The volume of groundwater in New Zealand 1994 to 2001

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EXECUTIVE SUMMARY

The volume of groundwater has been estimated using a simple geometric technique for the unconfined and confined aquifers of New Zealand. Estimates of groundwater volumes on an aquifer-by-aquifer basis, are summed to give regional and national estimates. The estimated groundwater volume for all of New Zealand is 612 x 10^9 m^3 to 619 x 10^9 m^3. The Canterbury region, with an estimated 430 x 10^9 m^3 of groundwater is the region with the largest groundwater storage. These volume estimates are greater than the volume available for abstraction because sustainable use requires that groundwater recharge, groundwater quality, and effects on 'receiving' environments be considered in setting abstraction limits.

Annual changes in groundwater volume in New Zealand aquifers were estimated by applying groundwater levels observed in regional indicator wells to the estimated level variation in the country's aquifers. The Canterbury region was found to be the most significant contributor to annual changes in national groundwater volumes.

The estimates of groundwater volumes obtained are presented in this report as cubic metres at the request of Statistics New Zealand so they can easily be compared with estimates of freshwater storage in rivers and lakes. Generally the regional groundwater volumes are in billions of cubic metres and eight significant figures appear to give the calculation a great accuracy. It is very unlikely that groundwater volume calculations are this accurate. Therefore, estimates of groundwater volumes in this report are given as billions of cubic metres to two decimal places in summary tables.

1.0 INTRODUCTION

New Zealand is currently the only country in the Organisation for Economic Co-operation and Development (OECD) that does not have a set of natural resource accounts. Water is an important natural resource, and groundwater is significant component of New Zealand's water resource.

This report describes the calculation of groundwater volumes in New Zealand in the period 1995 to 2001. The methods used to calculate groundwater volumes are described, with a worked example given for the aquifers in one region. Weaknesses in the data are summarised. The estimated volumes in the period 1995 to 2001 are presented by region and by aquifer type. Changes in groundwater volumes are compared with changes in nation-wide rainfall over the period.

2.0 BACKGROUND

New Zealand is currently the only country in the OECD that does not have a set of natural resource accounts. The Ministry for the Environment (MfE) and Statistics New Zealand (SNZ) are working on the development of natural resource accounts for New Zealand. These accounts are stock and flow accounts (in volume and dollar units) for natural and physical resources including forestry, fisheries, land, subsoil assets (gas, coal, oil) and freshwater. Groundwater 'stocks' and 'flows' are parts of this set of accounts.

The groundwater 'stock', i.e. groundwater volume, in New Zealand has been previously estimated. A large portion of New Zealand's total water storage is in its groundwater resource – Toebes (1972) estimated 80%, or $1.7\text{x}10^{12}$ m^3, of the nation's water is held as groundwater. This water is an important water source for agriculture, industry, public water supply and recreation (White, 2001). Toebes (1972) used a simple assumption to calculate groundwater volumes: he estimated the New Zealand land volume above sea level and multiplied by an average porosity. This calculation is an extreme simplification as a considerable part of this volume is unsaturated, porosity generally decreases with depth, and not all aquifers are unconfined.

The first attempt to map New Zealand's aquifers at a national scale was by White (1997) with assistance from regional councils. Two hundred New Zealand aquifers were identified on an improved map in White (2001). Information on groundwater systems in New Zealand is quite immature, as exampled by the quite recent attempts to get something as relatively simple as a map of

New Zealand aquifers. In comparison, resource information about surface waters are relatively well developed. Information about groundwater must improve in the future as this water resource becomes viewed more as a key resource by regions whose surface water resources become fully allocated.

The purpose of this project is to provide regional, and national, estimates of groundwater volumes. This is based on groundwater aquifer area (from the maps of White, 2001), aquifer thickness (from the literature and from regional councils) and aquifer type (from the literature and from regional councils).

The estimation of groundwater flows follows the estimation of groundwater volumes, and is left to a future project.

3.0 METHODS

Heath (1983) defines *underground water* as 'all water beneath the land surface". Underground water occurs in two zones - the *unsaturated zone*, which contains both water and air, and the *saturated zone* where pore openings are full of water. Water in the saturated zone is referred to as *groundwater*. Heath (1983) also defined *aquifer* as 'a rock unit that will yield water in a usable quantity to a well or spring'.

The definitions of *groundwater* and *aquifer* of Heath (1983) are used in this report. Therefore groundwater volume estimates do not include water in the soil and unsaturated zone. The quality of groundwater is not considered in this report. Not all groundwater is potable. For example the chemical quality of groundwater can be poorer than drinking water guidelines (Davies, 2001) and some shallow groundwater contains bugs (Sinton, 2001).

Determination of the availability of groundwater for abstraction is the role of regional councils (Fenemor and Robb, 2001). Consideration of natural groundwater recharge, storage volumes, effects on users' wells, and environmental effects, usually means that the water available for sustainable abstraction is less than the total volume available.

3.1 Aquifer area

White (2001) identified and listed approximately 200 groundwater aquifers in New Zealand (Fig. 1, Table 1, Fig. 2, Table 2). This list is used as a basis for estimating groundwater volumes on both a regional and national level for this project.

Each groundwater aquifer is listed, and an area for the aquifer is estimated by measuring aquifer areas within polygon boundaries from White (2001). In some cases, proportions of the area within polygon boundaries were attributed to aquifers based on GNS experience in the area. In some cases an area is mapped to contain many aquifers, and detailed maps are often unavailable.

3.2 Aquifer types

Each aquifer is classified as unconfined or confined. Where aquifers have portions that are both confined and unconfined (e.g. Heretaunga Plains aquifer in the Hawke's Bay is unconfined in the west but confined near the coast), the aquifer is assigned the classification which is thought to dominate the larger aquifer volume. Aquifers which are described as semi-confined are given a confined classification.

A classification is determined by GNS depending on geology type and using previous experience in cases where no classification for an aquifer was available.

3.3 Aquifer thicknesses

The aquifer thickness, or more specifically, the saturated aquifer thickness, is necessary to calculate the aquifer volume. An average thickness is used, as in general aquifer thicknesses can be highly variable throughout each aquifer.

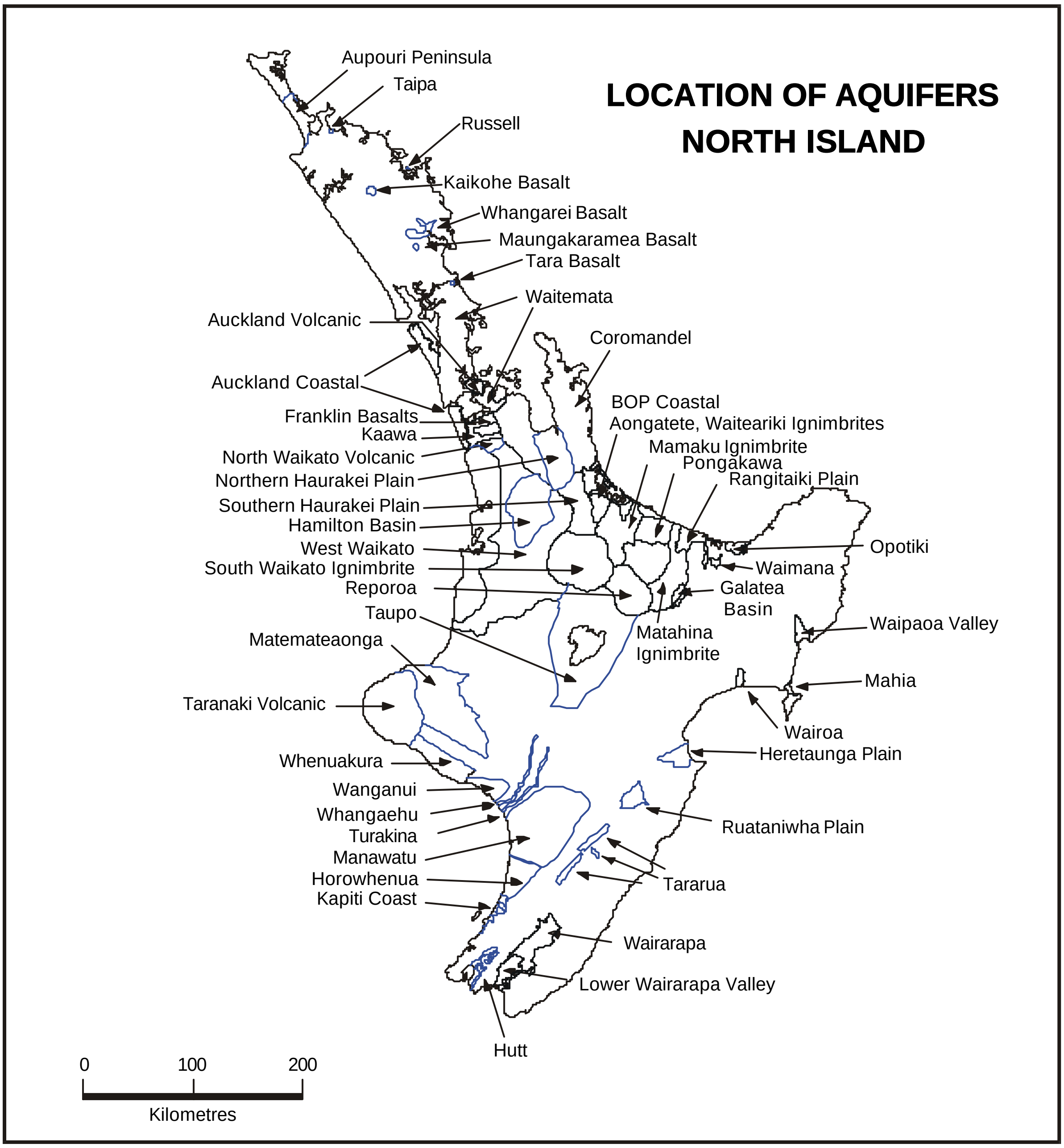

Figure 1. Location of North Island aquifers (White, 2001).

Table 1. Regions and names of North Island aquifers.

Region and Aquifer Name
Northland
Aupouri
Kerikeri
Okaihau
Waimate North
Pakaraka
Ngawha
Kaikohe
Matarau
Glenbervie
Three Mile Bush
Maunu
Whatitiri
Maungatapere
Maungakaramea
Ruawai
Tara
Mangawhai
Waitemata Formation
Auckland volcanics
South Auckland volcanics
Tauranga Group sediments
Kaawa Formation
Greywacke
Auckland coastal aquifers
South Auckland volcanics
Tauranga Group sediments
Kaawa Formation
Hinuera Formation
Coromandel volcanic
Coromandel sand
Waiotapu Ignimbrite
Whakamaru ignimbrites
Taupo ignimbrites
Taupo sand
Otorohanga and Orahiri limestone
Aongatete Ignimbrite
Waiteariki Ignimbrite
Western Bay Rhyolite
Mamaku Plateau
Matahina Ignimbrite
Pongakawa Breccia
Rangitaiki Plains
Coastal Aquifers
Waihi Beach Rhyolite
Katikati Gravel
Mt Maunganui sand
Matakana Island sand
Maketu warm water
Maketu Pumice
Opotiki
Galatea Basin

Gisborne
Waipaoa Valley
Te Hapara sand
Shallow fluvial
Waipaoa Gravel
Makauri Gravel
Matokitoki Gravel
Waiapu and Tolaga Bay flats
Taranaki
Matemateaonga Formation
Taranaki Volcanic
Marine Terrace
Whenuakura Formation
Region and Aquifer Name
Hawke's Bay
Northern Coastal
Wairoa Valley
Nuhaka coastal
Nuhaka limestone
Mahia sand
Mahia alluvium
Mahia
Esk Valley
Heretaunga Plains
Poukawa Basin
Papanui Stream Valley
Ruataniwha Plains
Manawatu-Wanganui
Wanganui
Wangaehui-Turakina
Rangitikei
Manawatu
Horowhenua
Tararua
Coastal

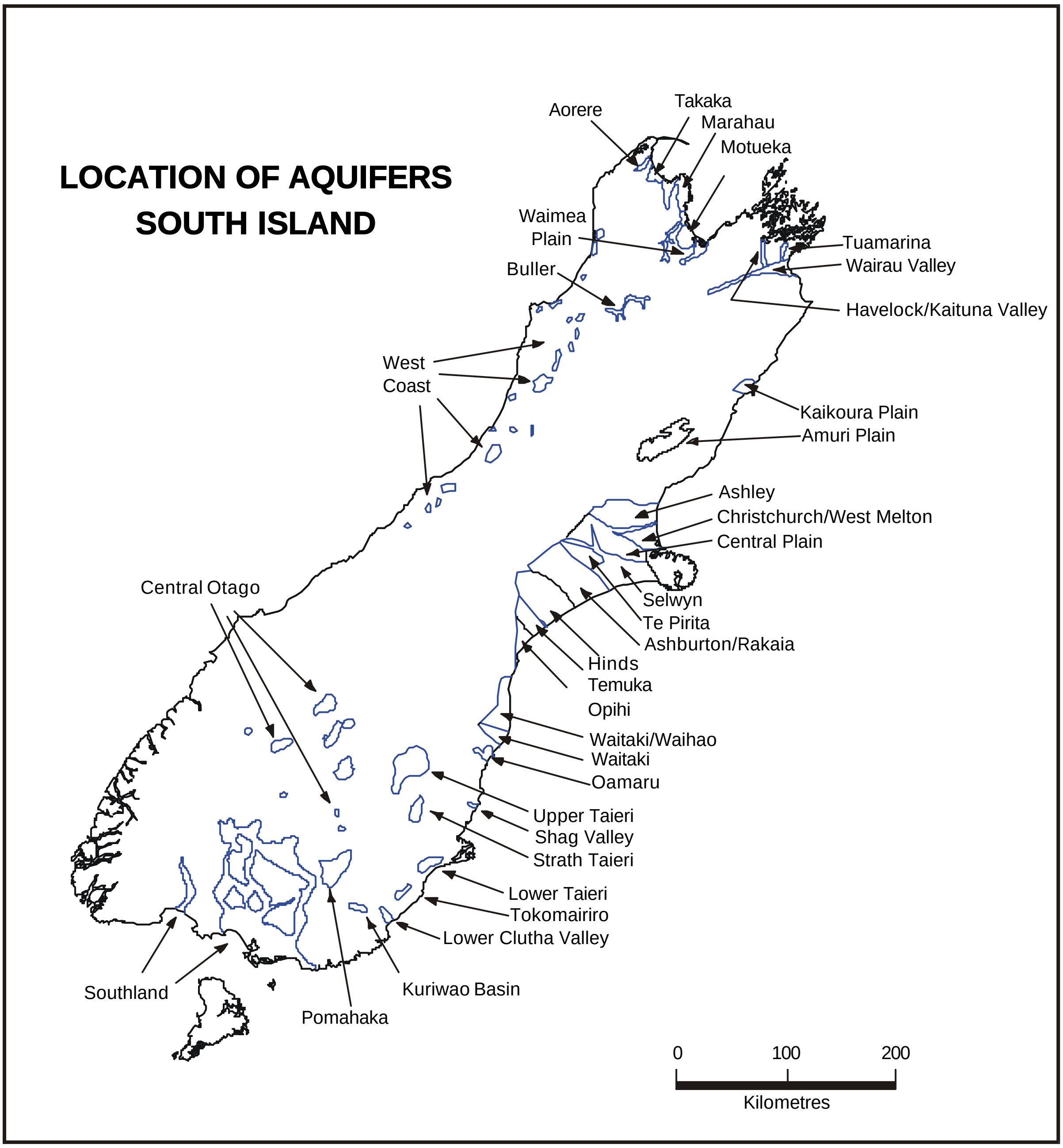

Figure 2. Location of South Island aquifers (White, 2001).

Table 2. Regions and names of South Island aquifers (White, 2001).

Region and Aquifer Name
Marlborough
Wairau
Southern Valleys
Benmorven
Brancott
Fairhall River Gravels
Taylor – Burleigh
Omaka – Hawkesbury
Omaka River Valley
Deep Wairau
Rarangi Shallow
Tuamarino Valley
Rai Valley
Pelorus Valley
Kaituna Valley
Upper Wairau Valley
Lower Awatere Valley
Tasman
Waimea Plains
Appleby Gravel Unconfined
Hope Minor Confined and Unconfined
Upper Confined
Lower Confined
Moutere Valley
Shallow Moutere
Middle Moutere
Deep Moutere
Motueka/Riwaka Plains
Takaka Valley
Arthur Marble
Takaka Limestone
Takaka Valley Gravel
Motueka River Terraces
Aorere Gravel
Buller River Terraces
Marahau River
Canterbury
North Canterbury
Kaikoura Plain
Hanmer Basin
Parnassus Basin
Culverden Basin
Waipara Basin
Banks Peninsula
Canterbury Plains
Ashley Downs
Waimakariri-Ashley plains
Christchurch-West Melton
Central Plains
Rakaia-Ashburton plains
Ashburton-Rangitata plains
Rangitata-Levels plains
South Canterbury
Fairlie Basin
Hakataramea Basin
MacKenzie Basin
Region and Aquifer Name
West Coast
West Coast alluvial

Otago
Lower Waitaki Alluvium
Papakaio
Waiareka and Deborah volcanic
Kakanui-Kauru Alluvium
Shag Alluvium
Lower Taieri Plain – East and West
Tokomairiro Basin
Lower Clutha Plain
Kuriwao Basin
Pomahaka Basin
Central Otago aquifers
Maniototo Basin
Strath Taieri Basin
Ettrick Basin
Roxburgh East
Alexandra Basin
Dunstan Flats
Earnscleugh Terrace
Manuherikia Alluvium
Springvale Terrace
Kingston
Pisa Terrace
Upper Clutha Valley
Lindis Valley
Lowburn Valley
Wanaka Basin
Hawea Basin
Glenorchy
Wakatipu Basin
Southland
Southland colluvial
Southland alluvial
Coastal aquifers
Tertiary lignite measures
Tertiary limestone
Chatton Formation
Caples and Murihiku Terrain

Data on aquifer thicknesses come from White (2001), other reports e.g. geophysical surveys and geological structure maps, or estimated by GNS where no data exist. Average thicknesses obtained from different types of data. Table 3 summarises the methods used. In some cases, an aquifer name actually represents several aquifers at different depths. The average thickness of the aquifer is taken to be the sum of the average thickness of each unit.

Table 3. Summary of aquifer thickness data types.

Format of thickness data	**Method used to estimate average thickness**
Single number (eg: 45 m)	Used the number supplied as the average thickness (eg: 45 m)
Range (eg: 20 m - 50 m)	Used the midpoint of the range as the average thickness (eg: 35 m)
Greater than (eg: >250 m)	Used the minimum as the average thickness (eg: 250 m)

3.4 Aquifer properties

There are two kinds of aquifers in the data set: unconfined aquifers and confined aquifers. The volume of water storage per volume of aquifer in an unconfined aquifer is called the porosity. The volume of water storage in confined aquifers per volume of aquifer is called the storage coefficient. Some aquifers have measured properties, and often the number quoted is a range. The number assigned to each aquifer is the mid-point of the range of quoted values where values exist.

Most aquifers do not have measured values of porosity or storage coefficient. A porosity of 0.2 has been assigned to the unconfined aquifers in New Zealand that do not have a measured porosity. Unconfined aquifers commonly have a larger porosity than this, it can be up to 0.36 for coarse gravel and up to 0.61 for silt (Domenico and Schwartz, 1990). A relatively conservative estimate of porosity has been chosen because: porosity usually declines with depth and some aquifers are up to 350 m thick; water retention means that not all water stored in the pores can be abstracted; and a wide range in aquifer materials means a high estimate is not appropriate.

Storage coefficient values or ranges are measured in 33 New Zealand confined aquifers. The mean storage coefficient of these is 0.008. This value has been assigned to New Zealand confined aquifers with an unknown storage coefficient.

Staff responsible for groundwater in each regional council (except Nelson and Hawke's Bay) got a copy of the parameters for aquifers in their region for comment following the assignment of aquifer areas, aquifer thicknesses, and aquifer properties. Nelson City Council were not sent a copy as they are not known to use groundwater. Hawke's Bay were not sent a copy as GNS has a staff member with expertise on groundwater in the Hawke's Bay (Cameron, 1997; Dravid and Brown, 1997), and the data are considered to be of high quality.

GNS received seven (of 14) replies from the regional council staff. Some of the regional councils made extensive changes to some of the parameters and added additional aquifers. These changes are included in the calculations.

3.5 Aquifer volume and aquifer water storage volume

The parameters required to estimate the value of water stored in the groundwater aquifers of New Zealand are:

1) Volume of the aquifer (including spatial extent and thickness)
2) Water levels in the aquifer to give the saturated thickness of the aquifer
3) Type of aquifer (e.g. confined, unconfined)
4) Either the porosity (for unconfined aquifers) or the specific yield (for confined aquifers)

The volume of water stored in a groundwater aquifer can be estimated by:

Unconfined aquifers

Volume = Average saturated thickness x area of aquifer x average porosity (1)

Confined aquifers

Volume = Average saturated thickness x area of aquifer x average storage coefficient (2)

The volume of water in cubic metres (m^3) contained in each aquifer is calculated by using Equation 1 or Equation 2, using an Excel spreadsheet.

3.6 Annual changes in volume

Not all aquifers have measurements of groundwater level. Therefore, a set of indicator wells are used to simulate nation-wide groundwater level changes. Annual changes in groundwater volumes in each aquifer are estimated using a set of indicator wells to represent groundwater level changes within each regional council area.

Indicator wells (Table 4) have been selected in consultation with regional councils on the following criteria:

a) wells are predominantly located in unconfined aquifers as these types of aquifers hold the majority of New Zealand's groundwater,
b) wells in confined aquifers are chosen to be near the unconfined/confined boundary, and/or recommended by regional councils,
c) wells are part of a region's monitoring network,
d) a reasonable length of record is available at each well, and
e) wells have water levels that can be expressed as level relative to sea level.

Indicator wells were chosen for all regions except Bay of Plenty, Gisborne, Nelson, and West Coast (Table 4). Suitable data were not available from three of these regions and groundwater is not used in Nelson.

Groundwater levels in these indicator wells are interpolated, from measured levels, at the following dates: June 30th 1994, June 30th 1995, June 30th 1996, June 30th 1997, June 30th 1998, June 30th 1999 June 30th 2000, and June 30th 2001 (Table 5). Measured levels do not span the above dates in the following wells: Manawatu Plains, Te Matai well (1994 to 1996), Otago confined (1994), Southland Howdens well (1994 and 1995). Estimates of groundwater levels in these wells are made by correlating well levels with nearest-neighbour indicator wells, as follows:

- Manawatu, Te Matai well correlated with Waikato Fergusson well levels in the period 1997-2001.

- Otago, confined Momona well correlated with Otago unconfined, Websters well, in the period 1995-2001.
- Southland, Howdens well correlated with Otago unconfined, Websters well in the period 1996-2001.

Groundwater level variations in Bay of Plenty are assumed to be the same as Waikato. Groundwater level variations in Gisborne are assumed to be the same as Hawkes Bay. Likewise, Southland groundwater level variations are used for West Coast groundwater level variations.

Annual level differences from the measured or estimated June 30th 1994 level are converted into water volume changes for each aquifer, from the aquifer volume calculated in section 3.5, and aggregated for each region (Section 6.0).

4.0 DETAILED EXAMPLE

The Aupouri aquifer (in Northland) is selected as a detailed example to demonstrate the calculation of groundwater aquifer volumes and changes in volumes. Table 6 lists raw data and calculations for the Aupouri aquifer as supplied in the accompanying spreadsheet, split into three sections. Section A lists the raw data and their sources, as follows:

Aquifer	**=**	**Name of aquifer**
Council	=	Regional authority with jurisdiction over the aquifer
Aquifer type	=	Type of aquifer (unconfined or confined)
Map polygon number	=	Reference to aquifer location in White (2001)
Area of polygon	=	Calculated area of the polygon in White (2001) or area of aquifer from another source
Aquifer fraction of polygon	=	Multiplier used on the polygon area
Actual area	=	Area of polygon x aquifer fraction of polygon
Aquifer thickness, observed	=	Aquifer thickness, if observed
Porosity (UNC), observed	=	Aquifer porosity, if observed
Transmissivity	=	Aquifer transmissivity if observed (not used in calculations)
Porosity (UNC), assigned	=	Porosity is set to the observed porosity, if it exists, or to 0.2 for unconfined aquifers. This is set to FALSE for confined aquifers. The Aupouri aquifer is confined, so no porosity is required, therefore the value in Table 4 is FALSE.
Aquifer thickness, assigned	=	Approximate mid-point of the saturated aquifer thickness observed from the literature, or estimated
Specific yield (SY), observed	=	Storage coefficient from the literature or field measurements. Often a range is quoted. A mid-point of the range is taken in this case.

Table 4. Indicator wells used to estimate aquifer volume changes.

Regional Council Group	Preferred aquifer and well for groundwater level reports		Location	NZMG co-ordinates	Screen depth (m)	Aquifer type	Years of instantaneous measurements 1994-2001
	Aquifer of indicator well	Indicator well name- site					
Northland	Kaikohe	5347011	Roadside at Kaikohe	2582800 , 6641000	6.0-8.8	Semi-Confined	1994 - 2001
Auckland	Auckland Volcanics	6498003	Angle St, Onehunga	2673100 , 6473400	N/A		
Waikato	Hamilton Basin	Fergusson	Near Hamilton	2715600 , 6379500	3.26	Unconfined	1994 - 2001
BOP							
Gisborne							
Hawkes Bay	Heretaunga Plains	857009 -7D	Heretaunga Plains	2834452 , 6168216	29.2	Confined	1994 - 2001
Wellington (Wairarapa)	Parkvale Zone, aquifer 2	1505551 Baring	Bristol Rd, Carterton	2725045 , 6013506	31-33	Confined	1994 - 2001
Taranaki	Taranaki Volcanics	GND0508	Carrington Rd	2604103 , 6231609	2.2-8.6	Unconfined	1994 - 2001
Horizons	Manawatu Plains	Te Matai #1	Man. R. Plain E of PN	2736800 , 6092600	35.4	Unconfined	1997 - 2001
Wellington (Wellington)	Waikanae Groundwater Zone	380027	McCardle, Waikanae	2685300 , 6050070	unknown	Unconfined	1994, 1996-2001
Marlborough	Wairau	Condor's Forest 6280398	Nth of Renwick, Wairau Plain	2577700 , 5968000	6	Unconfined	1994 - 2001
Tasman	Takaka Marble	2970710	Hamama	S8: 186 737	N/A	Confined	1994 - 2001
Canterbury	Ch-West Melton	M35/0931	West Melton	2459890 , 5746883	29	Confined	1994 - 2001
Otago -coastal	Lower Taieri Plain	Momona well, I44/0848	Lower Taieri, west	2292700 , 5472500		Confined	1995 - 2001
Otago unconfined	Deborah Volcanics	Websters well, J41/0178	Oamaru	2344800 , 5560500		Unconfined	1994 - 2001
Southland	Edendale	Howdens, F46/0192	South of Edendale	2183905 , 5416655	15 (est)	Unconfined	1996 - 2001
West Coast							

Table 5. Groundwater levels (metres above mean sea level) in indicator wells June 30th 1994 to June 30th 2002.

Region	**Indicator well number**	**Indicator well levels (m amsl)**							
		Jun 30 94	**Jun 30 95**	**Jun 30 96**	**Jun 30 97**	**Jun 30 98**	**Jun 30 99**	**Jun 30 00**	**Jun 30 01**
Northland	1	165.890	167.370	166.540	167.100	168.090	166.930	167.100	167.120
Auckland	2	2.439	2.763	2.755	2.507	2.471	2.409	2.482	2.488
Waikato	3	39.514	40.369	40.313	39.903	39.793	39.388	39.547	39.885
Bay of Plenty	4	39.514	40.369	40.313	39.903	39.793	39.388	39.547	39.885
Taranaki	5	115.200	115.530	115.100	112.950	115.620	116.080	115.770	115.400
Hawkes Bay	6	15.019	15.387	15.339	15.422	14.949	15.434	15.162	15.095
Man-Wang	7	32.368	32.438	32.433	32.445	32.469	32.352	32.361	32.291
Wellington-wgtn	8	9.130	8.940	9.440	8.860	9.000	8.200	8.940	8.580
Wellington-wai	9	64.160	64.000	64.800	64.850	63.210	63.710	64.300	62.750
Tasman	10	34.145	33.815	32.305	31.881	35.118	33.787	36.601	33.703
Marlb	11	35.630	36.199	34.819	35.180	35.138	35.190	35.545	34.873
Canty	12	82.842	83.848	83.733	83.365	82.804	82.908	82.874	82.502
Otago conf	13	0.816	0.484	1.050	1.250	0.579	0.083	0.968	0.364
Otago unconf	14	30.950	30.590	30.373	29.855	29.137	28.400	28.137	29.878
Sthld	15	18.508	18.415	18.203	18.384	18.204	17.716	17.782	18.204
					no record				

Indicator well level estimates are made as follows:

1. Manawatu-Wanganui levels for '94, '95 and '96 are estimated by linear estimates from a correlation of Waikato and Manawatu-Wanganui levels.
2. Otago confined level for '94 is estimated by linear estimates from a correlation of Otago unconfined and Otago confined levels. NB poor correlation.
3. Southland levels for '94 and '95 are estimated by linear estimates from a correlation of Otago unconfined levels and Southland levels.

Aquifer	**=**	**Name of aquifer**
Specific yield (SY), assigned	=	Storage coefficient is 0.008 which is the mean of published, or mid-point range estimates, of all the confined aquifers in the data set.
Method of obtaining data columns	=	All set to 1, which indicate all raw data came from White (2001)

Section B of Table 6 lists the calculations to estimate groundwater volume in the aquifer.

Aq area (A2)	=	Area of polygon converted into m^2
Aq thickness (T2)	=	Aquifer thickness (m)
Aq Vol Rock (RV)	=	A2 x T2. The result estimates the volume of *material* in the saturated part of the aquifer (m^3)
UNC (m^3)	=	Volume of water in aquifer *if* it was an unconfined aquifer (m^3). This value is zero if the aquifer is confined.
CON (m^3)	=	Volume of water in a confined aquifer = RV x SY (m^3).
Aq water vol	=	Sum of UNC and CON above, and represents the estimate of water stored in this aquifer.

Section C of Table 4 lists the calculations to estimate changes in groundwater volumes.

Groundwater level changes in the aquifer, from the level on 30th June 1994 are as estimated, using the Kaikohe indicator well levels (Table 5). Calculations start with the June 30 1994 aquifer volume and add the volume of water as determined by the water level change. Equation 2 (Section 3.5) is used to calculate the change in volume (as this is a confined aquifer) where average saturated thickness has been substituted for the water level change,

e.g. (value for June 30 1996) = (June 30 1994 water volume) + (0.855 x A2 x SY).

The estimated volume of groundwater in the Aupouri aquifer is added to the estimated volume of groundwater in Northland, and the estimated value of groundwater in New Zealand.

Table 6. Worked example of estimated aquifer volume changes.

A														**Method of obtaining data (code references the methods sheet)**					
Aquifer	Council	Aquifer type	Map polygon number	Area of polygon (km²)	Aquifer fraction of polygon	Actual area (km²)	Aquifer thickness (m)	Porosity (for UNC aquifers)	Transmissivity (m2/day)	Porosity (for UNC aquifers)	aquifer thickness (m)	Specific yield/ storativity	Specific yield/ storativity	aquifer type	thickness	porosity	s yield	trans	aquifer area
							observed	observed		assigned	assigned	for confined aquifer, observed	assigned						
Aupouri	NRC	CON	1	512	1	512	12 to 90		12 to 850	FALSE	50	0.07 to 0.00002	0.035	1	1		1	1	1

B					
Volume calculations			Aq water. vol.	Aq water. vol.	Aq water vol
Aq. Area (m^2)	Aq thickness	Aq. Vol. Rock (m^3)	UNC (m^3)	CON (m^3)	total (m^3)
512000000	50	25600000000	0	896000000	896000000

C: Estimated groundwater volume (m^3)							
Jun 30 94	Jun 30 95	Jun 30 96	Jun 30 97	Jun 30 98	Jun 30 99	Jun 30 00	Jun 30 01
896000000	922521600	907648000	917683200	935424000	914636800	917683200	918041600

5.0 DATA LIMITATIONS

The following limitations in the data and methodology have been identified.

Aquifer values

1) All groundwater aquifers in New Zealand are unlikely to have been identified, and therefore are not included in these calculations. These are likely to be small aquifers, for which little data exist.

2) Many aquifer areas were measured off 1:50 000 scale maps and/or figures where polygonal boundary data do not exist - there may be some large errors in these estimates.

3) Some aquifers are represented by a geographic area. In some cases, the aquifer only occurs in parts of the area. In these cases, the area of the aquifer will be overestimated.

4) Some aquifers fall into a semi-confined category. These aquifers have been assumed to follow the properties of a confined aquifer.

5) Aquifer volumes have been calculated assuming the aquifer can be modelled a 'slab', i.e. volume is average height x area. In general, aquifer thicknesses are highly variable throughout the aquifer and a 'true' average thickness is rarely known.

6) Specific yield and porosity are also generally variable both spatially and with depth, and these data are often sparse. Estimates of these parameters are assumed to be averages throughout each aquifer. In some cases, data are not available, and estimates are made.

7) The volume estimates obtained do not necessarily reflect the amount of water than can be abstracted from an aquifer due to physical, chemical, and/or economic issues. For example the full volume of groundwater in an aquifer is usually not totally abstractable for reasons including the following: the management authorities, and most users, would think it imprudent to take all the water from the aquifer; dewatering would likely cause significant environmental effects; and the volumes are generally so large that infrastructure would not be able to cope with this water on the surface. To many regional councils, particularly those in water-short

areas, groundwater allocation is based on the estimate of the recharge flux from rainfall and from rivers. In this situation the storage volume is a minor consideration in allocation to users. Wholesale decline of groundwater levels can have significant economic effects. For example, wells may have to be deepened, land may be unirrigable due to low groundwater levels, land may subside, and groundwater quality may be impacted by salt water intrusion from the sea.

Volume changes

8) It is assumed the indicator well assigned to a region is representative of all groundwater changes in all aquifers in that region. Generally, there are different responses (in amplitude and response times) in different aquifers depending on characteristics such as confining nature, depth, porosity, and location of the recharge zone.

9) The associated Excel spreadsheet shows volumes and changes in volumes to the nearest cubic metre. Significance is attached to at most first two significant figures in these numbers because of data limitations. However, results in the summary tables and text are given to two decimal places of 10^9 m^3 to show differences in the predicted volumes in summary tables (Table 9 and Table 10) and summary text.

Possible sources of error in volume calculations occur because generally the average saturated thickness, area of aquifer, and porosity/storage coefficient are not well known. Assuming that each of these factors is known within 10% then the water volume (equations 1 and 2) will be known within 30%. The use of indicator wells introduces unknown errors in predicted level changes in aquifers. Assume, for example, the level change is 10% in error for the aquifer and aquifer area and porosity has no error. An example of a change in volume calculation is:

$100 \times 10^6 \pm 10 \times 10^6\ m^3 - 90 \times 10^6 \pm 9 \times 10^6\ m^3 = 10 \times 10^6 \pm 19 \times 10^6\ m^3$

i.e. a 190% error results from this calculation.

With a 30% error the calculation is:

$100 \times 10^6 \pm 30 \times 10^6\ m^3 - 90 \times 10^6 \pm 27 \times 10^6\ m^3 = 10 \times 10^6 \pm 57 \times 10^6\ m^3$

i.e. a 570% error results from this calculation.

i.e. the error becomes 'magnified' when taking differences. Large differences, on a percentage basis, will occur with small differences in annual volumes because of this process.

The errors of saturated thickness, aquifer area, and porosity/storage coefficient are not quantifiable for New Zealand aquifers because the information is generally sparse. Therefore, no error analysis on the properties of the 200+ aquifers has been undertaken. Trends in groundwater volumes can be considered, because groundwater levels to up and down and aquifer area, aquifer basement, and porosity/specific capacity are constant with time over the five year period of the volume calculation.

10) Estimates of groundwater volume will improve in quality over time as more information becomes available from:

- the collection of new data through consents and regional investigations, and
- increasing the number of groundwater level indicator wells.

6.0 NEW ZEALAND GROUNDWATER VOLUMES, 1994 TO 2001

Appendix 1 summarises the aquifers, by region, used to estimate groundwater volumes. Tables 7 and 8 summarise aquifer volumes and changes for each region.

It is estimated that there was 614 x 10^9 m^3 of groundwater stored in New Zealand's aquifers in 1994, with 630 x 10^9 m^3 (97%) stored in unconfined and 20 x 10^9 m^3 (3%) stored in confined aquifers.

Canterbury had, by far, the largest quantity of water stored in unconfined aquifers (427 x 10^9 m^3), followed by Bay of Plenty (28 x 10^9 m^3), Southland (28 x 10^9 m^3), and Waikato (27 x 10^9 m^3).

The Waikato, Bay of Plenty and Canterbury regions had the largest quantity of water stored in confined aquifers (6.8 x 10^9 m^3, 2.9 x 10^9 m^3 and 2.5 x 10^9 m^3 respectively). The Nelson and West Coast regions are the two regions that do not have any identified confined aquifer storage.

Overall, Canterbury had the most groundwater (430 x 10^9 m^3) with Gisborne (0.6 x 10^9 m^3), having the least (Table 7). No aquifers are identified within the Nelson City boundaries.

The estimated volume of groundwater in New Zealand is significantly larger than estimated annual national groundwater usage. National use of groundwater is estimated as 0.6 x 10^9 m^3/yr if nation-wide use is 14% of allocation. White (2001) tabulates groundwater allocation as 126.9 m^3s^{-1} for New Zealand. This is equivalent to 4 x 10^9 m^3/yr. Use is typically less than allocation. For example, groundwater use by domestic, industrial, and irrigators in the area between the Ashburton River and Ashley River between 1994/95 and 1998/99 (White et al., in review) is estimated as a mean of 14% of allocation.

Table 7. Estimates of regional groundwater storage volumes for 30th June 1994.

Region	Estimate of groundwater storage volume (x 10^9 m^3)	Percentage of total New Zealand storage
Northland	2.03	0.3
Auckland	10.09	1.6
Waikato	33.97	5.5
BOP	31.4	5.1
Gisborne	0.56	0.1
Taranaki	24.74	4
Hawkes Bay	9.76	1.6
Manawatu-Wanganui	3.79	0.6
Wellington	4.86	0.8
Marlborough	0.84	0.1
Nelson	0	0
Tasman	9.4	1.5
Canterbury	429.53	69.9
West Coast	11.24	1.8
Otago	10.21	1.7
Southland	31.63	5.2
NZ sum	614.06	100

Table 8. Summary of estimated groundwater volumes for each region.

Region	Aquifer type	Volumes in billion m^3							
		Jun 30 94	**Jun 30 95**	**Jun 30 96**	**Jun 30 97**	**Jun 30 98**	**Jun 30 99**	**Jun 30 00**	**Jun 30 01**
Northld	UNC	1.1	1.18	1.14	1.17	1.22	1.16	1.17	1.17
	CON	0.93	0.96	0.94	0.95	0.97	0.95	0.95	0.96
	SUM	2.03	2.14	2.08	2.12	2.19	2.11	2.12	2.12
Auckld	UNC	6.77	6.87	6.86	6.79	6.78	6.76	6.79	6.79
	CON	3.31	3.32	3.32	3.31	3.31	3.31	3.31	3.31
	SUM	10.09	10.18	10.18	10.11	10.1	10.08	10.1	10.1
Waikato	UNC	27.13	28.8	28.69	27.89	27.67	26.88	27.19	27.85
	CON	6.84	6.92	6.92	6.88	6.87	6.83	6.85	6.88
	SUM	33.97	35.72	35.61	34.77	34.54	33.72	34.04	34.73
BOP	UNC	28.46	28.6	28.59	28.52	28.5	28.44	28.46	28.52
	CON	2.94	2.97	2.97	2.95	2.95	2.94	2.94	2.95
	SUM	31.4	31.57	31.56	31.48	31.46	31.38	31.41	31.47
Gisb	UNC	0.54	0.55	0.55	0.55	0.54	0.55	0.54	0.54
	CON	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	SUM	0.56	0.57	0.57	0.57	0.56	0.57	0.57	0.57
Taranaki	UNC	24.41	24.53	24.38	23.62	24.56	24.72	24.61	24.48
	CON	0.33	0.33	0.33	0.32	0.33	0.33	0.33	0.33
	SUM	24.74	24.86	24.7	23.94	24.89	25.05	24.94	24.81
Hawkes Bay	UNC	9.67	9.72	9.72	9.73	9.66	9.73	9.69	9.68
	CON	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	SUM	9.76	9.81	9.8	9.81	9.75	9.82	9.78	9.77
Man-Wang	UNC	3.41	3.42	3.42	3.42	3.42	3.41	3.41	3.4
	CON	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	SUM	3.79	3.8	3.8	3.8	3.81	3.79	3.79	3.78

Region	Aquifer type	Volumes in billion m^3							
		Jun 30 94	**Jun 30 95**	**Jun 30 96**	**Jun 30 97**	**Jun 30 98**	**Jun 30 99**	**Jun 30 00**	**Jun 30 01**
Well	UNC	4.62	4.59	4.74	4.73	4.47	4.53	4.64	4.38
	CON	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.23
	SUM	4.86	4.83	4.98	4.97	4.71	4.76	4.88	4.62
Marl	UNC	0.43	0.46	0.4	0.42	0.41	0.42	0.43	0.4
	CON	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	SUM	0.84	0.87	0.81	0.82	0.82	0.82	0.84	0.81
Nelson	UNC	0	0	0	0	0	0	0	0
	CON	0	0	0	0	0	0	0	0
	SUM	0	0	0	0	0	0	0	0
Tasman	UNC	9.06	9	8.74	8.66	9.24	9	9.5	8.98
	CON	0.34	0.34	0.33	0.33	0.34	0.34	0.34	0.34
	SUM	9.4	9.34	9.07	9	9.58	9.34	9.84	9.32
Canty	UNC	427.03	429.28	429.02	428.2	426.95	427.18	427.1	426.27
	CON	2.5	2.52	2.52	2.51	2.5	2.5	2.5	2.49
	SUM	429.53	431.8	431.54	430.71	429.44	429.68	429.6	428.76
West Coast	UNC	11.24	11.22	11.17	11.21	11.17	11.06	11.08	11.17
	CON	0	0	0	0	0	0	0	0
	SUM	11.24	11.22	11.17	11.21	11.17	11.06	11.08	11.17
Otago	UNC	10.19	10.06	9.99	9.8	9.54	9.28	9.18	9.81
	CON	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	SUM	10.21	10.08	10	9.82	9.56	9.29	9.2	9.82
Southld	UNC	28	27.87	27.57	27.82	27.57	26.89	26.98	27.57
	CON	3.63	3.63	3.61	3.62	3.61	3.59	3.59	3.61
	SUM	31.63	31.49	31.18	31.45	31.19	30.47	30.57	31.19
NZ sum	UNC	592.08	596.15	594.96	592.53	591.72	590	590.78	591.03
	CON	21.98	22.13	22.09	22.05	22.03	21.94	21.97	22.01
	SUM	614.06	618.28	617.06	614.58	613.75	611.94	612.76	613.05

Table 9. Summary of estimated annual groundwater volume changes for each region.

Region	Aquifer type	Region-by-region summaries, annual volume changes in billion m^3							
		Jun 30 94	**Jun 30 95**	**Jun 30 96**	**Jun 30 97**	**Jun 30 98**	**Jun 30 99**	**Jun 30 00**	**Jun 30 01**
Northld	UNC	0	0.08	-0.04	0.03	0.05	-0.06	0.01	0
	CON	0	0.03	-0.02	0.01	0.02	-0.02	0	0
	SUM	0	0.11	-0.06	0.04	0.07	-0.08	0.01	0
Auckld	UNC	0	0.09	0	-0.07	-0.01	-0.02	0.02	0
	CON	0	0	0	0	0	0	0	0
	SUM	0	0.1	0	-0.07	-0.01	-0.02	0.02	0
Waikato	UNC	0	1.67	-0.11	-0.8	-0.21	-0.79	0.31	0.66
	CON	0	0.08	-0.01	-0.04	-0.01	-0.04	0.01	0.03
	SUM	0	1.75	-0.11	-0.84	-0.22	-0.83	0.32	0.69
BOP	UNC	0	0.14	-0.01	-0.07	-0.02	-0.07	0.03	0.06
	CON	0	0.02	0	-0.01	0	-0.01	0	0.01
	SUM	0	0.16	-0.01	-0.08	-0.02	-0.08	0.03	0.06
Gisb	UNC	0	0.01	0	0	-0.01	0.01	-0.01	0
	CON	0	0	0	0	0	0	0	0
	SUM	0	0.01	0	0	-0.01	0.01	-0.01	0
Taranaki	UNC	0	0.12	-0.15	-0.76	0.94	0.16	-0.11	-0.13
	CON	0	0	0	0	0	0	0	0
	SUM	0	0.12	-0.15	-0.76	0.94	0.16	-0.11	-0.13
Hawkes Bay	UNC	0	0.05	-0.01	0.01	-0.06	0.07	-0.04	-0.01
	CON	0	0	0	0	0	0	0	0
	SUM	0	0.05	-0.01	0.01	-0.06	0.07	-0.04	-0.01
Man-Wang	UNC	0	0.01	0	0	0	-0.01	0	-0.01
	CON	0	0	0	0	0	0	0	0
	SUM	0	0.01	0	0	0	-0.02	0	-0.01

Region	Aquifer type	Region-by-region summaries, annual volume changes in billion m^3							
		Jun 30 94	**Jun 30 95**	**Jun 30 96**	**Jun 30 97**	**Jun 30 98**	**Jun 30 99**	**Jun 30 00**	**Jun 30 01**
Well	UNC	0	-0.03	0.14	-0.01	-0.26	0.06	0.12	-0.26
	CON	0	0	0	0	-0.01	0	0	-0.01
	SUM	0	-0.03	0.15	-0.01	-0.26	0.06	0.12	-0.26
Marl	UNC	0	0.02	-0.05	0.01	0	0	0.01	-0.03
	CON	0	0	0	0	0	0	0	0
	SUM	0	0.02	-0.06	0.01	0	0	0.01	-0.03
Nelson	UNC	0	0	0	0	0	0	0	0
	CON	0	0	0	0	0	0	0	0
	SUM	0	0	0	0	0	0	0	0
Tasman	UNC	0	-0.06	-0.27	-0.08	0.57	-0.24	0.5	-0.51
	CON	0	0	0	0	0.01	0	0.01	-0.01
	SUM	0	-0.06	-0.27	-0.08	0.58	-0.24	0.5	-0.52
Canty	UNC	0	2.25	-0.26	-0.82	-1.25	0.23	-0.08	-0.83
	CON	0	0.02	0	-0.01	-0.01	0	0	-0.01
	SUM	0	2.27	-0.26	-0.83	-1.27	0.23	-0.08	-0.84
West Coast	UNC	0	-0.02	-0.05	0.04	-0.04	-0.11	0.01	0.09
	CON	0	0	0	0	0	0	0	0
	SUM	0	-0.02	-0.05	0.04	-0.04	-0.11	0.01	0.09
Otago	UNC	0	-0.13	-0.08	-0.19	-0.26	-0.26	-0.09	0.63
	CON	0	0	0	0	0	0	0	0
	SUM	0	-0.13	-0.08	-0.19	-0.26	-0.26	-0.09	0.63
Southld	UNC	0	-0.13	-0.3	0.25	-0.25	-0.68	0.09	0.59
	CON	0	-0.01	-0.01	0.01	-0.01	-0.03	0	0.02
	SUM	0	-0.14	-0.31	0.26	-0.26	-0.71	0.1	0.61
NZ sum	UNC	0	4.06	-1.18	-2.44	-0.81	-1.71	0.78	0.25
	CON	0	0.15	-0.04	-0.04	-0.02	-0.1	0.04	0.04
	SUM	0	4.22	-1.22	-2.48	-0.83	-1.81	0.82	0.29

Total New Zealand groundwater volume is estimated to be between 612 x 10^9 m^3 (estimate as of June 30th 1999) and 618 x 10^9 m^3 (estimate of June 30th 1995) from July 1994 to July 2001. Errors in these estimates could easily be 30% with a 10% error on each of saturated thickness, aquifer area, and porosity/storage coefficient. The estimated range of groundwater volume in the period (6 x 10^9 m^3) is a relatively small proportion of the total groundwater volume and probably less than the error in volume estimates. Canterbury groundwater volume has the largest annual variation of all regions in the July 1994 to July 2001 period. For example, groundwater volume is predicted to change by 2.3 x 10^9 m^3 between July 1994 and July 1995. The smallest volumetric changes (of the order of $\pm$ 5 x 10^5 m^3/yr) occur in Gisborne confined aquifers.

The annual variations in groundwater levels (Tables 8 and 9) are partially explained by the annual variability of rainfall (Table 10). An estimate of the annual mean rainfall across New Zealand is made by (Woods pers. comm.) interpolating daily rainfall from the NIWA Climate Database daily rainfall gauges onto a 0.05 degree grid, and then calculating a mean rainfall for all grid points on land. Relatively high rainfall in 1994/95 and 1995/96 is potentially related to increasing groundwater in the period. Lower rainfall in the period 1996 to 2001 may reflect lower groundwater volumes.

Table 10. Estimated annual rainfall across New Zealand, 1994-2001 (Woods pers. comm.).

New Zealand rainfall	mm
1 Jul 1994 to 30 Jun 1995	1727
1 Jul 1995 to 30 Jun 1996	1733
1 Jul 1996 to 30 Jun 1997	1524
1 Jul 1997 to 30 Jun 1998	1538
1 Jul 1998 to 30 Jun 1999	1610
1 Jul 1999 to 30 Jun 2000	1563
1 Jul 2000 to 30 Jun 2001	1497

Groundwater volume variation in Canterbury is a significant component of groundwater volume variations in New Zealand. Therefore it is possible that rainfall variation in Canterbury will have a significant influence on nation-wide groundwater volume variations.

7.0 SUMMARY

The volume of groundwater in New Zealand aquifers has been estimated in the period June 1994 to June 2001 using a simple geometric technique for the unconfined and confined aquifers. Data have been accumulated and processed for each known aquifer, and then summed to give regional and national estimates of groundwater volume. The estimated groundwater volume in New Zealand aquifers is between 612 x 10^9 m^3 and 618 x 10^9 m^3 in the period. The variation of groundwater volume is likely to be less than the errors in the total volume estimates.

Canterbury is the region with the largest groundwater storage. It is estimated that around 430 x 10^9 m^3, or approximately 70% of New Zealand's groundwater, is stored in aquifers in this region. Waikato, with approximately 34 x 10^9 m^3 of groundwater, is predicted as the region with the second-largest groundwater volume. All other New Zealand regions are predicted to have over 1 x 10^9 m^3 of groundwater except Marlborough (0.8 x 10^9 m^3), Gisborne (0.6 x 10^9 m^3) and Nelson City (which does not have any known aquifers).

Annual changes in groundwater volume in New Zealand aquifers were estimated based on extrapolating water level variations in eight indicator wells over the country's aquifers in the period June 1994 to June 2001 and assuming that aquifer basement, aquifer area, and aquifer porosity/specific capacity are not varying with time. The Canterbury region was found to be the largest contributor to annual changes in groundwater volumes with a predicted maximum year-to-year annual volume change of 2.3 x 10^9 m^3 between June 1994 and June 1995. The annual range in groundwater storage is predicted as significantly greater than the estimated annual use of groundwater of 0.6 x 10^9 m^3/yr. National groundwater volume variability is only broadly related to national rainfall variability. An analysis of regional rainfall patters is required to further test the hypothesis that groundwater level variations are due to rainfall.

The estimates obtained are presented as cubic metres at the request of Statistics New Zealand so they can easily be compared with estimates of water storage in surface water features. Eight significant figures seen in the groundwater volume calculations in the Excel spreadsheet appear to give the calculation a great accuracy. It is very unlikely that groundwater calculations are this accurate.

It is expected that estimates of New Zealand groundwater volume can be improved over time.

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Otago	Tom Heller
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Appendix 1. Summary of aquifers included in the volume calculations, sorted by region.

Aquifer	Region
Aupouri	Northland
Kerikeri	Northland
Okaihau	Northland
Waimate North	Northland
Pakaraka	Northland
Ngawha	Northland
Kaikohe	Northland
Matarau	Northland
Glenbervie	Northland
Ruatangita sst	Northland
Three Mile Bush	Northland
Maunu	Northland
Whatitiri	Northland
Maungatapere	Northland
Maungakaramea	Northland
Ruawai	Northland
Tara	Northland
Mangawhai	Northland
Waitemata Formation	Auckland
Auckland volcanics	Auckland
South Auckland volcanics	Auckland
Tauranga Group sediments	Auckland
Kaawa formation	Auckland
Greywacke	Auckland
Auckland coastal aquifers	Auckland
Hinuera Formation	Waikato
Tauranga Group sediments	Waikato
Coromandel volcanic	Waikato
Coromandel sand	Waikato
Waiotapu Ignimbrite	Waikato
Whakamaru Ignimbrites	Waikato
Taupo eruption ignimbrite	Waikato
Oruanui eruption ignimbrite	Waikato
Rangitaiki Ignimbrite	Waikato
Kaingaroa Ignimbrite	Waikato
Otorohanga and Orahiri limestone	Waikato
Aongatete Ignimbrite	Bay of Plenty
Waiteariki Ignimbrite	Bay of Plenty
Western Bay Rhyolite	Bay of Plenty
Mamaku Ignimbrite	Bay of Plenty
Matahina Ignimbrite	Bay of Plenty
Pongakawa Breccia	Bay of Plenty
Rangitaiki Plains (assumes shallow system)	Bay of Plenty
Waihi Beach Rhyolite	Bay of Plenty
Katikati Gravel	Bay of Plenty

Aquifer	Region
Mt Maunganui sand	Bay of Plenty
Matakana Island sand	Bay of Plenty
Maketu warm water	Bay of Plenty
Maketu Pumice	Bay of Plenty
Opotiki	Bay of Plenty
Galatea Basin	Bay of Plenty
Te Hapara sand	Gisborne
Shallow fluvial	Gisborne
Waipaoa Gravel	Gisborne
Makauri Gravel	Gisborne
Matokitoki Gravel	Gisborne
Waiapu and Tolaga Bay flats	Gisborne
Matemateaonga Formation	Taranaki
Taranaki Volcanic	Taranaki
Marine Terrace	Taranaki
Whenuakura Formation	Taranaki
Wairoa Valley	Hawkes Bay
Nuhaka coastal	Hawkes Bay
Nuhaka limestone	Hawkes Bay
Mahia sand	Hawkes Bay
Mahia alluvium	Hawkes Bay
Mahia	Hawkes Bay
Esk Valley	Hawkes Bay
Heretaunga Plains	Hawkes Bay
Poukawa Basin	Hawkes Bay
Papanui Stream Valley	Hawkes Bay
Ruataniwha Plains	Hawkes Bay
Wanganui	Manawatu - Wanganui
Wangaehui-Turakina	Manawatu - Wanganui
Rangitikei	Manawatu - Wanganui
Manawatu	Manawatu - Wanganui
Horowhenua	Manawatu - Wanganui
Tararua	Manawatu - Wanganui
Coastal	Manawatu - Wanganui
Waiotohu-Unc	Wellington
Waiotohu-Con	Wellington
Otaki - Con	Wellington
Otaki - Unc	Wellington
Hautere	Wellington
Coastal	Wellington
Coastal	Wellington
Waikanae- Con	Wellington
Waikanae- Unc	Wellington
Raumati-Paekakariki-Unc	Wellington
Raumati-Paekakariki-Con	Wellington
Lower Hutt	Wellington
Upper Hutt	Wellington

Aquifer	Region
Black Creek	Wellington
Wainuiomata	Wellington
Mangaroa	Wellington
Pakuratahi	Wellington
Akatarawa	Wellington
Upper Opaki	Wellington
Opaki-Unc	Wellington
Opaki-Con	Wellington
Rathkeale	Wellington
Masterton-Unc	Wellington
Masterton-Con	Wellington
Te Ore Ore-Ucn	Wellington
Te Ore Ore-Con	Wellington
Upper Plain-Unc	Wellington
Upper Plain-Con	Wellington
Fernridge	Wellington
West Taratahi	Wellington
East Taratahi-Unc	Wellington
East Taratahi-Con	Wellington
Mangatarere	Wellington
Carterton-Unc	Wellington
Carterton-Con	Wellington
Parkvale-Unc	Wellington
Parkvale-Con	Wellington
Matarawa	Wellington
Fern Hill	Wellington
Hodders	Wellington
Greytown	Wellington
Middle Ruamahanga-Unc	Wellington
Middle Ruamahanga-Con	Wellington
Moroa	Wellington
Ahikouka	Wellington
Battersea-Unc	Wellington
Battersea-Con	Wellington
Tauherenikau	Wellington
Woodside-Unc	Wellington
Woodside-Con	Wellington
Te Maire Ridge	Wellington
South Featherston-Unc	Wellington
South Featherston-Con	Wellington
Riverside	Wellington
Tawaha	Wellington
Martinborough Terraces-Unc	Wellington
Martinborough Terraces-Con	Wellington
Huangarua-Unc	Wellington
Huangarua-Con	Wellington
Lower Valley	Wellington

Aquifer	Region
Pirinoa Terraces	Wellington
Wairau	Marlborough
Benmorven	Marlborough
Brancott	Marlborough
Fairhall River Gravels	Marlborough
Taylor – Burleigh	Marlborough
Omaka – Hawkesbury	Marlborough
Omaka River Valley	Marlborough
Deep Wairau	Marlborough
Rarangi Shallow	Marlborough
Tuamarino Valley	Marlborough
Rai Valley	Marlborough
Pelorus Valley	Marlborough
Kaituna Valley	Marlborough
Upper Wairau Valley	Marlborough
Lower Awatere Valley	Marlborough
Appleby Gravel Unconfined	Tasman
Hope Minor Confined and Unconfined	Tasman
Upper Confined	Tasman
Lower Confined	Tasman
Shallow Moutere	Tasman
Deep Moutere	Tasman
Motueka/Riwaka Plains	Tasman
Arthur Marble	Tasman
Takaka Limestone	Tasman
Takaka Valley Gravel	Tasman
Motueka River Terraces	Tasman
Aorere Gravel	Tasman
Buller River Terraces	Tasman
Marahau River	Tasman
Kaikoura Plain	Canterbury
Hanmer Basin	Canterbury
Parnassus Basin	Canterbury
Culverden Basin	Canterbury
Waipara Basin	Canterbury
Banks Peninsula	Canterbury
Ashley Downs	Canterbury
Waimakariri-Ashley plains	Canterbury
Christchurch-West Melton	Canterbury
Central Plains	Canterbury
Rakaia-Ashburton plains	Canterbury
Ashburton-Rangitata plains	Canterbury
Rangitata-Levels plains	Canterbury
South Canterbury	Canterbury
Fairlie Basin	Canterbury
Hakataramea Basin	Canterbury
MacKenzie Basin	Canterbury

Aquifer	Region
West Coast alluvial	West Coast
Papakaio	Otago
Lower Taieri Plain – East and West	Otago
Lower Waitaki Alluvium	Otago
Waiareka and Deborah volcanic	Otago
Kakanui-Kauru Alluvium	Otago
Shag Alluvium	Otago
Tokomairiro Basin	Otago
Lower Clutha Plain	Otago
Kuriwao Basin	Otago
Pomahaka Basin	Otago
Maniototo Basin	Otago
Maniototo Basin	Otago
Strath Taieri Basin	Otago
Ettrick Basin	Otago
Coal Crk+Roxburgh East	Otago
Dunstan Flats	Otago
Earnscleugh Terrace	Otago
Manuherikia Alluvium	Otago
Springvale Terrace	Otago
Kingston	Otago
Pisa Terrace	Otago
Lindis Valley	Otago
Lowburn Valley	Otago
Wanaka Basin	Otago
Hawea Basin	Otago
Glenorchy	Otago
Wakatipu Basin	Otago
Clydevale Basin	Otago
Wairuna Basin	Otago
Upper Clutha Valley	Otago
Caversham Sandstone	Otago
Southland alluvial	Southland
Coastal aquifers	Southland
Tertiary lignite measures	Southland
Tertiary limestone	Southland
Chatton Formation	Southland
Caples, Murihiku Terrain and Southland colluvial	Southland