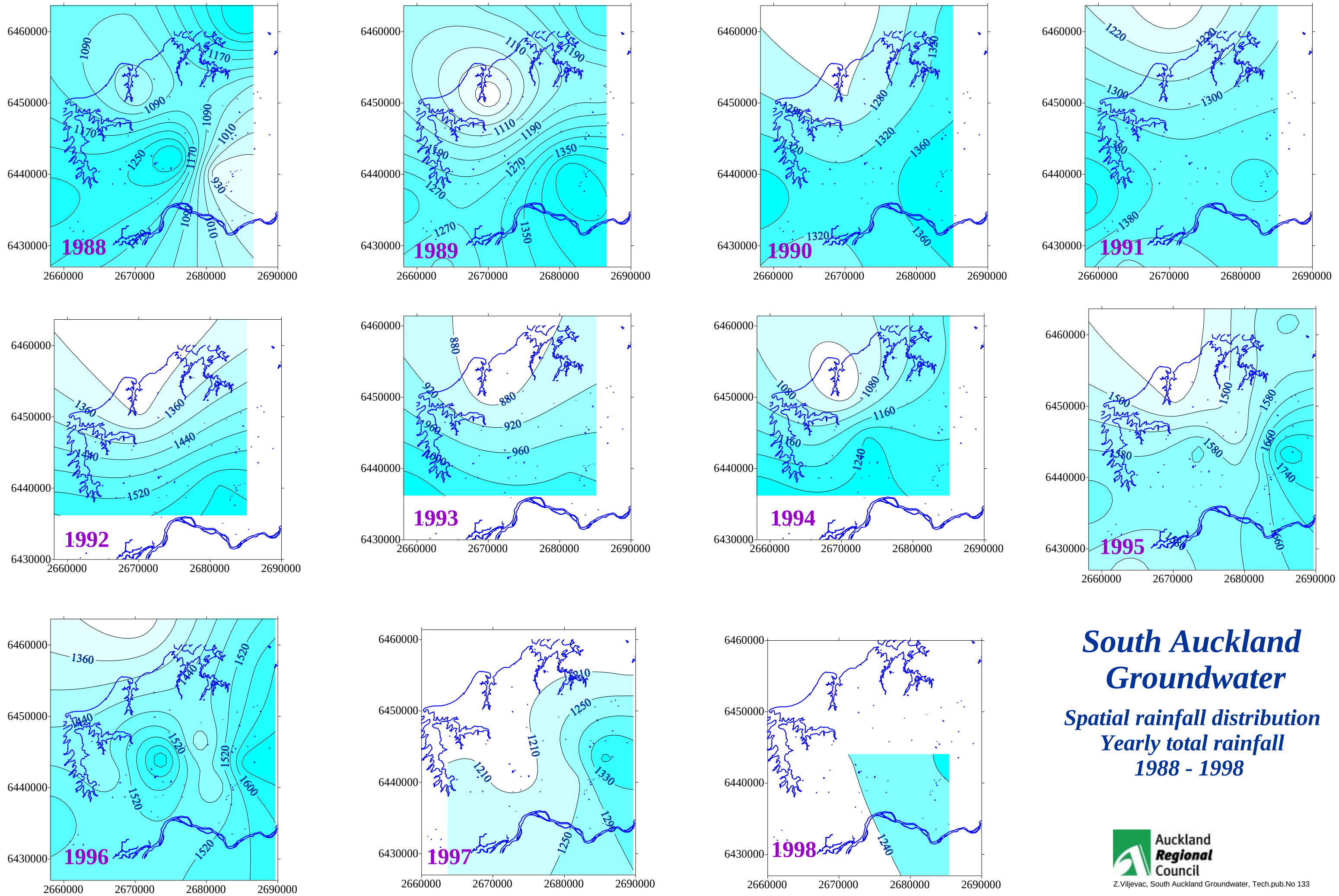


Figure 4.5 spatial rainfall distribution (recorded)

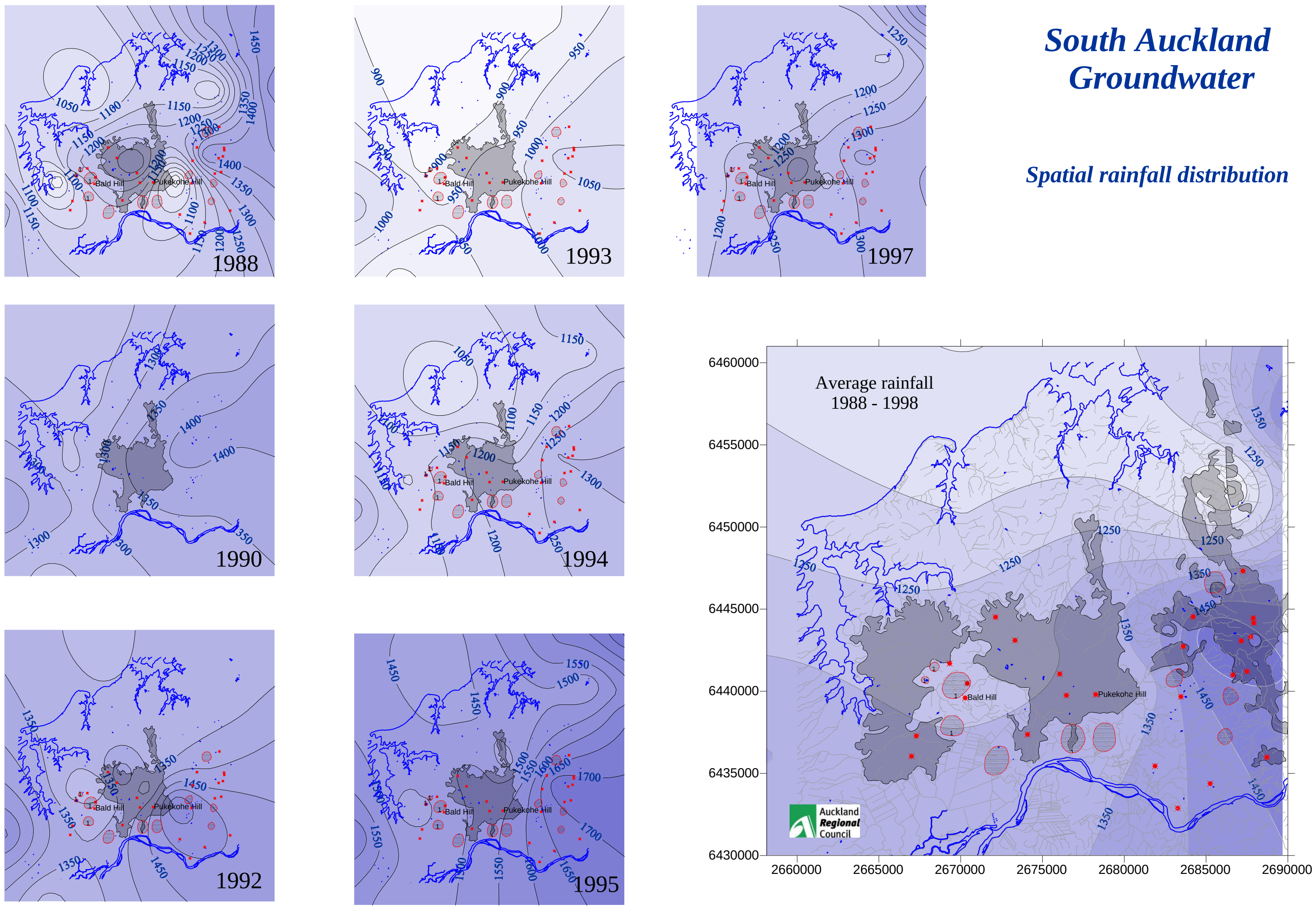


Figure 4.6 Spatial rainfall distribution (simulated) (A3)

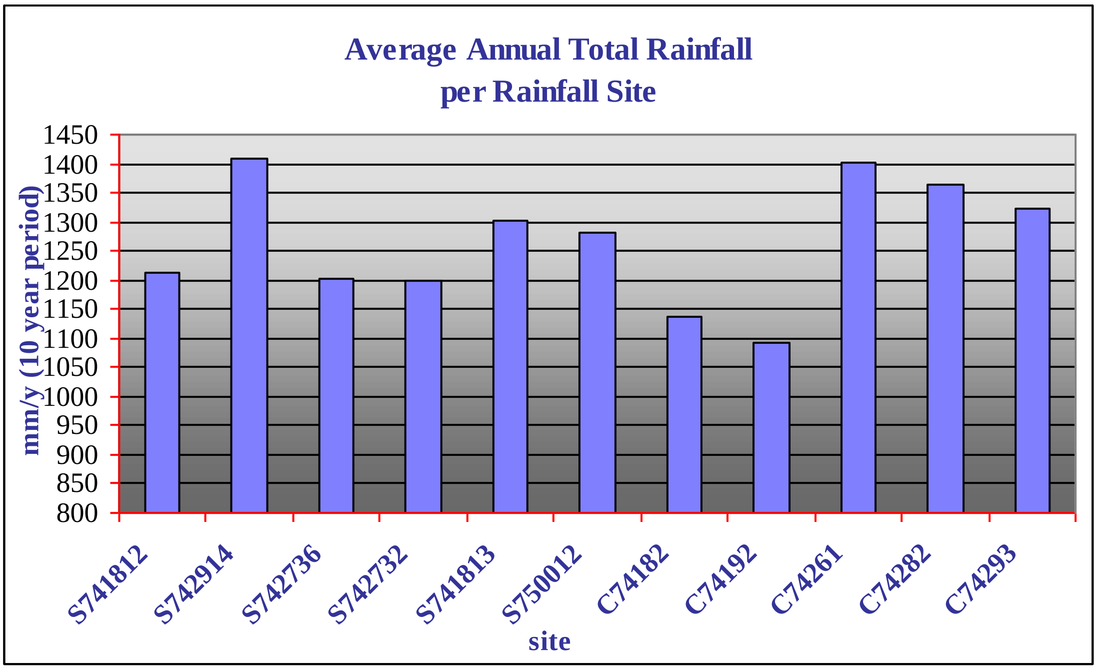


Figure 4.7 Rainfall variation between rainfall monitoring sites

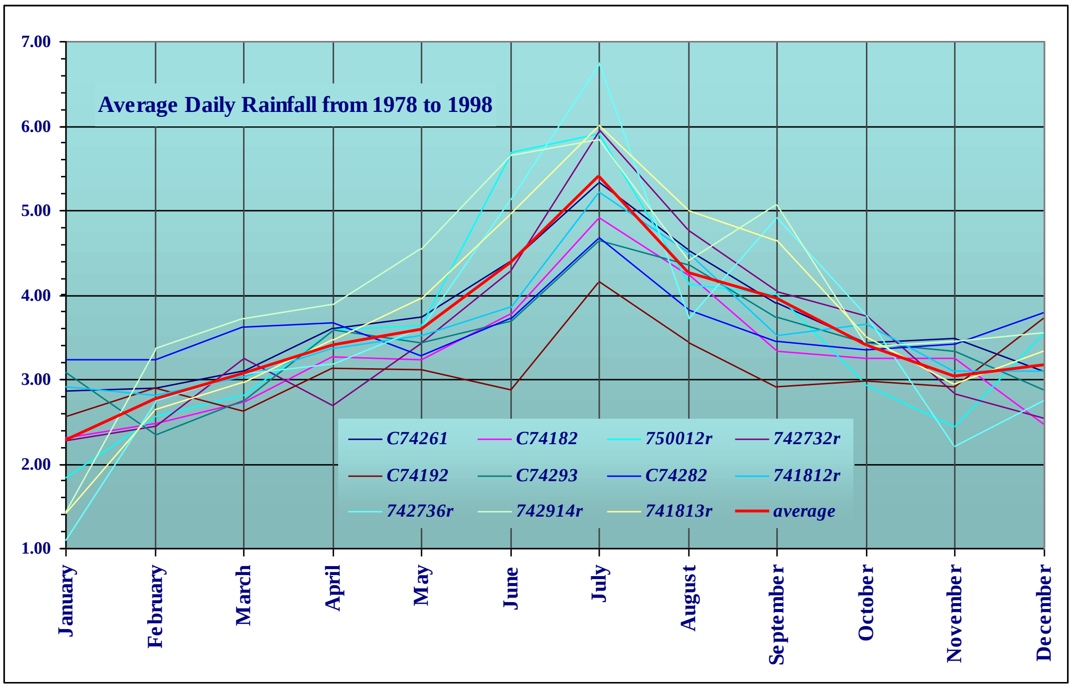


Figure 4.8 The seasonal rainfall variation between monitoring sites

4.1.1. Evaporation / evapotranspiration

Evapotranspiration is a parameter used in the water balance equation to calculate groundwater recharge.

Evapotranspiration is a sum of **evaporation** from surface water and soil moisture **transpired** by vegetation and basically the process by which surface water and shallow subsurface water are released to the atmosphere. Evapotranspiration mainly depends on topography, soil type, vegetation, land use, type of basement rock, number of sunny days, wind intensity and varies significantly from place to place.

Potential evapotranspiration occurs if an adequate and permanent soil moisture supply exists at all times. This is the amount of water, which will be released from the surface and vegetation if unlimited soil moisture is present.

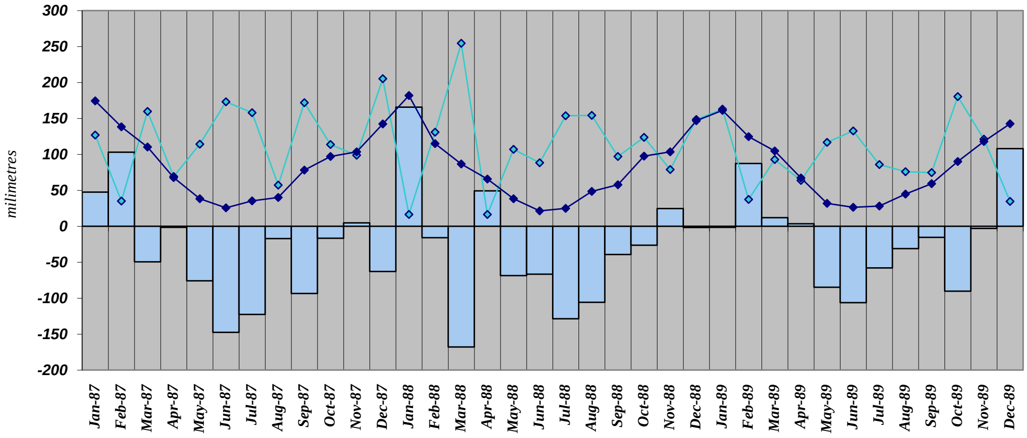
Actual evapotranspiration is derived from potential evapotranspiration and depends on soil moisture differences.

Potential evapotranspiration for Auckland region has been estimated at 1136 mm/y and actual of approximately 778 mm/y (ARC, 1996). This figure corresponds with the estimation of the actual evapotranspiration for the Auckland region estimated by NZMS, which indicated that 70% of potential evapotranspiration occurs when there is a soil moisture deficit (ARC, 1996). In this report actual evapotranspiration was estimated to be between 735 mm/year and 760 mm/year based on comparison between Auckland Airport site and DSIR site at Pukekohe.

Figures 4.8 and 4.9 are comparing rainfall and evaporation at the Pukekohe DISR station and Auckland Airport.

The Diagram 4.9 shows rainfall and evaporation fluctuation from the 1997 to 1999. The rainfall shows more steady seasonal fluctuation than evaporation.

Rainfall / Evapotranspiration Analysis for the Pukekohe Hill



	Jan-87	Feb-87	Apr-87	May-87	Jul-87	Aug-87	Oct-87	Nov-87	Jan-88	Feb-88	Mar-88	May-88	Jun-88
Rf-ET	47.55	103.1	-1.37	-75.92	-122.5	-17.18	-16.70	4.65	165.5	-15.90	-167.8	-68.65	-66.74
ET	126.8	35.10	69.07	114.2	157.9	57.28	113.7	98.85	16.32	130.8	254.3	106.8	88.24
Avg Rf	174.4	138.2	67.70	38.30	35.40	40.10	97.00	103.5	181.9	114.9	86.50	38.20	21.50

	Aug-88	Sep-88	Nov-88	Dec-88	Jan-89	Mar-89	Apr-89	Jun-89	Jul-89	Sep-89	Oct-89	Dec-89
Rf-ET	-105.7	-39.33	24.65	-1.80	-1.53	11.85	3.46	-106.2	-57.85	-15.43	-90.39	107.9
ET	154.2	96.93	78.85	148.5	162.8	92.85	63.65	132.6	85.85	74.73	180.3	34.57
Avg Rf	48.50	57.60	103.5	146.7	161.3	104.7	67.10	26.40	28.00	59.30	90.00	142.5

Figure 4.8 Pukekohe rainfall and evapotranspiration analysis

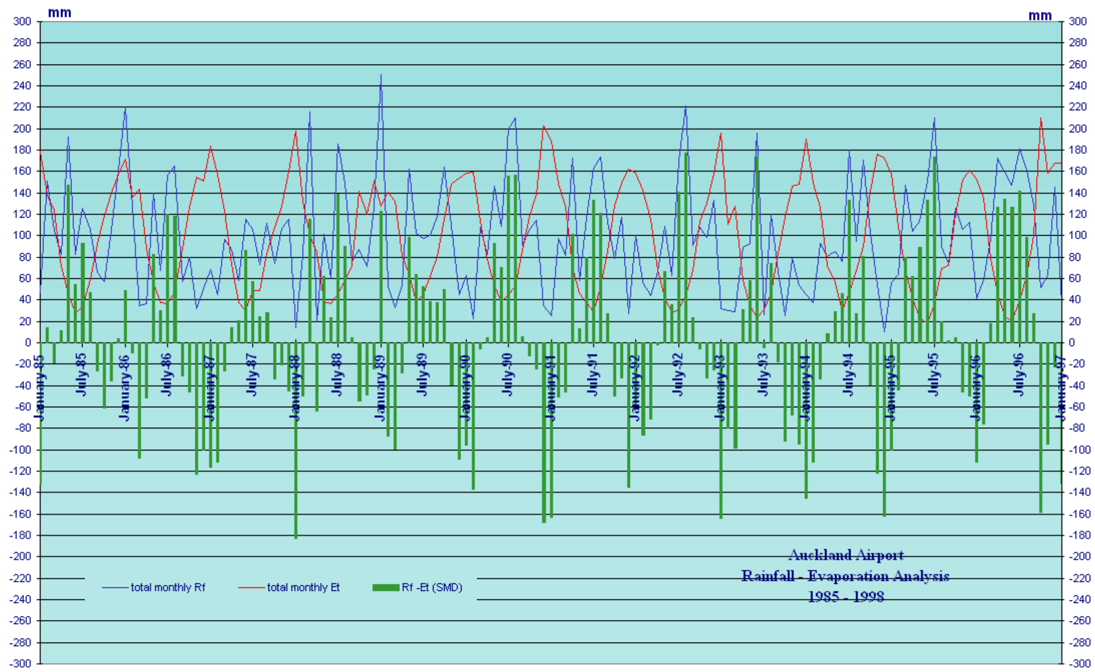


Figure 4.9 Auckland Airport rainfall and evapotranspiration analysis

For the recharge comparison (Chapter 7) between infiltration rate and rainfall/evapotranspiration rate a conservative figure of 760 mm/y was converted into monthly evapotranspiration rates. The evapotranspiration values across the area may considerably vary and an average figure is not always the best option. More accurate evapotranspiration values could be obtained by "in situ" measurements.

The evapotranspiration in the Franklin area in some of previous reports was estimate to be 736 mm/y, 728 mm/y and 847 mm/y (ARC, 1996).

4.2. Stream Discharge

In the northern part of the study area there are seven major surface water catchments. Apart from Oira Stream, they drain from the Pukekohe volcanic plateau and receive discharge from the volcanic aquifer (Figure 1). These catchments are: Waitangi (19.5 km^2), Mauku (38 km^2), Whangamaire (23 km^2), Whangapouri (51 km^2), Oira (18.5 km^2) Ngakoroa (38 km^2) and Hingaia (57 km^2).

In the southern part of the study area (Environment Waikato) a number of small catchments are fed by the water from the Pukekohe volcanic aquifer. The largest is Tutaenui Stream followed by several streams on the southern slopes of the Pukekohe Hill. The Bombay and Drury Volcanic Aquifer are drained by the Hingaia and Ngakaroa catchments. Whangamaire, Whangapouri, Mauku and Tutaenui (Whakapipi) streams are sourced from the Pukekohe Volcanic Aquifer and Waitangi stream is the major drain for part of the Glenbrook Volcanic.

Flow and stream discharge was analysed using data from long term flow sites within the area and compared with a number of individual gauging sites. Flow was simulated in the streams with no data or with occasional or low quality record.

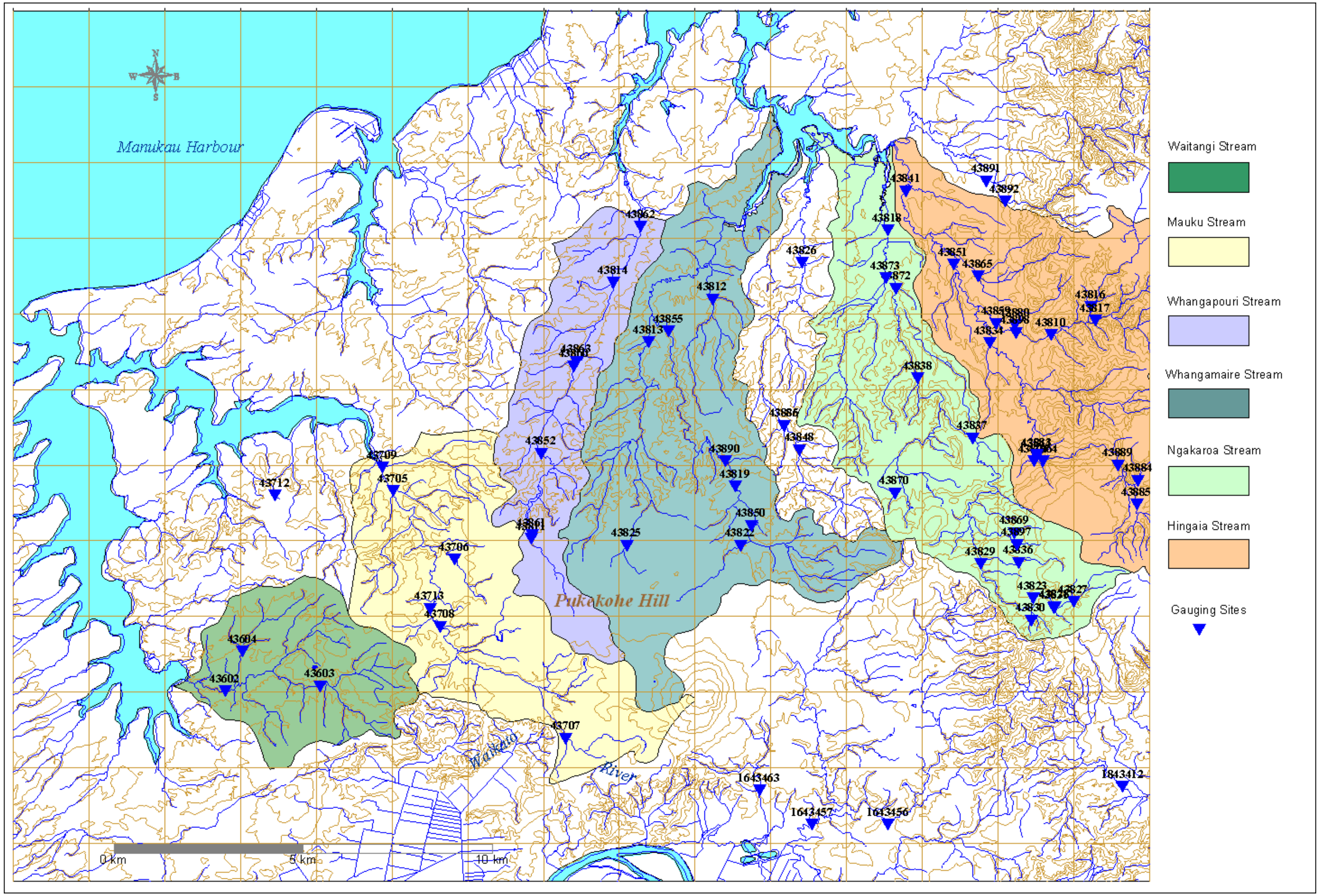


Figure 4.10 Location of flow sites (A3)

4.2.1. *Continuous Water Level Recorder Sites*

In the study area there are three automatic water level recorder sites. A description is given in Table 4.2. Site number 43602 is located on the Waitangi Stream at State Highway 22 bridge. This site records the flow from an area of 17.6km^2 and has operated since 1966 under maintenance of The National Institute for Water and Atmospheric Research (NIWA). The ARC maintains site 43811 located at Patumahoe Weir in the upper catchment of Whangamaire Stream, and site 43829 on the upper Ngakoroa Stream. Site 43811 has a catchment of 4.35km^2 and has a groundwater catchment of approximately 10km^2, with a continuous flow record from 1976. Site 43829 at Mill Road has recorded since 1980 and a catchment of 4.73km^2.

Table 4.2 Automated water level recorder sites (Flow sites)

Automatic Water Level Recorder Sites **South Auckland**			
Site Name	Patumahoe Weir	S H Bridge	Mill Rd
Site Number	43811	43602	43829
Catchment	Whangamaire	Waitangi	Ngakoroa
Site Commenced	29/09/76	30/03/66	28/03/80
Site Ceased	Current	Current	Current
Map Reference	R12 736440	R12 655400	R12 855432
Easting	2673690	2665500	2685576
Northing	6444064	6440000	6443227
Latitude	37:11:42S	37:13:51S	37:11:46S
Longitude	174:50:21E	174:44:55E	174:58:27E
Elevation	57	?	143
Catchment Area	4.35	17.6	4.73
River Number	438000	436140	438300
HYDSYS Variable	100 (water levels)	100 (water levels)	100 (water levels)

4.2.2. *Manual Gauging Sites*

A total of approximately 100 manual gauging sites exist in the study area. The Data are shown in Appendix 4, Table A4.1 and were used in the simulation of the discharge for streams with insufficient information.

4.2.3. *Flow Duration*

A simple method for describing stream flow at a site is to demonstrate the relationship between any given discharge and the percentage of time that the discharge is equalled