MARLBOROUGH DISTRICT COUNCIL

Taylor River Catchment Characterisation - Doctors Creek

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Executive Summary

State of the Environment sampling identified Doctors Creek, upstream of the Taylor River as one of the worst sites in regard to water quality. In the Surface Water State of the Environment report 2013, Doctors Creek ranked in the bottom five of the 34 sites monitored.

During base-flow, Doctors Creek supplies a significant portion of surface flow to the lower reach of the Taylor River which is part of the River Reserve. Therefore, the degraded water quality of Doctors Creek affects the water quality of the Taylor River.

The Taylor River reserve is a particularly popular recreational area for walking, running, cycling and rafting. In some areas the river is also used for swimming.

In recognition of the significant value of the Taylor River, funding for a catchment characterisation study was approved by the Environment Committee in 2012. The funding was divided into two parts.

(a) The Assets and Services Department was to investigate and report on the influences of Blenheim's stormwater on the water quality of the Taylor River.

(b) The Environmental Science team was to focus on the predominantly rural sources in the Doctors Creek catchment and the Taylor River upstream of Doctors Creek. The report presented represents this part of the study.

The Taylor River upstream of Doctors Creek contributes less than 10% of the flow to the lower Taylor River system. Additionally, some parts of the Taylor River around New Renwick Road were dry during most of 2014 resulting in a disconnection in the surface flow from the upper catchment. The results of the 2013/14 investigation also showed that water quality of the small flow that did contribute to the lower Taylor River was generally good. For this reason the focus of the investigation went primarily to the Doctors Creek catchment.

High nitrate concentrations were found to mainly originate from groundwater that emerges in Doctors Creek and its tributaries, particularly groundwater that flows in from the west. Nitrate concentrations in groundwater are naturally very low, but leachate from land use activities, particularly irrigated cattle pasture and cropping results in elevated concentrations.

Most Dissolved Reactive Phosphorus (DRP) also originated from groundwater, but a combination of the removal of bank vegetation and the sheep grazing on vineyards was found to be an additional source during the winter months.

Increases in turbidity during base-flow were found to have several causes. Construction works in and around the waterways together with livestock access to the waterway caused significant amounts of fine sediment to accumulate on the stream bed. Additionally, the removal of bank vegetation resulted in high sediment inputs during rainfall events. Once fine sediment had accumulated on the stream bed, it was easily remobilised back into the water column by wildfowl and livestock moving in the water. The spraying of aquatic weed intensified sediment release, as it exposed the sediment to higher water velocities. After a prolonged period of low flow another less common source of turbidity was identified. High nutrient concentrations combined with the lack of shade resulted in excessive growth of filamentous algae. Some filaments had grown so extensively small parts were being broken off by the water current or wildfowl and were floating downstream. The cumulative effect of these free floating algae pieces resulted in a steady increase in turbidity in a downstream direction.

Health risks to swimmers indicated by high E. coli concentrations was a major concern. Concentrations were generally higher in summer as lower flows resulted in reduced dilution. Human sources were found in Yelverton Stream, while wildfowl and ruminant sources were the cause of faecal contamination in other parts of Doctors Creek. Some of the highest concentrations were measured downstream of an area where cattle had direct access to the waterway.

Continuous measurements of water temperature, dissolved oxygen saturation and pH showed that all three parameters exceeded the guidelines during summer. This was caused by a lack of shading due to

the absence of tall vegetation along most of the stream banks, but also the excessive growth of aquatic plants. The guidelines for these parameters are based on ecological values, which means guideline exceedances are likely to result in reduced biodiversity. This was confirmed when Macroinvertebrate (Aquatic Insect) and fish data were analysed.

Median concentrations of heavy metals monitored (arsenic, copper, zinc and lead) were all below the 95% Species Protection trigger values.

Pesticide sampling found concentrations of only one herbicide (Terbuthylazine) above detection limit, but levels were very low.

The exclusion of livestock, better bank management and avoiding work in flowing water ways would result in a significant improvement of water quality in Doctors Creek.

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1. Introduction

Doctors Creek is one of the main tributaries of the Taylor River and is part of a number of spring-fed streams located to the north and west of Blenheim, referred to as the 'Southern Springs'. During base-flow, these springs contribute more than 90% of the flow to the Taylor River. Unlike most of the other springs, Doctors Creek also receives water from a hill catchment to the south of the spring belt. However, during base-flow and particularly in summer, nearly the entire flow of the creek originates from emerging groundwater. The Doctors Creek catchment has a size of 54.5 km^2 and constitutes more than 35% of the Taylor River catchment (Figure 1).

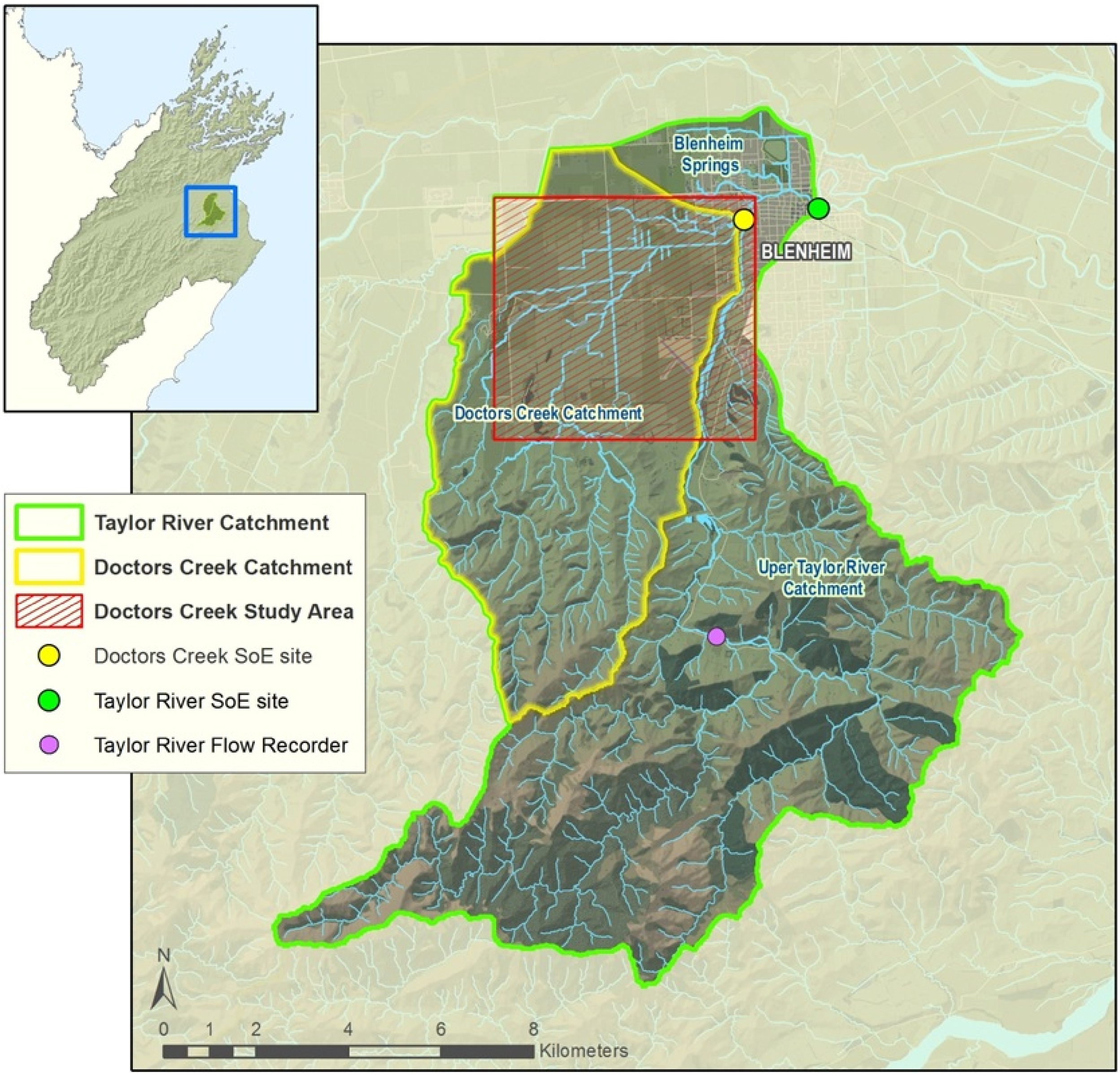

Figure 1: The Taylor River and Doctors Creek catchments. The focus area of this report is shown in red. Also shown are sites where monthly sampling is carried out as part of the State of the Environment (SoE) program and the location of the flow recorder on the upper Taylor River (Taylor River at Borough Weir).

Monthly sampling of Doctors Creek and the Taylor River as part of the State of the Environment program showed the water quality of both water bodies to be degraded. In the State of the Environment report 2013, Doctors Creek ranked in the bottom five of the 34 sites monitored. The water in the Taylor River had a slightly better, but still only marginal quality. Due to the large contribution of Doctors Creek to the Taylor River flow, the poor water quality of Doctors Creek is a significant cause of water quality degradation in the Taylor river. The Taylor River and the associated River Reserve are of significant recreational and aesthetic value for the residents of Blenheim and good water quality of the river is an important factor for the enjoyment of the reserve. The main concerns, particularly for Doctors Creek, are reduced water clarity and high E. coli concentrations.

Parts of the Taylor River are used for contact recreational activities, like swimming. Therefore additional weekly monitoring of E. coli concentrations during the summer months is carried out to assess the risk of infection with water borne diseases from faecal contamination. This sampling is done at the Riverside Park, a few meters upstream of the State of the Environment sampling site. The monitoring has shown water was unsafe for contact recreation several times every year. The site was graded as ‘very poor’, meaning that swimming is generally not recommended. An investigation into the sources of high E. coli concentrations found ducks and dogs were the primary sources in the lower Taylor River. The investigation also revealed that the highest E. coli concentrations were found in Doctors Creek and its tributaries.

The results of the State of the Environment and the recreational water quality sampling exposed significant water quality problems for the Taylor River and its tributary, Doctors Creek. Due to the recreational importance of the Taylor River for the community, the Council’s Environment Committee recommended a detailed catchment study of the Taylor River and its tributaries. Funding for this study was approved for the 2013/2014 financial year. It was recognized that the effects of the urban environment were quite different from problems arising in the rural parts of the catchment. Consequently the study was divided into two parts.

1. A stormwater monitoring project would investigate the effect of urban stormwater on the water quality of the Taylor River downstream of the confluence with Doctors Creek. This study also includes the Blenheim springs.

2. A catchment characterisation for Doctors Creek and the Upper Taylor River catchment was to investigate the rural influences on water quality. The report presents the findings for this part of the study.

For each part, funding was provided for investigative sampling and the writing of a report. For the second (rural) part of the study, it was decided to mostly restrict the investigative sampling to base-flow conditions. The catchment is located in an area of relatively low rainfall[1]. Consequently, base-flow conditions are characteristic of the state of the waterways during most of the year. Flood conditions represent relatively rare events of limited duration. Additionally, flood events are highly variable in regard to intensity and duration. This means water quality during a flood not only changes during the event, but also varies from one event to the next making representative sampling very difficult. If flood events were included, a time-period of several years would be required for the investigation. The time-frame for this study was restricted to slightly more than a year. Nevertheless, for parameters that were potentially affected by processes occurring during flood events, samples were also taken at higher flows.

Over 60 sites were sampled, mainly in the Doctors Creek catchment. Earlier flow gaugings and field observations had shown the flow contribution of the Taylor River catchment upstream of the confluence with Doctors Creek was less than 10% during most of the summer. A significant length of the Taylor River dries out during prolonged dry periods and surface flow only reappears a short distance upstream of the confluence with Doctors Creek. Consequently, it was decided to investigate the water quality in the Upper Taylor River during the winter months, when flows were higher and the river would carry surface flow along its whole length. Based on field observations this occurs if the flow recorded at the Borough Weir exceeds 0.15 - 0.25 m^3/s.

Unfortunately, after the first sampling round of the upper Taylor catchment was carried out in July 2014, a dry winter resulted in no other sampling opportunity at base-flow (Figure 2).

[1] Average annual rainfall in Blenheim is 630mm

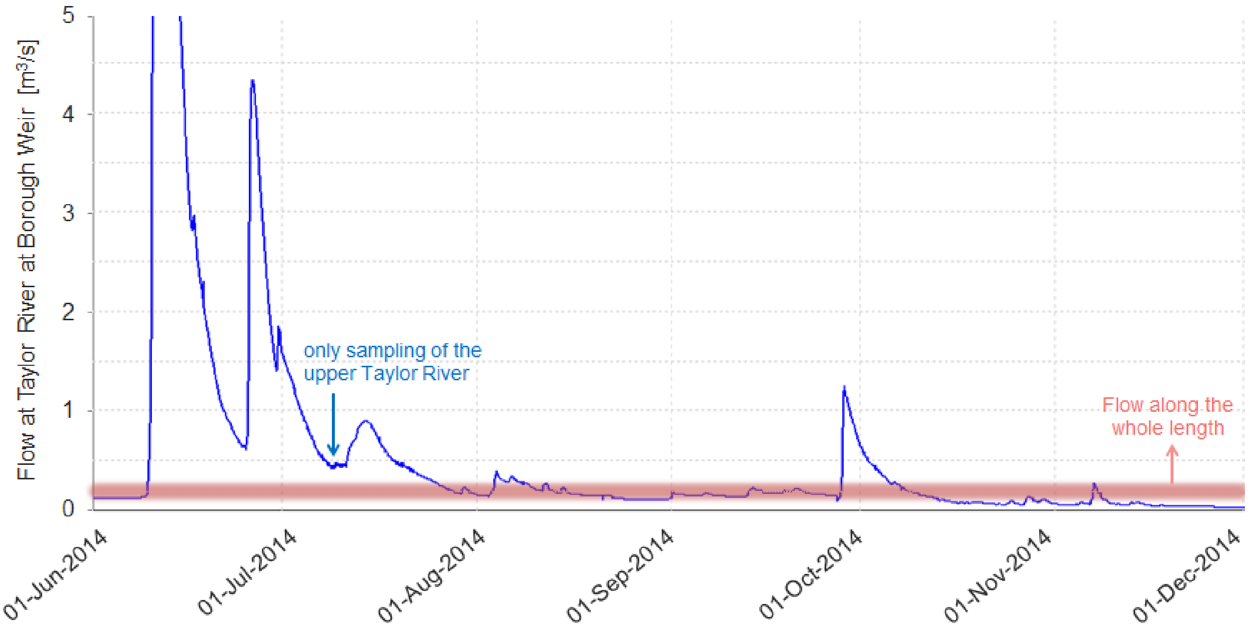

Figure 2: Taylor River flow at Borough Weir. Flows above the red line indicated continuous surface flow along the whole length of the river, downstream of the flow site.

Nevertheless, as part of the investigation more than ten samples were taken from the Taylor River, just upstream of the confluence with Doctors Creek. The water quality at this site was generally very good, which means the upper Taylor River catchment is unlikely to be a significant contributor to the degraded water quality found further downstream.

For this reason, the focus of this report is the Doctors Creek catchment and particularly the waterways that carry surface flow for a significant amount of time. These are located in the lower lying areas marked red in Figure 1.

Figure 3: The dry river bed of the Taylor River at the New Renwick Bridge, 1.5km upstream of the confluence with Doctors Creek.

2. Geology and Groundwater

The geology of the Doctors Creek catchment is predominantly a result of sedimentary processes. The gravels filling the lower parts of the Doctors Creek area were deposited through a succession of cool (glacial) periods followed by warmer (interglacial) periods. During glaciations average air temperatures was as low as 10^{o}C. Precipitation usually fell as snow. Snow accumulated and compacted to form glaciers and less water flowed into the sea, resulting in the lowering of sea levels. Glacial meltwaters transported material eroded by the movement and pulverising action of glaciers towards the sea, depositing it as large 'outwash plains' which now form the thick layers of sediment in the lower Wairau Plain today. The cooler air temperatures during the glaciation periods also caused hill erosion as alteration of freezing and thawing weakened rock. Water that seeped into cracks in rock would freeze and expand as ice, widening gaps until the rock split. Additionally, plants struggled to grow in the colder climate reducing the protective vegetation cover. This would result in the exposure of bare rocks to strong winds, which picked up smaller silt and clay particles and deposited them as loess on the surrounding hills.

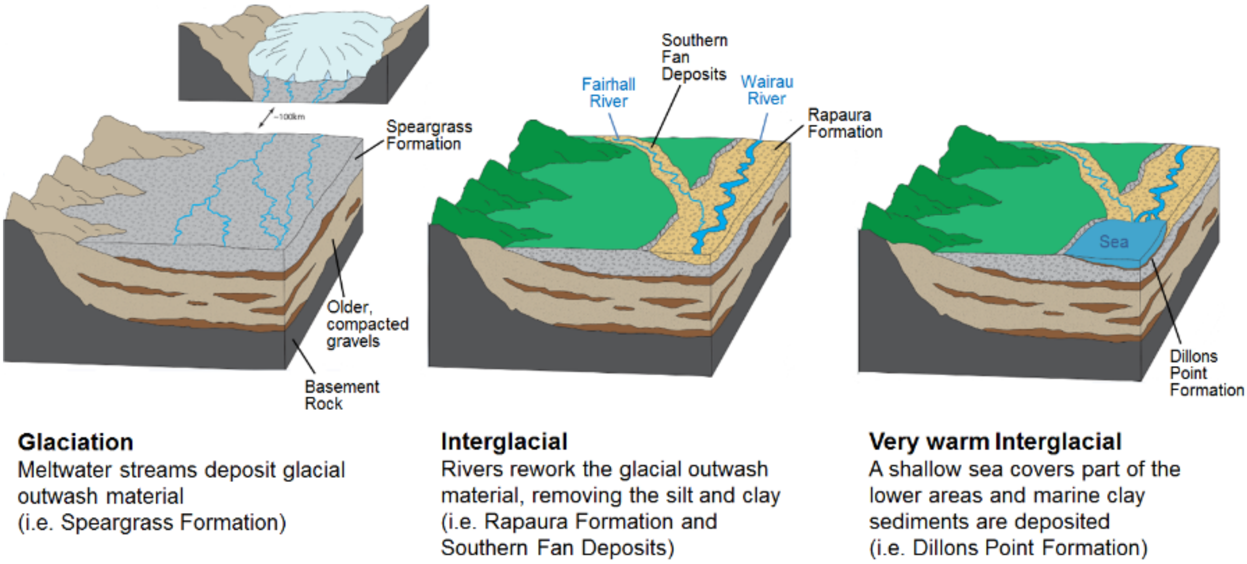

Figure 4: Development of the Geology of the Doctors Creek catchment.

The material deposited by the glacial meltwaters ranges in size from cobbles to fine clay. So these poorly sorted materials consist of larger pieces embedded into a matrix of silt and clay. This results in relatively low groundwater yields, as the pores through which the groundwater flows are small, allowing only relatively limited amounts of water to pass. Groundwater is mainly flowing in isolated channel-like structures consisting of gravels with higher permeability (Figure 7). The Speargrass formation, that dominates the surface geology of the lower Doctors Creek catchment is part of the glacial outwash plain, that was deposited during the last glaciation period some 20,000 years ago (Otira Glaciation) (Figures 4 and 5)

During the warmer, interglacial, periods air temperatures increased, glaciers retreated and sea levels rose. During some of these interglacial periods the sea rose higher than levels today and a shallow sea covered lower areas of the Wairau Plain, including parts of the Doctors Creek catchment. Remnants of this temporary sea cover are layers of fine clay deposits. These marine sediments are nearly impermeable for groundwater, resulting in a restriction of groundwater flow. In the Doctors Creek catchment, clay sediments from the most recent sea intrusion form the Dillons Point Formation, which is forcing groundwater to the surface resulting in the spring-fed system of waterways we see today (Figure 6).

When temperatures were slightly lower, the glacial deposits were reworked by the Wairau River in the North and the Taylor, Fairhall and Omaka Rivers in the East and West. In the last 7,000 years, these rivers have cut into the Speargrass formation and removed the finer silt and clay from the matrix, creating a gravel that is more permeable for groundwater. The most permeable gravels were created by the larger Wairau River. These are referred to as the 'Rapaura formation'. Wells tapping into these gravels have the highest groundwater yields in the Doctors Creek catchment. Because the Taylor, Fairhall and Omaka rivers have a much smaller flow compared to the Wairau River, they have removed less of the finer sediment from the gravels. As a result groundwater yields from wells in these gravels are between those of the low-yielding Speargrass formation and the high-yield Rapaura formation. To underline the difference to the Rapaura formation created by the Wairau River, the gravels created by the smaller rivers are referred to as ‘Southern Fan deposits’ (Figures 4 and 5).

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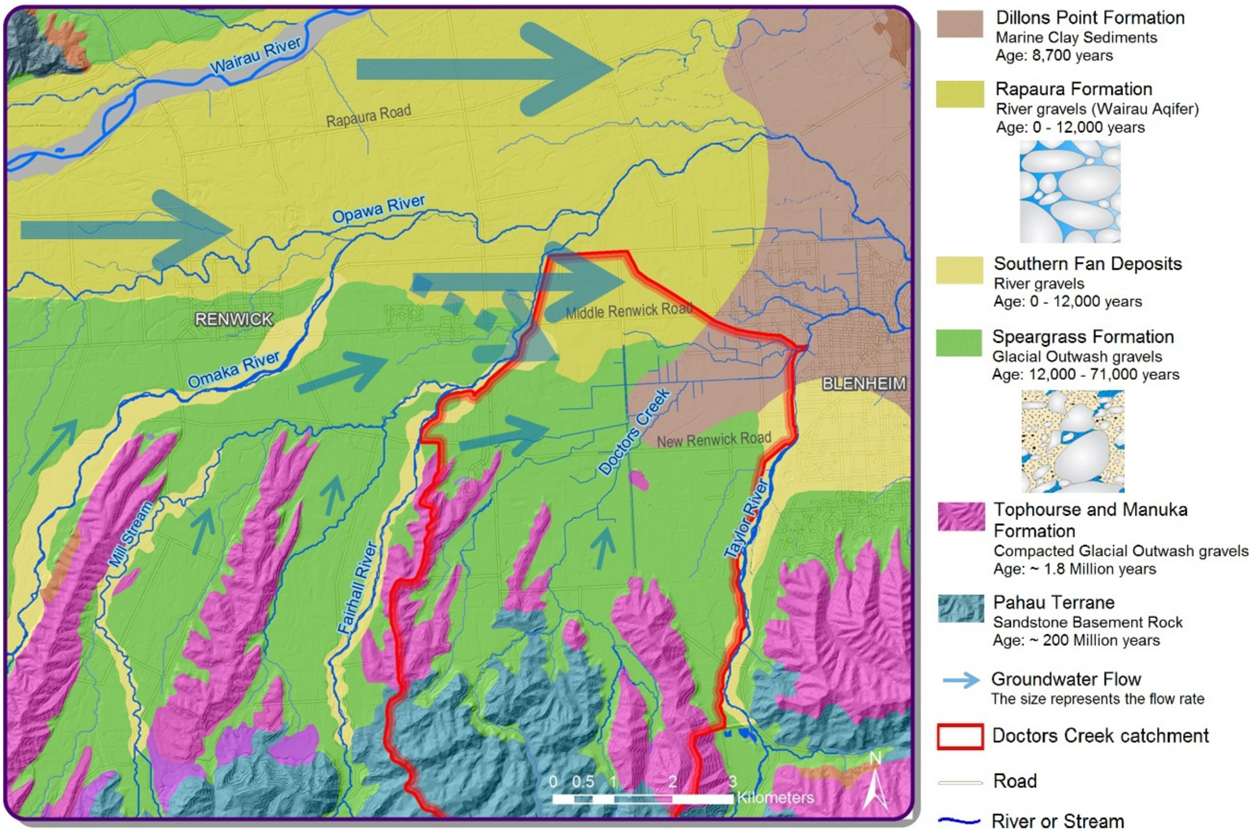

Figure 5: Geology of the wider area around the Doctors Creek catchment. The blue arrows indicate direction and rate of groundwater flows.

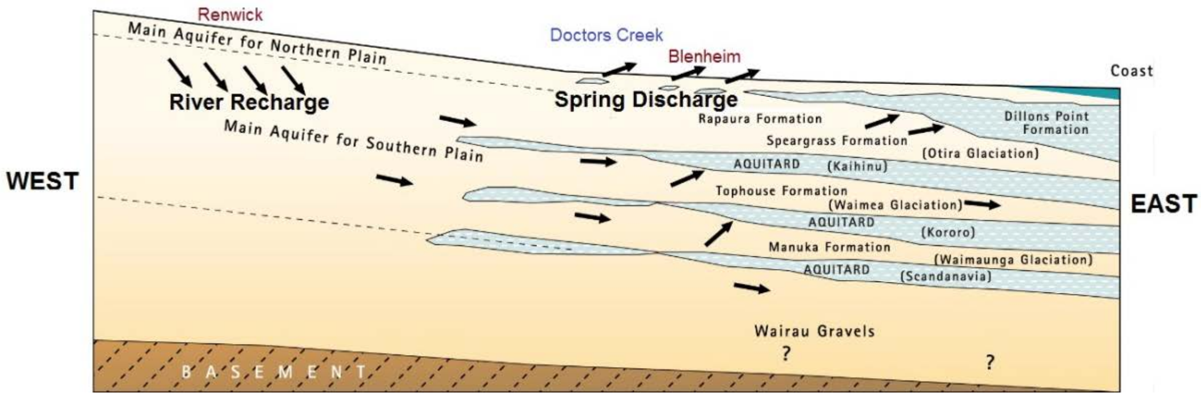

Figure 6: Cut through the Geology of the lower Wairau Plains from West to East.

Underneath the Rapaura, Speargrass and Dillons Point formations are older sediments that consist of compacted gravels and clay-lenses that originate from a number of earlier glaciation and interglacial periods (Figure 6). These gravels are only sporadically water-bearing with low yields. Parts of this older sediment extent to the surface at the lower hills in the south of the Doctors Creek catchment (Tophouse and Manuka Formation - Figure 5). At higher elevations the 200 Million year old basement rock of sandstone and mudstone, the Pahau terrane, is exposed.

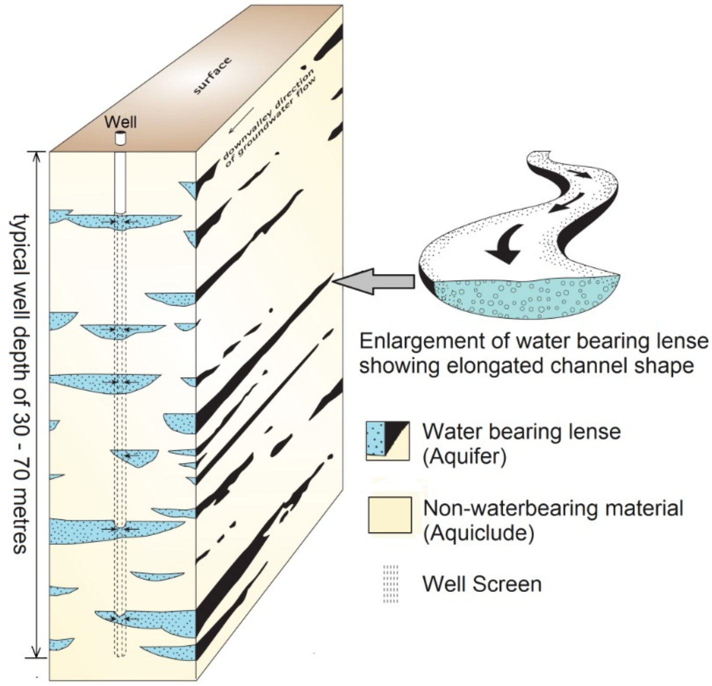

Figure 7: Structure of groundwater flow in the glacial deposits of the Speargrass Formation.

During the 1997/98 summer drought, shallow wells dried out and explorative drilling found groundwater at a depth of around 150m in gravels that are approximately 80,000 years old. This is now referred to as the ‘Wairau Deep Aquifer’. Average groundwater age is 20,000 years which suggests that groundwater flow rates are extremely low. The groundwater is under artesian pressure, which means the water levels in wells tapping into this aquifer rise above ground level. The high pressure could lead to a slow upward movement resulting in the leaching of this older water into shallower, younger groundwater. However, the physical extent of the Deep Wairau Aquifer and connectivity to upper groundwater systems are as yet unknown.

The general direction of groundwater flow in the Doctors Creek area is from the South to the North and West to East (Figure 5). The groundwater in the South moves very slowly northwards and is potentially quite old.

The northern part of the Doctors Creek catchment (North of New Renwick Road) can be described as a groundwater mixing zone. Groundwater from the south joins groundwater from the Omaka and Fairhall Rivers to the west. Further north, groundwater from the Wairau River also flows into the area. The actual direction of groundwater flow here depends on the amount of rainfall that has fallen in the area. After long dry periods the groundwater flow from the Omaka and Fairhall valleys reduces and more groundwater flows in from the Wairau aquifer to the north (dotted arrow in Figure 5). The groundwater flow in the Wairau Aquifer (Rapaura Formation) is significantly greater compared to groundwater flow in the areas dominated by the Speargrass Formation further to the south. As a result, the amount of groundwater inflow into the waterways in the Doctors Creek catchment generally increases in a northerly direction. During base-flow conditions in the summer months, most of the water that leaves the Doctors Creek catchment at the confluence with the Taylor River originates from the Wairau aquifer.

A good indicator of groundwater age is the concentrations of dissolved ions in the water. The longer water is in the ground, the more ions from the rock through which it is flowing are dissolved into it. One such ion is chloride. Higher chloride concentrations usually indicate older water[2]. Figure 8 shows the chloride

[2] Exceptions are wells close to the coast, for example.

concentration in Doctors Creek and its tributaries, as well as in water from wells drawing groundwater from different depths. In the surface waters, chloride concentrations are highest in the south and steadily decrease in a northerly direction. Chloride concentrations in the shallow wells are similar to concentrations in nearby waterways. There are no productive shallow wells south of New Renwick Road. Therefore, chloride concentrations can only be measured in deeper wells located around the lower Ben Morven Road. These wells range in depth between 30 and 70 meters. There is a distinct variation in chloride concentration in these wells, with very high values in the east and significantly lower values in the west. The higher values in the east are reflected in higher chloride concentrations in the eastern tributary of Doctors Creek upstream of Ben Morven Road. This means comparatively older water is rising to the surface in this area. The two wells located furthest to the east are thought to belong to a very small aquifer system that is potentially not connected to other parts of the Doctors Creek catchment [6]. Nevertheless, the well located immediately to the east of Doctors Creek is assumed to be part of the system that feeds the creek and the chloride concentration of 180 g/m^3 is of similar magnitude to the wells furthest to the east. The highest chloride concentration that was measured in surface water was significantly lower (69.5 g/m^3), which suggest dilution from sub-surface flow originating from relatively recent rainfall events.

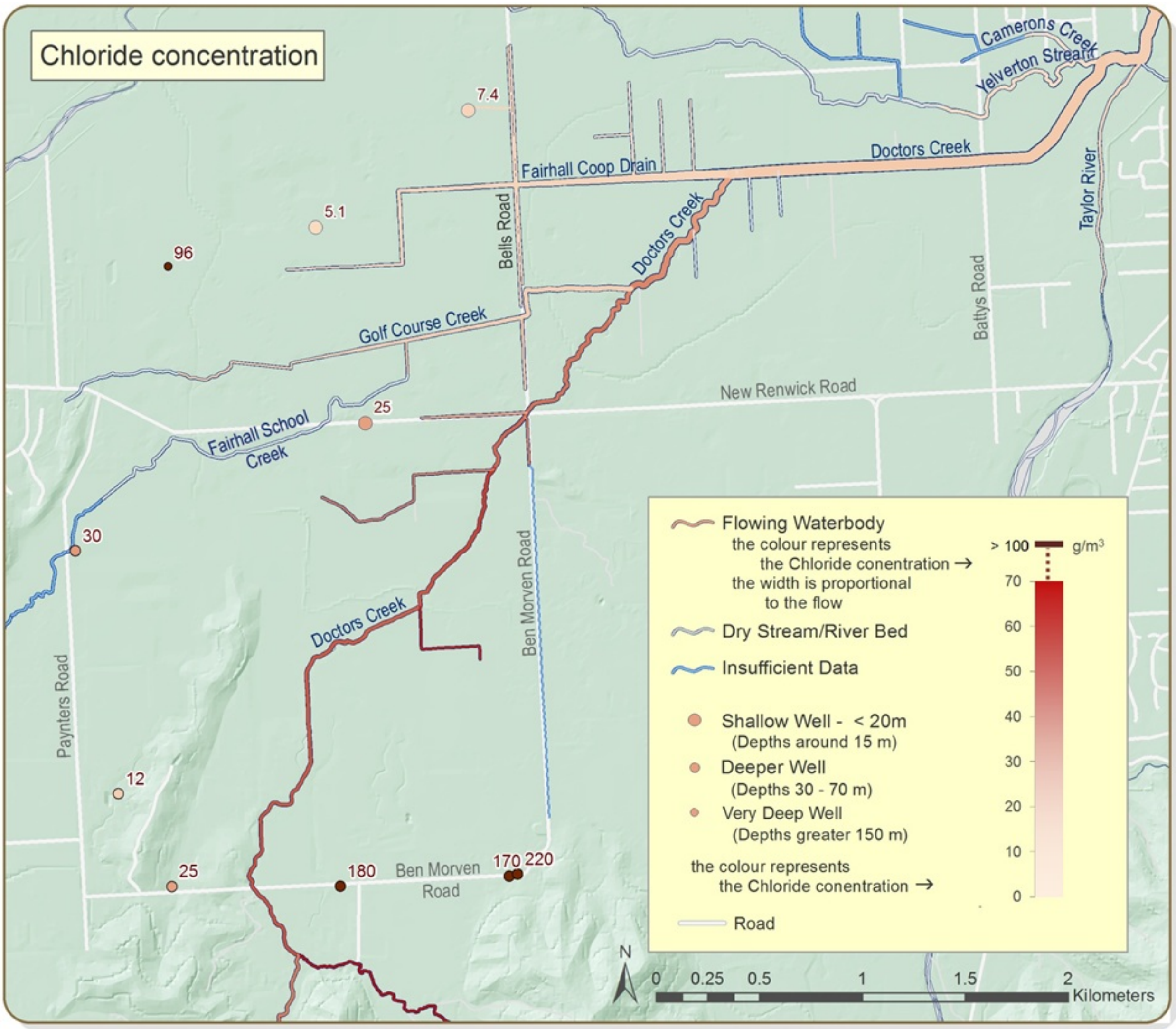

Figure 8: Chloride concentration in surface waters and groundwater in the Doctors Creek catchment. Numerical values are shown for the wells only.

A very deep well located to the west of Fairhall Coop Drain has an average chloride concentration of 96 g/m^3. This is a monitoring well for the Deep Wairau Aquifer, which potentially underlies the entire catchment. Surprisingly, chloride concentrations are lower compared to those measured in the shallower wells in the south of the catchment. This might indicate the influence of marine sediments on the chloride concentration in the shallower wells. Still, these wells represent groundwater that is potentially quite old and makes a significant contribution to the surface flow of Doctors Creek to the south of New Renwick Road.

Specific conductivity[3] can also be used as an indicator of groundwater age. The higher the ion concentration of groundwater, the higher the conductivity. There is a good correlation between the chloride concentration and specific conductivity of samples taken from Doctors Creek (Figure 9). To investigate if the change in the age of emerging groundwater is gradual or if older groundwater is rising in defined areas, specific conductivity was measured in the Ben Morven Road Drain. The measurements were taken after a prolonged period without significant rainfall, when groundwater levels in the area were low enough, so that none of the tile drains were adding any water from adjacent vineyards, but the main drain was still carrying water for nearly the entire length. Apart from a small surface inflow about half-way, any flow increase was due to groundwater inflow through the bed of the drain. The nearly perfectly straight morphology and northerly direction made it perfect for the investigation. The specific conductivity of other road drains along New Renwick Road and Bells Road was also measured. The results are shown in Figure 9. The water furthest south is actually quite young suggesting a dominance of subsurface inflows that are remnants of rainfall that had fallen some months earlier. The age of the inflowing groundwater increases in a downstream direction, reaching a peak about 400m upstream of the New Renwick Road Bridge and decreases again further downstream. The area with the highest conductivity is close to an inferred fault [6]. This indicates that older water from the deeper aquifer is entering the shallower aquifer in distinct locations, in areas were impermeable layers are damaged, rather than through relatively even seepage.

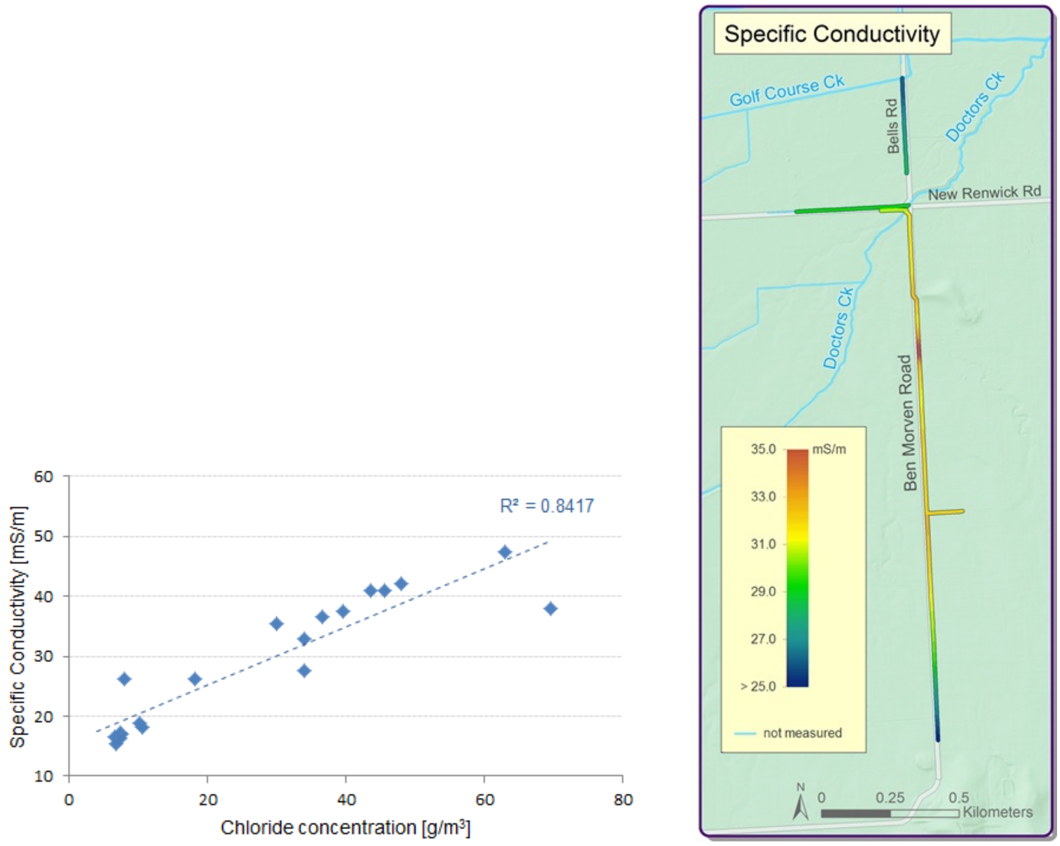

Figure 9: Correlation between Specific Conductivity and Chloride concentrations for samples from the Doctors Creek catchment. On the right: Specific Conductivity in road drains along Ben Morven Road, Bells Road and New Renwick Road.

[3] Conductivity adjusted to a standard temperature of 25°C. This allows comparison of conductivity values independent of water temperature.

3. Hydrology

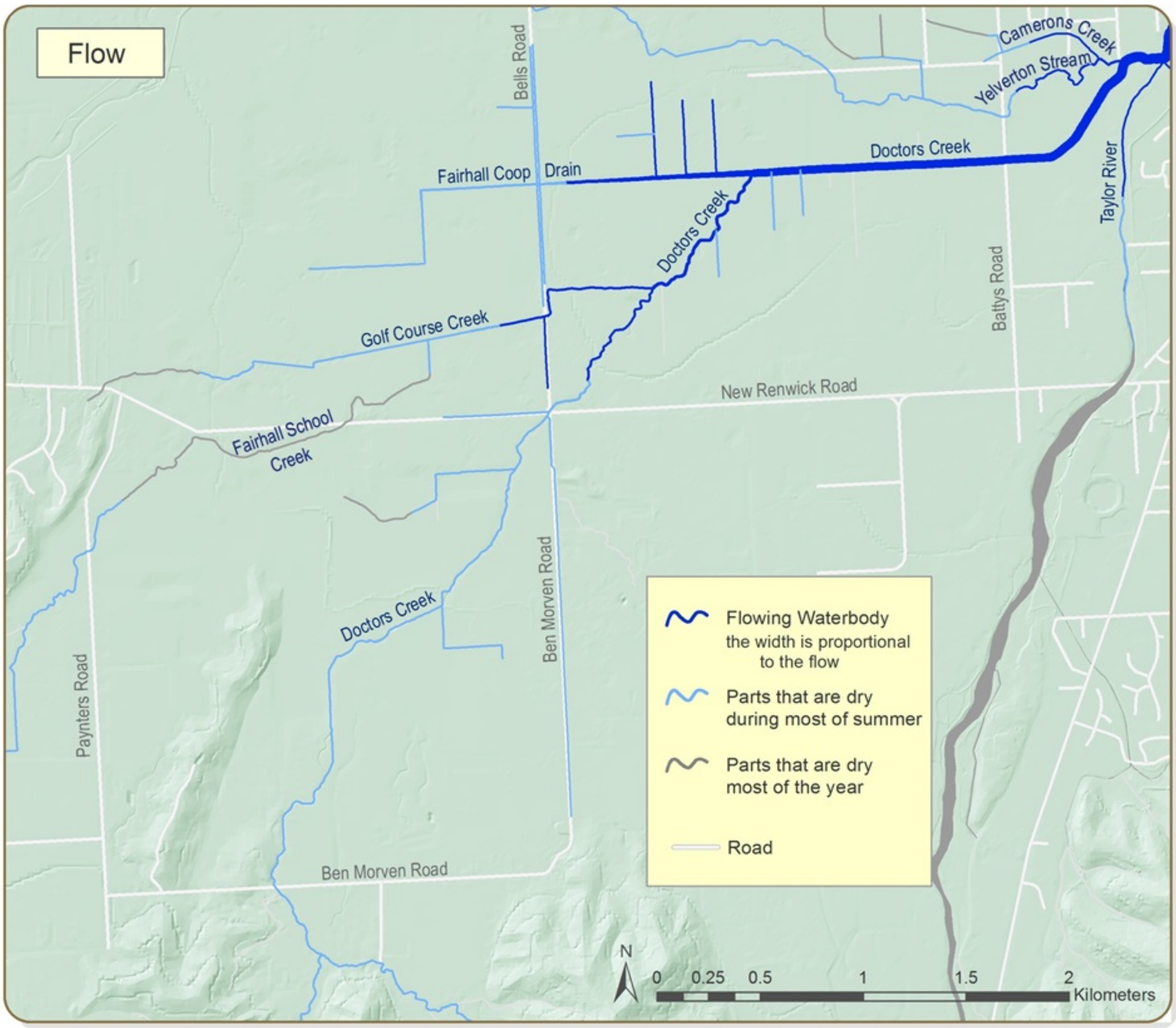

Figure 10: Flow pattern in Doctors Creek during base flow in winter (all channels not grey) and summer (dark blue channels only).

The Doctors Creek catchment typically contributes flows between 0.1 to 1.4 m^3/s (100 to 1400 L/s) to the Taylor River system. There is a strong seasonal variability, with high winter flows resulting from surface run-off in the upper catchment to lower spring-fed summer flows.

The hills in the south of the Doctors Creek catchment are dominated by small ephemeral streams that only flow during short periods after significant rainfall. The waterways in the lower catchment, on the other hand, are dominated by groundwater inflow and flow permanently. This is the result of groundwater being forced to the surface by an impermeable layer of marine sediments that extend into that area from the east (see Section 2). After prolonged periods without significant rainfall, more and more of the waterways dry out. During summers, only channels north of New Renwick Road carry water. In very dry summers, as the one observed in 2001, all that remains is a short stretch of surface flow emerging at Batty's Road, flowing to the confluence with the Taylor River.

Gaugings of several sites in the catchment revealed that Doctors Creek is gaining flow along most of its flatter topography. From the lower Benmorven Road through to the confluence with the Taylor River the flow increases not only as a result of tributaries, but also from groundwater inflow via tile drains and through the bed of the creek. The amount of groundwater inflow into Doctors Creek increases significantly in a north-east direction. Flows carried by the main tributaries, Golf Course Creek and Fairhall Coop Drain, are disproportionate to the area of their surface catchments. Despite a much larger catchment, flow in the main stem of Doctors Creek is generally lower than flows in Golf Course Creek and Fairhall Coop

Drain at the points where the tributaries join. During a gauging carried out in February 2013, the flow in Fairhall Coop Drain upstream of Doctors Creek was more than four times that of Doctors Creek itself. Flow downstream of this confluence further increased by another 30% before joining the Taylor River.

The waterways of neighbouring catchments, the Taylor, Fairhall and Omaka Rivers, behave quite differently. While the mid reaches carry surface water all year round, the water of the lower reaches disappears into the river gravels and leaves the catchments as groundwater. The Taylor River, for example, is dry at the New Renwick Road Bridge during the summer months as well as dryer periods during the rest of the year and only flows after significant rainfall.

Unfortunately we do not have continuous flow measurements for Doctors Creek, but a large number of gaugings were carried out just upstream of the confluence with the Taylor River. The closest continuous flow recorder is located on the Taylor River at Borough Weir. However, due to the significant effect groundwater inflow has on the hydrology of Doctors Creek, but not the Taylor River, the flows at the two sites do not correlate well (Figure 11).

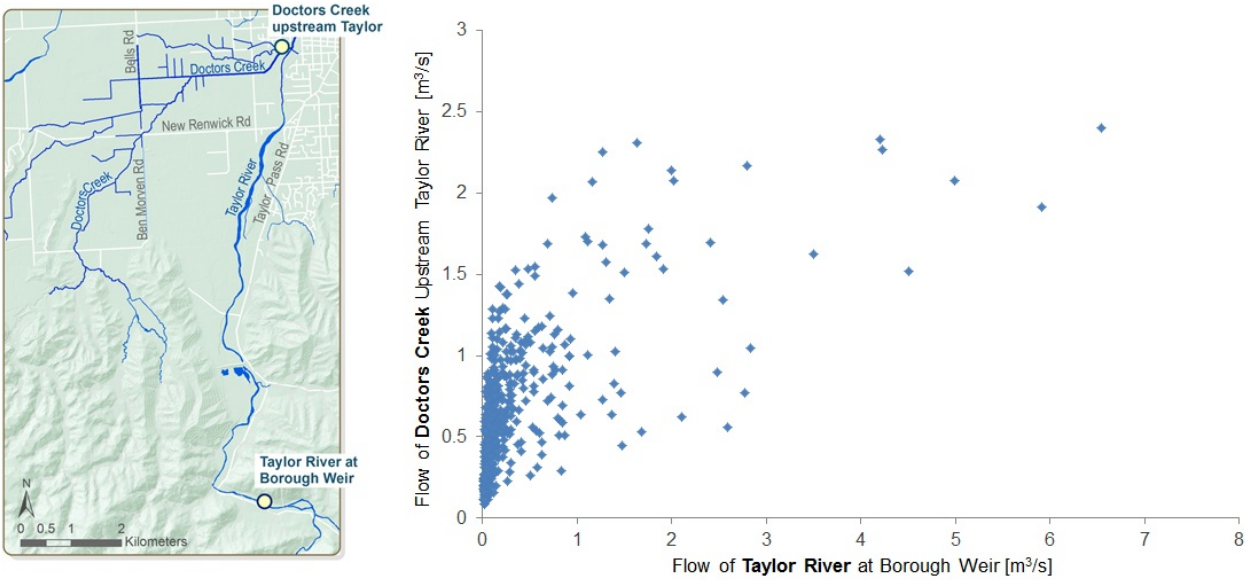

Figure 11: Correlation between the flow in Doctors Creek upstream of the Taylor River and the Taylor River at Borough Weir.

The flow in Doctors Creek does, however, follow the water levels in nearby wells; particularly bore 3010 to the west of the catchment (Figure 12). The good match with this well also indicates the larger contribution of water from the Wairau aquifer in the north to the overall flow in Doctors Creek.

The large influence of groundwater inflow makes Doctors Creek susceptible to the effects of groundwater abstraction in relatively close proximity to the waterway. Pumping of nearby wells reduces the flow in Doctors Creek by either lowering the groundwater level around the well or by direct abstraction from surface water into the bore. A loss of up to 10 L/s from the flow in Doctors Creek has been observed during water abstractions from adjacent bores [35]. The sensitivity of the flow in Doctors Creek to groundwater abstraction increases from Bells Road towards the east, but fortunately the number of wells and the amount of water abstracted decreases in this direction also. In order to retain sufficient flow for the protection of ecological values, a trigger level of 150 L/s upstream of the Taylor River was put in place. At flows below this trigger level, pumping of most wells in the area has to be stopped. However, this excludes the extraction of water for domestic use and the supply of stock water. As a result of resource consent hearing conditions, some other water takes are also excluded.

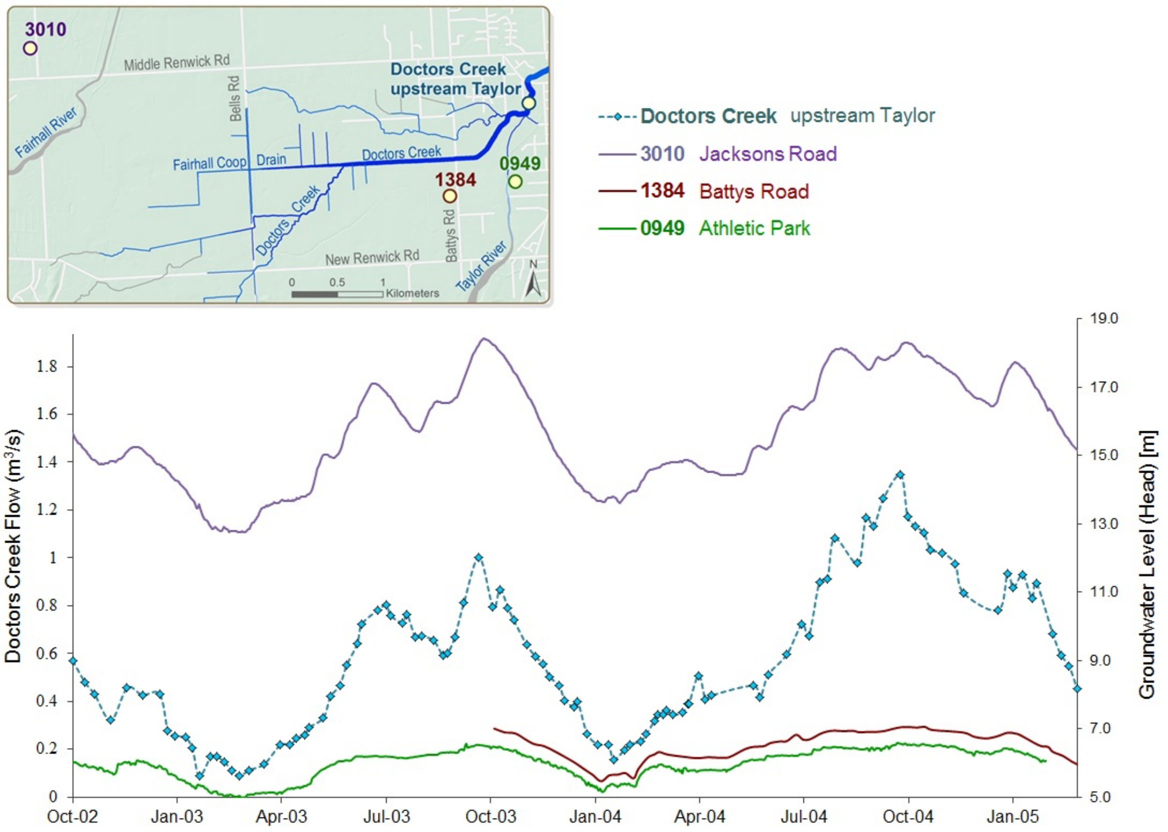

Figure 12: Flow in Doctors Creek upstream of the Taylor River compared to groundwater levels measured in nearby wells.

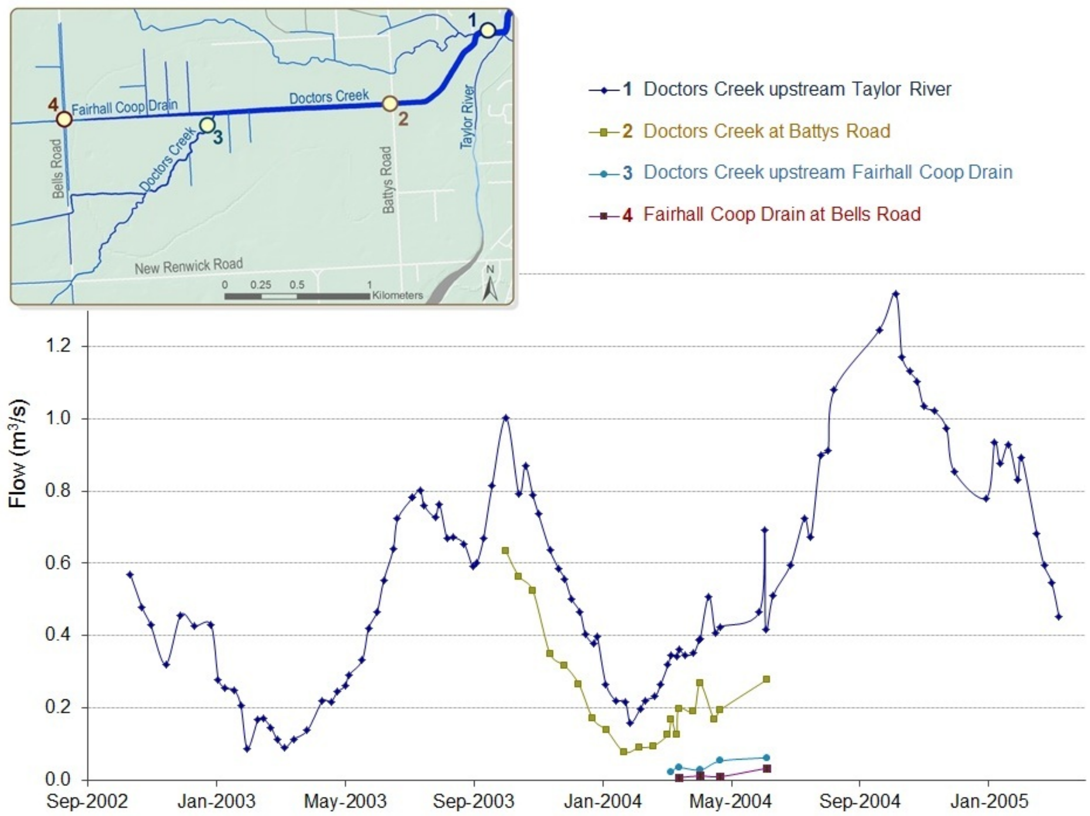

Figure 13: Results from flow gaugings in the northern part of the Doctors Creek catchment.

4. Soils

Soils are an important buffer from the effects of land use on surface and groundwater quality, because of their ability to capture and store nutrients such as phosphorus and nitrogen, as well as pathogens and other contaminants.

Soils of the Paynter series cover most of the low lying areas in the Doctors Creek catchment (Figure 15). These clay-rich soils are often associated with shallow groundwater, which limits root depth and makes soil prone to compaction by animals and vehicles (see structural vulnerability - Figure 15). The very high clay content is responsible for excessive water retention, low aeration and lower soil temperatures. To optimize agricultural potential, an extensive network of surface and sub-surface drainage channels has been installed in most of the low lying areas. Soils above artificial drains often exhibit cracks, which allow water to move quickly through the soil into the underground drainage system [36]. This reduces the contact of infiltration water with the soil, which in turn minimizes the ability of the soil to absorb nutrients and other contaminants. The sub-surface drains discharge directly into Doctors Creek and its tributaries. This means that during irrigation or rainfall, nitrate and other contaminants applied to the surrounding land as fertilizer as well as animal dung enter the waterways with potentially very little soil filtration.

Figure 14: Profile of a Paynter soil.

Soils of the Renwick series are the second largest soil type in the lower Doctors Creek catchment. These soils have a naturally high nitrogen leaching potential (Figure 15). Renwick soils are generally well drained, but shallow.

The more elevated areas of the Doctors Creek catchment are dominated by soils of the Wither series. These soils developed from the loess covering the hills of the southern valleys. A dense subsurface layer of hard soil, referred to as ‘fragipan’, restricts water infiltration and root depth. Although there is generally only a moderate risk for erosion of this soil type, on slopes the risk is increased, which can result in significant removal of soil by rainwater. In an erosion study carried out in 1985/86 ‘Wither Hill 15DH’ soil had some of the highest density of erosion features of the more than 30 soil types monitored [34]. Tunnel and gully erosion can frequently be seen on the hills of the upper Doctors Creek catchment (Figure 16). Soil carried into waterways by rainwater reduces the water clarity during rainfall events and results in the accumulation of fine sediment on the stream bed. This affects the survival of aquatic animals and the very fine sediments are easily moved back into the water column by wind or wildfowl, causing a reduction in water clarity during low flows.Fine sediment is also a potential source of phosphorus.

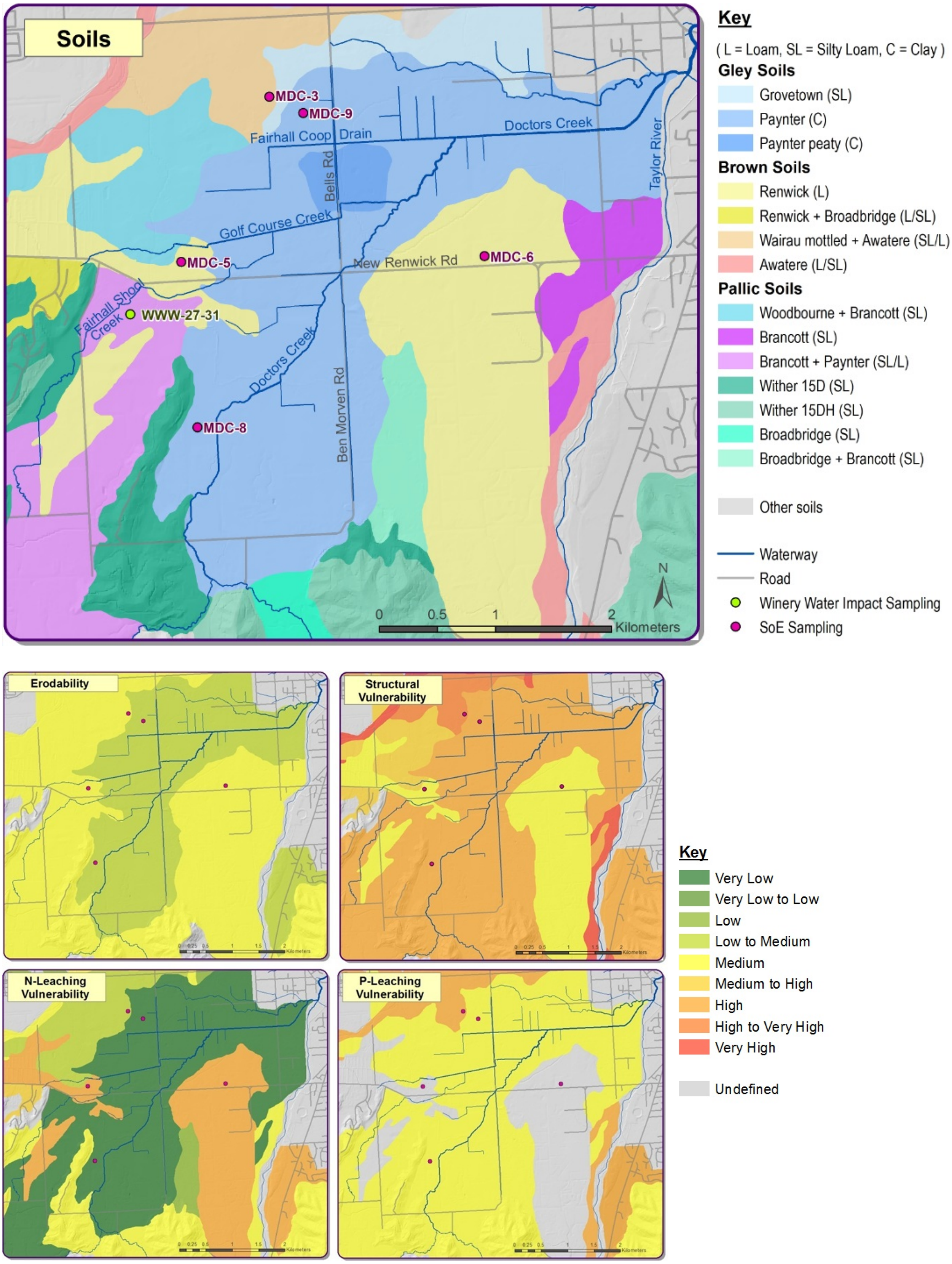

Figure 15: Top: Soil types (i.e. Gley) with soil series (i.e. Renwick) in the lower Doctors Creek catchment; bottom: Soil properties that might affect water quality in Doctors Creek (based on SMap [25]).

Figure 16: Arial photograph showing extensive erosion of an area with Wither-Hill-15DH soil in the upper Doctors Creek catchment.

Brancott soils can be found in the catchment of Fairhall School Creek, which is one of the smaller tributaries of Doctors Creek. These soils are relatively deep and have a high base saturation, which makes them resistant to acidification. Like the Wither soils, a fragipan is limiting rooting depth. Brancott soils have a very low nitrogen leaching potential, but the limited ability to retain phosphorus can lead to an increased risk of phosphorus leaching when waste water or fertilizers are applied at a high rate.

A number of soils in the region are monitored on a regular basis as part of the State of the Environment Soil Quality Monitoring program. Since 2000 soil samples have been collected from an increasing number of sites and sites re-sampled every five to seven years. The objective of the program is to assess soil health and detect trends or changes in soil conditions. Five of the monitoring sites are located in the lower Doctors Creek catchment (Table 1). The samples are analysed for a range of soil chemical, biological and physical parameters. Table 2 shows the results for samples taken in 2000, 2007 and 2012 for sites in the Doctors Creek catchment. Also shown is the target range for individual parameters based on Hill and Sparling (2009) [22] and Taylor (2011) [44]. These were the guidelines used in the assessment of results in the recent Soil State of the Environment reporting [14].

Site	Soil type	Landuse
MDC-3	Wairau fine sandy loam	Dairy*
MDC-5	Renwick silt loam	Cropping
MDC-6	Renwick shallow silt loam	Dryland Pasture
MDC-8	Paynter heavy silt loam	Cropping/Pasture
MDC-9	Paynter heavy silt loam	Dairy*

* Cropping/Pasture in 2013/2014

Table 1: Soil Quality State of the Environment sites located in the lower Doctors Creek catchment. The location of the sites is shown in Figure 15.

Soil pH

Indicator for acidity or alkalinity of the soil.
PH affects nutrient and contaminant availability, plant growth and the functioning of beneficial soil organisms.

Site	2000	2007	2012	Target Range**
MDC-3	6.6	6.4	6.5	5.0 - 6.6
MDC-5	5.7	5.9	5.9	5.0 - 7.6
MDC-6	6.2	6.0	6.1	5.0 - 6.6
MDC-8	7.0	6.2	7.0	5.0 - 7.6
MDC-9	6.4	6.3	6.5	5.0 - 6.6

Total Carbon [%]

Good measure of organic matter in soils.
Organic matter helps retain moisture and nutrients and contributes to soil stability.

Site	2000	2007	2012	Target Range**
MDC-3	3.4	4.0	4.1	3.0 - 12.0
MDC-5	2.35	2.3	2.2	3.0 - 12.0
MDC-6	2.51	3.4	4.5	3.0 - 12.0
MDC-8	2.55	2.9	3.2	3.5 - 12.0
MDC-9	5.2	5.6	3.5	3.0 - 12.0

Total Nitrogen [%]

Important measure of soil fertility.
Most of the Nitrogen is bound in the organic matter. High nitrogen concentration can increase the risk for nitrogen leaching to groundwater.

Site	2000	2007	2012	Target Range**
MDC-3	0.29	0.4	0.38	0.25 -0.70
MDC-5	0.23	0.23	0.26	N/A
MDC-6	0.23	0.35	0.39	0.25 -0.70
MDC-8	0.24	0.34	0.33	N/A
MDC-9	0.51	0.59	0.39	0.25 -0.70

Olsen P [mg/L]

Important measure of soil fertility.
Olsen P is the phosphorus available to plants. Very high values can indicate the potential for phosphorus loss to groundwater and surface water.

Site	2000	2007	2012	Target Range**
MDC-3	26	31	22	20 - 35
MDC-5	46	21	35	20 - 35
MDC-6	27	33	36	20 - 35
MDC-8	50	32	30	20 - 45
MDC-9	87	93	80	20 - 35

Bulk density [t/m^3]

Weight of a specific volume of soil.
Low values indicate increased risk of erosion, while high values indicate soil compaction resulting in reduced water infiltration and increased runoff.

Site	2000	2007	2012	Target Range**
MDC-3	1.4	1.3	1.2	0.4 - 1.4
MDC-5	1.4	1.4	1.6	
MDC-6	1.3	1.3	1.3	
MDC-8	1.3	1.4	1.4	
MDC-9	1.0	1.1	1.3	

Macroporosity [%]

Measure of the proportion of large pores.
It is an indicator of soil compaction. Macropores are important for the airation of soils and the drainage of water. Macropores are usually the first pores to be lost during soil compaction.

Site	2000	2007	2012	Target Range**
MDC-3	4.4	8.9	3.3	6 - 30
MDC-5	7.5	11.8	2.9	6 - 30
MDC-6	14.4	13.1	7.7	6 - 30
MDC-8	5.3	5.4	2.6	6 - 30
MDC-9	3.1	5.4	1.0	6 - 30

Table 2: Results for samples taken in the years 2000, 2007 and 2012 for the sites located in the lower Doctors Creek catchment. Also shown are the target ranges for the individual parameters. (Target Ranges depend on soil type and/or land use)**

Values for soil pH were within the acceptable range for the respective land uses for all samples taken. The lowest pH value was measured for the dryland pasture soil at site MDC-5, which was below the optimal range for pasture growth (5.8 – 6.2) [40] in 2000 and remained close to the lower optimum in later years. About half of all pasture sites monitored between 2007 and 2012 in Marlborough had pH values outside the optimal range [14].

The amount of nitrogen in soil is closely linked with the total carbon content. Total soil carbon is a good measure for the amount of organic matter in a soil and more than 90% of the total soil nitrogen is usually bound in this organic matter. As was observed for other soils under cropping in Marlborough, site MDC-5 had a very low carbon content, with values consistently below the target range [14]. Subsequently, this site also had some of the lowest total nitrogen content of the sites in the catchment. Another site with relatively low carbon content is MDC-8. The soil at this site is a Gley soil and total carbon measurements were consistently below the target range for this soil type.

Site MDC-9, a Gley soil under pasture, had some of the highest values for total carbon and total nitrogen. Very high nitrogen content in soils can result in increased nitrate loss to groundwater, however, measurements for MDC-9 are still well below the upper target limit. Additionally, many other factors influence the amount of nitrogen leached from a soil. These include the carbon to nitrogen ratio of the soil and physical soil conditions, such as soil depth, soil texture and stoniness.

The other main plant nutrient, phosphorus, is measured in soils as Olsen P, which provides an estimate for the phosphorus available to pasture or crops. More than half of the drystock pasture sites, as well as some dairy and cropping sites in Marlborough had Olsen P concentrations below the target range in samples taken between 2007 and 2012 [14]. In the Doctors Creek catchment, none of the sites had Olsen P levels below the target range; instead three of the five sites monitored had at least one sample with Olsen P levels above the upper target limit. One of the pasture soils (MDC-9) had Olsen P concentrations significantly above recommended concentrations in all of the samples taken. However, the soil at this site is of the clay-rich Paynter series which is not prone to phosphorus leachate.

Two of the physical soil characteristics measured as part of the Soil Quality State of the Environment program are bulk density and macroporosity. Low bulk density can indicate an increased risk of erosion; high values are a sign for soil compaction. Low macroporosity is an additional indicator for compaction. Compacted soil has fewer large pores, as the macro pores are usually the first pores to be lost. Soils with reduced pore volume have a limited supply of air to plant roots and reduced water infiltration. Instead of infiltrating into the soil, rain and irrigation water predominantly flows across the land surface into nearby waterways. This run-off picks up soil and contaminants like animal droppings and phosphorus, washing them into the streams, affecting water quality and the in-stream habitat for aquatic life. The only sample from the Doctors Creek catchment with a bulk density above the target range was taken in 2012 from a cropping site, MDC-5. A number of other cropping sites in Marlborough also exceeded the target limit [14]. Nationally, arable cropping and horticultural soils record the highest bulk densities when compared with other land uses [41].

Results of macroporosity show that nearly all of the sites had lost large pores to some compaction. The only site with macroporosity consistently above the lower limit was MDC-6, a dryland pasture site and the only site that is not irrigated. Soils are particularly prone to compaction when moist, which might explain the higher soil compaction at the other sites.

None of the sites in the Doctors Creek catchment had bulk densities below the target range or macroporosities above the upper limit.

Figure 17: Compacted soil with low Total Carbon content under cropping at site MDC-5.

Trace Metals are also monitored as part of the Soil Quality State of the Environment program. While some trace metals are required for plant growth in very small quantities, others have no beneficial effects. These include arsenic and cadmium. At very high concentrations all trace metals can have a negative effect on soil fauna and plant growth and if carried into a water way via soil erosion, trace metals can also affect aquatic life.

Table 3 shows the trace metal concentrations for the sites in the Doctors Creek catchment. None of the samples taken from these sites had levels above the limits suggested by the New Zealand Water and Waste Association [34].

Trace Elements [mg/kg]

Most Trace Elements occur naturally in soils and are required for plant and animal growth in small quantities. High concentrations can have a negative impact on plant and animal health and originate mainly from fertilizer impurities.

Element	Arsenic			Cadmium			Chromium			Copper		
Limit#	20			1			600			100		
Site	2000	2007	2012	2000	2007	2012	2000	2007	2012	2000	2007	2012
MDC-3	6.0	4.0	4.2	0.2	0.2	0.2	16	14	16	19	17	14
MDC-5	4.0	4.0	3.2	0.2	0.1	0.2	18	17	18	17	14	9
MDC-6	3.0	3.0	2.1	0.1	0.1	0.1	18	19	19	12	11	8
MDC-8	3.0	4.0	2.5	0.2	0.1	0.2	15	17	13	13	13	7
MDC-9	6.0	6.0	4.7	0.3	0.3	0.3	23	21	22	24	24	20

Element	Nickel			Lead			Zinc			Mercury		
Limit#	60			300			300			1		
Site	2000	2007	2012	2000	2007	2012	2000	2007	2012	2000	2007	2012
MDC-3	11	10	12	23	24	20	102	83	66			0.03
MDC-5	13	12	12	14	13	11	91	75	68			0.03
MDC-6	13	15	13	11	12	8	69	79	57			< 0.01
MDC-8	9	11	8	13	14	9	75	84	52			0.02
MDC-9	15	14	13	18	16	14	95	94	77			0.04

based on limits suggested by NZWWA 2003

Table 3: Concentrations of Trace Metals in samples taken as part of the Soil State of the Environment program in 2000, 2007 and 2012 for sites located in the lower Doctors Creek catchment.

Another common pressure on Marlborough's soils is the application of winery waste water. The wine industry is a major contributor to the economy and a large proportion of the lower Doctors Creek catchment has been planted in vines. A by-product of the wine making process is winery waste water. Gabzdylova et al. (2009) [11] estimated that in New Zealand, for every litre of wine produced, approximately ten times the amount of wastewater is generated. In Marlborough the application of this wastewater to land is the preferred option of disposal.

A technical report published by the Marlborough District Council in January 2012 investigated the impact of winery wastewater on soils in the region [13]. Twentyseven sites were sampled; one of these was located in the Doctors Creek catchment. At each site several soil samples were taken from areas irrigated with winery wastewater, but also from a nearby area not subject to winery wastewater irrigation – the 'control'. Table 4 shows the results for the site in the Doctors Creek catchment compared to the control site and the regional means.

		pH	Olsen P mg/L	ECf mS/cm	Exchangable Potassium me/100g	Exchangable Sodium me/100g
Control (Doctors Creek)		5.8	13	0.04	0.35	0.22
Winery wastewater appliction	Doctors Creek	5.7 - 6.3	20 - 21	0.02 - 0.04	0.87 - 1.18	0.12 - 0.41
	Regional Mean	6.5	21	0.14	2.2	0.48

Table 4: Results for soil samples (0 - 7.5cm) taken from a site of winery waste water application in the Doctors Creek catchment. Also shown are the result for a soil sample taken from a nearby control site and the regional mean (average) for all sites subject to winery waster application sampled as part of the survey.

As was the case for most sites receiving winery waste water, potassium and sodium concentrations were mostly higher compared to the local control site. Potassium concentrations were particularly elevated, but were still well below the regional mean. Both, sodium and potassium originate from cleaning products used in the winery, but additional potassium originates from grape lee and spent grape juice. When winery waste water is applied to soil, magnesium and calcium ions in the soil are replaced with sodium and potassium ions from the waste water. This can result in the reduction of water and air movement into the soil as the soil particles become less stable and release small clay particles that clog the soil pores [23].

Although winery wastewater application resulted in an Olsen P increase for the Doctors Creek site, this was not observed at other sites in the region. However, Olsen P concentrations are still relatively low compared to some of the pasture sites mentioned earlier.