# Aquifer Dynamics and Resilience Review

Technical publication No. 12-001

January 2012

MARLBOROUGH
DISTRICT COUNCIL

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MDC Technical Report No: 12-001

File Reference/Record No: E345-002-001/126540

January 2012

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Acknowledgements: Amy Nicholson (MDC) for the data collection and to Paul White (GNS Science) for making the revisions.

# Executive Summary

The following attributes were used to compare the dynamics and resilience of the main economically or ecologically important aquifers in Marlborough:

1. *Groundwater outflow: stream baseflow versus quickflow*
2. *Groundwater outflow: stream flow stability during drought*
3. *Aquifer storage volume*
4. *Groundwater inflow using surface water baseflow as a proxy*

Aquifers were ranked as high, medium or low based on each of these parameters which in turn were combined to form an overall resilience rating.

*General characteristics of three classes of aquifer resilience include:*

- *high resilience where high inflows and high outflows mean that the aquifer is supporting flow in groundwater-fed streams that is relatively uniform over time. These aquifers store a large amount of groundwater*
- *medium resilience where the aquifer is supporting flow in groundwater-fed streams that is relatively variable over time. These aquifers store a moderate amount of groundwater*
- *low resilience where the aquifer is supporting highly variable spring-fed streams and aquifer storage is low*

The results provide a starting point for assessing which water allocation method is best suited to the physical attributes of each groundwater resource in Marlborough. Management approaches should take advantage of natural limitations or opportunities in the reservoir characteristics of individual aquifers. Key management considerations for the three classes of aquifer resilience could include:

- *high resilience aquifers where maintenance of groundwater-fed stream flow is a priority*
- *medium resilience aquifers where maintenance of groundwater-fed stream flow and management of storage are priorities*
- *low resilience aquifers where management of groundwater use is very important because these aquifers have low inflows and low storage*

# Contents

# 1. Introduction

Marlborough District Council (MDC) is reviewing the water components of the District Plan and as part of this process hydrology staff have been tasked with preparing technical reports to identify management options for the Council.

The aim of this report is to rank the resilience of economically or ecologically important groundwater systems as a contribution to the assessment of water resource management approaches for Marlborough aquifer systems. In this report, aquifer resilience is the inherent ability of the aquifer to sustain groundwater water volumes and groundwater budget components (e.g. groundwater flows and spring flow discharging from the aquifer) in natural droughts.

Aquifer systems are ranked by four criteria: groundwater outflow to streams with an assessment of stream baseflow versus quickflow, groundwater outflow to streams with an assessment of stream flow recession rates during periods of low rainfall, estimates of aquifer volume and groundwater inflow from streams with an assessment of surface water baseflow during droughts. In addition groundwater flow budgets considering rainfall recharge and surface water recharge to groundwater were recommended by Paul White, the GNS Science reviewer; however more work is needed on the rates of rainfall and river recharge to groundwater before they are useful. Surface water baseflow was used instead as a measure of the reliability of recharge in droughts.

The resilience of each aquifer is ranked in this report as an index to allow comparisons across the Marlborough district. The resilience ranking is relevant to the maintenance of ground and surface water use as part of the review of water allocation policy. This report also discusses the implications of aquifer resilience rankings on groundwater and surface water management policies. Not all aquifers were included in the study because of a lack of information.

# 2. Aquifer resilience ranking

Aquifer resilience is the inherent ability of an aquifer to sustain groundwater volumes and spring flow discharges in natural droughts. Aquifer resilience is expressed as a ranking which is measured with the equation:

$$RI = BQ+HL+AV+WB$$

| | |
|---|---|
| RI | Overall aquifer resilience index, ranking |
| BQ | Groundwater outflow: stream baseflow/quickflow, ranking |
| HL | Groundwater outflow: half-life of stream flow recession, ranking |
| AV | Aquifer volume, ranking |
| WB | Groundwater inflow: surface water baseflow, ranking |

The calculation sums components, themselves rankings which are developed in the following sections. Individual components are expressed as a three-tiered ranking with the sum also expressed as a three-tiered ranking (Table 1).

**Table 1: Aquifer resilience index**

| Aquifer resilience index | Groundwater outflow: stream baseflow versus quickflow | Groundwater outflow: stream flow stability during drought | Aquifer storage volume | Groundwater inflow: surface water baseflow |
|---|---|---|---|---|
| High | 1 | 1 | 1 | 1 |
| Medium | 2 | 2 | 2 | 2 |
| Low | 3 | 3 | 3 | 3 |

The indices based on stream baseflow/quickflow and stream flow recession measure the relative importance of groundwater outflow to surface water flow. Aquifer volume is ranked with, for example, unconfined aquifers that cover a large area ranked as high, and confined aquifers that release small volumes of water for falls in well level ranked as low.

Groundwater inflow from rainfall and surface water is important to the maintenance of groundwater budgets during dry periods, so perennial or high inflows make for reliable groundwater reservoirs. In this report surface water baseflow is used as a proxy for groundwater inflow.

# 3. Groundwater outflow: stream baseflow versus quickflow

Typically, stream flow is a combination of base flow and quickflow. Base flow is provided by springs and seeps which are crucial to the maintenance of stream flow in dry periods. Quickflow is sourced from runoff.

Waterways in the Marlborough District include base-flow dominated streams such as Spring Creek, Fulton Creek and Waterlea Creek. These creeks are almost exclusively fed by springs and flow is relatively uniform over time (Table 2). In contrast, flow rates in streams that are dominated by quickflow are typically highly variable over time.

Flow statistics are used to identify the relative importance of baseflow and quickflow. The ratio of median flow (M) to mean flow (A) is close to one where streams are baseflow-dominated and much less than one where streams are quickflow-dominated.

The ratio M/A indicates that baseflow dominates stream flow for the following streams: Spring Creek, Fulton Creek, Waterlea Creek and Murphys Creek. Therefore the baseflow/quick flow ranking is one for these streams.

The baseflow/quick flow ranking is two for Mill Stream, Doctors Creek and Are Are Creek. This is because baseflow is between 60% and 90% of mean flow. The baseflow/quick flow ranking is three for Waikakaho River, Tuamarina River and Flaxbourne River because baseflow is 50% or less of mean flow.

**Table 2: Baseflow/quickflow ranking for some Marlborough streams**

| Stream | Median flow (M) $m^3$/sec. | Mean flow (A) $m^3$/sec. | M/A | Baseflow/quick flow ranking |
|---|---|---|---|---|
| Spring Creek | 4.05 | 4.1 | 1 | 1 |
| Fulton Creek | 0.315 | 0.325 | 1 | 1 |
| Waterlea Creek | 0.099 | 0.0975 | 1 | 1 |
| Murphys Creek | 0.819 | 0.814 | 1 | 1 |
| Mill Stream | 0.306 | 0.354 | 0.9 | 2 |
| Doctors Creek | 0.594 | 0.691 | 0.9 | 2 |
| Are Are Creek | 0.166 | 0.271 | 0.6 | 2 |
| Waikakaho River | 0.141 | 0.279 | 0.5 | 3 |
| Tuamarina River | 0.453 | 1.01 | 0.4 | 3 |
| Flaxbourne River | 0.073 | 0.788 | 0.1 | 3 |

# 4. Groundwater outflow: stream flow stability during drought

The rate of stream flow recession during dry periods indicates something of the nature of the groundwater reservoir that supplies flow to the springs:

- *slow recession rates may indicate that the groundwater catchment supplying spring flow has a relatively large reservoir or relatively large groundwater inflow*
- *fast recession rates may indicate that the groundwater catchment supplying spring flow has a relatively small reservoir, a relatively small groundwater inflow or relatively high proportion of groundwater use to groundwater inflow*

The flow recession of groundwater-fed streams and rivers and springs is compared for relatively dry conditions during the summer of 2009/2010 to assess the resilience of groundwater outflows when water demand is high. Summer rainfall in 2009/2010 was relatively low, corresponding to a 1 in 5 year event (Table 3).

**Table 3: Return period for summer rainfall in the period 2001 to 2010, Blenheim combined rainfall recorder site**

| Summer period | Summer rainfall (January, February, March in) (mm) | Return period[1] |
|---|---|---|
| 2001 | 19.6 | 70 |
| 2002 | 145.2 | 1.7 |
| 2003 | 65.7 | 7.8 |
| 2004 | 161.4 | 1.4 |
| 2005 | 177.6 | 1.3 |
| 2006 | 125.6 | 2.2 |
| 2007 | 79.6 | 5.4 |
| 2008 | 96.4 | 3.9 |
| 2009 | 118.6 | 2.3 |
| **2010** | **79.8** | **5** |

[1] Return period is calculated for the full period of record, 1942 to 2010.

Wairau Plain streams that demonstrate very slow flow recessions include Spring Creek, Fulton Creek, Waterlea Creek, Murphys Creek (Figure 1) showing that the Wairau Aquifer has a large storage to buffer flow against the variability of recharge. Mill Stream at Wairau Valley also has a slow recession rate.

By contrast flow in Doctors Creek and Are Are Creek fall more quickly, especially during the drier months after Christmas, which might reflect pumping as well as the natural process of groundwater drainage.

The highest rates of recession occur in the gravels of the Tuamarina River, Flaxbourne River and Waikakaho River. In the case of the Flaxbourne River and Are Are Creek, there were limited flow measurements for stable, dry conditions to fully define the recession rates and more record is needed under differing seasonal conditions. The slopes of the recession curve for the Waikakaho River, and to a lesser extent Doctors Creek and the Tuamarina River, have multiple slopes that steepen as conditions get drier. The rate of decrease of groundwater levels is not constant because the shape of these smaller aquifers is not uniform and there are boundaries which cause the rate of drainage to vary with time.

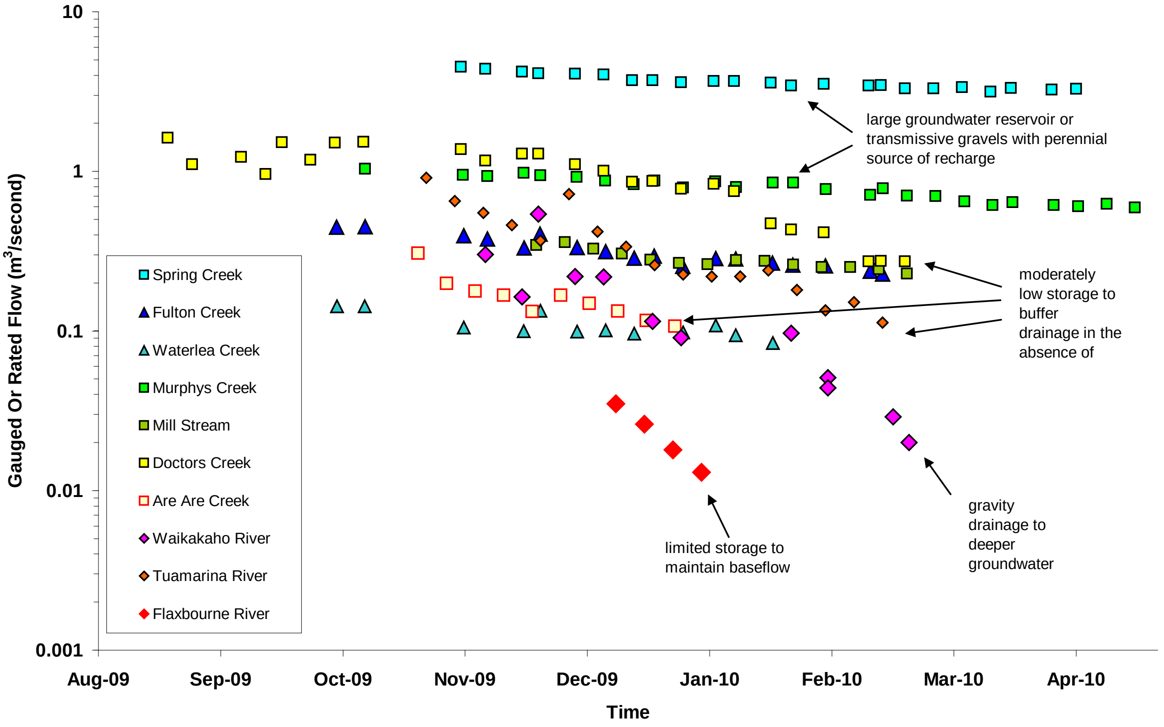

**Figure 1: Stream flow recession in the period 2009-10**

The shape of the individual flow recession curves appears reasonably unique. It probably reflects differences in geology, type of sediments forming the aquifer, water table slope and the depth to basement rock. Localised pumping can also have an effect on low flows, especially large takes such as the Picton public water supply near the Tuamarina River, and the Blenheim municipal supply wellfields.

The time it takes for surface flow to halve (the ‘half-life’) is an arbitrary way of quantitatively comparing differences in flow recession rates. Half-life of flow recession rates over as many summer seasons as possible were analysed, however the flow record is limited in some waterways, and not all summer seasons are suitable because dry conditions are not observed.

Only those summers with relatively stable baseflow were used in the analysis with wetter summers left out. There was limited record at some sites and more information is needed to confirm the initial estimates for the Flaxbourne River and Waikakaho River in particular.

Coefficient of variation (COV), i.e. the standard deviation of flows divided by the mean flow, is a measure of variability of flow.

The ranking of stream flow stability (Table 4) has:

- 1 = very slow recession and relatively stable flow over time
- 2 = slow recession and less stable flow over time
- 3 = relatively fast recession and relatively variable flow over time

**Table 4: Flow recession ranking for some Marlborough streams**

| Stream | Half life of flow recession (days) | Measure of flow variability (COV) | Stream flow stability ranking |
|---|---|---|---|
| Spring Creek | 243 | 0.136 | 1 |
| Fulton Creek | 181 | 0.211 | 1 |
| Waterlea Creek | 180 | 0.278 | 1 |
| Murphys Creek | 168 | 0.174 | 1 |
| Mill Stream | 140 | 0.547 | 2 |
| Doctors Creek | 65 | 0.634 | 2 |
| Are Are Creek | 54 | 1.393 | 2 |
| Waikakaho River | 40 | 1.432 | 3 |
| Tuamarina River | 42 | 1.656 | 3 |
| Flaxbourne River | 15 | 3.101 | 3 |

Around half the waterways are located on the Wairau Plain and are the most studied hydrologically with more flow gaugings than waterways farther afield. The half-life of flow in spring-fed streams associated with the Wairau Aquifer declines with distance from the Wairau River, which provides most of the recharge water and moderates climatic fluctuations. For example flow in Spring Creek has a much longer half life than flow in Murphys Creek.

This classification shows there is a physical difference between the groundwater resources of the northern and southern parts of the Wairau Aquifer. The un-named groundwater resources forming the lower terrace at Wairau Valley are also more resilient than expected based on the transmissivity of the gravels and their storage capacity. This infers a greater rate of groundwater inflow from the Southbank hill catchments than stream gaugings indicate.

Aquifer systems outside of the Wairau Plain have limited reservoir storage capacity as shown by short half-life of spring flow and relatively large COV. In the Tuamarina River Valley the most permeable sediments hosting the highest yielding aquifer are thin, so although it is located in a relatively high rainfall catchment compared to Blenheim, it is a less reliable aquifer in a drought. Flow in the Flaxbourne River takes only about 2 weeks to halve which shows that it has negligible storage in the gravels forming its bed.

More record is needed to confirm the half-life for flow in Are Are Creek. Experience suggests it may have been assigned an unrealistically high recession rate, possibly because it partially penetrates the alluvial gravels forming the aquifer.

The resilience of the coastal confined aquifers couldn’t be assessed at this stage because there are very few flow gaugings available for Roberts Drain, Pipitea wetland or the Marakoko Drain. In part this reflects the difficulties measuring the very slow velocities associated with the flat groundwater gradient, showing that spring flows are small. Because of the very low storage characteristics of the Wairau Aquifer Coastal Sector, this boundary area of the Wairau Aquifer is potentially one of the most sensitive to overpumping.

## 4.1 Stream flow stability rank = 1

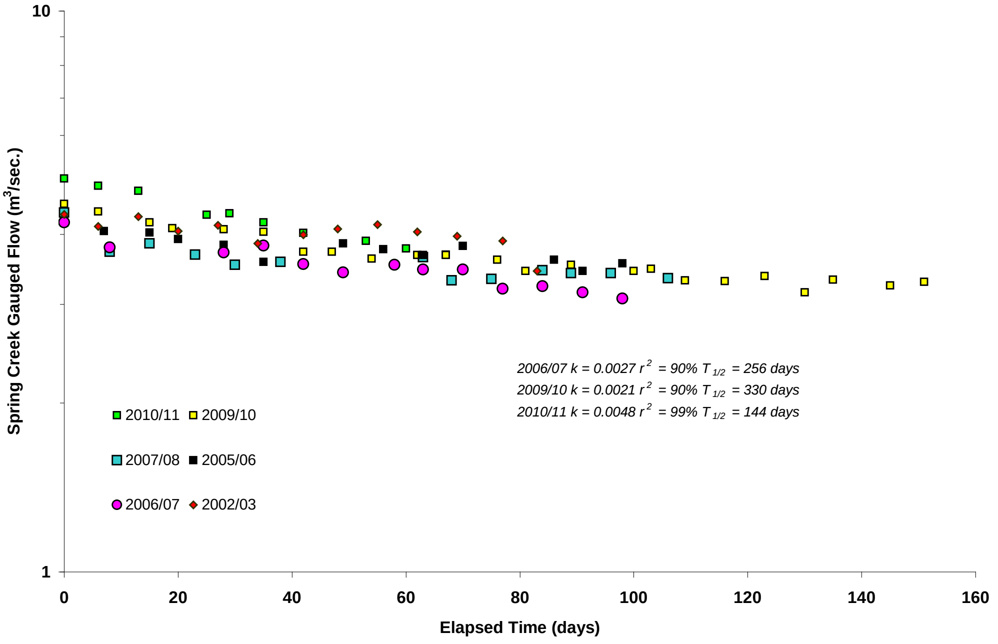

**Figure 2**: **Spring Creek flow recession**

Spring Creek flow (Figure 2) has the longest half life of any of the groundwater-fed springs with an average of 243 days (Table 4). This makes sense as Spring Creek is the closest to the Wairau River which is the ultimate source of spring recharge. Spring Creek flow is measured weekly.

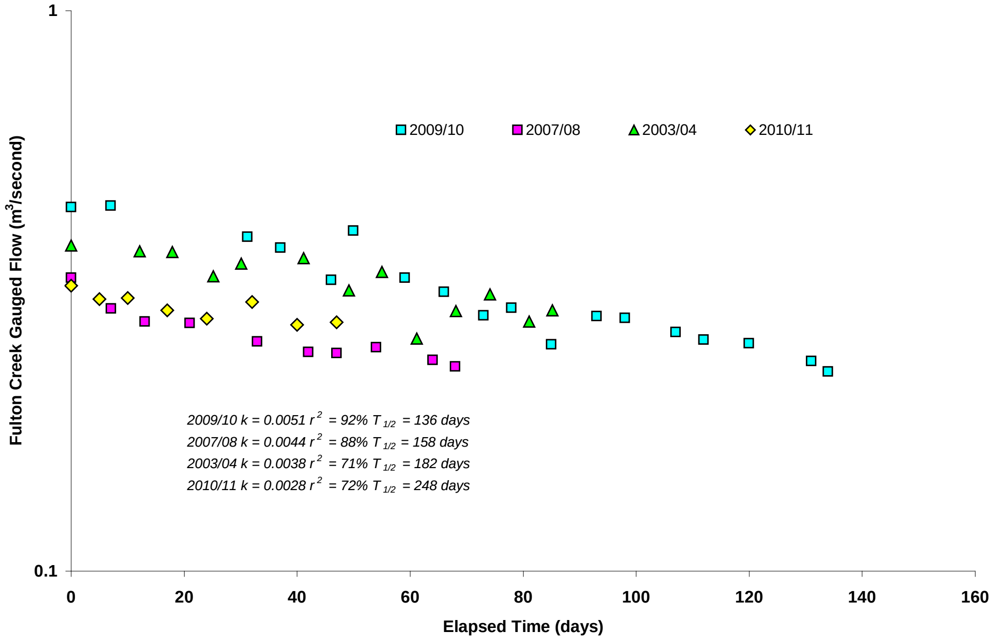

**Figure 3: Fulton Creek flow recession**

Fulton Creek (Figure 3) rises in the Springlands area of western Blenheim and is much further from the Wairau River meaning recharge water has further to travel. The aquifer is also less transmissive beneath the southern Wairau Plain meaning it takes longer to recover from pumping and relies on a higher contribution of rainfall recharge compared to Spring Creek. The average time it took for flow to halve in Fulton Creek for the 4 seasons (Figure 3) was 181 days. Flow is gauged manually each week upstream of the confluence of Fulton Creek and Taylor River.

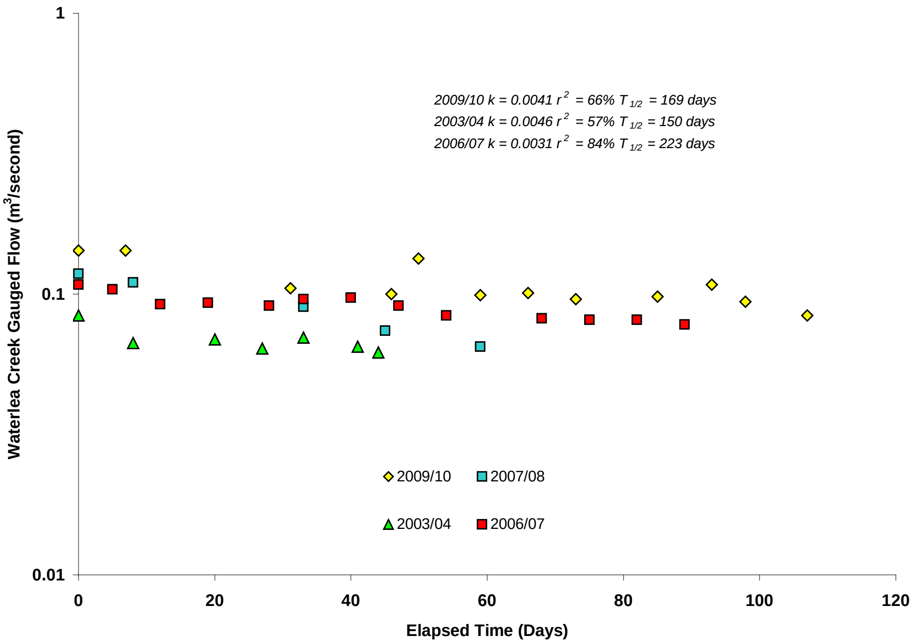

**Figure 4**: **Waterlea Creek flow recession**

Waterlea Creek (Figure 4) is also one of the Blenheim urban springs. It has an average half life of 180 days which is similar to Fulton Creek. This is not surprising as they are located close together and rely on a common source of groundwater for recharge. Flow is gauged manually each week upstream of the confluence of Waterlea Creek and Taylor River.

## 4.2 Stream flow stability rank = 2

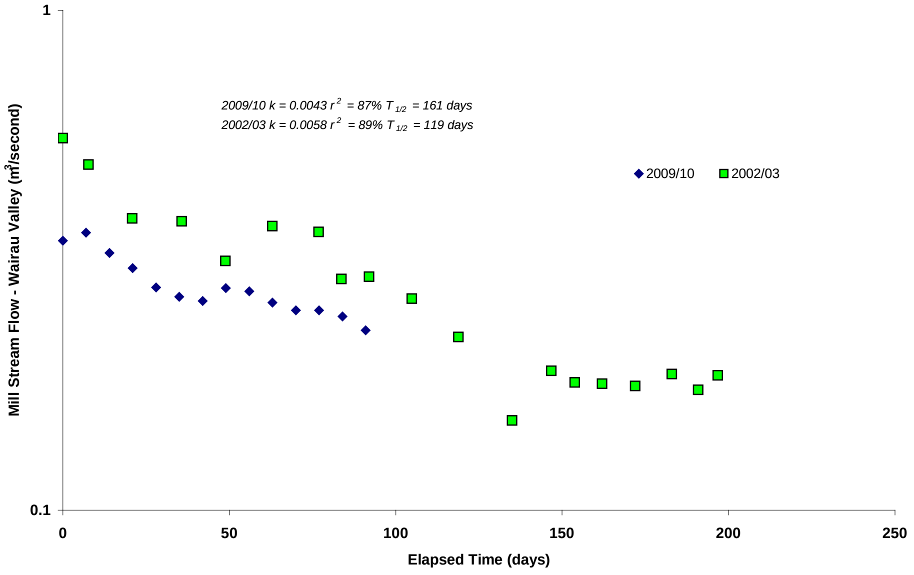

**Figure 5**: **Mill Stream flow recession**

Mill Stream (Figure 5) was recognised relatively recently by MDC staff as a groundwater-fed spring. Its high ecological and natural character values depend in part on the upwelling groundwater that replenishes it. The average time it takes for Mill Stream flow to halve in its middle reaches at the Ormond Aquaculture flow recorder site is 140 days. This is a relatively long half life which is similar to the urban springs in Blenheim and implies the existence of a reasonably large body of groundwater.

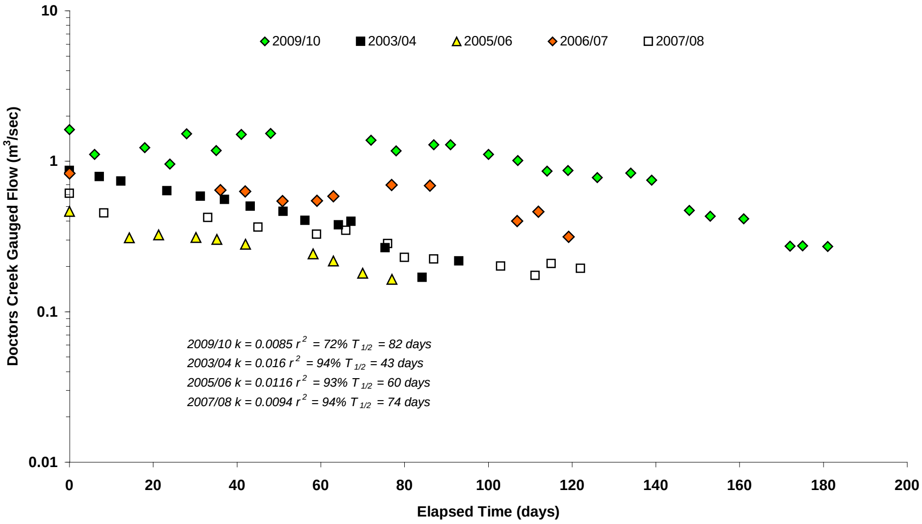

**Figure 6**: **Doctors Creek flow recession**

Doctors Creek (Figure 6) receives most of its recharge from the Southern Valleys catchments along with some Wairau Aquifer water. Over summer the rate of recharge arriving from the Southern Valleys catchments naturally declines because of the ephemeral nature of the local rivers.

As a consequence there is less throughflow which together with the lower storage of the confined aquifer means springs recede more quickly than those in the neighbouring Wairau Aquifer. This is reflected in the half life of Doctors Creek which averaged 65 days for the 4 seasons plotted. This is significantly lower than Spring Creek or even the nearby urban springs. Flow is gauged manually each week upstream of the confluence with the Taylor River.

## 4.3 Stream flow stability rank = 3

Well defined recession plots aren't yet available for the Waikakaho River, Tuamarina River or Flaxbourne River summer low flows as at the time of writing there was only a single season of uninterrupted recession record available which isn't definitive.

# 5. Aquifer storage volume

The volume of groundwater stored by an aquifer is a fundamental measure of aquifer resilience. Groundwater storage is analogous to money in the bank and groundwater recharge is akin to income. However not all of the groundwater can be allocated for use. Firstly, not all groundwater in an aquifer can be pumped out. Secondly, most groundwater has to be retained for environmental purposes and to support the natural functioning of the aquifer. For example minimum groundwater throughflows are needed to avoid seawater intrusion at the coastal boundary, to provide hydrostatic support for aquifer forming sediments to avoid subsidence, maintain acceptable spring flows and to generate a gradient for regional groundwater circulation.

**Table 5: Volume of groundwater stored in Marlborough aquifers**

| **Wairau Plain Aquifer System** | **Groundwater Storage (millions of $m^3$)** | **Ranking** |
|---|---|---|
| Wairau Aquifer Recharge Sector | 180 | 1 |
| Wairau Aquifer Springs Sector | 5.9 | 2 |
| Omaka River Aquifer | 5.4 | 2 |
| Rarangi Shallow Aquifer | 3.8 | 2 |
| Tuamarina River Aquifer | 1.6 | 2 |
| Wairau Aquifer Coastal and Lower Wairau Sectors | 1.3 | 2 |
| Are Are Creek Aquifer combined | 1 | 2 |
| Woodbourne Sector | 0.6 | 3 |
| Waikakaho River Gravels Aquifer | 0.5 | 3 |
| Wairau Valley Aquifer | 0.5 | 3 |
| Omaka Aquifer | 0.4 | 3 |
| Flaxbourne River Gravels Aquifer combined | 0.4 | 3 |
| Brancott Aquifer | 0.3 | 3 |
| Fairhall River Gravels Aquifer | 0.3 | 3 |
| Riverlands Aquifer combined | 0.3 | 3 |
| Benmorven Aquifer | 0.2 | 3 |
| Southern Springs Sector | 0.2 | 3 |
| Taylor River related Aquifers | 0.1 | 3 |

The bulk of Wairau Plain groundwater is stored in the porous gravels forming the Wairau Aquifer Recharge Sector (Table 5) and this explains why the flows in springs draining this area are so robust in a drought (Table 4). Aquifer storage (Table 5) is ordered from those with the highest storage at the top of the table to the lowest at the bottom.

The volume of groundwater an aquifer can store isn't always proportional to its area because the thickness or porosity of the gravels can vary and also influence its water holding capacity. For example the Lower Wairau and Coastal Sectors of the Wairau Aquifer underlie a greater land area than the recharge sector, but the storativity of the sediments is very low by comparison and they only store a fraction of the water.

Storativity refers to the amount of water an aquifer takes up or releases from storage as groundwater level changes. Storativity is related to porosity and values may vary by 1000 times, with high values in unconfined aquifers and low values in confined aquifers.

The quantum of groundwater stored in an aquifer is only part of the story because groundwater inflow and boundary effects have to be taken into account when allocating groundwater. For instance the rates of abstraction from the Rarangi Shallow Aquifer, Riverlands or Wairau Aquifer Coastal Sector situated along the Cloudy Bay margin are limited by the proximity of the ocean and the potential for seawater intrusion.

# 6. Groundwater inflow: surface water baseflow

The rate of recharge to a groundwater system is as important as the volume of water an aquifer stores. Despite the massive reservoir capacity of large groundwater systems such as the Wairau Aquifer, they need constant replenishment to offset large natural losses by spring drainage.

Continual recharge is essential for small aquifers with limited storage if they are to be of any practical use as water supply reservoirs. Without recharge the aquifer drains quickly, especially if it is located on a steep gradient. This is why the state of the associated river or stream providing recharge is so important to the seasonal status of these riparian type aquifers.

**Table 6: Baseflow of surface water recharge to Marlborough aquifers**

| Aquifer System | Groundwater inflow: surface water baseflow ($m^3$/second) | Ranking |
|---|---|---|
| Wairau Aquifer Recharge/Springs Sectors | 5 | 1 |
| Wairau Aquifer Coastal & Lower Wairau Sectors, Riverlands Aquifer combined | 0.5 | 2 |
| Wairau Valley Southbank | 0.1 assumed | 2 |
| Taylor River related aquifers, Southern Springs, Fairhall River Gravels Aquifer, Brancott Aquifer, Omaka Aquifer, Benmorven Aquifer | 0.05 | 3 |
| Omaka River Aquifer including Woodbourne Sector | 0.08 | 3 |
| Flaxbourne River Gravels Aquifer combined | 0.005 assumed | |
| Rarangi Shallow Aquifer | limited runoff from ranges in summer | 3 |
| Waikakaho River Gravels Aquifer | 0.005 assumed | 3 |
| Are Are Creek Aquifer combined | Likely to be low | 3 |
| Tuamarina River Aquifer | Likely to be low | 3 |

The baseflow of surface water recharge is ranked from highest to lowest (Table 6). The Wairau Aquifer is the only system with a high ranking which reflects the perennial nature of Wairau River flows. Inflows to groundwater from the Waikakaho River, Flaxbourne River, and the streams draining the Southbank hill country are uncertain and have been estimated.

# 7. Overall aquifer resilience ranking calculation

The individual rankings of each of the 4 components are combined to provide an overall aquifer resilience rating (Table 7). In some cases individual rankings are missing and the overall rating is based on those that are available. Ratings are listed from highest at the top to lowest at the bottom.

**Table 7: Overall resilience ranking of Marlborough aquifers and groundwater resources**

| Aquifer or suite of aquifers | Aquifer or sector | Groundwater outflow : stream baseflow versus quickflow | Groundwater outflow : stream flow stability during drought | Aquifer storage volume | Groundwater inflow: surface water baseflow | Overall resilience rating |
|---|---|---|---|---|---|---|
| **Wairau Aquifer** | Recharge Sector | 1 | 1 | 1 | 1 | high |
| | Springs Sector | 1 | 1 | 2 | 1 | high |
| | Lower Wairau Sector & Coastal Sector | n/a | n/a | 2 | 2 | medium |
| **Are Are Creek Aquifer combined** | | 2 | 2 | 2 | 3 | medium |
| **Wairau Valley Aquifer** | | 2 | 2 | 3 | 2 | medium |
| **Rarangi Shallow Aquifer** | | n/a | n/a | 2 | 3 | medium |
| **Riverlands Aquifer** | | n/a | n/a | 3 | 2 | medium |
| **Southern Springs Sector** | | 2 | 2 | 3 | 3 | medium |
| **Omaka River related aquifers** | Omaka River Aquifer | n/a | n/a | 2 | 3 | medium |
| | Woodbourne sector | n/a | n/a | 3 | 3 | low |
| **Southern Valleys Aquifers** | Brancott Aquifer | n/a | n/a | 3 | 3 | low |
| | Taylor River related Aquifers | n/a | n/a | 3 | 3 | low |
| | Omaka Aquifer | n/a | n/a | 3 | 3 | low |
| | Fairhall River Gravels Aquifer | n/a | n/a | 3 | 3 | low |
| | Benmorven Aquifer | n/a | n/a | 3 | 3 | low |
| **Tuamarina River Aquifer** | - | 3 | 3 | 2 | 3 | low |
| **Flaxbourne River related aquifers** | - | 3 | 3 | 3 | 3 | low |
| **Waikakaho River Gravels Aquifer** | | 3 | 3 | 3 | 3 | low |

# 8. Implications of aquifer resilience ranking for water management policy

Currently water permits granted by MDC are largely treated in the same way regardless of which aquifer groundwater is sourced from, and for most, the daily rate of pumping is fixed in terms of a maximum daily volume.

These approaches don't account for:

- *natural differences in aquifer dynamics*
- *seasonal variability in recharge rates or water demand*
- *cumulative effects generated by multiple abstractions*

In practice how much groundwater can safely be pumped from wells varies continuously in time and place. The size of an aquifer, its physical structure and the way in which it is recharged all influence groundwater availability.

General characteristics of three classes of aquifer resilience (Table 7) include:

- *high resilience where high inflows and high outflows mean that the aquifer is supporting flow in groundwater-fed streams that is relatively uniform over time. These aquifers store a large amount of groundwater*
- *medium resilience where the aquifer is supporting flow in groundwater-fed streams that is relatively variable over time. These aquifers store a moderate amount of groundwater*
- *low resilience where the aquifer is supporting highly variable spring-fed streams and aquifer storage is low*

Management approaches should take advantage of natural limitations or opportunities in the reservoir characteristics of individual aquifers. Key management considerations for the three classes of aquifer resilience (Table 7) could include:

- *high resilience aquifers where maintenance of groundwater-fed stream flow is a priority*
- *medium resilience aquifers where maintenance of groundwater-fed stream flow and management of storage are priorities*
- *low resilience aquifers where management of groundwater use is very important because these aquifers have low inflows and low storage*