Environment Southland spring gauging programme

Review and recommendations for future monitoring

Liquid Earth
April 2012

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Executive Summary

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Since 2000, approximately 1,200 individual flow gaugings have been undertaken as part of the Environment Southland spring gauging programme. In light of the large amount of flow data available, this report provides a review of the current monitoring programme against its overall objectives and provides recommendations for future monitoring.

Based on a preliminary review of the available data it is concluded that:

- The existing spring gauging programme has largely achieved its original objective of characterising the magnitude of discharge in the major springs and spring-fed stream systems in the Southland Region. Given the inherent natural variability, it is unlikely that additional monitoring at a significant proportion of current sites will serve to further improve baseflow discharge estimates;
- Following several attempts, establishment of automatic flow monitoring sites on spring-fed streams has proved unsuccessful due to difficulties associated with obtaining a stable stage/discharge relationship due to the effects of macrophyte growth. Future measurement of spring-fed stream discharge is therefore largely reliant on manual flow gauging and/or correlation with other environmental variables (e.g. groundwater levels or existing flow monitoring sites);
- Monitoring of spring fed streams does not provide a particularly effective indicator for monitoring groundwater quantity state in source aquifers.

In terms of the future spring gauging programme it is recommended Environment Southland consider the following:

- In the short-term undertaking a detailed assessment of the available data to develop and document correlations between discharge in springs and spring-fed streams and other environmental variables (e.g. groundwater levels and streamflow records). Where these correlations are adequate to enable estimation of discharge using alternative (existing) environmental monitoring, the gauging programme can be scaled back and/or resources redeployed to extend monitoring to additional springs and spring-fed streams which currently have limited flow information;
- Investigate the potential for greater utilisation of springs as indicators of groundwater quality state in source aquifers and associated impacts on surface water receiving environments. It is noted that the need to increase water quality monitoring in spring-fed streams was also identified in a recent review of Environment Southland's state of the environment (SOE) rivers and streams water quality monitoring programme (Ausseil, 2010[1]); and,
- Where appropriate, refocus monitoring/investigations to better characterise local-scale groundwater/surface water interactions in high value streams or where pressure from resource development is highest.

[1] Ausseil, O., 2010; *Environment Southland: Review of the State of the Environment Water Quality Monitoring Programme*. Report prepared for Environment Southland. 56p.

1. Introduction

Due to their unique flow variability and water quality characteristics springs and spring-fed streams form a unique and highly valued component of Southlands aquatic environment. Discharge in these streams also makes a significant contribution to baseflow in Southland's major rivers and streams.

Since 2000, a significant amount of flow gauging data has been collected by Environment Southland from springs and spring-fed streams. This monitoring has involved by semi-regular monitoring at key sites in the major spring systems supplemented by investigations to identify and characterise springs quantify discharge at a large number of sites across the Southland Region. Given the large amount of gauging data that has been collected over the past 12 years, this report provides an assessment of the spring gauging programme against its overall objectives and provides recommendations intended to help determine future directions for this monitoring.

1.1. Background

Interaction between groundwater and surface water is an integral component of the hydrology of a majority of surface waterways. Baseflow is the term applied to describe the relatively stable discharge of groundwater to rivers and streams from surrounding hydraulically connected aquifer systems. Baseflow is a key component of stream flow as it maintains discharge between individual rainfall events when *quickflow* (a combination of direct runoff and lateral movement of water through the soil profile) predominates.

Figure 1 shows a schematic representation of a stream hydrograph prior to, and following, a rainfall event illustrating changes in the relative proportions of quickflow and baseflow discharge which create a time variant stream hydrograph. The hydrograph illustrated shows a rapid rise in discharge during or immediately following a rainfall event reflecting runoff directly to rivers and streams (i.e. quickflow). Over time stream discharge declines as quickflow reduces and baseflow discharge comprises an increasing portion of stream discharge so that during extended flow recession virtually all flow is derived from groundwater discharge.

In addition to its importance in maintaining stream flows between individual rainfall events, baseflow discharge also exerts a significant influence on both physical and chemical water quality in rivers and streams, particularly during periods of extended flow recession.

The relative proportions of baseflow and quickflow vary between individual rivers and streams reflecting the physical characteristics of each catchment which may exert a significant influence on the hydrological regime and associated physical characteristics of the stream. For example, spring-fed streams typically exhibit unique aquatic habitats that reflect the stable baseflow and limited quickflow occurring in these groundwater dominated catchments.

Baseflow makes a significant contribution to river and stream flows throughout the Southland Region. In the inland basins (e.g. the Waimea Plains, Oreti Basin and Te Anau Basin) interaction between groundwater and surface water typically follows a consistent pattern. Many tributary streams lose flow to groundwater recharge around the basin margins as they emerge from foothill catchments onto the alluvial terraces. In turn, appreciable quantities of baseflow discharge occurs either via direct seepage into the main river channels or spring-fed streams near the downstream basin margins. In the coastal lowlands groundwater/surface water interaction occurs on a more localised scale with infiltrating rainfall moving laterally through shallow unconfined aquifers to provide baseflow to the numerous first and second order streams that drain these areas.

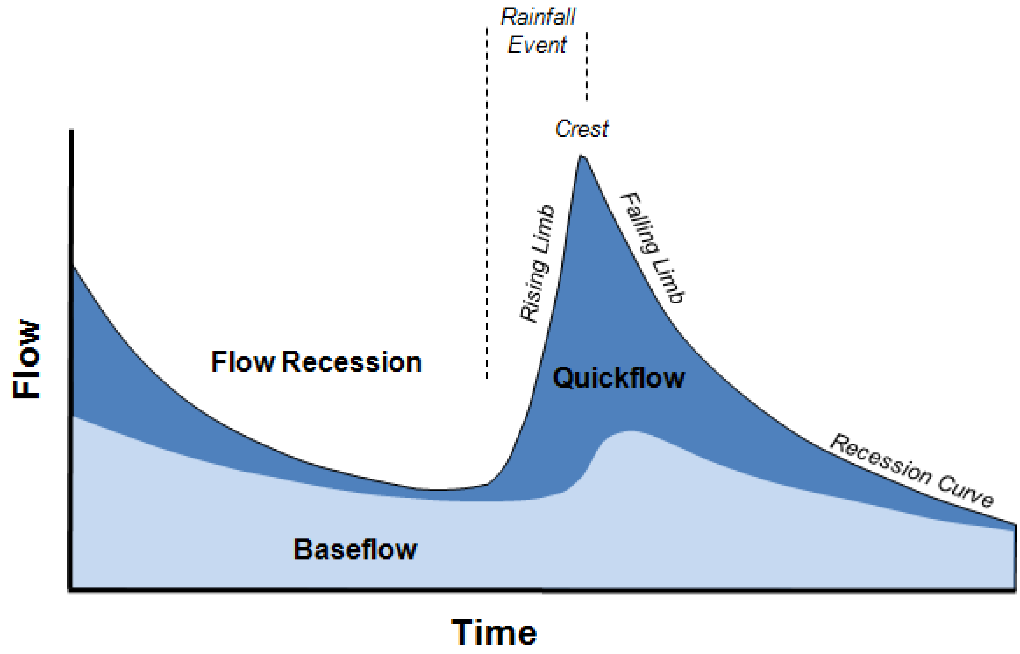

Figure 1. A schematic stream hydrograph illustrating the varying contribution of baseflow to stream discharge (note periods between rainfall events when baseflow comprises virtually the entire stream discharge)

1.1.1. Springs

Springs are formed where the water table intersects the earth's surface and groundwater discharges to the surface.

Hydrogeologists recognise a wide variety of spring types, and several physical classification schemes have been developed to describe the interaction between springs, the underlying groundwater and the surrounding landscape. The most basic classification separates gravity springs (in which water flows down an elevation gradient) and artesian springs (in which the potentiometric level of groundwater is higher than the land surface and the water discharges under pressure). Fetter (1980) described five main classes of springs:

Depression spring - A topographical depression which intersects the water table in an unconfined aquifer allowing groundwater to flow to the surface.

Contact spring - Situations where a permeable, water-bearing stratum overlies an impermeable stratum. Water discharges where the contact zone between the strata intersects the land surface. Depending on the orientation of the geological strata such a zone may be marked by a line of springs.

Fault spring - A faulted, impermeable rock stratum is located downslope of a groundwater flow path.

Sinkhole spring - Where the process of dissolution of carbonate rocks (karstification) has led to the development of a sinkhole that intersects the water table.

Fracture spring - The fracture zone between two opposing rock strata provides a flow path for groundwater to discharge.

Figure 2 provides a schematic illustration of the major spring types

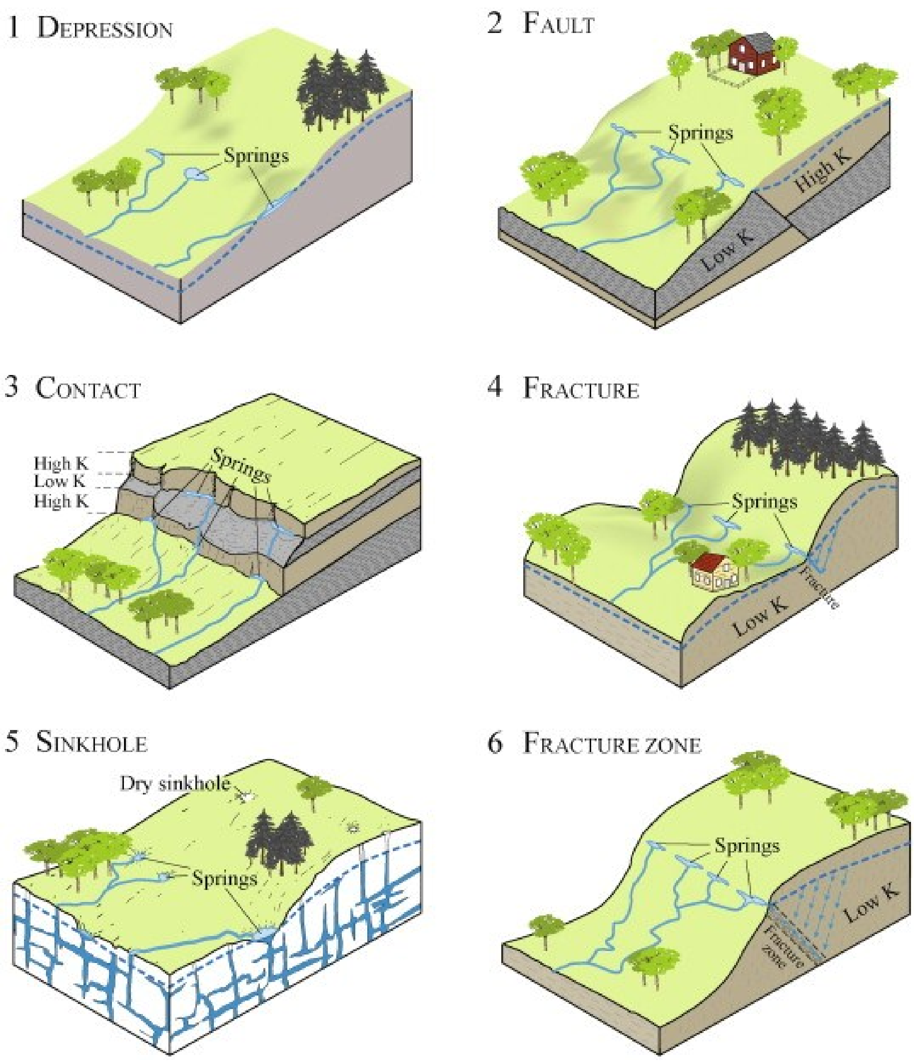

Figure 2. Schematic Illustration of the major spring types (modified from Fetter, 2001[2])

Depression springs are the most common spring type in the Southland Region. These features occur in situations where the water table intersects the land surface in topographical low points and generally take one of the two forms illustrated in **Figure 3** below:

[2] Fetter, C., W. 2001; *Applied Hydrogeology*. Prentice Hall, New York, 598pp

- springs along the base of alluvial terrace risers where the water table intersects the land surface and;
- linear depression springs formed where the water table intersects the land surface along an extended depression in the land surface (such as an abandoned channel meander on an alluvial floodplain).

Depression springs associated with alluvial terrace risers typically occur as point discharges with a majority of flow occurring within a small area. An example of a terrace spring in Southland is Clear Creek which originates along the outer margin of the Edendale Terrace in the Seaward Downs area.

In contrast, groundwater inflow to linear depression springs occurs progressively along the stream channel rather than at discrete points. This type of spring is commonly included in waterways classified as spring-fed streams.

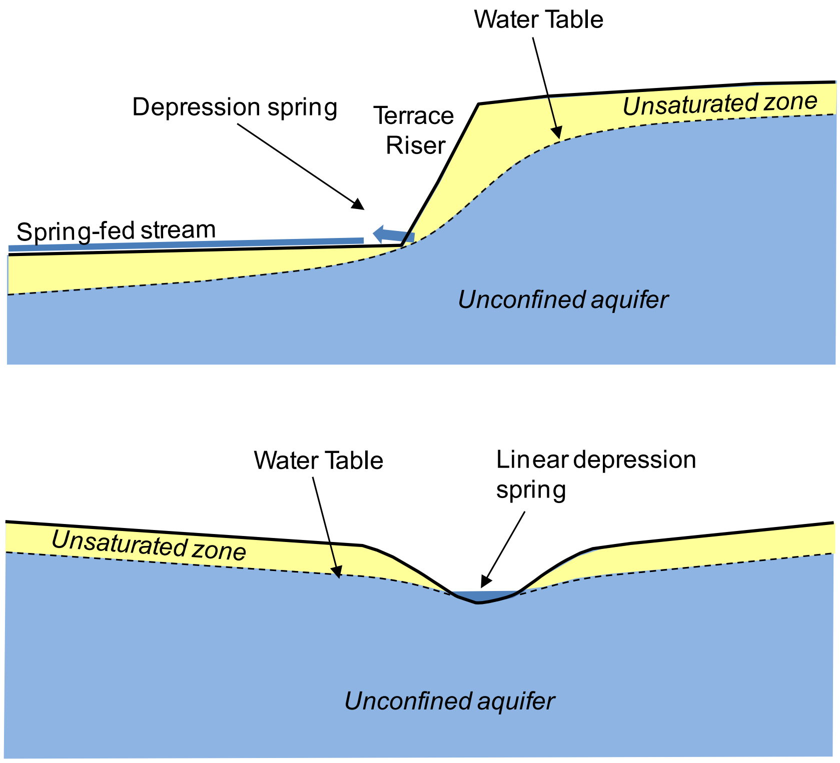

Figure 3. Schematic illustration of the most common types of depression spring in the Southland Region

1.1.2. Spring-fed streams

While baseflow discharge occurs in virtually all rivers and streams, the proportion of baseflow versus quickflow comprising overall stream discharge can vary widely reflecting the physical characteristics of the catchment. The term spring-fed stream is typically applied to waterways where baseflow predominates over quickflow. These streams generally exhibit limited flow variability reflecting the relatively stable baseflow input. This limited flow variability often exerts a significant influence on channel morphology, streambed sediment type and water quality (particularly in terms of suspended sediment) forming a unique aquatic habitat.

Within individual spring-fed streams the location and magnitude of baseflow discharge can vary along the length of the stream reflecting topographical variations and changes in the texture and permeability of sediments comprising both the streambed and underlying aquifer and may also vary over time reflecting changes in relative head resulting from seasonal groundwater variations.

There is a relatively gradational change between what can be described as spring-fed stream (essentially comprising a linear depression spring which receives a relatively minor contribution from quickflow) and streams which, although carrying appreciable baseflow discharge are more dominated by discharge associated with individual rainfall events (i.e. quickflow). For example, **Table 1** lists the calculated baseflow index for various Southland streams. These data indicate that baseflow makes a varying contribution to total discharge in the streams analysed of between 0.43 and 0.63 (i.e. between 43 and 63 percent of total discharge is derived from groundwater inflow) reflecting the nature of groundwater/surface water interaction within the contributing catchment.

Table 1. Calculated baseflow contribution to rivers and streams in the Southland Region

Catchment		Base Flow Index	Catchment Area (km^2)	Mean Annual Streamflow mm/year	
				Total	Baseflow
Waimea Stream at Mandeville	1990-2011	0.43	398	269	115
Waihopai River at Kennington	1990-2011	0.44	154	547	241
Waikaka Stream at Willowbank	1990-2011	0.49	318	323	159
Mokoreta at McKays Road	1990-2011	0.55	418	730	400
Mataura River at Parawa	1990-2011	0.63	801	709	443
Makarewa River at Counsell Road	1990-2011	0.45	991	478	218
Waituna Creek at Marshall Road	2001-2011	0.48	108	493	237

1.2. Classification of Springs and Spring-Fed Streams

Given the varying contribution of baseflow to different catchments, it is often difficult to differentiate between streams that are spring-fed (i.e. have a dominant groundwater influence) from those more influenced by quickflow. As part of the Regional Water Plan process, Environment Southland developed criteria to identify whether a particular waterway can be characterised a spring-fed. These criteria include:

- **Discharge** - the Brightwater Spring near Garston is the largest recorded spring in the Southland Region carrying a relatively stable discharge which has never been recorded in excess of 1,900 L/s. Streams with a discharge greater than 1,900 L/s are therefore considered as likely to be dominated by quickflow.

- **Ratio of median flow to mean annual low flow**. Streams which are dominated by baseflow discharge tend to exhibit relatively stable flows year-round while discharge in quickflow dominated streams tends to be more variable, both due to runoff during rainfall events and minimal baseflow discharge during dry periods. Reflecting this variable discharge, the criteria selected to identify spring-fed streams is where the ratio of median flow to Mean Annual Low Flow (MALF) is less than 1.5.
- **Seasonal water temperature variation**. Modelling work by Environment Southland staff has shown that as the baseflow contribution increases, the annual variation in water temperature decreases. The two water temperature criteria used to classify spring-fed streams are:
  - Where the annual temperature range is less than 8 degrees Celsius; and
  - Where the mean daily water temperature in July is 3 or more degrees Celsius higher than the ambient air temperature

2. Existing Spring Gauging Programme

2.1. Programme Overview

The first formalised monitoring of spring-fed stream discharge in the Southland Region was initiated in the mid-1990's as part of investigations undertaken for the Oteramika Trial Catchment Project. This monitoring involved semi-regular measurement of discharge in four spring-fed streams draining the Edendale groundwater zone between 1995 and 1998. Following completion of this project no specific monitoring of spring-fed streams was undertaken until 2000 when irregular gaugings on the major spring-fed streams commenced as part of investigations to improve definition of the extent and magnitude of groundwater/surface water interaction across the Region.

In 2002 a specific spring discharge characterisation programme was formally initiated as part of a wider programme to improve characterisation of the Regions water resources. The specific objective of the programme was to:

'*Improve knowledge of groundwater contribution to baseflow in rivers and streams in Southland and improve definition of catchment-scale water balance in the Regions major aquifer systems*'[3]

Specific tasks identified within this project included to:

- *Identify major spring discharges in Southland e.g. Clear Creek, McKeller Stream etc (if necessary include field visits/survey and record data on field sheets)*
- *Identify areas where baseflow is controlled by groundwater discharge e.g. Central Plains, Winton*
- *Catalogue available gauging information on spring-fed streams*
- *Classify known springs and groundwater discharges according to discharge volume/type etc (see Canterbury Regional Council Report U98/7)*
- *Group streams according to known baseflow/discharge characteristics (e.g. correlation with existing flow recorders, specific discharge etc).*

This programme established a semi-regular gauging of the major spring-fed stream systems primarily aimed at quantifying baseflow contribution in the Mataura and Oreti catchments. Flow measurement was largely restricted to nominated gauging sites with limited resources devoted to field investigations to identify and characterise springs generally in response to specific resource consent applications.

Over time the spring-gauging programme has been incorporated into the wider Environment Southland State of the Environment (SOE) monitoring programme with a slight change in emphasis (certainly implied if not directly stated) from water resource characterisation, to monitoring of springs as an indicator of the condition of the contributing groundwater resource.

With greater resourcing since the mid-2000's in response to increased pressure on the Regions water resources, data available to characterise discharge in springs and spring-fed streams has increased significantly as part of general water resource investigations or specific investigation/monitoring programmes, with either regular or spot gauging data now available from upwards of 50 sites that may be characterised as either springs or spring-fed streams.

[3] Environment Southland internal project plan EMGRD3 2001/02

It is noted that automatic flow monitoring sites established on the Meadow Burn (at several locations) and Murray Creek operated for a relatively limited period due to the effect of macrophyte growth during the spring to autumn period which made maintaining a reliable stage/discharge relationship very difficult, if not impractical. This issue is common to most spring-fed streams and is the main reason why spring flow measurement is solely restricted to manual gaugings.

Figure 4 shows the location of sites gauged on a regular basis as part of the current (2011/12) spring gauging programme.

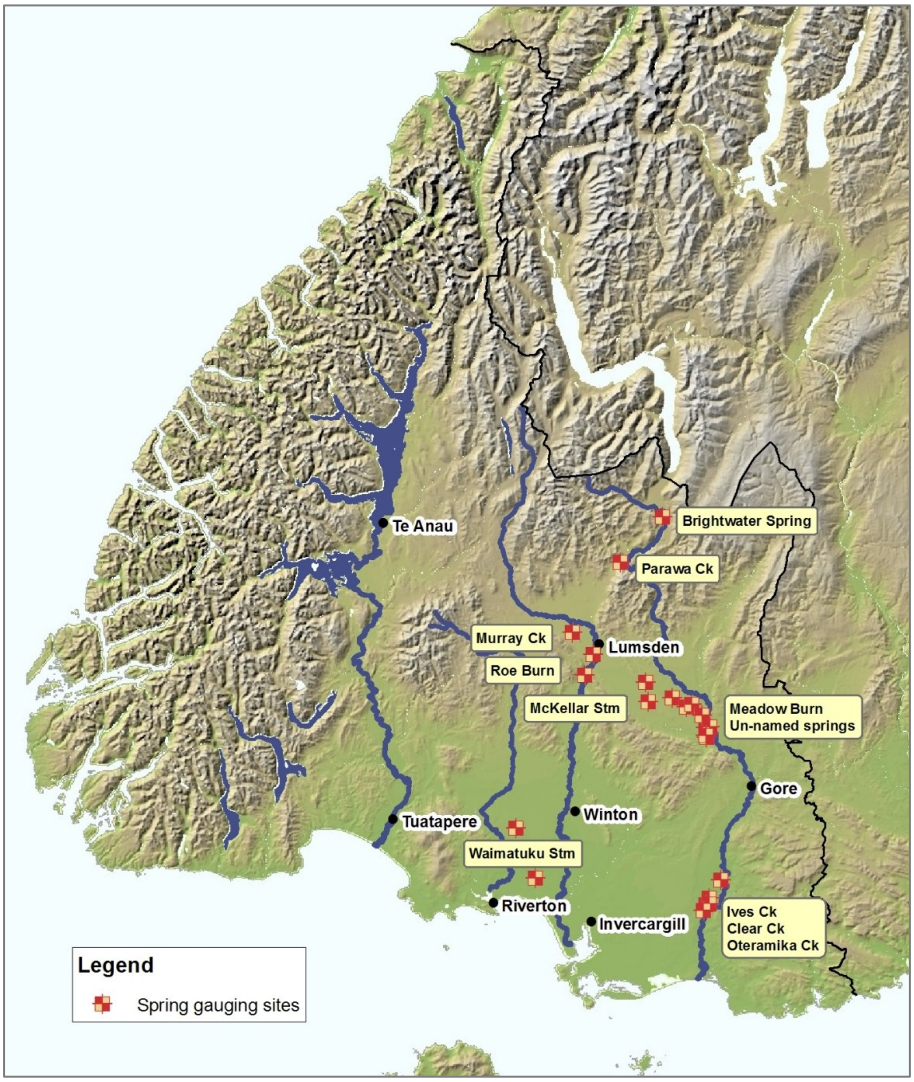

Figure 4. Gauging sites currently included in the Environment Southland spring gauging programme (Environment Southland, 2010)

In addition to sites gauged on a semi-regular basis for the formal spring gauging programme, a significant amount of gauging information has also been collected over recent years from a large number of springs and spring-fed streams as part of one-off or short-term investigations or other surface water monitoring programmes (e.g. the surface water low flow gauging programme and water balance concurrent gaugings). Many of these investigations have essentially served to scope the nature and magnitude of discharge in smaller spring-fed streams or were undertaken in response to localised issues (such as groundwater/surface water interaction in the vicinity of resource consent applications).

Figure 5 shows a plot of the location of spring and spring-fed streams for which ES currently holds some gauging information, along with potential spring sites identified during discussions with Southland Fish and Game and the Department of Conservation (which either have no gauging information or are yet to be investigated). Overall, the data show that, aside from springs located along the riparian margin of the Oreti River, Environment Southland currently holds flow information for a significant proportion of currently identified spring-fed streams in the Southland Region. The following section provides a brief overview of the available data.

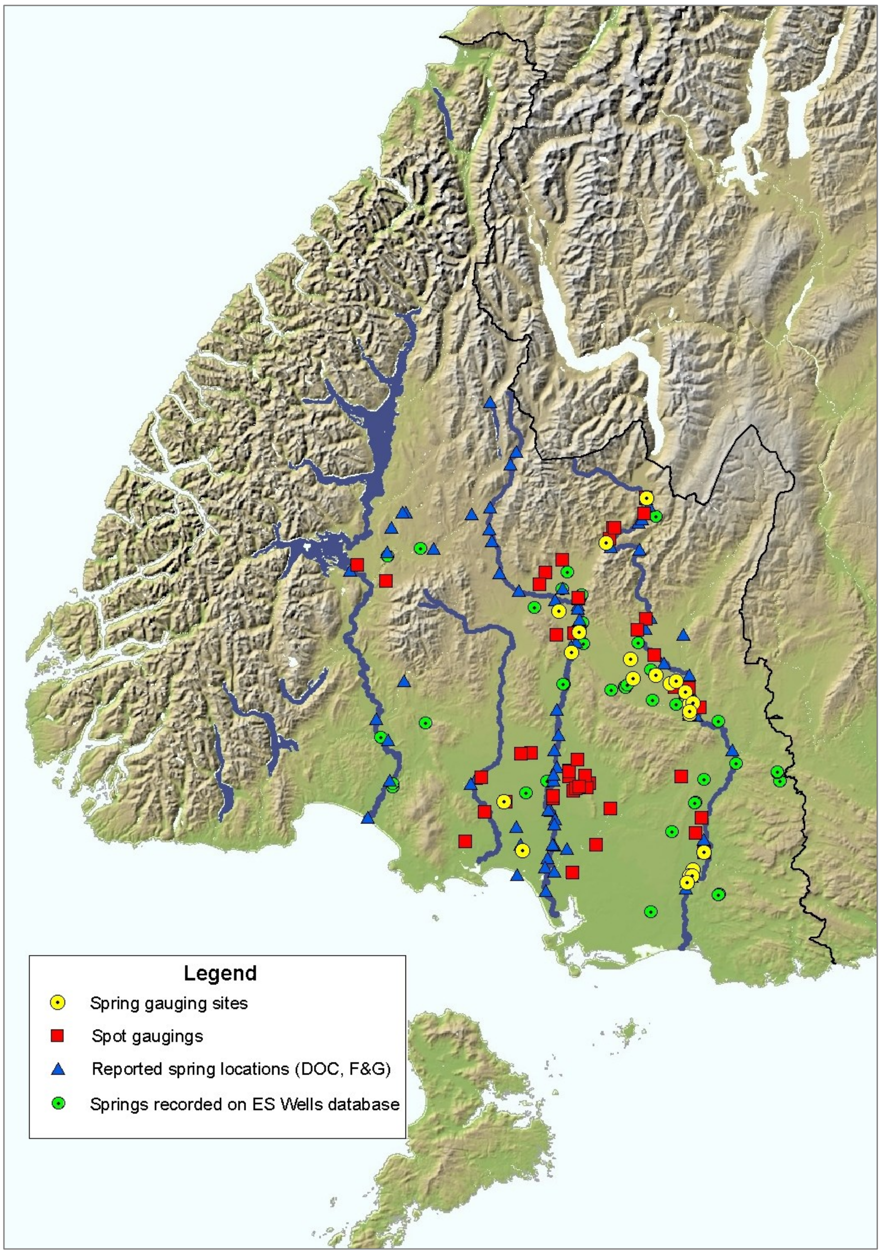

Figure 5. Location of springs and spring-fed streams monitored as part of the wider Environment Southland spring gauging programme along with the recorded spring locations

2.2. Overview of gauging programme

Over time sites included in the spring gauging programme have evolved due to a combination of factors including:

- The physical environment of individual sites (site access, suitability of channel profile, macrophyte growth etc);
- Analysis of gauging results (e.g. where gauging results are well correlated between sites) and;
- Changing priorities for information to better define aquifer water balance or groundwater/surface water interaction in particular areas (particularly with regard to assessment of resource consents).

Table 2 provides an overview of the data set available from the primary sites that have been included in the spring gauging programme since 2000. These data show a significant number of sites have a monitoring record exceeding 40 individual flow measurements over the period 2000 to 2012. The overall data set comprises approximately 1,175 gaugings from the 25 sites listed (an average of approximately 50 gaugings per site).

The data (in combination with gaugings undertaken for the water balance concurrent gauging programme) show that a number of the spring systems monitored carry appreciable baseflow discharge, particularly in their lower reaches. The Brightwater Spring is the largest recorded spring in Southland with a median discharge of approximately 1,640 L/s. Other significant spring-fed streams include the Meadow Burn (median discharge of 640 L/d at Round Hill Road), the lower reaches of Oteramika Stream (680 L/s at McCall Road), Murray Creek (420 L/s at Double Road), the Roe Burn (580 L/s at the Oreti confluence) and Parawa Creek (420 L/s at Five Rivers-Athol Highway). To illustrate the potential significance of spring discharge in terms of overall catchment water balance (particularly during periods of low flow), the combined discharge of springs routinely monitored in the mid to upper Mataura catchment is roughly equivalent to 20 percent of the mean annual low flow (MALF) recorded in the Mataura River at Gore.

As discussed in the previous section, the spring flow data set from the primary gauging sites is augmented by gauging results from a significant number of one-off, short-term and specific flow investigations undertaken in numerous springs and spring-fed streams distributed across the Southland Region. Many of these gaugings are undertaken for the regional low flow gauging programme[4] but serve to compliment data from the spring gauging programme. Examples of the data set available from these sites include McKellar Stream (71 gaugings from 11 sites), Quoich Creek (10 gaugings from 2 sites), Stag Stream (42 gaugings from 4 sites) and Flaxy Creek (18 gaugings from 4 sites). When these gaugings are included, the cumulative gauging data set is estimated to increase to in excess of 1,500 individual flow measurements.

Given the large spring flow data set, the following section provides example analysis to assist a review of the existing spring gauging programme in its current form.

[4] This gauging programme is undertaken during periods of low flow in order to better characterise surface water flow characteristics (i.e. MALF, specific discharge etc) in smaller tributary streams across the Southland Region

Table 2. Summary of data available from the spring gauging monitoring programme sites (2000 to 2012)

Spring Grouping	Gauging Site	Number of Gaugings	Median Discharge (m^3/s)	Currently Monitored
Riversdale	Meadow Burn at Round Hill Road	113	641	Yes
	Meadow Burn at Fingerpost-Pyramid Road	72	161	Yes
	Meadow Burn at Stock Bridge	40	187	Yes
	Meadow Burn at York Road	68	34	Yes
	Spring at Fingerpost-Pyramid Road	30	62	No[a]
	Spring at Mandeville-Riversdale Highway	29	55	No[a]
	Spring 1 at Kingston Crossing-Mandeville Road	24	43	No[a]
	Spring at Tayles and Fingerpost-Pyramid Road	26	102	No[a]
	Total	**402**		
Edendale	Spring at Shield Road	42	37	Yes
	Oteramika Stream at McCall Road	39	677	Irregular
	Ives Creek at Island Edendale Road	41	247	Irregular
	Clear Creek at Mataura Island Road	78	297	Yes
	Clear Creek at Settlement Stalker Road	40	19	Yes
	Ota Creek at Coal Pit Road	8	47	Irregular
	Total	**240**		
Castlerock	Murray Creek at Edward Road	38	40	Yes
	Murray Creek at Double Road	75	418	Yes
	Roe Burn at Sutherland Road	22	20	No
	Roe Burn 80m u/s Oreti Confluence	19	584	Yes
	Total	**154**		
Upper Mataura	Parawa Creek at Five Rivers-Athol Highway	65	418	Yes
	Brightwater Spring u/s Mataura Confluence	73	1,638	Yes
	Total	**138**		
Waimea Plains	Longridge Stream at Balfour-Ardlussa Road	37	22	Yes
	Longridge Stream at Orr Road	45	138	Yes
	Total	**82**		
Central Plains	Waimatuku Stream at Robertson Road	55	51	Yes
	Waimatuku Stream at Wallacetown Highway	75	1,184	Yes
	Bog Burn at Winton-Spar Bush Road	21	93	No
	Total	**151**		
	Cumulative Total	**1,175**		

2.3. Evaluation of Monitoring Results

2.3.1. Quantification of baseflow discharge

Figure 6 shows a plot of gauging results from Brightwater spring and Parawa Creek in the Upper Mataura catchment. The data illustrate the limited flow variability observed in Brightwater Spring, with flow varying between 1,450 and 2,140 L/s in the 73 gaugings undertaken between 2001 and 2012. Flow variability at this site is tightly constrained ranging from -12% to +30% percent of the median discharge (1,640 L/s), reflecting the dominance of baseflow discharge in this stream.

Flow gaugings from Parawa Creek exhibit greater flow variability with a baseflow generally of the order of 300 to 800 L/s but interspersed higher discharges exceeding 2,000 L/s (typically during winter). The increased flow variability in this stream is interpreted to reflect the relatively stable baseflow discharge from the main channel which drains the central area of the Upper Mataura Valley, augmented by surface runoff from smaller tributaries draining the surrounding hills during the winter months. Analysis of the available gauging results indicates flow variability in Parawa Creek ranges from -49% to +400% of the median flow of ~550 L/s.

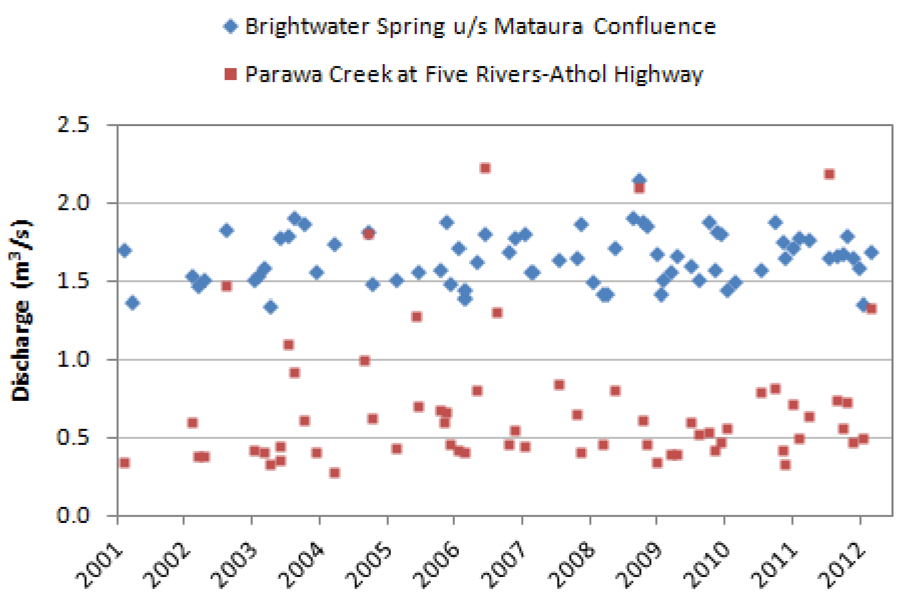

Figure 6. Gauging results from Brightwater Spring and Parawa Creek, Upper Mataura catchment.

Figure 7 shows a plot of measured discharge in two spring fed streams draining the Edendale groundwater zone in the Seaward Downs area. Again, baseflow and flow variability are relatively tightly constrained:

- Clear Creek at Mataura Island Road - 78 gaugings, flow variability -29% to +41% of median flow (325 L/s)
- Spring at Shield Road - 42 gaugings, flow variability -57% to +89% of median flow (37 L/s)

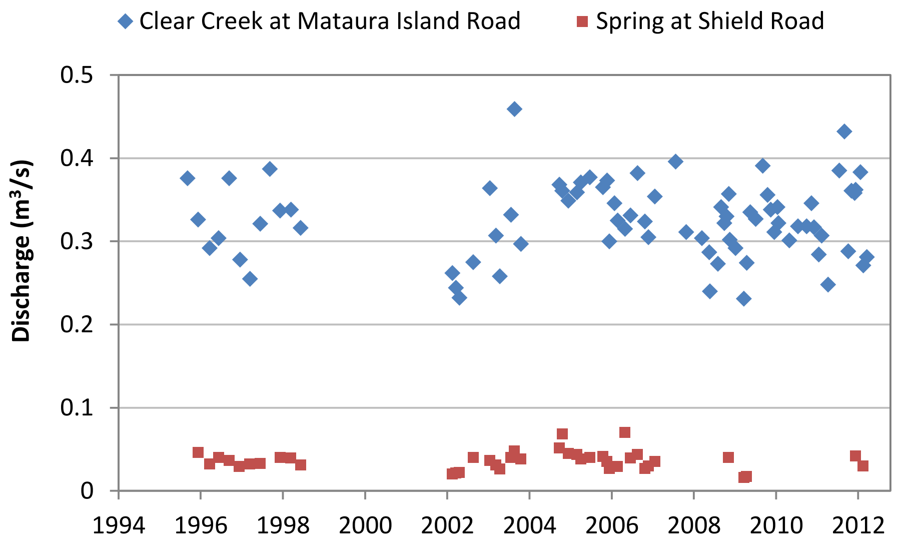

Figure 7. Gauging results from Clear Creek and Spring at Shield Road, Seaward Downs

Gauging sites included in the current spring gauging programme generally exhibit flow variability similar to that observed in the Edendale springs (typically minimum and maximum flow are within approximately +/- 50 percent of the median flow) so baseflow discharge in a majority of these streams is relatively well defined. As a result, the current spring gauging programme can be considered as having essentially achieved its initial objective of quantifying groundwater discharge (within natural variability) in the major spring-fed streams in the Southland Region.

Given the natural variability of observed streamflow is unlikely that ongoing monitoring of these streams will serve to significantly improve baseflow discharge estimates in these streams. It is therefore concluded that:

- ***The existing spring gauging programme has essentially achieved its initial objective of quantifying baseflow discharge (allowing for natural variability) in the major spring-fed stream systems included in the current monitoring programme.***

2.3.2. Springs as groundwater quantity indicators

Since approximately 2005 the spring gauging programme has been incorporated into the wider Environment Southland SOE monitoring programme as an indicator of groundwater quantity. However, due to the natural variability of stream discharge, the resulting data set does not lend itself to statistical trend analysis in the same way as groundwater level monitoring. For example, analysis of spring-fed stream discharge undertaken for the 2011 *Our Uses* SOE Report (Environment

Southland, 2011) identified a statistically significant trend in only 1 out of the 21 sites analysed (~5%) compared to the 36% of the 93 groundwater level monitoring sites analysed.

Given the amount of spring gauging information available the relative level of resourcing required to undertake stream gauging compared to groundwater level monitoring, it would appear reasonable to conclude that:

- ***Spring discharge is a relatively poor indicator for assessing groundwater quantity state and trends***

It is therefore suggested that future assessment of state and trends in groundwater quantity be primarily focussed on groundwater level monitoring, with spring gauging information utilised to help quantify the magnitude of any associated environmental effects. This monitoring is particularly useful in situations where changes in groundwater storage have occurred over time in response to resource development. For example, information on temporal changes in flow in the Meadow Burn in response to an apparent decline in summer minimum groundwater levels formed a central part of Environment Southland's successful defence of its decision to decline further applications for groundwater abstraction from the Riversdale groundwater zone through the Environment Court appeals process[5].

2.3.3. Relationships between spring discharge and other environmental variables

The rate of groundwater discharge to springs and spring-fed is driven by the head difference between water level in the source aquifer and stage height in the spring or stream. Allowing for the different quickflow contribution in different catchments, discharge in these waterways generally tracks temporal variations in groundwater levels. **Figure 8** shows a plot of measured discharge in Murray Creek at Double Road and groundwater levels measured in an Environment Southland monitoring bore (E44/0198) located on Sutherland Road (located approximately 12 kilometres west of the Double Road gauging site) illustrating how stream discharge generally tracks seasonal variations in groundwater level.

[5] Environment Southland v South Otago Holdings (ENV-2009-CHC-102)

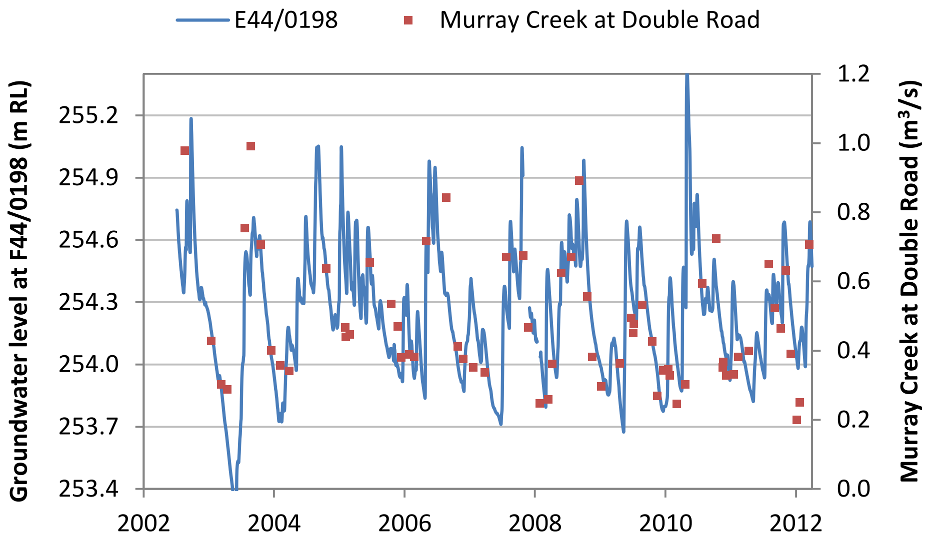

Figure 8. Groundwater level in the Castlerock groundwater zone at F44/0198 and measured discharge in Murray Creek at Double Road

Figure 9 shows the observed correlation (R^2 = 0.48) between E44/0198 and Murray Creek at Double Road. This relationship shows groundwater levels at this location are moderately well correlated with discharge in Murray Creek.

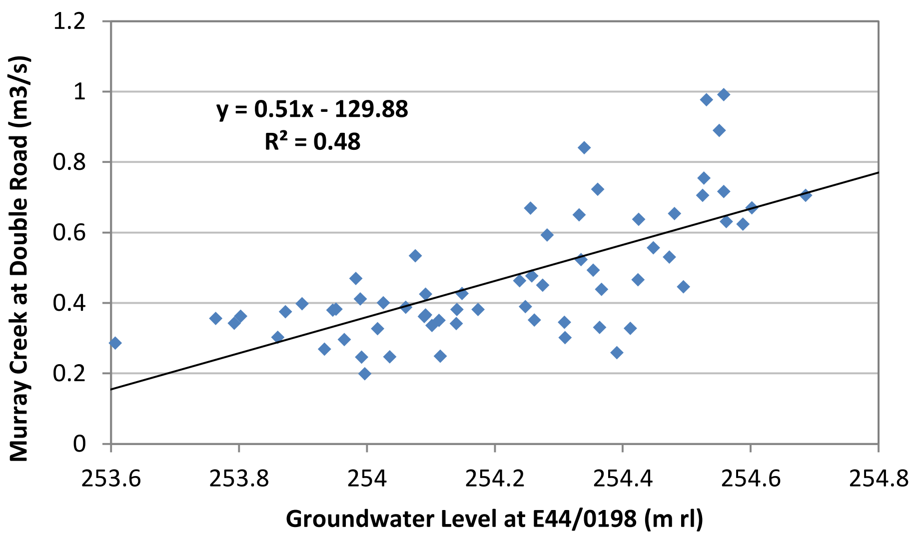

Figure 9. Linear correlation between groundwater levels at F44/0198 and discharge in Murray Creek at Double Road

A similar inter-relationship is observed between groundwater levels and spring or spring-fed stream flow in a majority of sites included in the current spring-gauging programme. Observed linear correlation coefficients (i.e. R^2 values) vary between 0.4 and 0.9, largely depending on factors such as relative locations of groundwater level monitoring and spring gauging sites, localised effect of pumping and/or well interference and the individual quickflow characteristics of the spring or spring-fed stream catchment. It is noted the best correlations with groundwater level (R^2 values greater than 0.7) are typically observed in streams such as the Brightwater Spring and the Meadow Burn which are sourced from highly permeable aquifers (i.e. where groundwater levels vary almost simultaneously across the entire aquifer system) which receive limited quickflow input.

Overall, available gauging data indicate that a majority of springs and spring-fed streams exhibit a moderate to good correlation to groundwater levels in the source aquifer or discharge in nearby rivers or streams. As a consequence it is reasonable to conclude that were sufficient data exists:

- ***Groundwater levels or measured stream flow can be utilised (depending on hydrogeological setting) as a means to estimate discharge in springs and spring-fed streams (within appropriate error bounds).***

Utilising groundwater levels as a proxy for physical measurement of discharge in springs and spring-fed streams has a number of potential advantages including:

- Measurement of groundwater levels in the Region's main aquifer systems is already a well established SOE monitoring programme which requires comparatively lower resources that are required for physical flow measurements; and
- Groundwater levels monitoring can be automated allowing a semi-continuous record of stream discharge to be established

However, correlation between groundwater levels and spring discharge also need allow for potential scatter resulting from localised effects on groundwater levels (e.g. pumping or well interference effects) and differences in the timing of groundwater level and stream discharge measurements (particularly when utilising manual groundwater level measurements).

When considering utilisation of groundwater levels one question that needs to be considered is how much gauging data is required to establish a reliable correlation between groundwater levels and spring discharge. To address this issue **Figure 10** and **Figure 11** below show examples of the observed groundwater/spring discharge correlations for Murray Creek at Double Road and the Meadow Burn at Fingerpost-Pyramid Road sites using both the entire data set and a subset of the available data (~50% of available flow gaugings) for each site. In both cases it is relatively clear that collection of additional gauging data does not serve to significantly alter correlations undertaken using a more limited data set. This suggests that at sites with multiple existing gaugings:

- ***Continuation of the existing spring gauging programme is unlikely to significantly improve existing correlations between groundwater levels and spring or spring-fed stream discharge***

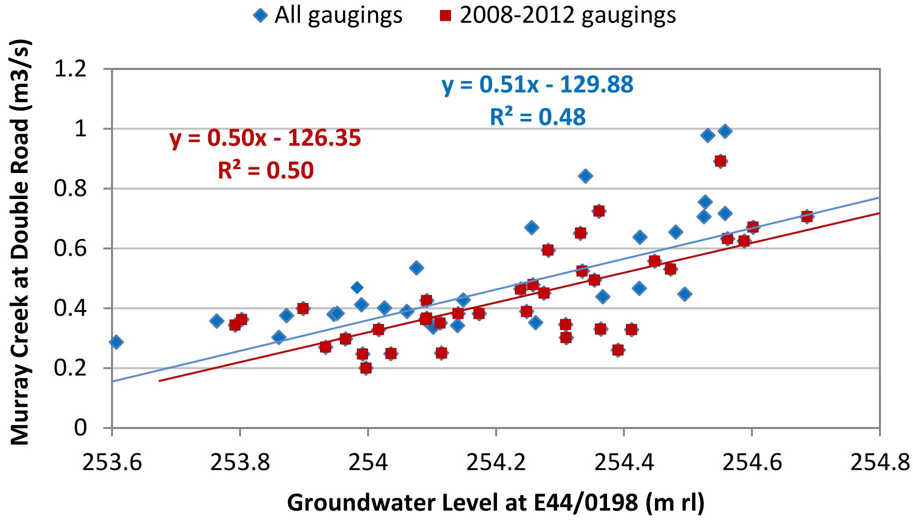

Figure 10. Correlation between groundwater levels at E44/0198 and gauged discharge in Murray Creek at Double Road using varying proportions of the available data

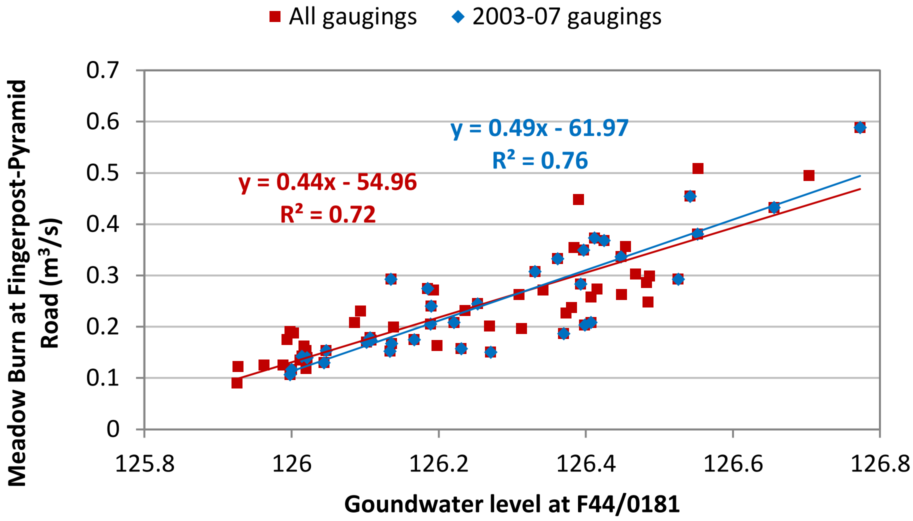

Figure 11. Correlation between groundwater levels at F44/0181 and gauged discharge in the Meadow Burn at Fingerpost-Pyramid Road using varying proportions of the available data

In addition to correlation with groundwater levels in the source aquifer, some stream gauging sites exhibit relatively good relationships with baseflow discharge in nearby rivers and streams, particularly when high flow data is excluded. For example, as shown in **Figure 12** below, gauged discharge in the Meadow Burn at Fingerpost-Pyramid Road and flow recorded in the Waimea Stream exhibit a relatively good correlation, particularly during moderate to low flow periods (in fact the observed correlation may be better than that observed with groundwater levels where catchments share similar baseflow characteristics)[6].

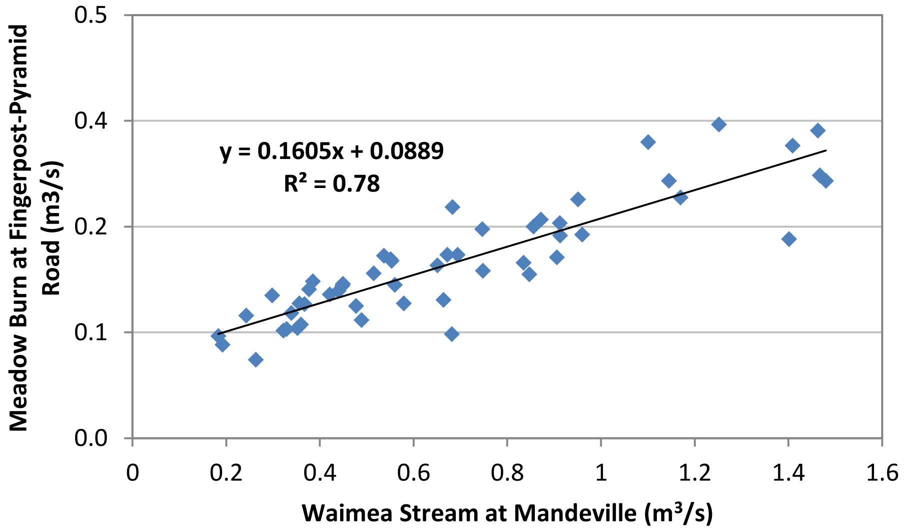

Figure 12. Correlation between gauged flow in the Meadow Burn and flows less than 1.5 m³/s recorded in the Waimea Stream at Mandeville

Similarly, as groundwater levels across an aquifer system generally vary in a relatively consistent manner (excepting localised drawdown effects associated with abstraction) baseflow discharge in springs and spring-fed streams draining the aquifer system are also typically well correlated. For example, as illustrated in **Figure 13**, a relatively good correlation is observed between discharge in individual spring-fed springs draining the Riversdale groundwater zone.

[6] It is also noted that the change in downstream discharge between concurrent gauging locations in spring-fed streams often exhibits a very good correlation with groundwater levels in the source aquifer. At the current time the Meadow Burn is the only spring-fed stream having with multiple sites regularly gauges as part of the spring monitoring programme

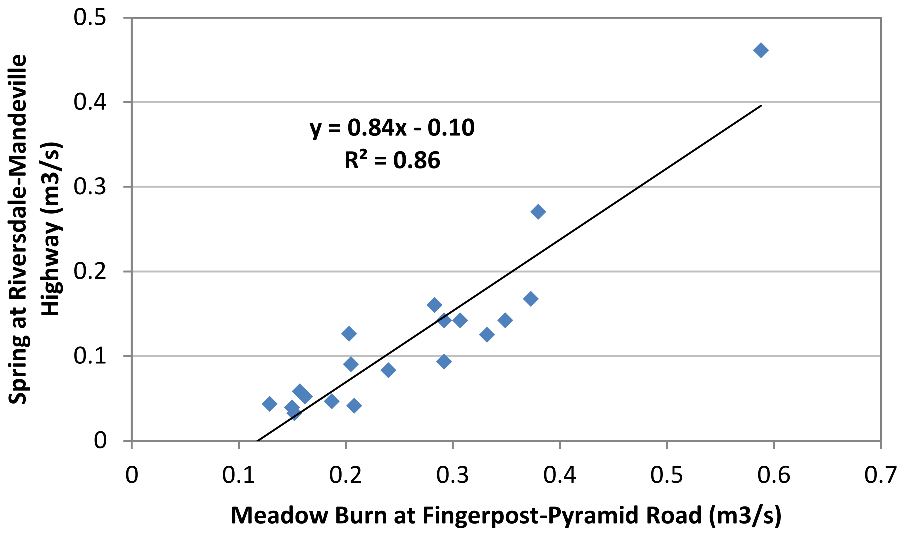

Figure 13. Correlation between measured discharge in the Meadow Burn at Fingerpost-Pyramid Road and Spring at Riversdale-Mandeville Highway

While this report has not attempted to assess the entire spring gauging data set, it is relatively clear from the analysis undertaken that discharge in springs and spring-fed streams can be correlated with groundwater levels in the source aquifer, baseflow discharge in nearby streams and discharge in other streams draining the same aquifer (depending on the characteristics of each hydrogeological/hydrological setting). It is therefore concluded that:

- ***Detailed hydrological analysis of the available data set will enable significantly improved characterisation of both temporal and spatial discharge in springs and spring-fed streams and improve understanding of overall baseflow contribution to surface water flows***

2.3.4. Hydrological Investigations

While the existing spring gauging programme has been largely successful in providing data to assist the characterisation of the overall contribution of major springs to the water balance in major catchments, uncertainty remains with regard interaction between groundwater and surface water in these systems on a local scale. Such information is often very important in the day-to-day management of groundwater and surface water resources, particularly regarding potential effects of water abstraction and overall resource management (including surface water quantity investigations and minimum flow setting).

Over recent years a series of investigations including concurrent gaugings, streambed conductance surveys and measurements of relative head difference have been undertaken on streams in the Riversdale groundwater zone (including McKellar Stream and the Meadow Burn). These investigations have significantly improved knowledge and understanding of the dynamic interaction between groundwater and spring-fed streams in this area.

So, while the existing spring gauging programme has largely quantified the contribution of major springs and spring-fed streams to catchment water balance in many areas of Southland, there remains considerable uncertainty regarding local-scale interactions between groundwater and surface water in these streams. It is therefore suggested that:

- ***Future work programmes should include greater emphasis on investigations designed to characterise local-scale interactions between groundwater and surface water in springs and spring-fed streams particularly in sensitive environments or where pressure associated with resource development is greatest***

3. Summary and Recommendations

Due to their unique flow variability and water quality characteristics springs and spring-fed streams form a unique and highly valued component of Southlands aquatic environment. In addition, given their location at the interface between the groundwater and surface water environments, springs also have significant value in terms of characterising the potential magnitude of effects resulting from changes in groundwater storage (i.e. levels) in the source aquifer due to climate variability and abstraction.

Ad-hoc monitoring of discharge in Southlands major spring systems commenced in 2000. In 2002 a specific spring gauging programme was formally initiated with the overall aim of '*improving knowledge of the groundwater contribution to rivers and streams in Southland and definition of catchment-scale water balance*'. Over time the spring gauging programme was incorporated into the wider Environment Southland SOE monitoring programme as an indicator of the water quantity condition in the source aquifer system.

Between 2000 and 2012 the spring gauging programme has involved semi-regular flow measurements undertaken at nominated points within the major spring systems, with the frequency of monitoring increasing during periods of low rainfall. This monitoring programme is supplemented by a large number of one-off or ad-hoc gaugings undertaken in a large number of springs and spring-fed streams as part of other Environment Southland monitoring and investigation programmes including water balance concurrent gaugings, water quality studies, habitat studies and the surface water low flow gauging programme which are not included within the direct scope of this review). Cumulatively, the current spring gauging data set comprises in excess of 1,500 individual flow measurements. In light of the amount of gauging information available, this review was initiated to consider potential future options for the spring gauging programme.

In terms of the primary objectives of the spring gauging programme the following conclusions are reached from a review of the available data:

- The existing data set from regularly gauged sites is sufficient to reliably characterise (given natural variability) the magnitude of discharge in the Regions major springs and spring-fed streams;
- Due to inherent natural variability, discharge in springs and spring-fed streams is a relatively poor indicator of groundwater quantity and trends state in source aquifers;
- Discharge in a majority of springs and spring-fed streams can be correlated either with groundwater levels in the source aquifer or baseflow measured in rivers and streams. This enables spring discharge to be estimated with a reasonable degree of reliability using data derived from existing groundwater level or flow monitoring sites (although flow estimates derived from such correlations will inevitably have relatively significant error bounds);
- Analysis of available data suggests continued monitoring of existing sites is unlikely to significantly improve estimates of baseflow discharge or correlations with groundwater level/stream discharge able to be derived from the existing data set;
- Monitoring of spring-fed stream discharge has enabled quantification of the potential magnitude of environmental effect associated with groundwater abstraction in particular hydrogeological settings (e.g. the Meadow Burn).

Given these findings it is recommended the existing spring gauging programme can be significantly modified to better achieve the overall programme objectives associated with water resource characterisation and SOE monitoring. This could include a scaling back of the existing monitoring programme and re-deployment of resources to specific investigations. This may include:

- In the short term, a detailed assessment of the available data to identify and document groundwater level, stream flow and inter-spring correlations that can be utilised to estimate spring and spring-fed stream discharge as a proxy for physical flow measurements. The assessment may identify a sub-set of existing monitoring sites where a continuation of existing monitoring is justified (such as highly valued/sensitive stream environments or springs and spring-fed streams draining aquifer systems which exhibit a statistically significant declining groundwater level trend or where additional monitoring data could improve the resolution of either flow variability or proxy correlations). Continued monitoring of spring-fed streams may also be a lowest cost option where limited alternative data exists to correlate with spring discharge;
- Investigations to determine the value of utilising water quality monitoring in springs and spring-fed streams as an indicator of overall groundwater quality in the source aquifer and its associated impact on surface water quality. Any such investigations should be integrated with other Environment Southland water quality monitoring and investigations programmes (in reality this is process is already occurring outside of the scope of the spring gauging programme);
- Redeployment of monitoring to enable groundwater level/streamflow correlations to be extended to springs and spring-fed streams that either have insufficient data at the current time to quantify baseflow discharge or which have not been included in monitoring undertaken to date[7]. This could involve incorporation of sites currently included in the water balance concurrent gauging programme into the more regular spring gauging programme;
- Where appropriate, further investigations should be undertaken to better characterise local-scale groundwater/surface water interactions in spring-fed streams utilising concurrent gaugings, mini-piezometers, water temperature/quality/isotope investigations.

[7] It is noted that gaugings should be undertaken at well defined locations and as far as possible integrated with other monitoring (e.g. timed to approximately coincide with groundwater level measurements or undertaken concurrently with other flow measurements undertaken in the same spring system)