Groundwater Allocation of the Alexandra Basin

GROUNDWATER

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Chairman’s foreword – Groundwater Allocation in the Alexandra Basin

Otago’s prosperity is largely based on water. The Clutha River drains much of the Otago region and has the largest annual discharge of any river in New Zealand. However, despite the large total water volumes present in the region’s water bodies, many areas of Otago are short of water. In many cases, irrigation particularly in these drier areas is critical to the continued well being of the people and communities who rely on the primary production it supports.

The Regional Policy Statements for Water provides for the Otago people and communities having access to water for their present and reasonably foreseeable needs.

Groundwater is frequently the sole or major source of water to supply basic water needs to communities and stock watering. Currently groundwater only supplies a small proportion of irrigation needs, however there is increasing pressure for people to turn to groundwater because surface water supplies are heavily allocated. Over abstraction can result in loss of supply to other users and therefore careful management is required to keep abstraction rates sustainable.

Groundwater resources have varying rates of recharge and often form a complex dependency with adjacent water courses, wetlands and stream networks. The effects of inappropriate land and water use and development on groundwater quantity and quality are often long term, and in some cases permanent. It is therefore important that particular consideration be given to the protection of aquifers for the continuing benefit of present and future generations.

Through the Regional Plan: Water and our Annual Plans we ensure linkage with the community to deliver the efficient use and protection of our groundwater aquifers.

This report describes the potential for the future allocation of water from the Alexandra Basin Aquifer. It is based on local knowledge, scientific evidence and monitoring information. The best way forward is to use to advantage this valuable resource but to maintain control so that over abstraction does not occur. This is a complex topic and further monitoring and review of the aquifer will continue to ensure a sustainable allocation.

Stephen Cairns.

Executive Summary

This report summarises knowledge about groundwater in the Alexandra Basin and recommends further work focused on improving water allocation.

Two main aquifers form the Alexandra Basin groundwater resource. The Alexandra Aquifer (Manuherikia Claybound, Dunstan Flats, and Manuherikia Alluvial sub-aquifers) forms the eastern part of the Alexandra Basin. Groundwater from the Manuherikia Claybound *sub-aquifer* flows into the Dunstan Flats and Manuherikia Alluvial sub-aquifers. Most of this groundwater is discharged to the Clutha River/Mata-Au. On the western side, groundwater from the Earnscleugh aquifer flows to the Clutha River/Mata-Au.

Through the review of the information available for groundwater allocation, it became apparent that future groundwater allocation from the Manuherikia Claybound Aquifer must have regard to other sub-aquifers of the Alexandra Basin.

Significant parts of the groundwater balance are uncertain; including how much groundwater is actually allocated. Complicating matters even further, large amounts of ‘groundwater’ have been allocated for bores that may draw the majority of their water from the Clutha River/Mata-Au through groundwater-surface water interaction.

A series of groundwater management options were considered which would allow the most effective use of the groundwater resource into the future.

The current approach of allocating a maximum fixed rate, based on rainfall recharge, was only considered suitable for first order estimates in conditions such as those for semi-arid climates of the Otago region.

The recommended approach for initial water allocation was for integrated water management, combining aspects of rainfall recharge and surface waters. For example, surface water allocation could be combined with up to 50% of rainfall recharge and water would be allocated regardless of origin. This is a simple and practical method that would initially suit most Central Otago catchments as surface and groundwater catchments appear to coincide. As more information becomes available through data collection and monitoring, a numerical groundwater model can be developed that can serve as a basis for long-term water allocation.

Having such an adaptive method also allows it to be combined with other potential options such as maintaining groundwater levels, setting thresholds or localised hotspot elimination tools. These options can be designed to best fit local conditions.

To gain maximum benefit from the groundwater resource it is essential that the components of the groundwater budget are monitored and analysed. As more information becomes available and the aquifers better understood, allocation can then be adapted to fit the relevant conditions.

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1. Introduction

This report provides a review of current and future potential groundwater allocation in the Alexandra basin. It includes a link between major water resources and groundwater and what is known about the hydrogeology of the area. Groundwater monitoring is also analysed and comparison of groundwater levels and river levels are made to show that there are important interactions between the two.

The groundwater budget has been assessed and future potential options for groundwater allocation are discussed. The most suitable options for the semi-arid Alexandra basin are identified and a methodology for allocation in the near and more distant future is provided.

1.1 Groundwater-surface water interaction and allocation

1.1.1 General Introduction

Groundwater is not an isolated resource and interacts with surface water. In natural, pre-development conditions unconfined aquifers (such as the Earnscleugh and Alexandra aquifers) receive recharge from rainfall and surface water and discharge groundwater to surface water and via evaporation. Recharge and discharge are normally equal; the groundwater system is in equilibrium, over long time periods.

When groundwater is used from unconfined aquifers connected to surface waters, groundwater levels decline and eventually a significant reduction in aquifer discharge to surface water occurs. Examples include reduced spring flow, reduced wetlands or decreasing stream network. Alternatively, extra recharge from surface water could occur (Bredehoeft, 1997).

Natural discharge, from the aquifers into streams, springs, lakes, and wetlands (termed *Groundwater Dependent Ecosystems*) could decrease (Sophocleous, 1997) and, if pumping equals recharge, eventually groundwater dependent ecosystems could dry up.

Groundwater therefore is normally allocated ensuring a minimum level of water is maintained in bores, or baseflow in surface water. Initially allocation is based on a ‘back of the envelope’ type calculation but as water resources are developed, more information becomes available and water allocation becomes more sophisticated and complex. It is important therefore to understand existing information and to recognize shortcomings and gaps in knowledge.

In the absence of adequate hydraulic data simple approaches can be used, such as those recommended by Lincoln Environmental (2001). Combined surface and groundwater allocation based on properly calibrated numerical models represent a more sophisticated allocation methodology. The trade-off is that a sophisticated allocation methodology requires more data and investment.

2. Sustainability and water resources

The ‘sustainability’ of groundwater occurs when pumping captures a proportion of the natural discharge without causing ‘adverse’ effects on surface water or other groundwater dependent ecosystems. Therefore it is important to recognise what Groundwater Dependent Ecosystems are and their importance in the Alexandra Basin. An inventory of water resources, Table 1, in the Alexandra Basin indicates that:

1. The Clutha River/Mata-Au dominates the basin. Its annual mean flow is magnitudes larger than the sum of all other water resources of the basin. Water is available for allocation from the Clutha River/Mata-Au.
2. Other important surface water courses include the Fraser River and the Manuherikia River, and the Waikerikeri Creek.
3. Excess rainfall, or rainfall recharge to groundwater is a relatively small component of the water budget.

Table 1 Major Water Resources of the Alexandra Basin and their relevance to groundwater

Water Resource	Mean annual flux Ml/yr	Comments/values
Clutha River/Mata-Au	15×10^6	Artificially controlled, incised major river. Water is available for allocation. Used for power generation, recreational/fishery. All groundwater in the basin is assumed to discharge to the Clutha River/Mata-Au. Evidence of episodic recharge from the Clutha River/Mata-Au exists.
Manuherikia River	4.5×10^5	Surface water allocated above mean flow, trout/native fishery, recreational. Gains from groundwater but via irrigation schemes some irrigation losses are actually recharging groundwater.
Fraser River	$\sim 4 \times 10^4$	(Augmented by Lake Dunstan). Allocated, trout fishery/spawning. $\sim 25 \times 10^3$ Ml/yr could be lost to groundwater, and less than 23×10^3 Ml/yr re-gained
Excess rainfall	4×10^3	Diffuse, episodic recharge to groundwater.
Waikerikeri Creek	2.4×10^3	Allocated, $\sim 1.2 \times 10^3$ Ml/yr lost to groundwater

The Clutha River/Mata-Au is the major drainage of the Alexandra Aquifer (Figure 1). Since 1992 the river has been artificially controlled between the Clyde and Roxburgh dams (MWH 2002). The river bed was artificially lowered in the mid 1990s. Water is available for allocation from the river.

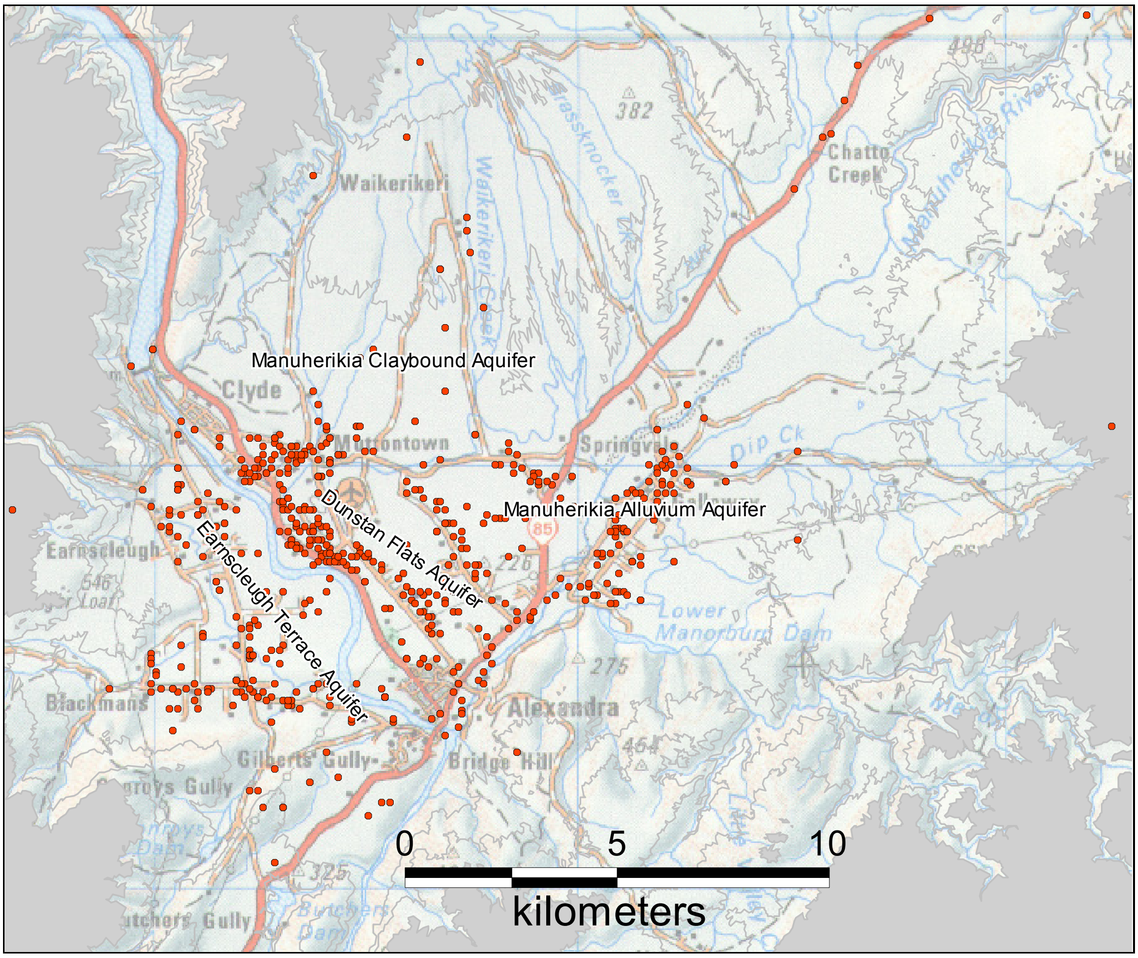

Figure 1. The Alexandra Basin. Red circles represent bores

The Manuherikia River receives groundwater from the Manuherikia Alluvium sub-aquifer, as indicated by the groundwater potentiometric map (MWH 2004). Most of the river flow is 'redistributed' by the Manuherikia, Galloway, and Springvale irrigation schemes. Irrigation channel losses and on-farm irrigation losses (irrigation return water) also recharge the Alexandra aquifer, but the amount of recharge from this source remains unknown. Various estimates of groundwater recharge from imported irrigation water include 3200 Ml/yr to Dunstan Flats sub-aquifer (MWH, 2002); 7.8-13 × 10^3 Ml/yr irrigation return water from the Manuherikia Scheme (Irricon, 1998) mainly to the Dunstan Flats sub-aquifer.

The Fraser River loses water to the underlying groundwater in the first four kilometres from the gorge to the Earnscleugh Road Bridge and gains some groundwater further downstream.

Water from the Waikerikeri Creek is abstracted for irrigation in the upper reaches. The lower part of the creek receives some by-wash water from the Manuherikia Irrigation Scheme. The creek loses almost all of its flow to groundwater near Muttontown. This loss was estimated previously as 2016 Ml/yr (MWH 2002) and 2333 Ml/yr (MWH, 2004). The current ORC estimate of 1200 Ml/yr (Hickey, pers. comm., 2005) is used in this report because it is the best available estimate recognising that the Waikerikeri Creek is ephemeral. The deviation of these estimates indicates the large uncertainties involved in estimating groundwater-surface water interaction in this catchment.

3. Hydrogeology

The climate of the Alexandra Basin is characterized by hot summers and cold winters and semi-arid conditions. Mean annual temperature is 10.6 ºC. Mean annual pan evaporation is just over 1000mm. The 350 mm mean annual rainfall is fairly evenly distributed, although average winter rainfall is lower than other seasons. Soil moisture deficit occurs, on average, between October-April. Only a small soil moisture excess, totalling on average 38 mm/year (MWH, 2002), for June-August, recharges groundwater from rainfall. Actual rainfall recharge to groundwater can vary enormously and episodic recharge (due to a single large rain or flood event) could be significant in these semi-arid or more precisely arid conditions. Therefore rainfall recharge would be more appropriately considered as 380mm per 10 years on average to reflect the long-term recharge rate and acknowledge the year to year variability of recharge.

The Alexandra basin is contained by schist mountain ranges and basement. Tertiary and Quaternary sediments fill up the basin. The tertiary deposits generally have low hydraulic conductivity, therefore most aquifers are in Quaternary units that represent a succession of glacial advances.

Several draft and published reports have focused on parts of the Alexandra Basin and fragmented water budgets were constructed ranging from flow net analysis to numerical modelling. The results should be considered as approximations only as most calculations are based on estimates rather than measurements. The exception to this is the Earnscleugh aquifer that received more attention because of mining development plans. As a result, detailed hydrogeological studies are available (Mintago Investment Ltd. & Aquafirma, 1995; and Mintago Investments, 1997). As the Clutha River/Mata-Au collects shallow groundwater flow from both sides, and the standard of information for the Earnscleugh aquifer is superior to the other sub-aquifers, a separate section of this report deals with Earnscleugh.

3.1 Component aquifers: The Earnscleugh aquifer (after Mintago Investments Ltd, 1997)

Gravels overlie the local hydrological basement of Tertiary carbonaceous mudstones or weathered schist in Earnscleugh. The gravels slope to the south-east, have a mean thickness of 24 metres, but are up to 38 metres thick (Mintago Investments Ltd, 1997).

A conceptual cross-section, after Mintago Investments Ltd. (1997) is shown in Figure 2. Sources of groundwater recharge are infiltration from the Fraser River (from Frasers Domain to Earnscleugh Road crossing), Omeo Creek infiltration (from Blackmans to McIntosh Road), deep-drainage (both natural and irrigation induced) through the soil and irrigation system losses (Mintago Investments Ltd, 1997). Groundwater discharge is to the lower Fraser River, springs in the lower Fraser River area, and Clutha River/Mata-Au.

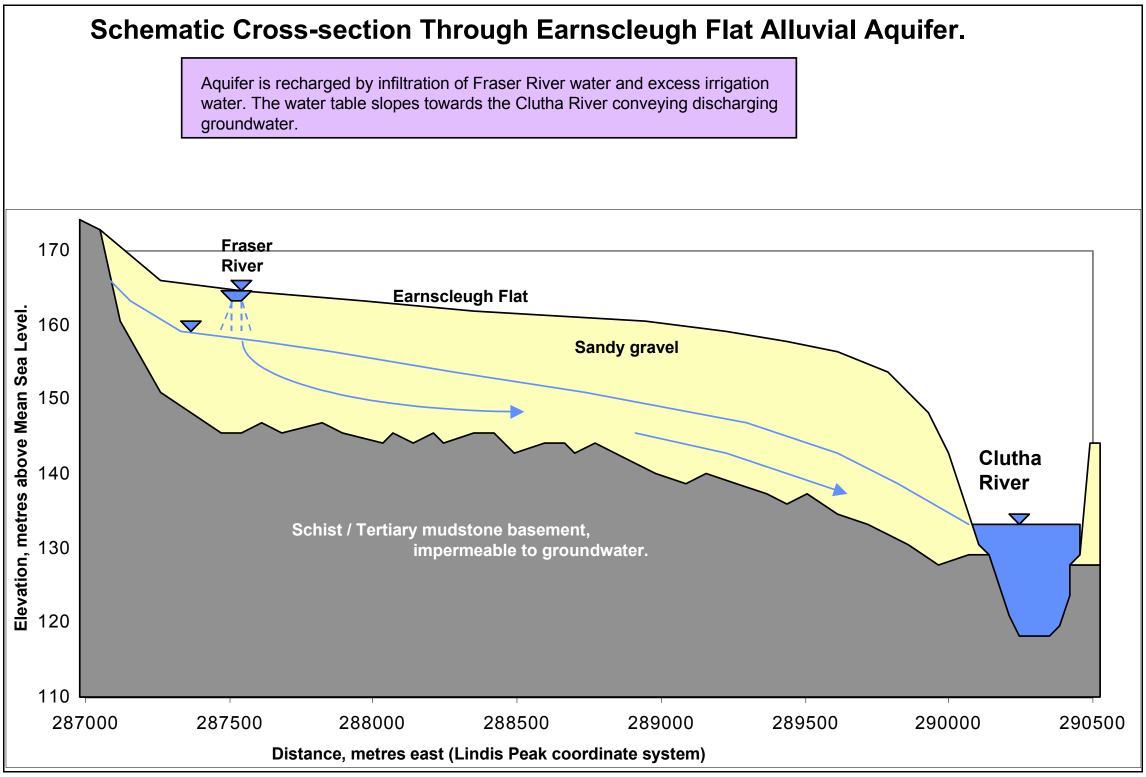

Figure 2 Conceptual cross-section (after Mintago Investments Ltd, 1997), Earnscleugh aquifer

The Fraser River (Figure 3) loses water to the underlying groundwater in the first four kilometres from the gorge to the Earnscleugh Road Bridge (Jowett, 1983 in Mintago Investments, 1997). Gaugings of August 1982 and June 1983 show some degree of gain to the river downstream of the Earnscleugh Road Bridge. Jowett (1983) infers that this is due to "*inflow from irrigation discharges, Conroys Creek and a substantial groundwater inflow just above Marshalls Road*".

Figure 3. The Earnscleugh aquifer and the Fraser River. The location of P46A and P73A monitoring bores are indicated by arrows

In 1997 four separate sets of multiple gaugings has each shown a measurable and significant loss of water from Frasers Domain to Laing Road crossing. Even after the artificial abstraction of river water for irrigation is removed from the balance (1,266 l/sec on 18 February 1997, the height of the irrigation season), this polarity of the water interchange remains (Mintago Investments, 1997).

In agreement with the 1982-3 flow gaugings, losses, averaging 800 l/sec, were observed within 3 - 4 kilometres downstream of Frasers Domain (Mintago Investments, 1997). River gains, averaging 740 l/sec, were observed downstream of the Earnscleugh Road crossing. However, not all this water is gained from groundwater especially during winter periods when interferences of irrigation race bywash and inflow of Omeo Creek occur between Laing Road and Earnscleugh Road.

From the analysis of the water table records and other published reports it appears that irrigation losses as soil drainage would make up a large part of the aquifer's water balance. Natural or diffuse rain recharge (water percolating through the soil) appears to be small. Only 40mm is expected to recharge groundwater (Mintago Investments, 1997).

Mintago Investment's water balance (rounded figures) for the Earnscleugh aquifer in 1997 was:

From Fraser River	+	25×10^3 Ml/yr
From irrigation losses	+	7×10^3 Ml/yr
From Omeo Creek	+	6×10^3 Ml/yr
Diffuse recharge	+	1×10^3 Ml/yr
To Clutha River/Mata-Au	-	20×10^3 Ml/yr
To Fraser River	-	19×10^3 Ml/yr
Groundwater use	-	1×10^3 Ml/yr

The most significant terms in the recharge (positive items) balance are interactions with the Fraser River/Omeo Creek and irrigation losses. Only 1×10^3 Ml/yr of the ~ 40×10^3 Ml/yr water balance can be attributed to diffuse rainfall recharge.

Testing for groundwater parameters has determined that the aquifers hydraulic conductivity lies in the range of 80 to 700 metres per day (Mintago Investments Ltd, 1997) indicating a very conductive aquifer. No data are available on specific yield (amount of water a unit area of an aquifer releases due to a unit water level decline).

All these data obtained for the Earnscleugh Aquifer were used to construct a numerical model, described in detail by Mintago Investments (1997). The model is covered 140 x 160 cells with a uniform cell size is 50 x 50 metres. The contacts between the Earnscleugh Aquifer and basement rocks are considered as no-flow boundaries.

Horizontal hydraulic conductivity for the model was assumed to be 280 m/day. Aquifer recharge was 40 mm/yr for diffuse rainfall recharge, 900 l/sec for appropriate Fraser River/Omeo Creek cells and a uniform 456 mm from return irrigation water. The model was calibrated using mean static water levels for 30 wells.

Figure 4 shows mean groundwater levels and indicates a general groundwater flow towards the Clutha River/Mata-Au.

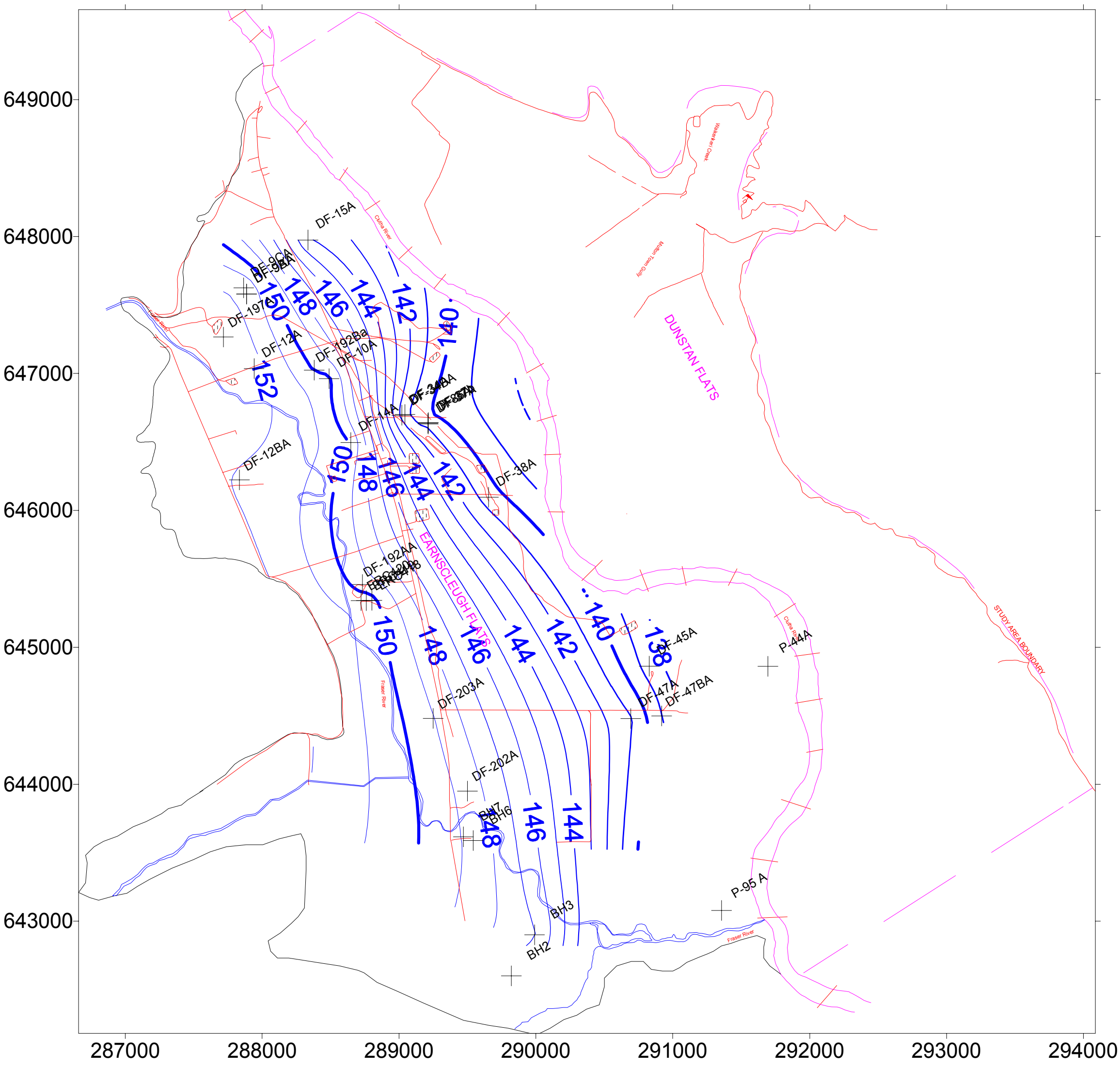

Figure 4 Mean groundwater levels for the period 1993 to 1997, after Mintago Investments (1997). The kriging method of interpolation is used. Contours are trimmed to fit the principal area of drilling information availability

3.2 The Alexandra Aquifer

The eastern part of the Alexandra Basin (Manuherikia Claybound, Dunstan Flats, and Manuherikia Alluvial sub-aquifers) appears to form a single aquifer that will be referred to in this report as the *Alexandra Aquifer* (Figure 1). Groundwater from the Manuherikia Claybound sub-aquifer flows into the Dunstan Flats and Manuherikia Alluvial sub-aquifers. These discharge groundwater to the Clutha River/Mata-Au, and to lesser extent to the Manuherikia River.

Although the lithology and hydraulic character of these sub-aquifers is different they form a continuous 'multi-lithology' aquifer. In multi-lithology aquifers, groundwater moves though geologically different media and a single hydraulic unit (or aquifer) is formed from several geologically different sub-aquifers. For water allocation purposes it is more appropriate to consider the entire multi-lithology aquifer as inter-flows between sub-aquifers further complicate (introduce more unknowns to calculations) already complex processes. Understanding contact between sub-aquifers and groundwater flow can be achieved by collating and interpreting groundwater level, pumping test, and bore log data. These require a comprehensive and timely database as a pre-requisite for better water allocation.

Groundwater in the Alexandra Aquifer is recharged by a combination of flow from surface water, rainfall percolating through the soil, and imported irrigation water from the Manuherikia Irrigation Scheme. The amount of water delivered to irrigators in this scheme has decreased lately.

Groundwater flow generally follows topography. Groundwater is discharged to the Clutha and Manuherikia Rivers. Approximately 600 users (Figure 1) rely on groundwater for domestic, stock, irrigation, and institutional water supply. Most groundwater is used for community water supply, irrigation, and domestic purposes.

Little is known about the hydraulic properties of the aquifers. The few pumping tests with available data indicate high hydraulic conductivity (k~100m/d) for the Dunstan Flats aquifer and low (k~1m/d) for the Manuherikia Claybound aquifer.

The Manuherikia Claybound sub-aquifer (Lindis outwash) is a gravel aquifer with high fine particle (silt and clay) content. Because some of the voids between gravel particles are occupied by the fine material not water, the hydraulic conductivity of the Manuherikia Claybound aquifer is expected to be smaller than ‘clean’ gravel aquifers. MWH (2004) indicates hydraulic conductivities between 0.4 and 10 m/day and assumed 0.2 for specific yield.

The hydraulic conductivity is assumed to be in the order of 100 m/day for the Dunstan Flats sub-aquifer. This represents an aquifer with a very large capacity to transmit water and is based on an ORC pumping test performed on a Dunstan Flats sub-aquifer well. In the absence of proper pumping tests even specific capacities could be used to estimate at least the magnitude of the hydraulic conductivity. Specific capacity is the ratio of pumping rate and drawdown. As no comprehensive report or database is available on aquifer hydrology/pumping tests in Otago it is difficult to ascertain if the generally accepted hydraulic conductivities of 100m/d for the Dunstan Flats sub-aquifer and 1m/day for the Manuherikia Claybound sub-aquifer are representative or not.

Specific yield was calculated as 0.1 for the Alexandra aquifer by Pattle Delamore Partners (1995). No other data are available on specific yield. The knowledge of specific yield is vital for converting groundwater level changes to flows. Specific yield can be calculated from certain pumping tests, geophysics or sometimes continuous (automated) groundwater level and climate recordings.

All the reviewed reports discuss the difference between groundwater allocation and actual groundwater use (the amount of water withdrawn) and the importance of groundwater recharge from the inefficient Manuherikia irrigation scheme. If irrigation efficiency is increased in the future a water allocation plan should not rely on irrigation return water.

4. Groundwater monitoring

Groundwater levels measured by Contact Energy and ORC monitoring sites indicate declining groundwater levels in both the Earnscleugh and the Alexandra Aquifers. The reasons for the decline are unknown but could be a combination of groundwater use, less recharge from imported water by the Irrigation Schemes, and climate.

Automated measurements of groundwater level have been made in the Dunstan Flats sub-aquifer in Bore P46a since 1986 (ORC, 2002). P46a is a PVC-lined bore, 30 m deep and 100 mm in diameter, located just to the south of Mutton Town Gully approximately 2.5 km south east of Clyde (Figure 3). It has been used by Contact Energy solely for groundwater monitoring since the automatic recorder was installed in 1986. The closest neighbouring well is approximately 125 m away.

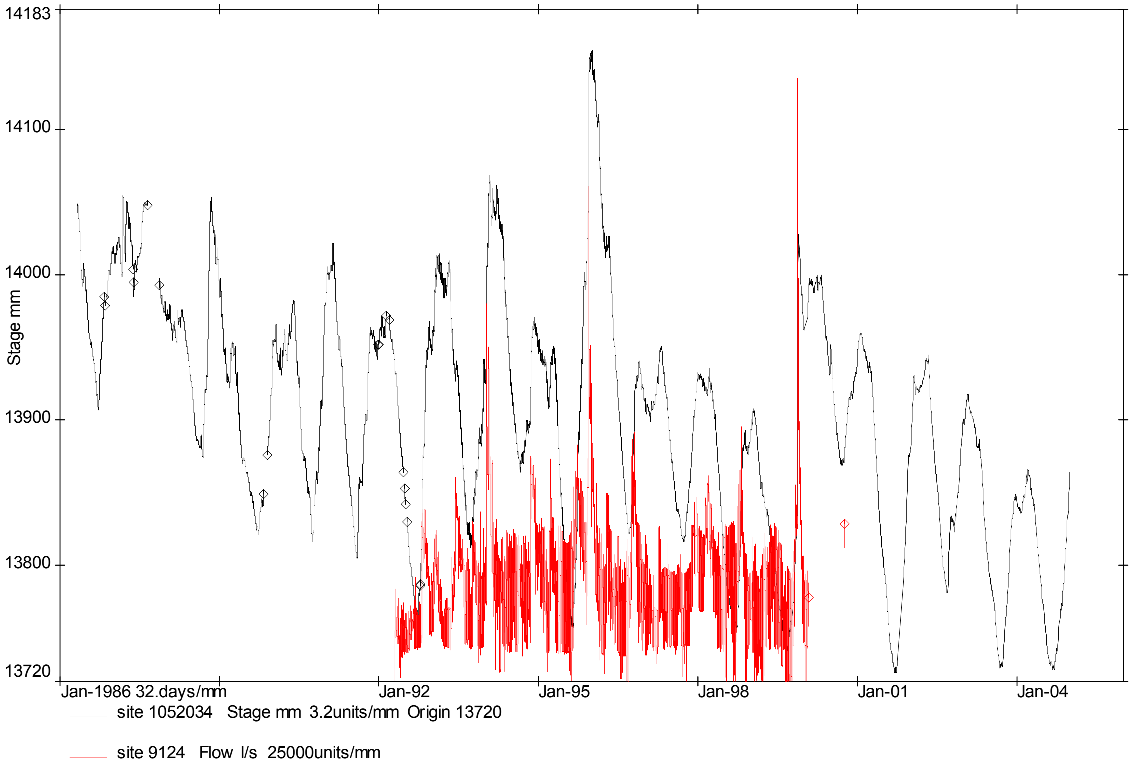

Figure 5 Large increases or episodic recharge events (late 1995 and 1999) coincide with the largest rises in hydrograph (black curve) for bore P46A, Dunstan Flats sub-aquifer. Groundwater data courtesy of Contact Energy. Major increases in groundwater level correspond to episodic high stages at the Clutha River/Mata-Au, site 9124, Clyde Power Station (red curve). On the vertical axis, 1 m groundwater stage is one tick.

Seasonal variation, with high levels at about January – February and lows in September can be observed in Figure 5. This seasonality is contrary to realistic soil water balance expectations (small episodic recharge in winter) and therefore is not rainfall recharge related. The magnitude of annual fluctuation and the pronounced groundwater recession curves indicate groundwater recharge in the order of 250-500 mm/yr, a magnitude larger than those expected from soil water balance.

The hydrograph in Figure 5 therefore probably represents episodic recharge from the Clutha River/Mata-Au super positioned to an annual cycle. When the river level is higher than groundwater, river water can infiltrate the aquifer (recharge from 'bank storage'). Once the river flow declines groundwater will continue to discharge to the river again. Figure 5 indicates this process in December 1995 and November 1999. AquaFirma (1998) also referred to distinct events following spring floods and the strong pattern of spring-summer rise and autumn-winter decline in groundwater levels. AquaFirma (1998) noted that river floods, fluctuations, and the more subdued recharge from irrigation return water were all exhibited in the hydrograph. Overall, the hydrograph in Figure 5 indicates a 1 to 1.5m decline in groundwater level.

Contact Energy's hydrograph for site P73A, Dunstan Sub-aquifer, approximately 400m from the Clutha River/Mata-Au (Figure 3), also shows recharge from bank storage in Figure 6. Notable episodic increases, larger than 2.5m occurred in late 1993, 1995, and 1999; after the spring floods. These rises are much larger than the more 'ordinary' 1 to 1.5m annual range shown in Figure 6. The overall decline at this site is approximately 1m.

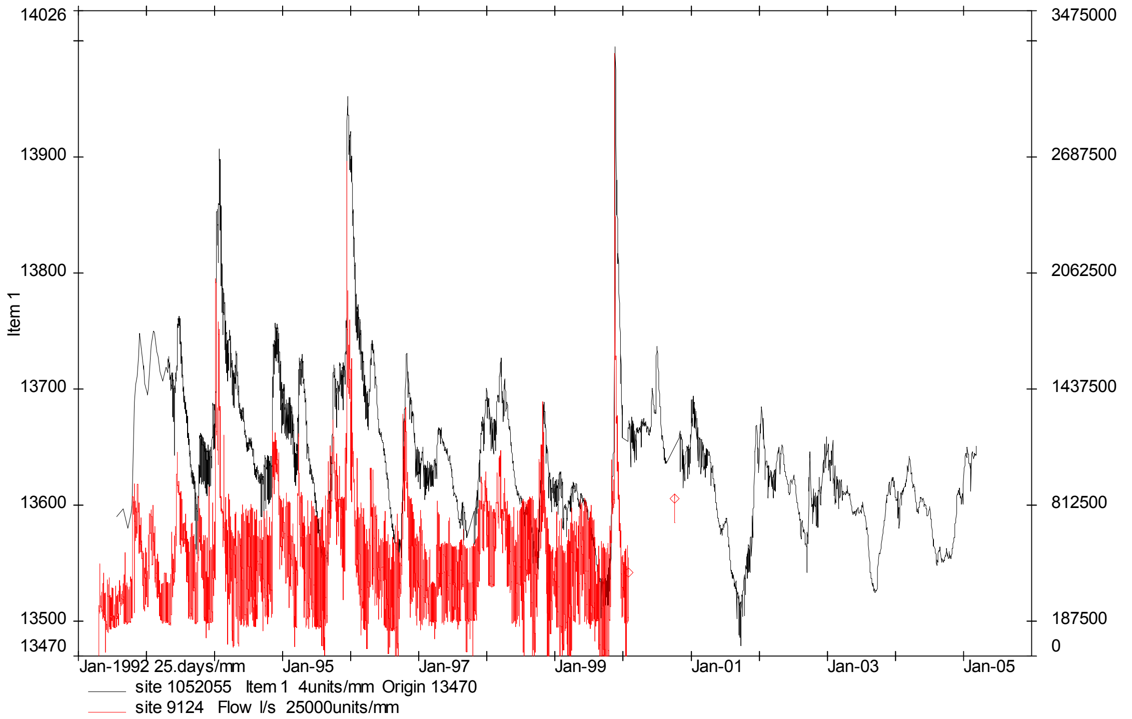

Figure 6 Groundwater level (black) at site P73A. Groundwater data courtesy of Contact Energy. Major increases (2.5 to 4.5m) in groundwater level correspond to episodic high stages (red) at the Clutha River/Mata-Au (late 1993, 1995, and 1999). The 'ordinary' annual groundwater range is approximately 1 to 1.5m. On the vertical axis, 1 m is represented by one tick.

Contact Energy also monitored groundwater levels in bore P82, in the Earnscleugh Aquifer. Groundwater level declined by about 1 m in 1993-99. The hydrograph for P82 also shows a very consistent pattern of annual fluctuations in the order of 3m. This site also indicates an annual recharge in the order of 0.5 m, a magnitude larger than those expected from diffuse recharge though soil water balance.

Eight additional ORC manual monitoring sites, situated in the Alexandra Basin, indicate a 1 to 1.5 m decline in groundwater levels over the period of 1997-2004. The overall trend therefore is about a 1 m decline over the period of the last five to seven years in the basin. Assuming a 'global' specific yield between 0.1 and 0.2 this indicates an approximately 1800 - 4700 Ml/yr net water deficit for the entire Alexandra Basin. Hydrographs from Contact Energy monitoring sites in the Earnscleugh Aquifer and in the Dunstan Sub-aquifer also indicate episodic recharge events associated with high spring flow events in the Clutha River/Mata-Au.

5. Current groundwater allocation

Consumptive groundwater allocation as at April 2005 is shown in Table 2.

Table 2 Alexandra Basin groundwater allocation

Aquifer	*Permits (purpose)*	*Total monthly allocation*
Manuherikia Claybound	16 (community water, stock, irrigation)	30 Ml
Manuherikia Alluvium	3 (community water)	5 Ml
Dunstan Flats sub-aquifer	35 (irrigation, community water, stock)	800 Ml
Earnscleugh aquifer	9 (irrigation, community water, stock)	115 Ml
Consented -Total	63 (irrigation and community water)	950 Ml
500 wells @10 m^3/day	permitted activity	150 Ml
Total		1100 Ml

Calculating how much groundwater is allocated from the Alexandra aquifer is not a straightforward process on an annual basis. Most permits do not have annual maximum allocation imposed. The majority have daily allocation, some have monthly allocation, and some do not. Annual water allocation is not simply 365 times the maximum daily quantity as demand may vary seasonally. Similarly, monthly allocation is not necessarily 30 times the daily allocation.

For a community water supply, however, twelve times the monthly maximum allocation could be a reasonable estimation of the annual allocation. For irrigation, probably a seven month long irrigation season would suffice. Complicating matters even further, several consents were issued for multipurpose, i.e. both for irrigation and water supply. In terms of annual allocation the best estimate is around 10000 Ml/year.

Allocation of the Dunstan Flats sub-aquifer represents the majority of groundwater allocation in the Alexandra Basin. A single permit, 2003.112, issued for community water supply for Alexandra (300 Ml/month) represents more than 25% of the total allocation of the Alexandra aquifer. Permit 2001.948, issued for water supply near Clyde, next to Lake Dunstan can obtain most of the allocated 300 Ml/month from surface water. In addition, shallow bores or wells, in the vicinity of surface water courses may obtain water from both surface and groundwater sources. So-called ‘Groundwater takes’ may actually be sourced from the Clutha River/Mata-Au in the Dunstan Flats sub-aquifer. This is because the lateral distance from the Clutha River/Mata-Au is small and the estimated hydraulic conductivity high. Because of this it is possible that true groundwater allocation is only 200 Ml/month in the Alexandra aquifer.

6. Future groundwater allocation

In considering the future groundwater allocation for the Alexandra basin, a review has been made of the best available information. Firstly a water balance is established and described, followed by a discussion on the potential future options.
In this review a conservative approach has been taken and the following assumptions have been made:

1. The aquifer is unconfined and connected to surface water bodies.
2. Aquifer hydraulics are largely unknown.
3. The catchment is heavily modified by imported irrigation water and return irrigation water from the Manuherikia Irrigation Scheme. A large fraction of the irrigation scheme water is assumed to recharge groundwater. The amount of water imported is decreasing and cannot be relied upon for long-term groundwater allocation.
4. Only groundwater allocation (not actual use) is addressed.

6.1 Groundwater budget for the Alexandra Basin

From the available data, a water balance has been established for the Alexandra Basin and is shown in Table 3. Several assumptions have been made and question marks within the table indicate unknown figures or processes.

Examining both Table 1 and Table 3 together reveals that large and potentially important components of the groundwater balance remain unknown. Even a small episodic recharge from the Clutha River/Mata-Au can have a huge effect on groundwater.

Some of the components, such as discharge to surface water are obtained from closing sub-aquifer balances. Overall, inflows are estimated as approximately 46 to 53 $\times 10^3$ Ml/yr, outflows approximately 49 to 55 $\times 10^3$ Ml/yr.

Independently from the groundwater balance calculations, monitored sites over time also show a small decline in groundwater levels.

Table 3 also indicates that:

- Surface to groundwater interactions are the largest components of the water budget
- In pre-development conditions, groundwater levels would have been significantly different than present. Imported irrigation water, that now recharges groundwater, must increase groundwater outflow to surface waters or decrease leakage from surface waters significantly.
- Recharge from the Fraser River is potentially larger than the rainfall recharge for the Earnscleugh aquifer.
- Recharge from the Waikerikeri is potentially larger than the rainfall recharge for the Dunstan Flats sub-aquifer.
- Groundwater allocation is a small part of the water budget.

Table 3 Groundwater budget for the Alexandra Basin.

Sub-aquifer (number of bores)	*Recharge 1000 Ml/yr*			*Discharge 1000 Ml/yr*		*Monitoring Trend Ml/year*
	Rainfall	Irrigation*	Surface water	Surface water	Allocation	
Earnscleugh aquifer (150)	1	7	31	39	1.6	-0.3 to -0.6
Manuherikia Claybound (150)	2.7	?	0	?	0.9	-1 to -4
Manuherikia Alluvium (100)	0.4	?	0	0.8 ?	0.6	-0.3 to -0.6
Dunstan Flats (200)	0.64	1.5 ? 3.2 ? 7 ?	1.2	3 ?	9 (3)	-0.3 to -0.6
Overall	4.7	9 to 16 ?	32	43 ?	12 (6)	-1.8 to -4.7

* Recharge from return irrigation water or inefficiency cannot be relied on for future allocation

Notes:

1. Allocation values in brackets are estimates of groundwater use considering surface-groundwater interaction.
2. Rainfall recharge is estimated at 40 mm/yr mean annual recharge.
3. Monitoring trends are converted to volume of water assuming a ‘global’ specific yield between 0.1 and 0.2.
4. Components missing are marked by ?, values followed by ? indicate large uncertainty.
5. Evaporative discharges were not considered.

The mean annual flow of the Clutha River/Mata-Au is 15x10^6 Ml/yr, which is approximately 300 times the groundwater budget of the entire Alexandra Basin. This indicates that groundwater discharge to the Clutha in the Alexandra Basin is unimportant to maintaining river levels. The main negative consequences of increasing groundwater allocation would be lowering groundwater levels and inducing more recharge from surface water (other than the Clutha River/Mata-Au).

The Manuherikia Claybound sub-aquifer is an integral part of the Alexandra aquifer. Monitoring indicates declining groundwater levels, which is probably due to large groundwater use in the Dunstan Flats sub-aquifer, although from Table 3 there appears to be some extra water available.

The Manuherikia Alluvial sub-aquifer, Dunstan Flats sub-aquifer, and Earnscleugh aquifer are all over-allocated based on the limited information conveyed in Table 3. They all rely on extra water from surface water or imported irrigation water.

7. Groundwater allocation for the Alexandra Aquifer–future potential options

A series of future potential allocation options can be considered for the Alexandra Basin:

- Option 1: to continue with the current approach;
- Option 2: follow a modified 'Lincoln' approach;
- Option 3: maintain minimum groundwater levels;
- Option 4: setting thresholds for trends;
- Option 5: using hotspot elimination tools; and
- Option 6; adopting a safe yield or sustainable yield limits.

Each option is described in turn below.

7.1 Continue current approach

When looking at the Manuherikia Claybound Aquifer in isolation (ORC report 2004/601) it was proposed to allocate a maximum of 520 Ml/yr from the aquifer. This value was based on the concept of excess rainfall, i.e. rainfall in excess of the median rainfall is the allocatable groundwater.

The calculation used was half of the (95th percentile – 50th percentile) annual rainfall multiplied by 0.0913 (9.13%). Assuming that total annual rainfall is normally distributed, one-half of the difference between the 95thpercentile and 50th percentiles is known as standard deviation of annual rainfall. This value is an important statistical measure about the spread of annual rainfall. Recharge was also considered by the report as a flat percentage (9.13%) of annual rainfall. Therefore the amount of groundwater proposed to be allocated was 0.0913 times the standard deviation of annual rainfall. Using this method, groundwater allocation should be around 900 Ml/yr for the entire Alexandra Basin.

However, rainfall recharge to groundwater is not a fixed percentage of the annual total rainfall. Even if recharge events are caused by infrequent and large rainfall events in arid or semi-arid environments, the method should be used as a first estimate only because the use of annual statistics will mask real recharge events (Scanlon et al., 2002 and DeVries and Simmers, 2002).

Therefore this approach is not appropriate for Alexandra or for other semi-arid climate areas of the Otago region.

7.2 The modified "Lincoln" approach

Recommended by Lincoln Environmental, Institute of Geological & Nuclear Sciences, and ESR, (2001) allocation is considered up to 50% of recharge for **initial** groundwater allocation. However, this method is considered to be "not conservative", and is therefore not preferred by ORC in over-allocated surface water catchments (Selvarajah, 2005, pers.comm.).

MWH (2002) followed this approach and used 40% of annual rainfall as an approximation of recharge. The 40% figure appears to be very high and almost certainly represents a crude estimate for a humid (probably very humid) climate. Even in high rainfall lower North Island conditions, Bekesi and McConchie (1999) calculated annual recharge as approximately 300mm/yr or 30% of annual rain.

40% of the annual 350mm in Alexandra rain would represent 140mm/yr and such a high value is not supported by climate data or soil water modelling. 140 mm/year is in excess of the 38 mm/yr (MWH 2004) and 25-50mm (Irricon, 1998) estimates based on monthly soil moisture balances.

A variation of this method could be implemented for integrated water management in the Alexandra Basin. Surface water allocation could be combined with up to 50% of rainfall recharge and water would be allocated regardless of its origin. For example, 50% of the 7-day mean annual low flow of surface waters could be added to 50% of rainfall recharge to get the total water allocation in a catchment. This is a simple and practical method that would suit most Central Otago catchments as surface and groundwater catchments appear to coincide.

This is the preferred option of this report for initial water allocation.

This approach to water allocation is both adaptive and integrated. It is a departure from previous thinking that was based on a deterministic sustainable yield, for example a fixed rate based on the perceived rainfall recharge. Such a change is justified by the unique semi-arid climate and the groundwater balance dominated by surface water in the Alexandra Basin. Another advantage of this method is that under specific local conditions it can be combined with other allocation options such as minimum groundwater levels, trends, or hotspot elimination tools.

7.3 Minimum groundwater levels to be maintained

Lowering of groundwater levels could be controlled by setting absolute level triggers, such as for the Ettrick aquifer or the North Otago volcanics. Once groundwater levels reach a pre-determined level, users of groundwater have to reduce their groundwater abstraction.

7.4 Setting thresholds for trends

This option is used in association with a relevant timeframe, for example groundwater levels should not decline more than 0.15 m/yr based on the mean of the last five years. When trends in excess of the threshold occur, groundwater allocation is reviewed. This method is an adaptive method that is environmentally flexible. It would require good monitoring data, and an acceptance from users that reduction (or an increase) of future groundwater allocation could occur.

When further information becomes available, this could be a groundwater allocation tool for the future.

7.5 Hotspot elimination tools

Hotspot elimination tools are intended to control local groundwater use although they also have some control over basin development. These avoid an undesired concentration of groundwater users in an area.

For example, a circle of a given radius is centred on the new application. A new permit is only issued if the cumulative takes within the circle are less than a threshold value (normally based on the groundwater balance or recharge). Although this method is intended to control local groundwater use it does, to a moderate extent, control total basin allocation. It can only be implemented if the site and quantity of allocation is known with high certainty. In the Alexandra basin it would require a GPS survey of bores and consents, and the consistent use of allocation quantities on water permits. It could be a valuable tool in the future to minimise bore interference.

7.6 Safe yield or sustainable yield limits

Allocation is maximised based on the safe yield or annual renewable yield concept. This method could be used in the Alexandra Basin if surface water resources were considered unimportant. The safe yield method is also an outdated technique (Bredehoeft, 1997; Jacobs and Holway, 2004; Sophocleous, 1997) that has been discredited by scientists in the last twenty years.

Therefore, this option is not considered further in this report.

8. The need for monitoring and review of groundwater allocation

Groundwater allocation plans normally use recharge *as a starting point*. It is pivotal, however, that such a figure is used and understood only **as a start and allocation is then tested, i.e. the components of the groundwater budget are monitored.** As more information and knowledge is collected/gained the initial allocation should be reviewed and potentially amended.

The ultimate groundwater allocation tool would be a numerical model that includes information/knowledge on the geometry and hydraulic properties of aquifer(s) and the inputs and outputs from/to the aquifers(s). Such an allocation/model would require an increase in groundwater level monitoring and hydraulic data acquisition.

Improvements to future scientific/technical work to achieve such a form of allocation could be:

1. Collate water level data, pumping tests, and bore-logs in an appropriate database.
2. Obtain ECNZ/Mintago Investment data and the numerical model and incorporate these into the ORC groundwater database.
3. Interpret pumping tests to hydraulic properties.
4. Once permits are renewed, classify them according to the source of water not by the means of drawing water. Use consistent and mandatory allocation fields.
5. Implement a surface water (including irrigation race) gauging programme to reliably estimate losses and gains to groundwater.
6. Review/improve monitoring in the Alexandra Basin. Consider taking over/financing the monitoring of P46A and P82 Contact Energy monitoring sites.

9. Conclusions and recommendations

Two main aquifers form the Alexandra Basin groundwater resource. The Alexandra Aquifer (Manuherikia Claybound, Dunstan Flats, and Manuherikia Alluvial sub-aquifers) forms the eastern part of the Alexandra Basin. Groundwater from the Manuherikia Claybound *sub-aquifer* flows into the Dunstan Flats and Manuherikia Alluvial sub-aquifers. Most of this groundwater is discharged to the Clutha River/Mata-Au. On the western side, groundwater from the Earnscleugh aquifer flows to the Clutha River/Mata-Au.

Significant parts of the groundwater balance are uncertain; including how much groundwater is actually allocated. Complicating matters even further, a large amount of ‘groundwater’ has been allocated for bores that may draw water from the Clutha River/Mata-Au through groundwater-surface water interaction.

The overall trend is about a 1 m decline over the period of the last five to seven years. Assuming a ‘global’ specific yield between 0.1 and 0.2 this indicates an approximately 1800 - 4700 Ml/yr net water deficit for the entire Alexandra Basin.

Major components of the groundwater balance are missing or can only be estimated. Some of the components, such as discharge to surface water are obtained from closing sub-aquifer balances. Overall, inflows are estimated as approximately 46 to 53 $\times 10^3$ Ml/yr, and outflows approximately 49 to 55 $\times 10^3$ Ml/yr. Independently from the groundwater balance calculations, monitored sites over time also show a small decline in groundwater levels.

Surface to groundwater interactions and recharge from imported irrigation water are the largest components of the water budget. Recharge from the Fraser River is potentially larger than the rainfall recharge for the Earnscleugh aquifer. Recharge from the Waikerikeri Stream is potentially larger than the rainfall recharge for the Dunstan Flats sub-aquifer. The mean annual flow of the Clutha River/Mata-Au is about 300 times the groundwater budget of the entire Alexandra Basin and therefore groundwater allocation is only a small part of the total water budget.

In pre-development conditions, groundwater levels would have been significantly different than present. Based on the available information, the Manuherikia Alluvium sub-aquifer, Dunstan Flats sub-aquifer, and Earnscleugh aquifer are all over-allocated and rely on extra water from surface water or imported irrigation water.

A series of options were considered which would allow the most effective use of the groundwater resource into the future.

The current approach of allocating a maximum fixed rate, based on rainfall recharge, was only considered suitable for first order estimates in conditions such as those for semi-arid climates of the Otago region.

The recommended approach for initial water allocation was for integrated water management, combining aspects of rainfall recharge and surface waters. For example, surface water allocation could be combined with up to 50% of rainfall recharge and water would be allocated regardless of origin. This is a simple and practical method that would initially suit most Central Otago catchments as surface and groundwater catchments appear to coincide. As more information becomes available through data collection and monitoring, a numerical groundwater model can be developed that can serve as a basis for long-term water allocation.

Having such an adaptive method also allows it to be combined with other potential options such as maintaining groundwater levels, setting thresholds or localised hotspot elimination tools. These options can be designed to best fit local conditions.

To gain maximum benefit from the groundwater resource it is essential that the components of the groundwater budget are monitored and analysed. As more information becomes available and the aquifers better understood, allocation can then be adapted to fit the current conditions.

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