or exceeded. The specific discharge appears not to differ at extreme high flows in up to 2 percents of the time. That exception possibly represents a few flood events when the rainfall was homogeneous across the region, therefore discharge per square kilometre was uniform. For the remaining 98 percent of the time within the analysed period, flows at Patumahoe Weir were consistently higher than at the other two sites. This conclusion supports the calculated median for specific discharge (90 percentile) of 21.57, 4.05 and 2.88 l/s/km^2 at Patumahoe, Ngakaroa and Waitangi respectively.

4.2.4. Seasonal Flows

A seasonal pattern of higher winter flows and lower summer flows is evident and a response to rainfall. A comparison of mean monthly flows is listed in Table 4.3. July, August and September are the three wettest months of the year (as highlighted Table 4.4). In contrast, January, February and March are the three driest months with the exception of flows at Patumahoe where minimum flows are delayed by a month. A delay of one month provides evidence to support the existence of a strong groundwater base flow source. The groundwater supply to stream flow at Patumahoe Weir, is slow to respond to seasonal weather changes. In other words, there is a delay between direct water entering at the ground surface (rainfall) and it leaving the groundwater system via Patumahoe Spring.

Table 4.3 Mean monthly stream flow in l/sec (Waitangi, Whangamaire, Ngakaroa)

Mean Monthly Stream Flow **Waitangi 43602, Whangamaire 43811, Ngakaroa 43829** Period: 1st of July 1980 to 30th of June 1999												
Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
43602	98	83	89	102	172	324	547	515	406	313	163	113
43811	121	109	105	107	119	137	176	190	180	167	145	133
43829	48	33	38	51	71	111	173	161	123	95	63	57

Further evidence of a strong groundwater source is indicated by the consistent nature of monthly mean flows. A comparison between the wettest and driest months of the year in Table 4.4, suggests that a reliable and continuous source of spring water supports stream flow at Patumahoe. There is a decrease of approximately 45% between the August mean flow of 190l/s and the March mean flow of 105l/s. In contrast, a decrease of approximately 85% between July and February mean flows occurs at Waitangi. The greatest differences between wettest and driest months on average occurring between 1st of July 1980 and 30th of June 1999.

Table 4.4 Flow comparison between wet and dry period

Comparison between Wet and Dry Months			
Site	**Wettest Month**	**Driest Month**	**% Difference**
43602 Waitangi	547l/s in July	83l/s in February	84.83%
43811 Whangamaire	190l/s in August	105l/s in March	44.74%
43829 Ngakaroa	173l/s in July	33l/s in February	80.92%

4.2.5. Low Flows

Low flows are of major concern in South Auckland during summer months. A combination of dry weather and water demand can reduce stream flows to below acceptable levels. All streams in the study area have critical levels to sustain the ecosystem in most summers. Water quality affects are caused by critically low dissolved oxygen levels and elevated temperatures. It is necessary to maintain stream flow as natural as possible during the critical summer months.

4.2.6. Base flow estimation

To estimate discharge from the volcanic aquifers into the streams a mean base flow estimation for a period of 20 years was used. For the separation of the base flow from measured and simulated flow data a method integrated in the HYDSYS database was used. Of the two methods available, the Separation Value method, which is more appropriate for the New Zealand conditions, was used in this analysis (HYDSYS database).

The base flow analysis for the Waitangi (43602) and Whangamaire (4311) Streams shows very strong groundwater component in the stream flow in range from 85 to almost 97% of the total discharge, however Ngakaroa Stream (43829) shows a much lower base flow range (70% to 90% of the discharge). These data are used for the recharge – groundwater availability calculation (Chapter 7).

The average base flow estimation for all three sites is shown in the Table 4.5.

Table 4.5 The base flow estimation for the Waitangi, Whangamaire and Ngakaroa streams

Stream	Average base flow m3/second	Average base flow m3/day	Mean annual flow m3/year
Waitangi (43602)	0.166258	14365	
Whangamaire (43811)	0.126327	10915	
Ngakaroa (43829)	0.054352	4696	

Figures 4.11 to 4.13 illustrate the relationship between rainfall intensity and base flow percentage in the total stream discharge, especially at higher rainfall intensity. This shows the strength of the base flow component in the total stream discharge.

For the Whangamaire Stream, Figure 4.11 shows that regardless of the rain intensity the base flow is in a range from 90% to 97.5% of the discharge. The majority of the water at that site is sourced from the groundwater and even at higher rainfall intensity the base flow component is high. The surface runoff contribution in the stream discharge is relatively small (approximately 5% to 10% of the total discharge).

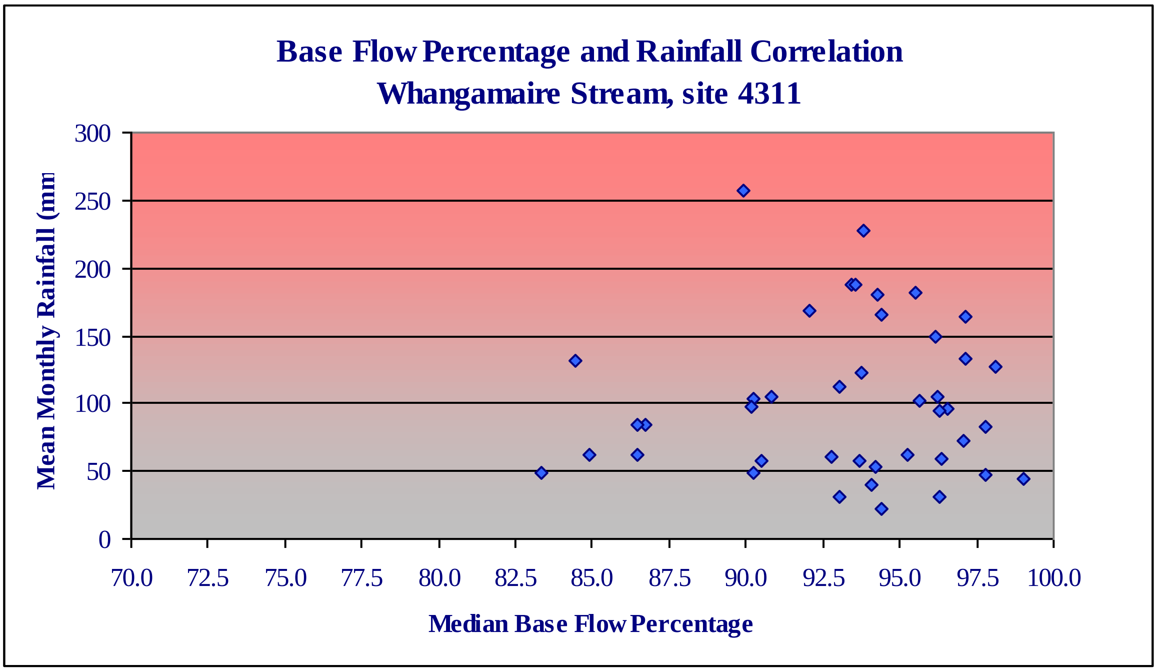

Figure 4.11 Correlation of rainfall and base flow percentage, Whangamaire Stream

The Waitangi Stream (Figure 4.12) shows a similar pattern within the range from 85% to 95% of the total discharge. A slightly smaller base flow percentage is shown for the higher range of rainfall (150 to 250 mm per month). Approximately 5% to 15% of water in the stream discharge comes from the surface runoff.

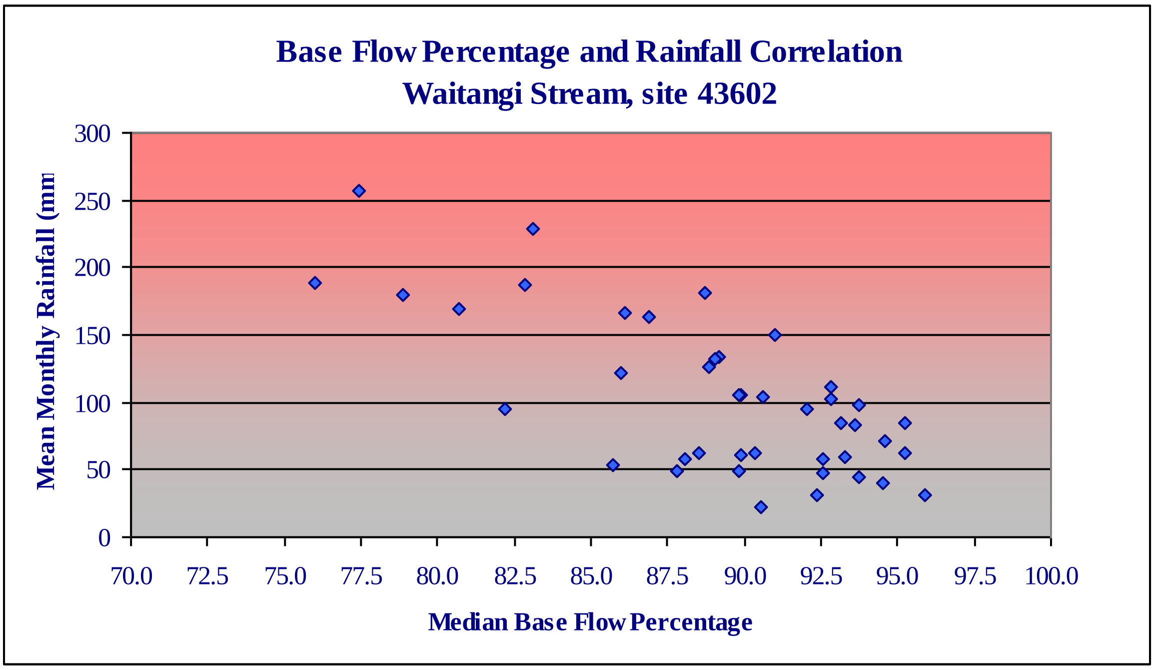

Figure 4.12 Correlation of rainfall and base flow percentage, Waitangi Stream

As the third representative site that drains the Bombay volcanic aquifer, Ngakaroa Stream (43829) shows that the groundwater (base flow) component is more variable in a range from 70% to 90% (Figure 4.13).

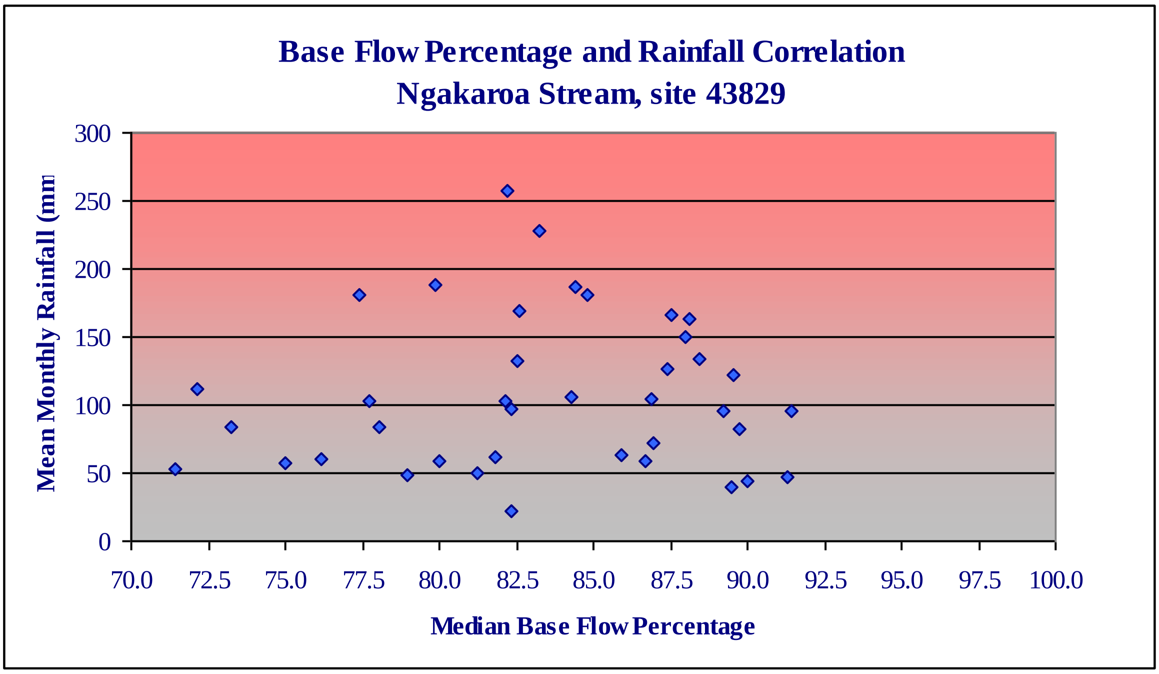

Figure 4.13 Correlation of rainfall and base flow percentage, Ngakaroa Stream

This could be caused by the large tuff area within the upper part of the catchment and higher surface runoff component in the total discharge. Tuff has slow and delayed release of water to the stream flow but at the same time allows quicker surface runoff.

The estimated discharge from the management areas (Chapter 7) in the Pukekohe Volcanic Aquifer is shown in Table 4.6. The estimation is based on mean base flow over a five year period using HYDSYS method for the extraction of the base flow rates. This five-year period (1992 – 1996) encompasses, as a contrast, extremely dry and wet periods. Missing data are simulated using correlations with long term flow recorder sites (Table 4.6).

Table 4.6 Estimated base flow discharge from the Pukekohe Volcanic aquifer

MANAGEMENT AREA	Stream Discharge m^3/year	Streams
Pukekohe	8,195,237.10	Tutaenui, Whangamaire East
South	5,263,928.30	P.Lane, Whakapipi, Puni Spring
West	6,582,367.80	Mauku
North	6,133,896.80	Whangapouri, Whangamaire West
Total from Pukekohe basalt	26,175,430.00	

These figures are used in the recharge / availability calculation (Chapter 7) as a minimum required residual flow in the streams discharging from the basalt aquifer.

The figures are considered conservative enough to maintain stream flow at all times, preventing adverse environmental effects regardless of groundwater abstraction.

5. WATER USE

5.1. Ground Water

Groundwater use varies from the allocation specified in a resource consent on both daily and annual basis. For the purpose of this investigation the use data were collated from the water meter readings returned as a condition of consent. Though not always complete it is assumed these records reflect actual use by the majority of the permit holders. Figure 5.1 and Figure 5.2 show spatial distribution of groundwater users from the Pukekohe and Kaawa aquifers.

In the study area there were 477 resource consents in 1999, allowing for the abstraction of groundwater. This represents an increase of 14 consents from 1998[1].
In total 167 consents take from the Kaawa aquifer, 80 consents from the Pukekohe Volcanic aquifer and 100 consents take from the Waitemata sandstone aquifers in the Karaka Glenbrook area. The remaining consents were to take water from outside of these aquifers (Drury, Bombay etc)

Figure 5.2 shows the distribution of groundwater use, allocation and number of users per aquifer.

[1] Years 1998 and 1999 are chosen for analysis because of the most complete data

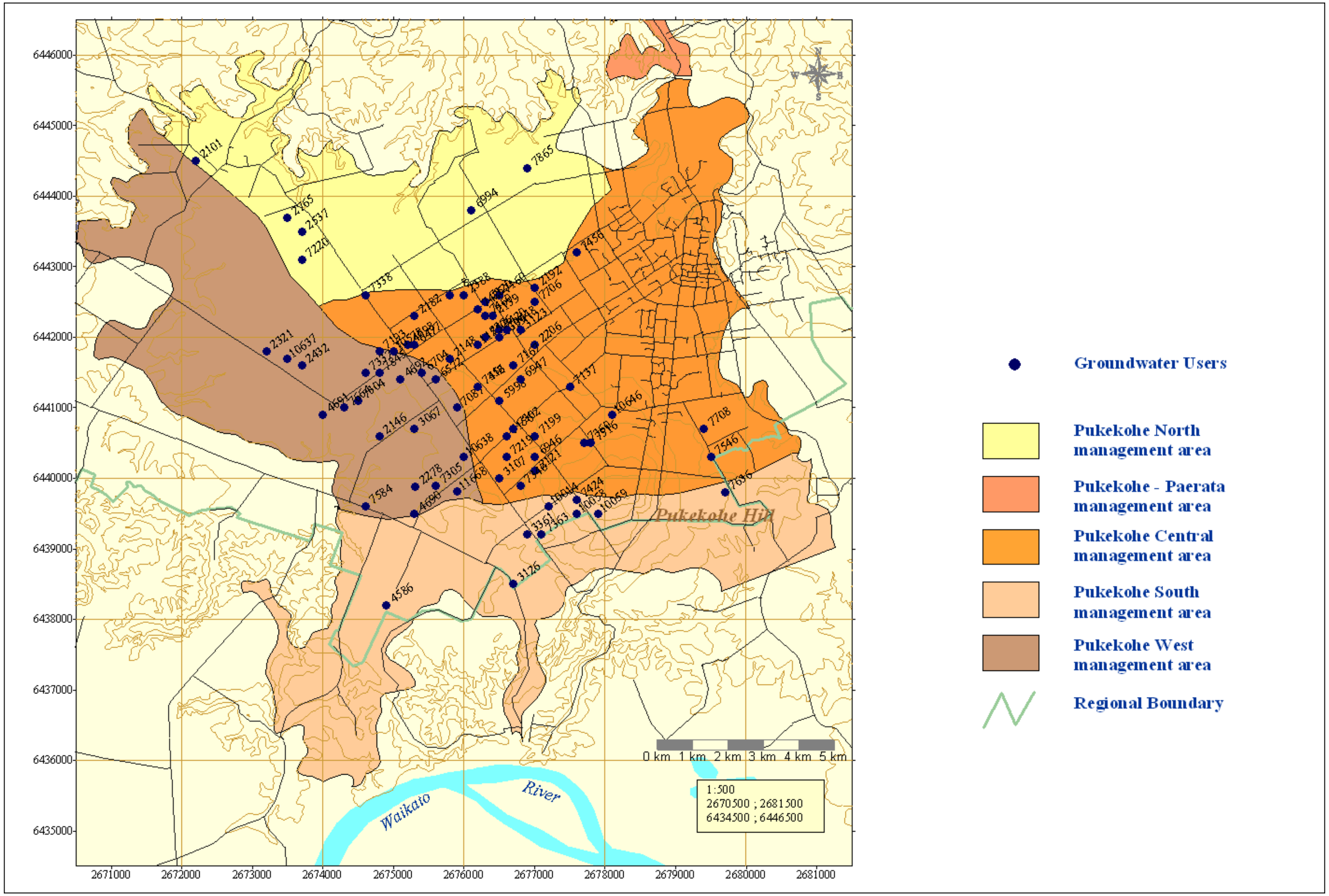

Figure 5.1 Pukekohe Volcanic Aquifer groundwater users

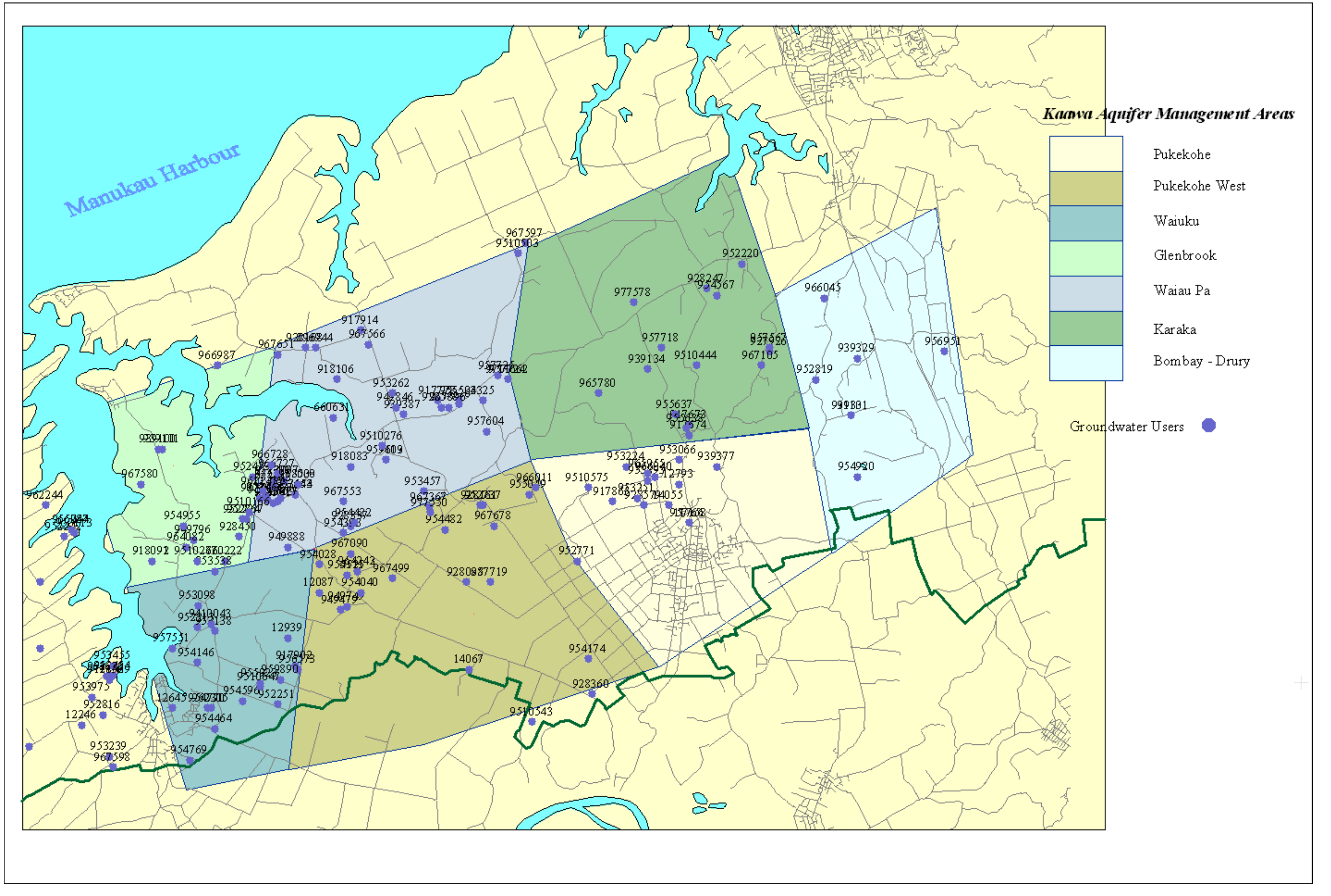

Figure 5.2 Kaawa Aquifer groundwater users

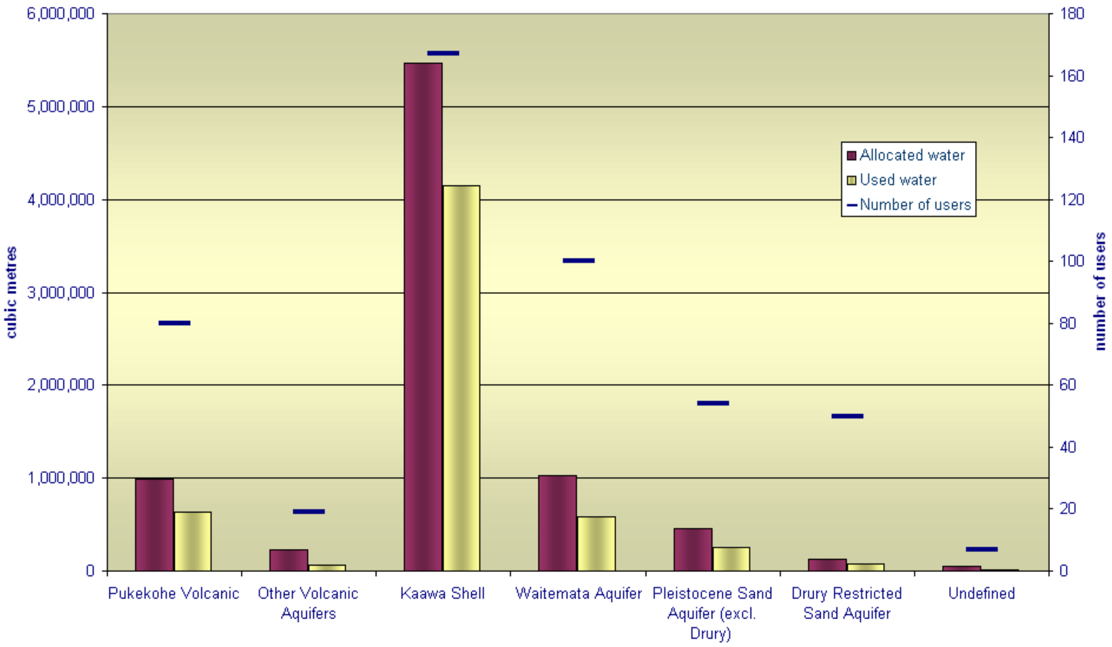

Figure 5.3 Groundwater uses distribution per aquifer

The highest allocation and use is from the Kaawa Aquifer with more than 5,000,000 cubic metres per year of groundwater allocated and with a metered use of more than 4,000,000 cubic metres per year (Figure 5.3). Pukekohe Volcanic Aquifer has groundwater availability of one million cubic metres per year with an allocation of 947,094 cubic metres per year. The aquifer was restricted for further allocation in 1996 due to a conservative approach taken with respect to availability based on information available at the time. The total amount of ground water allocated to all aquifers in Franklin area in 1999 was 8,326,340 cubic metres per year, and 81,153 cubic metres per day. Total annual water use in 1999 was estimated from metered use records to be 5,676,971 cubic metres.

Figure 5.4 shows the distribution of resource consents according to the type of use in 1999 and also the percentage of use from the total annual allocation.

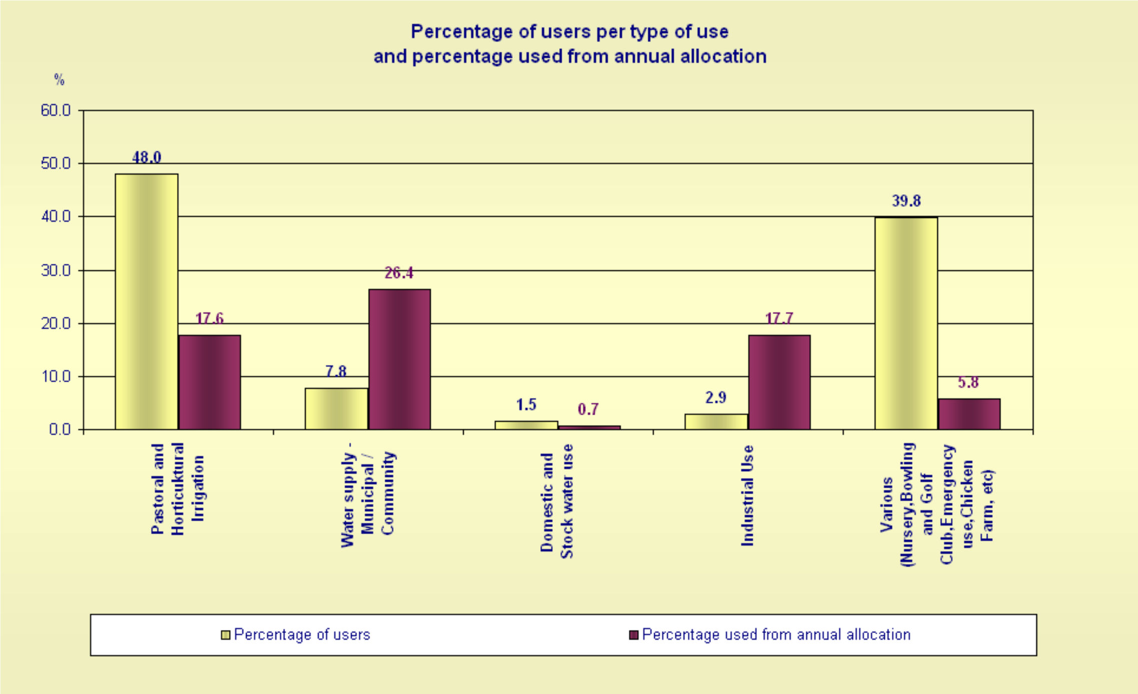

Figure 5.4 Percentage of groundwater use by type of use and total annual allocation

The majority of the groundwater users in 1999 (approximately 48% in terms of number of users) were for pastoral and horticultural irrigation. This includes golf fairways and sports field irrigations.

The second largest individual group of use was miscellaneous use with 39.8% and third group was community and municipal supply with about 7.8%. These percentages may vary from year to year depending on change in land use.

This ratio differs from a volume perspective with the largest groundwater allocation to municipal and community supply utilising 26.4% of water allocated. The second largest groundwater allocation is various industrial uses utilising 17.7% of the allocated resource. The third groundwater use by allocated volume is pastoral and sports field irrigation with 17.6% of total allocation followed by miscellaneous use of 5.8%. Stock and domestic use (consented) is last with only 0.7% of the total allocation per year.

Allocations range from approximately 200 to 2,000,000 cubic metres per year or 1.48 to 5,200 cubic metres per day.

Accuracy of the records of annual water use depend on the quantity and quality of water meter readings being returned to the ARC by consent holders. Total annual water use may be higher than that recorded in database records returned by users.

5.1.1. Kaawa Aquifer Groundwater use

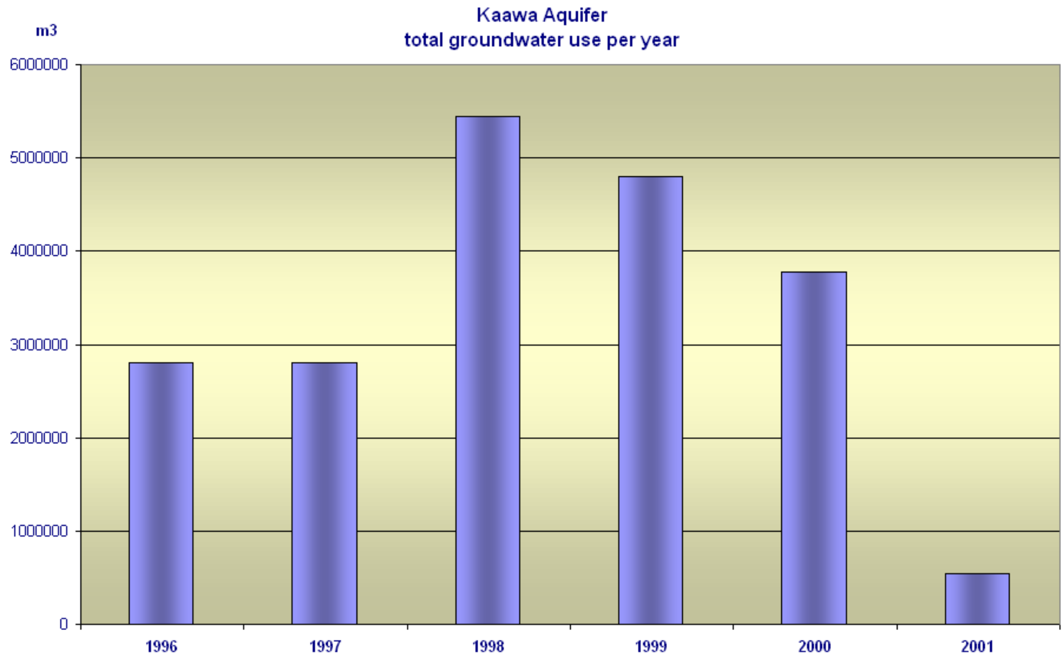

Figure 5.5 Groundwater use from the Kaawa aquifer in period from 1996 - 2001

Figure 5.2 shows location of groundwater allocations from the Kaawa Aquifer within management areas.

Figure 5.5 shows total actual abstraction from the 1996 to 2001 from the Kaawa aquifer. The increase in water use between 1996/7 and 1998 and the subsequent decline may represent a combination of climatic variability and a more accurate record of use. Values for 2001 represent an incomplete record.

The diagram in Figure 5.6 illustrates annual groundwater allocation within each of the new Kaawa management areas shown as a percentage of total water allocation for the complete Kawa aquifer.

The highest allocation of 29.6% is calculated to be in Karaka management area (currently over allocated due to existing allocations related to previous water availability) followed by Waiuku and Pukekohe management areas with 25% and 24.8% respectively.

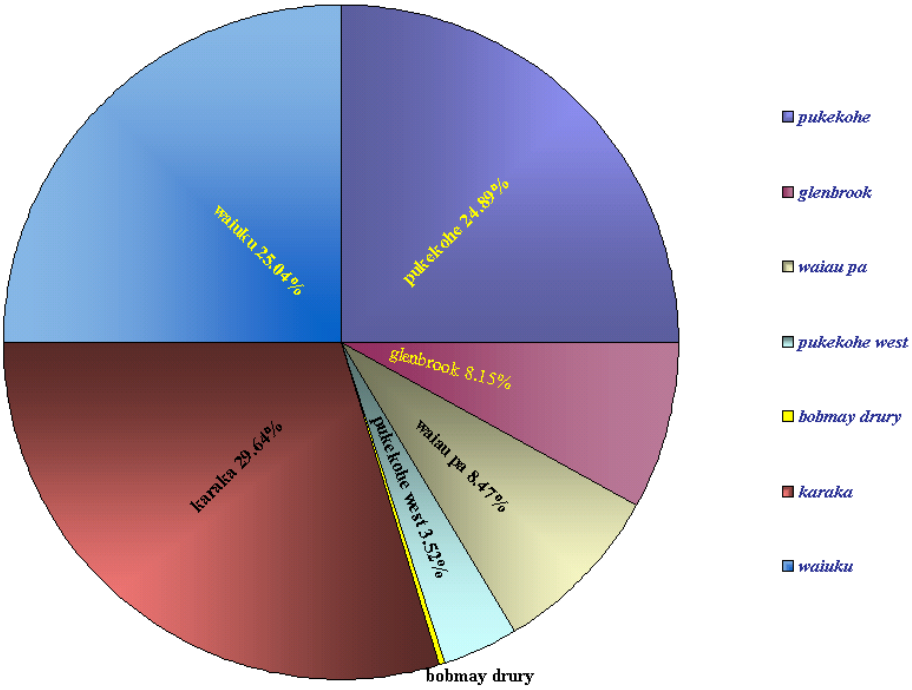

Figure 5.6 Groundwater use percentage from the Kaawa aquifer per new management area

The Glenbrook - Waiau Pa management area has a combined use of 16.6% of total Kaawa allocation. The smallest use is in the Bombay-Drury Kaawa management area with less than 1%. Pukekohe West management area with the largest land area in the aquifer has a relatively small portion with only 3.5% of the allocation.

Water abstraction from the Kaawa aquifer is partially influenced by the accessibility – the considerable depth from the surface to the aquifer related to the thickness of the overlying deposits. The number of water abstractions is higher in the areas such as Karaka, Waiuku and parts of Pukekohe where lesser thickness of the overlying sediments mean shallower bores. In areas such as Bombay – Drury or Pukekohe West where this thickness can be considerable and bores to the Kaawa aquifer are expensive.

Combining the groundwater allocation/use and its spatial and seasonal distribution it is possible to target less utilised areas for new water demanding developments.

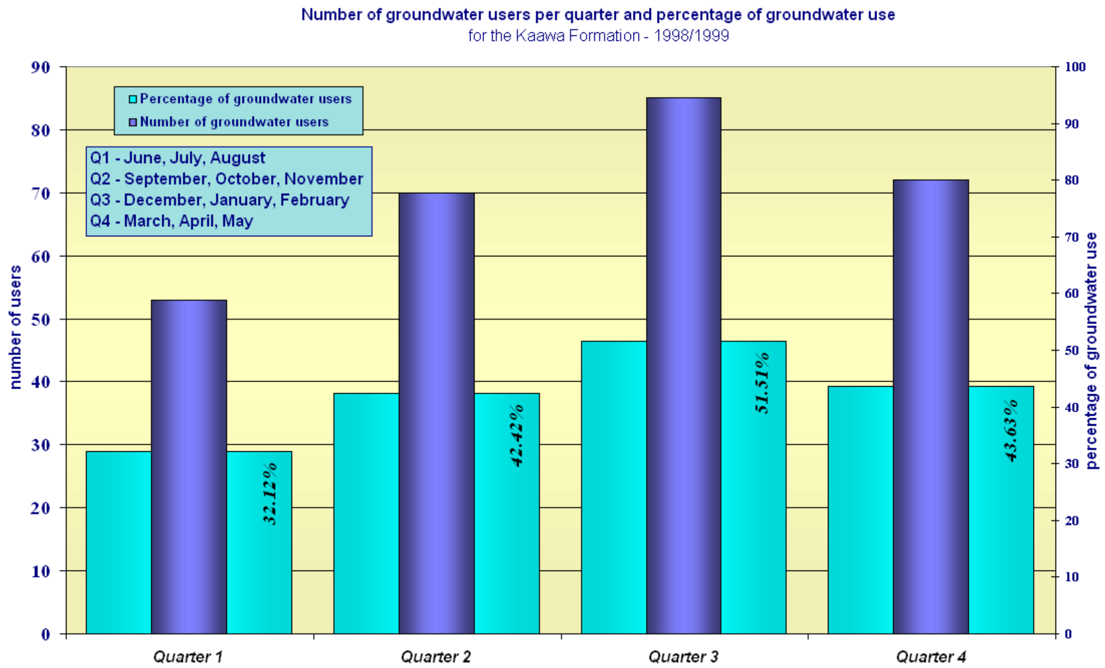

Figure 5.7 Percentage of groundwater users per quarter

An analysis of the groundwater use data for 1998 and 1999, split into average quarterly[2] use shows that the greatest number of users (51.5%) use water in the summer period from December to February (quarter 3). This is an increase of almost 20% from the winter period in the quarter 1 (June to August) when about 32% of users use groundwater (Figure 5.7). Approximately 42.4% and 43.6% of the users are using groundwater from the Kaawa aquifer in the period from September to November and March to May respectively (quarters 2 and 4).

[2] Quarter periods taken from the Compliance Monitoring Programme used by ARC to manage compliance with requirements to monitor water use:
Quarter 1 – June to August, Quarter 2 – September to November, Quarter 3 – December to February, Quarter 4 – March to May

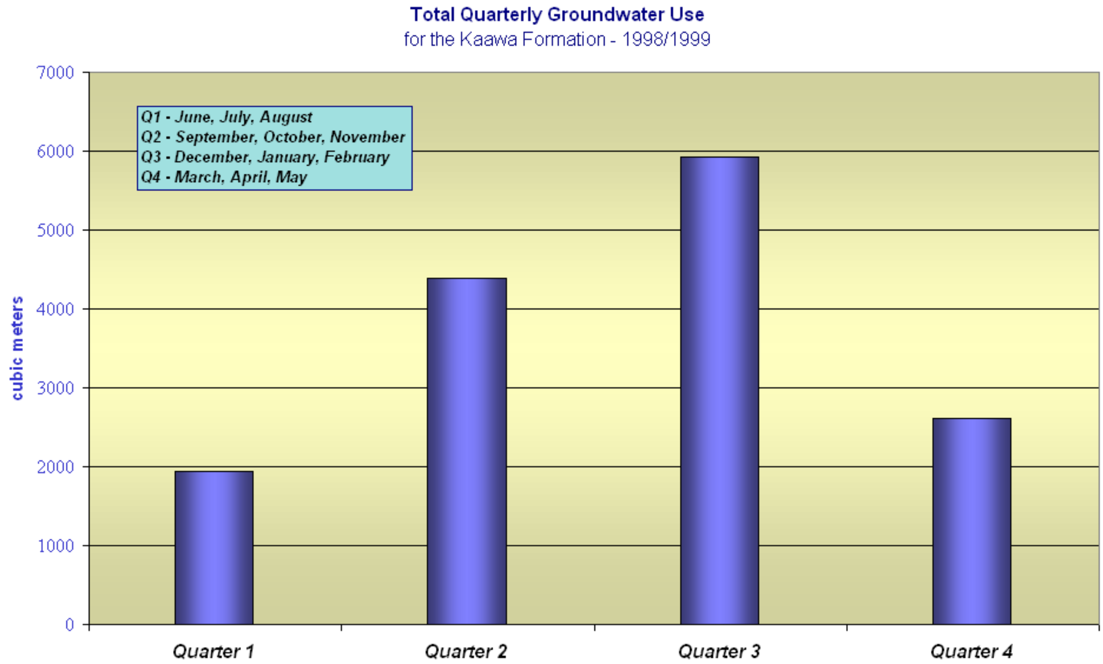

Figure 5.8 Quarterly water use from the Kaawa formation

Figure 5.8 shows increase in groundwater use towards the summer and the highest quarterly groundwater use is recorded in the summer period (from December to February – quarter 3). The lowest groundwater use is recorded in the quarter 1 from June to August.

From the comparison between number of users and differences in water use between the 2nd and 4th quarter (Figures 5.7 and 5.8) it can be concluded that the overall water use is related to the seasonal irrigation pattern of the dominant demand sector of pastoral and horticultural use.

5.1.2. Pukekohe Volcanic Aquifer

Pukekohe Volcanic aquifer had annual groundwater allocation limited to 1 million cubic metres per year therefore the maximum use should not exceed that figure.

The map on Figure 5.1 shows spatial distribution of the groundwater users in the Pukekohe Volcanic Aquifer.

Figure 5.9 shows total annual groundwater allocation for the 1999. The allocation was close to the groundwater availability and further allocation from that aquifer was restricted.

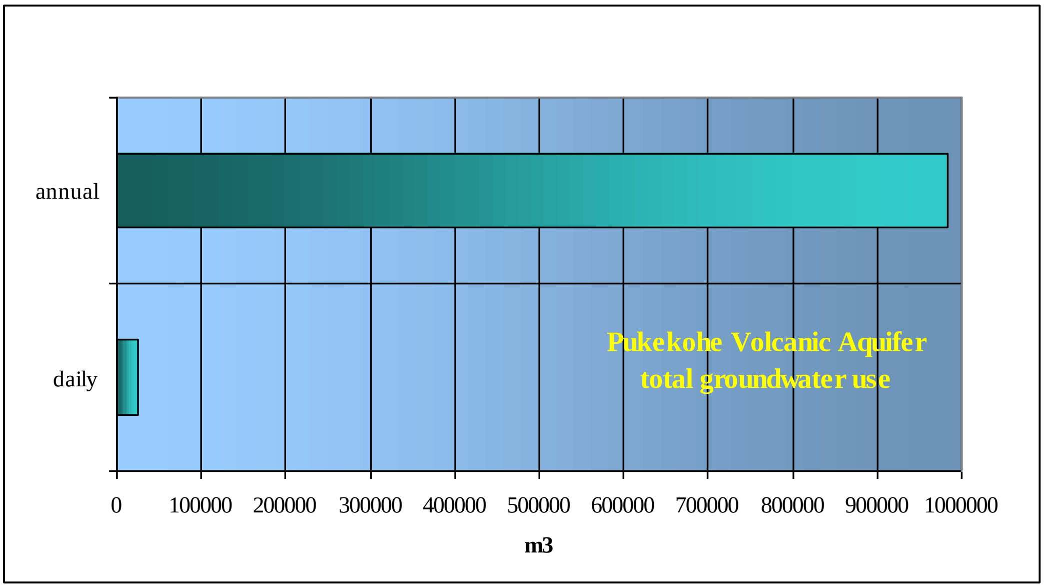

Figure 5.9 Maximum annual and daily water allocation for the 1999

The new management approach (Chapter 9) divides the annual availability for the aquifer into separate management areas. The increased estimated groundwater availability calculated in Chapter enables that restriction to be lifted.

Figure 5.10 shows the distribution of the actual groundwater use by the proposed volcanic aquifer management area. It shows that consent holders in the Pukekohe Central volcanic management area are using more than 400,000 cubic metres per year followed by the Pukekohe west volcanic management area with about 300,000 cubic metres of water used. The smallest use is in the Pukekohe South Volcanic management area. This area is split between Environment Waikato and Auckland Regional Council and there is a relatively small number of users. Potential cross boundary issues will be addressed in consultation with Environment Waikato (Chapter 9).

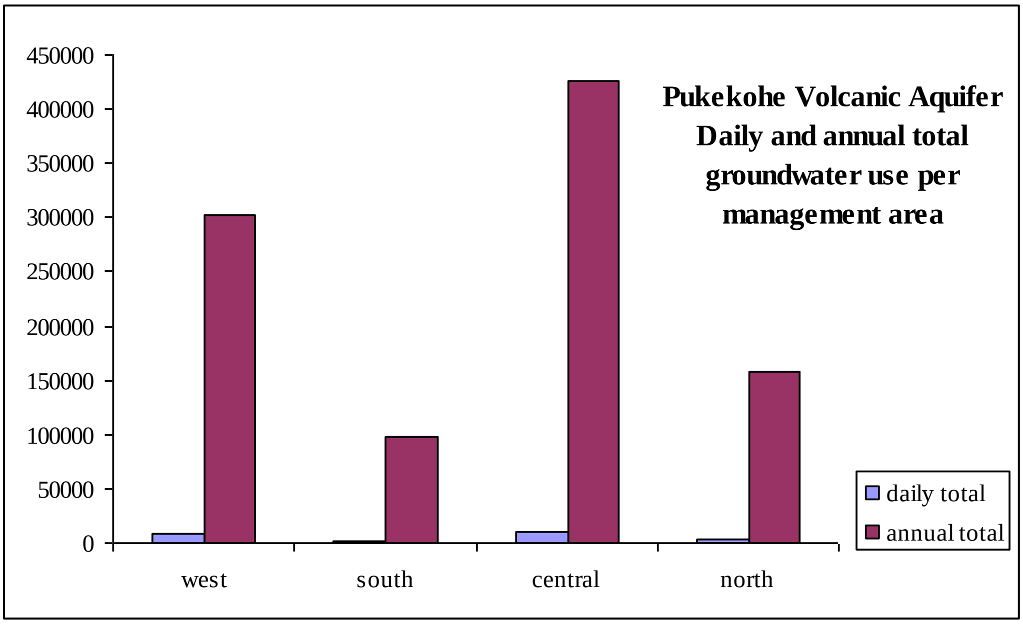

Figure 5.10 Groundwater use from the Pukekohe Volcanic aquifer by the management area

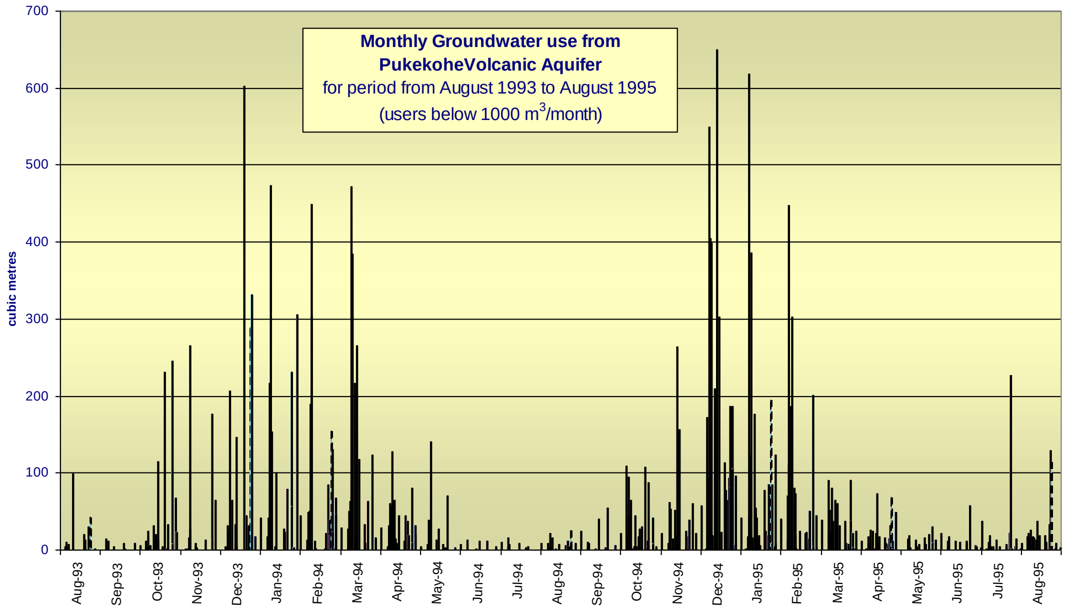

Figure 5.11 Monthly Water use for the period from 1993 to 1995

Seasonal character of the groundwater use in the Pukekohe volcanic aquifer is illustrated in the Figure 5.11. This is a comparison of two different hydrological periods - a dry period in the 1993/94 and wet period in the 1994/95. Only users with abstraction below 1000 cubic metres per month were analysed for display purposes bit this includes the majority of use.

The diagram shows a substantial increase in use in both periods at the beginning of October with another peak in use in December. The increase in use was extended in dry period until the end of May while in the wet season groundwater use was in decline from March with the lowest point in Jun and July. The peak use was almost one month longer in the dry period than in wet period.

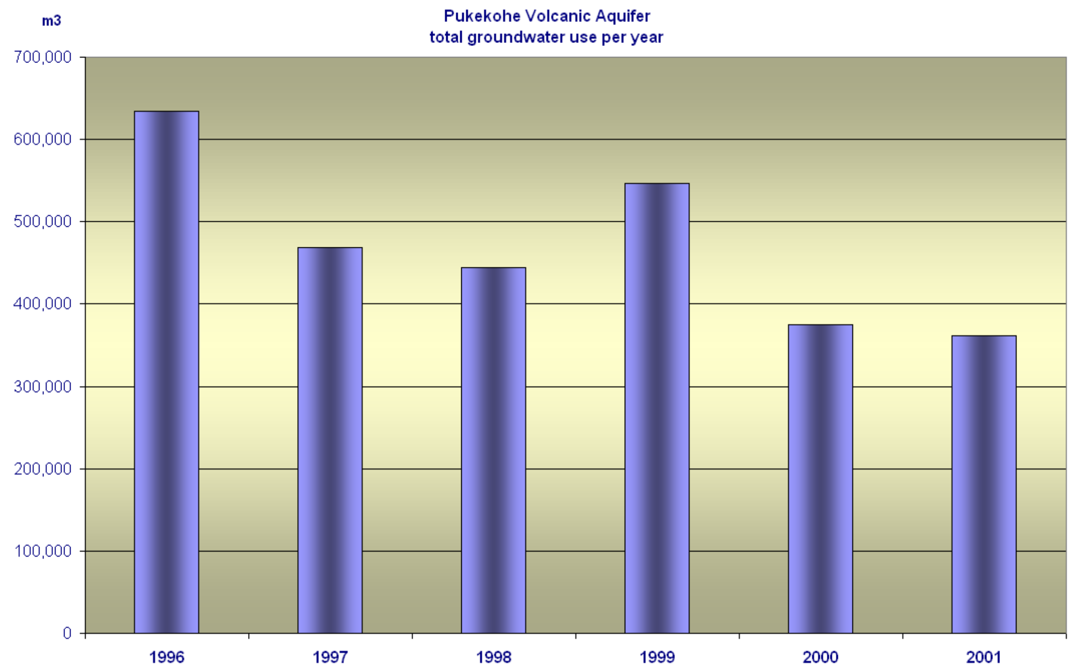

Figure 5.12 Groundwater use from the Volcanic aquifer in period from 1996 - 2001

Figure 5.12 shows the abstraction from the Pukekohe Volcanic aquifer in the period from 1996 to 2001. Total abstraction is the most of the time significantly than annual allocation. The increase in 1999 and the following decline in water use in 2000 and 2001 may represent a combination of climatic variability and incomplete water use record.

Groundwater users must be encouraged in both the accurate and timely reading of water meters and returning data for input into the ARC database. Good records of water use enables better understanding of aquifer behaviour, protection and management.

5.2. Surface Water

Approximately 130 consents were issued for the abstraction of surface water from South Auckland streams in 1999. Abstraction of surface water in South Auckland is either from streams (86 consents) or from dams (44 consents).

A total of 102 consents were issued for the pastoral and horticultural irrigation and the sports fields representing 78% of the total number of surface consents. Glass houses, nurseries, bowling and golf greens make up 14% and industrial use 4%. Surface water was is an important component of the municipal supply to Pukekohe. Daily allocation ranges from 5 to 11,500 cubic metres. The total surface water use during 1999 was 836,697 cubic metres, increasing from 691,653 cubic metres recorded during 1998. This increase reflects an improvement in consent holders sending in records of their water use to the ARC, rather than a change in water use or consent numbers.

Surface water use is not directly related to the groundwater availability estimation therefore it was not investigated further.

6. CONCEPTUAL MODEL

The modelling process and the recharge estimation consists of a several equally important steps. The first step is construction of the **conceptual model (Chapter 6)** which defines the recharge mechanism, hydrogeological conditions and relations between the different units. Also the conceptual model verifies and define the purpose and aims of the modeling. From the conceptual model developed is **recharge model (Chapter 7)** and performed water balance calculation. As the third and final stage from the conceptual model and expected recharge pattern developed is **numerical model (Chapter 8)** and performed numerical modeling as a verification of the validity of the conceptual model and recharge calculation. The high importance of the conceptual model is very high and results of the recharge modelling and numerical modelling depend on quality of the conceptual model.

6.1. Model boundaries

An essential part of the modeling approach is to identify the boundary conditions for the recharge model and to determine the setting for groundwater flow and movement through the aquifers. Physical and hydrogeological boundaries, potential recharge and discharge zones for the Kaawa Formation were defined (Figure 6.1). Hydrogeological relations between the different lithological groups were established and are presented in Figure 6.3.

One of the major geological characteristics of the area is the block tectonics of the Waitemata basement, with a large number of vertical (sub vertical) and mostly straight lined faults. The Waitemata Group sediments were partially eroded during the regression - transgression period and the deposition of the Kaawa Formation (Chapter 2). The significance of that is to direct the deposition of the Kaawa Formation and forming base for the Kaawa aquifer.

Several major faults bounding the area were identified and are considered as the main aquifer and model boundaries. These faults are: Waikato Fault at the south, Drury Fault in the east and Glenbrook Fault in the north (Figure 6.2). The central area surrounded by those faults is generally lowered and the Kaawa Formation, overlying less permeable Waitemata sediments, is dipping and thickening towards the south.

Three types of hydrogeological boundaries are assumed: **no flow** boundary (no flow exchange through the boundary); **constant head** boundary with potential discharge; and **drain or discharge** boundary that allows discharge from the area.

Eastern and southern boundaries represented by the Drury Fault and Waikato Fault are considered as no flow boundaries. In the numerical model the St. Stephens fault and Waiuku – Pukekohe fault zone (Kaawa aquifer groundwater divide) are considered as a no flow boundary.

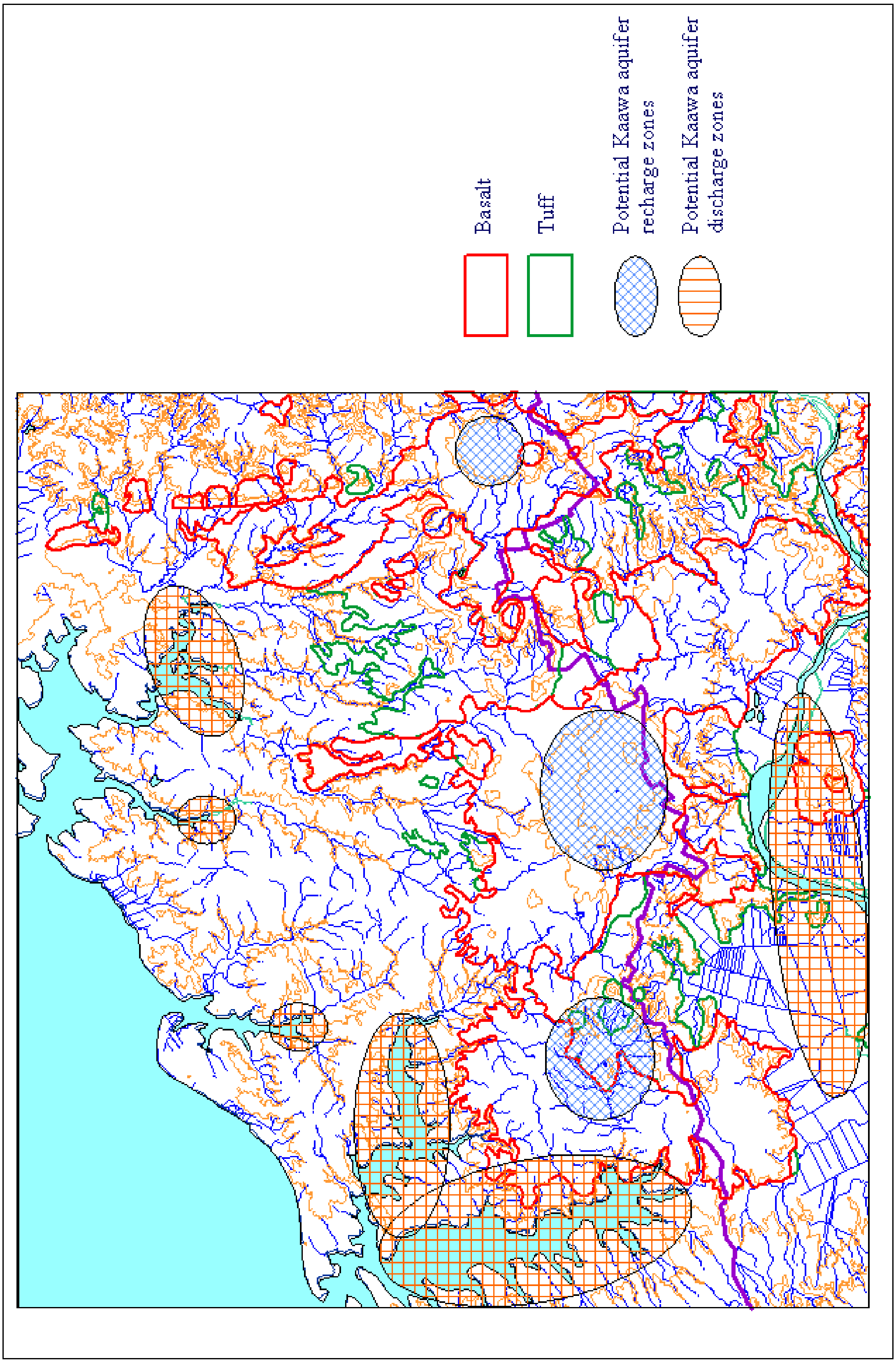

Figure 6.1 Potential Kaawa aquifer recharge and discharge zones

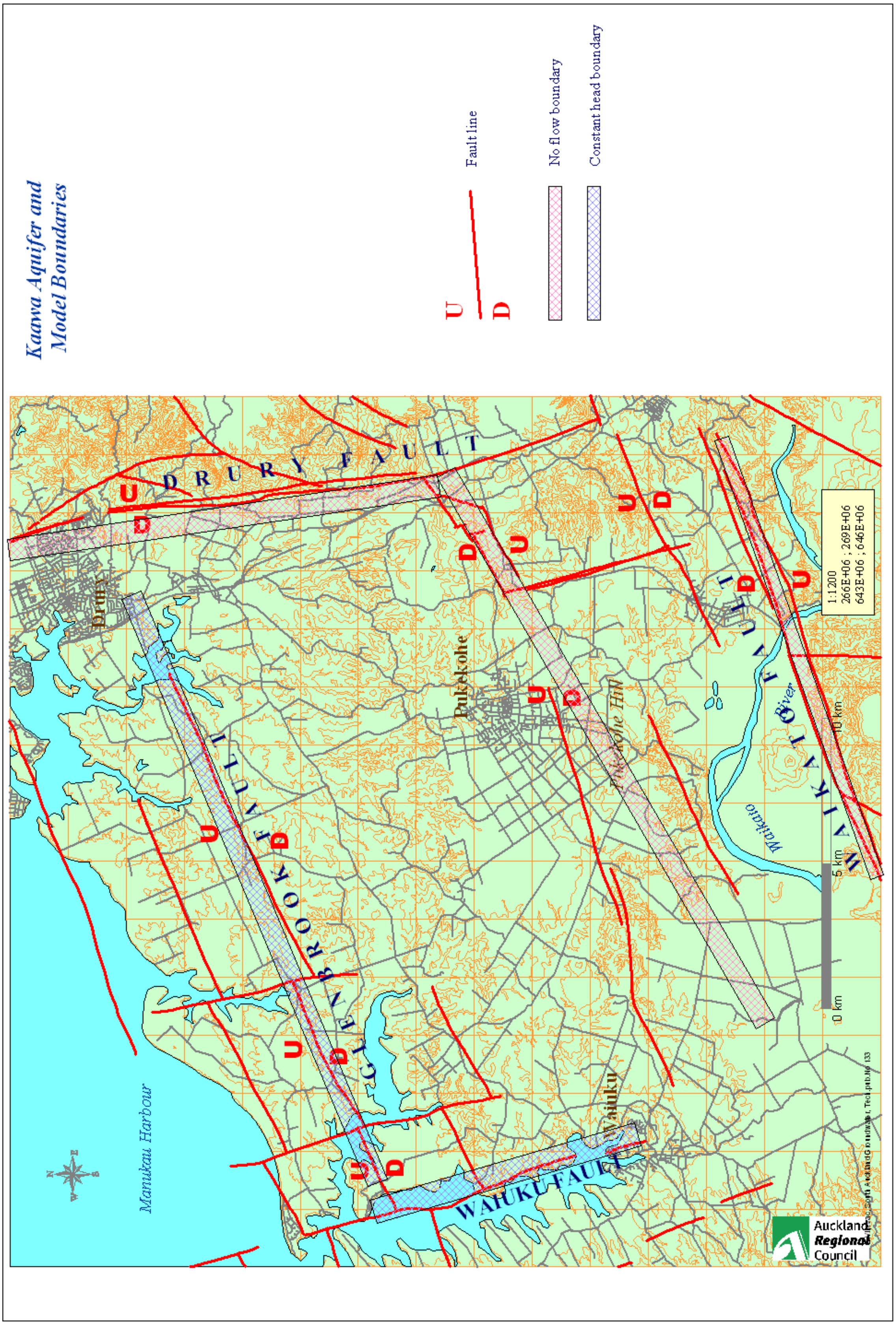

Figure 6.2 Model and Kaawa aquifer boundaries

The northern boundary is less certain than southern and eastern boundaries. A number of parallel faults (generally striking E-W) are intersected by perpendicular faults creating a complicated pattern of uplifted and downthrown blocks. This boundary is represented by the Glenbrook Fault, which can also be described as a constant head boundary and as a no flow boundary (Figure 6.2).

The arrangement of lithological units along the Glenbrook Fault (Kaawa Formation – Waitemata sediments – Pleistocene sands) allows some flow exchange across the boundary, mainly as flow above the Waitemata sediments, discharging through the thin Kaawa sediments into the harbour (Figure 6.3). The western boundary is located along the Waiuku River, between Awhitu Peninsula and Manukau Lowlands (Figures 6.1 and 6.2) is a constant head boundary. It is assumed, because of differing hydrogeological properties, that no flow exchange occurs between the bedrock (Waitemata Group) and the Kaawa Formation. That is assigned as a no flow boundary in the hydrogeological model. The locations and the types of boundaries are shown on (Figure 6.2).

Pleistocene sediments (Tauranga Group) overlying Kaawa Formation form a shallow and relatively thin cover which acts (in its lower surface) as an aquitard confining the Kaawa Aquifer.
It is hypothesised that Volcanic rocks at the surface intersect sediments underneath, with their lava (or scoria) conduits providing a groundwater path for the Kaawa aquifer recharge. This is driven by the relatively high permeability of the volcanic rocks, the head difference between groundwater levels in volcanic and Kaawa aquifers and the relatively good permeability of the Kaawa Formation.

6.2. Conceptual recharge model

The Conceptual model for recharge to the Kaawa aquifer is based on the following assumptions:

1. Recharge occurs only in higher elevated areas (e.g. above average spring elevation)
2. Recharge occurs in areas covered by volcanic rocks (Tuff-Basalt)

3. Recharge to the Kaawa aquifer may occur in the vicinity of volcanic cones where groundwater heads in the basalt are considerably higher than water heads in Kaawa Formation
4. Hydraulic parameters of the various lithological (stratigraphic) units enables flow exchange
5. Absence of vertical leakage between confining and confined lithological units
6. No or very little flow occurs between Kaawa Formation and basement rocks (Waitemata or Greywacke) and overlying Pleistocene sediments
7. Discharge from the Kaawa Formation occurs at the fault zones in the areas of lower elevation such as Waikato River valley, Manukau Lowland (coastal area) and Waiuku River where the water level in the Kaawa aquifer exceeds topographic surface elevation (artesian water).

Taking into account the assumptions described, the Kaawa Aquifer is considered as a confined leaky aquifer and Figure 6.3 shows a conceptual model of the recharge to the aquifer. This model is represents a cross section from the Waikato valley across the Pukekohe Hill and Manukau Lowlands to the Manukau Harbour (orientation S - N).

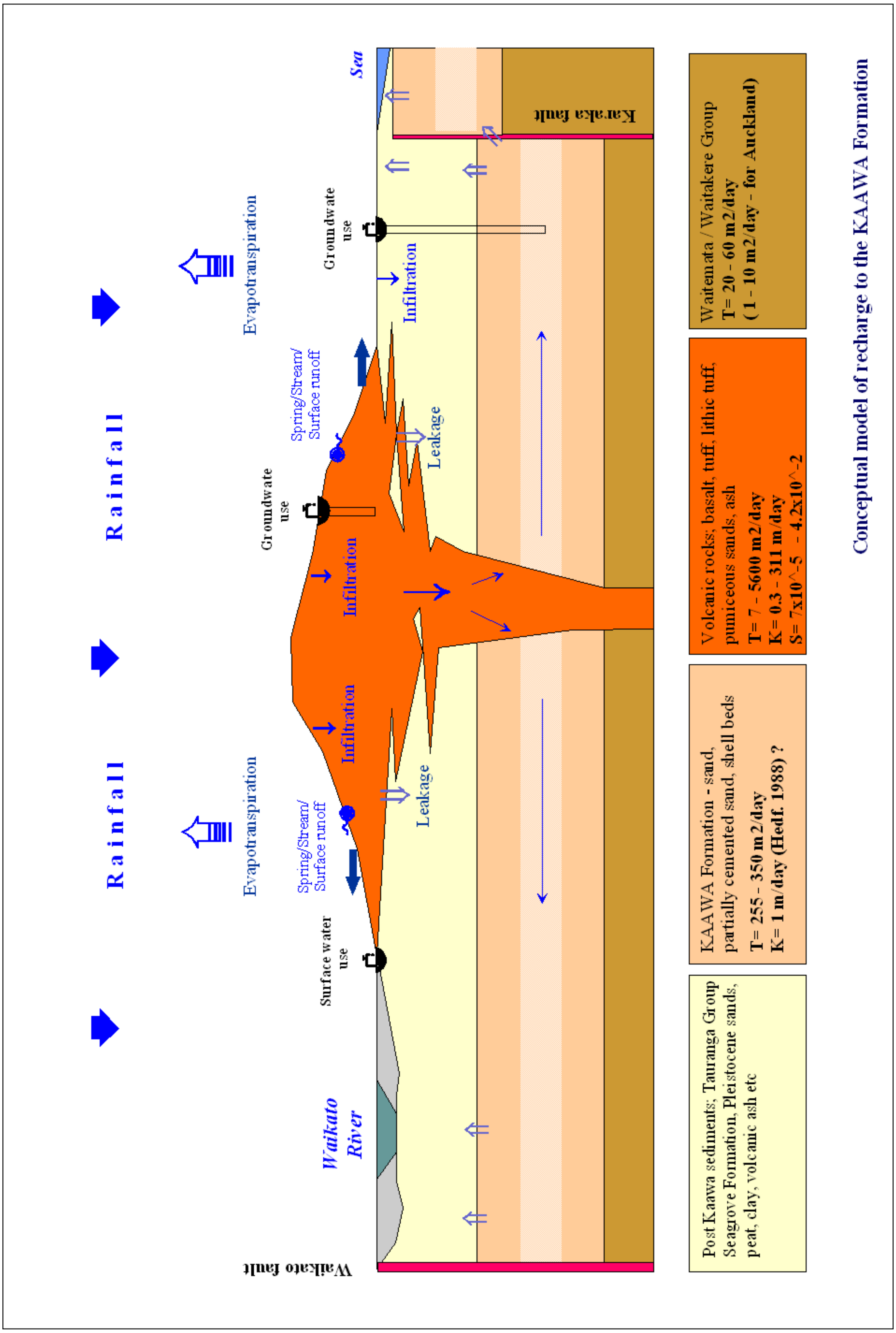

Figure 6.3 Conceptual model of the recharge to the Pukekohe Volcanic and Kaawa aquifers

Figure 6.3 is a schematic interpretation of the layered structure of the area and a schematic illustration of the conceptual model of the recharge to the Kaawa aquifer. This model is described as follows:

- Rainfall infiltrates into the volcanic soil and basaltic / scoriaceous aquifer (Chapter 4). After infiltration the losses from the aquifer are as spring discharge and groundwater use.
- Volcanic deposits and volcanic cones mainly cover the areas of highest elevation. Because of specific hydrogeological characteristics described in Chapter 3, they form good groundwater storage is possible which enables long term (delayed) infiltration, enhancing the recharge to the underlying sediments.
- Main recharge occurs through vertical flow via volcanic conduits.
- Pleistocene sediments overlay the Kaawa Formation forming a less permeable confining layer.
- Waitemata Group forms low permeable basement rock, overlaid by Kaawa Formation.

A large number of volcanic cones (Chapter 2) penetrate underlying sediments creating conduits, what allows downward groundwater flow. The higher relative porosity of lava / scoria conduits allows recharge to underlying Kaawa sediments. Because of high hydraulic pressure (water “column” in the conduit), groundwater is pushed through the conduit inducing downward flow into the surrounding sediments of the Kaawa aquifer (Figures 6.3 and 6.4).

Flow lines constructed within the volcanic rocks (Figure 6.4) show the concept of the groundwater flow and the location of potential recharge areas to the volcanic and underlying rocks.

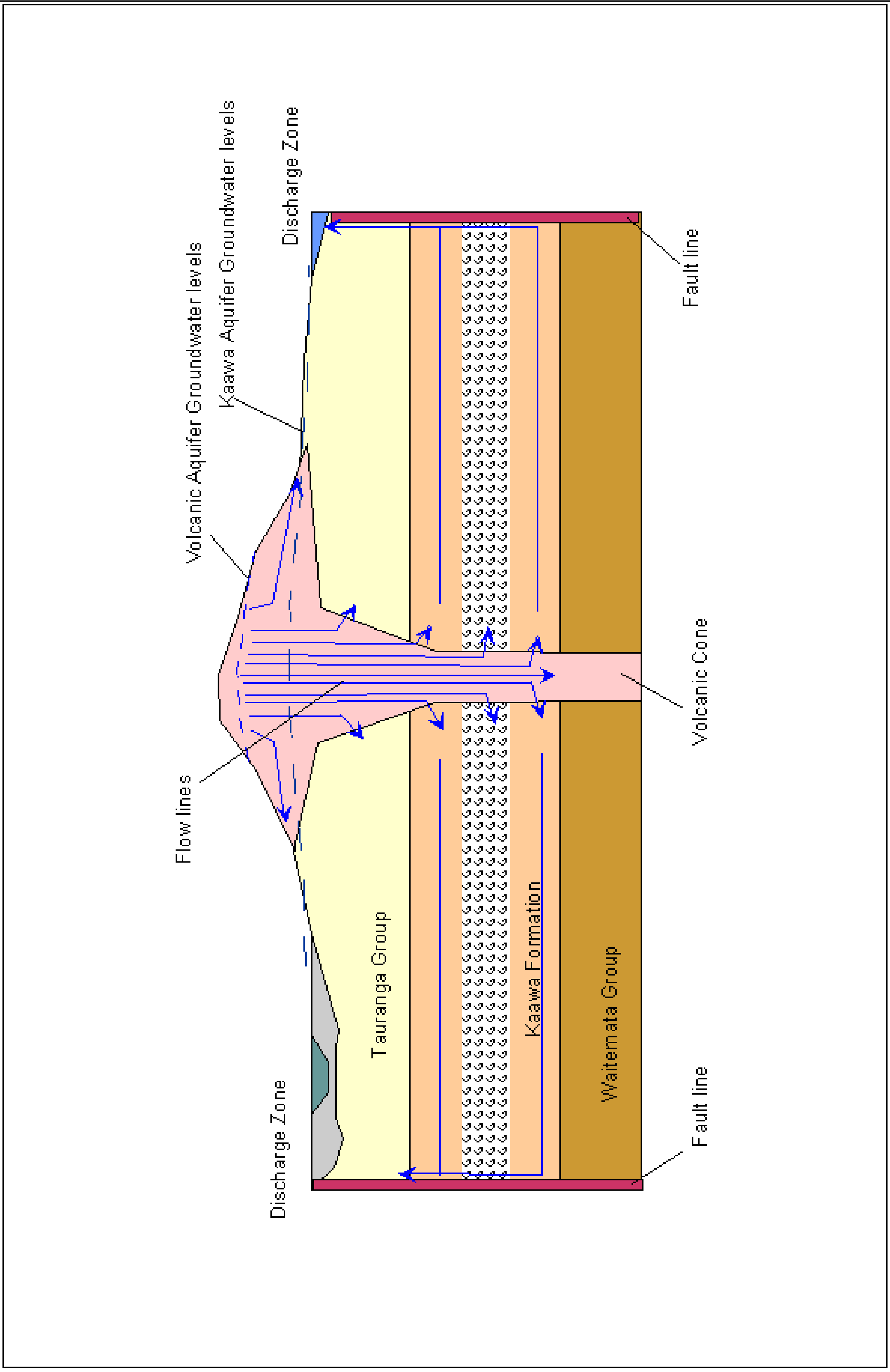

Figure 6.4 Concept of the groundwater flow exchange between the aquifers

Recharge to the volcanic aquifer occurs in areas with vertical or oblique downward flow lines regarding groundwater table (Figure 6.4). Where flow lines follow the water table and they are "parallel" to the groundwater surface. In such areas surrounding springs the recharge is minimal and subject to quick discharge. Areas with upward flow lines are considered as discharge zones.

Figures 6.5 and 6.6 show the relationship between groundwater elevation in the Volcanic and Kaawa aquifer. Figure 6.5 shows a west – east cross section through the Pukekohe Hill and Figure 6.6 a cross section from the Pukekohe Hill towards Manukau Lowlands (south – north).

Rainfall is the main recharge source for the Pleistocene sediments. Along with the potential for some deep infiltration from the basalt. Discharge zones of the Pleistocene sediments are assumed to be in the areas such as the Pleistocene / Alluvium contact in the south and coastal areas and stream valleys in the north. It is most probable that

the groundwater discharge from the Pleistocene sands has some contribution to the wetland in the Aka Aka area.

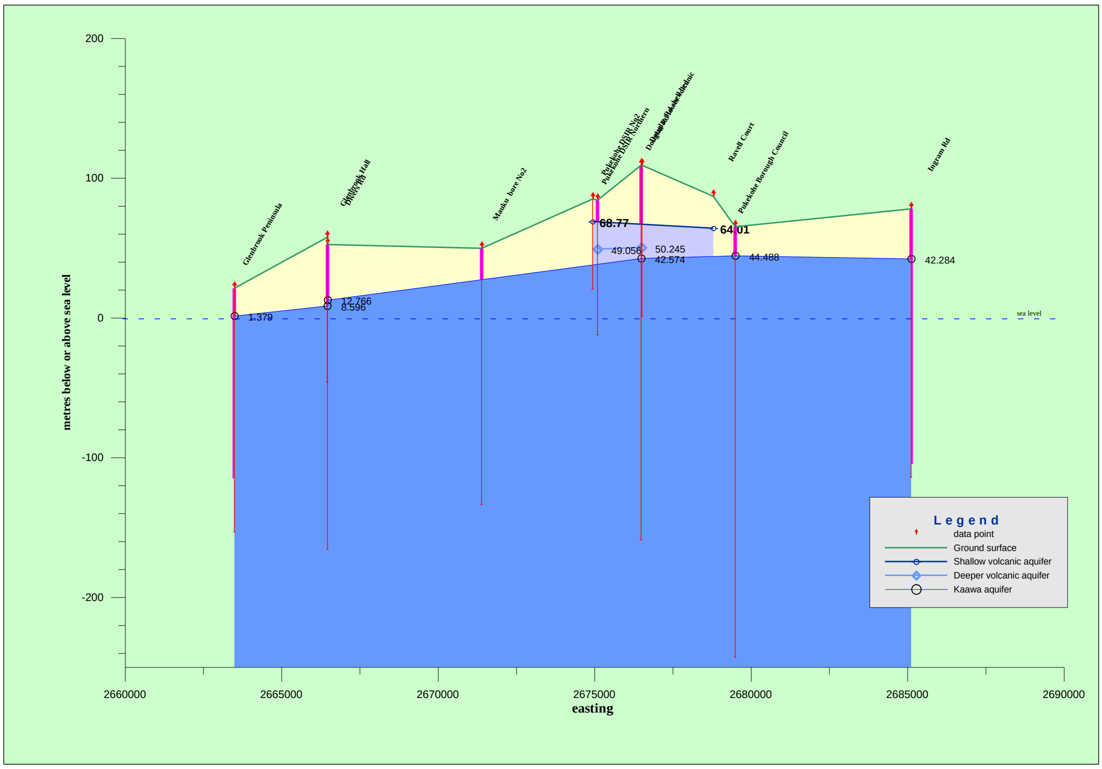

Figure 6.5 Groundwater level comparison Basalt – Kaawa formation

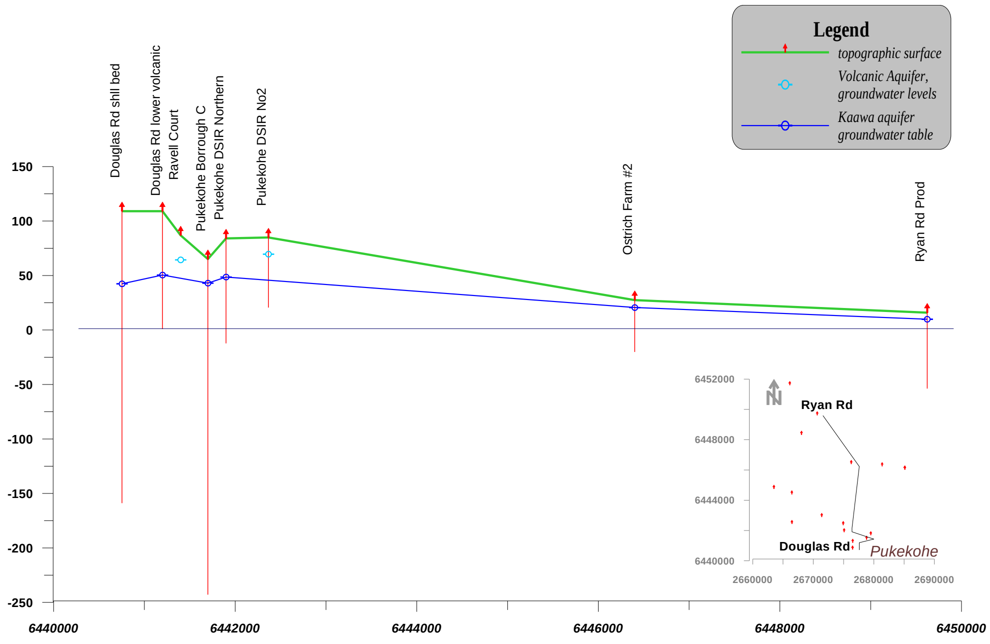

Figure 6.6 Groundwater level difference between Kaawa and Pukekohe volcanic aquifer

6.3. Conclusion

Recharge to the Kaawa Formation occurs directly from the volcanic aquifer (basalt and tuff). Recharge to the Kaawa aquifer as a result of leakage from the overlaying Pleistocene sediments is considered unlikely because of significant differences in hydraulic parameters which confine the Kaawa aquifer.

The concept of recharge through the volcanic conduits is supported on several grounds:

- The highest groundwater levels in the Kaawa aquifer occur in areas of high ground elevation usually associated with volcanic cones such as Pukekohe Hill.
- The high groundwater levels in volcanic aquifer, the head difference combined with the location of volcanic conduits and confined Kaawa aquifer conditions creates a classic artesian system.
- The recharge area has typically higher water table elevation than the distant groundwater heads in the confined part of the aquifer.
- The groundwater is “pushed” through the basalt conduits driven by hydraulic pressure and infiltrates into the Kaawa sands and shell beds.
- Shell beds being more permeable than sand/sandstone, create a major pathway for the groundwater flow. Flow lines through the Kaawa aquifer are largely sub parallel or parallel to the aquifer’s bottom and upper boundary. On reaching a no flow boundary (e.g. Waikato, Drury or Karaka Fault) they change into upward flow forming discharge zones (Figure 6.4).

Using this conceptual model, recharge volumes of the aquifers were calculated, from which the available water for allocation is derived (Chapter 7).

7. RECHARGE MODEL AND WATER BALANCE

7.1. Introduction

Calculation of the recharge to the Pukekohe Volcanic and Kaawa aquifer is based on the conceptual model of recharge (chapter 6). This model shows what is understood to be a recharge process from the rainfall event to the Kaawa aquifer recharge and discharge into the sea.

Starting from the basic water balance equation (equation 7.1) recharge **R** to an aquifer is equal to all inputs reduced by all the losses.

Equation 7.1

$$\mathbf{R = In - Out} \text{..}$$

Replacing **In** and **Out** with the list of contributing parameters, we will get a general recharge equation with a number of input and output parameters (equation 7.2).

Equation 7.2

$$\mathbf{R = (Rf + In) - (Ev + Tr + Rn + Dspr + Dsea + Lk + Wuse)} \text{ ....}$$

On the positive side of this equation is **Rf** –rainfall and **In** - infiltration into the aquifer from other sources such as other aquifers or streams and rivers. Losses from the system are represented by a number of parameters: **Ev** - evaporation, **Tr** - transpiration, **Rn** - surface runoff, **Dspr** - spring discharge, **Dsea** - discharge into the sea, **Lk** - leakage and seepage from the aquifer into the adjacent aquifers and **Wuse** - water abstraction from the aquifer.

Water use (**Wuse**) is not a necessary part of the estimate of recharge to an aquifer equation unless a particular aquifer provides source of the recharge to other aquifers.

Water availability equals the **R** (recharge) minus all other requirements such as minimum spring/stream discharge, maintenance of the groundwater levels, maintenance of the recharge to the other aquifers, salt water intrusion prevention and prevention of other possible negative environmental effects.

However, this equation has a number of parameters which are sometimes difficult to obtain. Some of the parameters should be estimated or derived from other measurements. The potential consequence of a lack of data is in inaccuracy and difficulty in calculation of recharge.

Because of the complexity of the recharge process, each of the two Franklin aquifers, Pukekohe Volcanic and Kaawa had to be looked at separately.

7.1.1. Pukekohe Volcanic

For the Pukekohe Volcanic aquifer this equation can be partially simplified taking into account that the rainfall is the only source of recharge and no groundwater discharge into the sea can occur. The equation is then as follows:

Equation 7.3

$$\mathbf{R_{volcanic} = Rf - (Ev + Tr + Rn + Dspr + Lk + Wuse)} \ldots\ldots\ldots\ldots\ldots\ldots$$

Parameters used in the equation 7.3 are partially measured and partially estimated or simulated.

The rainfall gauged on 11 sites within the area shows very high spatial variation. Evaporation is measured using an open pan method for some period and using data from the Auckland Airport estimated for the rest of the period.

The estimation of the evapotranspiration is very difficult due to a very large diversity of the land use across the area.

The amount of surface runoff from the volcanic cones is uncertain and very difficult to estimate because of a lack of information. It is assumed that the surface runoff is generally low, because of the relatively high infiltration rate, and mostly related to the occasional summer storm events (chapter 4).

Spring discharge was estimated and simulated using flow data from automatic sites within the area and low flow gauging data from a number of locations.

It was attempted to estimate the stream and spring discharge from the basalt body as near as possible to the edge of the basalt aquifer. Table 7.2 shows estimated discharge from the basalt only.

Infiltration from the volcanic aquifer(s) to the Kaawa aquifer through the volcanic conduits was the most difficult to estimate. The size (diameter) of the volcanic conduits is mostly unknown and had to be estimated using some data from the Auckland Isthmus (Searle,).

Aquifer parameters are often unavailable from a particular location and data from the nearest measured location or other appropriate places had to be used.

7.1.2. Kaawa Formation

Derived from the equation 7.2 and 7.3 the equation for the recharge to the Kaawa Formation is as follows:

Equation 7.4

$$\mathbf{R_{Kaawa} = In\ (\ = Lk) - (\ Dsea + Lk_2)}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

It is considered that the recharge into the Kaawa aquifer strongly depends on water supply from the overlying volcanic aquifers. The geological setting (chapter 2) does not support the likelihood of recharge from the other aquifers surrounding the Kaawa Formation (Chapter 3). If that is the case, it would only be a minor contribution to the total Kaawa recharge.

Figure 7.1 illustrates the relationship between Volcanic and Kaawa aquifer recharge. The emphasis is on infiltration (Lk) from the volcanic through the volcanic conduit into the Kaawa Formation aquifer (Chapter 3.).

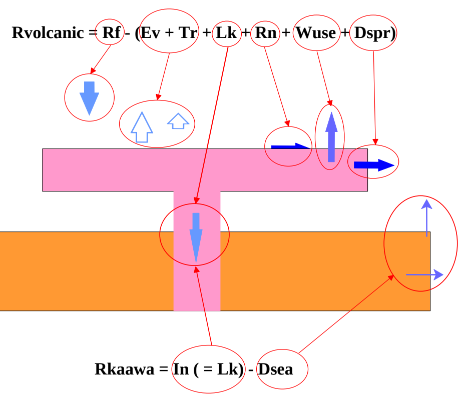

Figure 7.1 Graphical illustration of the recharge components

Combining equations 7.3 and 7.4 after the process of parameter estimation and simulation of the missing parameters, it is possible to calculate recharge and consequently water availability for the Kaawa aquifer.

Previous reports have suggested a relatively wide range of recharge rates were calculated For the Pukekohe Volcanic aquifer.

7.1.3. Historic recharge estimations

Approximate net recharge to the Pukekohe Volcanic aquifer, based on the average rainfall and evapotranspiration values over a ten year period, is calculated to be about 125 mm/y (ARC, 1996). This figure was an average recharge value for the entire aquifer.

Various authors, using the same approach, calculated a wide range of net recharge to the volcanic aquifer (Table 7.1).

Table 7.1 Historic net recharge estimations for the Pukekohe Volcanic aquifer

Source	Year	Net recharge	Recharge
Petch	1991		500 – 700 mm/year)
Petch & all	1991	35 mm/year	
White and all	1996	15 – 92 mm/year	
ARC	1996	125 mm/year	

The recharge result obtained by this method has been used in this research for comparison with the result obtained using a combination of a soil moisture method (measured infiltration rate) and the flow net calculation.

Figure 7.2 shows monthly recharge to the Pukekohe volcanic aquifer based on the basic water balance equation (Equation 7.1). The evaporation rate of 75% was estimated for the area using data from the Pukekohe DISR site and comparison with the evaporation data from the Auckland Airport (chapter 4).

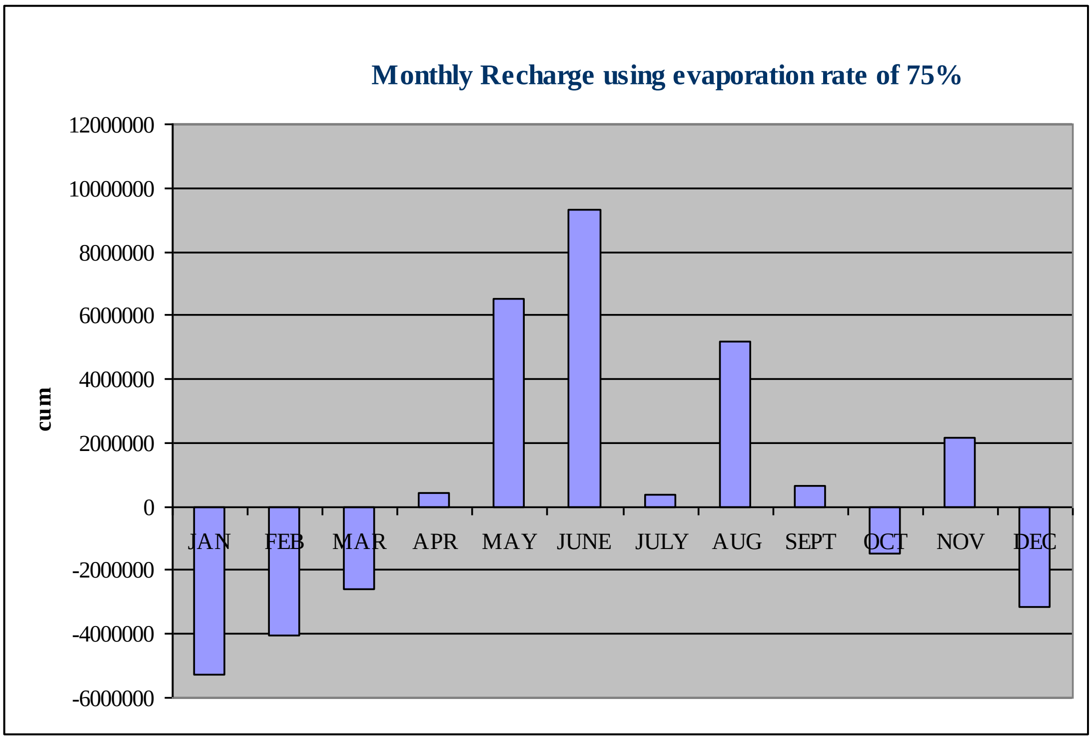

Figure 7.2 Pukekohe volcanic recharge estimation using evaporation rate

The diagram shows that the main recharge occurs during the four months of the year with an annual recharge of about 23.5 million cubic metres. Estimated annual discharge from springs and streams is about 27 million cubic metres.

For a better understanding of the recharge mechanism and recharge rates to the Volcanic aquifer and therefore recharge to the underlying Kaawa Formation, it was necessary to understand the rainfall – soil moisture – infiltration relationship.

One of the recommendations which emerged from the ARC work in 1996, was to estimate quantitative recharge to the Pukekohe volcanic aquifer (ARC, 1996).

7.1.4. Field investigation by GNS[3]

To perform such an estimation an experimental site in Pukekohe was established. The GNS and ARC undertook a 3-year monitoring program (M. Rosen, 2000, P. White 2002).

The first study site was located within the climate station compound on the property of the Crop and Food Research centre at Cronin Road in Pukekohe. The location of all monitoring sites is shown in Figure 7.3.

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[3] Institute of Nuclear and Geological Science, Wairakei

This site was selected for three major reasons:

- The soil present at the station is yellow brown loam - the most common type of soil in the Pukekohe area,
- Accessibility to geological and climate data for the location and
- Close proximity of a bore tapping water from the shallow volcanic aquifer.

Figure 7.3 Location of the GNS infiltration sites

The result of recharge estimates using a TDR method (which includes three different methods) is approximately 700mm presented as a total annual rainfall recharge (M.Rosen, 2000).

The value of 680mm/year is the recharge amount for the volcanic aquifer used in this study. This is the recharge figure for the period of March 1997 to March 1998 at the study site. The recharge figure is calculated using several methods and already includes all potential losses stated in the Equation 7.2. Therefore this figure represents measured recharge (gross recharge) into the aquifer and incorporates evaporation, transpiration and surface runoff deduction.

The figure of 680mm/year (M.Rosen, 2000) indicates infiltration of approximately 54% of annual rainfall for the monitored year and the study area.

Because of similar conditions across the volcanic aquifer, soil and lithology, this percentage can be used as the infiltration rate for any part of the aquifer. Spatial variation in the annual rainfall should be taken into account. In this report the soil moisture experiment and the derived infiltration rate is the basis for the recharge estimation into the volcanic aquifers. Consequently it is also the base for the recharge estimation to the Kaawa aquifer.

7.2. Recharge to the Pukekohe Volcanic Aquifer

Recharge to the Pukekohe Volcanic Aquifer occurs exclusively from the rainfall and there is no other source of water such as infiltration from rivers or neighbouring aquifers.

Hence, the spatial and temporal distribution of rainfall has the biggest impact on quantity of the recharge, within the content of local hydrogeological characteristics of the aquifer (Chapters 2 and 3).

The Pukekohe Volcanic aquifer is geologically the result of multiple eruptions from several vents and a large number of volcanic cones (Chapter 2). Volcanic deposits consist of a number of lava (basalt) layers interbedding and interfingering with a series of tuff and scoria deposits.

The area encompasses Pukekohe Hill as the highest point, Pukekohe Township and the large plateau towards Patumahoe and Mauku Stream (Figure 7.4).

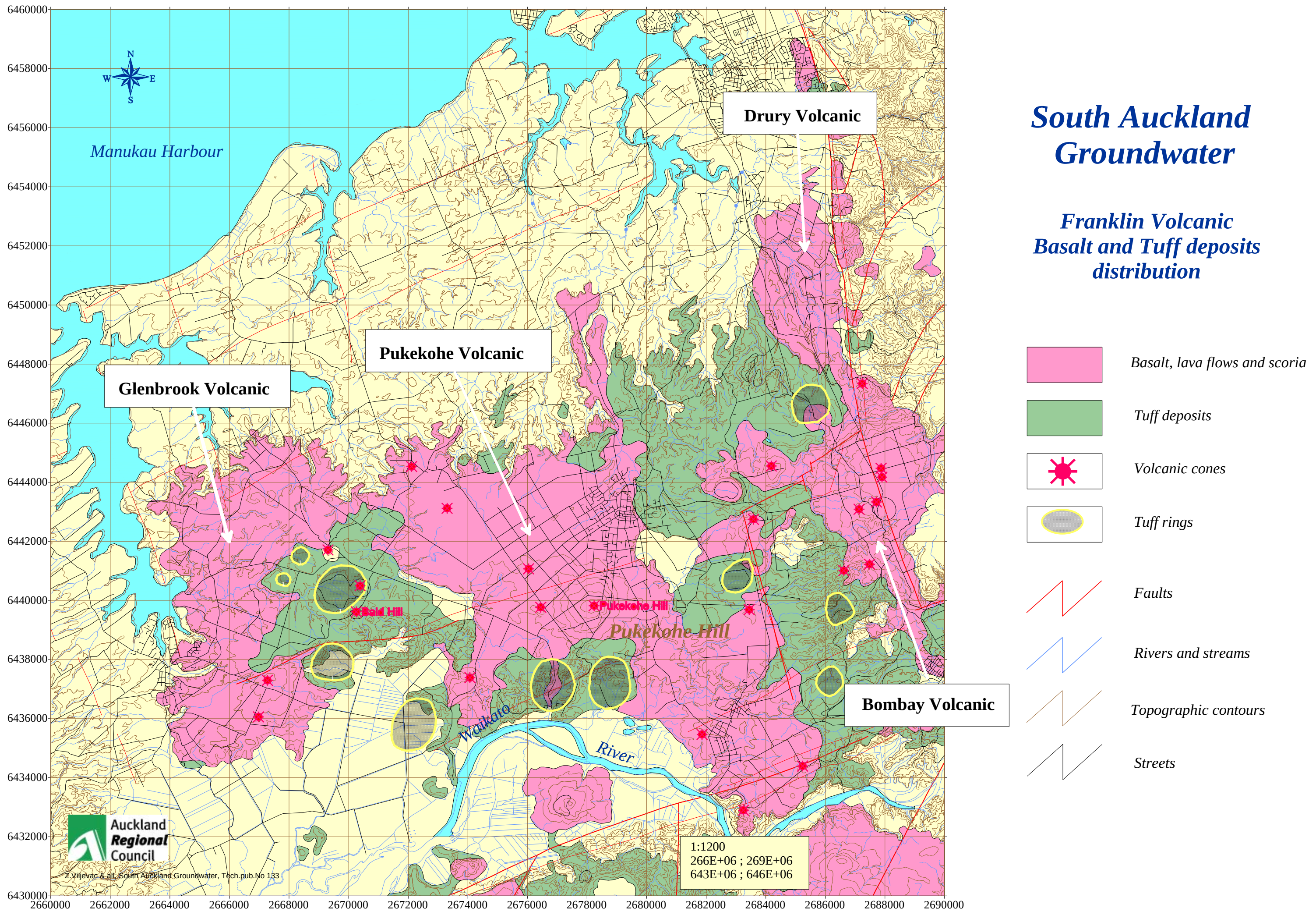

Figure 7.4 Volcanic rock, major volcanic cones and tuff rings (after GNS, 1995, Rafferty 1987)

Pukekohe Volcanic Aquifer covers approximately 56 km^2 with spatially very variable thickness. Thickness of the lava layers, excluding volcanic cones, can be up to 150m (corresponding to multiple lava flows) but generally that thickness is much smaller and significantly lessens towards the edges of the basalt body. Primary porosity is generally low between 1% and 10%, however actual porosity is much higher and can be more than 25%. Fresh exposure of the volcanic rocks is very rare. The soil, Brown Granular Loam, is of variable thickness and tends to smooth the rough lava surface.
Hydrogeological characteristics of the aquifer and soil cover have an important function in the recharge pattern.

7.2.1. Groundwater levels and recharge

Recharge to the Pukekohe Volcanic aquifer has an importance not only for the groundwater replenishment in the aquifer, but also as a major contribution in the recharge to the Kaawa Formation. Pukekohe Volcanic Aquifer contributes with approximately 1/2 of the total recharge to the Kaawa Aquifer.
Infiltration to the Kaawa Formation occurs through the number of volcanic conduits from the basalt aquifer intersecting the Kaawa Formation (Chapter 6).
Geological setting and spatial variation of the rainfall control an direct the groundwater recharge. Rainfall analysis for the last ten years in the Pukekohe area shows considerable variation in rainfall from year to year as well as across the area. That variation can exceed 350 millimetres either annually and spatially. This analysis also shows that regardless of the season or year the most intense rainfall regularly occurs in the Pukekohe Hill area and to the east of the area decreasing towards Manukau Harbour (Chapter 4).
In combination with geological and hydrogeological properties this produces a spatial variation and differentiation in groundwater levels.
Pukekohe Volcanic aquifer is divided into a five recharge units on the basis of geological and aquifer characteristics (Figure 7.5). Purple lines on the map delineate recharge units.

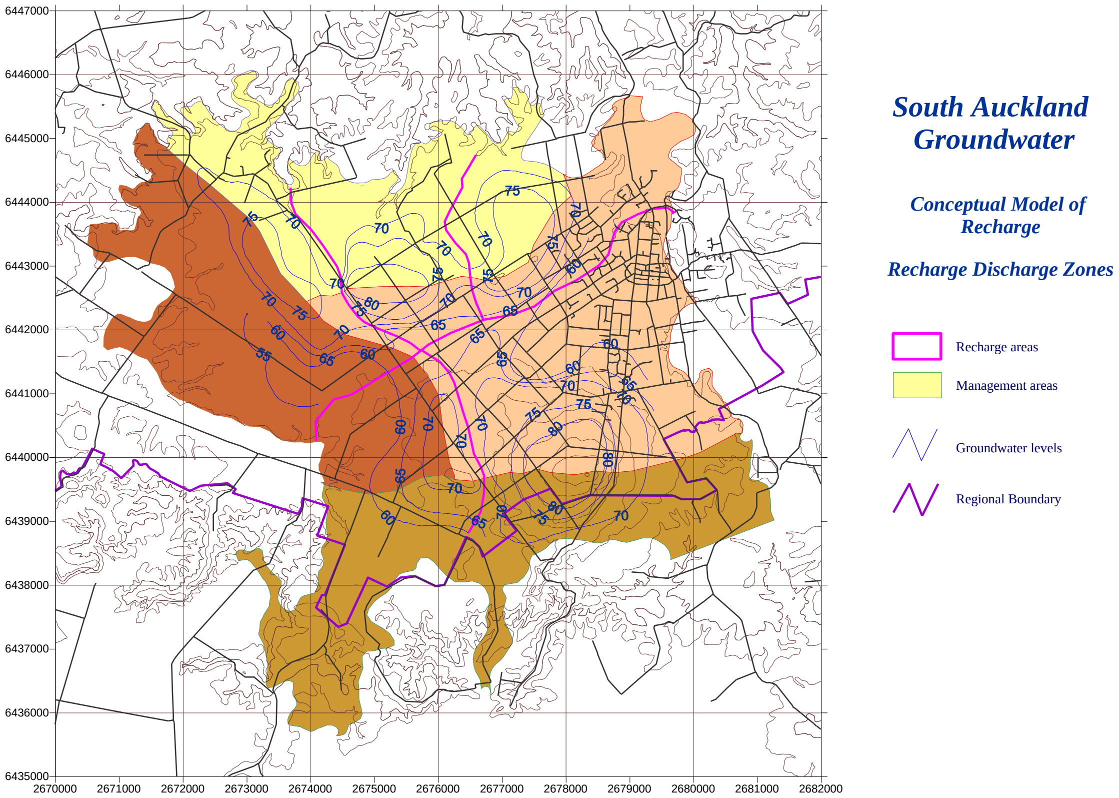

Figure 7.5 Groundwater levels in the volcanic aquifer and recharge areas

The groundwater level configuration shows spatial distribution of high groundwater levels and distinguishes the recharge units (Figure 7.5).

The contours indicate two areas of high-elevated groundwater. The first is in the Pukekohe Hill - Puni Spring area and another in the Pukekohe – Patumahoe Spring area with the groundwater elevations of approximately 80 to 100m amsl (Figure 7.5).

Groundwater flow is generally radial towards the edge of the basalt body. In the central Pukekohe area the groundwater flow is mainly from south and north towards the centre of the aquifer with further flow towards the east and the west indicating discharge and recharge areas.

This indicates that the recharge is not uniform across the aquifer and occurs mainly in the areas with higher groundwater elevation. Higher seasonal differences in groundwater levels occur between recharge and discharge areas (Chapter 3).

The soil moisture and recharge research in the Pukekohe area (Rosen & all, 2000) shows that the residence time for water in the soil before it reaches the unsaturated zone is between 4 and 8 months (for 2 metres of soil). The research also shows that the rainfall events with less than 10 mm of rain, mainly occurring during the summer period, have no effects on soil moisture at a depth of 75 cm. This suggests that recharge will not occur unless rainfall events exceed 10 mm. .

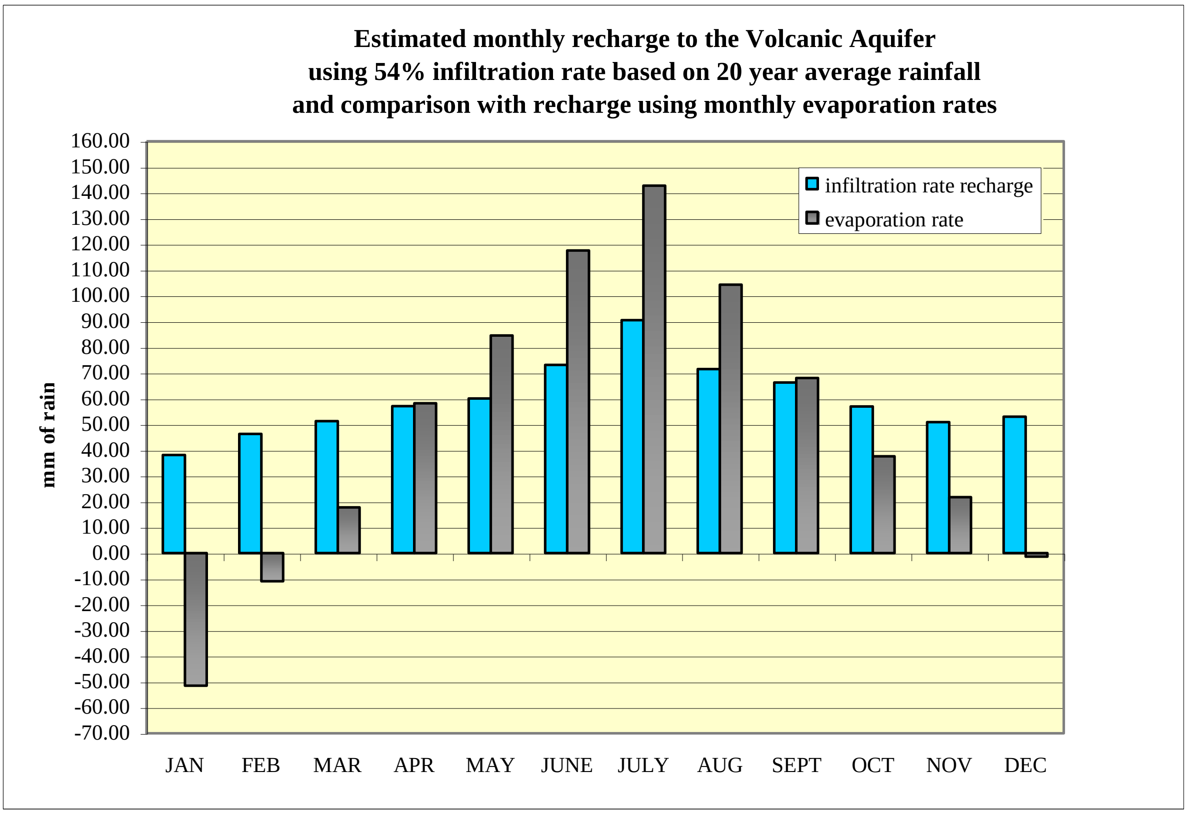

Figure 7.6 Comparison of the monthly recharge using infiltration rate and evaporation

Therefore the main recharge to the aquifer occurs in the winter period (from May to October) when sufficient soil moisture exists to enable infiltration into the aquifer (Figure 7.6).

Figure 7.6 is constructed to compare monthly distribution of the recharge rates using an infiltration method (IGNS) and recharge using rainfall and evaporation rates. The annual infiltration rate of 680 mm or 54% of the annual rainfall for the studied period (Rosen & all, 2000) was taken as the base for the monthly infiltration, which is in this case 54% of the monthly rainfall. This is compared with the rainfall / evaporation and soil moisture recharge calculation for the Pukekohe area using the average monthly data (Chapter 4).

There is a noticeable difference in recharge, particularly in the summer period. The infiltration method shows that the recharge is more evenly distributed through the year than .

The IGNS work showing an annual recharge for the area of approximately 680 mm/y is substantially higher than the calculated net recharge for the area using the water balance method. To obtain net recharge to the aquifer, from the gross recharge (difference between rainfall and evapotranspiration) spring and stream discharge should be extracted.

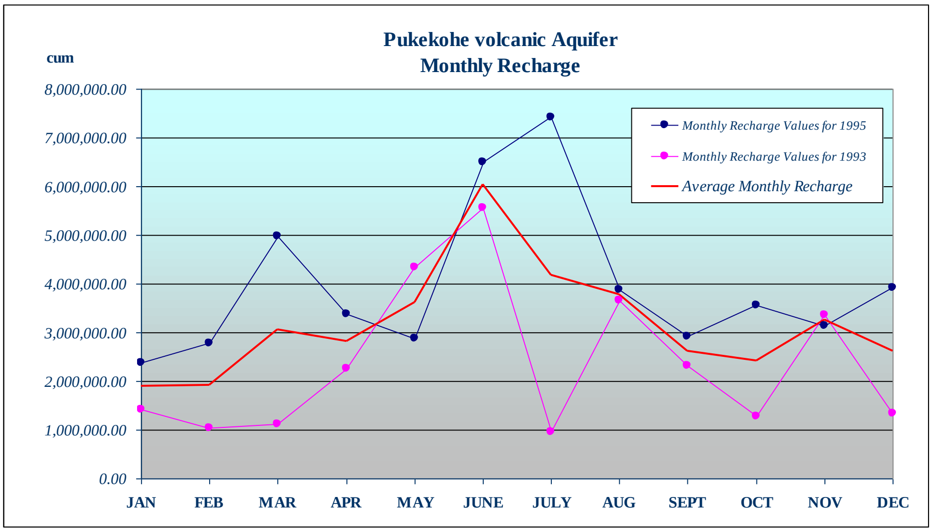

Figure 7.7 Pukekohe Volcanic. Recharge comparison between dry and wet year (1993,1995)

Figure 7.7 compares monthly recharge between a “dry” year (1993) with average total rainfall of 950 mm and a “wet” year (1995) with average total rainfall of 1650 mm (Chapter 4, Figure 4.4). The diagram shows that the recharge follows the same pattern in both periods and the highest occurs betwen April and August. During the “dry” year the recharge is irregular with greater oscillations than in wet years.

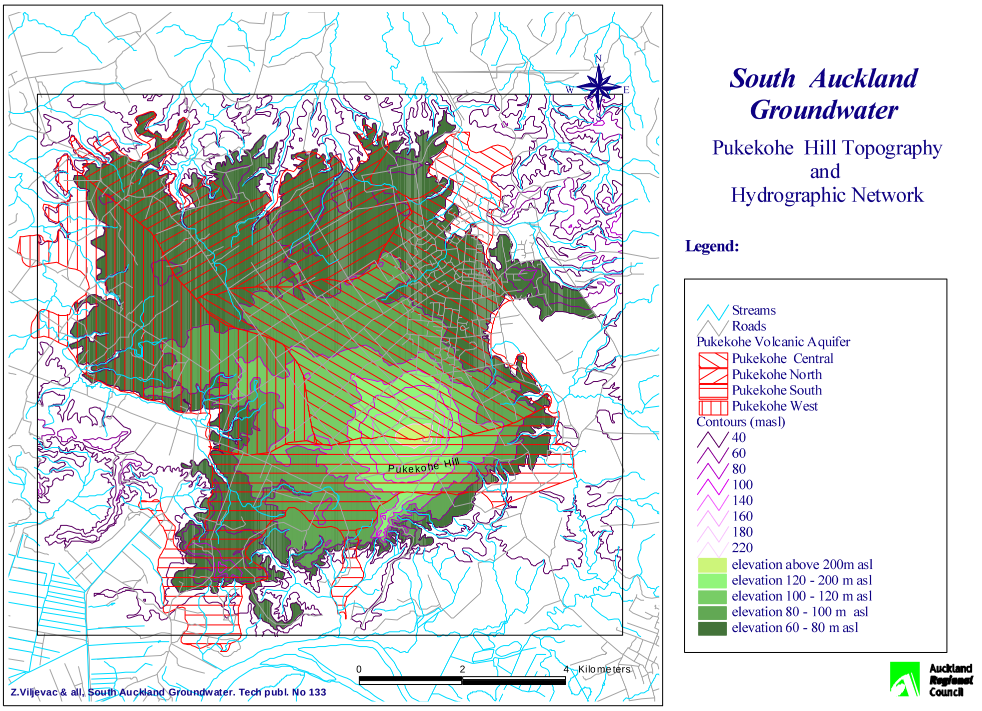

Figure 7.8 Pukekohe volcanic aquifer surface elevation

Figure 7.8 shows the topographic elevations at the surface of the Pukekohe Volcanic aquifer. Different green shades represent differences in elevation and the slope gradient. The map shows a slightly steeper gradient in the Pukekohe Hill area (mainly between 120 and 180 m amsl) However, the northern slopes, Pukekohe plateau with the Pukekohe township and Mauku area have a relatively flatter gradient. The map also shows that the most of the streams draining this aquifer occur in the zone between 60 and 80 metres amsl. That indicates that in this area (especially in the vicinity of the water courses) probable surface drainage occurs more likely than in the areas with no surface flows.

7.2.2. Recharge

Total annual recharge to the Pukekohe Volcanic Aquifer, applying infiltration rate of 680 mm/year (M. Rosen, 2000) is approximately 38,500,000 m^3.

The recharge figures and values contributing in the groundwater availability estimation are shown in Table 7.2 per each Pukekohe Volcanic aquifer management area.

Table 7.2 Recharge to the Pukekohe Volcanic Aquifer per management area

MANAGEMENT AREA	Recharge (680mm)	Stream Discharge	Net recharge m3/year	Flow to Kaawa aquifer	Availability m^3/year
Pukekohe	12512000.00	8195237.10	4316762.90	3461015.60	855747.30
South	9091600.00	5263928.30	3827671.70	3178400.30	649271.40
West	9234400.00	6582367.80	2652032.20	2230910.90	421121.30
North	7670400.00	6133896.80	1536503.20	1117577.40	418925.80
	38,508,400.00	**26,175,430.00**	**12,332,970.00**	**9,987,904.20**	**2,345,065.80**

The recharge is estimated using the following input parameters:

- The recharge areas represented with highs in groundwater levels (Figure 7.5) are used to calculate recharge into the aquifer which are afterwards merged into the management areas for the availability calculation.
- The infiltration rate of the 680 mm/year was applied uniformly across the area but it can be affected by spatial or seasonal rainfall distribution. This mainly occurs in years when the total annual rainfall is lower than 1200 mm. This amount of infiltration (680 mm/year) is approximately 54% of the total rainfall from the observation period. In the case of considerable and long rainfall deficit, the recharge in some parts of the management area can decline and the water availability can be affected (Figure 7.10).

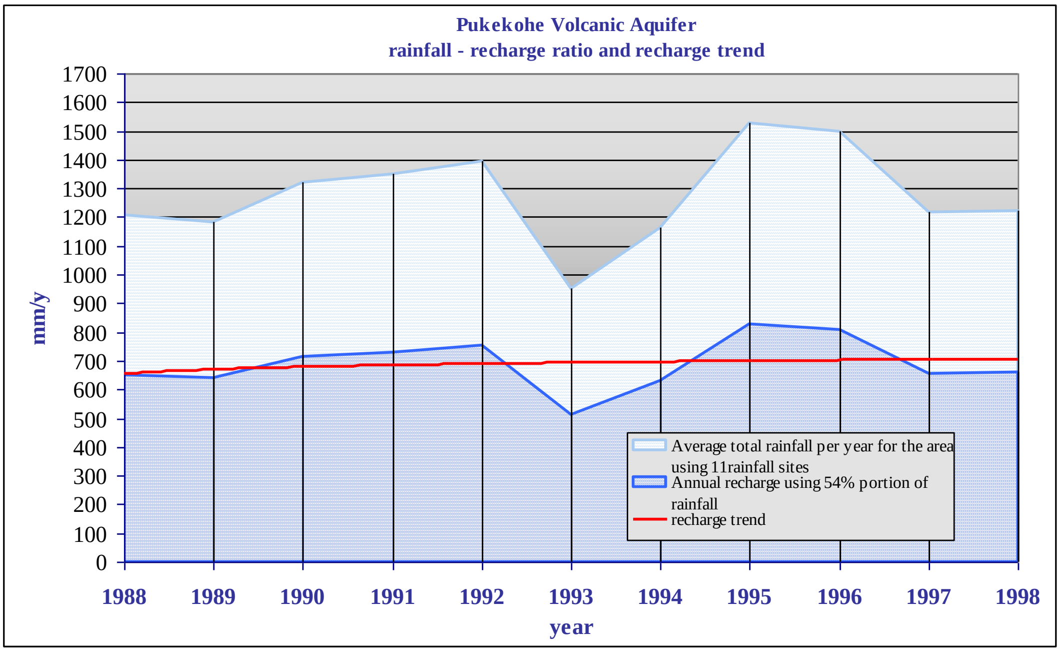

Figure 7.9 Rainfall recharge ratio for the 10 year period

Gross Recharge

The Recharge estimation is performed by the following procedure:

- The infiltration rate of 680mm/year is applied over the Volcanic area to obtain values of the gross recharge (Table 7.4)..

Table 7.3 Annual gross recharge per management area

MANAGEMENT AREA	Area km^2	Annual gross recharge m^3
Pukekohe Central	18.40	12,512,000.00
Pukekohe South	13.37	9,091,600.00
Pukekohe West	13.58	9,234,400.00
Pukekohe North	11.28	7,670,400.00
Total area and recharge	**56.63**	**38,508,400.00**

Stream Discharge

- The stream/spring discharge was deducted to obtain net recharge values. Stream and spring discharge (Table 7.3) from the Pukekohe Volcanic aquifer is estimated to be around 26,175,000 m^3 per year. For the spring and stream discharge, base flow is averaged at the nearest discharge point from the volcanic aquifer. The missing records of the stream/spring discharge for each of the management areas is estimated from the simulated flow data (Chapter 4). Figures 4.13 to 4.15 in the Chapter 4 show the range of base flow averages for sites equipped with an automatic flow recorder. Percentage of the base flow used in this report is an average of 80% to 95% of the total discharge.

Table 7.4 Estimated stream (base flow) discharge by the management area

MANAGEMENT AREA	Stream Discharge	Streams
Pukekohe	8195237.10	Tutaenui, Whangamaire (East)
South	5263928.30	Parker Lane, Whakapipi, Puni Spring
West	6582367.80	Mauku
North	6133896.80	Whangapouri, Whangamaire (West)
Total from Pukekohe basalt	**26,175,430.00**	

Net Recharge

- From the gross recharge values the estimated stream and spring discharge rate is deducted for each of the management areas to yield net recharge. The estimation method is described earlier in this chapter. This figures represent the potential amount of groundwater available for the Kaawa aquifer recharge and groundwater (Table 7.5).

Table 7.5 Net recharge values for the Pukekohe Volcanic aquifer

MANAGEMENT AREA	Annual gross recharge m^3	Stream Discharge m^3/year	Net recharge m^3/year
Pukekohe	12512000.00	8195237.10	4316762.90
South	9091600.00	5263928.30	3827671.70
West	9234400.00	6582367.80	2652032.20
North	7670400.00	6133896.80	1536503.20
Total	**38,508,400.00**	**26,175,430.00**	**12,332,970.00**

Availability in Pukekohe Volcanic Aquifer and Recharge to The Kaawa Aquifer

- Next step in the process is the deduction of the estimated flow to the Kaawa aquifer from the net recharge to obtain groundwater availability for use. Estimation of the Kaawa recharge figures is described in the Chapter 7.3. This amount of water is a part of the change in storage. Because of the seasonal character of the water use (summer period) this volume could be abstracted from the storage but will be replenished in the winter period. Table 7.6 shows the amount of water available for use and amount of water which constitutes Kaawa aquifer recharge. The estimated availability is reasonably conservative allowing unimpeded stream discharge (base flow) and Kaawa aquifer recharge.

Table 7.6 Pukekohe Volcanic water availability for groundwater use and Kaawa aquifer recharge

MANAGEMENT AREA	Net recharge m^3/year	Flow to Kaawa aquifer m^3/year	Availability m^3/year
Pukekohe Central	4316762.90	3461015.60	855747.30
South	3827671.70	3178400.30	649271.40
West	2652032.20	2230910.90	421121.30
North	1536503.20	1117577.40	418925.80
Total	**12,332,970.00**	**9,987,904.20**	**2,345,065.80**

The net recharge as is shown in Table 7.5 is total annual water in the volcanic aquifer which will recharge the Kaawa aquifer if there is no water abstraction. Water abstraction from the Volcanic aquifer can affect the spring and stream discharge and also the Kaawa aquifer recharge. To prevent adverse effects from the water takes the amount of water for allocation is calculated which supports continuous base flow in the streams and sufficient recharge to the Kaawa aquifer. Sufficient recharge to the Kaawa aquifer provides adequate in/out flow which will prevent potential negative effects such as saline water intrusion and aquifer compaction. Flow requirements through the Kaawa management areas are calculated using flow net (paragraph 7.3).

In the discharge zones the minimum requirement for the outflow from the Kaawa Formation is assumed to be 50% of the total outflow. The availability and management areas are further described in Chapter 9.2.

7.3. Recharge to the Kaawa Aquifer

The conceptual model of recharge described in Chapter 6, outlines the mechanism of the Kaawa aquifer recharge as infiltration through the volcanic cones which intersect the Kaawa Formation. The three major volcanic centres, Pukekohe, Bombay and Glenbrook Volcanic (Figure 7.4) provide the recharge water source.

The role of the volcanic cones is essential in the recharge model (Chapter 6). Using principles of the Darcy's Law[4] an estimation of the amount of water flowing through the volcanic conduits and infiltrating into the Kaawa Formation can be obtained. Figure 7.10 shows groundwater contours and groundwater divides which were the base for the flow net creation (Figure 7.11) and calculation of the groundwater flows. Location of the recharge and discharge areas identified in Chapter 6 have an effect on the groundwater flow calculation.

[4] An equation that can be used to compute the quantity of water flowing through an aquifer (Equation 7.5)

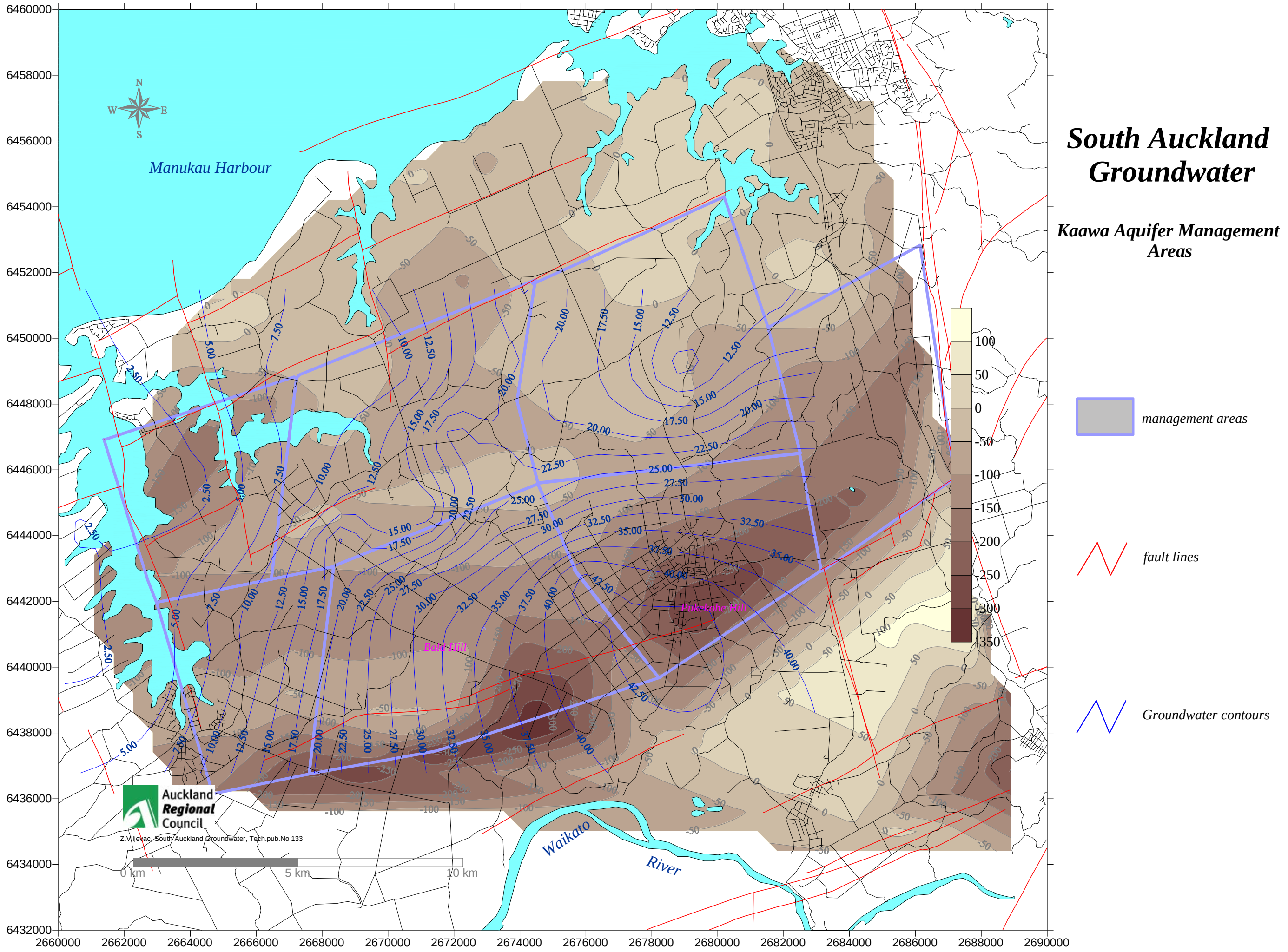

Figure 7.10 Kaawa aquifer groundwater levels

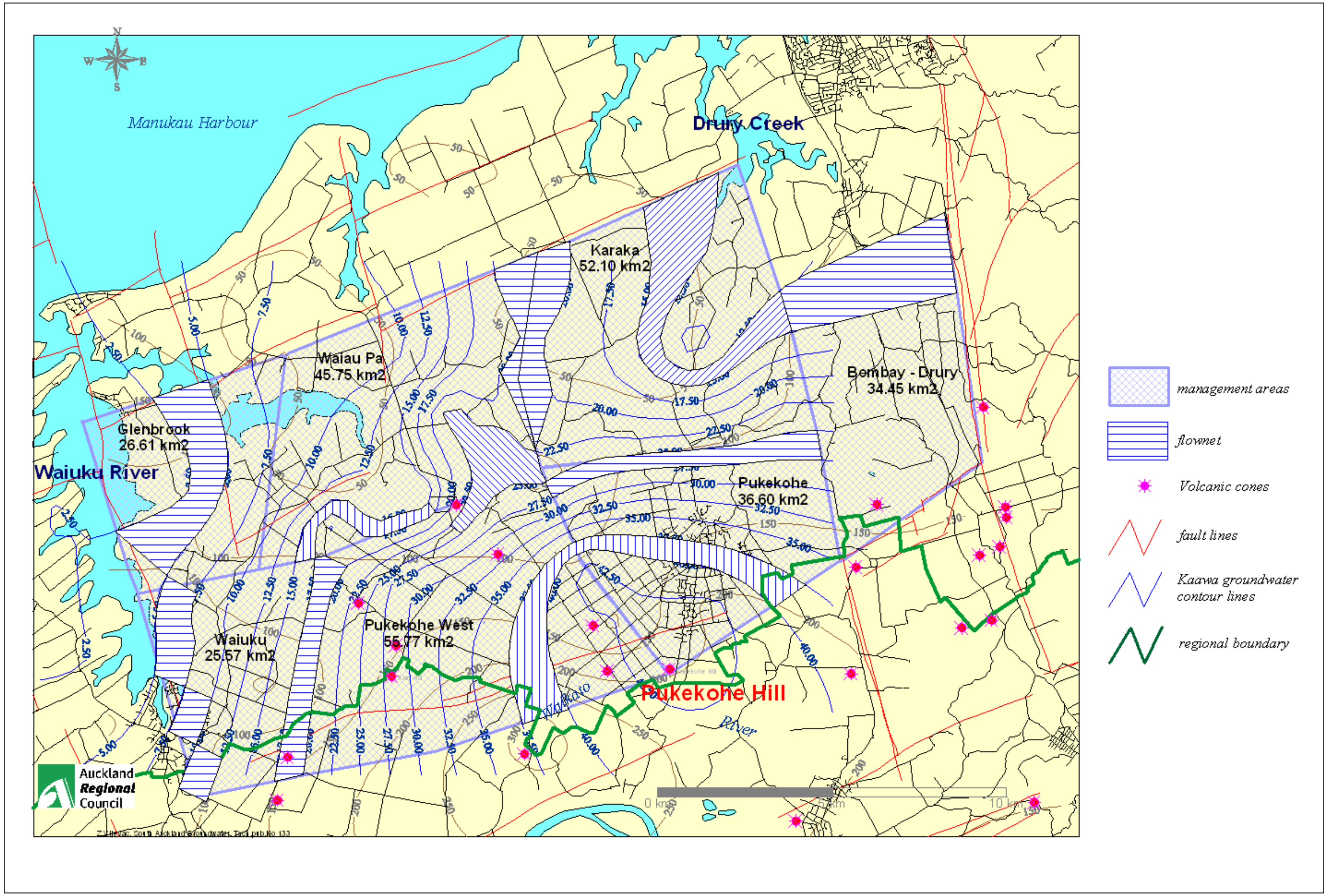

Figure 7.11 Kaawa aquifer flow net

Figure 7.11 shows the flow net pattern used in the recharge / discharge / availability calculation. On this map the major volcanic centres which are used in the infiltration calculation are indicated. The flow net method is used to estimate discharge from the Kaawa aquifer, amount of the through flow between management areas and amount of the recharge from the Pukekohe Hill area. The calculation of the quantity of flow is based on the assumption that there is a linear hydraulic gradient and confined aquifer conditions with steady groundwater movement. Therefore the Darcy's law states (Equation 7.5):

Equation 7.5 Darcy's Law equation for the quantity of flow

$$Q = -KA\frac{dh}{dl}$$

Inputing known or estimated values for the conductivity ***K***, cross-sectional area of the through flow ***A*** (*aquifer thickness* x *width of the zone*), difference in groundwater head between two contours ***dh*** and distance between two contours ***dl***, the total flow ***Q*** through any part of the aquifer can be calculated.

If there is no recharge or other loss from the area the through flow out and in should be equal. An example of the flow calculation using flow net method is shown in the Equation 7.6.

Equation 7.6 Example of daily discharge from the segment of flow net

$$Q = -2.5x302500\ \frac{2.5}{1300}$$

$$Q = 1454\,m3/day$$

It is assumed that the thickness of the aquifer is uniform along the whole length of the zone, distance between contours are consistent along the zone and a conductivity value is applied from the nearest test site or averaged value from sites close to the zone.

Each zone is divided into the several units to mitigate potential effects of the differences in conductivity values, distance between contours or thickness of the aquifer (Figure 7.11). This calculation is used to estimate daily groundwater flow between the management areas or discharge from management areas.

The layered structure of the Kaawa Formation has consequential differences in vertical and horizontal conductivities. The Kaawa Formation generally consists of 3 layers with different hydrogeological characteristics: shell bed(s) and two sand units (Chapter 2).
The aquifer test results were used where it was considered appropriate and data was available. However in the areas with no data or with a range in values of aquifer parameters, the values were averaged using the nearest points.
Recharge calculation through volcanic conduits is based on Constant Head aquifer test concept. The equation for hydraulic conductivity used in this test is given in the Equation 7.7 from which **Q** = volume of water entering the aquifer is calculated.

Equation 7.7 Constant Head aquifer test equation for conductivity value

$$K = \frac{1}{2\pi L}\left(\frac{Q}{he}\right)\ln(R/r)$$

In this equation **K** is conductivity, **L** is thickness of the aquifer and **he** is constant excess head. **R** and **r** are radius of influence and radius of the well respectively. From this the equation for volume of water entering the aquifer (if **K** is known value) can be derived:

Equation 7.8 Volume equation based on Constant Head aquifer test

$$Q = \frac{K 2\pi L he}{\ln(R/r)}$$

Figure 7.14 represents hydraulic model of the groundwater flow from the basalt aquifer through the volcanic conduit to the Kaawa aquifer. The estimation of the potential recharge was performed using the equation 7.8.

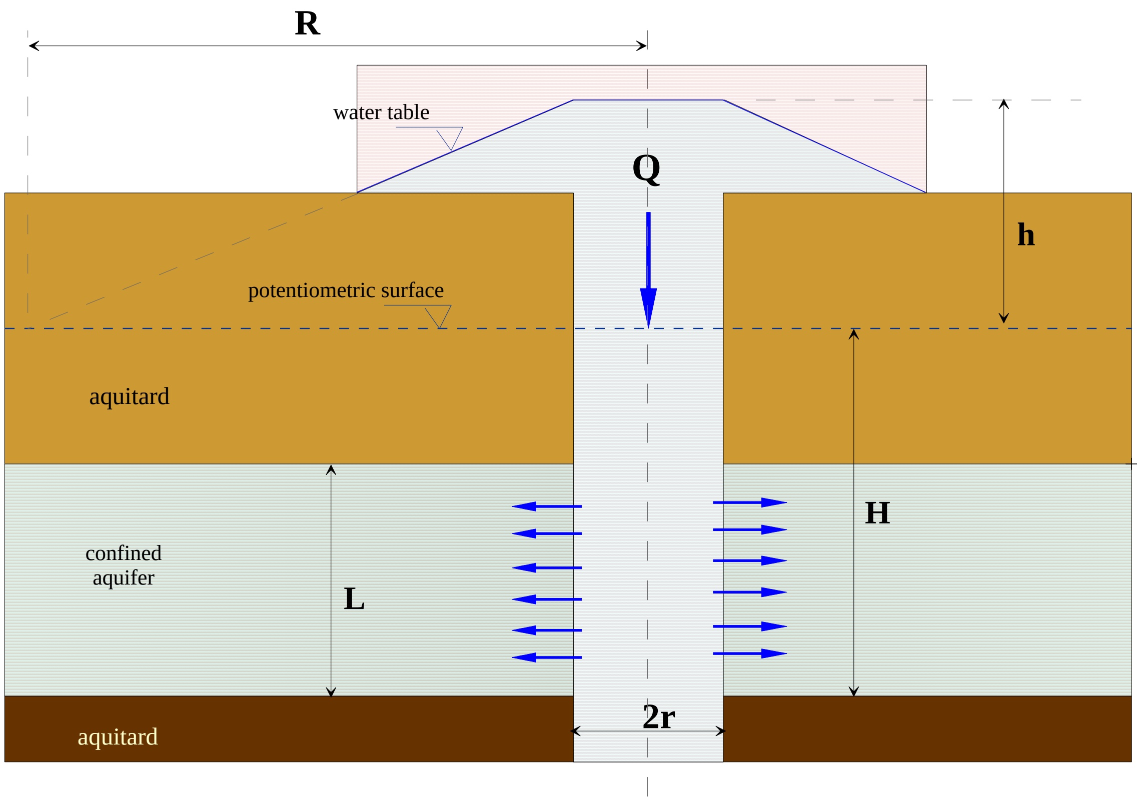

Figure 7.12 Model of the recharge through the volcanic conduits.

Recharge to the Kaawa aquifer is a seasonal function of the head difference in the volcanic aquifer and Kaawa aquifer (Chapter 3). The oscillation in groundwater levels in the Kaawa aquifer is a function of recharge and discharge cycle in the volcanic aquifer and change in hydraulic pressure in the volcanic cones.

Recharge Calculation

The recharge to the Kaawa aquifer is estimated by the infiltration rate from the volcanic cones and flow net analysis was used to split groundwater flows and groundwater availabilities within the management areas.
Total annual recharge of the Kaawa aquifer is approximately 19 million cubic metres and about 10 million comes from the Pukekohe Hill area (Pukekohe Hill and several other volcanic cones).

The recharge estimation is completed in several steps:

- Estimation of recharge from the Pukekohe Hill
- discharge from the discharge zones identified in the model,
- Estimation of the flow exchange between management areas,
- Quantity of the additional recharge from other volcanic areas (Glenbrook and, Bombay Drury Volcanic).

Table 7.7 shows annual recharge and discharge to and from the Kaawa management areas and estimated water availability for each of the management areas.

Table 7.7 Recharge to the Kaawa aquifer

MANAGEMENT AREA	inflow, m^3/year	outflow m^3/year	groundwater availability, m3/year
Pukekohe	3,728,474	1860085.20	1860085.00
Karaka	1243872.20	621077.35	161621.00
Pukekohe West	5345703.10	3573840.65	1780036.00
Waiuku	4070047.81	1620754.66	2451109.00
Glenbrook - Waiau Pa	3161134.01	1562043.92	1560043.00
Bombay - Drury	1467601.57	728030.16	717851.00
Total	**19,016,967.14**	**9,960,967,58**	**8,990,201.51**

The recharge estimation is performed for each of management areas, calculating inflow to and outflow from the area.

The availability is estimated by reserving 50% of the water flowing into a management area for allocation and allowing the remaining 50% to flow to the area down the gradient or for discharge into discharge area (areas identified in Chapter 6). The proportion of 50% of the flow is considered conservative enough to prevent potential salt water encroachment and adverse environmental effects particularly in discharge zones. A conservative approach is necessary for several reasons:

- The hydraulic conductivity in some areas of the Kaawa aquifer is averaged and estimated from the nearest data point and the values are therefore not spatially uniform. The Kaawa aquifer shows high sensitivity to the changes in hydraulic conductivity (Chapter 8), therefore it is necessary to be sufficiently conservative in the estimation of the outflow from the aquifer to allow enough flow to prevent possible adverse effects on the aquifer (saline intrusion). This figure allows for an error in the calculation of hydraulic conductivity up to 20%.

- Outflow from the Kaawa aquifer was mainly unknown and the real mechanism and discharge points are still unknown (no physical evidence of discharge) therefore the conservative approach is a necessity.
- Through flow from one management area to another is split in half though in some areas such as Karaka and Glenbrook - Waiau Pa the outflow is only a quarter of the initial recharge amount (inflow). The required outflow as suggested in previous guidelines is 15% of the total flow, therefore a figure of 50% is considered to be adequate conservative.

In the Pukekohe West Kawa management area the inflow was split into a three parts. The zone discharges into the Waiuku and Glenbrook -Waiau Pa areas and because of the additional recharge from Glenbrook Volcanic, there is enough flow to maintain recharge to the other zones and maintain outflow from the aquifer which will prevent salt water intrusion.

Pukekohe Kaawa management area (Figure 7.11), described in Table 7.8 has a major source of water from the Pukekohe Hill area, and discharges into the Karaka Kaawa management area and the Bombay – Drury Kaawa management area. Availability is 50% of the area's inflow. The inflow (recharge) from the Pukekohe Hill area is divided into the two parts, one flowing into the Pukekohe West Kaawa management area and another recharges Pukekohe Kaawa management area.

Table 7.8 Pukekohe Kaawa management area, availability calculation

Pukekohe Kaawa management area			
from /in		out/to	
Pukekohe Hill	3,728,474		
		1,243,872	Karaka management area
		616,213	Bombay Drury manag. area
availability		**1,860,085**	
total	**3,728,474**	**3,720,170**	

Karaka Kaawa management area (Figure 7.11) is down gradient from the Pukekohe Kaawa management area which is the only source of its recharge (Table 7.9). This management area discharges into the Drury Creek. Water available for use (availability) is about 50% of the inflow. Amount discharging into the Drury Creek area is about 620,000 m^3/year which is about 20% of the total flow in the area. This is more than the "guideline" percentage of 15% used elsewhere for the salt water intrusion prevention.

Table 7.9 Karaka Kaawa management area, availability calculation

Karaka Kaawa management area			
from /in		out/to	
Pukekohe manag. area	1,243,872		
		616,213	Drury Creek area
availability		**621,078**	
total	**1,243,872**	**1,237,291**	

Bombay - Drury Kaawa management area (Figure 7.11) has its main source of recharge from the Bombay Volcanic aquifer and partially from the Pukekohe Kaawa management area. Total water available for use is about 720,000 m3/year (approximately 50% of the in flow) allowing the same to flow out from the area into the Drury Creek area.

Table 7.10 Bombay – Drury Kaawa management area, availability calculation

Bombay-Druryt Kaawa management area			
from /in		out/to	
Volcanic cones	1,467,602		
		728,030	Drury Creek area
availability		**717,851**	
total	**1,467,602**	**1,445,881**	

This group of management areas are located east of the general groundwater divide (Figures 7.10 and 7.11) for the Kaawa aquifer which divides Kaawa groundwater into its eastern and western parts (Chapter 3).

The group of the management areas in the west are slightly larger with more water available for use.

Pukekohe West Kaawa management area (Figure 7.11) is the largest one with recharge from the Pukekohe and Glenbrook Volcanic aquifers. The recharge calculation is shown in the Table 7.11. The availability is 1/3 of the groundwater inflow because this area is the recharge source for two other management areas. Additional water recharge comes from several volcanic cones distributed across the management area (Figure 7.11).

Table 7.11 Pukekohe West Kaawa management area, availability calculation

Pukekohe West Kaawa management area			
from /in		out/to	
Pukekohe Hill	2,185,742		
Volcanic cones	3,159,962		
		1,614,119	Waiuku manag. Area
		1,959,721	Waiau-Pa manag. Area
availability		**1,780,036**	
total	**5,345,703**	**5,353,877**	

Waiuku Kaawa management area (Figure 7.11) has recharge sources (inflow) from the Pukekohe West Kaawa management area and several volcanic cones in the Glenbrook Volcanic Field. The discharge from the area is in the Waiuku River and potentially to the Awhitu Peninsula. The discharge from the management area is approximately 40% of the total flow or approximate amount which is flowing from the Pukekohe West Kaawa management area. The remaining recharge from the Glenbrook volcanic cones is available for the groundwater use.

Table 7.12 Waiuku Kaawa management area, availability calculation

Waiuku Kaawa management area			
from /in		out/to	
Pukekohe West	1,614,119		
Volcanic Cones	2,455,929		
		1,336,222	Awhitu Peninsula - Waiuku River
		284,533	Glenbrook -Waiau Pa ma. Area
availability		**2,451,109**	
total	**4,070,048**	**4,071,864**	

Glenbrook – Waiau Pa Kaawa management area (Figure 7.11) is made up of two areas, the Glenbrook Kaawa management area and Waiau Pa Kaawa management area. Glenbrook Kaawa management area is almost completely located in the recharge zone (Chapter 6) and availability is calculated together with the Waiau Pa management area. The volume which discharges through a very wide zone is about 50% of the flow through. Recharge sources are from the Pukekohe Volcanic aquifer (volcanic cone in Mauku), Pukekohe West and Waiuku Kaawa management areas.

Table 7.13 Glenbrook – Waiau Pa Kaawa management area, availability calculation

Glenbrook - Waiau Pa Kaawa management area			
from /in		out/to	
Pukekohe West	1,959,721		
Waiuku	284,533		
Volcanic cones	916,880		
		1,562,044	Waiuku River
availability		**1,560,043**	
total	**3,161,134**	**3,122,087**	

Groundwater availability is further discussed in the Chapter 9.

8. NUMERICAL MODEL

8.1. Background

The numerical (computer) model is a tool which simulates a real world situation when solving problems or developing different scenarios which can not be performed empirically.
Using given information, a groundwater model performs complex analyses, enabling informed predictions on groundwater behaviour, groundwater flow, velocity and interaction with the environment.
The aim of the numerical modelling is verification and evaluation of the conceptual model of the recharge.

8.2. Numerical conceptual model

The conceptual numerical model is based on the conceptual recharge model described in Chapter 6.
The Waikato Fault in the south, Drury Fault in the east and Glenbrook Fault in the north (Figure 6.2, Chapter 6) confine the Kaawa aquifer on three sides.

Conceptual recharge to the Kaawa aquifer is based on the following assumptions:

1. Recharge occurs in areas covered by volcanic rocks
2. Recharge to the Kaawa aquifer occurs in the vicinity of the volcanic cones where groundwater levels in the basalt are considerably higher than the water levels in Kaawa Formation
3. Hydraulic parameters of the lithological (stratigraphic) units enables flow exchange
4. Absence of vertical leakage between confining overlying Pleistocene sediments and confined Kaawa Formation
5. No flow occurs between Kaawa Formation and basement Waitemata or Greywacke rocks
6. Discharge from the Kaawa formation occurs at the fault zones in the areas of lower elevation such as Waikato River valley, Manukau Lowland (coastal

area) and Waiuku River where the water level in the Kaawa aquifer exceeds topographic surface elevation (artesian water).

The recharge occurs under the following conditions:

- Rainfall infiltrates into the volcanic soil and basaltic / scoriaceous aquifer (Chapter 4). The losses from the aquifer are spring discharge and groundwater use.
- Volcanic deposits and volcanic cones mainly cover the areas of highest elevation. Because of specific hydrogeological characteristics described in Chapter 3, they form good groundwater storage which enable infiltration
- Main recharge occurs through vertical flow via volcanic conduits.
- Pleistocene sediments overlay the Kaawa Formation forming a less permeable confining layer.
- Waitemata Group forms low permeable basement rock to the Kaawa Formation.

Volcanic cones (Chapter 2) penetrating underlying sediments create conduits which allow downward groundwater flow. Higher hydraulic pressure in the conduit (water "column"), pushes groundwater through the conduit inducing downward flow through the conduit and infiltration into sediments with higher permeability than surrounding lithology (Figures 8.2 and 8.3).

Figures 8.1, 8.2 and 8.3 show the development of the conceptual model from the geological cross section to the recharge concept and numerical model. The lack of information (bore log record) in the volcanic cone areas means the cones are not accurately represented on the geological cross section in Figure 8.1 (Chapter 2, Figures 2.3 to 2.6).

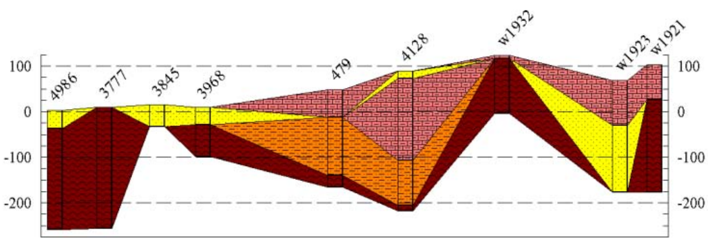

Figure 8.1 Geological cross section

Combining the geological setting, hydrogeological properties and the water balance the conceptual recharge model shown in Figure 8.2 was developed (Chapter 6). This was the basis for the developing numerical conceptual model (Figure 8.3).

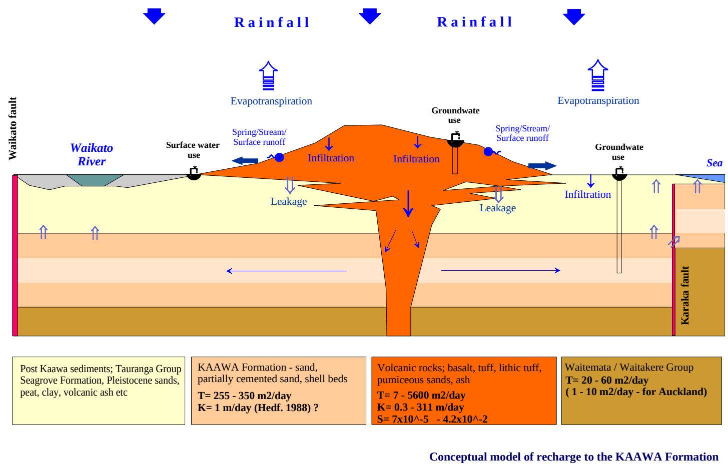

Figure 8.2 Conceptual recharge model (see Chapter 6)

The Conceptual numerical model shown in Figure 8.3 illustrates the layered structure of the area, relationships between parts of the model structure and proposed boundary conditions.

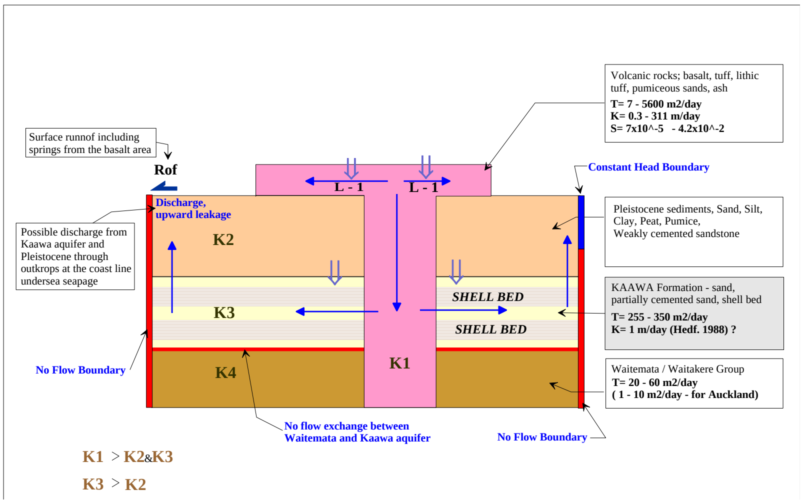

Figure 8.3 Conceptual numerical model

The recharge simulation to the Kaawa Formation was performed using volcanic conduits as injection wells. The radius of the volcanic conduits is estimated to be in average 50m (100m diameter). It is considered an appropriate size in comparison to the size of some volcanic cones in the Auckland area. In the calibration, some recharge through the potential seepage zones into the Kaawa aquifer was also investigated.

8.2.1. Code Selection

Visual MODFLOW 2.8 was used for the numerical simulation. This is a computer modelling program developed by the Waterloo Hydrologic (Canada). This is a fully integrated three dimensional graphical programme developed as a modelling environment for groundwater flow and contaminant transport.

This model utilises programmes MODFLOW and MODPATH, developed by the U.S. Geological Survey which simulate groundwater flow using a block - centred finite difference method. The code is based on Darcy's law for the flow between cells and discretization of the continuity equation. The code also assumes that the given parameters are constant over each grid cell. The finite difference equations are solved using WHS Solver (WHSSolv). WHS solver approaches a solution of a large set of partial differential equations iteratively through an approximate solution.

Variable data quality and very heterogeneous conditions in vertical and horizontal directions were the reason that the transient model was not further explored. A result which could satisfy all given conditions was not possible to achieve.

8.3. Data selection and preparation

8.3.1. Boundary conditions

Assigning the boundary conditions of the groundwater system to the numerical model requires replication of the real groundwater system and the solution of the partial differential equations relating to groundwater flow.

The boundary conditions are assigned to every point on the boundary (Figure 8.4). Those conditions could be:

- No flow boundary – special case of the specified flow boundary where the flux equals zero is assigned to the aquifer boundary as inactive cells. There are two types
    - a) impermeable areas along the fault lines

- b) groundwater divide lines

- Constant head boundary – assigned in the seepage (discharge) areas and at the edge of he basalt aquifer:
    - a) cells in the Kaawa aquifer discharge areas (variable depending on elevation of the Kaawa Formation upper surface)
    - c) cells at the border of the volcanic body (topographic elevation at the edge of the basalt body from 45 – 65 m amsl)

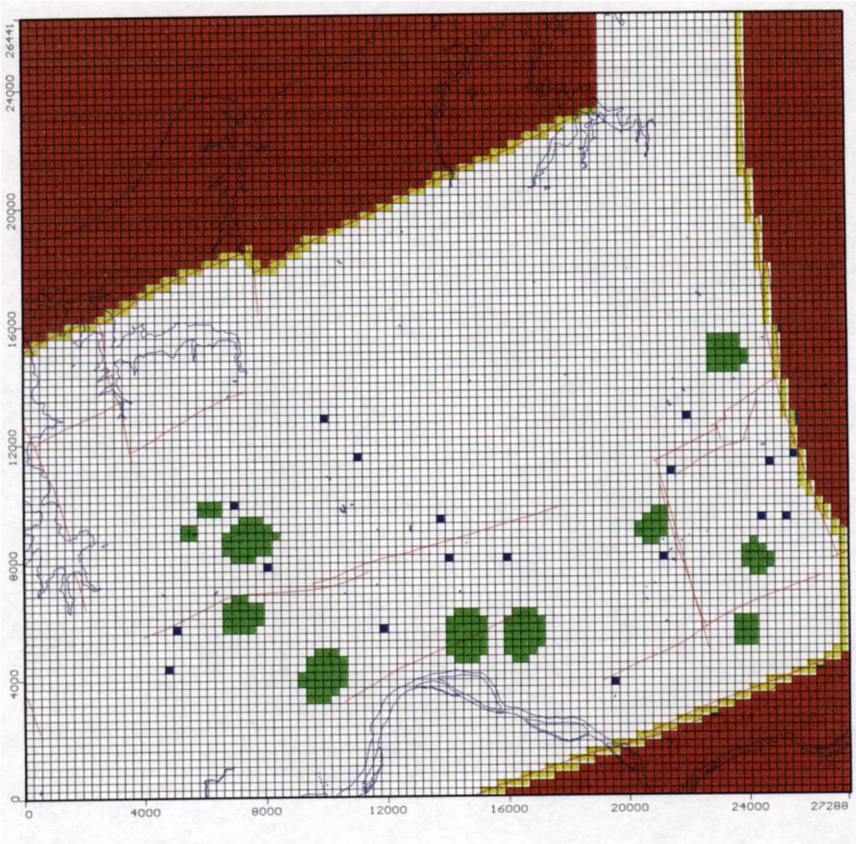

Figure 8.4 No flow boundary for the Kaawa Formation

- Specified flow boundaries – the flux is specified across the boundary
    - a) injection wells
    - b) parts of the Kaawa discharge zones
    - c) spring discharge points

Eastern and southern boundaries of the Kaawa aquifer are represented by Drury Fault and Waikato Fault and are considered as no flow boundaries. The northern boundary is less certain than the southern and eastern boundaries. A number of parallel faults (generally striking E-W) are intersected by perpendicular faults creating a complicated pattern of uplifted and lowered blocks. This boundary is represented by the Glenbrook Fault, which can also be described partially as a constant head boundary and partially as a no flow boundary (Chapter 6).

The western boundary is considered to be a no flow boundary in the Waiuku River area and specified flux boundary south of the Waiuku township. The edge of the basalt body is considered as a constant head boundary. The cells in the areas of spring and stream discharge from the basalt are assigned as a specified flux boundary.

8.3.2. System geometry and discretization

The conceptual model is represented by a three dimensional grid structure with specified elevations of the top and bottom surface of each layer. Those elevations are based on the geological interpretation.

The model is horizontally divided into 100 x 100 rectangular cells (Figure 8.5). In the vertical direction the model consists of eight units (Figure 8.6) which are grouped into a four layers with associated similar hydraulic properties.

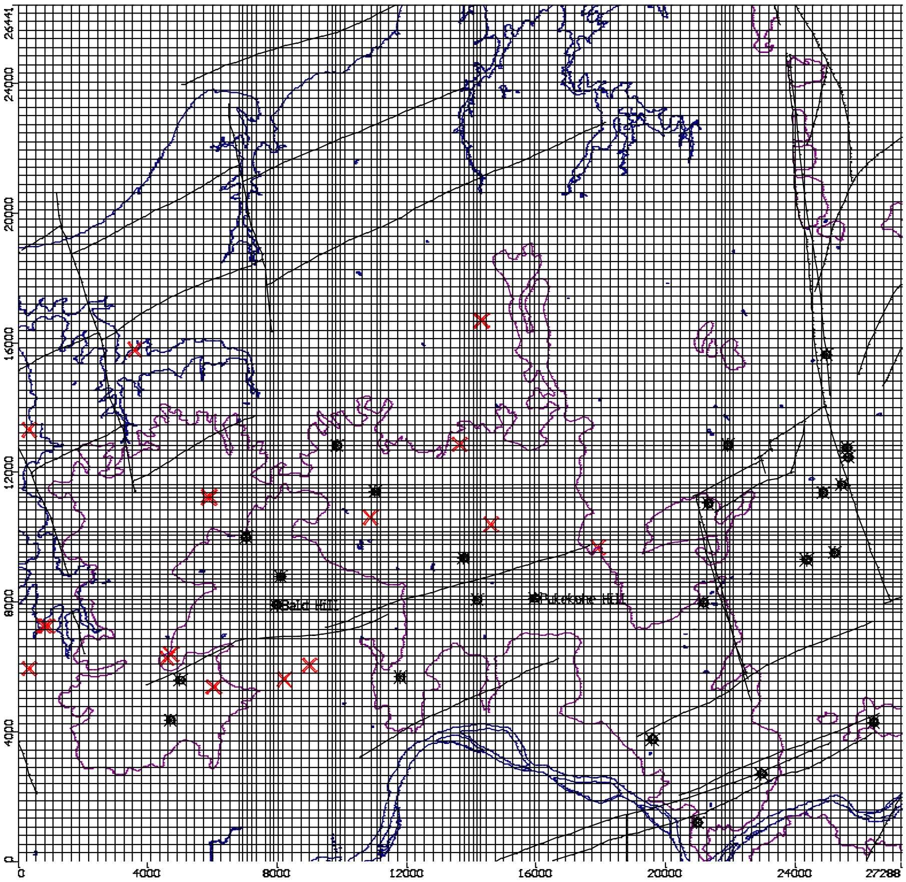

Figure 8.5 Geometry of the model with location of observation bores

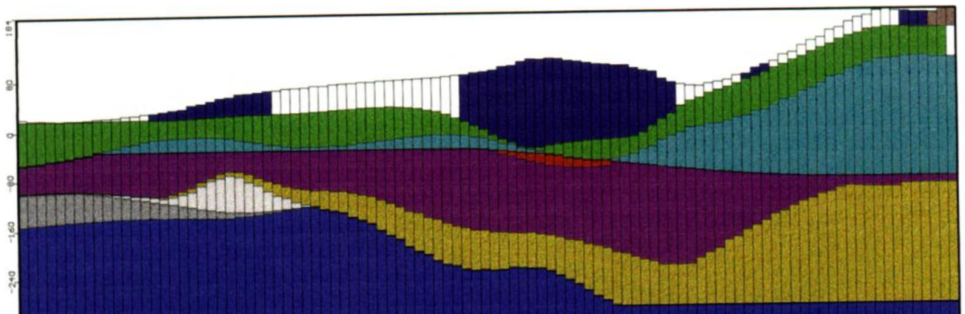

Figure 8.6 Cross section (N-S) through the model showing layers

The size of the horizontal nodes (cells) should match the curvature of the water table. According to the hydraulic gradient for both of the aquifers (which is 0.005 to 0.025) the grid spacing of less than 100 metres should be sufficient to calibrate the model (nodes are smaller than gradient). In the areas such as volcanic cones this spacing may not be sufficient and nodes are refined to 25 and 50 metres (Figure 8.5).

8.3.3. Groundwater levels

One of the requirements for the numerical modelling of groundwater flow is the specification of initial values for hydraulic heads. The initial conditions are the known head distribution at the initial time $\mathbf{t_0}$. The water level data were used from the observation bores for the specification of the initial heads. The chosen period was from January 1993 to January 1995. Some bores are equipped with automatic recorders and some were monitored on a fortnightly basis.

8.3.4. Infiltration rates

A component of the water budget is the infiltration rate. The estimated infiltration rate is based on the results of research conducted by GNS (Chapter 7).

The infiltration rate of 680 mm/year is applied directly to the basalt area as the recharge rate. As discussed in Chapter 7, this infiltration rate is a gross recharge figure with surface runoff and evapotranspiration already deducted.

8.3.5. Hydraulic properties (Volcanic and Kaawa)

Hydraulic properties for aquifers are described in Chapter 3. The main characteristic is a large heterogeneity in the aquifers and variation in transmissivity particularly in the volcanic aquifer.

The aquifers were subdivided into 11 different areas according to transmissivity. The highest transmissivity for both of the aquifers is observed in the Pukekohe Hill area. The lowest transmissivity in the Kaawa aquifer is measured in Bombay – Drury area. Generally the transmissivities measured in the Kaawa aquifer are lower in the periphery and northern part than in central and southern part of the aquifer.

Conductivity values from the surrounding Kaawa sediments are used for the infiltration modelling through the volcanic conduits. Because of the difference in the conductivities between Volcanic conduit (higher) and the Kaawa Formation (lower), the Kaawa aquifer conductivity is the limiting factor for infiltration.

8.3.6. Calibration process

Steady state calibration varies parameters iteratively to simulate an average groundwater level with tolerance of ±0.01m (closure criteria). Steady state conditions occur when the water entering an aquifer equals outflow, without change in aquifer's storage. Throughout the calibration process the recharge rate was kept unchanged and transmissivity values were considered as a variable and adjusted to achieve steady state.

In the calibration process the transmissivity values were generally increased in the Kaawa Formation by about 10% to 20%. However in the volcanic aquifer, transmissivity values were reduced (particularly values over 1000 m^2/d) to calibrate infiltration against the piezometric levels. The infiltration rate was considered as a constant. Abstraction based on annual allocation was applied, as a cumulative annual abstraction from within each of the management areas (Chapter 5).

The allocation is a more conservative figure than actual use, therefore the modelling result is considered conservative.

The abstraction from the aquifer, is deducted from the recharge (infiltration rate) and this figure is used for the calibration against groundwater levels and outflow.

Figures 8.7 and 8.8 shows simulated groundwater levels using the reduced infiltration rate. Figure 8.7 shows a similar pattern when compared with measured groundwater levels (Chapter 3) with the exception of the northern part of the aquifer (area A and B). Zones A and B in the Figure 8.7 show an inflection in the modelled groundwater levels from those measured and presented in Chapter 3. The reason may be due to the effect of the Whangamaire and Whangapouri stream drainage. However the possibility of a groundwater abstraction effect (which is not evident in the observation wells) can not be excluded. Figure 8.8 shows a similar anomaly in the north-west and north-east part of the Kaawa aquifer. The water levels at the same discharge rate show a reduction of about 2 metres. This could be due to relatively high groundwater use in the Karaka (north-east) or Waiau Pa (north-west) management areas.

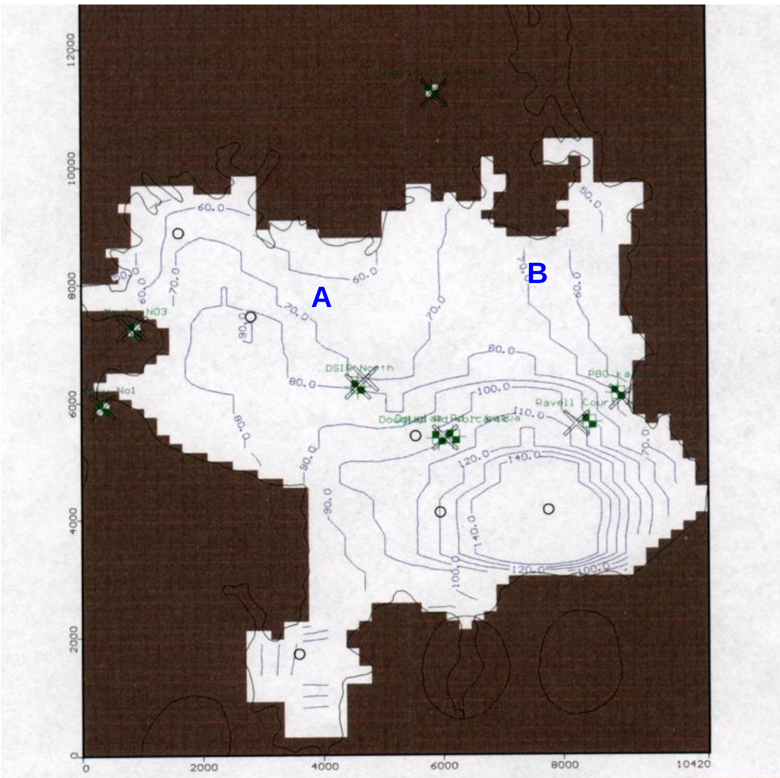

Figure 8.7 Pukekohe volcanic aquifer, calibrated groundwater levels

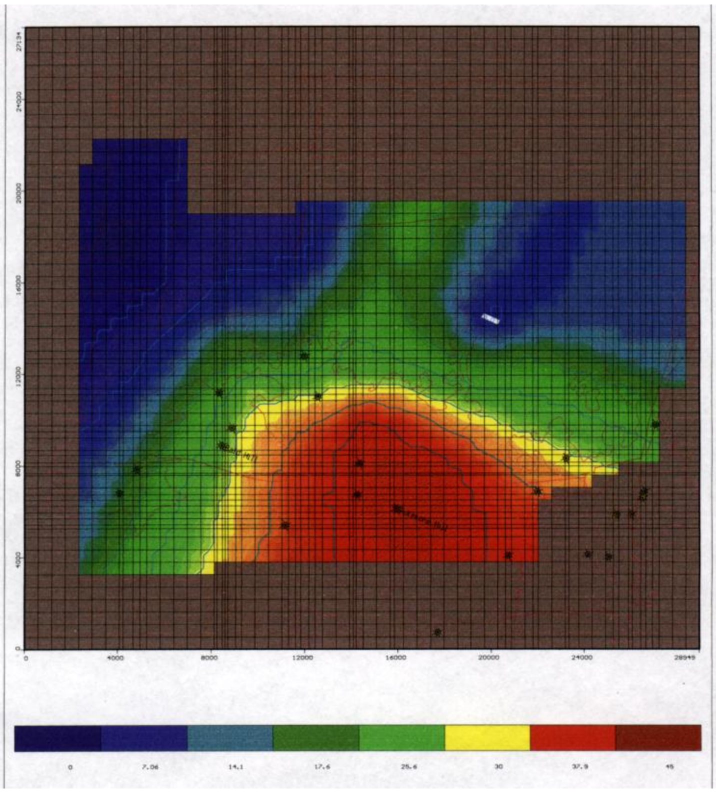

Figure 8.8 Kaawa aquifer, calibrated groundwater levels

Modelled recharge to the Kaawa aquifer (north of the regional divide) is approximately 12.5 million cubic metres per year which is similar to the calculated flow net discharge (Chapter 7).

A recharge/outflow towards south (south of the regional divide) of approximately 6 to 8 million cubic metres per year is suggested by the modelling results.

8.4. Model sensitivity

Sensitivity analysis provides information about the importance of the parameters in the calibration process and their effect on the modelling outcome. The sensitivity of the model to changes in conductivity was highlighted by comparing the changes in simulated groundwater levels which result from using different conductivities.

Forty five simulations were conducted in order to check changes in the groundwater levels by changing hydraulic conductivity in each zone by one order of magnitude. Groundwater levels in the volcanic aquifer responded to the reduction in the conductivities by 20% with increase of 4 to 5 metres. The Kaawa aquifer responded to an increase in the conductivity with a drop in water levels of about 2 metres and corresponding increase in discharge rates.

A reduction in recharge to the volcanic aquifer of approximately 25% affected groundwater levels (particularly in the recharge areas) but did not effect stream discharge and the Kaawa aquifer recharge. A further reduction in recharge by up to 50% causes the majority of the cells in the volcanic aquifer (particularly eastern part) to become dry.

Recharge to the Kaawa aquifer is particularly sensitive to the change in conductivities.

This demonstrates high sensitivity of the model to both changes in conductivities and the amount of recharge. The most important calibration parameter appears to be hydraulic conductivity. The consequence of this is in reliability of the model and accuracy of the modelling results. The conductivity changes may result in change in groundwater flow direction and also reduced or increased recharge. More accurate information on aquifer parameters may improve the modelled results.

8.5. Conclusion

The numerical modelling has verified the conceptual model and overall modelling approach demonstrate viability of the conceptual model.

For a complex, multi layered regional model such as this, the level of accuracy achieved is considered acceptable. Sensitivity analysis shows that the model is very sensitive to the change in hydraulic conductivities and change in infiltration rates.

Modeled recharge to the Kaawa formation is suggested to be approximately 18 to 20 million cubic metres per year. Approximately 12.5 million cubic metres flow north and between 6 to 8 million cubic metres per year south of the major groundwater divide

The model also shows a number of limitations influencing modeling results.

The model limitations are:

- spatial distribution and number of aquifer tests,
- accuracy of the stream discharge values (at the edge of the volcanic aquifer),
- the small number of observation bores (spatial distribution and number per aquifer compared to the high heterogeneity)
- in some areas insufficient geological information, particularly in the vicinity of the volcanic cones
- inability of the model to handle transient modelling

Despite a number of limitations, the sensitivity analysis shows that the parameters used enable satisfactory approximation of the groundwater system in the steady state simulation.

9. GROUNDWATER MANAGEMENT

Toitu te marae o Tane	If the domain of Tane is sustained
Toitu te marae o Tangaroa	And the domain of Tangaroa is sustained
Toitu te Iwi	So too will the people be sustained

9.1. Statutory Framework

9.1.1. Introduction

Inefficient taking and use of water can limit the number of users that can benefit from a water source. Taking more water than is needed, wasting water, poor matching of water use with actual needs and supply system losses all reduce the amount of water available for other people to use and can also unnecessarily increase the volume of wastewater needing disposal.

Changed water level and flow regimes in aquifers caused by the taking of groundwater may lead to reductions of base flow to streams, the degradation of freshwater ecosystems and wetlands, the degradation of ground water quality through saltwater intrusion and contaminant transport, loss of recharge to adjacent aquifers, aquifer consolidation and reduction in the temperature of geothermal waters. Such changes can result in reduced water availability, both for present and future generations. Groundwater availability is defined as the quantity of water that can be sustainably abstracted from the aquifer by groundwater users (ie without causing adverse effects). It is sometimes referred to as safe yield.

How aquifers are managed in the Auckland Region is outlined in the Proposed Auckland Regional Plan: Air Land and Water 2001 (see below and henceforth PARP:ALW 2001). The Kaawa and Franklin basalt aquifers are within a High Use Aquifer Management Areas in the PARP:ALW 2001. High use aquifer management areas are those particularly vulnerable to the effects of changed water level and flow regimes outlined above, primarily due to a significantly high level of abstraction in relation to groundwater availability.

Meeting existing and future water demands from aquifers, while also sustaining other dependent ground and surface water resources, requires groundwater abstractions to be carefully controlled and managed. Accordingly groundwater availabilities are set in the PARP:ALW 2001. The main purpose of this report is to outline how water availabilities for the volcanic and Kaawa aquifers in the PARP:ALW 2001 were determined, and to justify the numbers in Schedule 2 of the Plan.

A review of the statutory documents follows which relate to managing groundwater.

9.1.2. Statutory Framework

Auckland Regional Policy Statement

This Regional Policy Statement (ARPS) was prepared in fulfillment of the requirements of the Resource Management Act 1991 (RMA). It was approved by the Auckland Regional Council on 16 August 1999, and became operative on 31 August 1999. The ARC prepared the ARPS 1999 in accordance with Section 59 of the RMA, which states the purpose of the policy statement is "…to achieve the purpose of the Act by providing an overview of the resource management issues of the region and policies and methods to achieve integrated management of natural and physical resources of the whole region". The ARPS 1999 provides a long-term direction for the Region, and a review will commence no later than August 2009.

Regional Plan

Regional Plans are developed as appropriate to address issues for which the Regional Council has responsibility. They must not be inconsistent with the ARPS 1999. The Proposed Auckland Regional Plan: Air Land and Water 2001 was notified on 23 October 2001.

Similar to the ARPS 1999, PARP:ALW 2001 sets in place objectives, policies, methods and rules for promoting sustainable management of water resources, providing greater certainty over the ways they are to be managed. This creates a greater awareness of the constraints and opportunities in the Region.

The PARP:ALW 2001 has the following Objectives relating to groundwater allocation:

> 6.3.1 To maintain water availability for consumptive use, to enhance access to water resources and to minimise wastewater generation so that the people of

the Auckland Region can provide for their social, economic and cultural well-being.

6.3.2 To maintain the quantity, levels and flows in the region's surface water bodies to safeguard their life-supporting capacity as well as preserving and protecting natural character and landscapes and significant habitat of indigenous freshwater fauna and habitat of trout, and maintaining and enhancing amenity values.

6.3.3 To maintain the quantity and levels of water in the Region's aquifers for purposes of safe-guarding spring flows, stream base flows, water quality, and geothermal temperature and amenity.

These objectives give rise to the following policies:

Policy 6.4.25 of the defines the water availability of an aquifer as the maximum amount of water that can sustainably be allocated from an aquifer, which shall be determined by taking into account:

(a) Aquifer recharge;
(b) The spatial distribution of bores; and
(c) Outflow requirements of the aquifer, including
i) flow at the coast, to prevent saltwater intrusion;
ii) requirements of streams and springs;
iii) recharge of adjacent or underlying aquifers….

Policy 6.4.26 sets the water availability for aquifers and/or groundwater management areas in its Schedule 2 for the purpose of avoiding, remedying or mitigating adverse effects on the environment. While 6.4.27 states that water allocated to users in an aquifer shall not exceed the water availability for that aquifer (as specified in Schedule 2 of the PARP:ALW 2001).

9.2. Management areas

The aquifers have been divided into the management areas to manage abstraction in a manner which is consistent with the model of recharge and availabilities described in Chapter7. The primary delineation criteria between areas is based on location of groundwater divides and groundwater flow direction. Other determinants are aquifers thickness and relationship to the recharge and discharge zones. Figure 9.1 shows the location and spatial relation between the management areas in the Pukekohe Volcanic and underlying Kaawa aquifer.

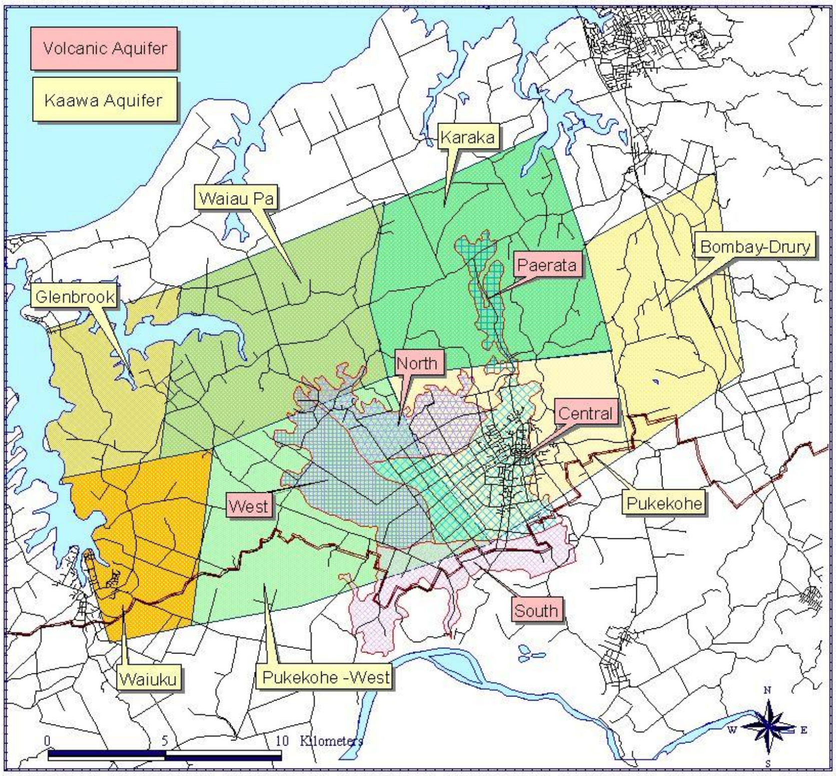

Figure 9.1 Pukekohe Volcanic and Kaawa Aquifer management areas

9.2.1. Pukekohe Volcanic Aquifer Management Zones

The Pukekohe Volcanic Aquifer covers approximately 56 km^2. The area is divided into four management areas (Figure 9.2). Criteria for delineation of the management areas includes reference to recharge and discharge zones, groundwater divides and groundwater flow direction within the basalt aquifer.

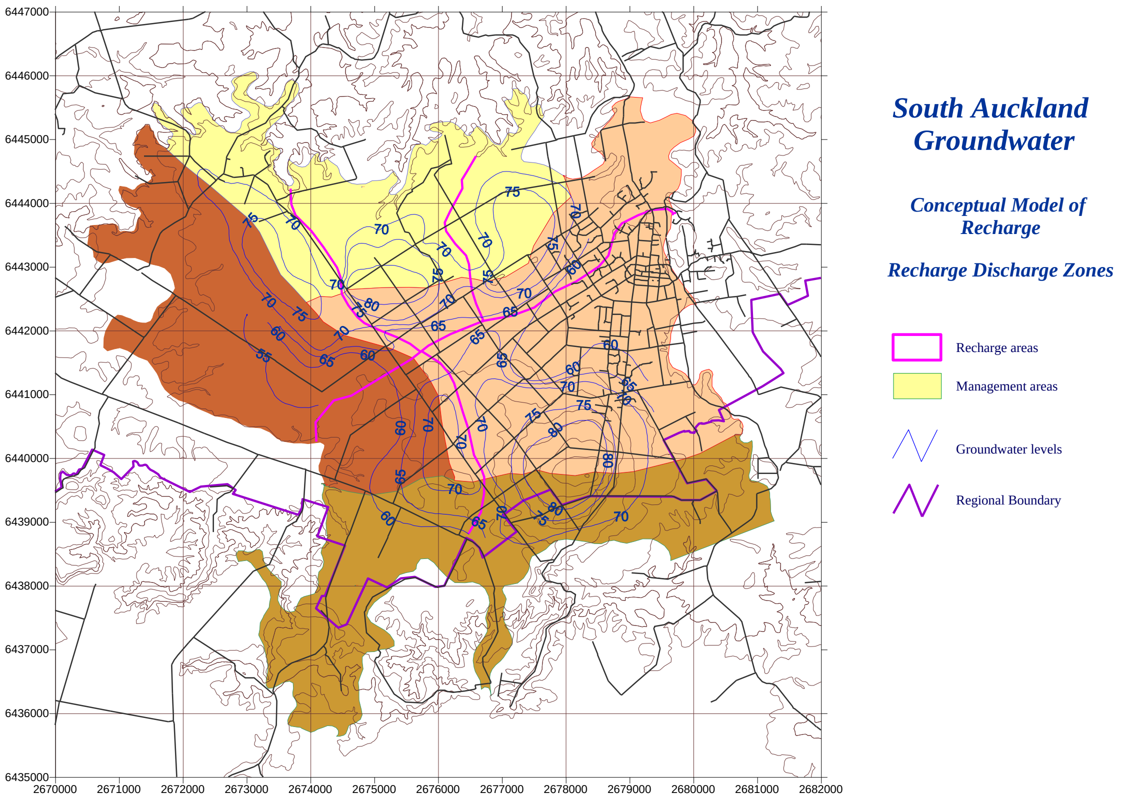

Figure 9.2 Pukekohe Volcanic Management areas and water availability

The boundaries of the management areas follow the major groundwater divides within the basalt aquifer (chapter 3). Conditions within one zone are reasonably independent from the conditions in other zones. These areas represent the appropriate area to implement common management objectives and practices which are outlined in the Auckland Regional Council ALW Plan. It is necessary to emphasize that each of these zones could be further divided into a number of smaller, individual areas with its own distinct circumstances. However it is considered impractical and can would achieve minimal improvement on the proposed management areas.

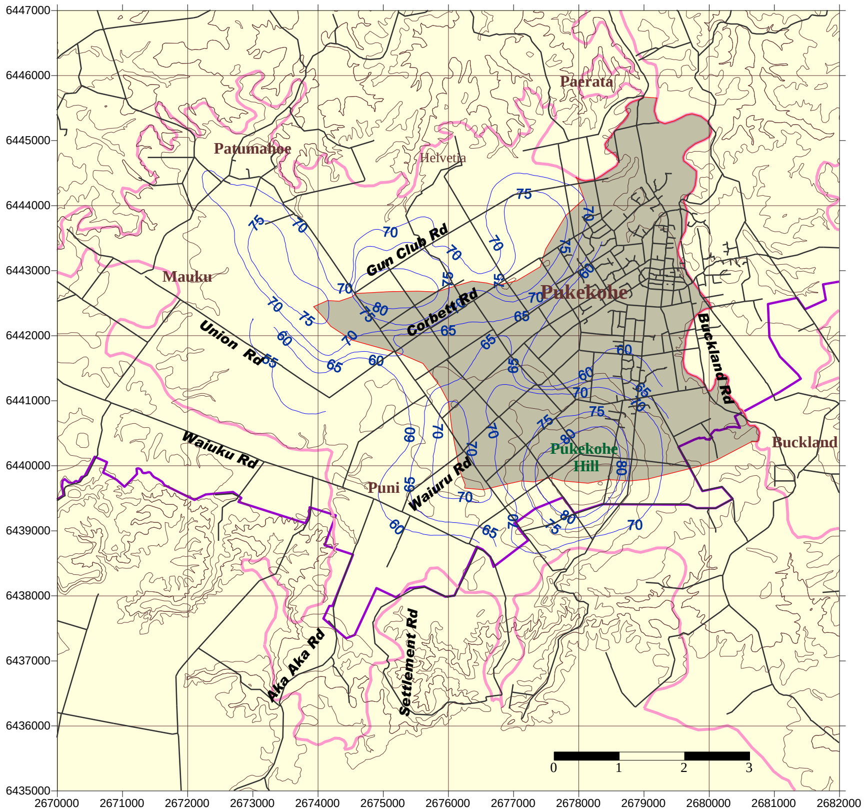

Figure 9.3 Pukekohe Volcanic Central management area

Pukekohe Volcanic Central management area

This management area is located on the northern slopes of Pukekohe Hill. It encompasses the Pukekohe Township, Pukekohe Hill, Patumahoe and Corbett Road. The area covers approximately 22.7km^2 (2270.6 ha) of agricultural and urbanised land. The groundwater resource is under significant demand in this area. Groundwater flow is mainly towards the central and eastern part of the zone. Flows from the southern boundary are generally towards the north, from the western boundary towards the east and from the northern boundary towards the south. This management area encompasses two major discharge points, Hickeys Spring (Whangapouri Stream) and Tutaenui Stream, northwest and southwest of the Pukekohe Township respectively.

Water use and spatial distribution of water users within the management area is described in Chapter 5 (Figure 5.2).

Pukekohe Volcanic South management area

An area of 13.38 km2 elongated in an east – west direction and encompasses the southern slopes of Pukekohe Hill and the Puni – Aka Aka Road area. The northern boundary of the area is also the regional groundwater divide directing surface and groundwater towards Manukau Harbour or Waikato River.

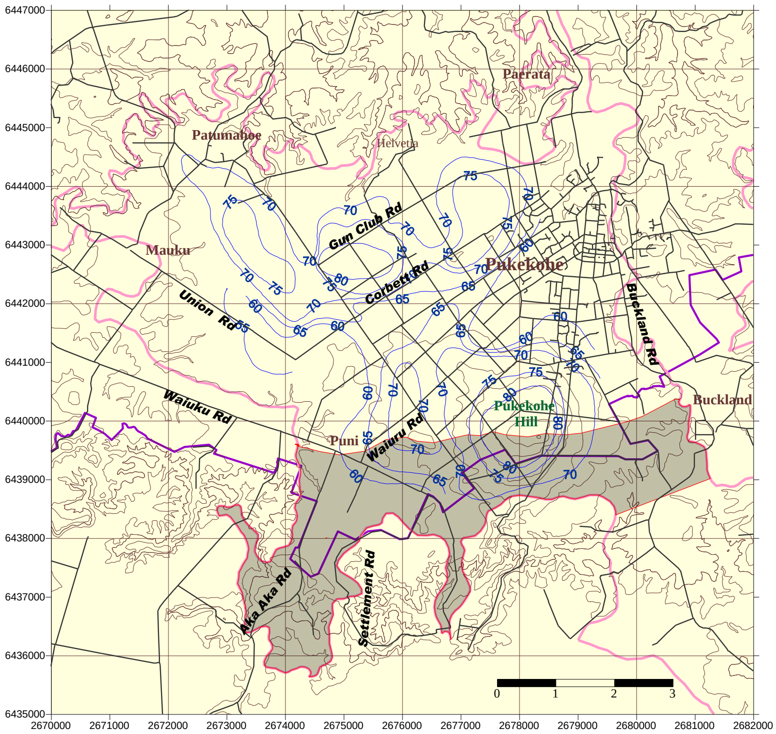

Figure 9.4 Pukekohe Volcanic South management area

The direction of groundwater flow is predominantly towards the south and south-west with a relatively steep gradient in the Pukekohe Hill area. The major groundwater discharge area is along the southern edge of the volcanic aquifer. Groundwater also discharges into a number of Waikato River tributaries. Around Puni the discharge is to the Mauku stream and consequently the Manukau Harbour. The aquifer is moderately utilised for the irrigation purposes, mainly between Aka Aka and Patumahoe roads (Chapter 5). This area requires co-management with the Environment Waikato since the springs and streams in the southern part of the management area are in the Environment Waikato region (Chapter 9,). They can be potentially effected by the groundwater abstraction on both sides of the regional boundary. Groundwater availability is given in Chapters 7 and 9 and must be shared between the Regions.

Pukekohe Volcanic West management area

This management area covers 13.58 km^2 of the Pukekohe basalt aquifer between Puni at the south and Mauku and Patumahoe at the north. Groundwater contours shows relatively steep gradient towards the west. The area is discharging into the Mauku Stream. The recharge zone corresponds to the groundwater level high, on the eastern side of the area bordering with Pukekohe Central and Pukekohe North Management areas. Management objectives in this area are sustainable spring and stream flow maintaining groundwater levels and the required water for the recharge to the Kaawa aquifer.

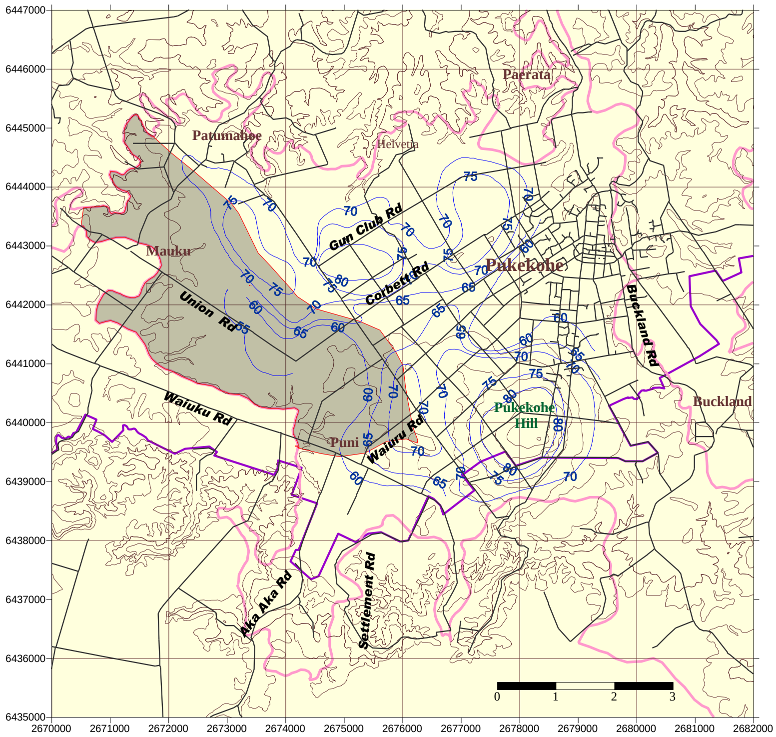

Figure 9.5 Pukekohe Volcanic West management area

Pukekohe North management area

Pukekohe North is the smallest management area of approximately 11.28km^2. It is located north-west of the Pukekohe township. Within this management area three zones of elevated water table are located which mark recharge areas that are feeding the aquifer. His area is moderately utilised for the irrigation purposes. The groundwater flow is mainly northwards discharging into the Whangapouri and Whangamaire streams.

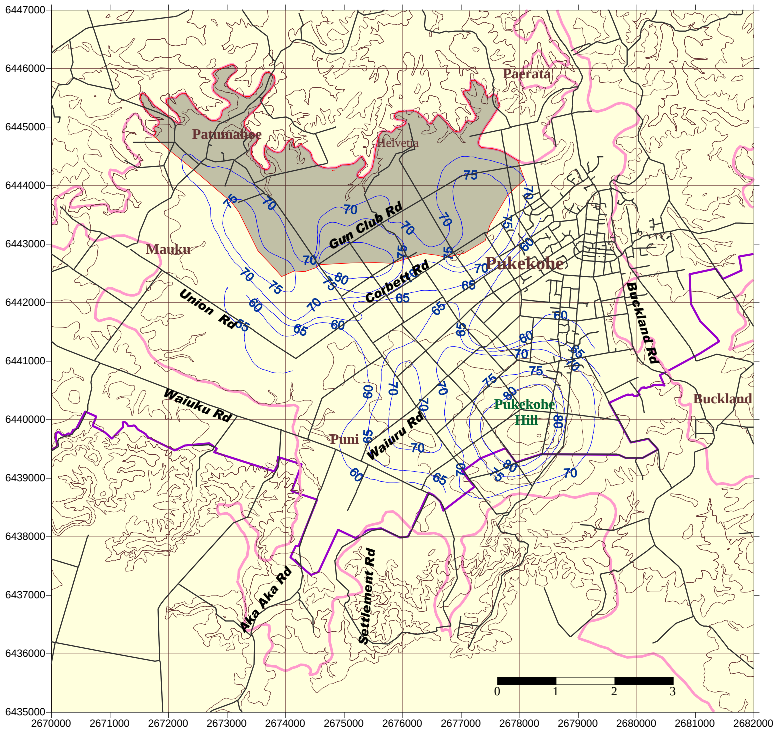

Figure 9.6 Pukekohe Volcanic North management area

Paerata

This, the most northern extension of the Pukekohe Volcanic aquifer (Figure 9.1) covers an area of 4.27 km^2. This area is narrow, approximately 5 km long and 1 to 2 km wide, basalt between from Paerata to the Pukekohe Golf Course (north of Karaka Road). It drains into the Whangapouri Stream and does not provide large quantities of water. There are no major groundwater users from this aquifer and a separate availability has not been calculated.

9.2.2. Kaawa Aquifer management areas

The delineation of the management areas is described in Chapters 2 and 3.

Figure 9.7 shows the extent of the Kaawa aquifer under the Auckland Regional Council management and the position of the management areas.

There are seven management areas making up the Franklin Kaawa aquifer: Pukekohe, Pukekohe West, Waiuku, Glenbrook, Waiau Pa, Karaka and Bombay-Drury. Four of those zones cross the regional boundary: Waiuku, Pukekohe West, Pukekohe and Bombay-Drury. The Management Zones are delineated using the following criteria which are: the location of groundwater divides, groundwater flow direction, groundwater elevation, thickness of the aquifer, existence of significant features in the palaeo relief (e.g. base rock ridges or substantial difference in depth) and location of the recharge areas (Chapter 3). Figure 9.8 illustrates a few of these criteria. Blue lines represent groundwater contours, which indicate the general groundwater flow direction illustrated by blue arrows. Groundwater contours and the groundwater flow direction indicate the location of groundwater divides what is the first criteria for the delineation into the management areas. Other criteria contributing to the delineation shown on Figure 9.8 are groundwater flow directions (blue arrows) and topography of the aquifer's base (brown shades). Additional criteria such as thickness of the aquifer, configuration of the aquifer's upper surface and changes in hydrogeological properties were used to further define the areas for separate management.

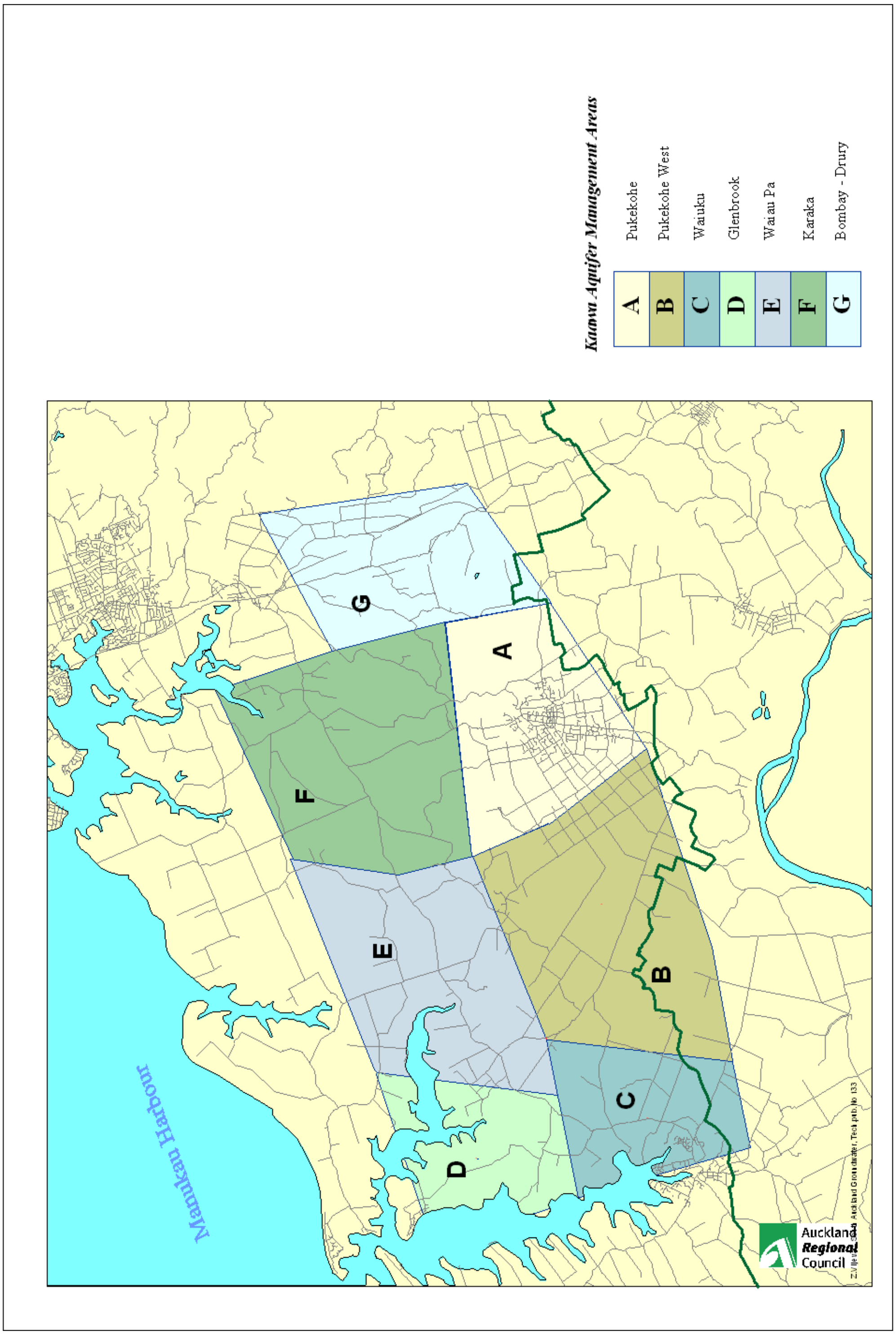

Figure 9.7 Kaawa Aquifer management areas

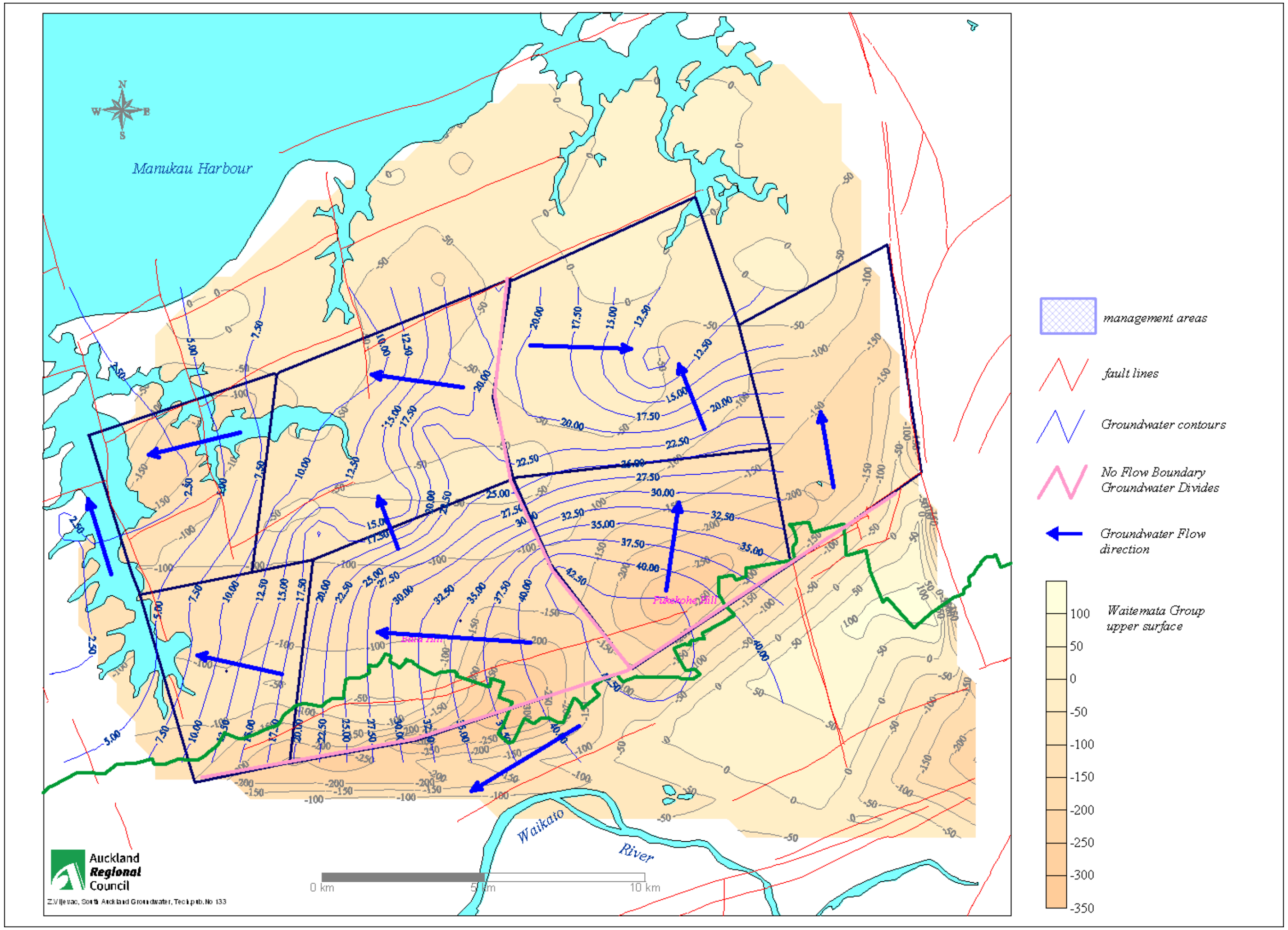

Figure 9.8 Kaawa Aquifer groundwater flow and aquifers physical characteristics

Water availability between management areas depends on the location of the management area within the Kaawa aquifer itself and in relation to the volcanic aquifer as a recharge source. The calculation of groundwater availability is described in Chapter 7 and tabulated in Table 9.3 (Chapter 9.3).

Pukekohe Kaawa management area

The Pukekohe Kaawa management area is located north east of the Pukekohe Hill directly underlying Pukekohe township (Figure 9.9). The area encompasses approximately 36.6 km^2.

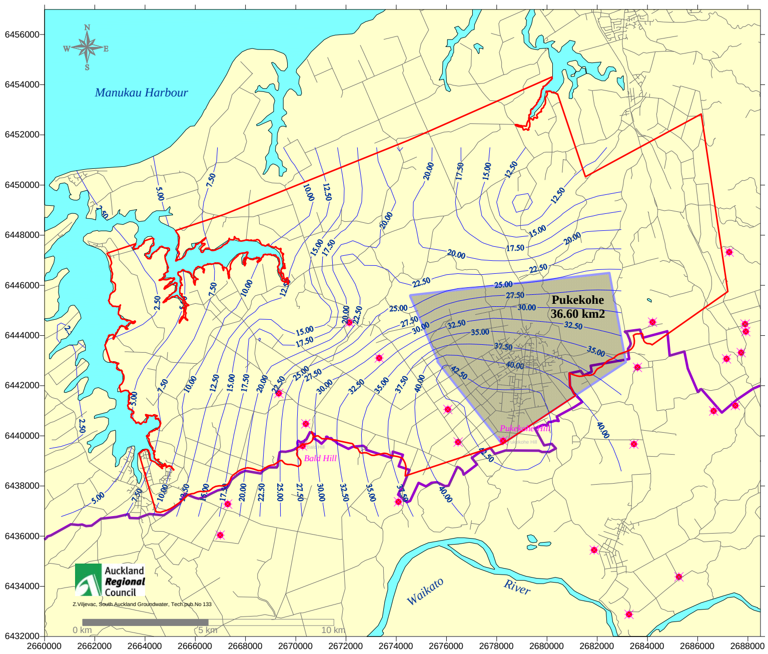

Figure 9.9 Pukekohe Kaawa management area

Thickness of the Kaawa formation in this area ranges from approximately 80m in the northern part to up to 190 metres in the south. Depth to the top of the Kaawa formation from the topographic surface varies significantly from 100 to 280 metres. Kaawa aquifer upper surface is deepest around the Pukekohe Hill area. The area is located east of the main north – west Kaawa groundwater divide and north of the major Manukau Harbour – Waikato River groundwater divide (Chapter 3). The groundwater flows are generally in the north – east direction going from the Pukekohe Hill towards the Karaka Flats. The source of the groundwater recharge is the Pukekohe Hill area (paragraph 3 and 6) which contributes a quarter of its available water. Pukekohe Kaawa management area contributes in the recharge of the Karaka Kaawa management area which is located down gradient (Chapter 7).

Pukekohe West Kaawa management area

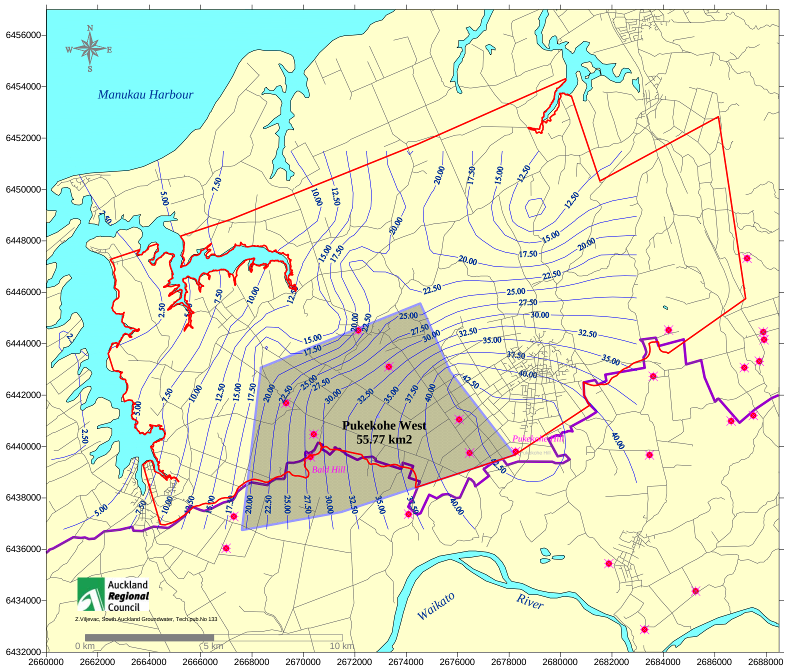

Figure 9.10 Pukekohe West Kaawa management area

The Pukekohe West Kaawa management area covers 55.7 km^2. It is located west of Pukekohe Hill and the Pukekohe township (Figure 9.10). Thickness of the Kaawa Formation in this area varies from approximately 100m in the northern part to up to 250 metres in the south. Depth to the top of the Kaawa formation from the ground surface varies from 80 to 160 metres with a significant increase in depth in the Bald Hill area where it is up to 150 metres from the surface. This management area has the deepest and the thickest Kaawa sediments in the whole area (Chapter 2). The area is located west of the main north – west Kaawa groundwater divide and north of the major Manukau Harbour – Waikato River groundwater divide (Chapter 3). The groundwater flows are generally towards the west, but in the northern part of the management area groundwater flow is changed to a north – north west direction going from Pukekohe

Hill. The source of groundwater is the Pukekohe Hill area which contributes a quarter of the recharge. Additional recharge from Bald Hill and Glenbrook Volcanic (Chapter 7). The Pukekohe West Kaawa management area contributes to the recharge of the Waiuku Kaawa management area and Waiau Pa Kaawa management area which are located down the gradient, west and north respectively.

Waiuku Kaawa management area

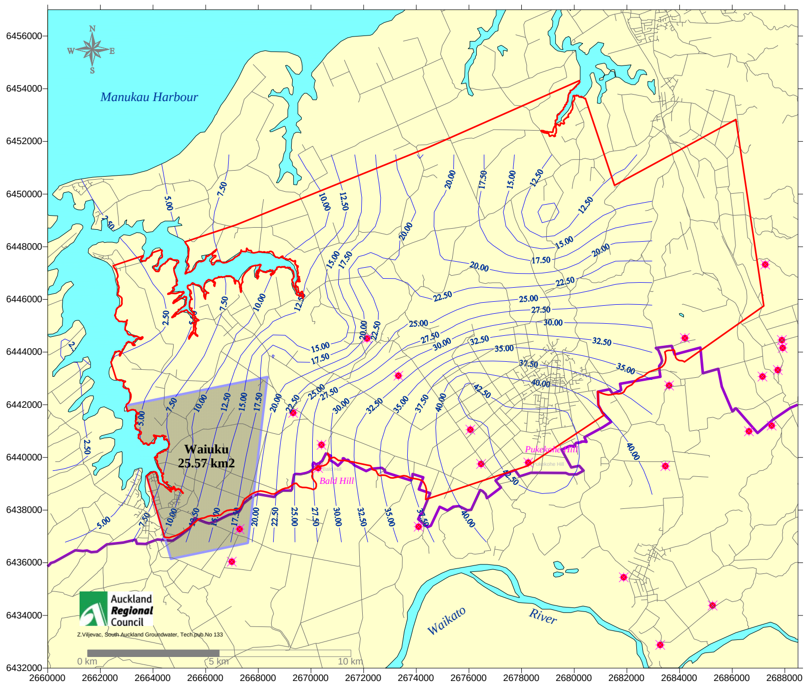

Figure 9.11 Waiuku Kaawa management area

The Waiuku Kaawa management area is located east of the Waiuku River and includes the Waiuku and Pukeoware townships covering approximately 25.5 km^2 (Figure 9.11). The area is located north of the major Manukau Harbour – Waikato River groundwater divide (Chapter 3). Groundwater flows are generally to the west – northwest and discharges in the Waiuku River area. The source of the recharge is groundwater flow from the Pukekohe West Kaawa management area with additional recharge from the Glenbrook Volcanic (Chapter 7). Thickness of the Kaawa formation in this area is relatively uniform but in places varies between approximately 60 and 100 metres. Kaawa formation from the topographic surface is up to 80 metres. This area is delineated from the Pukekohe West Kaawa management area because of Glenbrook Volcanic recharge input to the aquifer. Because of that additional recharge this area can be managed separately.

Glenbrook - Waiau Pa Kaawa management area

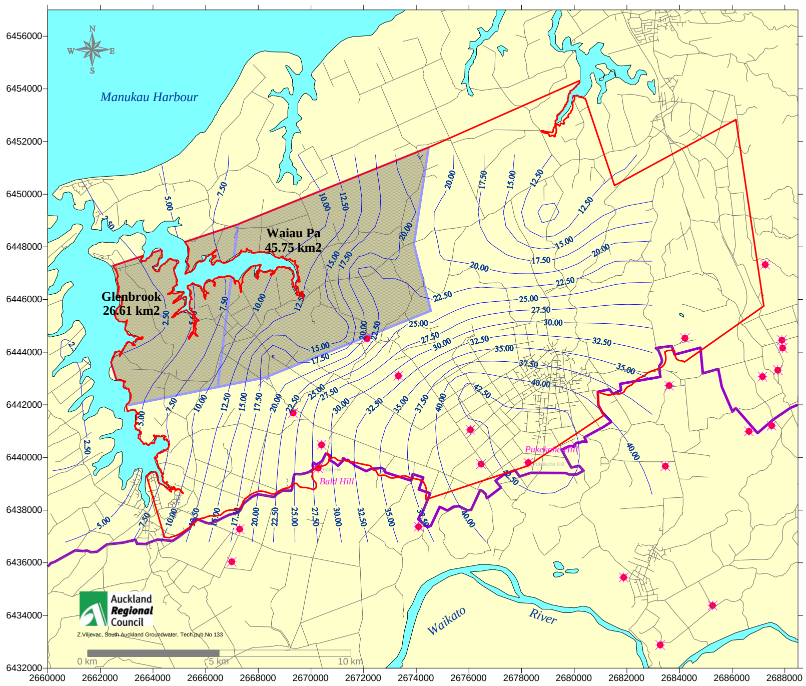

Figure 9.12 Glenbrook - Waiau Pa Kaawa management area

The Glenbrook - Waiau Pa management area is located east of the Waiuku River (Figure 9.12) covering approximately 72 km^2. The area encompasses part of the Glenbrook Peninsula, Taihiki River and extends up to Patumahoe and Te Hihi settlements. Thickness of the Kaawa formation in this area is mostly 50 metres or less, except in the Glenbrook area where thickness can be up to 130 metres. The top of the Kaawa formation is close to the topographic surface and on average does not exceed 50 metres of depth. The area is located in the northern part of the Kaawa aquifer bordering the Glenbrook Fault in the north (Chapter 2). Separated is from the Pukekohe West Kaawa management area because of general change in flow direction and significant reduce in aquifer thickness (Chapter 2). Groundwater flows are generally to the west – northwest and discharges into the Waiuku and Taihiki River area. The source of groundwater recharge is groundwater flow from the Pukekohe

West management area (Chapters 3 and 6) with additional recharge from the Patumahoe and Mauku part of the Pukekohe Volcanic aquifer. Because of the ease of accessibility to the aquifer due to its shallow location, the area is relatively highly utilised as a water supply (Chapter 5).

Karaka Kaawa management area

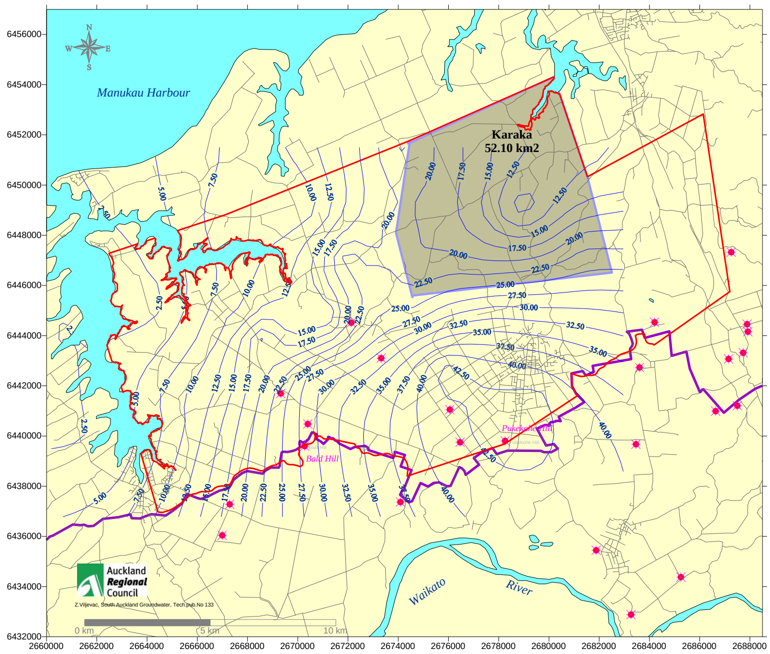

Figure 9.13 Karaka Kaawa management area

The Karaka Kaawa management area covers approximately 52 km^2. It is located in the Manukau lowlands north of the Pukekohe township (Figure 9.13). Thickness of the Kaawa formation in this area varies from less than 50 metres to approximately 80 metres. Bore record shows lessening in thickness and an absence of the Kaawa Formation in the northern part of the area. Depth to the top of the Kaawa formation from the ground surface small and varies from less than 40 to approximately 80 metres. This is the reason for relatively high groundwater use from the area. Groundwater flows are converging from the west and south towards Karaka in the north-east part of the area. Groundwater contours indicate a discharge zone in the Drury Creek area. The source of groundwater recharge is only the groundwater flow from the Pukekohe management area (paragraph 3 and 6).

Bombay-Drury Kaawa management area

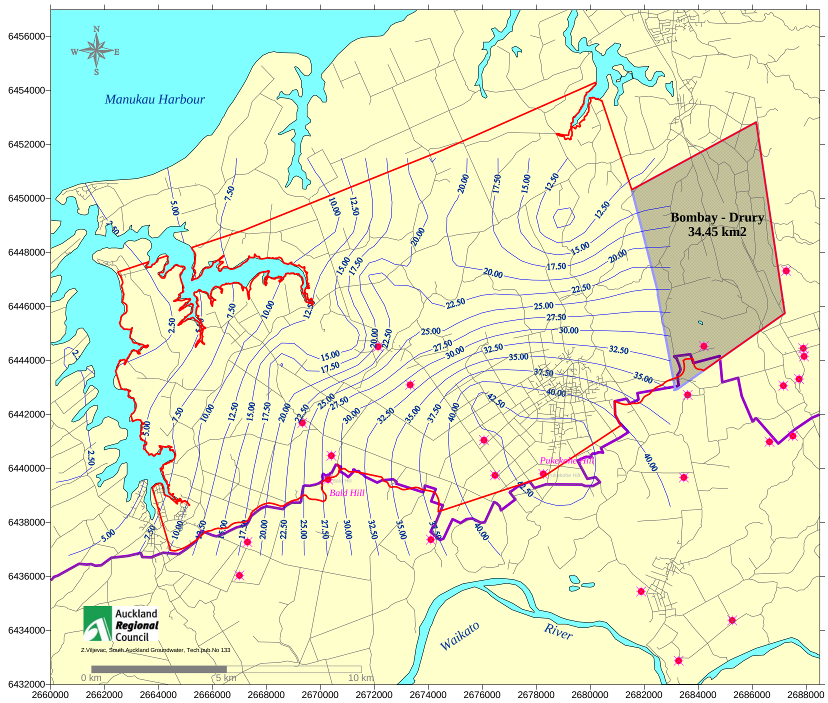

Figure 9.14 Bombay – Drury Kaawa management area

The Bombay – Drury Kaawa management area (Figure 9.14) is located between the Pukekohe Kaawa management area in the north and the Drury Fault in the east (Chapters 2 and 3). Southern boundary of the area is the St Stephens Fault and thick uplifted Waitemata Group. In the north the boundary is defined by the gradual extinction of the Kaawa Formation (Chapter 2). The area underlies Bombay and Drury volcanic aquifer and covers approximately 34.5 km^2. Thickness of the Kaawa Formation in this area is from about 160 metres in the south of the area and up to 100 metres in the north. Depth to the top of the Kaawa Formation from the ground surface can be between 60 and 180 metres.

The area is located north of the major Manukau Harbour – Waikato River groundwater divide (Chapter 3). Groundwater flows are generally to the north and discharge into the Drury Creek area. The source of the groundwater recharge is mainly recharge from the overlying Bombay Volcanic aquifer and partially from the Pukekohe Kaawa management area (Chapter 7). Water use and spatial distribution of users from the Kaawa aquifer is described in the Chapter 5.

9.3. Groundwater Availability

Groundwater availability is defined as the quantity of water that can be sustainably abstracted from an aquifer by groundwater users. It is sometimes referred as safe yield.

Groundwater availability was derived from the difference between infiltration rate and the amount of water needed to maintain stream flows, recharge to other aquifers and maintain saline water interface.

A detailed calculation of recharge and groundwater availability is described in Chapter 7.

9.3.1. Pukekohe Volcanic Aquifer

The water availability figures are rounded to the closest 50 or 100 cubic metres.

Figure 9.2 shows the location of Pukekohe Volcanic Management Areas and the associated water availability. Table 9.1 lists the estimated water availability for the Pukekohe Volcanic Aquifer per management area and total availability for the entire aquifer.

Table 9.1 Pukekohe Volcanic Aquifer water availability

Pukekohe Volcanic Aquifer	Area km2	Availability m3/year	Annual allocation
Pukekohe Volcanic **Central** Management Area	*18.40*	**855,750.00**	474,141.00
Pukekohe Volcanic **South** Management Area[5]	*13.37*	**650,000.00**	90,340.00
Pukekohe Volcanic **West** Management Area	*13.58*	**420,000.00**	243,763.00
Pukekohe Volcanic **North** Management Area	*11.28*	**420,000.00**	138,850.00
Total availability		**2,345,750.00**	947,094.00

A split of availability in the Pukekohe Volcanic South management area between Environment Waikato and Auckland Regional council is proposed asshown in Figure 9.15. This is necessitated because the aquifer and associated management area is bisected by the southern boundary of the Auckland Region.

[5] The availability shared with EW

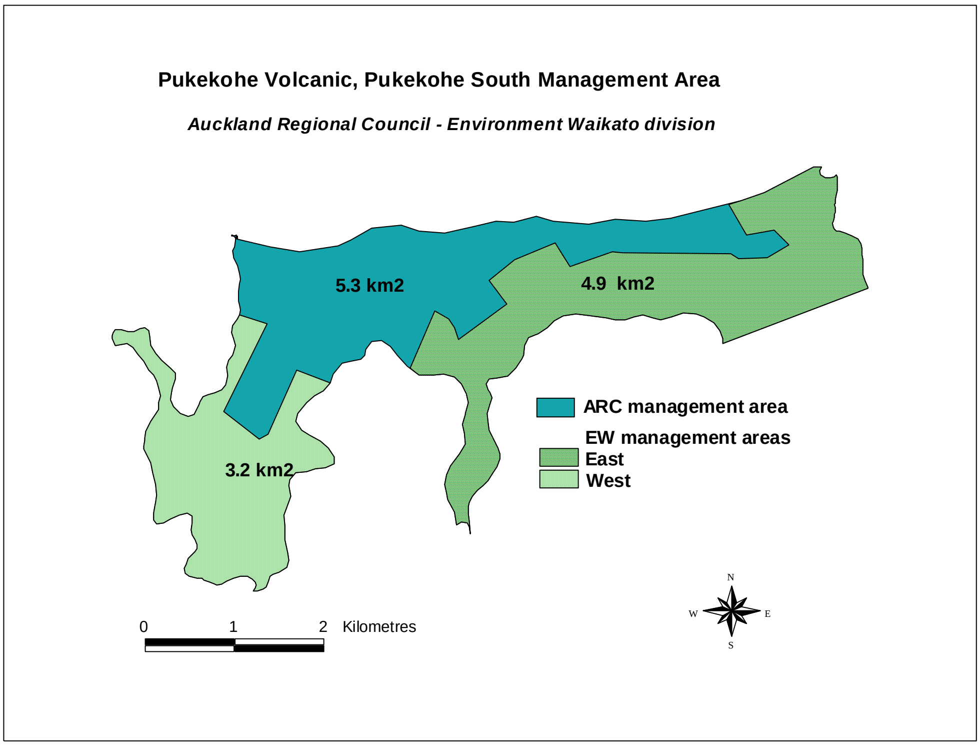

Figure 9.15 Pukekohe South Management Area, ARC-EW management areas

The consequent split of groundwater availability by the regions is given in Table 9.2. The boundary between the regions has divided the portiont of the aquifer administrated by EW into two parts. An availability figure is suggested for of the management area in the Waikato Region using the same principle as for the Auckland Regional Council. The actual management approach for these areas rests with EW.

Table 9.2 Pukekohe South management area, Water availability split

Pukekohe Volcanic Aquifer			**Area km^2**	**Availability m^3/year**	**Annual allocation**
Pukekohe Volcanic **South** Management Area (*13.37km^2*)	**ARC**		*5.3*	**258,050.00**	90,340.00
	EW	east	*4.9*	***154,700.00**	
		west	*3.2*	***237,250.00**	
Total availability				**650,000.00**	

*A suggested sustainable allocation limit

The Pukekohe Central volcanic management area has the biggest surface area and therefore the biggest availability. However availability is not only a reflection of the size of the area but also depends on rainfall distribution and recharge pattern (see paragraph 7.).

Figure 9.16 shows water availability and annual allocation per management zone in the Pukekohe Volcanic area. The diagram suggests that in most of the management areas almost half of the estimated availability is still available for further use.

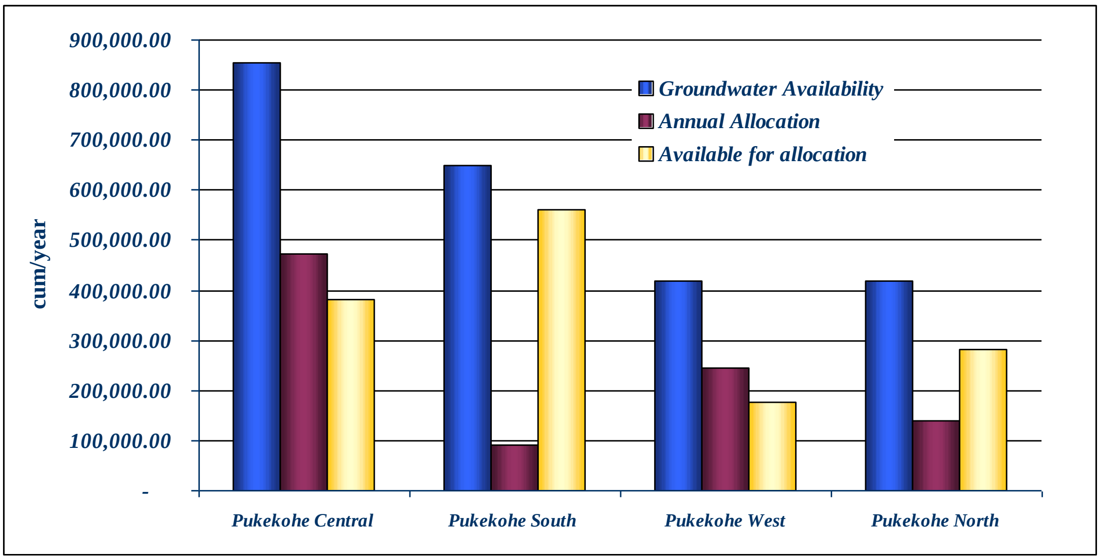

Figure 9.16 Pukekohe Volcanic Aquifer water availability and allocation

Due to the general aquifer characteristics (Chapters 2 and 3) and the management approach as described, it is not possible to access the complete allocation from location.

9.3.2. Kaawa Aquifer

Groundwater available for the Kaawa aquifer is divided amongst the management areas (Chapter 7) and shown in Table 9.3.

The estimated availabilities have incorporated an allowance for the recharge of the adjacent management areas and also enough outflow to prevent potential saline intrusion. Not withstanding these figures, the allocation to any new application should take into account specific conditions at the location.

Table 9.3 Kaawa Aquifer groundwater availability

Franklin Kaawa Aquifer	Area km2	Availability m3/year	Annual allocation
Pukekohe Kaawa Management Area	*36.60*	**1,860,094.54**	1,246,950.00
Pukekohe West Kaawa Management area	*55.77*	**1,780,035.95**	356,570.00
Waiuku Kaawa management Area	*25.56*	**2,451,109.45**	881,595.00
Glenbrook / Waiau Pa Kaawa Managment Area	*72.09*	**1,560,042.52**	1,143,380.00
Karaka Kaawa Management Area	*52.10*	**616,944.59**	798,870.00
Bombay-Drury Kaawa Management Area	*34.51*	**717,851.39**	342,000.00
Total Availability		**8,986,078.43**	4,769,365.00

Figure 9.17 gives an indication of the amount of groundwater still available for allocation.

The diagram shows that the management areas such as Waiuku and Pukekohe West have more than a half of their estimated availabilities still available for allocation. Glenbrook - Waiau Pa and Pukekohe Kaawa management areas have more than half of their estimated availabilities already allocated.

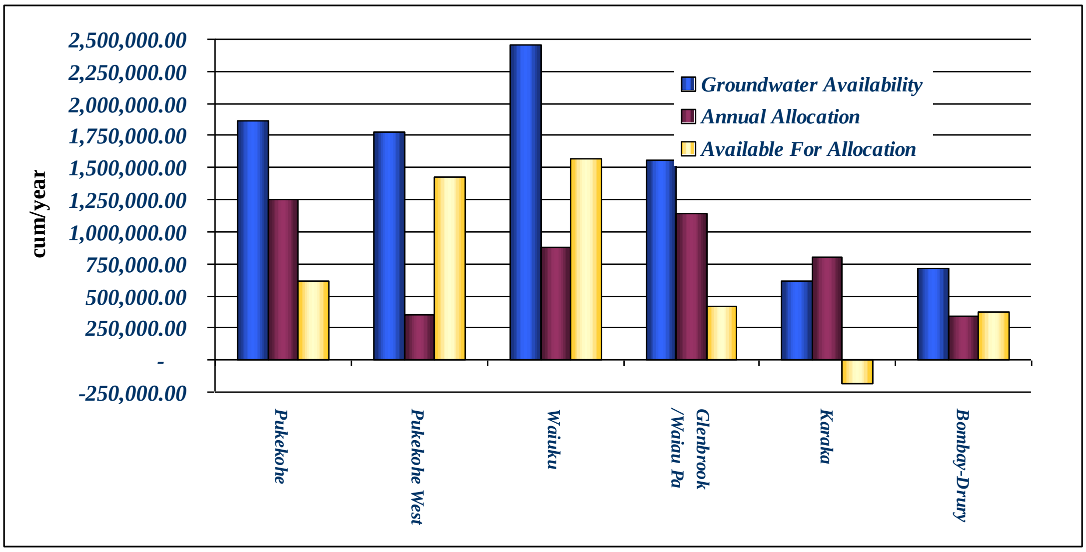

Figure 9.17 Kaawa aquifer water availability and allocation comparison

The Karaka Kaawa management area is currently over allocated due to newly defined management area delineations.

9.3.3. Conclusion

Water availability for allocation to resource consents from the Volcanic aquifer provides an allowance for stream discharge (average annual baseflow) and recharge to the Kaawa aquifer.

As in a volcanic aquifer, availability from the Kaawa aquifer is divided into management areas according to aquifer characteristics. Separate availability calculations provide sustainable groundwater through flow both within and between management areas, while maintaining sufficient discharge to prevent saline intrusion.

These groundwater availability figures are a constraint to water allocation, and have been included in PRP:ALW 2001. It should also be noted that within any individual management area not all availability can be considered as available at any one location. Groundwater is managed according to Fourth Schedule provisions of the RMA, and will be consistent with rules in the PRP:ALW 2001. The processing of the resource consents requires assessment of potential adverse effect of an activity. The management guidelines contained in this report will provide essential input to this process.

9.4. Resources Consents

Under Section 14 (3)(b) of the RMA, groundwater taken for an individual's reasonable domestic needs, or the reasonable needs of their animals for drinking water, does not require a resource consent. This is providing the taking does not, or is not likely to have an adverse effect on the environment.

Otherwise Policy 6.5.42 of the PARP:ALW 2001 determines the taking and use of groundwater from an aquifer in a High Use Aquifer Management Area is a Discretionary Activity requiring a resource consent to ensure aquifer sustainability.

> Policy 6.4.34 states that any proposal to take and use groundwater for which a resource consent is required shall demonstrate that:
>
> (a) Water availability for the aquifer will not be exceeded;

(b) The taking of groundwater will not reduce groundwater levels to below a minimum level at a location in an aquifer set by this plan;

(c) The taking of groundwater will avoid, remedy or mitigate adverse effects on surface water flows, including:

  i) base flow of streams and springs; and
  ii) any stream flow requirements;

(d) The taking of groundwater will not cause saltwater intrusion or any other contamination;

(e) The taking of groundwater will not cause adverse interference effects on neighbouring bores to the extent where the neighbouring bore owner is prevented from obtaining their lawfully established water requirements except:

  i) where the affected bore is a (shallow) partially penetrating bore;
  ii) it is practicably possible to locate the pump intake at a greater depth within the affected bore; and
  iii) it can be demonstrated that the bore accesses, or could have accessed, the resource at a deeper level within the same aquifer;

(f) That the proposed bore is capable of extracting the quantity applied for;

(g) The taking of groundwater will sustain the potential of aquifers to meet the reasonably foreseeable needs of future generations and to avoid, remedy or mitigate adverse effects on the environment, particularly:

  i) maintaining recharge to other aquifers; and
  ii) avoiding aquifer consolidation and surface subsidence;

(h) Mitigation options have been incorporated where appropriate, including but not limited to:

  i) alternative rates and timing of abstractions;
  ii) providing alternative water supplies; or
  iii) water conservation options in times of reduced water availability; and

(i) Monitoring has been incorporated where appropriate, including but not limited to:

  i) measurement and recording of water use;
  ii) measurement and recording of water flows and levels; or
  iii) sampling and assessment of water quality and freshwater biota.

Rules in the PARP:ALW 2001 relating to resource consents are as follows:

6.5.3 The taking and use of fresh groundwater in accordance with section 14(3)(b) of the RMA is likely to have an adverse effect on the environment unless it complies with the following condition:

(a) The location and/or rate of the taking shall not adversely affect any lawfully established taking of water.

6.5.4 If the taking and use of fresh groundwater in accordance with section 14(3)(b) of the RMA does not comply with the condition of Rule 6.5.3, then the taking and use shall cease until a resource consent for the taking and use under Rule 6.5.44 has been applied for and granted by the ARC.

9.4.1. Quality Sensitive Aquifer Management Areas

Description

Quality Sensitive Aquifer Management Areas include those aquifers which, due to their geology, have the potential for contamination from the discharge of contaminants to land or into groundwater. These aquifers are shallow and unconfined and hence are susceptible to pollution from surface sources, such as excess fertiliser application or discharges of contaminants such as stormwater or sewage. The potential for contamination is highest in the volcanic aquifers where discharge to aquifers is most direct. Protection of both the quality and quantity of water within aquifers is therefore critical. They are important sources of water for rural and municipal water supply purposes, as well as providing base flow to surface streams. The Franklin Volcanic aquifers are Quality Sensitive Aquifers.

Management Approach

The main purpose of this management area, in addition to controlling abstraction of water, is to protect the quality of the water within the aquifers. Discharges of contaminants are discouraged where this is likely to have significant adverse effect on the quality of water within these aquifers. A resource consent will generally be required to determine the potential effects of any discharge on these aquifers.

9.5. Cross boundary issues

There are seven territorial authorities within the Auckland Region managing the Region's air, land and water resources: Auckland City, North Shore City, Waitakere City, Manukau City, Rodney District, Franklin District, and Papakura District. There are two regional councils adjoining the Auckland Region: Waikato Regional Council (Environment Waikato) and Northland Regional Council. Significant 'cross-boundary' issues can arise in the management of these resources due to the responsibilities of the ARC and the other local authorities.

9.5.1. Integrated Management

The RMA includes various provisions to address cross boundary issues and encourage the integrated management of the natural and physical resources of the Auckland region. District plans are required to be not inconsistent with the PARP:ALW 2001. There is provision within the RMA for the integration of administrative functions through joint and combined hearings with territorial authorities or adjacent regional councils when consent applications or the possible effects cross administrative boundaries.

9.5.2. Issues which cross Local authority boundaries

Many activities that take place on land can have an effect on the Region's air, land and water resources. Section 30 (1)(c) of the RMA gives regional councils responsibility for controlling the use of land for a number of purposes, including soil conservation, the maintenance and enhancement of water quality, the maintenance of water quantity, and the avoidance or mitigation of natural hazards. Section 31(b) of the RMA gives territorial authorities responsibility for controlling the effects of the use of land. Therefore, both TAs and regional councils have responsibilities for land use relating to soil and water.

The Pukekohe Volcanic and Franklin Kaawa Aquifers cross the boundary between the Auckland and Waikato Regions. Activities within these aquifer areas, such as the taking of groundwater and increases to impervious surfaces associated with land subdivision, have the potential to have effects which can 'migrate' into the Environment Waikato region. Accordingly, the sustainable management of the environment needs to consider an inter-regional perspective.

9.5.3. Process policies to address cross boundary issues

To promote the integrated management and use of the air, land and freshwater resources of the Auckland Region across administrative and jurisdictional boundaries, policies in the PARP:ALW 2001 requires the following processes be used:

9.5.3.1 When considering consent applications, regard shall be had to the effects of the activity on the provisions of any relevant district plan, regional plan, or other council-adopted planning document. A copy of any consent application which may have more than minor adverse effects across a regional boundary shall be referred to that regional council.

9.5.3.2 Liaison shall occur with adjoining regional councils and territorial authorities to promote integrated management and ensure as far as practicable that a consistent approach is maintained between resource management issues which cross territorial authority and regional council responsibilities.

9.5.3.3 Liaison shall occur with other statutory bodies on legislative issues that affect the management of air, land and water resources in the Auckland Region.

10. REFERENCES

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