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Water Quality in the Linkwater Area

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Executive Summary

Linkwater is an area located between the Pelorus Sound/Te Hoiere and Queen Charlotte Sound/Tōtaranui. The hills are covered in native bush at higher altitude and production pine forest on the lower slopes. The river flats are predominantly grazed by dairy cattle. The three largest streams in the area are Cullen Creek, Linkwater Stream and Ada Creek. Cullen Creek and Linkwater Stream are both monitored as part of the State of the Environment programme. The results from this monitoring have shown that water quality is either degraded or at risk from degradation. The Proposed Marlborough Environment Plan (PMEP) requires that Catchment Enhancement Plans are developed for these streams. In order to support future improvement efforts, the causes of water quality degradation need to be known. This was the aim of the study presented in this report.

A total of 33 stream sites were monitored between 2013 and 2017. Ada Creek, the second largest stream in the area, was also included in the study. Monitoring consisted mainly of water quality sampling, but flow measurements and macroinvertebrate sampling were also carried out.

Dissolved Reactive Phosphorus concentrations were naturally comparatively high, but leaching from pasture and release from fine sediment on the stream bed were additional sources. Elevated dissolved nitrogen concentrations in the streams were mainly the result of leaching from dairy pasture.

E. coli concentrations were highest in un-fenced reaches, such as beef pasture and small dairy streams. Surface run-off from cattle races in close proximity to waterways was another source of faecal contamination. This run-off was also a source of fine sediment in waterways. Additional sources of sediment were erosion of bare soil under dense pine forest and vehicle crossings, such as a road ford across Cullen Creek.

Of the three catchments monitored, Ada Creek generally had the best water quality. The main reasons were good riparian management for most of the stream length and less intensive irrigation of dairy pasture. Linkwater Stream had the poorest water quality. Livestock access to waterways, surface run-off and erosion were the main causes of degraded water quality. Nitrogen in upwelling groundwater in the lower reaches of Linkwater Stream was the source of the highest Dissolve Inorganic Nitrogen concentrations monitored during the study.

The report makes several general recommendations for improving stream water quality in the Linkwater area. Enhancement efforts should not be restricted to the streams monitored. The causes of degradation identified in this study also affect other streams in the area.

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1. Introduction

Linkwater is located between the Queen Charlotte/Tōtaranui and Pelorus/Te Hoiere Sounds. At the narrowest part it consists of five kilometers of low-lying flats. Mount Duncan forms the highest point of three large catchments, Cullen Creek, Linkwater (Duncan)[1] Stream and Ada Creek. The largest stream is Cullen Creek, which drains into the Mahakipawa Arm of the Pelorus/Te Hoiere Sound. Linkwater Stream and Ada Creek drain to the East into the Queen Charlotte Sound.

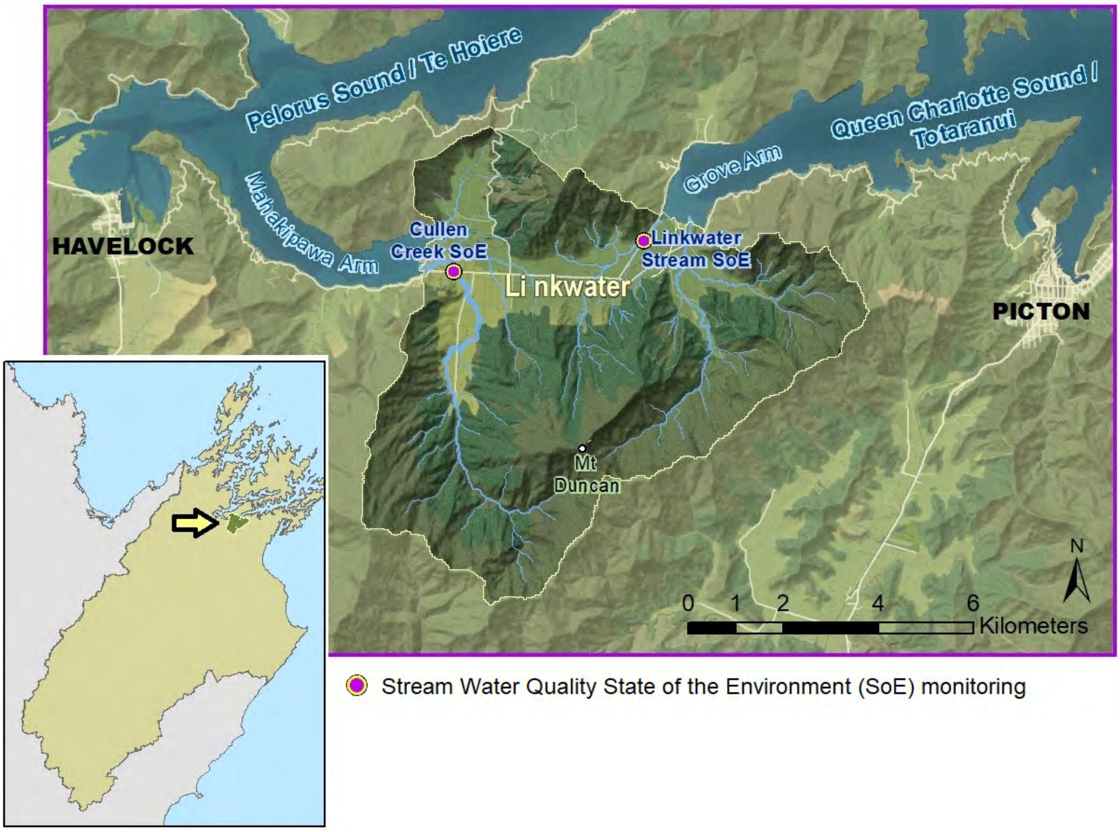

Figure 1: The Linkwater catchment area with the two SoE monitoring sites on Cullen Creek and Linkwater Stream.

The higher elevations are covered in regenerating native bush. The lower slopes have been planted in production forest and the river-flats have been converted to pasture. Linkwater has the highest proportion of dairy pasture in the Marlborough Sounds. Currently, more than 80% of its pasture is grazed by dairy cattle.

Cullen Creek and Linkwater Stream are monitored monthly as part of the State of the Environment (SoE) programme. The monitoring sites are located near the mouth of each stream. The results from this monitoring show that water quality in Cullen Creek is generally better than in Linkwater Stream. Both streams are classified as having fair or marginal water quality. Linkwater Stream is listed in the Proposed Marlborough Environment Plan (PMEP) as a degraded waterbody, while Cullen Creek is listed as a waterbody that is at risk of degradation. The PMEP requires the development of Catchment Enhancement Plans for these streams. However, before water quality can be improved, the sources causing degraded water quality need to be known. This report presents a summary of investigative sampling carried out over several years form 2013 until 2017. Additional flow measurements were planned for 2018/2019, but could not be completed.

There are number of contributing factors that influence water quality. These include Geology, Soils, Hydrology and Landuse. The initial sections of this report provide a short overview of the available information on these aspects of the Linkwater area.

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[1] In some earlier reports Linkwater Stream is called Duncan Stream.

2. Geology

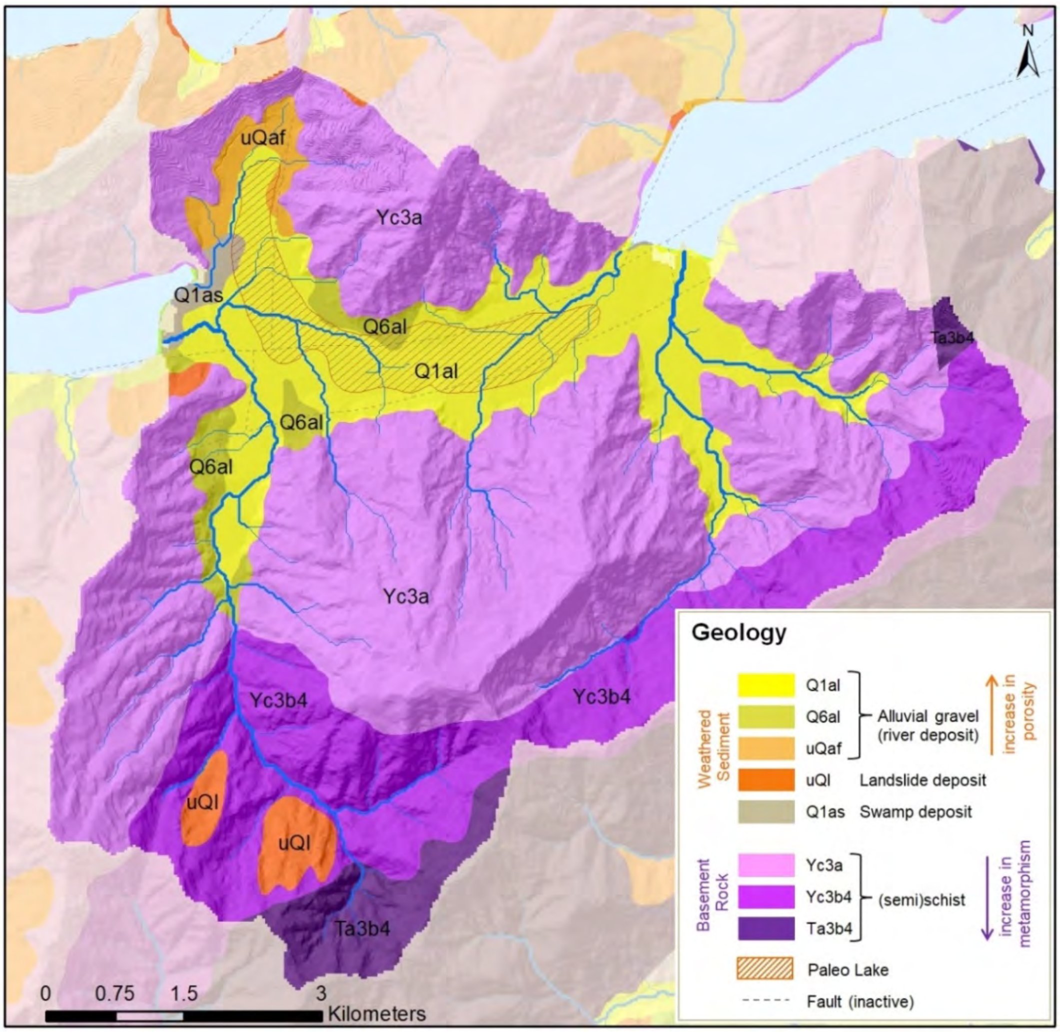

Figure 2: Geology of the Linkwater area.

The underlying basement rock in the Linkwater area is Haast Schist of the Caples terrane (Figure 2). The Schist was originally a mixture of continental, oceanic and volcanic sediment, which had accumulated on the ocean floor, off the East coast of the Gondwana Super-continent [7]. Between 250 to 290 Million years ago the shift in tectonic plates caused the ocean floor to be moved towards Gondwana (Figure 3). The oceanic crust was thrust under the much thicker continental crust of Gondwana. The ocean floor was folded and compressed and parts accreted onto the continental crust. The increased pressure and heat during this process caused partial melting and recrystallization of both crusts. The sedimentary rock was metamorphed into schist. The greater the heat and pressure during this process the greater the metamorphism. This created a succession of rock from the weakly metamorphed semischist that forms the basement rock of most of the Linkwater area to the more metamorphed schist in the upper parts of Cullen Creek. The degree of metamorphism in schist is represented by chlorite grades, ranging from I - IV. The chlorite grade of the Linkwater schist is referred to as Chlorite III, which is characterised by a distinct layering. In these higher grade schists the original laying of the sediments was completely destroyed during metamorphism and is not associated with the current layering in the schist. During metamorphism, the pressure from the overlying rocks caused the minerals to form on the surfaces most affected by the pressure. Micas[2] and green chlorite are the first crystals to grow under these conditions [35]. Both of them have a flaky appearance and can easily be split. Micas are also the minerals most easily eroded into clays. This means that not only soil, but the actual basement rock is highly erodible. This is evident in frequent slips observed along roads in the Marlborough Sounds following heavy rainfall.

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[2] The Marlborough Schist is a quartz-albite-muscovite-chorite schist. Muscovite is the mica mineral in the schist.

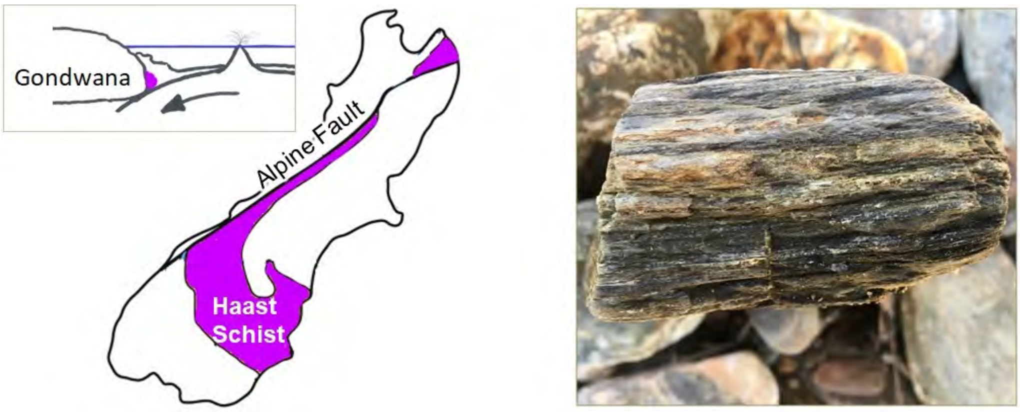

Figure 3: Formation and distribution of Haast Schist. The photo on the right shows an example of the chlorite III schist found in Linkwater.

During the transformation into schist, metallic particles that were scattered within the rock came together. This resulted in the formation of gold deposits [35]. Over time, these deposits were eroded away, but the eroded gold accumulated in the gravels of rivers and streams, particularly in Cullen Creek.

The Haast Schist of the Marlborough Sounds is also found in Otago and was moved along the Alpine Fault over a distance of 480 kilometers (Figure 3).

The Marlborough Sounds are made up of a series of tilted blocks sandwiched between fault lines that are roughly parallel to the Wairau fault. These faults formed in the recent 24 million years. The Linkwater area is divided into blocks by two faults. However, these faults have not been active since the previous warm period, 70,000 years ago.

Rivers cut into the basement rock forming steep-sided valleys mainly when the land was lifted up until 5 million years ago [30]. The rivers filled the lower parts of their catchments with erosion material referred to as alluvial gravels. During the latest ice age, the Otiran glacial period 14,000 to 70,000 years ago, the Te Hoiere/Pelorus River was flowing along the Kaituna Valley into the Wairau River and there have been suggestions that a tributary flowed westwards across the Linkwater flats from the valleys that now form the Queen Charlotte Sound/Tōtaranui. This comparatively large tributary would have caused significant deposits of well sorted river (alluvial) gravel. However, the gravels in the Linkwater area are more typical of deposits from the smaller, local streams [27]. Bore logs show poorly sorted gravels to depths of up to 80 meters with increasing clay and silt deposits towards the Queen Charlotte Sound/Tōtaranui [27]. It is therefore unlikely that a large river flowed across Linkwater.

The Sounds started to subside and tilt North-East approximately 1.5 million years ago. Following the last ice age, the climate warmed and sea level rose until 7,500 years ago [30]. The sea rose over 100 meters before reaching its current level [21]. This is considered to be the main cause for the drowning of the river valleys [30] which give the Marlborough Sounds their characteristic shoreline.

Bore holes show that the Linkwater area was never covered by the sea, however several bore logs have a layer of blue coloured[3] organic material, which is the result of a former lake or swamp. This lake covered a large area of the low-lying flats during the last ice age [27]. The lake was likely formed as a result of gravel deposited by Cullen Creek, cutting off the flow of one of the streams from the mid catchment that were flowing towards the Pelorus/Te Hoiere Sound at that time. Flow direction as it is seen today, is a result of the tilting of the land toward the northeast. This tilting is also the reason that the north-flowing rivers have larger catchments and subsequently greater flows than the streams flowing south.

Apart from Cullen Creek, all streams flowing into the Mahakipawa Arm, enter the sea via a swampy area north of Cullen Creek (Q1as sediment). Although not shown on geological maps a small area of similar swamp deposits is likely to be present along the eastern edge, where streams flow into the Queen Charlotte/Tōtaranui Sound.

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[3] The blue colour is a result of the reduction of iron oxides when organic material is present

3. Soils

The Haast schist parent material developed into different soils depending on a variety of influencing factors including altitude and slope. Weathering of the schist and schist-based gravels on the low-lying flats is extensive and has likely occurred since early warm-periods between ice ages [23]. The soils are therefore relatively deep.

Information on soils in the Linkwater area is limited. Soil maps are based on a 1960 survey, which was mainly based on landform. It was acknowledged in the publication, that 'the survey does not give more than a general picture of the soil pattern' [28]. The soils of the river flats were assigned to the Koromiko soil series, while most of the soils on sloped land was grouped into the Kenepurū soil series. Unfortunately, the characteristics of the soil units assigned were not well defined. In order to improve our knowledge of soil characteristics in the region, Marlborough District Council (Council) has carried out several soil surveys. This included nine auger observations across two transects in the Linkwater area [13]. Only the western flats of the Linkwater area were included in this survey. The survey identified three different soils in the river flat; one Recent soil, the Koromiko, and two Brown soils, the Kaituna and Manaroa [13] (Figure 4).

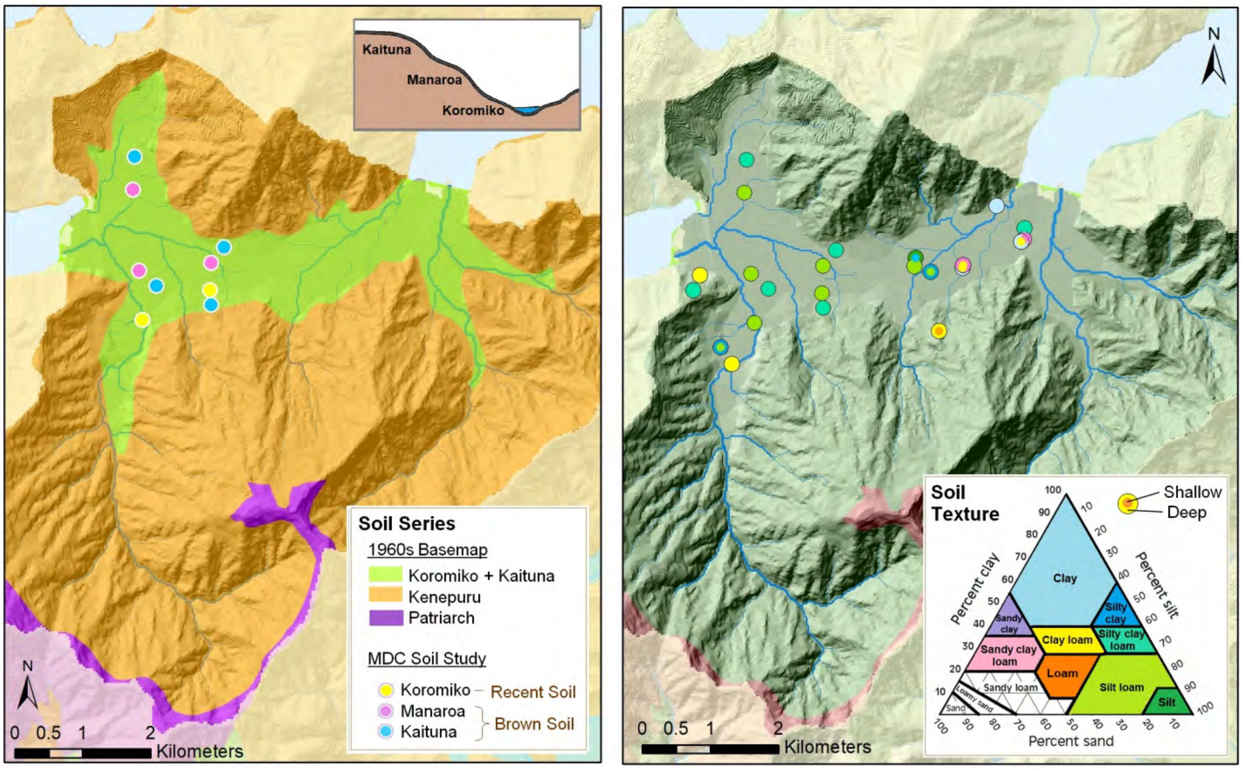

Figure 4: Soils Series and Soil Texture in the Linkwater area. Soil textures are based on the MDC soil survey and resource consent information.

The soils encountered during the Linkwater survey were all deep and well drained, with good water holding capacity. This means that the risk of direct losses from application of dairy effluent is generally low. However, the risk on the recent Koromiko soils is higher. The ability of the soils to retain phosphorus was categorised as moderate.

Brown soils are the most abundant soil type in New Zealand, covering roughly 43% of the country. The brown colour is a result of iron oxide that coats the soil particles. Brown soils usually have a loamy texture. The texture or grain size of soil particles is an important factor influencing the erodibility of soil. Clay-rich soils are generally quite resistant to erosion as the clay tends to bind the soil particles together. In contrast, soils high in silt and fine sand tend to erode more easily. Loamy soils, which are dominated by silt and very fine sand are therefore most erodible.

Soil erosion has major impacts on the ecological health of streams, particularly if the eroded material settles on the bed of streams or estuaries. Eroded soil also introduces phosphorus into the water column, which can cause an increase in algae growth in the stream and the marine environment.

Information on soil texture obtained during the Council soil survey and from resource consent applications, shows that most soils are silty or loamy (Figure 4). This means that erosion risk is quite high. The subsoils are more erodible than the top soil with more dispersive clay [22]. This means erosion increases if the subsoils are exposed, such as during the cutting of forestry roads.

Soils at higher altitude are well studied concerning erosion risk, but there is little information on soil characteristics. Above 200m the soils likely developed from weakly weathered erosion material formed during the ice ages when vegetation cover was sparse [23]. On steeper slopes, erosion and down-hill water movement results in relatively shallow soils, compared to the deep soils found on the flats.

4. Groundwater and Hydrology

Groundwater resources in the Linkwater area are comparatively well studied and were summarised in a 2009 GNS report [27]. The focus has been mainly on Cullen Creek. Cullen Creek is the largest stream in the area and the gravels associated with it likely contain the most important groundwater resource. There is very limited information on the groundwater resources associated with the river gravels of Ada Creek, which is the second largest stream in Linkwater. However, it can be assumed that Ada Creek gravels are similar to those of Cullen Creek. The gravels that fill the lower river flats of these two waterways are quite deep, but are poorly sorted. This means that wells are generally not very high yielding unless the well taps into an old stream channel. Well logs show sands, silts and clay-bound gravels to depths of up to 80m [8] (Figure 5). Some well-logs also contain layers of fine lake sediment and peat.

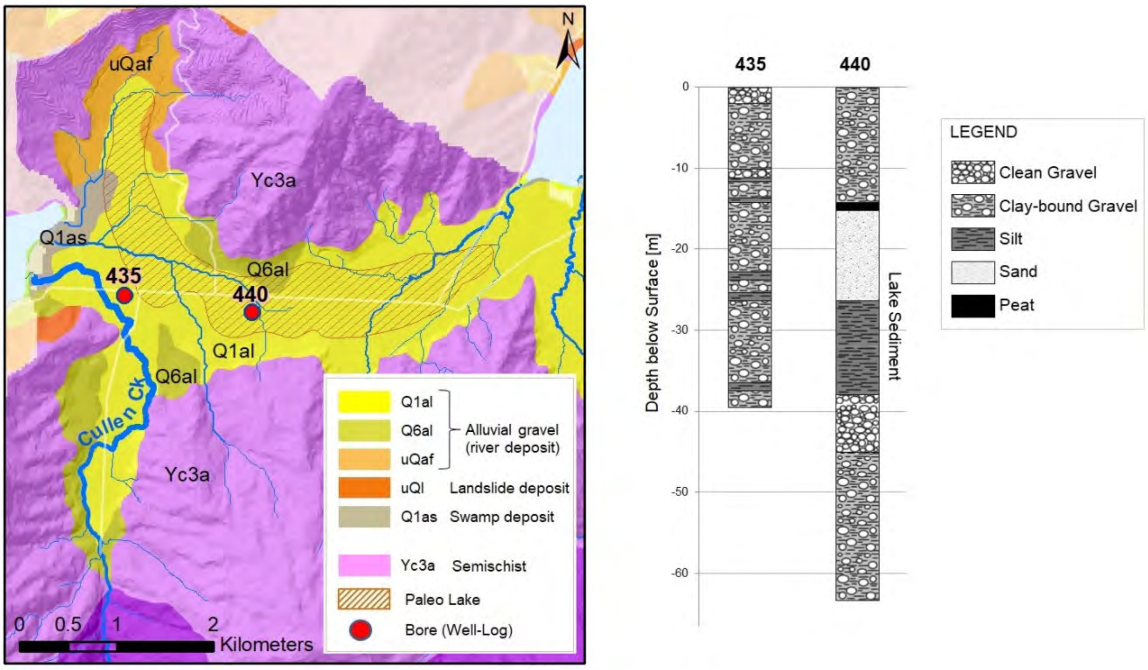

Figure 5: Examples of well-logs from bores drilled into the alluvial gravel in the Linkwater area.

Shallow groundwater wells show immediate response to rainfall. This means shallow groundwater is relatively young and consists mainly of rainfall that recently infiltrated the ground [8]. Apart from water-bearing gravel layers, the schist underneath the gravels also contains large amounts of groundwater in fractures, cracks and crevices [27].

The age of groundwater ranges significantly from 3 to 110 years, with a general increase in age with depth [8]. Water samples taken from Cullen Creek had mean residence times of less than 3 years indicating that the stream is mainly fed by rainfall recharge [27].

The underlying geology has significant effects on the surface flow of streams in the area. The two larger streams, Cullen and Ada Creek produce gravels with less fine sediment allowing better groundwater flow as the smaller particles are washed out of the gravels. This results in a substantial loss of surface flow into the underlying gravels. During long dry spells, the entire surface flow of the lower parts of Cullen Creek and Ada Creek is lost and the stream bed is dry. The much smaller Linkwater Stream flows continuously throughout the year. This is caused by fine sediment that was deposited on the bottom of a former lake (Paleo Lake, Figure 6). The lake sediment acts as barrier for groundwater and stops loss of surface flow to the deeper gravels. Field observations indicate that groundwater was rising back to the surface in the lower parts of Linkwater Stream. The lower paddocks were often waterlogged, with small emerging springs above the height of the water level in Linkwater Stream.

Only a small number of flow measurements were available for the streams in the Linkwater area. The flow of Cullen Creek was measured on a number of occasion in the 1980s at the Queen Charlotte Drive Bridge on the same day as the Kaituna River to the west. The Kaituna River has a significantly larger catchment reaching further to the south. Still, the small number of data points suggests that flows correlate well.

Flow data was particularly sparse for Linkwater Stream and Ada Creek. To obtain a better understanding of the hydrology of these two streams, flow was measured along several sites in June 2017 (Figure 6). These flow measurements represent high (winter) baseflow conditions.

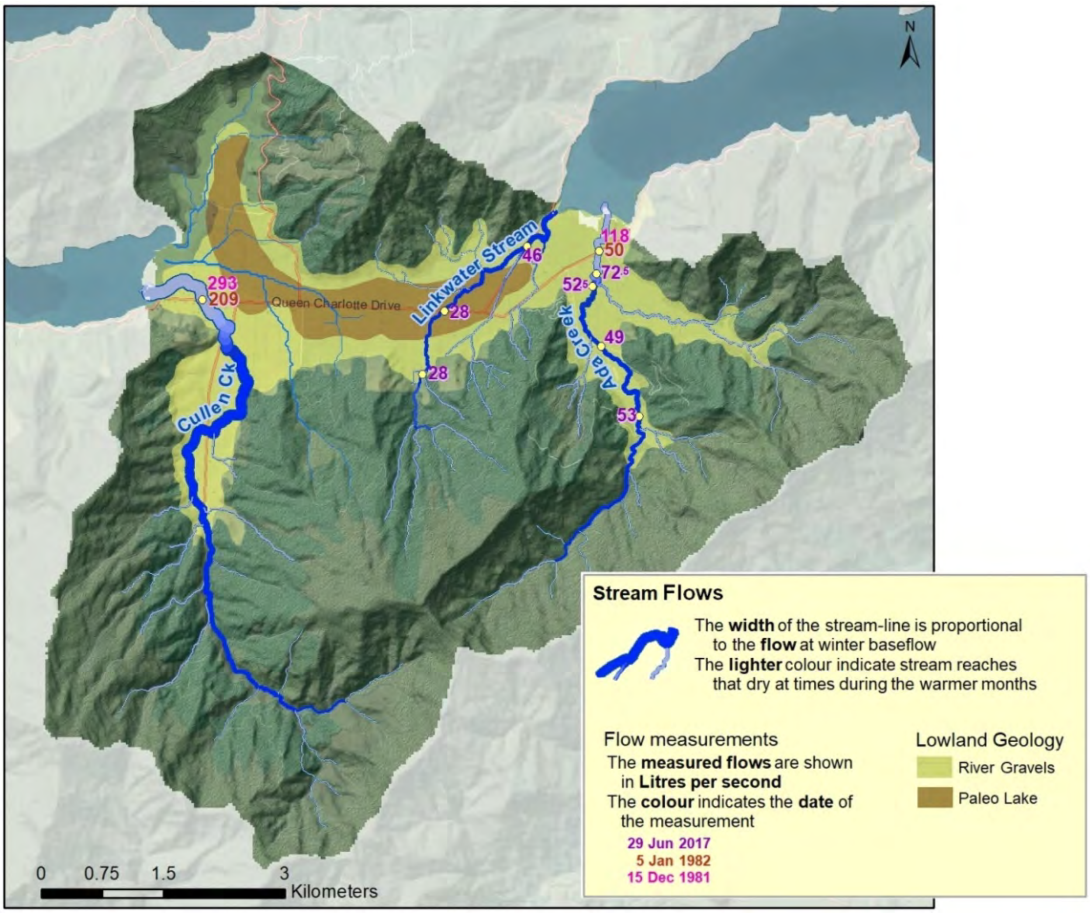

Figure 6: Winter base-flow of the three largest streams in the Linkwater area.

Flows of the most upstream sites of both streams were proportional to the catchment area. Specific discharges were very similar with 7.5 L/s/km^2 for Ada Creek and 7.9 L/s/km^2 for Linkwater Stream. Ada Creek had already flown a short distance through an area with a shallow layer of river gravels explaining the slightly lower specific discharge. The flow in the mid reaches of both streams changes very little, indicating a steady loss of surface flow to the river gravels. Increased flows in the lower reaches are mainly the result of tributary streams.

In the early 1980s the lower Ada and Cullens Creek were gauged on several occasions at the Queen Charlotte Drive. These flow measurements show that Cullen Creek loses proportionally less flow to the gravels compared to Ada Creek. During conditions similar to recent gaugings, the specific discharge of Cullens Creek was two to three times higher than that of Ada Creek.

5. Landcover and Landuse

Land use activities have the greatest influence on water quality. The Linkwater area is currently dominated by three land uses. Native vegetation and production forest in the hills and pasture on the river flats. Most of the pasture is grazed by dairy cattle with only small areas grazed by beef.

Figure 7: Current Landuse in the three largest Linkwater catchments.

The Linkwater area was originally covered in podocarp forest, which included Kahikatea, Totara, Matai and Rimu [30], similar to the forest still found in parts of the Te Hoiere Pelorus catchment. At higher altitude (above 500m) the vegetation was dominated by beech and Kamahi with occasional Southern Rata [30].

Ngāti Mamoe, resident at the time of Cook's arrival, only cultivated some of the shoreline flats [1]. Widespread clearance of the native forest began with the arrival of the first European settlers. Initially the flatter land was cleared for timber, which was used to finance the establishment of pastoral farming [1]. There were five sawmills operating in the Linkwater area during the 1860's. By 1870 the land had been converted to ploughed fields and the mills had moved to the Pelorus and Kaituna Rivers [1]. By 1910 nearly two thirds of the flat land in the Marlborough Sounds had been cleared [1].

Following the logging, the remaining vegetation was burned to establish pasture for sheep and cattle. The ash provided initial fertility for good pasture growth, but by the 1950s the fertility of the land had declined to the point where fertilizer needed to be applied to continue farming. The combination of low soil fertility, steep topography, poor road access and insufficient supply of freshwater led to the abandonment of large areas of pasture, which were left to revert back to native bush [24]. Today, native vegetation is mainly restricted to higher altitude and consists almost entirely of regenerating bush [7].

In 1888, the first gold was discovered west of Linkwater and later in Cullen Creek. Up to 1,000 miners lived in the township of Cullensville located on the mid reaches of Cullen Creek [21]. The small township included a bank, a courthouse, three hotels, five bakeries, a butchery, blacksmiths, billiard saloons and a school [6, 7]. Unfortunately, none of the buildings remain, but signs mark the location of some. Approximately three kilometres of Cullen Creek was worked, but the mining was comparatively short lived and suffered from periodic flooding.

Establishment of production forest began mainly in 1963 with Pine (*Pinus radiate*) as the predominant tree species planted [18]. The majority of the pine forest is now in its second rotation with large areas ready to be harvested again.

6. Stream Water Quality

6.1. State of the Environment Monitoring

Cullen Creek and Linkwater Stream are sampled monthly as part of the regional State of the Environment (SoE) programme. Sampling is carried out at the bottom of the catchment, but upstream of tidal influences. This allows assessment of catchment-wide, cumulative influences on water quality.
The results of the SoE programme are presented using the CCME Water Quality Index. The index is a number between 0 and 100, with higher values representing better water quality. Based on the index, water quality can be categorised into five different classes. The classes "fair", "good" and "excellent" represent acceptable water quality, while water ways in the "marginal" and "poor" categories need to be improved where possible.

Figure 8 shows the water quality indices for all sites monitored as part of the SoE programme. CullenCreek and Linkwater Stream are highlighted in yellow and it can be seen that both streams had marginal water quality. This prompted a catchment characterisation study with a focus on water quality. The following sections present the results of this study.

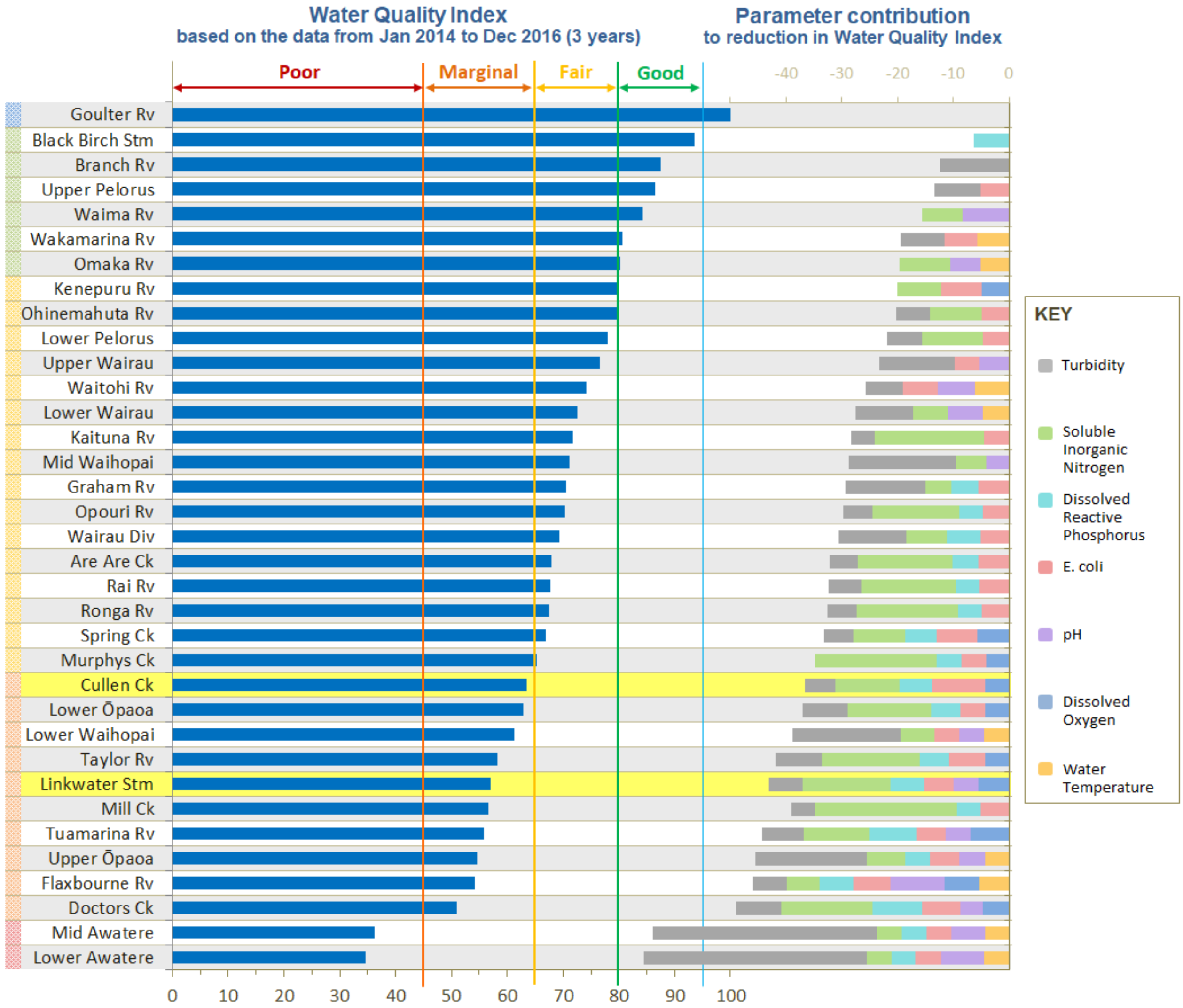

Figure 8: Water Quality Indices for all sites monitored as part of the State of the Environment programme. The sites are ranked from highest Water Quality Index at the top and lowest index at the bottom. The blue bar on the left side of the graph shows the values of the Water Quality index. The right side of the graph shows the contribution that the different parameters (see KEY) have on the reduction of the water quality index.

6.2. Water Quality Study

In order to identify the causes of degraded water quality a number of additional sites were sampled. The study focused on the three largest catchments, Cullen Creek, Linkwater Stream and Ada Creek. It can be assumed that land use practices that cause water quality degradation in one of these catchments are also impacting on the water quality of White Pine Creek and smaller streams in the north-west of the Linkwater area.

A total of 33 sites were sampled (Figure 9), with 26 of these sites sampled several times. Sampling was restricted to base flow conditions. Water quality is highly variable during flood events, making representative sampling very difficult. Additionally, analysis of the SoE data for Cullen Creek and Linkwater Stream showed that water quality remained marginal if samples that were taken during flood flows are removed from the calculation of the water quality index [18].

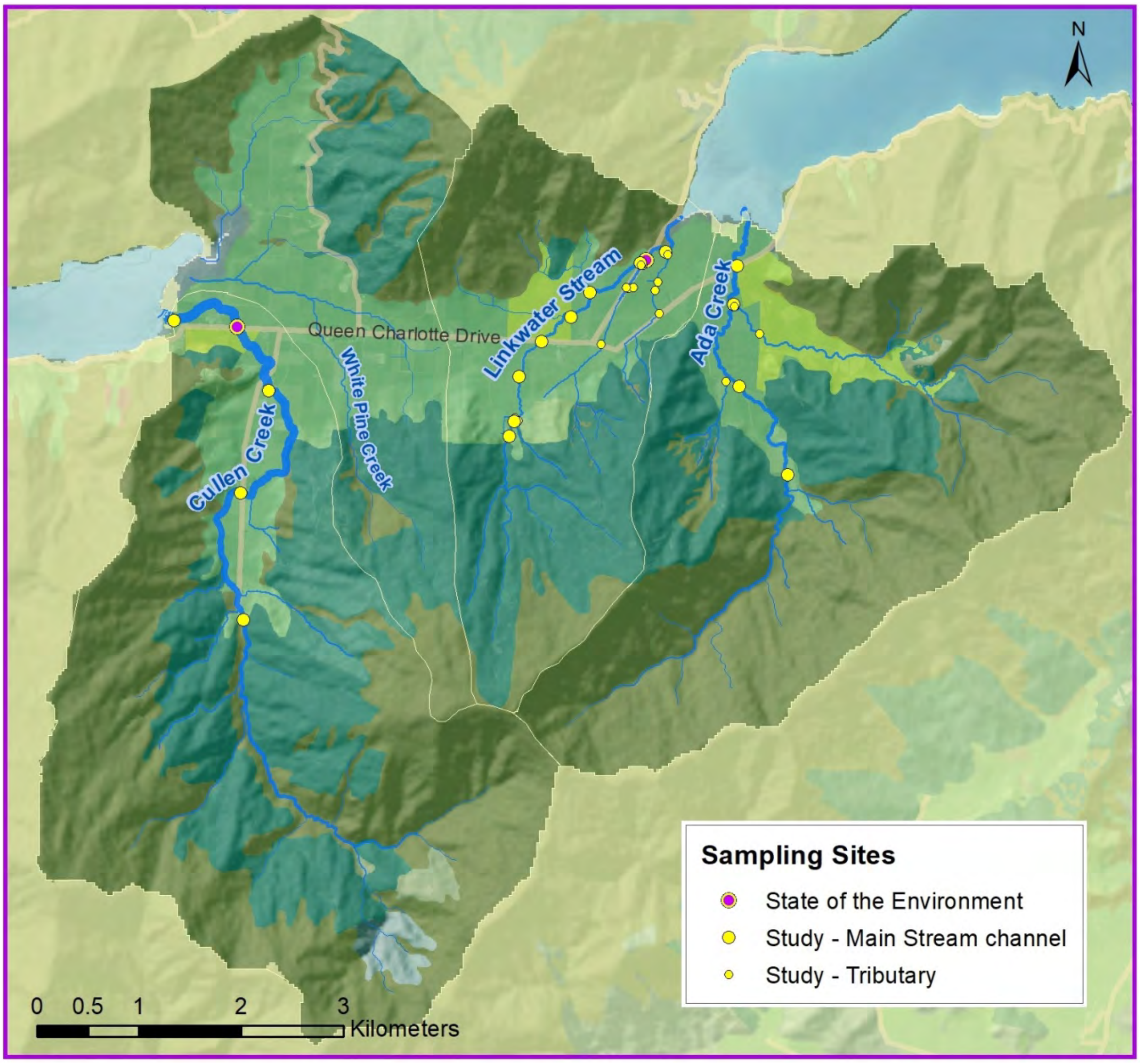

Figure 9: Sites sampled as part of this study.

The following sections present the results for parameters that were identified through the SoE programme as contributing to degradation in water quality.

6.2.1. Dissolved Inorganic Nitrogen (DIN)

Nitrate, ammoniacal nitrogen and nitrite are the forms of nitrogen that are easily taken up by plants. They are collectively referred to as ‘Dissolved Inorganic Nitrogen’. In surface water and shallow groundwater most of the Dissolved Inorganic Nitrogen is in the form of nitrate. In well oxygenated water nitrate is the most stable form of dissolved nitrogen and the other two forms, ammoniacal nitrogen and nitrite are quickly oxidised into nitrate by aquatic bacteria

Any nitrogen in animal waste or nitrogen fertilizer applied to land that is not taken up by vegetation is potentially carried into groundwater by rainfall or irrigation water. Very high nitrate concentrations (> 11.3 g/m^3) can make groundwater unsafe for human consumption as nitrate interferes with oxygen transport in the blood of very young children (‘Blue-Baby-Syndrome’). In waterways, high nitrate concentrations can be toxic to some aquatic animals, including fish and koura (freshwater crayfish). The limit of 1.5 g/m^3 for nitrate in the National Policy Statement for Freshwater Management 2017 is based on this toxicity [29].

At lower concentrations nitrate and the other forms of soluble inorganic nitrogen can cause nuisance algae growth on the stream bed. This is not only visually unpleasing, but the algae also smother available habitat for many aquatic insects, which in turn are food for fish. This can cause a significant reduction in biodiversity. The guideline of 0.165 g/m^3 for Dissolved Inorganic Nitrogen used in this report is based on this effect and is also the guideline value used for State of the Environment reporting [3, 15].

Figure 10 shows the Dissolved Inorganic Nitrogen concentrations (DIN) at the two SoE sites on Cullen Creek and Linkwater Stream as well as measurements from a monitoring bore near Cullen Creek (Well 0447). All three sites have concentrations generally above the guideline for prevention of nuisance algae growth, but do not reach toxic levels. Well 0447 is located in close proximity to Cullen Creek and represents shallow groundwater. The data shows that nitrogen concentrations in the well are significantly higher than in Cullen Creek. This means that groundwater inflow is likely to be the main cause of high DIN concentrations in the creek. This is not unusual. In most catchments leaching of nitrogen from pasture and other land uses cause elevated DIN concentrations in groundwater and subsequently streams and rivers. Leaching is the process by which rainfall or irrigation water dissolves nutrients and other contaminants from organic material or fertiliser deposited onto land. If sufficient water is supplied, the water will carry the contaminants into the ground beyond the reach of plant roots and into groundwater[4]. During baseflow conditions, most of the water flowing in stream is subsurface flow or groundwater that re-emerges to the surface. Cattle urine has been found to be a major source of leached nitrogen [24]. Nitrogen leaching is therefore higher under dairy pasture compared to pasture grazed by sheep. Leaching losses are lowest under forestry and native bush. This means that large areas of forest can provide dilution of nitrogen input from pastoral farming. Cullen Creek has a greater proportion of the catchment in native bush or forestry compared to Linkwater Stream (Figure 7). This is the reason for the higher DIN concentrations observed in Linkwater Stream.

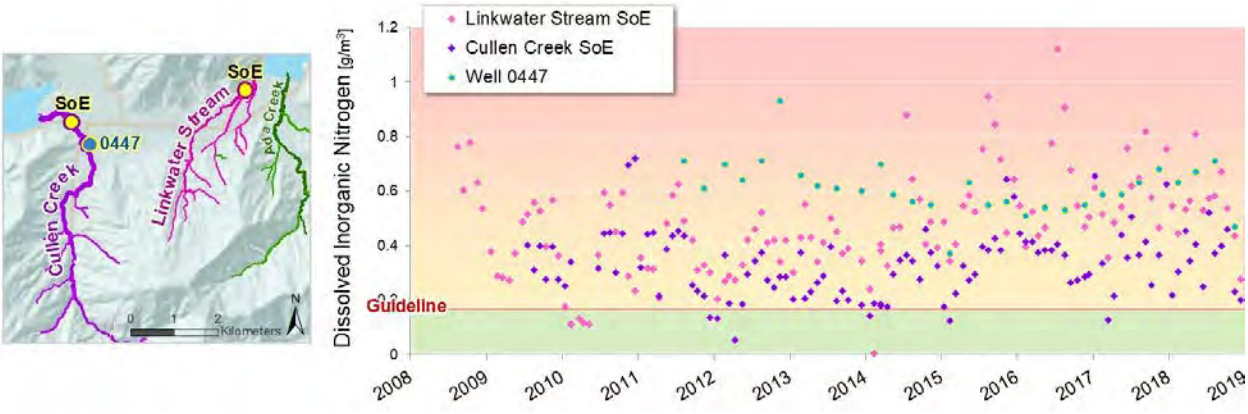

Figure 10: Dissolved Inorganic Nitrogen (DIN) concentrations at the two SoE sites and Well 0447.

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[4] Similar to the way tea leaches out of a teabag. The hot water dissolves organic substances from the leaves in the teabag and carries them outside of the bag.

Because the main source of nitrogen for all streams in the Linkwater area is leaching from dairy pasture, the two SoE sites could be expected to have DIN concentrations that are well correlated. However, this is not the case. This is likely caused by differences in the underlying geology. The gravels in the Cullen Creek catchment tend to allow groundwater to flow more freely, compared to the river gravels underlying Linkwater Stream which is influenced by the presence of impermeable lake sediment (see Section 4).

Figure 11 shows the DIN concentration observed during the study. DIN levels in the upper catchments dominated by native bush and forestry were as expected, very low. All three streams showed a consistent downstream increase in DIN concentrations. This is not surprising, as the influence of dairy pasture becomes greater downstream. However, the rate and magnitude of the increasing DIN concentrations varied significantly between the streams.

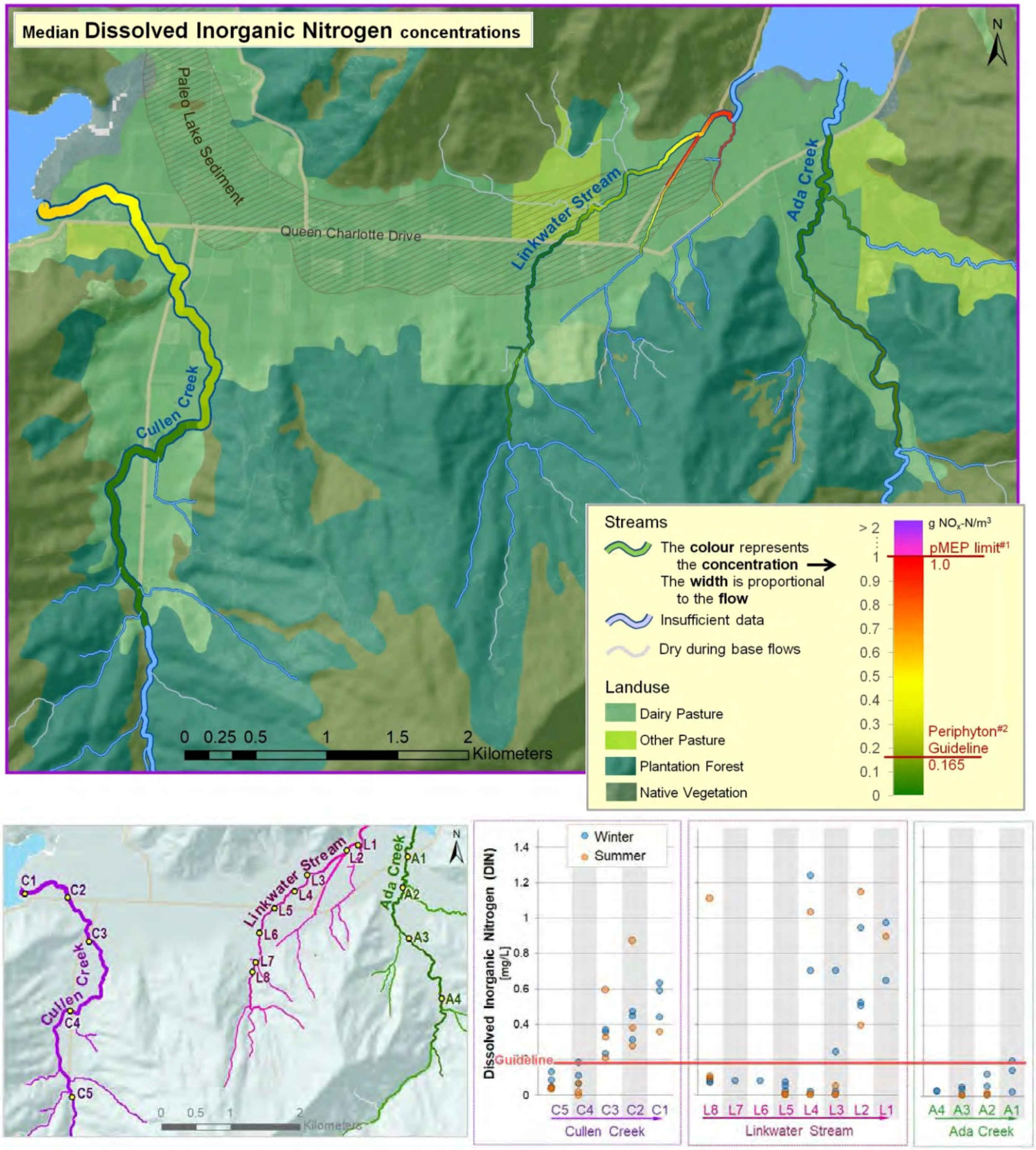

Figure 11: Dissolved Inorganic Nitrogen (DIN) concentrations measured in the streams of the Linkwater area during the study.

DIN concentrations in the lower parts of Linkwater Stream were more variable compared to the other two waterways. This indicates direct inputs of nitrogen in addition to leachate from pasture. The greatest variation could be seen downstream of a small area of beef pasture (Site L4). This strongly points to animal droppings in the waterway as the source of the additional nitrogen. This part of the stream is not fenced, which allows animals to enter the waterway. The two sites in the lowest reaches of Linkwater Stream (L2 and L1) had the highest DIN concentrations. Although leaching is likely to be the main reason, the steep increase in DIN levels over a relatively short distance warranted further investigation. A number of additional samples were taken from waterways in the lower Linkwater area during the colder months when DIN concentrations tend to be highest. The investigation revealed a number of small springs. This upwelling of groundwater roughly coincides with the thinning of sediment from a former lake in this area (see Section 4) that impedes groundwater flow further upstream.
The upwelling groundwater had very high DIN concentration

Figure 12). However, DIN levels decreased again where Linkwater Stream and one of its tributaries flowed through water-logged paddocks. These paddocks would have originally formed a wetland and were still performing some of the cleaning functions associated with wetlands. The high water level causes a lack of oxygen in the soil. Under these conditions, dissolved nitrogen is converted into a gaseous form. The process is called denitrification and removes nitrogen from the water, releasing it into the air. This causes the decrease in DIN levels observed in the lowest reaches.

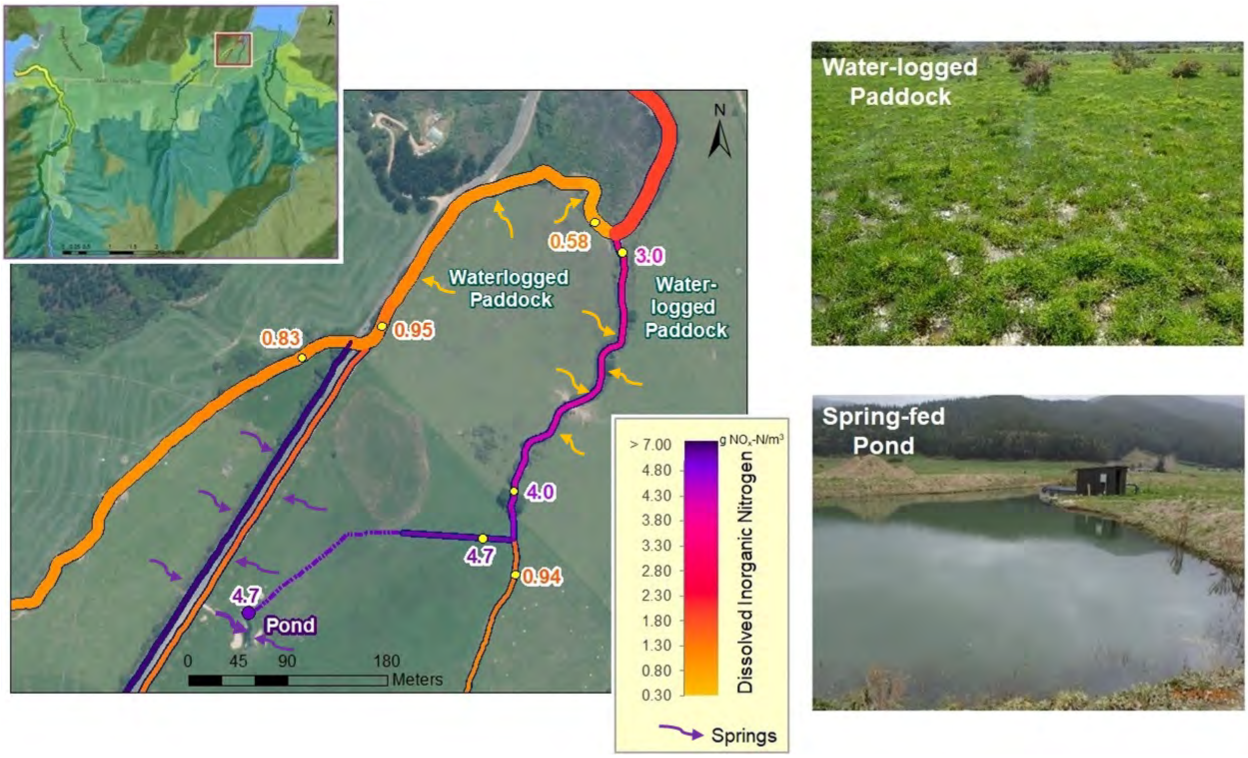

Figure 12: Dissolved Inorganic Nitrogen concentrations in the Lower reaches of Linkwater Stream. Shown are some of the measurement values and the location of a spring-fed pond and waterlogged paddocks.

DIN levels should change with the proportion of pasture in the area upstream of a sampling site, because leaching from pasture is the main source of DIN in streams. DIN concentrations in Cullen Creek and Ada Stream correlate well with percentage of upstream pasture (Figure 13). This is not the case for Linkwater Stream. The reason is the more complicated underlying geology of the Linkwater Stream catchment.

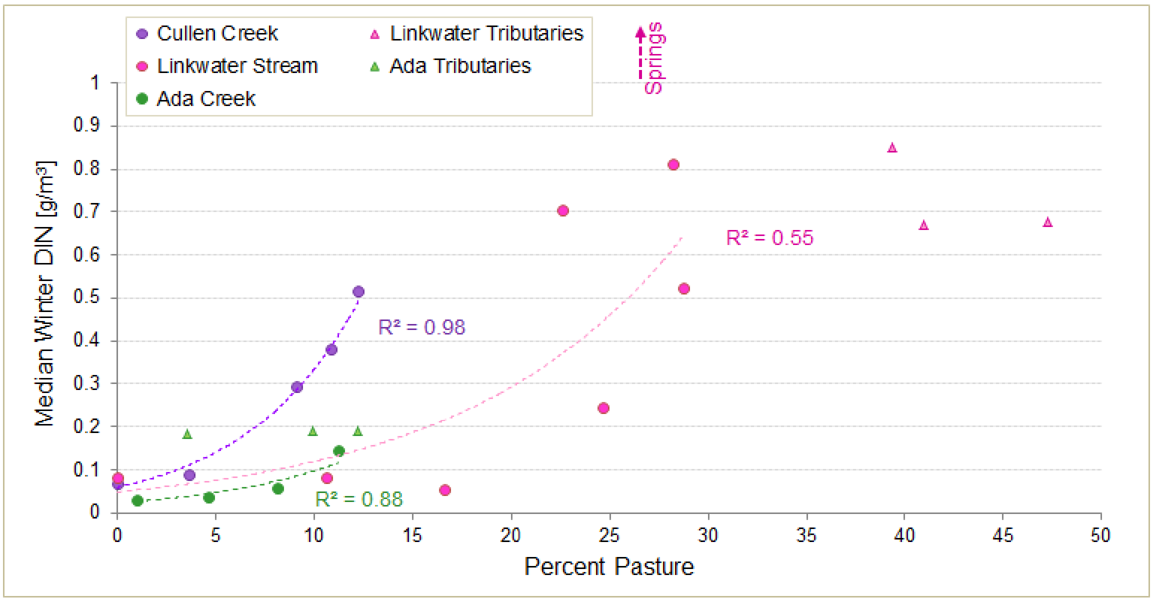

Figure 13: Correlation between winter median DIN concentrations and the proportion of pasture upstream.

Overall, Cullen Creek had significantly higher DIN levels for the same percentage of pasture. This means that pasture in Cullen Creek is leaching more nitrogen. Based on field observations, the reason is likely more intensive irrigation in the Cullen Creek catchment. Irrigation provides additional water that can carry nitrogen into the ground beyond the reach of plant roots (Figure 14). This increase the amount of nitrogen leached into groundwater and subsequently streams. Most of the pasture in the Ada Creek catchment was rarely irrigated. This explains the generally lower DIN concentrations in Ada Creek.

DIN concentrations in the tributaries did not follow the correlation patterns observed in the main stream channels. Tributaries in the Ada Creek catchment had generally higher DIN concentrations caused by livestock access. Discrepancies observed for the Linkwater tributaries are likely a result of concentrated groundwater inflows and modifications to the natural drainage catchment. A number of additional, artificial drains have been dug to remove water from adjacent paddocks.

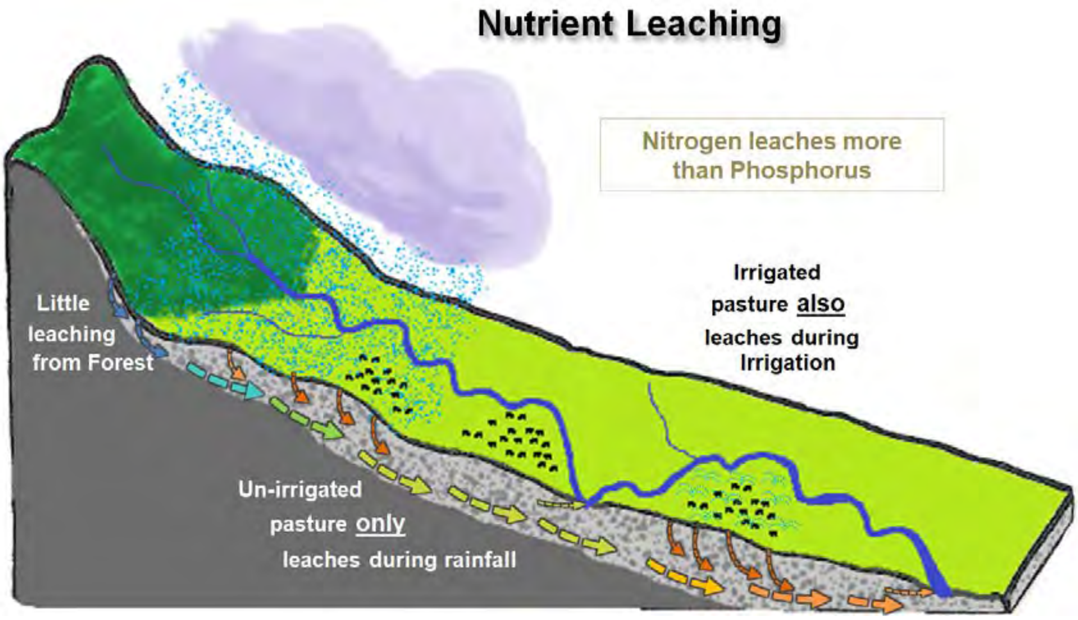

Figure 14: Nutrient leaching under forest, un-irrigated pasture and irrigate pasture.

6.2.2. Dissolved Reactive Phosphorus (DRP)

Dissolved Reactive Phosphorus (DRP) is a measure for the amount of phosphorus in the water column that can easily be taken up by plants. Together with elevated DIN concentrations, high levels of DRP can result in excessive growth of algae. These algae can smother the stream bed, which results in the reduction of habitat for fish and aquatic insects. Excessive algae cover also impacts on the amenity and recreational values of a waterway.

DRP concentrations are usually significantly lower than nitrogen concentrations, as phosphorus is easily absorbed onto soil particles. Phosphorus is therefore less mobile than nitrate. Leaching of phosphorus does, however, occur if the soil becomes saturated with phosphorus due to frequent application of phosphorus fertilizer. This has been observed under cropping in some parts of New Zealand [22]. Still, most of the phosphorus in streams originates from eroded soil from the surrounding land surface.

The guideline of 0.015 g/m^{3}used in this report is based on limits set by Biggs (2000) to prevent nuisance algae growth in rivers and streams [3]. This is also the guideline used for the State of the Environment reporting.

Dissolved Reactive Phosphorus (DRP) concentrations measured as part of the SoE programme in Cullen Creek and Linkwater Stream are generally close to the guideline level (Figure 15). The occasional very high DRP concentrations in the streams are generally associated with flood flows when the water is muddy, carrying sediment and other material washed into the stream by surface run-off.

The concentrations in both streams do not differ significantly, but DRP levels in Well 0447 tend to be slightly higher. This indicates that groundwater is a source of phosphorus during baseflow.

Olsen P levels[5] measured during the Council soil survey were mostly low or adequate. However, two of the nine soils sampled had high Olsen P levels [13]. The soils have moderate phosphorus retention capability, which means that excessive application of Phosphorus fertiliser will result in leaching.

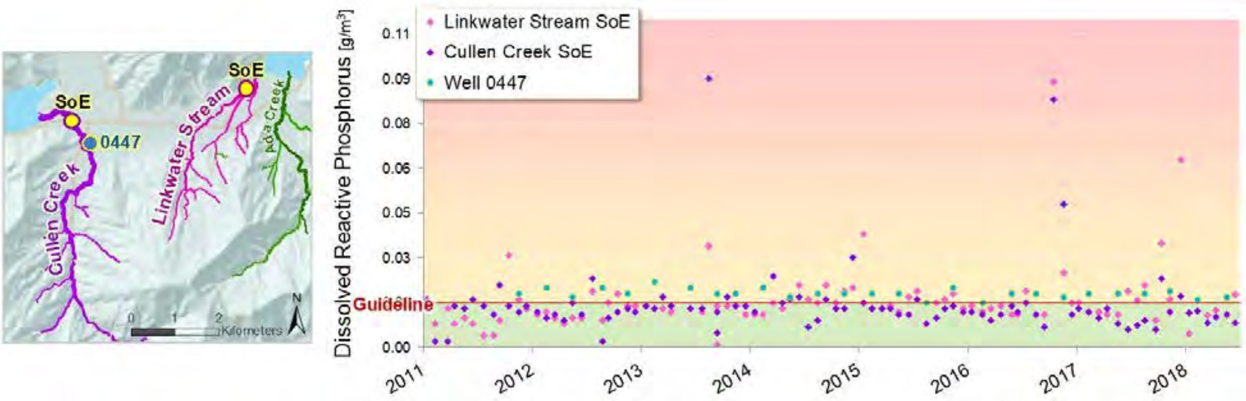

Figure 15: Dissolved Reactive Phosphorus (DRP) concentrations at the two SoE sites and Well 0447.

A recent investigation into the water quality of two other Marlborough Sound Streams, the Waitohi and Waikawa Streams, found that elevated phosphorus concentrations were caused by natural processes, such as the weathering of basement rock [34]. It is likely that this is a contributing factor for the Linkwater catchments as well.

Indeed, the study results seem to confirm this. The DRP concentrations at the most upstream sites were generally among the highest (Figure 16). In fact, in Ada Creek, DRP levels are consistently decreasing in a downstream direction. Ada Creek has the least amount of irrigation and is therefore the catchment with the lowest leaching potential. Based on this, leaching from pasture is likely the reason for the stable DRP levels observed in Linkwater Stream. Irrigation of pasture was most frequently observed in the Cullen Creek catchment, which caused a downstream increase in DRP concentrations.

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[5] Olsen P is a measure for the amount of phosphorus in the soil that is available to plants.

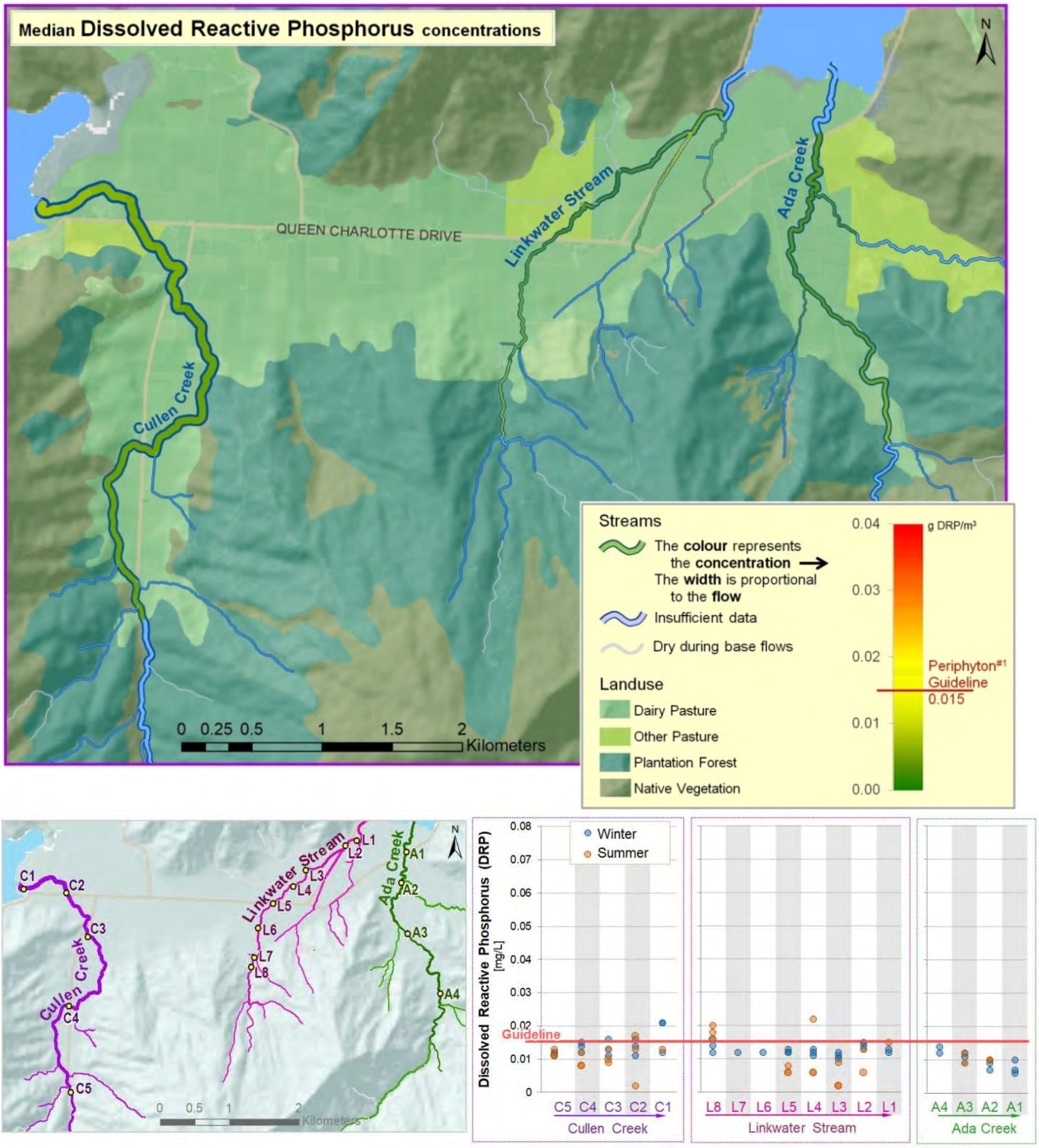

Figure 16: Dissolved Reactive Phosphorus (DRP) concentrations measured in the streams of the Linkwater area during the study.

DRP levels were often lower in summer, particularly in Linkwater Stream. This is caused by uptake of the phosphorus by algae growing on the stream bed. Linkwater Stream has the least amount of tall riparian vegetation on the river flats. Mature trees on the stream banks of Cullen Creek and Ada Stream shade the waterway preventing excessive algae growth.

Surprisingly, DRP concentrations at the most upstream site of Linkwater Stream were highest during summer. This site is located in mature pine forest. Field notes indicated that it was also the site with the highest amount of fine sediment cover on the streambed. This is despite comparatively high water velocities due to a steep streambed gradient. Investigation into the source of the fine sediment revealed that the lack of undergrowth in the densely planted pine forest resulted in predominantly bare ground. Erosion of the soil could be seen in many areas. Sediment is the one of the main sources of DRP in streams.

6.2.3. E. coli

> E.coli are bacteria found in the gut of warm-blooded animals and humans. Most E. coli strains are not harmful to human health, but their presence indicates contamination with faecal matter, which might contain harmful organisms such as Campylobacter or Cryptosporidium.
>
> The main source of faecal contamination in rural areas is stock access to water ways. Particularly cattle have a high affinity to water. Additionally, animal droppings on land adjacent to a waterway can be washed into the stream or river during rainfall. This can result in very high E. coli concentrations during rainfall, particularly after long dry periods.
>
> The E. coli guideline of 550 E.coli/100mL used in this document is based on guidelines for water quality of recreational waters released by the Ministry for the Environment and the Ministry for Health in 2003 [25].

Analysis results of samples taken during monthly SoE monitoring show that E. coli concentrations are occasionally very high (Figure 17). In the earlier years of monitoring concentrations were often highest in Cullen Creek. Very high E. coli levels are mostly associated with rainfall when surface run-off carries animal faeces into nearby waterways.

In recent years, E. coli concentrations have been noticeably lower, particularly in Cullen Creek. This is likely linked to the requirement by the dairy industry to fence out cattle from larger waterways. Unfortunately, some of the most recent SoE samples from Linkwater Stream had high E. coli levels at comparatively low flows. These samples were taken after the sampling for this study was completed and further investigation might be required.

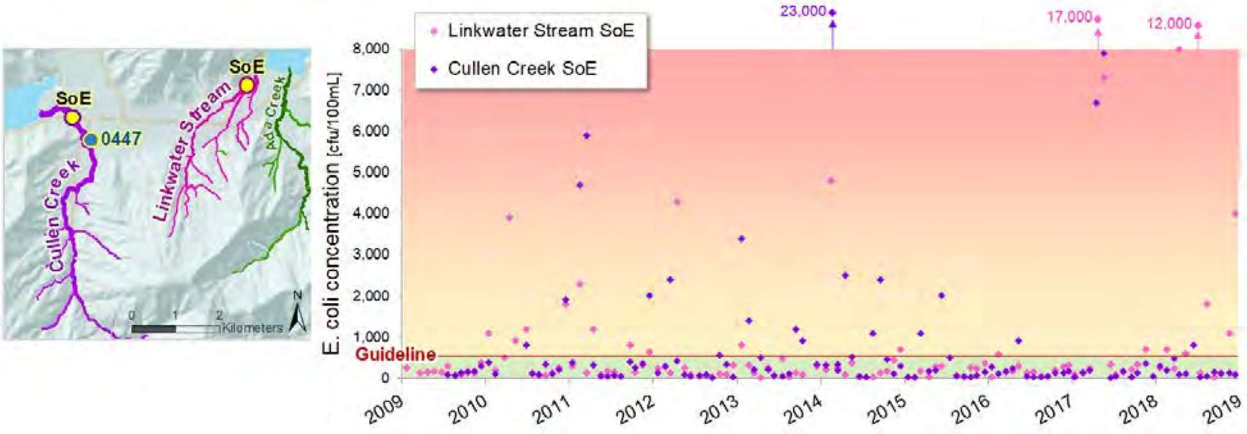

Figure 17: E. coli concentrations at the two SoE sites on Cullen Creek and Linkwater Stream.

The majority of samples taken during the study had E. coli concentrations below the guideline (Figure 18). Not surprisingly, E. coli levels were generally higher during summer when lower flows provide less dilution of faecal material deposited into streams.

Most noticeable was an increase in E. coli concentrations in the mid-section of Linkwater Stream. Here the stream flows through one of the few areas of non-dairy pasture where livestock have not been fenced off. During the study period, only 20-30 beef cattle were grazing in this area, but the stream provided the main source of water for the animals (Figure 19, left). A similar case was observed during a water quality study in Doctors Creek [17]. Here too, a comparatively small number of extensively grazed cattle were causing a significant increase in E. coli levels in the creek.

The main tributary of Ada Creek also flows through an area of beef pasture, along which the waterway is not fenced off. However, the paddocks upstream of the sampling site were rarely grazed and only one sample had a high E. coli concentration.

Livestock access to the waterway was also the reason for elevated E. coli concentrations in one of the smaller tributaries of Ada Creek. In this case it was dairy cattle that had access to the stream causing contamination with faecal material (Figure 19, bottom right). Small streams are excluded from the fencing requirement by the dairy industry.

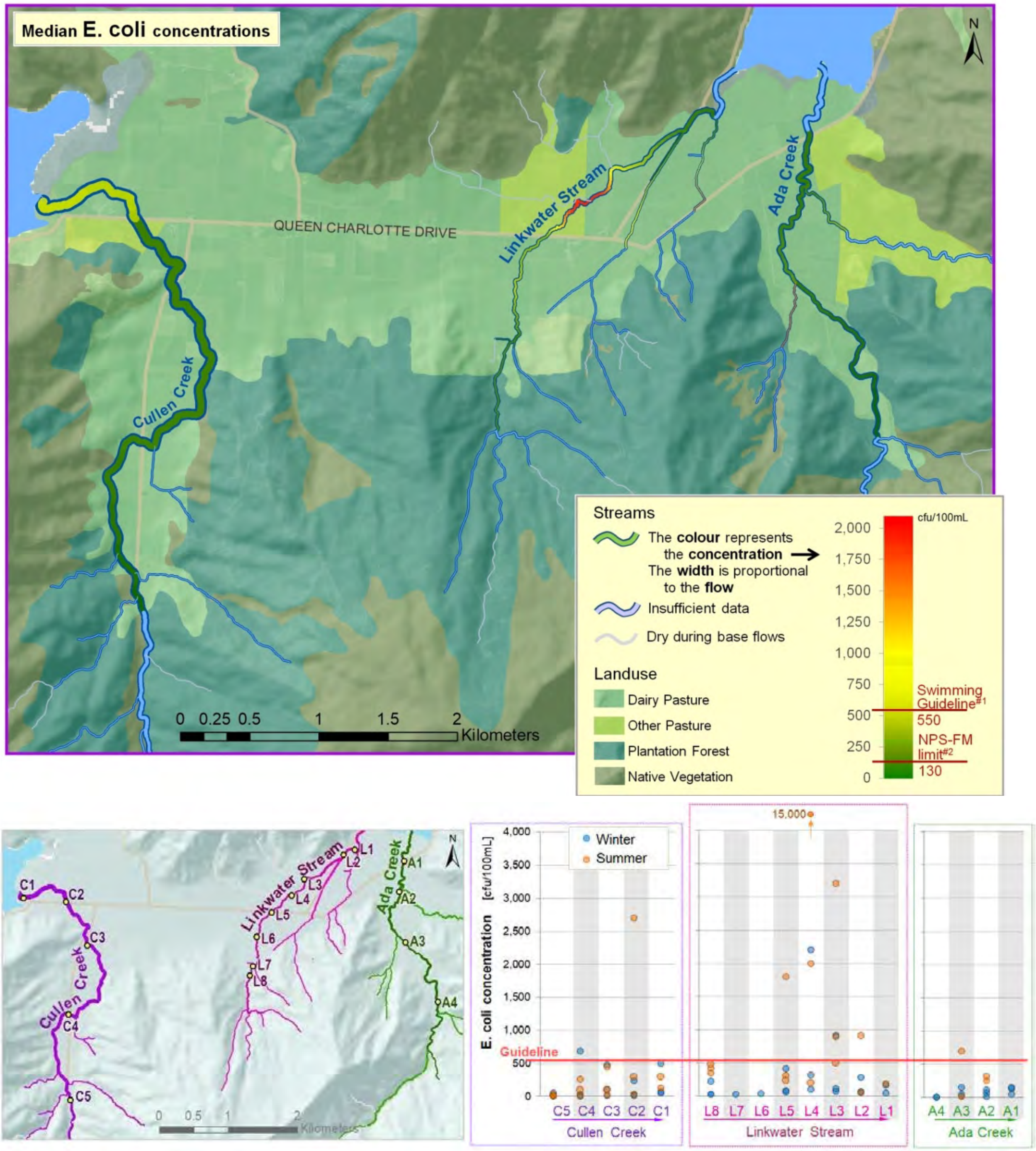

Figure 18: E. coli concentrations measured in the streams of the Linkwater area during the study.

Elevated E. coli levels in small tributaries of Linkwater Stream were mainly caused by run-off from cattle-races rather than direct stock access (Figure 19, middle). Although sampling was carried out during dry weather, irrigation near the streams rather than rainfall was causing surface run-off. Run-off was also evident in sections of pasture were travelling irrigators crossed Linkwater Stream.

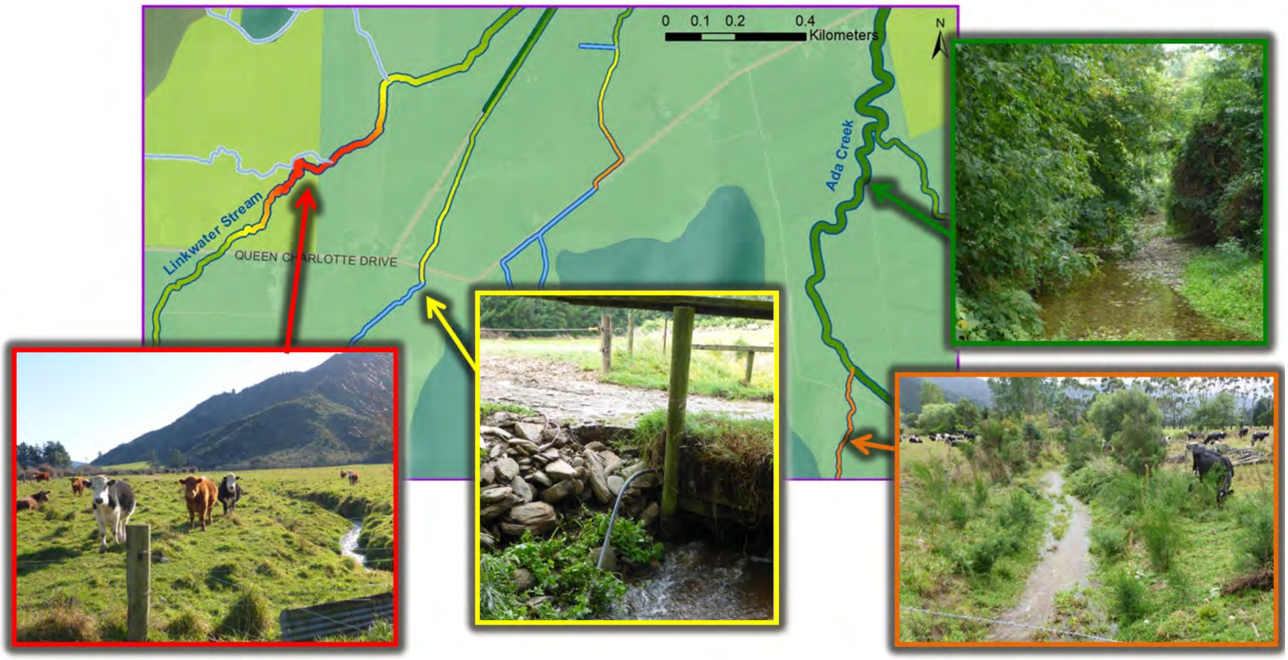

Figure 19: Photos of stream sections in the Linkwater area with different E. coli levels. LEFT: Beef pasture with unfenced waterway. MIDDLE: Run-off from nearby cattle race. RIGHT TOP: Mature riparian vegetation along fully fenced waterway. RIGHT BOTTOM: Unfenced small tributary in dairy pasture.

In some catchments wildfowl, such as ducks, seagulls and shags, can also be the cause for high E. coli concentrations. Although, there are a large numbers of birds in the neighbouring estuaries, only a few ducks were seen on the streams in the Linkwater area.

6.2.4. Turbidity and Fine Sediment

Turbidity is a measure for water clarity. Measurements are obtained using a sensor that emits light and measures the scattering of that light by particles suspended in the water column. Turbidity measurements are expressed in Nephelometric Turbidity Units (NTU).

Naturally, high turbidity is primarily caused by fine sediment that enters the water way from surrounding land surfaces, either in the form of slips or removed from stream and river banks due to the erosive action of flowing water. Removal of vegetation along the edges of water ways can significantly increase erosion of the banks. A lack of dense vegetation on adjacent land surfaces can result in high sediment input during rainstorms. Heavy animals can also cause damage to stream banks, generating increased bank erosion. Another source of increased turbidity are construction works in and around streams and rivers.

Once sediment has entered the water, it will be deposited onto the stream bed in areas where water velocities are relatively low. Large amounts of fine sediment can smother the stream bed and reduce quality and availability of habitat for aquatic insects and fish. Additionally, fine sediment cover decreases the amount of suitable spawning habitat for fish.

Apart from ecological effects, high turbidity also affects the aesthetic value of water ways.
The guideline of 5.6 NTU used for this report is the trigger level for lowland rivers suggested by the ANZECC 2000 Guidelines based on recreational and amenity values [15].

Turbidity is generally not a significant concern for the streams in the Linkwater area. During base flow conditions the water is usually clear, particularly since most of the stream margins are fenced, stopping dairy cattle from accessing the water ways. High Turbidity levels in SoE samples are almost exclusively associated with rainfall and flood flows.

Sampling for the study was done during baseflow only and the samples taken had very low turbidity. Figure 20 shows photos taken during a visit to the area when some rain had fallen. Run-off could be seen entering streams from nearby cattle races. Apart from sediment, this run-off would also wash nutrients and faecal material into the waterways.

Figure 20: Examples of rainfall run-off entering streams in the Linkwater area.

Sediment causing high turbidity in the water column will settle on the stream or sea bed once water carrying the sediment has slowed down.

Significant amounts of fine sediment cover were mainly observed in Linkwater Stream. Even in the upper reaches with greater water velocity, fine sediment was accumulating in calmer parts of the stream bed. Here, erosion from bare soil under mature pine forest was the main source of sediment (see Section 6.2.2). The Linkwater catchment is comparatively small, with most of the area in river flats. This means that flushing flood flows that remove fine sediment from the stream bed are smaller. This lessens that ability of the stream system to cope with erosion inputs. In the lower reaches, the stream bed is dominated by gravel, particularly in areas that are fenced off. This means that despite the lower flushing potential, the bed of Linkwater Stream does not naturally have high fine sediment cover. An additional source of fine sediment in Linkwater Stream was stream bank erosion. In some areas, the stream had been fenced off very close to the stream edge and trampling by cattle had caused the collapse of the stream bank. Unlike Cullen Creek and Ada Creek, Linkwater Stream does not have stabilizing riparian planting.

The stream bed of Cullen Creek and Ada Creek were dominated by gravel and cobble sized river stone with little fine sediment cover. An exception was an area around a ford across Cullen Creek. Crossing vehicles were introducing fine sediment from the road into the stream (Figure 21). A farm track 80m upstream of the road ford adds further sediment. This results in a thick cover of fine sediment on the stream bed for more than 100m upstream and downstream of the road ford.

Figure 21: Cullen Creek Ford (photos right and middle supplied by local property owner). On the left are close-up photos of the stream bed taken during the study (Upstream = upstream of the farm track).

6.2.5. Continuous Monitoring

There are a number of measurements that change during the day and are therefore better measured continuously. These include water temperature, dissolved oxygen and pH. Still, spot measurements taken as part of the SoE programme can provide some indication.

Water Temperature

The water is cooler during the night, warming during the day with temperatures usually reaching a maximum around mid-afternoon. Water temperatures are particularly high in streams where the vegetation along the banks has been removed or is kept short, thereby allowing the sun to directly heat the water. Groundwater inflow, on the other hand, can keep the water temperature quite stable, even reducing the seasonal variability.

High water temperatures have a negative impact on the survival of stream invertebrates and fish. Some mayflies (*Ephemeroptera*) are not found in streams with water temperatures above 21.5°C [32] and native fish like the Banded Kokopu (*Galaxias fasciatus*) are also effected by long term maximum temperatures above this value [3].

Dissolved Oxygen

Like us, plants and animals living in streams and rivers need oxygen to breath. The amount of oxygen dissolved in the water changes in a distinct pattern over a 24 hour cycle. During the day aquatic plants release oxygen into the water as part of their photosynthetic activity. At night this oxygen supply is gone and oxygen is used up by the respiration of animals, plants and the activity of microorganism. For this reason, oxygen concentrations are usually lowest in the early morning. There is also oxygen exchange with the atmosphere through the water surface, but this process is relatively slow. In areas of a stream where the water surface is broken by turbulences (i.e. riffles), the surface area is increased, which means significantly more oxygen is exchanged.

The amount of oxygen that can be dissolved depends on the temperature of the water, as warmer water can carry less oxygen than cooler water. Because of this dependency on water temperature the dissolved oxygen “saturation” instead of the dissolved oxygen concentration is often used.
100% dissolved oxygen saturation represents the amount of oxygen that can physically be dissolved into a water body at a given temperature. The photosynthetic activity of aquatic plants can increase the dissolved oxygen saturation significantly above 100%.

Low dissolved oxygen concentrations effect the growth and survival of aquatic invertebrates and fish [3, 10]. Studies have shown that trout become effected if dissolve oxygen saturation decreases to values below 70% [10]

pH

The pH is a measure for the acidity or alkalinity of the water, ranging between 0 (strong acid) and 14 (strong alkaline). Pure water has a neutral pH of 7. Photosynthetic activity by aquatic plants increases the pH of the water, resulting in daily variations similar to those in Dissolved Oxygen with a maximum around mid-afternoon. Discharges of decomposing organic material can lower the pH and many heavy metals are more toxic at a lower pH.

The optimal range for trout is between 6.7 and 7.8 [15]. Although trout can tolerate a pH ranging from 5 to 9.5, growth and reproduction of the fish will be impaired. It is assumed that guidelines protecting trout will also be sufficient for native fish.

The results of the monthly SoE monitoring, indicate that water temperatures are sufficiently cool to not impact on aquatic ecology. However, dissolved oxygen and pH occasionally fell below acceptable levels. Low oxygen and pH levels are mainly observed in Linkwater Stream.

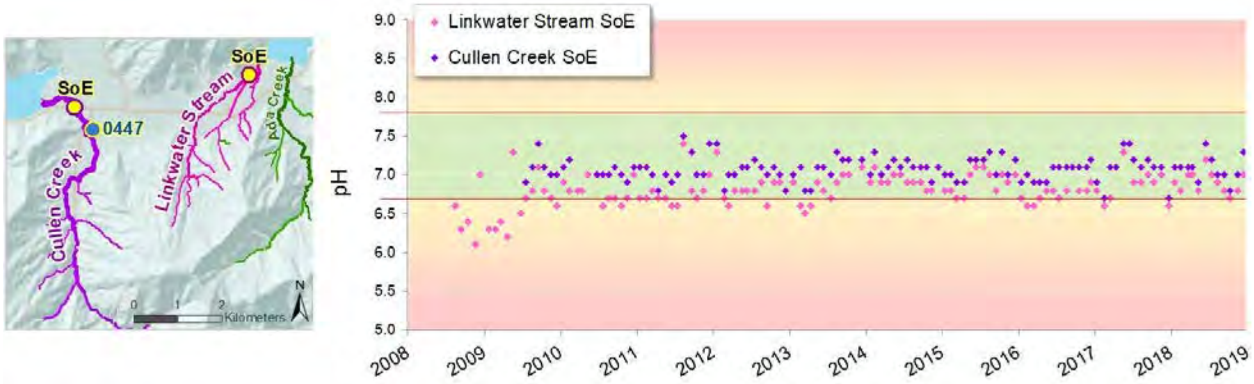

Figure 22: pH levels at the two SoE sites on Cullen Creek and Linkwater Stream.

To investigate the variation of water temperature, dissolved oxygen and pH in Linkwater Stream, a monitoring sonde was deployed at two sites. The deployment was done in summer, in pool areas where negative effects on aquatic ecology are most likely. Measurements were taken every 15 minutes over a period of two days.

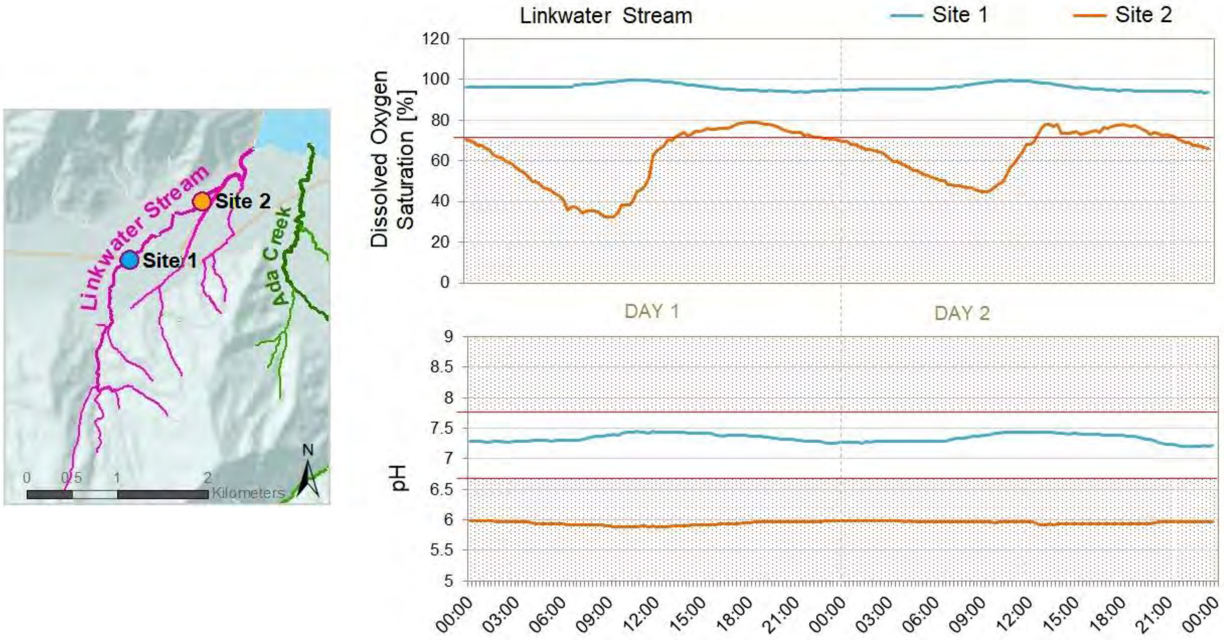

Figure 23: Dissolved Oxygen Saturation and pH measured continuously over two days in Linkwater Stream.

Water temperatures were consistently sufficiently cool at both sites. Dissolved Oxygen Saturation and pH were at acceptable levels at Site 1, but at Site 2, further downstream, both parameters were below guideline levels most of the time (Figure 23). The most common cause for low pH and oxygen levels in streams is the breakdown of organic material. In Linkwater Stream, there were no obvious signs of accumulated organic matter, such as leaves or other plant material. Animal droppings from cattle upstream (see Section 6.2.3) are a potential source of introduced organic material. Additionally, downstream of Site 2, groundwater is being forced to the surface. Groundwater tends to have lower dissolved oxygen levels. Although, no springs were noted at Site 2 it is possible that groundwater was entering the stream through the stream bed.

6.3. Aquatic Ecology

Aquatic animals live in streams 24/7, all year round. They are therefore the best indication of stream health. Monitoring stream animal alerts us to potential contamination that is not picked up by spot measurements. However, monitoring aquatic animals directly is difficult and costly. To allow some assessment of ecological health, macroinvertebrates are sampled at SoE sites on an annual basis.

6.3.1. Macroinvertebrates

Macroinvertebrates are insects and other soft-bodied animals that can be seen with the naked eye.

The different species have a varying degree of resistance to contamination. Some sensitive species, will not be present in streams with degraded water quality. Stark [33] developed a pollution index based on the number of macroinvertebrates from different species found in a sample. This is the Macroinvertebrate Community Index (MCI). Generally, the higher the MCI score the better the water quality. A MCI score that is higher than 80 is indicative of acceptable water quality.

There are a number of additional factors that influence the MCI score. One of them is the habitat type. To allow comparison of samples taken from different streams, the same habitat needs to be sampled. SoE samples are taken from riffle habitats. Riffles are the fast flowing, shallow parts of a stream. These generally represent the best habitat available as they are well oxygenated and have the least amount of fine sediment cover.

MCI scores of samples taken from the SoE sites had values consistently above 80, indicating acceptable water quality (Figure 24). Low dissolved oxygen levels observed in an upstream pool during the study (see Section 6.2.5) are likely not effecting MCI scores at the SoE site, as samples are taken from well oxygenated riffle habitats.

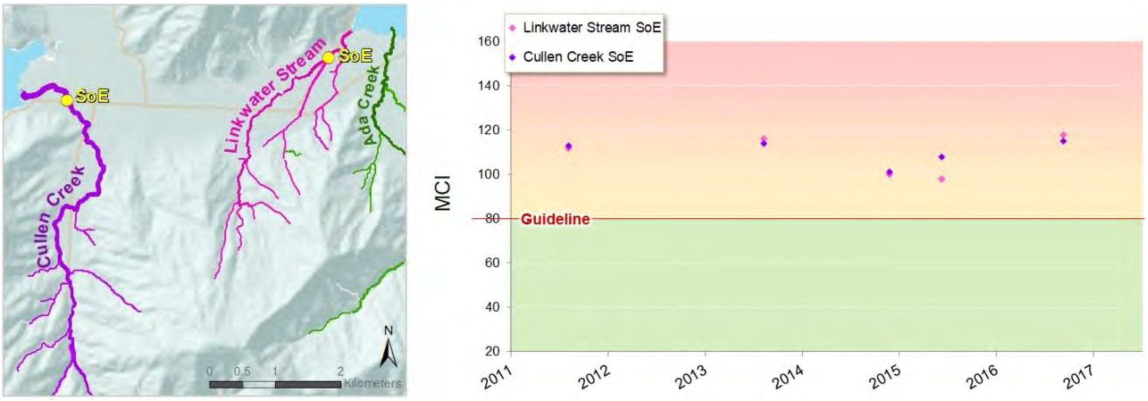

Figure 24: MCI scores at the two SoE sites on Cullen Creek and Linkwater Stream.

To assess stream health at other sites in the area, Macroinvertebrate samples were taken from additional stream reaches during the summer months. In order to compare the results with the those from the SoE programme, samples were taken from riffle habitats.

All samples had MCI scores above the guideline of 80 (Figure 25). There was a general decrease in MCI scores in a downstream direction. In Cullen Creek, MCI samples were taken upstream and downstream of a road ford that is causing significant sedimentation of the stream bed (see Section 6.2.4). There was a noticeable decrease in the MCI score. The effect on the aquatic ecology is likely more severe in the run habitats where most of the fine sediment settles.

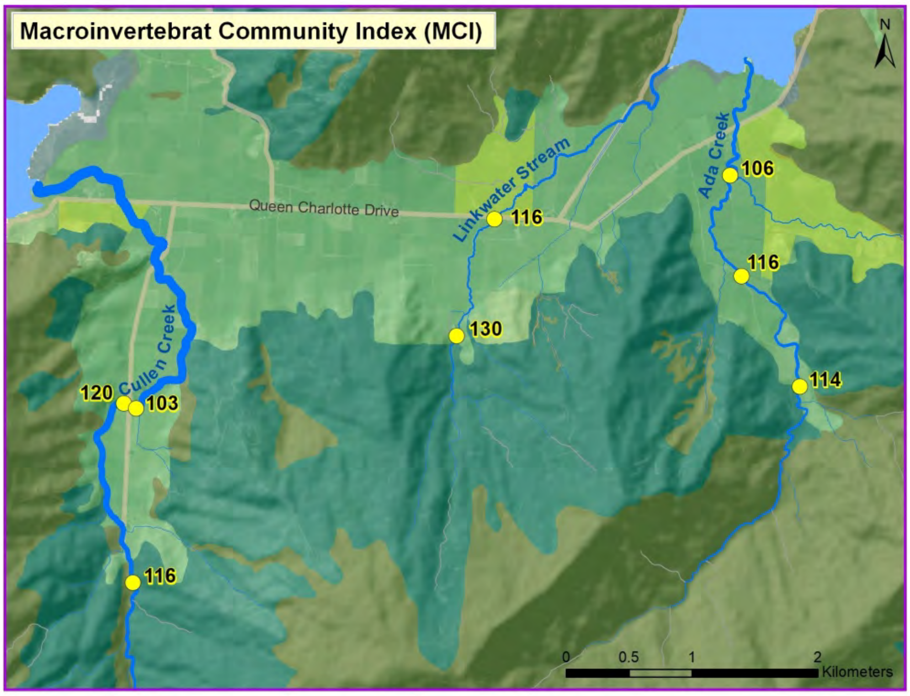

Figure 25: Macroinvertebrate Community Indices (MCIs) from additional samples taken during the study.

6.4. Fish

Fish are not regularly monitored as part of the SoE programme. However, there have been fish surveys carried out by the Department of Conservation. Unfortunately the surveys have been limited to Cullen Creek. A comparatively intensive surveys was carried out in 1995, using an electric fishing machine in six reaches along Cullen Creek and one of its tributaries [1]. The fish species most often caught during the survey was the Bluegill Bully (*Gobiomorphus hubbsi*). A number of Common Bully (*Gobiomorphus cotidianus*) and one Smelt (*Retropinna retropinna*) were caught at the most downstream site only. Redfin Bullies (*Gobiomorphys huttoni*) were restricted to small upland streams.
Two Short-jawed Kokopu (*Galaxias postvectis*) were caught in the most upstream part of Cullen Creek. Another DOC survey of this upstream site (Site 5) in 2000 also found Koaro (*Galaxias previpinnis*) [19].

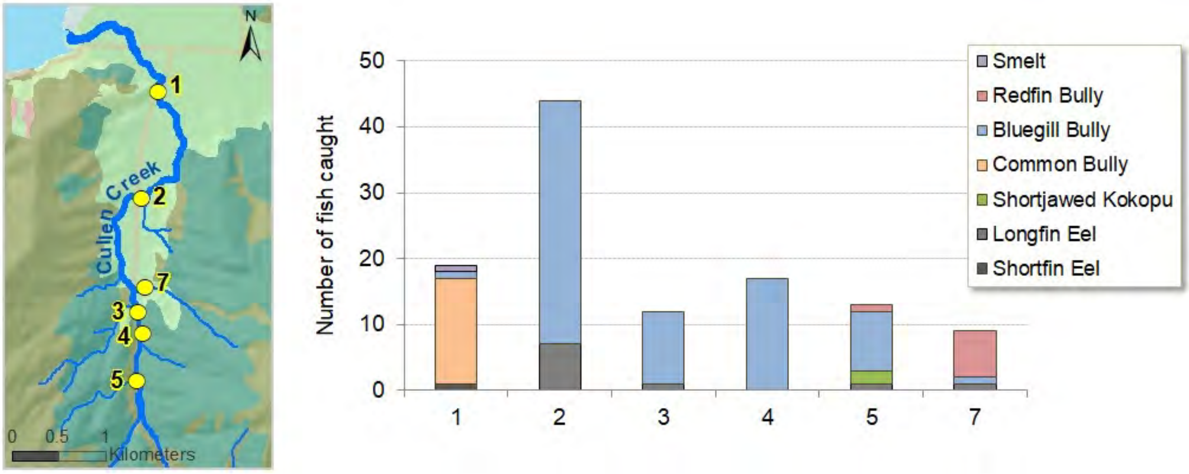

Figure 26: The number of fish caught during a DoC Fish Survey of Cullen Creek carried out in 1995.

Fish were not monitored as part of the study. However, during the sampling, Inanga (*Galaxias maculatus*) and Redfin Bully were observed in Linkwater Stream, including the stream reaches flowing through dairy pasture. Comparatively large numbers of fish could be seen in Ada Creek, particularly during dryer periods when fish concentrated in pools (Figure 27).

Figure 27: Fish seen in Ada Creek during the water quality study. TOP: Redfin Bully (Gobiomorphys huttoni). BOTTOM: Common Bully (Gobiomorphus cotidianus).

7. Summary

Linkwater is an area located between the Pelorus Sound/ Te Hoiere and the Queen Charlotte Sound/Tōtaranui. Land use is dominated by production forest on the lower slopes and dairy pasture on the river flats. Two of the streams, Cullen Creek and Linkwater Stream are monitored near their outflow into the sea as part of the State of the Environment programme. This monitoring identified a number of parameters that are exceeding guideline levels. These are:

- Elevated dissolved nutrient concentrations (both nitrogen and phosphorus),
- High E. coli concentrations (mainly during higher flows),
- Low pH levels (mainly in Linkwater Stream)
- Low Dissolved Oxygen levels

In order to identify the causes of degraded water quality, sampling of additional sites throughout the two catchments was carried out between 2013 and 2017. The investigation also included Ada Creek, the second largest stream in the Linkwater area. A total of thirty three sites were sampled for physical and chemical parameter analysis, with eight of the sites also sample for macroinvertebrates. Sampling was carried out during base-flow conditions only.

Dissolved Inorganic Nitrogen concentrations were above guideline level in the lower parts of Cullen Creek and Linkwater Stream, but not Ada Creek. The main cause of elevated nitrogen was leaching from pasture, which was highest for intensively irrigated areas. Leaching is also causing some of the elevated DRP levels, particularly in Cullen Creek. However, DRP concentrations appear to be naturally high due to weathering processes. In the upper reaches of Linkwater Stream, fine sediment on the stream bed was an additional source of DRP. The fine sediment cover was caused by erosion of bare soil under densely planted pine forest. Similar erosion is likely to also occur in pine forest in the upper Cullen Creek and Ada Creek catchments. However, both streams have larger catchments with a greater proportion of area at higher altitude covered in native bush. This results in greater flood flows, which remove the fine sediment from the stream bed. High amounts of fine sediment cover in Cullen Creek were restricted to an area of a road ford. Here, vehicles traveling on the gravel road and through the creek are a significant and frequent source of fine sediment. Macroinvertebrate samples taken from riffles upstream and downstream of the ford showed that the sediment input had negative ecological effects, which are likely more severe in the run habitats, not sampled.

During rainfall, additional sources of fine sediment are run-off from nearby cattle races and areas of the stream where the bank has been damaged by livestock. Run-off was not just created during rainfall, but could also be seen during irrigation of pasture near waterways. Apart from sediment, this run-off also carries nutrients and faecal matter into the streams. During baseflow, the main source of faecal material, however, was livestock access to waterways. Because most of the streams flowing through dairy farms had been fenced off, a beef farm caused the most notable increases in E. coli concentrations. This was despite significantly lower stocking density. However, small, unfenced tributaries within dairy pasture had similarly elevated E. coli levels.

Overall, Ada Creek had the best water quality of the streams monitored. This was due to less intensive irrigation and mature riparian vegetation along most of the stream, particularly in the mid reaches. As a result, large schools of fish could be seen in Ada Creek even within reaches flowing through dairy pastures. Of the other two streams monitored, Cullen Creek generally had the better water quality. Similar to Ada Creek, Cullen Creek has mature riparian vegetation along most of the stream banks.

Stock access and run-off from irrigation water were the main causes for the poorer water quality in Linkwater Stream.

During rainfall, run-off from cattle races that run adjacent to streams is causing contamination with sediment, nutrients and faecal material in Ada, Cullen and White Pine Creek.

It is important to note, that although only the three largest streams were monitored, the findings of this study also apply to other, smaller streams in the Linkwater area.

8. Recommendations for improving water quality

- **Identify critical source areas on the individual farms and reduce their impact on water quality.**

  These include areas of surface run-off during irrigation, small un-fence tributaries and swales.

- **Fence-off livestock from waterways.**

  Include small dairy streams and streams through beef-pasture.

- **Establish tall riparian vegetation to stabilise stream banks and reduce algae growth; particularly along Linkwater Stream**

  Leaching losses from dairy pasture are difficult to reduce. Management of instream algae growth by limiting plant nutrients in the Linkwater area is made harder by the naturally high phosphorus concentrations. Therefore, the most effective way of minimising nuisance algae growth is through shading of the streams in this area.

- **Prevent surface run-off from cattle races from entering streams.**

- **Minimise erosion from plantation forests.**

  Allow (native) undergrowth to develop along waterways to reduces erosion of soil.

  There was very limited forestry harvest occurring during the study, but increased sediment inputs following clear-felling has been observed in other catchments [e.g. 8, 12]. Therefore, leaving unharvested buffers along streams will reduce further input of fine sediment. This holds particularly true for the highly erodible soils found in Linkwater.

Figure 28: Examples of Critical Source Areas in Linkwater.

Figure 29: Although White Pine Creek was not included in the study, similar contamination sources mean that the recommendations also apply to this stream.

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11. Appendix

11.1. Site List

The table below lists the sites sampled as part of the study.

Main = Main stream channel
Trib = Tributary stream

	Site	Short Name	Type	Easting	Northing
Cullen Creek	Cullen Creek at Mouth	Cul01	Main	1670877	5428866
	Cullen Creek at Queen Charlotte Drive	Cul02	SoE	1671491	5428803
	Cullen Creek at Road Bridge	Cul03	Main	1671802	5428178
	Cullen Creek at Cullensville Road Ford	Cul04	Main	1671531	5427179
	Cullen Creek Upstream Second Ford	Cul05	Main	1671559	5425938
Linkwater Stream	Duncan Stream at Outlet	Linkw SoE	SoE	1675490	5429455
	Linkwater Stream Study - Site 03	Linkw 03	Main	1675680	5429536
	Linkwater Stream Study - Site 04	Linkw 04	Trib	1675703	5429508
	Linkwater Stream Study - Site 05	Linkw 05	Trib	1675620	5428935
	Linkwater Stream Study - Site 06	Linkw 06	Trib	1675052	5428634
	Linkwater Stream Study - Site 07	Linkw 07	dry	1674945	5429166
	Linkwater Stream Study - Site 08	Linkw 08	Main	1674941	5429135
	Linkwater Stream Study - Site 09	Linkw 09	dry	1674761	5428926
	Linkwater Stream Study - Site 10	Linkw 10	Main	1674759	5428899
	Linkwater Stream Study - Site 11	Linkw 11	Main	1674468	5428657
	Linkwater Stream Study - Site 12	Linkw 12	Trib	1674208	5427910
	Linkwater Stream Study - Site 13	Linkw 13	Trib	1674243	5427887
	Linkwater Stream Study - Site 14	Linkw 14	Main	1674201	5427878
	Linkwater Stream Study - Site 15	Linkw 15	Main	1674156	5427736
	Linkwater Stream Study - Site 16	Linkw 16	Trib	1675459	5429407
	Linkwater Stream Study - Site 17	Linkw 17	Main	1674249	5428318
	Linkwater Stream Study - Site 18	Linkw 18	Main	1675435	5429426
	Linkwater Stream Study - Site 19	Linkw 19	Trib	1675442	5429405
	Linkwater Stream Study - Site 20	Linkw 20	Trib	1675606	5429243
	Linkwater Stream Study - Site 21	Linkw 21	Trib	1675317	5429180
	Linkwater Stream Study - Site 22	Pond	Trib	1675364	5429183
	Linkwater Stream Study - Site 23	Linkw 23	Trib	1675300	5429188
	Linkwater Stream Study - Site 24	Linkw 24	Trib	1675578	5429160
Ada Creek	Ada Creek at Queen Charlotte Drive	Ada 01	Main	1676381	5429397
	Ada Creek Study - Site 02	Ada 02	Main	1676344	5429021
	Ada Creek Study - Site 03	Ada 03	Trib	1676353	5429003
	Ada Creek Study - Site 04	Ada 04	Trib	1676598	5428735
	Ada Creek Study - Site 05	Ada 05	Main	1676402	5428223
	Ada Creek Study - Site 06	Ada 06	Trib	1676269	5428268
	Ada Creek Study - Site 07	Ada 07	Main	1676871	5427357
	0447 Morrison Linkwater	Well0447	Well	1671838	5428220

11.2. **Sampling Results**

The following tables show the results for the additional spot sampling carried out for the study. Not included are the results from the monthly State of the Environment monitoring.

Note that the sites are identified using the “Short Names” from the Site List (Appendix 11.1).

NO3-N = Nitrate-Nitrogen
NOx-N = Nitrite/Nitrate-Nitrogen
NHx-N = Total Ammoniacal Nitrogen
DRP = Dissolved Reactive Phosphorus

15 August 2013

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Cul01	0.36	0.36	<0.010	0.012	70	1.83	7.2
Cul02	0.28	0.28	<0.010	0.014	30	1.5	7.4
Cul03	0.21	0.21	<0.010	0.013	110	1.37	7.3
Cul04	0.068	0.068	<0.010	0.012	30	0.03	7.5
Cul05	0.044	0.044	<0.010	0.011	50	1.09	7.4

30 October 2013

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbitidy [NTU]	pH
Cul01	0.43	0.43	0.011	0.021	500	2.9	7.1
Cul02	0.31	0.31	< 0.010	0.016	240	1.78	7.2
Cul03	0.23	0.23	< 0.010	0.016	480	2.6	7.1
Cul04	0.06	0.061	< 0.010	0.014	690	1.39	7.5
Cul05	0.043	0.043	< 0.010	0.012	7	1.01	7.4

25 July 2014

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Cul01	0.62	0.62	0.015	0.021	49	3.8	7.2
Cul02	0.47	0.47	< 0.010	0.011	15	2.3	7.3
Cul03	0.35	0.35	< 0.010	0.011	13	1.49	7.2
Cul04	0.107	0.107	< 0.010	0.015	5	0.97	7.4
Cul05	0.082	0.082	< 0.010	0.012	10	0.9	7.3

30 January 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Ada02	0.015	0.016	0.005	0.01	260	0.38	7.5
Ada04	0.002	0.003	0.005	0.011	120	0.48	7.6
Ada05	< 0.002	0.003	0.005	0.009	10	0.33	7.5
Ada06	0.027	0.029	1.01	0.016	180	1.4	7.7
LinkwSoE	0.38	0.39	0.005	0.013	60	0.42	7.2
Linkw03	0.88	0.88	0.018	0.015	190	3.1	7.3
Linkw04	1.41	1.41	0.034	0.02	230	14.9	7.1
Linkw05	0.177	0.184	0.034	0.043	290	9.4	7.6
Linkw06	0.048	0.052	0.034	0.022	490	7.7	7.7
Linkw08	0.015	0.017	0.037	0.009	3200	3.2	7.6
Linkw11	< 0.002	0.002	0.005	0.008	310	1.46	7.6
Linkw10	0.006	0.007	1.029	0.022	15000	11.8	7.6
Linkw15	0.09	0.091	0.005	0.018	430	2.9	7.7

5 March 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Linkw05	0.028	0.029	1.017	0.012	150	27	6.8
Linkw06	0.002	0.003	0.005	0.018	150	1.46	7
Linkw08	0.004	0.004	0.005	< 0.004	900	1.11	7.3
Linkw10	< 0.002	< 0.002	0.005	0.006	2000	1.39	7.3
Linkw11	< 0.002	< 0.002	0.005	0.006	1800	0.49	7.4
Linkw15	0.104	0.104	0.005	0.02	350	1.97	7.3

1 April 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Ada02	< 0.002	< 0.002	0.005	0.01	320	0.54	7.3
Ada04	< 0.002	< 0.002	0.005	0.008	430	0.87	7.3
Ada05	< 0.002	< 0.002	0.005	0.012	700	0.62	7.2
Ada06	0.009	0.011	0.005	0.008	420	2.6	7.6
Linkw05	0.4	0.41	0.005	0.104	3000	17.4	7.3
Linkw06	< 0.002	< 0.002	0.005	0.012	210	1.99	7.4
LinkwSoE	0.141	0.143	0.005	0.006	920	1.78	6.8
Linkw08	< 0.002	< 0.002	0.005	< 0.004	500	0.77	7.5
Linkw10	< 0.002	< 0.002	0.005	0.006	200	0.63	7.6
Linkw11	< 0.002	< 0.002	0.005	0.006	240	0.7	7.5
Linkw15	0.103	0.104	0.005	0.016	480	1.92	7.5

4 May 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Ada01	0.02	0.02	0.005	0.006	130	0.23	7.4
Ada02	0.005	0.005	0.005	0.007	63	0.23	7.4
Ada03	0.125	0.126	0.005	0.006	430	0.25	7.5
Ada04	0.09	0.092	0.005	0.006	160	0.4	7.5
Ada05	0.007	0.007	0.005	0.009	150	0.26	7.4
Ada06	0.109	0.11	0.005	0.011	120	2.6	7.7
LinkwSoE	0.49	0.5	0.005	0.015	290	0.45	6.9
Linkw03	0.61	0.62	0.028	0.012	170	3.9	6.9
Linkw04	1.18	1.18	0.048	0.012	620	4.8	6.6
Linkw05	0.75	0.76	0.032	0.015	110	3.2	7.2
Linkw06	0.21	0.22	0.02	0.025	110	1.81	7.3
Linkw08	0.017	0.018	0.005	0.011	900	0.81	7.5
Linkw10	0.015	0.016	0.005	0.013	2200	3.3	7.6
Linkw11	0.02	0.022	0.005	0.013	420	1.05	7.6
Linkw15	0.085	0.086	0.005	0.016	230	2.2	7.6

17 June 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Ada01	0.192	0.192	0.005	0.01	150	0.28	7.3
Ada02	0.053	0.053	0.005	0.01	110	0.59	7.2
Ada03	0.53	0.53	0.005	0.012	27	0.4	7.4
Ada04	0.53	0.53	0.005	0.014	19	0.54	7.4
Ada05	0.033	0.033	0.005	0.012	20	0.48	7.3
Ada06	0.179	0.179	0.005	0.01	34	1.68	7.5
Ada07	0.027	0.027	0.005	0.014	14	0.62	7.2
LinkwSoE	0.51	0.51	0.012	0.014	59	0.85	6.8
Linkw05	1.33	1.33	0.026	0.01	100	2.4	7
Linkw06	0.62	0.63	0.041	0.018	52	5.8	7.2
Linkw08	0.24	0.24	0.005	0.012	80	1.34	7.3
Linkw10	0.23	0.23	1.012	0.012	110	1.77	7.3
Linkw11	0.049	0.05	0.005	0.012	90	1.56	7.3
Linkw16	0.66	0.67	0.005	0.022	38	11.8	7.1
Linkw15	0.066	0.066	0.005	0.012	33	3	7.3

26 June 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Cul01	0.59	0.59	< 0.010	0.013	130	0.89	7.2
Cul02	0.45	0.45	< 0.010	0.013	29	0.57	7.2
Cul03	0.37	0.37	< 0.010	0.013	22	0.58	7.2
Cul04	0.187	0.187	< 0.010	0.012	16	0.58	7.3
Cul05	0.133	0.133	< 0.010	0.011	17	0.66	7.2

12 August 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Ada01	0.139	0.14	0.005	0.007	47	0.85	7.4
Ada02	0.118	0.118	0.005	0.009	15	0.67	7.3
Ada03	0.183	0.185	0.005	0.006	25	0.86	7.5
Ada04	0.183	0.186	0.005	0.008	32	0.79	7.7
Ada05	0.05	0.05	0.005	0.011	50	1.03	7.2
Ada06	0.26	0.26	0.005	0.01	22	1.5	7.5
Ada07	0.024	0.025	0.005	0.012	5	0.6	7.1
LinkwSoE	0.94	0.94	0.005	0.013	70	4	7
Linkw17	0.077	0.077	0.005	0.012	40	2	7.3
Linkw03	0.97	0.97	0.005	0.013	52	2.6	6.7
Linkw04	2.1	2.1	0.013	0.012	22	1.21	6.3
Linkw05	0.84	0.84	0.012	0.01	80	3.6	6.8
Linkw06	0.8	0.81	0.038	0.009	100	6.4	7.1
Linkw08	0.7	0.7	0.005	0.01	120	6.4	7.2
Linkw10	0.7	0.7	0.005	0.011	320	5.2	7.2
Linkw11	0.069	0.07	0.005	0.012	70	3	7.3
Linkw12	0.121	0.128	0.025	0.022	200	2.8	7.2
Linkw13	0.33	0.33	0.005	0.005	110	3.3	7.3
Linkw14	0.076	0.077	0.005	0.012	31	2.3	7.2
Linkw15	0.076	0.076	0.005	0.014	34	2.4	7.2

17 December 2015

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Cul02	0.85	0.85	0.023	0.017	2700	0.8	7.5
Cul03	0.59	0.59	< 0.010	0.01	450	0.87	7.3
Cul04	0.009	0.009	< 0.010	0.008	260	1.07	7.6
Cul05	0.03	0.031	< 0.010	0.011	14	0.65	7.5

4 March 2016

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Cul02	0.38	0.38	< 0.010	0.002	300	0.24	7.2
Cul03	0.32	0.33	< 0.010	0.009	100	0.27	7
Cul04	0.001	0.001	< 0.010	0.008	100	0.28	7.5
Cul05	0.035	0.036	< 0.010	0.013	14	0.58	7.5

7 July 2016

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Linkw05	0.53	0.53	0.02	0.014	37	5.6	6.9
Linkw06	0.69	0.7	0.047	0.008	120	6.5	7.2
Linkw16	1.32	1.33	0.012	0.028	19	1.47	6.5
Linkw18	0.83	0.84	< 0.010	0.013	120	3.6	6.9
Linkw19	6	6	0.024	0.021	46	0.75	6.5
Linkw20	3.4	3.4	0.027	0.012	27	3	6.5
Linkw21	1.05	1.06	0.049	0.015	100	5	7.2
Linkw22	4.7	4.7	0.027	0.013	50	3.4	6.5
Linkw23	8.4	8.4	0.026	0.026	16	0.63	6.3
Linkw24	0.85	0.85	0.053	0.013	49	4.1	6.5
LinkwSoE	0.95	0.95	< 0.010	0.014	160	2.8	6.9

11 October 2016

Site	NO3-N [g/m^3]	NOx-N [g/m^3]	NHx-N [g/m^3]	DRP [g/m^3]	E.coli [cfu/100mL]	Turbidity [NTU]	pH
Linkw04	3	3	0.017	0.014	20	1.39	6.3
Linkw20	4	4.1	0.025	0.008	65	1.55	6.2
Linkw24	0.94	0.95	0.049	0.018	180	2.7	6.4
Linkw25	1.44	1.44	0.012	0.014	600	3.5	6.6
Linkw26	3.2	3.2	0.019	0.012	38	1.16	6.3
Linkw27	4.7	4.7	0.017	0.006	100	0.89	6.2
Linkw05	0.136	0.139	0.022	0.03	80	3	6.9
Linkw22	4.7	4.7	< 0.010	0.006	600	1.52	6.3
Linkw03	0.58	0.58	< 0.010	0.014	500	2.7	6.9
LinkwSoE	0.69	0.7	< 0.010	0.02	210	2	7.5

11.3. Flow Measurements

Flow measurements in litres per second used for the analysis in this study.

Site	Easting	Northing	29/06/2017	5/01/1982	15/12/1981
Cullen Creek at Queen Charlotte Drive	1671493	5428797		293	209
Duncan Stream at Outlet	1675490	5429455	46		
Linkwater Site 11	1674468	5428657	28		
Linkwater Site 14	1674201	5427878	72.5		
Ada Creek Site 02 - 03	1676340	5429119	72.5	118	50
Ada Creek Site 02	1676291	5429058	52.5		
Ada Creek Site 05	1676402	5428223	49		
Ada Creek Site 07	1676871	5427357	**53**		