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Water Quality in the Tuamarina River Catchment

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Executive Summary

The Tuamarina River is a North-Bank tributary of the lower Wairau River. Land use in the catchment is dominated by pasture on the river flats (mainly dairy) and production forestry on the lower hills. In the lower parts of the catchment the river flows through the large Para Wetland. State of the Environment monitoring at the bottom of the catchment has shown that water quality is in the marginal category.

To identify the causes of the poor water quality ten additional sites throughout the catchment were sampled several times in 2015 and 2016.

The results of this investigation showed that the wetland had a significant influence on the water quality in the river. The wetland is both a sink for soluble inorganic nitrogen and a source for dissolved reactive phosphorus. In an earlier study carried out in 2002/2003, the wetland had a similar effect on nitrogen, but no effect on phosphorus concentrations. It is likely that large-scale aerial spraying of willows within the wetland in recent years has caused the wetland to become a phosphorus source.

Both nutrients originate mainly from groundwater inflows. However, there are potentially additional direct inputs in Koromiko Stream and Unnamed Creek.

Dissolved oxygen saturation is also effected by the wetland, but oxygen levels are already quite low upstream. Short-term continuous monitoring revealed that oxygen saturation upstream of the wetland is consistently above the guideline, but does not reach levels above 80%. In the lower part of the wetland dissolved oxygen saturations are around 60%, while several kilometres downstream of the wetland oxygen saturation has the greatest variability, at times falling to levels as low as 47%. This is the result of prolific aquatic plant growth. During the monthly State of the Environment sampling, measurements as low as 22% have been recorded. This means that low dissolved oxygen levels potentially have the most severe impact on the ecology of the lower Tuamarina River.

E. coli concentrations at the State of the Environment sampling site reach very high levels mostly during flood flows, but the lack of flood flows during the study period made investigation of the sources impossible. During base flow, E. coli concentrations in the main river were mainly below the guideline of 550 E. coli/100mL. However, in the upper and mid catchment E. coli levels were often close to the guideline level, which was likely caused by stock access. In the tributaries, E. coli concentrations were highest in Unnamed Creek and the Lagoon. While stock access is the most probable cause in Unnamed Creek, an abundance of wildfowl is the most likely source in the Lagoon.

Very notable, however, is the significant reduction in E. coli concentrations within the catchment since earlier studies in 1977/1978 and 2002/2003. This reduction in E. coli levels is a direct result of fencing off livestock from waterways and the installation of stock bridges and culverts.

In 2013, significantly high turbidity values were recorded on two occasions during State of the Environment monitoring. The flood flows in which these high values were observed were not unusually large, but they coincided with large-scale clear felling of production forest in the catchment. There were no large floods during the study period, therefore, sediment sources could not be investigated. However, in 2017 a flood with flows similar to those causing the high turbidity in 2013 did occur, but the water remained relatively clear. At this latter time only a relatively small area of production forest had been clear-felled.

The report presents a number of recommendations. For monitoring of water quality, the recommendations include continuation of monthly State of the Environment sampling at the current site and additional regular monitoring of dissolved reactive phosphorus upstream of the wetland.

Recommendations for the improvement of water quality include riparian planting and further fencing off of livestock.

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1. Introduction

The Tuamarina River is a North Bank tributary of the lower Wairau River with a catchment area of 102 square kilometres. The narrow valley flats are flanked by hills with heights between 600 and 1000m. The hills have a roughly equal coverage of production pine forest and native vegetation, with natives usually at the higher elevations. The river flats are dominated by pastures, which are mainly grazed by dairy cattle.

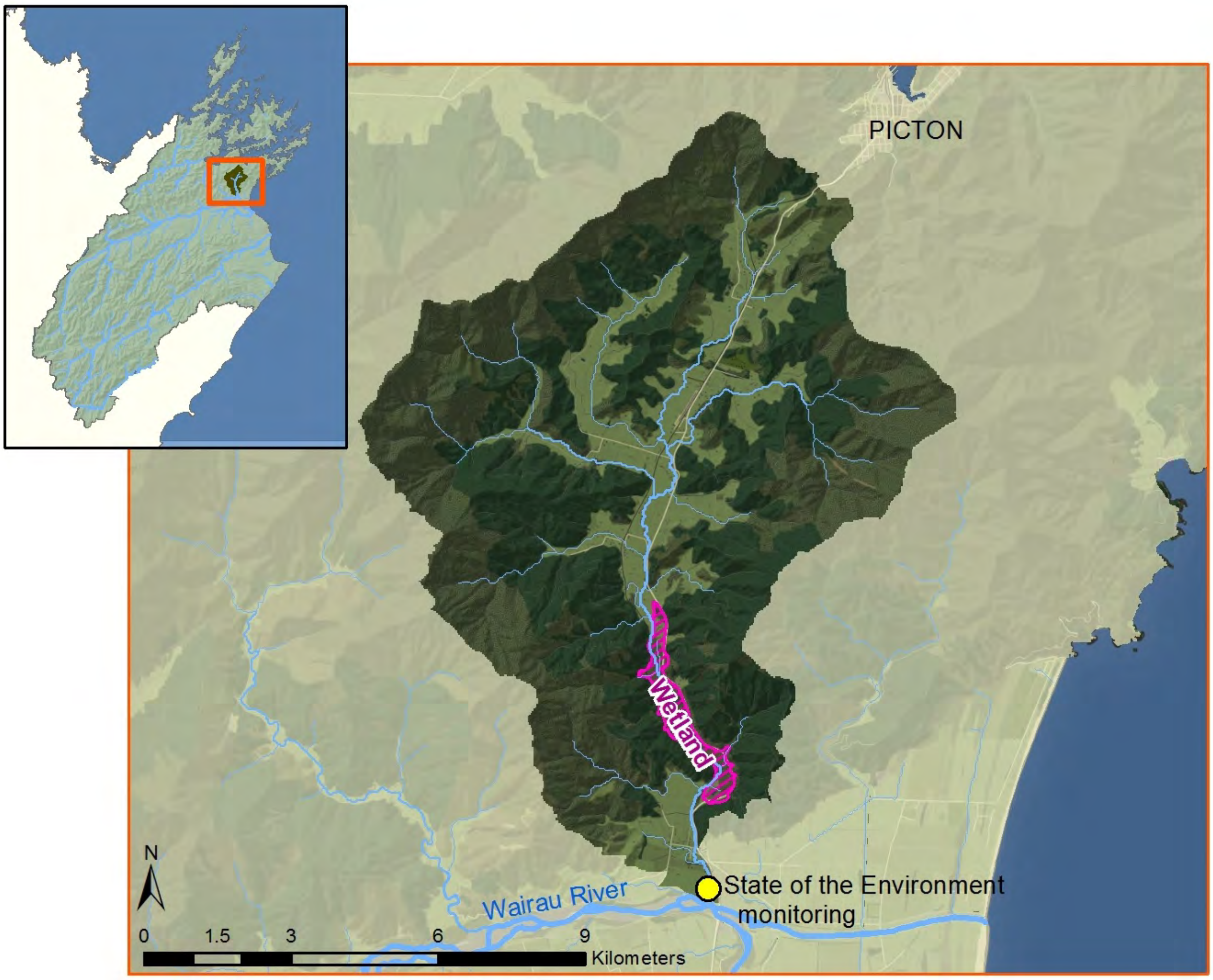

Figure 1: The Tuamarina River catchment. Also shown are the extent of the Para Wetland and the location of the State of the Environment monitoring site.

In the lower reaches, the river flows through the largest remaining wetland in the Wairau catchment, the Para Wetland (Figure 1). A comparatively small area downstream of the wetland has been converted into vineyard.

Regular monitoring of the Tuamarina River water quality is carried out at the bottom of the catchment just upstream of the confluence with the Wairau River. This State of the Environment monitoring has shown that water quality is in the marginal category, which is considered unacceptable unless caused by natural sources. There are a number of parameters that indicate deteriorated water quality. These include elevated nutrient concentrations, low dissolve oxygen levels during summer and occasionally extremely high turbidity levels.

To allow more detailed characterisation of the water quality in the Tuamarina River, additional sampling was carried out in 2015 and 2016[1] at a number of sites along the main river and some of its tributaries.

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[1] Some initial sampling was performed in 2014, but the main investigation was carried out in 2015 and 2016. Therefore, in this document this recent study will be referred to as the 2015/2016 study.

The main aim of this study was the identification of contamination sources in the catchments that might explain the poor water quality at the State of the Environment site. Another purpose was to provide a better understanding of the influence the large wetland has on water quality.

Due to the large size of the catchment and limited river access, only a large scale investigation was possible. Nevertheless, the results of the study can be used to identify areas that need further investigation to pin-point contamination sources.

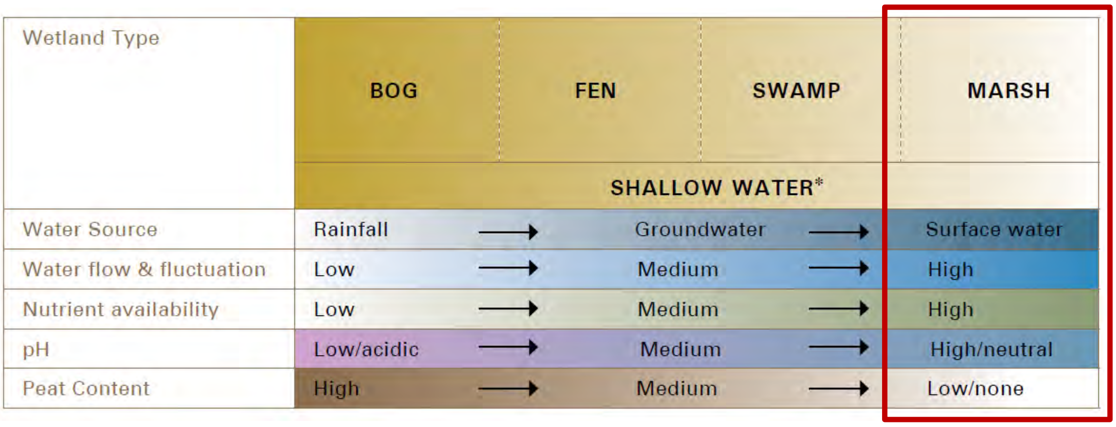
Although the focus of the investigation was water quality, this report provides a broader characterisation of the catchment including summaries of the Geology, Hydrology, Soils and River Ecology, as these are inextricable linked to the water quality in the river.

Figure 2: Aerial view of the Tuamarina mid catchment showing the pastoral land use on the river flats and production forestry on the hills.

2. The Para Wetland

One of the most unique features of the Tuamarina River catchment is a large wetland in the lower reaches, the Para Wetland. Covering an area of 120 hectares (1.2 km^2), it is the largest remaining wetland in Marlborough and has been given national significance status. At least 89% of the region's wetlands have been drained or cultivated. The resulting scarcity of large wetlands in the region makes the Para Wetland an area of high ecological value [16].

The Para Wetland formed as a result of a low land gradient in the lower reaches of the Tuamarina River. This significantly slows the water flow resulting in water logged soils and ponding of water. Along over three kilometres of river length the river bed changes by less than one meter. In contrast, further upstream in the Koromiko area, the bed level changes by almost 20 meters along the same distance. Additionally, during flood events, high water levels in the Wairau River cause the Tuamarina River to back up resulting in further flooding of the wetland area. Based on the Landcare wetland categorization system [33], the Para wetland is considered a Marsh (Figure 3).



Wetland Type	BOG	FEN	SWAMP	MARSH
	SHALLOW WATER*			
Water Source	Rainfall →	Groundwater	→	Surface water
Water flow & fluctuation	Low →	Medium	→	High
Nutrient availability	Low →	Medium	→	High
pH	Low/acidic →	Medium	→	High/neutral
Peat Content	High →	Medium	→	Low/none

Figure 3: Key environment characteristics of wetland types (Source: Peters and Clarkson (2012)).

Like many other wetlands in the country, the Para Wetland did not remain in its natural state. In order to reduce flooding to adjacent paddocks, the river has been straightened over time by creating a U shaped channel through the wetland. Aerial photographs show that the last remaining meanders in the northern part of the wetland were removed some time after 1948 (Figure 4). It is likely that the river originally moved through the entire wetland in similarly tight meanders. The straightening of the channel has reduced the water supply to the wetland area. The soil removed during the creation of the artificial channel was deposited alongside the river, creating a bund which further decreases the hydrological connection.

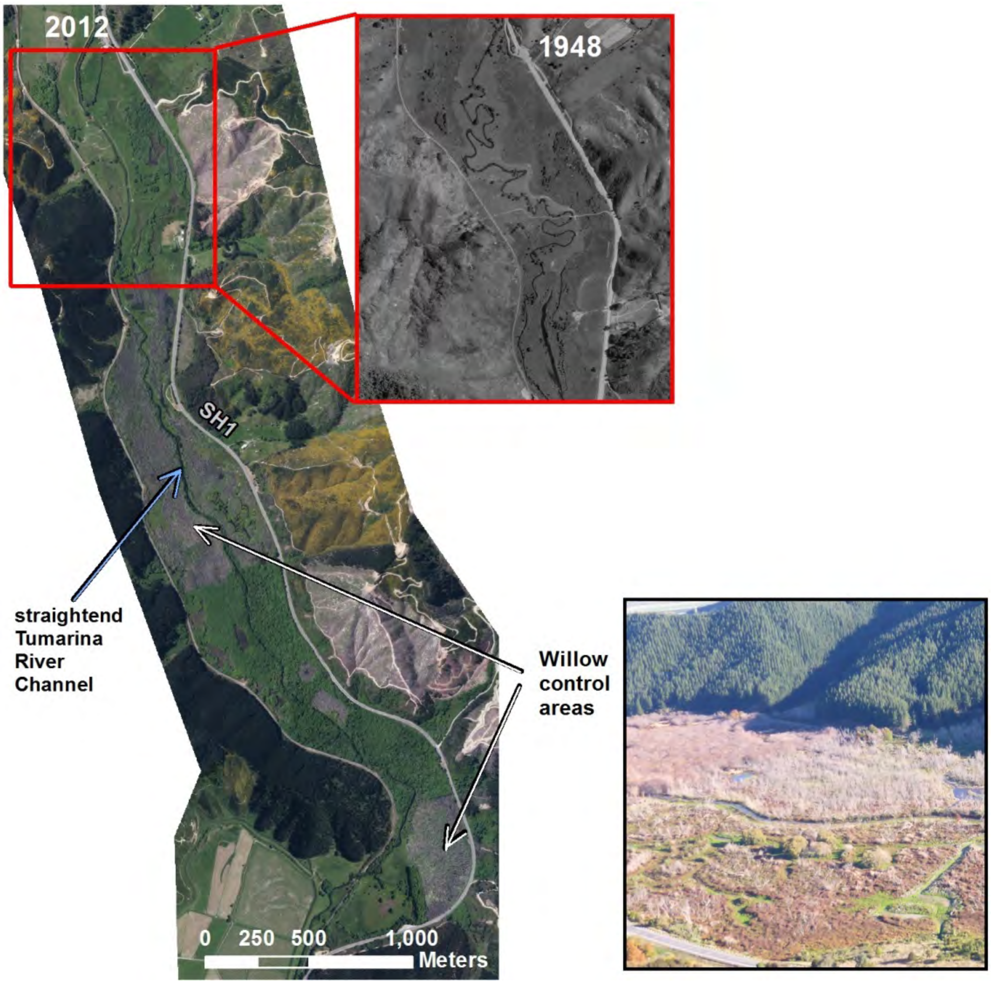


Figure 4: Aerial photographs of the Para Wetland from 2012 and 1948. Also shown is a photo of the wetland after willows were sprayed (Willow control area).

The original vegetation of the wetland consisted predominantly of large flax areas, with stands of kahikatea forest and cabbage trees, as well as pockets of raupo and Carex sedgeland [Jones 1998]. Introduced willows [2] have replaced most of the native plant cover, but small stands of kahikatea, kowhai and a number of flax and coprosma species remain [16]. A vegetation survey carried out in 1998 revealed that only approximately 15% of the wetland remained in native wetland communities. However, the survey also found significant areas of the nationally threatened native swamp nettle, *Urtica linearifolia* and other regionally uncommon plants, such as *Ranunculus macrous* and *Epilobium pallidiflorum*.

In recent years aerial spraying of the willows was carried out (Figure 4), which is followed up by regular ground control of remaining willows and planting of natural vegetation. The work is done by the NZ Fish & Game Council, who manages almost the entire wetland area with financial assistance from the Department of Conservation, Council and other contributors.

Figure 5: An area of the Para Wetland where aerial willow control was carried out several years ago. Most of the tree trunks have fallen over into the shallow water.

It is planned to let over 90% of the wetland regenerate to sedge, flax and raupo plant communities. A number of open water hunting areas are also being created. These consist predominantly of excavated ponds with small artificially elevated islands that provide for bird nesting and hunting [30]. Planting of some non-native vegetation, such as swamp oak, weeping willow and exotic legumes for some areas within the wetlands is also planned to support the population of the hunted waterfowl.

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[2] Mainly crack willow, with patches of grey willow and fertile willow hybrids

3. Geology and Groundwater

The basement rock of the Tuamarina catchment consists of semischistose sandstone and siltstone, which is a partly metamorphosed sedimentary rock (mainly greywacke). The degree of metamorphisis increases towards the west. This means Greywacke argillite and lower grade schist form the basement rock in the eastern hills, while the western part of the catchment is comprised of higher grade schist [35]. GNS maps estimate the origin in the Triassic and Jurassic periods, 252 to 145 Million years ago [11]. In the valley floor this basement rock has been covered by several layers of river sediments. These, so-called alluvial sediments are relatively coarse sands and gravels which have spaces through which groundwater can flow. During warmer geological phases the sea level rose to levels higher than those observed today. As a result the sea extended further inland and into the lower parts of the Tuamarina valley. During those periods fine marine silts and clays were deposited, creating layers that cannot be penetrated by groundwater. As a result the valley floor consists of several layers of water bearing river gravels, aquifers, which are separated by layers of fine silt, aquitards (Figure 6). The lower, southern part of the valley is also covered by layers of swamp deposits. Swamp deposits on the surface are indications for the original extend of the Para Wetland, reaching as far north as Speeds Road (Figure 6).

The comparatively flat valley floors with a lack of river terraces suggest that the river is currently filling the valley floor with sediment rather than eroding down into older sediments [35].

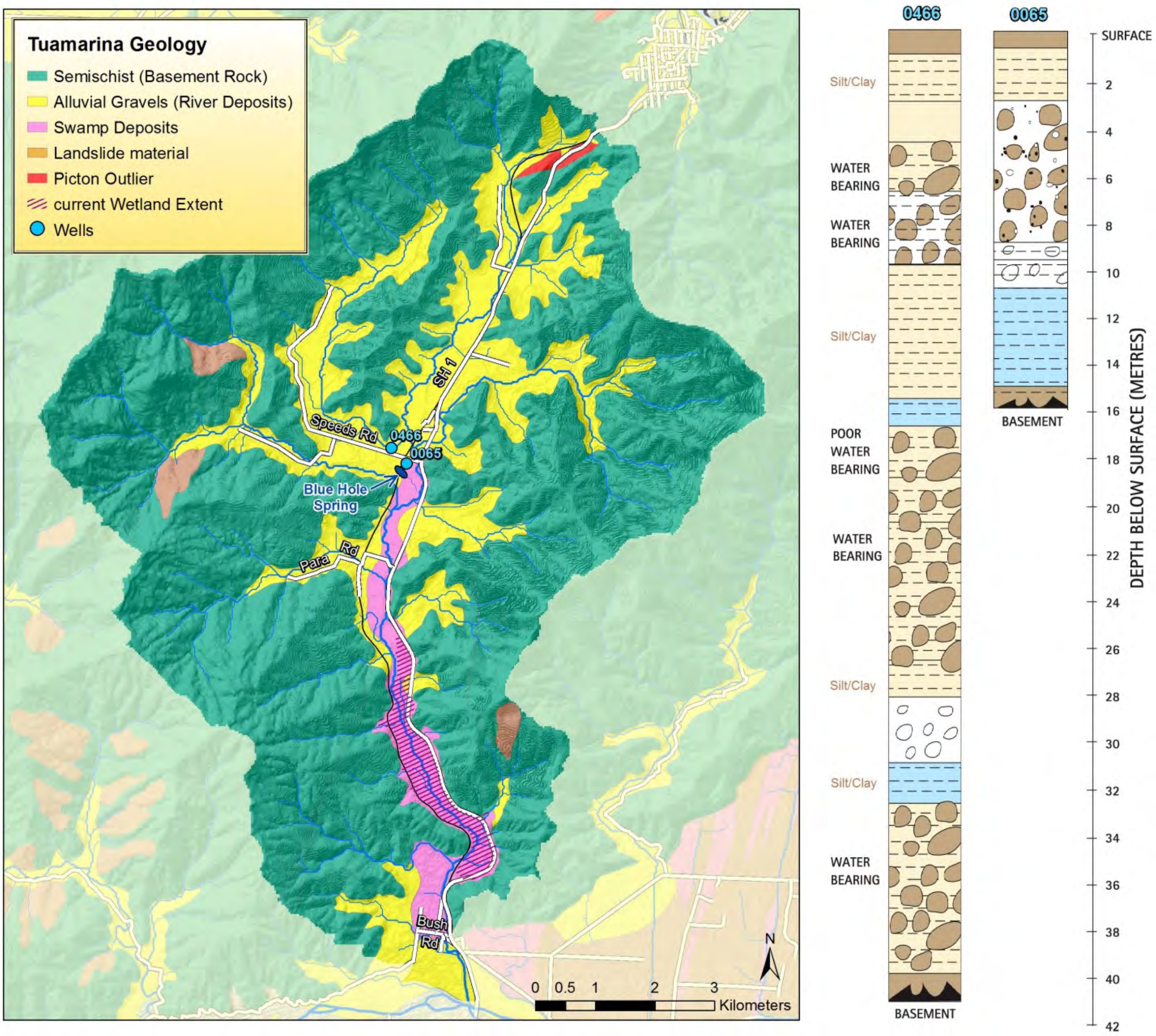

Figure 6: Left: Geology of the Tuamarina catchment. Right: Lithologic section for two wells near Speeds Road.

Groundwater resources in the Tuamarina catchment have been relatively well studied. A number of investigations were undertaken in the early 1990s to establish the Speeds Road Well Field that supplies Picton with drinking water. Originally these wells were quite shallow (< 10m), tapping only into the alluvial layers close to the surface. Following a drought in 2000/2001 during which the wells almost ran dry, the wells were deepened to draw additional water from deeper aquifers. The groundwater from these wells is on average 13 years old [6].

Near the Speeds Road Well Field a significant amount of groundwater is forced to the surface forming springs, the largest being the 'Blue Hole Spring' (Figure 6). The reason is a reduction in the size of the water carrying layer of alluvium in this area [6]. The water from the springs significantly contributes to the flow of the Tuamarina River, particularly during the drier months. This means that the ecological functioning of the Para Wetland also depends on these groundwater sources. Pump tests of wells near Speeds Road showed that large groundwater abstractions have an effect on river flows and that pumping during the summer months could in actual fact abstract water from the river itself [39].

Groundwater from deeper aquifers in the northern part of the catchment is significantly older and pressurised. Some of the wells had to be drilled to depths greater than 50 meter to find sufficient water [6].

At the southern part of the catchment, upstream of Bush Road, the layer of fine marine silt and clay is more than 25 metres thick and wells have to penetrate this layer to provide sufficient groundwater. However, the silt and clay layer becomes thinner further south, which is probably the result of erosion by the Wairau River [6].

There are a number of faults located within the Tuamarina catchment; however none of the faults have been active for the last 120,000 years [6]. The shifting of the land along the faults has created discontinuities in the water bearing layers which affects the yield of some of the wells.

In the most northern part of the catchment, a small area of marine conglomerate and siltstone with coal measures, called 'Picton Outlier', can also be found [11].

4. Hydrology

Rainfall varies significantly across the catchment. The northern parts receive an average of 1,400 to 1,500 mm of rain per year, while only 800 to 900 mm of rain falls in the areas closest to the Wairau River confluence in the south [38]. There is also some variation due to elevation, with higher rainfall in the hills compared to the river flats. Apart from private rain gauges, a NRFA rain gauge at the entrance to the Koromiko Airport is currently recording rainfall in the catchment.

With an area of 102 square kilometres, the Tuamarina River catchment is the largest North Bank tributary of the lower Wairau River. The main stem of the Tuamarina River has a length of 21.2 kilometres and flows from Te Tara-o-Te-Marama/Mount Freeth in the North to the confluence with the Wairau River in the South of the catchment. The four largest tributaries are Speeds Valley Stream, Bragg Creek, Koromiko Stream and Para Stream. These tributaries join the main stem along a relatively short, 3 km, section of the Tuamarina River located in the middle of the catchment (Figure 7). One of the largest springs is also located in this area (see Groundwater section). There is limited flow information for these tributaries. One of the few sets of flow measurements was collected for the 1977/78 water quality study. Unfortunately, the flow was not always measured at the confluence with the Tuamarina River. The results show that in winter, stream flows correlate reasonably well with the area of the catchment drained at the particular sites (Figure 7). The exception is Koromiko Stream, which appears to have had a significantly higher flow.

In summer, flows are generally very low and some of the tributaries dry up completely. In the 1978 summer study, Koromiko Stream and Un-named Creek were dry at all five sampling occasions. During the summer months of the latest 2015/2016 study, all tributaries were dry at the sampling sites at times. These tributaries have quite porous gravel substrate in the lower reaches, so that flow continues through the gravel when surface flows have ceased.

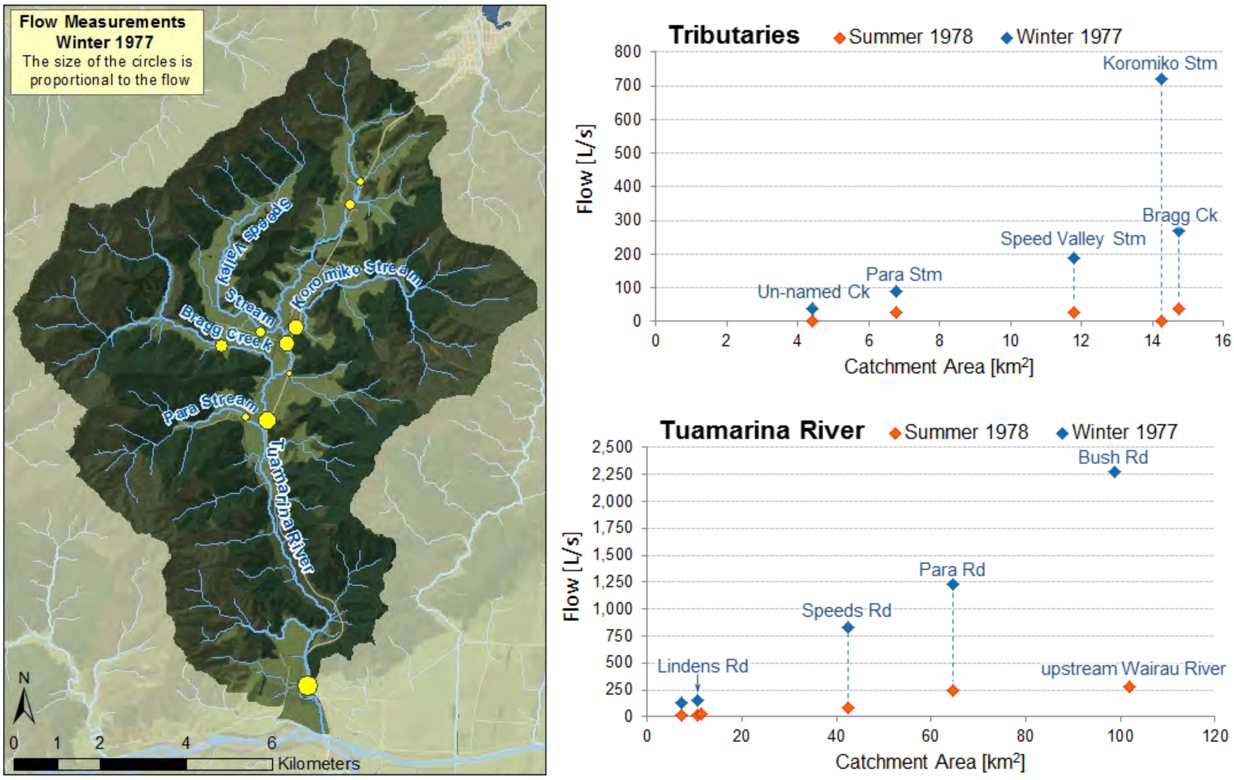

Figure 7: Left: Flow Measurements in the Tuamarina River catchment in winter 1977. Right: Relationship between catchment area and flows measured in winter 1977 (blue) and in summer 1978 (orange).

In the severe drought of 2000/2001, not only the tributaries, but also the main river dried up upstream of the Blue Hole Spring just south of Speeds Road.

In summer the Blue Hole Spring represents a significant contributor to the river flow. This is apparent from the notable increase in flow seen between Speeds Road and Para Road in the flow measurements taken in summer 1978 (Figure 7). A number of earlier gaugings carried out in December 1972 showed that the Tuamarina River flow increased on average 131 L/s between Speeds Road and the Blue Hole Spring confluence 500m downstream. During the height of the 2001 drought the spring contributed 42 L/s to the flow in the river [6]

The 1977 measurements show that in winter, the Tuamarina River flow increases quite consistently along the length of the river and the springs have less influence on the overall flow.

A continuous flow recorder was installed at Para Road in April 2004 and continues to operate to the present day. An additional stage recorder is located at Boat Point, but the prolific weed growth at this site make the conversion into flow data difficult.

The river has a mean flow of 1.62 m^3/s and a median flow of 0.692 m^3/s at the Para Road recorder site. The highest recorded flow was observed on the 17th of April 2014 with 269.5 m^3/s.

During large Wairau River floods, water has been seen to flow upstream into the Tuamarina River and into the lower reaches of the Para Wetland. This is caused by the low gradient of the lower Tuamarina catchment.

5. Soils

A soil survey carried out in the Koromiko area in 2014 provided valuable information for the management of the soils in this area. Previously, soil maps dating from 1968 were the only soil information publicly available. These maps were based on reconnaissance scale mapping only, with soils identified solely through general landforms and parent rock. In the 2014 survey, the soil was assessed and sampled at 21 sites in the lower lying areas of the mid catchment. The sites were chosen to ensure sufficient coverage of topographical differences [35]. The 1968 mapping had identified two soil types for this area, Kaituna and Koromiko soils. The 2014 study result showed that Koromiko and Kaituna soils were the most common soils found, but for the majority of sites the actual soil types were quite different from the original mapping (Figure 8). In addition to these two soil types, Ronga, Manaroa and Rai soils were also found.

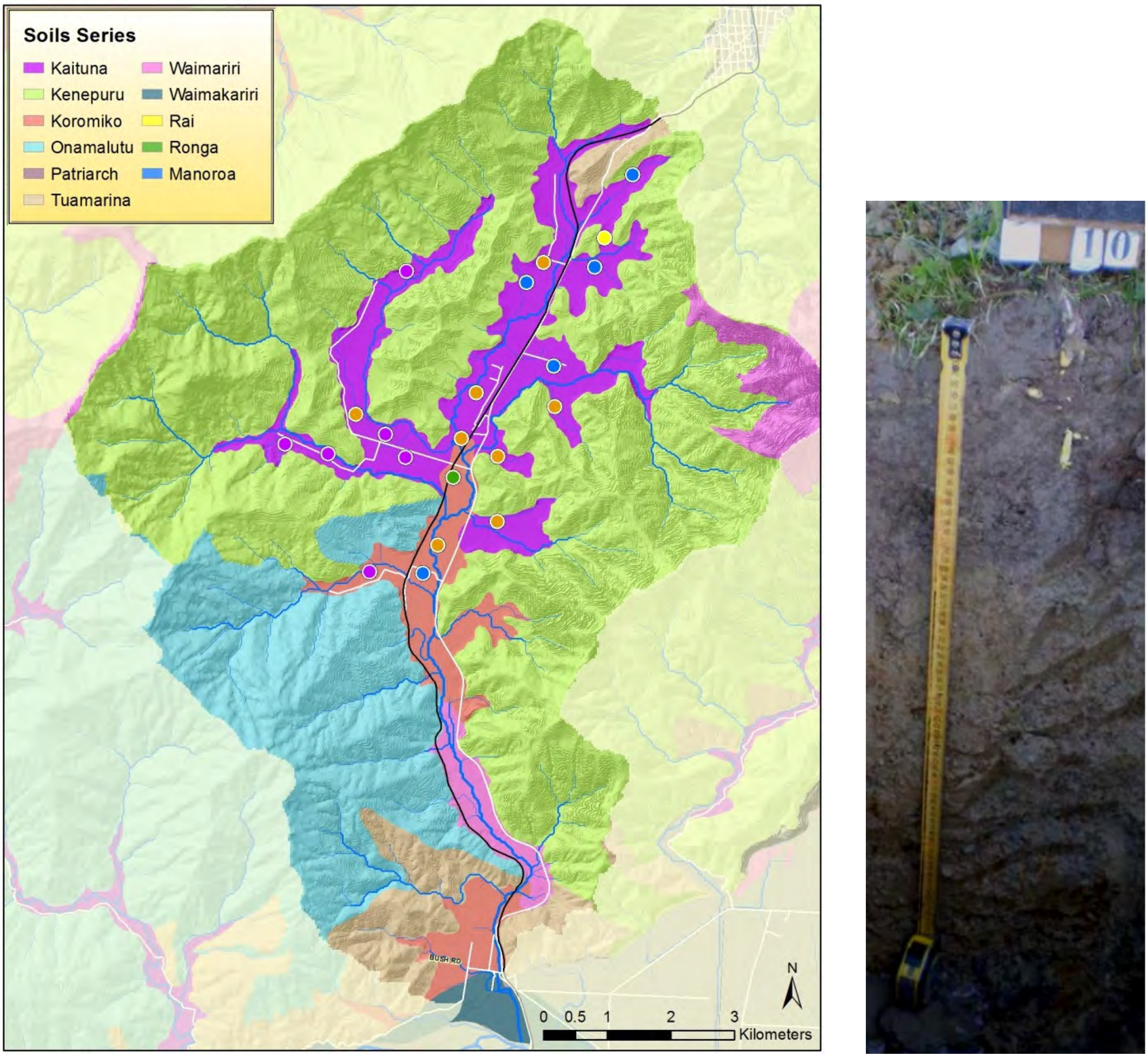

Figure 8: Left: Soil Series based on the 1968 soil maps (background map) and soils identified during the Koromiko Soil Survey 2014 (circles). Right: Soil profile of a Koromiko Soil, the most common soil encountered in the 2014 survey.

Apart from one site with Ronga soil, which is a Recent soil, all soil types encountered during the 2014 study were Brown soils. Brown soils are the most common soils in New Zealand [19]. They have yellow-brown subsoils, which derive their colour from iron oxides that form a thin cover around the soil particles. The soils sampled had silty or silty/clayey structures and had moderate to deep soil depths. Figure 9 & Figure 10 show some of the soil properties measured during the survey, assessed using the Landcare Research SINDI Tool.

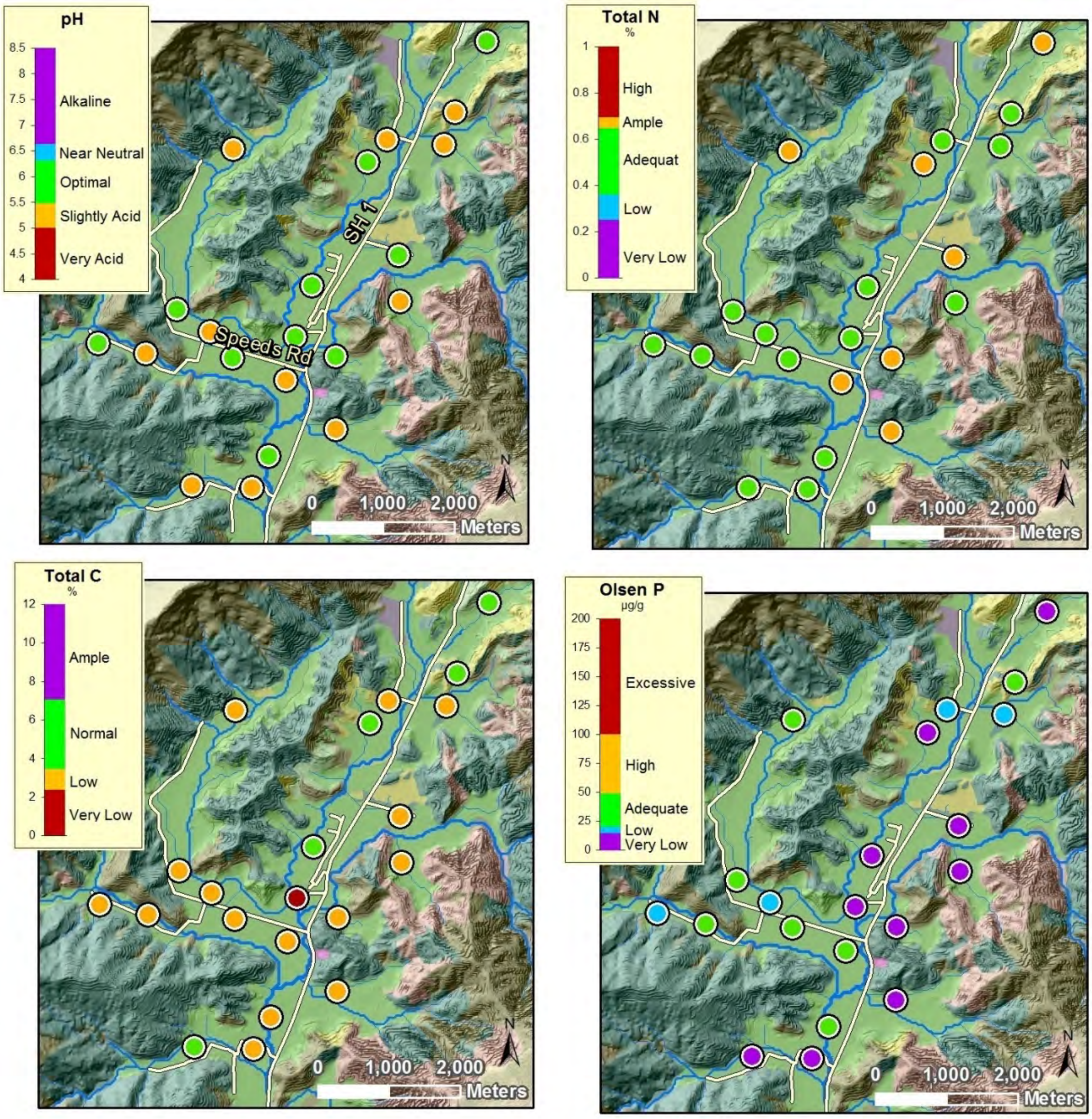

Figure 9: Average soil properties for the sites surveyed in 2014.

The pH of the soils was in the optimal range or slightly acidic. Low soil pH reduces nutrient availability for plant growth and impacts on the functioning of beneficial soil organisms. It also can increase the uptake of contaminants by plants. Fortunately, none of the soils exceeded the heavy metal concentration limits suggested by NZWWA 2003. However, cadmium concentrations were approximately double the background value at the majority of sites. This is likely a result of impurities in fertilisers applied to these soils.

Nutrient concentrations in soils need to be maintained at high enough levels to support good plant growth. However, very high nutrient concentrations can lead to leaching of these nutrients into groundwater and subsequently into streams and rivers. The percentage of Total Nitrogen measured in most of the soil samples was adequate for plant growth, but some sites had slightly elevated levels, indicating a higher potential for leaching. Most of the nitrogen is usually bound in organic matter. High organic matter content can reduce the amount of nutrients leached to groundwater after fertilizer or effluent is applied. The soils sampled in the 2014 survey had generally low percentages of Total C, which is indicative of low organic carbon content in the soils. This indicates a relatively high leaching potential for nutrients.

Phosphorus is generally well bound to the soil, but can leach to groundwater if concentrations are very high. The soils sampled in 2014 had adequate to very low Olsen P levels, which means that currently phosphorus leaching from these soils is minimal.

Agricultural cultivation and stock trampling can cause compaction of the soils. This leads to increased run-off during rainfall and irrigation. As a result the natural filter function of the soil is bypassed and a greater amount of contaminants (e.g. faecal matter and sediment) enters nearby waterways. Most of the soils sampled in the 2014 survey showed some compaction, indicated by high Bulk Densities and low Macroporosity. At most sites Macroporosity was at the very low end of the scale.

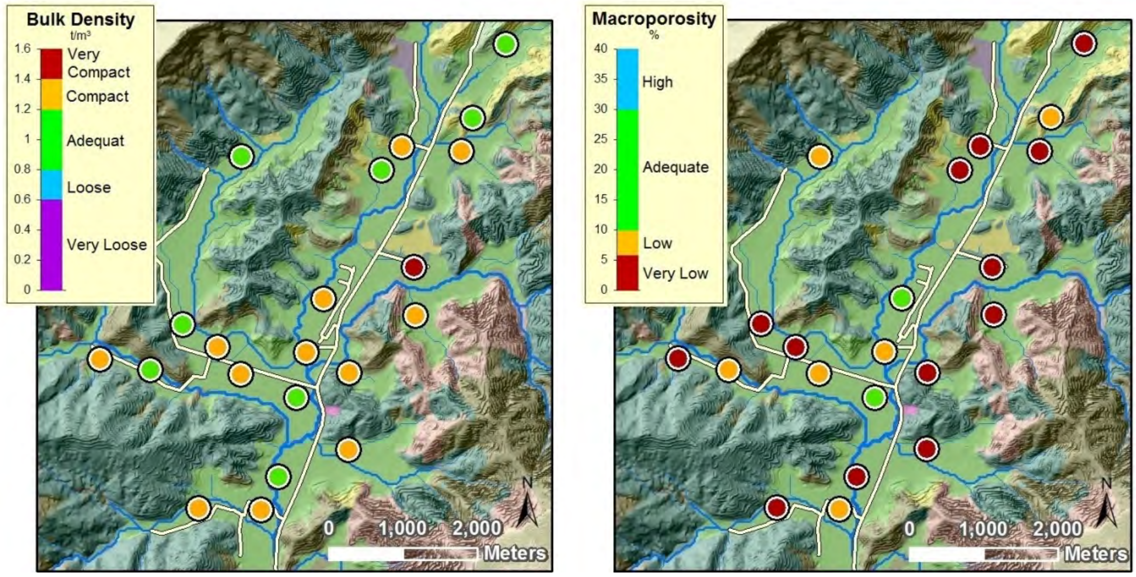

Figure 10: Average values for Bulk Density and Macroporosity for the sites surveyed in 2014.

6. Water Quality

6.1. Monitoring History

Including the most recent investigation, three surveys into the water quality of the Tuamarina River were conducted over the last 40 years. The first survey was carried out in 1977/1978 by the Marlborough Catchment and Regional Water Board. A total of 12 sites were sampled five times in winter and another five times in late summer. During the summer sampling, two of the sites could not be samples as they were dry. Eleven of the original sites were re-sampled once in May 2002 and another time in December 2003.

In the latest survey carried out in 2015/2016, eight of the original sites and two additional sites were sampled on up to ten separate occasions.

Since 2007 the Tuamarina River has also been monitored as part of the State of the Environment program. The sampling site is located at the bottom of the catchment, just upstream of the confluence with the Wairau River.

6.2. Influences on water quality

Land use has the greatest influence on water quality for most parts of the Tuamarina River.

Nearly 20% of the catchment is used for the production of pasture and the majority of this pasture is grazed by dairy cattle. Despite the intensification of dairy production witnessed in other areas of the country, the number of cattle in the Tuamarina catchment has changed little. In fact, the number of dairy cattle has slightly decreased from 1,877 in 1977 to 1,710 in 2016.

A source of frequent pollution in the earlier water quality surveys were stream crossings. These are stream sections where dairy cattle are driven through the waterway on a regular basis; moving to and from the milking shed. As the cattle cross the streams, some of them defecate into the water. The cattle faeces deposited contain nutrients, organic matter and faecal bacteria, all of which have an effect on the water quality downstream of the crossings. These contaminants impact on the aquatic ecology on the waterway, but also result in a high health risk to recreational users for many kilometres downstream.

A survey of stream crossings in the Tuamarina catchment was carried out in 2005 and found a total of 44 crossing, 15 of those were considered high priority crossing. High priority crossings are crossings that are used relatively frequently and by a large number of cattle.

In the initial agreement between Council and dairy representatives, high priority crossing had to be replaced with bridges or culverted crossings by August 2007, while other crossing could be eliminated as resources became available. To help with the financial burden, resource and building consents for stock crossings were processed free of charge and a resource consent template was provided for small crossings. By 2008, one year after the deadline, 10 of the 15 high priority crossing still remained in the Tuamarina catchment. All were located on three of the nine farms. At the time of the latest water quality investigation in 2015/2016 all high priority crossing had been eliminated, while 11 of the original 29 low priority crossing remained.

At the time of the first survey in 1977/78 water quality was additionally impacted by direct discharges of dairy effluent, as well as discharge from two dairy factories and a piggery [22]. These activities had ceased by 2002 when the second survey was carried out.

Impacts on water quality from pastoral land uses are not confined to direct discharges, such as those mentioned above, however. Nutrients from fertiliser and animal excrements that are not taken up by pasture plants leach through the soils into subsurface flow and groundwater during rainfall and irrigation. The nutrients subsequently end up in tributary streams and the Tuamarina River when the groundwater resurfaces. Nitrogen is particularly mobile in the environment as it does not bind well to soil. Over-application and subsequent saturation of the soil with phosphorus can also lead to leaching of this nutrient.

More than 35% of the Tuamarina catchment has been planted in production forest – predominantly *Pinus radiata*. For the majority of the growing cycle these forests have little impact on water quality. Expectations are the application of fertilizer to plantation forests which can lead to increased nutrient concentrations in water waterways.

Unlike pasture, trees provide shading to aquatic ecosystems thereby keeping stream cool during the summer months. This is essential for the survival of some sensitive aquatic species.

However, during harvest the impact on water quality can be significant. As nearly all of the production forest is located on sloping land, rainfall results in the mobilisation of exposed top soil and sediment on roads and landing sites. Increased sediment inputs into streams as a result of forestry harvest is a well-acknowledge phenomenon [ie; 5, 10]. Formation of erosion gullies and smothering of waterways by sediment can be prevented by leaving wide riparian buffers, but unfortunately this is currently not common practice. Increased sediment inputs are usually observed for roughly 2 – 5 years following the harvest [17].

6.3. Water Quality Survey Results

6.3.1. Soluble Inorganic Nitrogen

Nitrate, ammonical nitrogen and nitrite are the forms of nitrogen that are easily taken up by plants. They are collectively referred to as 'Soluble Inorganic Nitrogen'. In surface water and shallow groundwater most of the Soluble Inorganic Nitrogen is in the form of nitrate.

Any nitrogen in animal waste or nitrogen fertilizer applied to land that is not taken up by the vegetation is potentially carried into groundwater by rainfall or irrigation water. Very high nitrate concentrations (> 11.3 mg/L) 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 mg/L for nitrate in the National Policy Statement for Freshwater Management 2014 is based on this toxicity [27].

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 it can also cause a reduction of biodiversity as the algae smother available habitat for many aquatic insects which in turn are food for fish. The guideline of 0.165 mg/L for Soluble Inorganic Nitrogen used in this chapter is based on this effect and is the guideline value used for State of the Environment reporting [4, 14].

At the State of the Environment site upstream of the Wairau River confluence, the majority of soluble inorganic nitrogen is in the form of nitrate (Figure 11). This is the usual case for natural rivers. In well oxygenated water nitrate is the most stable form of soluble nitrogen and the other two forms, ammonical nitrogen and nitrite are quickly oxidised into nitrate by aquatic bacteria.

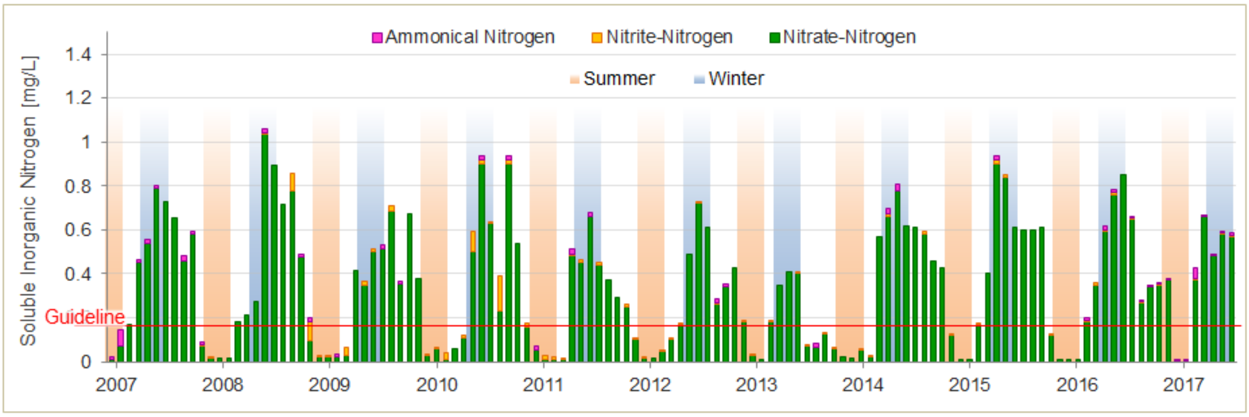

Figure 11: Soluble Inorganic Nitrogen concentrations at the State of the Environment site located just upstream of the confluence with the Wairau River. Also shown are the contribution of the different forms of nitrogen, as well as an indication of the warmest (summer) and coolest (winter) months.

Also typical are generally higher soluble inorganic nitrogen concentrations in winter. These are caused by reduced plant growth and therefore less nitrogen uptake by terrestrial and aquatic plants during the cooler months. Also, the often wetter soil conditions result in greater leaching of nitrogen into groundwater and subsurface flows. In summer, reduced leaching and uptake by algae and other plants results in very low soluble inorganic nitrogen concentrations in the water column. In the Tuamarina River, soluble inorganic nitrogen concentrations are generally above the guideline level in winter, but significantly lower in summer (Figure 11).

The long term monitoring shows little changes apart from natural year-to-year variability associated with varying rainfall patterns. This is not surprising as land use has changed very little over the years.

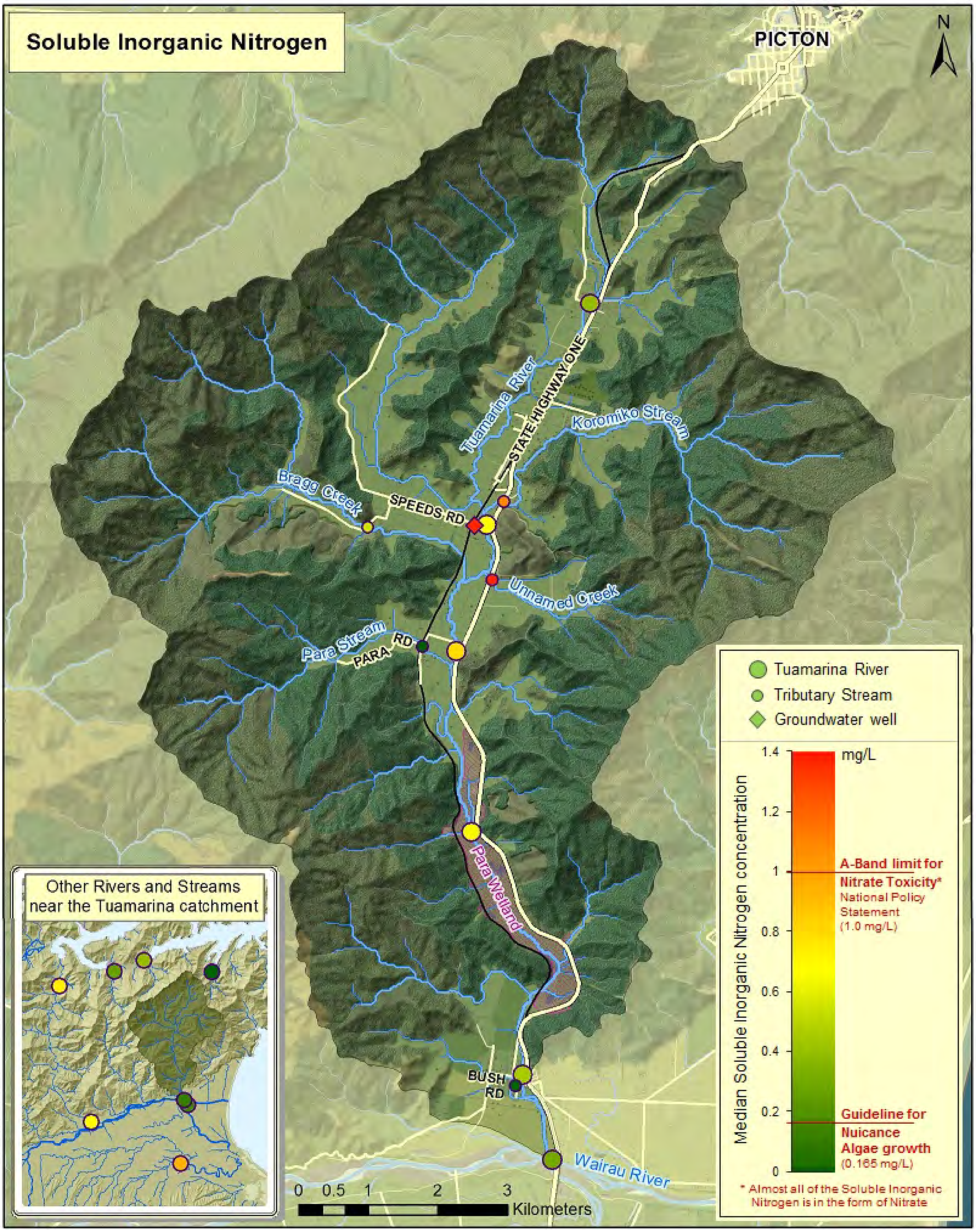

Figure 12: Median Soluble Inorganic Nitrogen concentrations measured in the Tuamarina River catchment during the 2015/2016 study.

The results of the 2015/16 catchment investigation show that soluble inorganic nitrogen concentrations are quite variable within the catchment. In the main river, concentrations peak in the middle of the catchment at Sites 5 & 6 (Figure 12 & Figure 13). Nitrogen levels here are comparable to other pastoral catchments in the region.

Downstream of the Para Wetland concentrations are lower. This is the result of nitrogen removal by transformation of nitrate into a gaseous form of nitrogen; a process that naturally occurs in most wetlands.

Nitrogen levels observed in the main river during the latest survey were similar to those observed in 2002/2003 (Figure 13). This reflects the unchanged land use and the absence of dairy intensification in the catchment.

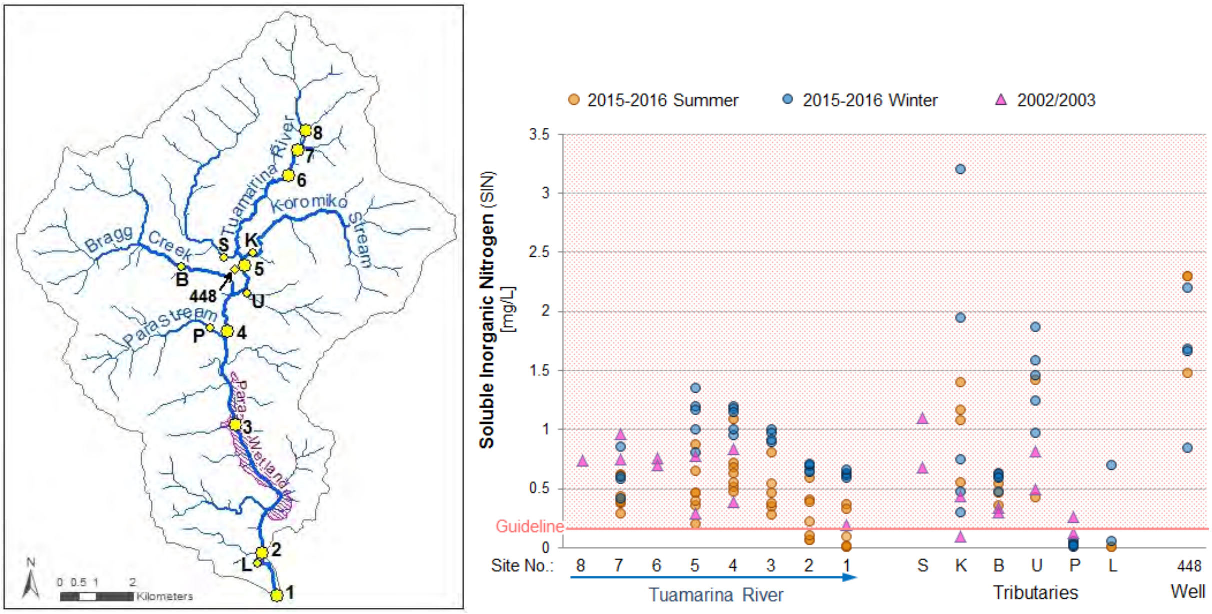

Figure 13: Soluble Inorganic Nitrogen concentrations measured as part of the 2002/2003 and 2015/2016 water quality studies carried out in the Tuamarina catchment.

In the 2015/16 study, the highest soluble inorganic nitrogen concentrations were observed in some of the tributaries, particularly Koromiko Stream and the Unnamed Creek. The nitrogen levels in these two streams showed significant variability, which is usually indicative of occasional direct inputs of nitrogen rich material in addition to the pasture-related elevated base concentrations caused by leaching.

Based on the 2002/2003 data, nitrate concentration in Speeds Valley Stream are also quite high and it is possible that concentrations in the lower reaches of Bragg Creek are of similar magnitude.

Soluble inorganic nitrogen concentrations in Para Stream were surprisingly low. As this waterway has a similar percentage of pasture as the sampling site on Bragg Creek, nitrogen concentration should be comparable to those observed in Bragg Creek. It is unclear if natural factors or better management practices are the reason.

Apart from surface water State of the Environment monitoring, regular long-term monitoring of nitrate concentration is carried out at two additional sites, Well 448 and the Tuamarina River at Speeds Road Bridge. These sites are monitored as part of the Picton Water Supply Scheme. Well 448 is one of the actual supply wells, which is located in relatively close proximity to the river. The comparison of nitrate levels at these sites shows consistently higher levels in groundwater compared to the nearby river at Speeds Road (Figure 14). Upwelling groundwater is a significant contributor to the flow of the Tuamarina River in this area. Therefore, the nitrate observed in the river originates from groundwater inflow, which is diluted by water already in the river. The furthest downstream site (upstream Wairau River) has lower concentration compared to the other two sites. This is consistent with observations made during the studies.

Additional long-term data sets such as those for the Speeds Road site are very valuable for the assessment of water quality in the Tuamarina catchment. The majority of land use pressures occur upstream of the this site, while the actual State of the Environment monitoring is carried out downstream of the Para Wetland, which moderates some of the effects of land uses in the catchment. Therefore, from a water quality management point of view, continuous monitoring of both sites would be desirable.

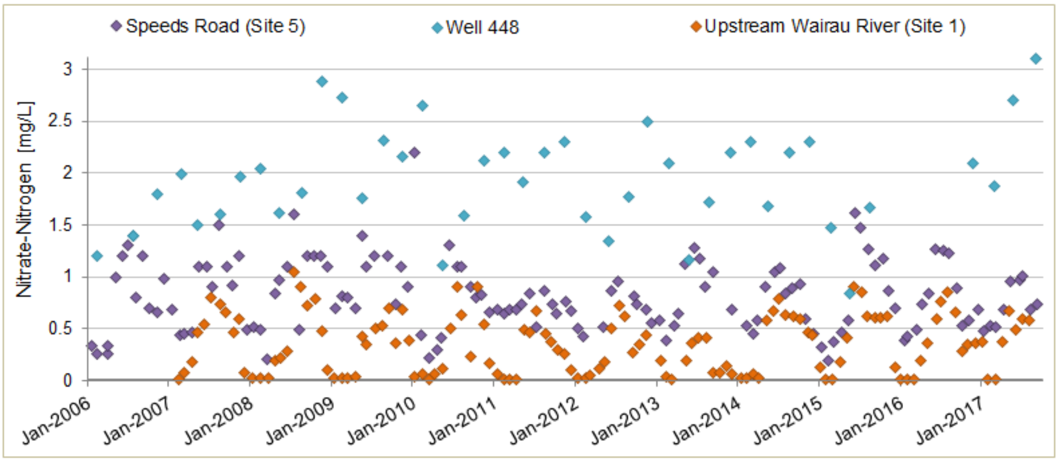

Figure 14: Nitrate Nitrogen concentrations in the Tuamarina River at Speeds Road and upstream of the Wairau River as well as in Well 448 near Speeds Road.

6.3.2. 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 nitrate 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 nitrate concentrations, as phosphorus is easily absorbed onto soil particles. It 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 [24].

The guideline of 0.015 mg/L used in this report is based on limits set by Biggs (2000) to prevent nuisance algae growth in rivers and streams [4]. This is also the guideline used for the State of the Environment reporting.

State of the Environment monitoring downstream of the Para Wetland show that DRP concentrations are often above the guideline level of 0.015 mg/L with no observable seasonal pattern (Figure 15). Because phosphorus binds well to soils, in many waterways high DRP levels are associated with higher turbidity as a result of land erosion during rainfall events. This does not appear to be the case for the Tuamarina River (Figure 15).

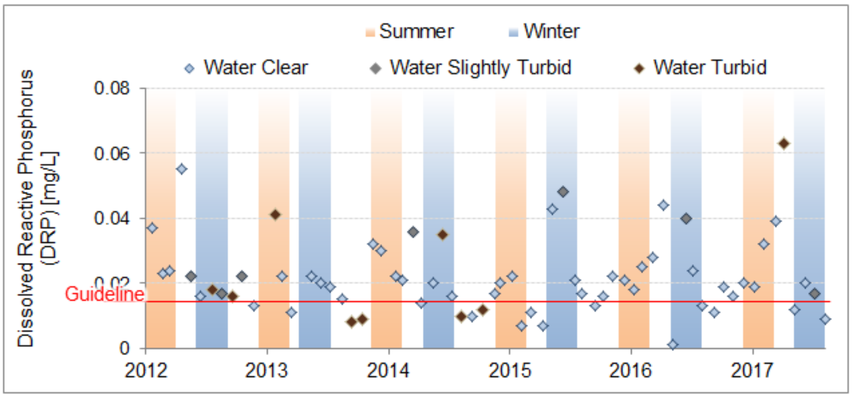

Figure 15: DRP concentrations in the Tuamarina River just upstream of the Wairau River.

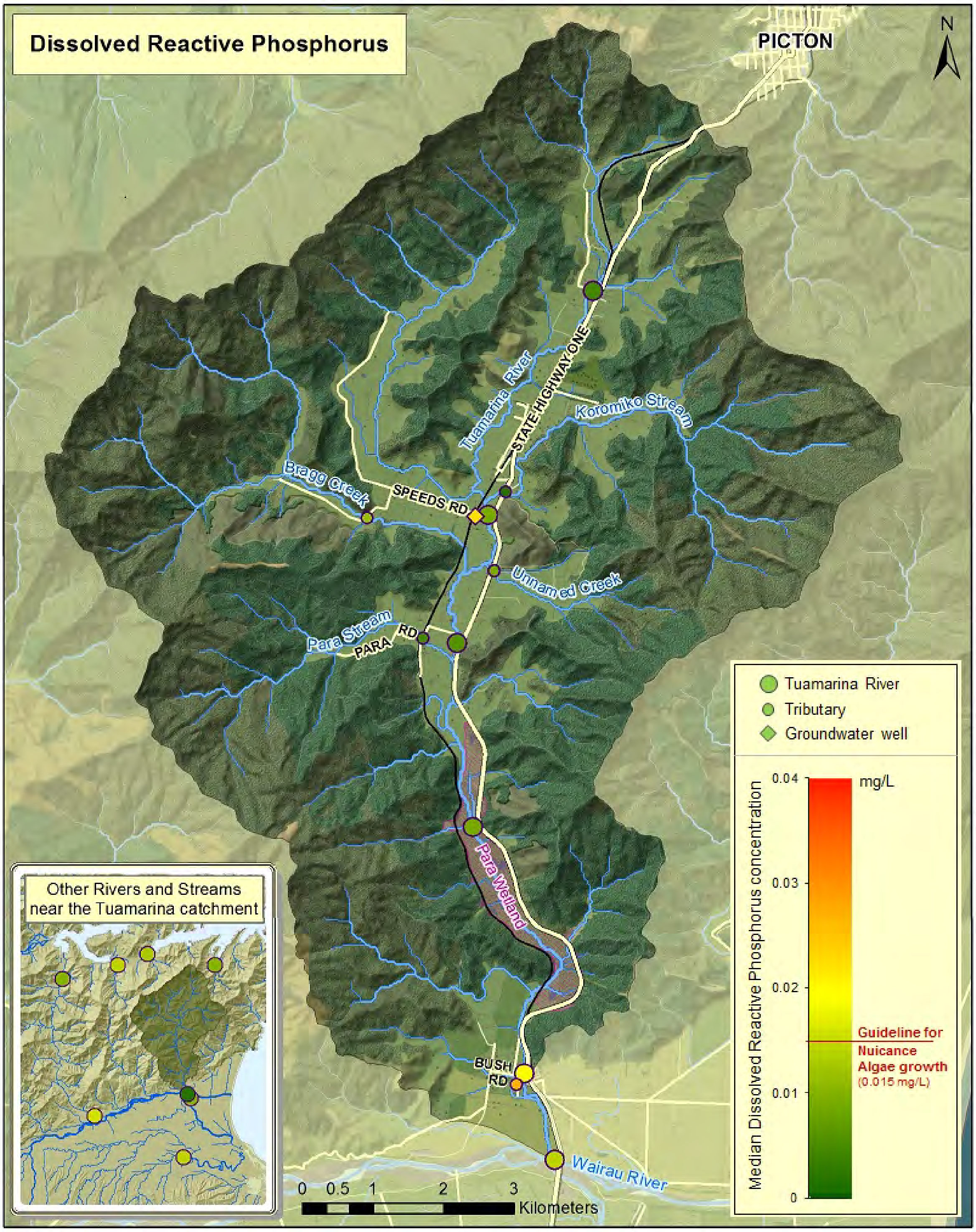

Figure 16: Median Dissolved Reactive Phosphorus (DRP) concentrations in the Tuamarina catchment during the 2015/2016 study.

The results from the 2015/2016 survey show that DRP concentrations in the Tuamarina River upstream of the Para Wetland are mostly below guideline levels with the lowest levels in the upper catchment and some of the tributaries (Figure 16).

DRP levels measured in the 2002/2003 surveys were similar for most of the sites in the upper and mid catchment, with the exception of Koromiko Stream (Figure 17). During this earlier study Koromiko Stream, Site 8 and Speed Valley Stream, had comparatively high DRP levels. Site 8 and Speed Valley Stream were not re-sampled as part of the latest survey and it is therefore unknown, if DRP levels have improved as they have in Koromiko Stream.

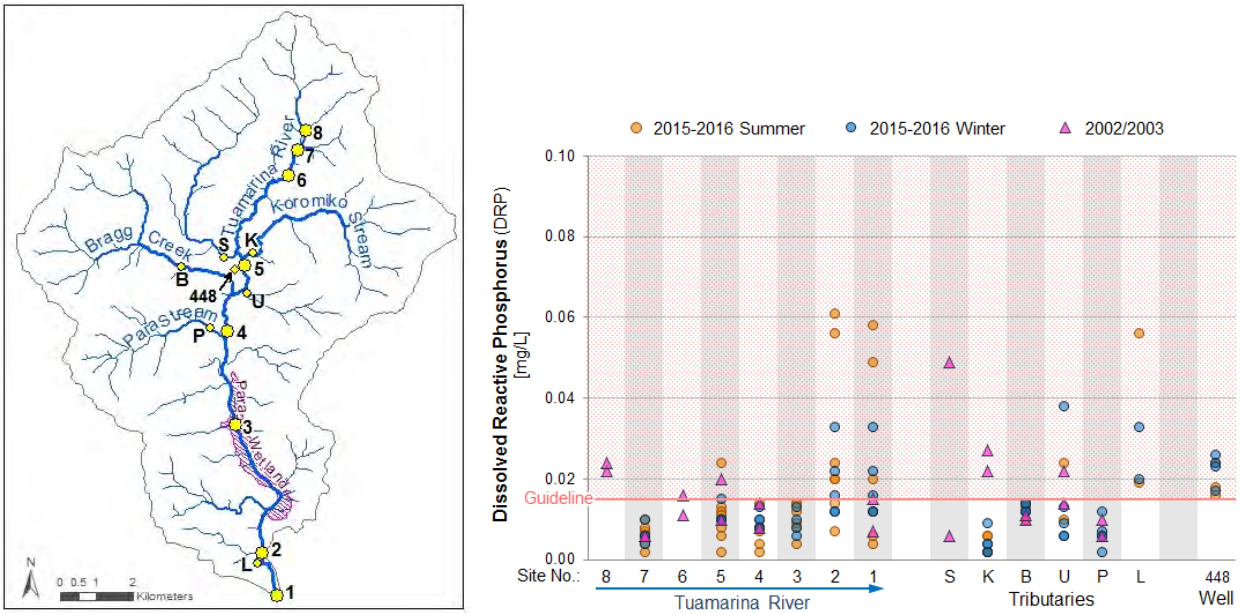

Figure 17: DRP concentrations measured as part of the 2002/2003 and 2015/2016 water quality studies carried out in the Tuamarina catchment.

The pasture soils sampled as part of the 2014 soil survey had very low phosphorus concentrations, which means that leaching from these soils is currently quite low. Nevertheless, concentrations in the groundwater well near Speeds Road are comparatively high. This could be a result of older, phosphorus-rich groundwater, but other factors, such as inappropriate effluent management or inadequate storage of organic material could also be at play.

The higher DRP concentrations in groundwater indicate that groundwater and subsurface flow are likely the main source of phosphorus in the mid reaches of the river. This explains the relative independence of phosphorus concentrations from suspended sediment concentrations or turbidity.

DRP concentrations below the Para Wetland are significantly higher than further upstream, which suggests that the Para Wetland currently is an additional source of phosphorus. A number of studies on artificial wetlands for the treatment of nutrient-rich water have shown that they can become saturated with phosphorus and instead of removing nutrients from the water, start to release phosphorus [e.g. 8, 37]. It is therefore possible, that phosphorus accumulated in in the wetland as a result of years of higher fertiliser use in the past is now being released. Other studies found release of phosphorus in natural wetlands as a result of re-flooding of wetland soils after restoration [e.g. 2]. If this was the case, DRP concentrations should be higher at higher flows when more of the wetland is flooded. However, there is no correlation between Tuamarina River flow and the DRP concentrations measured downstream of the wetland[3]. Another possible source is the release of phosphorus as a result of the recent large-scale willow control. The additional phosphorus could be released from the decaying trees or released from sediments as a result of lower oxygen levels in the shallow ponded areas. After the willows died, these shallow ponds are less shaded which results in higher water temperatures. The higher the water temperature the less oxygen can be dissolved in water. This could cause a release of phosphorus from the pond (and river) sediment as phosphorus is more mobile in low-oxygen environments. If this was the case, we would see an increase in phosphorus concentrations following the years of willow control. Unfortunately, reliable State of the Environment data for DRP is only available since 2012[4], when willow control was well on the way.

There are two sets of measurements taken during the 2002/2003 survey, before large scale willow-control had started. These show that concentrations downstream of the wetland were comparable to those

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[3] No correlations for the entire data set or individual years

[4] Pre 2012, a different laboratory provider was used. A variable step-change was noticed in the DRP data for a number of site following the laboratory change, but since no comparative sample analysis was done, pre 2012 data cannot be compared to the current data.

observed upstream. Although two data points provide limited information, they do indicate that the extensive spraying of willows in the wetland might be one of the reasons for the higher DRP concentrations currently observed.

Site 3, which is located within the willow control area of the wetland, has DRP concentrations similar to Site 4 upstream of the wetland. However, it is possible that the cumulative effects are only noticeable further downstream and all we can say at this point is that the higher DRP concentrations downstream of the wetland could be the result of several possible causes.

Concentrations in the Tuamarina Lagoon are also quite high. This could be linked to the abundant waterfowl, including a shag colony, resident in the lagoon. Due to the very small flow from this area into the much larger Tuamarina River it is unlikely to be a major source of phosphorus in the river itself. Because DRP concentrations in the Lagoon are very similar to those in the river downstream, another possibility could be that some water in the wetland is lost to groundwater flow, which resurfaces in the Lagoon area.

6.3.3. E. coli concentrations

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 like 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, particularly after long dry periods.

Large numbers of wildfowl (i.e. ducks, seagulls and shags) can also cause high E. coli concentrations, especially if flows are low.

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].

The monthly State of the Environment sampling shows that E. coli concentrations are mainly below guideline level, but can occasionally be very high in the lower Tuamarina River (Figure 18). With the exception of one sample result, high levels are associated with flood events and turbid water. This means that high E. coli concentrations are generally a result of surface run-off during rainfall events.

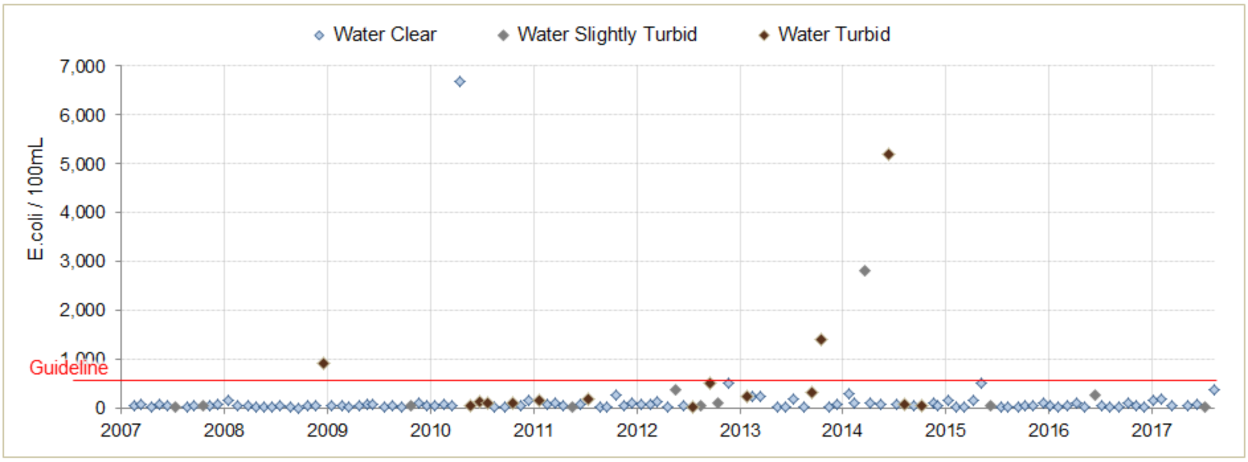

Figure 18: E. coli concentrations in the Tuamarina River just upstream of the Wairau River.

During the recent 2015/2016 investigation sampling was carried out during baseflow conditions only and concentrations are likely to be higher during rainfall when surface run-off washes animal droppings into waterways. The results of the study show, that during base flow E. coli concentrations in the main river were generally higher in the upper and mid reaches and lowest at the furthest downstream site (Figure 19).

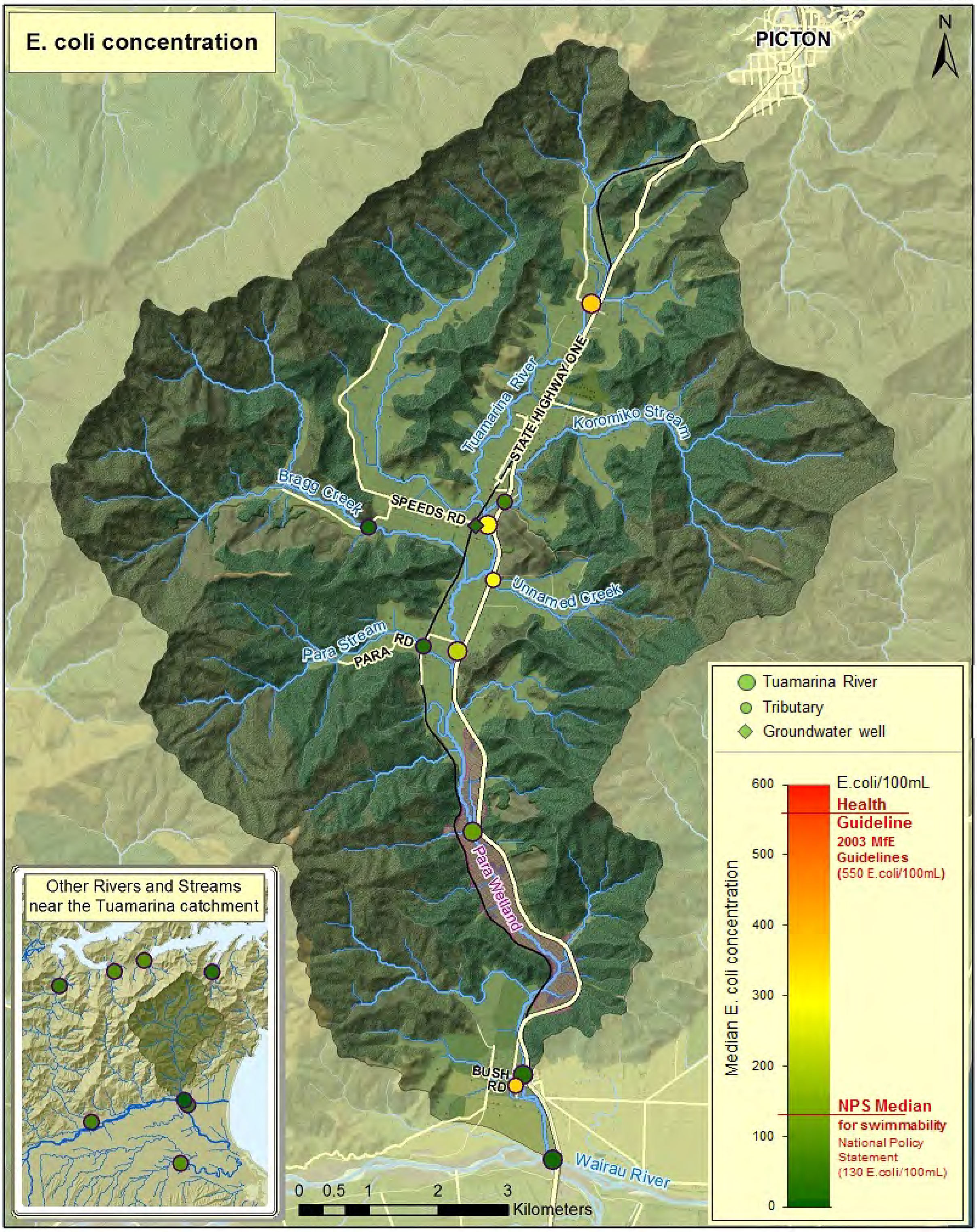

Figure 19: Median E. coli concentrations in the Tuamarina catchment during the 2015/2016 study.

There is no pastoral land use in the catchments of the tributaries that flow into the Para Wetland. This likely contributes to the lower E. coli concentrations observed in the lower reaches of the Tuamarina

River. Areas downstream of the Para Wetland are dominated by Vineyard and extensive sheep pasture with cropping, which are land uses that generally do not contribute significant amounts of E. coli contamination. It is unclear if the wetland itself acts as a filter further reducing E. coli loads. A reduction in E. coli concentrations is achieved in many constructed wetlands, however, the straightened river channel through the Para Wetland, minimises wetland-river interactions, likely lessening the potential filter function of the wetland.

Faecal contamination from livestock is likely to be the cause for the elevated E. coli levels in the upper and mid reaches of the Tuamarina River. The most upstream sample is indicative of the effects of pastoral land use other than dairy. Beef and sheep graze the pasture upstream of this sampling site and most of the stock has direct access to waterways.

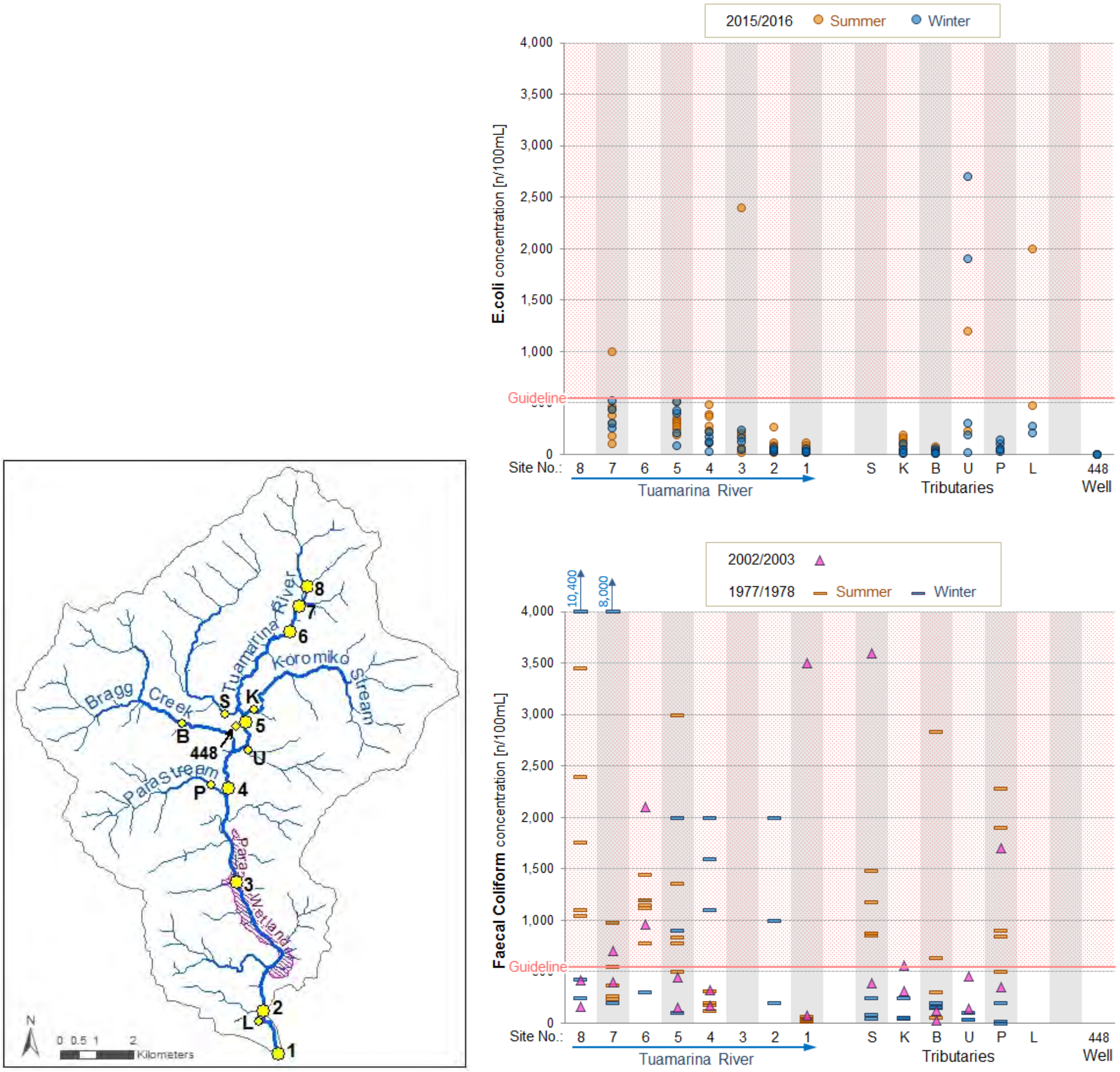

Figure 20: E. coli concentrations in the Tuamarina catchment, measured as part of the 2015/2016 study (top graph) end earlier studies in 1977/1978 and 2002/2003 (bottom graph).

Concentrations in the tributaries varied considerably, with high concentrations in the Unnamed Creek and the Lagoon outflow (Figure 20).

Unnamed Creek drains a dairy farm and E. coli in this stream likely originate from dairy cattle, but human sewage cannot be ruled out.

The Lagoon outflow drains a ponded area that is home to a breeding colony of more than 15 shags and a number of ducks (Figure 21). Elevated E. coli concentrations are therefore likely a result of wildfowl with higher E. coli levels in summer when flows and subsequently, dilution is lower. However, the inflow into Tuamarina River from the Lagoon is very small compared to the flow in the actual river and has therefore little effect on the Tuamarina River water quality.

Figure 21: The Tuamarina Lagoon. Note the shags in the tree in the top-centre-right of the picture.

Consistently low E. coli concentrations in Koromiko Stream and the upper reaches of Para Stream and Bragg Creek show that dairy farming does not necessarily result in high E. coli concentrations.

Faecal bacteria concentrations [5] during earlier investigations were significantly higher than those observed in the most recent survey (Figure 20). In the earlier surveys faecal coliform concentrations regularly exceeded the guideline value at nearly all sites. The decommissioning of point sources such as effluent discharges and stock crossings has led to the substantial improvements observed. Additionally, recent requirements to keep dairy cattle out of waterways have resulted in further reduction of the E. coli concentrations in the Tuamarina River. Nevertheless, as the recent measurements of the Unnamed Creek show, some improvements are still to be made. Also, livestock still has direct access to waterways in the upper reaches, resulting in the higher E. coli concentrations observed there.

In the recent study, there was no monitoring of Speeds Valley Stream and the lower reaches of Braggs Creek and it is unclear if these contribute to the higher E. coli concentrations in the Tuamarina River in this area. During monitoring cattle could be observed in small drains and swales in the lower reaches of these streams, likely affecting water quality in this area.

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[5] In earlier surveys Feacal Coliforms rather than E. coli concentrations were monitored. E. coli are one type of Feacal Coliforms, which means that the values for Feacal Coliform concentrations can be higher than the values for E. coli concentrations. Currently, both Feacal Coliform and E. coli concentrations are measured and the results show that the values for both measurement are often the same or very similar.

6.3.4. Turbidity

Turbidity is a measure for water clarity. Measurements are obtained using a sensor which 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 if water velocities are relatively low (such as in the lower Tuamarina River). Large amounts of fine sediment can smother the stream bed and reduce quality and availability of habitat for aquatic insects, which are the main food source for 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 ANZEEC 2000 Guidelines based on recreational and amenity values [1].

One of the reasons for the marginal water quality in the Tuamarina River, prompting this study, were extremely high turbidity measurements taken in 2013 and 2014 (Figure 22). The greatest flood on record was observed in 2014 causing significant erosion along the banks of the Tuamarina River. A sample taken during a smaller, but still substantial flood following the extreme event had a turbidity of 180 NTU; probably a result of continuous bank erosion. However, two of the highest turbidity measurements of 1,650 and 2,200 NTU were taken several months earlier before the record flood had occurred. These turbidity values are a magnitude above the highest levels observed in the neighbouring catchments. For example, the highest turbidity recorded as part of the State of the Environment program in the Waitohi River to the North is 75 NTU. The maximum turbidity in Cullens Creek and Linkwater Stream to the North-East are 62 NTU and 49 NTU, respectively; and the highest turbidity measured in Are Are Creek to the West is 124 NTU.

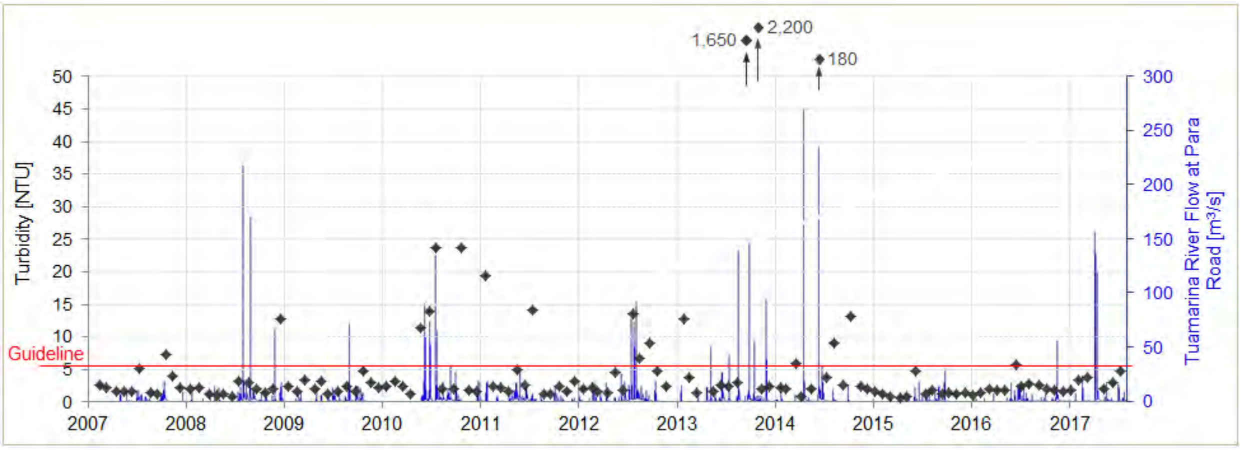

Figure 22: Turbidity in the Tuamarina River at the confluence with the Wairau River (black) and Tuamarina River Flow at Para Road (blue).

There was no noteworthy bank erosion along the main stem of the Tuamarina River recorded at the time the extremely high turbidities were observed. Significant bank erosion only occurred as the result of the higher flood several months later in 2014. Therefore, other sources of sediment must have caused the very high turbidity values observed in 2013. Aerial photos taken the previous year, 2012, revealed large areas of exposed soil in the catchment due to the recent harvest of production forest (Figure 23). Cases of increased sediment in waterways and with it turbidity in the years following forest harvest are well documented in scientific literature [e.g. 10, 5].

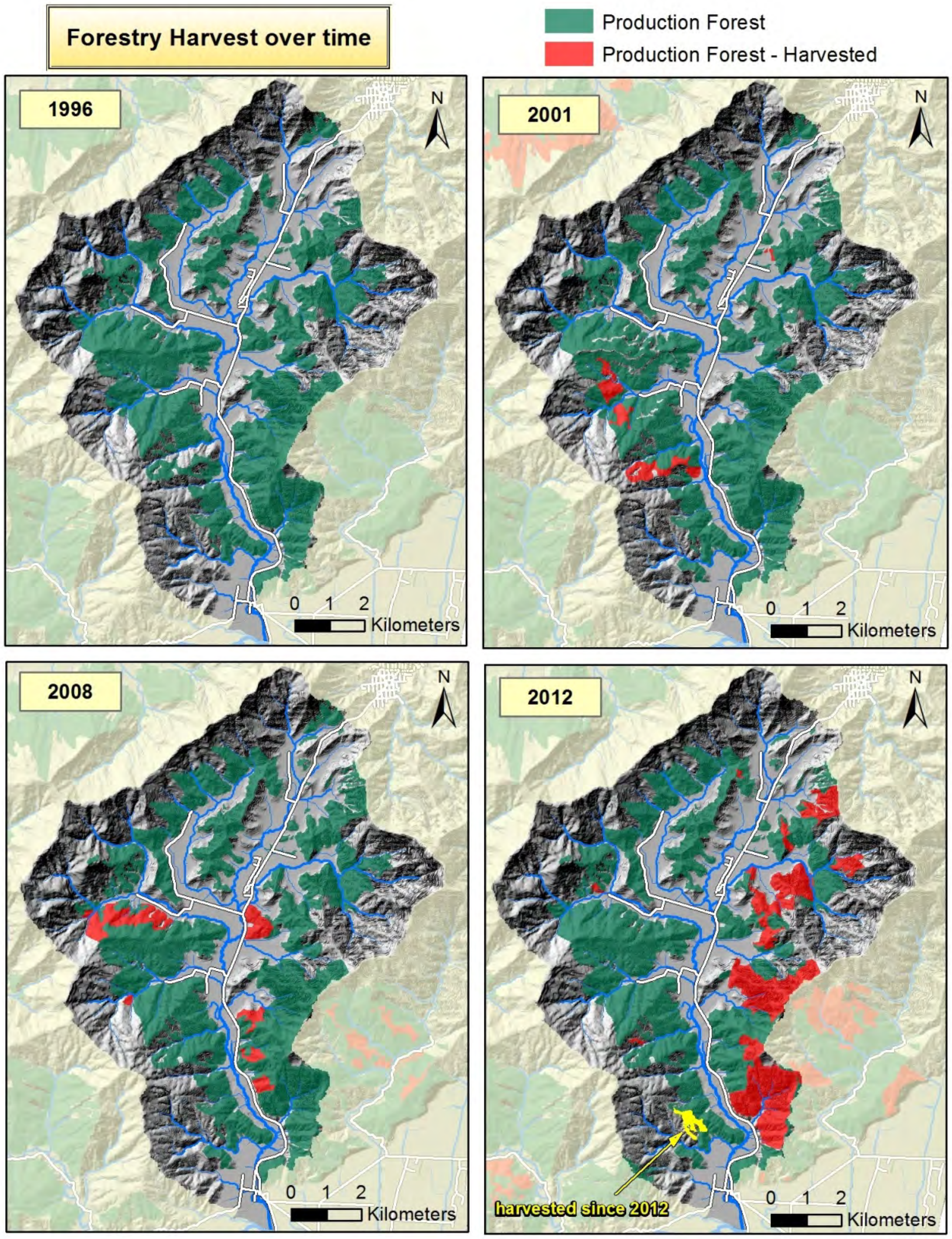

Figure 23: Harvest of production forest in the Tuamarina catchment over the last 20 years.

Sources of sediment in the Tuamarina River could not be investigated during the study in 2015/2016, as no significant flood flows occurred during this period (Figure 22). Additionally only a very limited area of forest had been harvested (Figure 23). Field visits during two flood flows in early 2017 that were of similar magnitude as the 2013 floods showed that the water remained relatively clear[6].

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[6] as there was no visible impact on the river, no samples were taken

As the highest turbidity measurements coincided with the largest areas of exposed soils due to forestry harvest, it is highly likely that erosion from these areas supplied the sediment resulting in the very high turbidity levels observed.

Because of comparatively low turbidity values measured in the Tuamarina River in recent years, the latest Water Quality Index for the period 2014-2016 indicates better water quality compared to indices which include the year 2013.

Large areas of production forest on the western flanks of the Tuamarina River are reaching maturity and will be harvested in the near future. Additional sampling during large-scale harvest could provide a better indication of the impact forestry harvest has on sediment loads in the river. In any case, however, should turbidity in the Tuamarina River increase again, a smaller study investigating the sources should be carried out.

Figure 24: A small area of productions forestry recently harvested in the lower reaches of the Tuamarina River at the Para Wetland. Note the steepness of the harvested area, which will likely result in the loss of sediment during rainfall.

During the base flow sampling carried out as part of the 2015/2016 study, turbidity was generally below the guideline value of 9 NTU for all sites monitored.

6.3.5. Water Temperature

The water temperature of rivers is naturally quite variable as it changes over the course of the day and with the season. 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 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 [34] and native fish like the Banded Kokopu (*Galaxias fasciatus*) are also effected by long term maximum temperatures above this value [3].

Monthly spot measurements at the bottom of the catchment suggest that water temperatures stay below the guideline of 21.5°C. Because water temperatures vary during the course of the day and spot measurements often do not coincide with the highest levels, continuous measurements are more useful. Higher water temperatures are generally more common in the lower reaches of waterways, as the rivers become wider and therefore less shaded by riparian vegetation. Indeed, spot measurements taken at sites in the upper and mid catchment during the 2015/16 survey showed that water temperatures here were lower compared to the lower Tuamarina River.

To capture maximum water temperatures in the Tuamarina River, a sonde, recording water temperature (and other parameters) at 15 min intervals was deployed just upstream of the confluence with the Wairau River. The highest water temperatures occur in late summer after long dry periods. Therefore, measurements with the sonde were taken on three occasions in February 2015, in March 2016 and in April 2016.

Figure 25 shows the temperatures recorded on these occasions over a 24-hour period. Water temperature varied in the order of two to four degrees Celsius. The highest water temperature, 20.4 °C, was recorded in February 2015 at 6:15pm. In March and April of the following year water temperatures were lower and peaking earlier in the day due to the shorter days.

There are a number of shallow open water bodies within the Para Wetland which are being warmed up by the sun throughout the summer months. This has particularly been the case in recent years, as large areas of natural shade have been removed by willow control. Some of these ponded areas stay connected to the main river throughout most of the year. Nevertheless, the sonde measurements show that they appear to have limited influence on the water temperature in the main river.

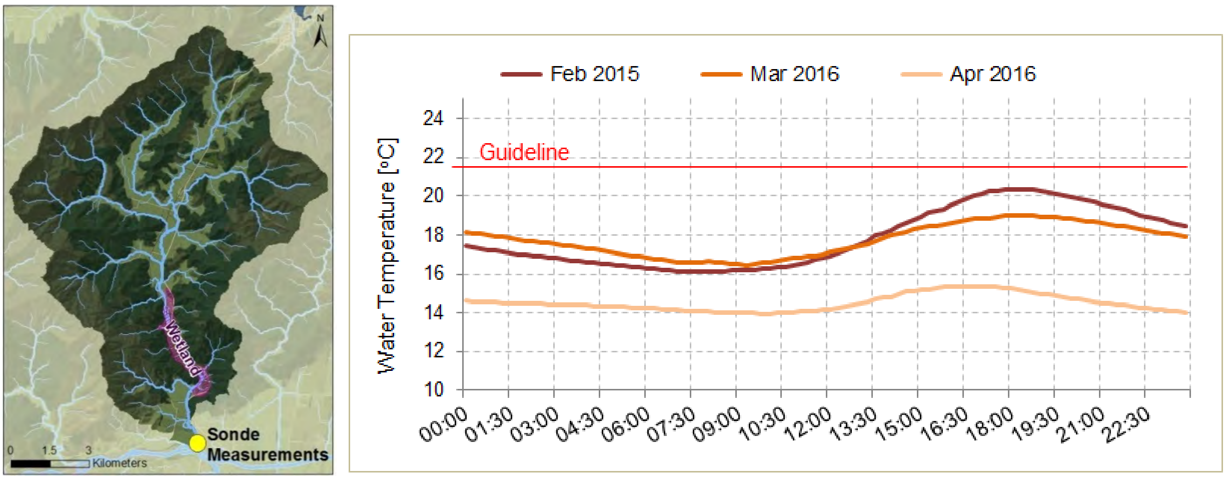

Figure 25: Water temperature in the Tuamarina River measured upstream of the confluence with the Wairau River.

6.3.6. Dissolved Oxygen Saturation

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, 7]. Studies have shown that Trout become effected if dissolve oxygen saturation decreases to values below 70% [7]

Spot measurements taken during the monthly State of Environment monitoring showed that dissolved oxygen saturation was often well below the guideline of 70% particularly in summer (Figure 26).

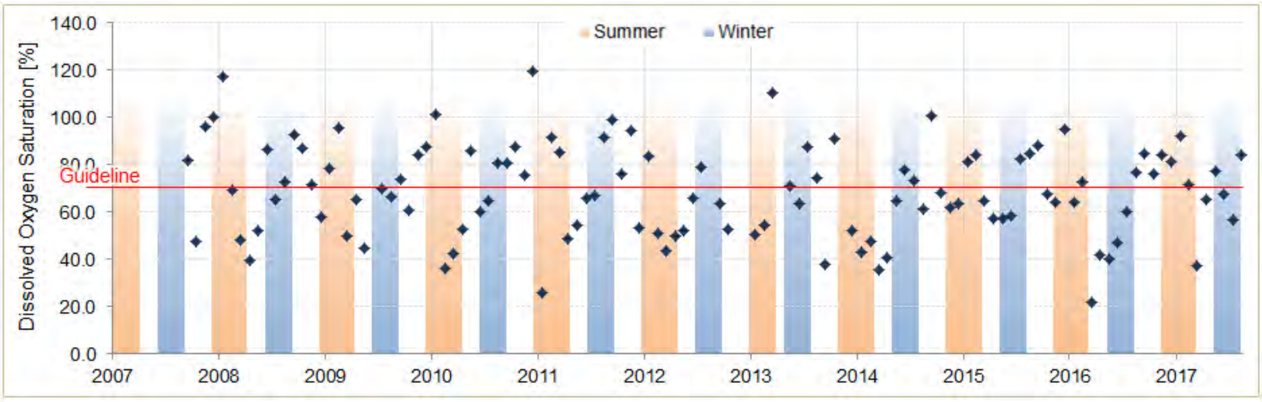

Figure 26: Dissolved Oxygen Saturation in the Tuamarina River upstream of the Wairau River.

In February 2015 continues monitoring over a period of one week showed that dissolved oxygen saturation was indeed reaching very low levels on a regular basis. Another round of continuous monitoring a year later in summer 2016 showed the same low oxygen levels.

Because low dissolved oxygen concentrations are extremely detrimental to aquatic animals it was important to determine if they are caused by human activities or a natural phenomenon.

Initially several spot measurements were taken at different locations along the lower part of the Tuamarina River. The measurements were taken on an overcast day as oxygen productions would be minimal. The results showed the oxygen levels were lowest at the lower end of the Para Swamp, but were higher upstream of the wetland. They also showed that the Lagoon was not contributing to the low oxygen observed in the river.

To gain a better understanding of the daily oxygen cycle in the river, a sonde was deployed at three sites in the lower Tuamarina River to measure oxygen levels in 15-minute intervals. Due to the availability of just one sonde the measurements were taken on consecutive days, but during similar sunny and warm weather conditions.

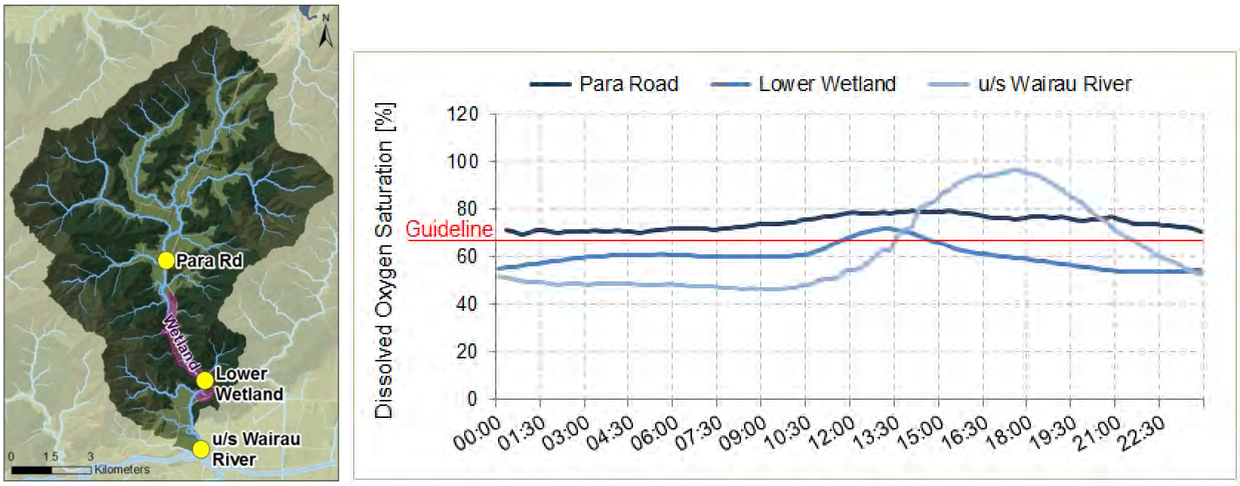

Figure 27: Dissolved Oxygen Saturations measured in April 2016 at three sites in the lower Tuamarina River.

The results of the sonde deployment showed that upstream of the Para Wetland at Para Road, dissolved oxygen levels vary only slightly (Figure 27). At this site the river is comparatively shallow with frequent riffles along its length. Riffles are areas of turbulent flow that cause a larger surface area between the water and the surrounding air. As a result more oxygen from air dissolves into the water column resulting in dissolved oxygen levels closer to the saturation level of 100%.

Notable is that despite the frequent presence of riffles, dissolved oxygen saturations at Para Road do not reach 100% as would be expected. This means a significant amount of oxygen is removed. This could be caused by faecal contamination as indicated by elevated E. coli concentrations at this site (see Section 6.3.3). Another factor is dumping of animal carcasses into the waterway, which, based on field notes, appeared to happen quite frequently at this site. Decomposition of animal remains in water removes oxygen from the water column during the process.

In wetlands, the water can have naturally low dissolved oxygen concentrations, but oxygen levels are further lowered by nutrient inputs, particularly phosphorus [23]. The sonde measurements from the lower Wetland show that levels are below the guideline level of 70% most of the time. A small peak caused by photosynthetic activity of aquatic plants occurred at roughly 1:30pm.

Further downstream, the daily variation in dissolved oxygen saturation is greatest with levels as low as 47% in the morning and nearly 100% saturation in the evening. The most likely cause is respiration and photosynthetic activity of the aquatic plant, which are very prolific in this part of the river (Figure 28). Interestingly, the oxygen curve for this site shows some lag. Normally, oxygen levels peak shortly after midday, as could be observed at the two upstream sites. The same lag was also observed in earlier sonde deployments showing that it is a persistent phenomenon. The actual reasons for this lag, however, are unknown, but could partially be linked to higher, more shading vegetation on the eastern bank of the lower river, resulting in greater sun exposure and with it higher photosynthetic activity during the latter part of the day.

Figure 28: The lack of riparian vegetation on the western bank of the Tuamarina River at the Bush Road (Site 2) causes prolific growth of aquatic plants in the deep river giving it a shallow appearance.

6.3.7. 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 [13]. 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.

PH Measurements of samples taken in the field as part of the State of the Environment program, indicate that, apart from occasionally high pH level in summer, values have usually been within the guidelines in recent years, (Figure 29). The highest pH levels are observed during the warmer months of the years, which is a result of greater photosynthetic activity by aquatic plant due to higher water temperatures and longer sunshine hours.

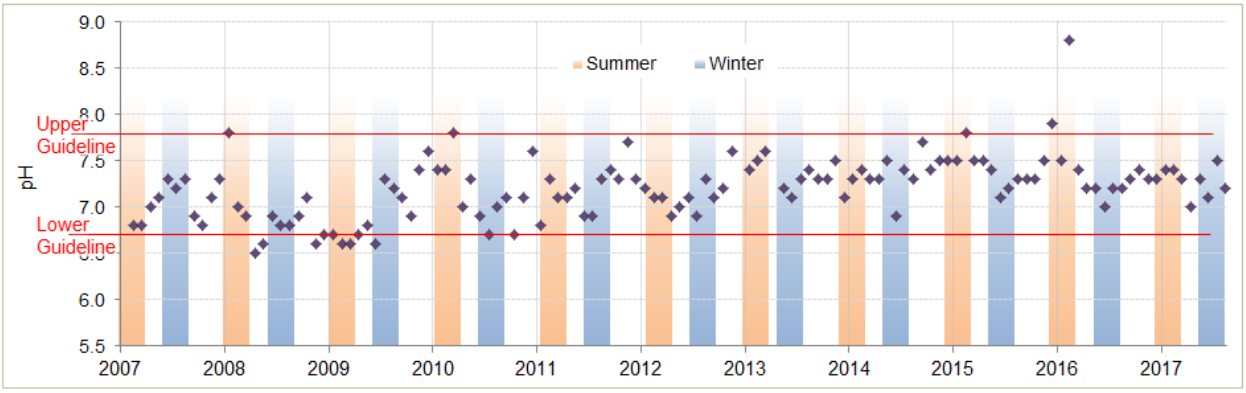

Figure 29: Measurements of pH in monthly samples taken from the Tuamarina River upstream of the confluence with the Wairau River.

In the earlier years of monitoring pH values were noticeably lower. A possible reason is the greater occurrence of river access by dairy cattle in the mid catchment. The natural conversion of ammonical nitrogen ($NH4^{+}$), the main form of nitrogen in faecal matter, into nitrate ($NO3^{-}$) results in the release of hydrogen ions (H^{+}) and with them a lowering of the pH[7]. The elimination of dairy crossings combined with the fencing of waterways in recent years has resulted in a significant reduction of the number of dairy cattle in waterways.

PH values of samples taken during the 2015/2016 study were consistently within in the acceptable range of 6.7 to 7.8 for the majority of sites. The exceptions were Para Stream and the Tuamarina Lagoon, which had slightly elevated pH levels. In the Lagoon high pH values were likely the result of photosynthetic activity of aquatic plants, which grow prolifically in the ponded areas. The reasons for elevated pH levels in Para Stream, however, are unknown as these occurred during the colder months of the year when photosynthetic activity is low. During the summer months Para Stream was dry at the site visited during the survey.

Similar to water temperature and oxygen levels, pH values change during the day. Therefore sonde measurements at 15-minute intervals were taken at the State of the Environment site on three different occasions in late summer. The greatest variation was observed in February 2015 with a peak pH value of 8.9, which was well above the upper guideline of 7.8. In March 2016 pH values varied significantly less and fell slightly below the lower guideline for half of the day. Measurements taken in April 2016 stayed within guideline values the entire time.

At all three sonde deployments, peaks in pH values coincided with maximum dissolved oxygen saturations. This is not surprising, as high pH values and oxygen levels are both a result of photosynthetic activity.

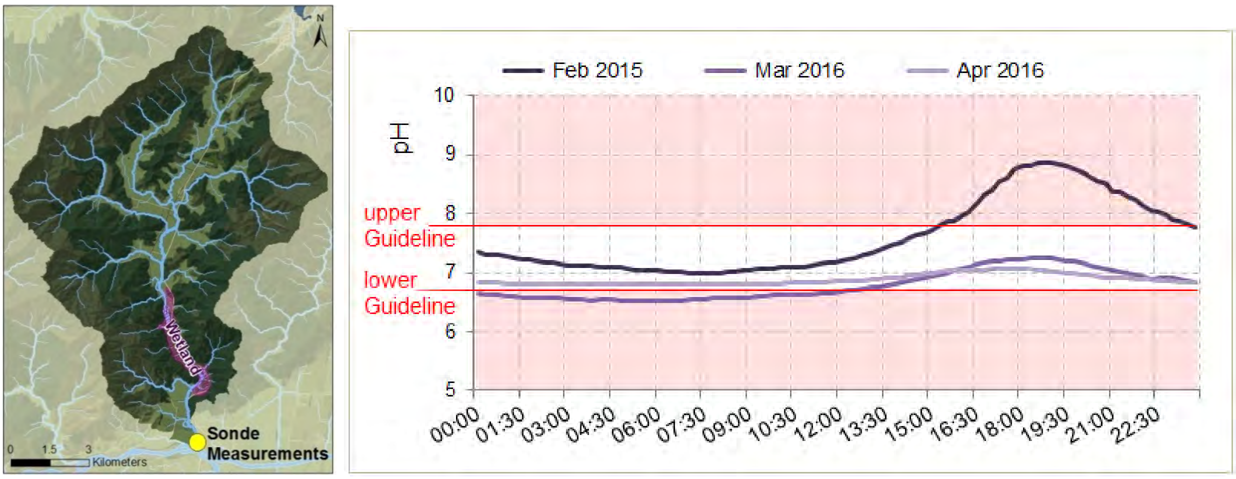

Figure 30: Sonde measurements of pH in the Tuamarina River just upstream of the confluence with the Wairau River.

It needs to be noted that sampling for the State of the Environment program often occurs just after lunch time, which explains why exceedances of the guidelines for pH are rarely picked up.

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[7] The pH is defined as the log-scale concentration of Hydrogen Ions ($pH = -\log[H^{+}]$)

7. Aquatic Ecology

Several fish surveys were carried out in the years between 1991 and 2001. A total of nine sites were sampled, some only once, others several times. Although quantitative data is available, different methods, including nets and electric fishing machines were used. This means that the quantitative data is often not comparable. Therefore, only the distribution of the fish will be discussed here.

Eight native fish species were found during these surveys. Banded Kokopu, Koaro and Redfin bully were only found at two or three sites, located in the upper reaches of some of the tributaries (Figure 32). Upland bully were found at more sites, but were also restricted to the upper or mid catchments of tributaries. Inanga and Common bully, on the other hand, were mainly caught in or close to the main channel of the Tuamarina River. Both of the New Zealand eel species were also found at several sites, but the Longfin eel had a significantly greater distribution within the Tuamarina catchment compared to the Shortfin eel.

Most of our native fish are found nowhere else in the world and many are under threat of extinction due to the destruction of their habitat and as a result of overfishing (whitebaiting and eel-fishery). For example, the numbers of Longfin eel, Koaro, Inanga and Redfin bully are declining and these species are currently classified as ‘At Risk’ [12].

The only introduced species recorded during the surveys was Brown Trout, found during one of the surveys in Para Stream. Field notes from the sampling site upstream of the confluence with the Wairau River indicated that occasionally trout can also be found at this site.

Koura, the New Zealand freshwater crayfish, were also caught during the fish surveys. They were found in the main river as well as some of the upper tributary catchments.

Between 2007 and 2015 several Macroinvertebrate (aquatic insect) samples were taken just upstream of the confluence with the Wairau River. Macroinvertebrate data is best presented as the MCI score, a number derived from the abundance and the tolerance to poor water quality of the species found. The MCI score for the lower Tuamarina River has a median value of 79, which puts it into the ‘poor’ category. It is likely that MCI scores for sites upstream of the Para Wetland are better, but unfortunately there is currently no data available to confirm this.

Figure 31: Longfin Eels were widely distributed in the Tuamarina catchment.

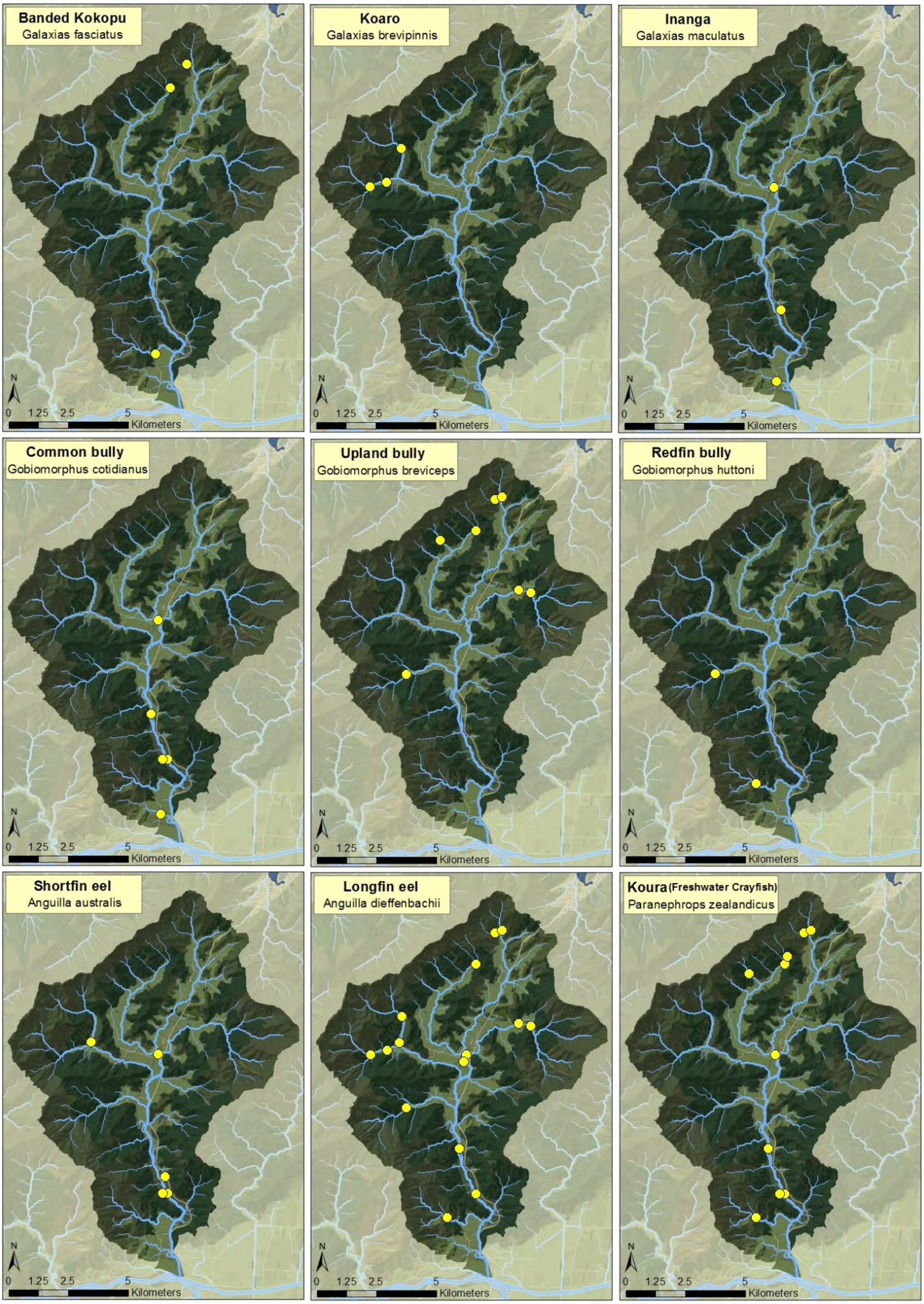

Figure 32: Distribution of native fish species and Koura found in the Tuamarina River catchment between 1991 and 2001.

8. Summary and Discussion

The Tuamarina River is a large North-Bank tributary of the Wairau River. Land use in the catchment is dominated by production forestry on the hills and pasture on the river flats. Native land vegetation is still present at higher elevations. In the lower reaches, the Tuamarina River flows through the largest remaining wetland of the region, the Para Wetland.

Monthly State of the Environment sampling is carried out at the bottom of the catchment, just upstream of the confluence with the Wairau River. The results from this monitoring have shown, that water quality in the Tuamarina River is in the marginal category. Sampling of additional sites throughout the catchment was carried out in 2015 and 2016 with the purpose of identifying the causes for the poor water quality. Results from earlier water quality surveys carried out in 2002/2003 and 1977/1978 were also included in the analysis.

The State of the Environment monitoring identified a number of parameters that are exceeding guideline levels. These are:

- Dissolved nutrient concentrations (both nitrogen and phosphorus),
- High E. coli concentrations (mainly during higher flows),
- Elevated pH levels
- Low Dissolved Oxygen levels
- High turbidity (particularly during higher flows in 2013 and 2014)

The majority of dissolved nitrogen and phosphorus in the Tuamarina River originates from inflowing groundwater and is therefore a result of leaching. Results of a soil survey carried out in 2014 found that the leaching potential for phosphorus is relatively low, but low organic carbon content meant that the soils had limited ability to bind nutrients. Of the pastoral land uses, dairy farming generally has the highest leaching rates for nitrogen [21]. Dairy is the dominant pasture use in the mid catchment. Therefore, elevated nitrogen levels are to be expected. The survey showed that soluble inorganic nitrogen concentrations were indeed above the guideline level in almost all waterways monitored during the survey. The exceptions were Para Stream, the Tuamarina Lagoon and summer concentrations downstream of the Para Wetland.

The highest nitrogen levels were observed in two of the tributaries, Koromiko Stream and Unnamed Creek. Concentrations here were very variable, which might suggest occasional direct discharges into these waterways.

In the main river, soluble inorganic nitrogen concentrations peak in the mid-catchment where most of the dairy pasture is located and significant amount of groundwater is forced to the surface, contributing to river flows. Downstream of the Para Wetland concentrations are lower. Artificial wetlands are widely used to remove contaminants such as nutrients from discharges and it is therefore no surprise that the large Para Wetland provides similar filter functions. Additionally, the lack of pasture along the flanks of the wetland likely provides some dilution from tributaries with lower nitrogen levels. Surprisingly, the wetland does not have the same effect on dissolved phosphorus levels. In fact, DRP concentrations downstream of the wetland are higher than upstream, making the wetland a source of phosphorus. It is possible that the long history of phosphorus inputs from the pastoral land use upstream has resulted in a state of phosphorus saturation for the wetland soils. Two sets of DRP measurements taken in 2002/2003 suggest that at that time the wetland had little impact on DRP levels. Concentrations downstream of the wetland were similar to those measured upstream. Pastoral land use has changed little since this earlier survey, but a noticeable change has been occurring in the wetland itself. Spraying of large areas of the wetland with herbicide has killed the willows, removing natural shading of water bodies and leaving large amounts of wood that is slowly decaying. It is unclear whether the additional phosphorus released originates from the wood decay or is released from the sediments due to warmer water temperatures and lower dissolved oxygen levels.

Regular monitoring of DRP concentrations upstream of the Para Wetland in the future would provide valuable information about changes in the nutrient dynamics in the river as the restoration of the Para Wetland progresses. Nitrate concentrations in the river upstream of the wetland are already measured on a regular basis at Speeds Road and it should be relatively easy to add DRP concentrations to the analysis.

The Lagoon, which flows into the Tuamarina River downstream of the wetland also has quite high DRP concentrations, which are comparable to those in the river. This might be the result of wetland water that is lost to groundwater and forced to the surface in the lagoon, but current knowledge about groundwater resources does not support this scenario. Another potential source is faecal matter from the large number of wildfowl that live in the lagoon area, as these are also the likely cause for elevated E. coli concentrations observed during the study. Nevertheless, the lagoon outflow is very small when compared to the much larger flow of the Tuamarina River at this point and it is therefore unlikely the that Lagoon is having a significant effect on the water quality in the main river.

Comparison of nutrient levels measured during the latest 2015/2016 study with those observed in 2002/2003 show that soluble inorganic nitrogen concentrations appear to have changed very little. They also indicate that the willow control has not affected the ability of the wetland to remove nitrogen.

High E. coli concentrations in the Tuamarina River are mainly associated with flood flows and are therefore likely a result of surface run-off during rainfall. There were no significant flood flows during the 2015/2016 study period. Also, exceedances of the E. coli guideline at the State of the Environment site are relatively rare, which means that a specific investigation into E. coli concentrations during flood flows is currently not necessary.

During base flow conditions, E. coli concentrations were mostly below guideline levels. The highest concentrations were measured in Unnamed Creek, which is a small waterway that drains a dairy catchment. The occasionally very high E. coli levels in this waterway are therefore likely the result of cattle having access to the creek.

In the main river, E. coli concentrations were often elevated and close to guideline levels in the upper catchment. Beef and sheep are grazing the pastures in this part of the catchment, often with direct access to waterways. Elevated E. coli concentrations in the mid catchment are likely the result of stock access to swales and small drains, as this was regularly observed near the Speeds Road area during the study.

However, comparison with data from previous studies shows a significant improvement in E. coli concentrations for almost all of the sites monitored. This is the result of removal of direct effluent and wastewater discharges in the early years, and the reduction of stream crossings and fencing off of dairy cattle in recent years.

State of the Environment monitoring indicated that one of the potentially most detrimental effects on aquatic ecology are low dissolved oxygen concentrations in the lower Tuamarina River. Dissolved oxygen, water temperature and pH levels change over the course of the day. Therefore, spot measurements taken as part of the State of the Environment sampling can only provide indicative results. For a better understanding of the daily variation, continuous data is required. A sonde, recording these parameters at 15-minute intervals was deployed at the State of the Environment site on three separate occasions in late summer, when these parameters usually reach their extremes. The results show that water temperatures stayed below guideline levels, while at times pH values exceeded both, the upper and lower guidelines. The sonde measurements also revealed that dissolved oxygen levels were below the guideline level of 70% for extended periods of time.

Water in wetlands can naturally have low dissolved oxygen levels. To understand the influence of the wetland on the oxygen saturation in the river, the sonde was also deployed at two additional sites, upstream of the wetland at Para Road and in the lower part of the wetland. The sonde measurements revealed that upstream of the Para Wetland oxygen levels were adequate throughout the day. This is likely the result of a riverbed dominated by gravel and cobbles with frequent riffles which aid oxygen exchange through the water surface. However, oxygen levels were still lower than could be expected for this part of the river, which indicates the presence of organic contamination, such as faecal matter or animal remains. During the study, the discarded remains of animals were found in the river on several occasions. The decomposition of animal carcasses releases nutrients into the waterway, lowers the pH, but also reduces dissolved oxygen levels.

Figure 33: Shellfish shells and pig carcass (left), fish remains (middle) and one of several pig-heads (right) found in the Tuamarina River and some of its tributaries during the 2015/2016 study.

Through the wetland and downstream, the river forms a deep channel with no riffles. The riverbed is dominated by fine sediment, which provides good substrate for the growth of aquatic plants.

The sonde measurements showed that in the lower wetland oxygen saturation was around 60% for most of the day with only a small peak after midday. Downstream of the wetland oxygen saturation had the greatest variability, with the highest, but also the lowest oxygen levels measured during sonde deployments. Interestingly, the oxygen curve showed a lag, peaking much later than at the sites upstream.

In summary, the results from the continuous monitoring show that some oxygen depletion is occurring within the Para Wetland, but the effect is exacerbated by the prolific growth of aquatic plants in the lower parts of the Tuamarina River. Aquatic plant growth is aided by the lack of shading by tall riparian vegetation. This means that the planting of tall riparian vegetation would improve oxygen levels in the lower parts of the river. To maximise the outcome, native plants should be chosen as these would also provide ecological values and extend the planting efforts in the wetland. Recently, observations at some councils have linked low dissolved oxygen levels to high abundances of the giant willow aphid [32]. Therefore, willows should not be used as riparian buffer plants for the lower Tuamarina River.

Extremely high turbidity values coincided with the most extensive soil exposure as a result of forestry harvest in the catchment. This indicates that the large areas of relatively fresh clear-felling were the cause for the high sediment loads in the river observed in 2013. Aerial photographs indicate that no riparian buffers were left during the harvest. Riparian buffers can significantly reduce the amount of sediment washed into waterways from clear-felled areas during rainfall.

8.1. Recommendations

8.1.1. Monitoring

- Continue monthly State of the Environment monitoring at the confluence with the Wairau River.
- Add DRP to the analysis for the regular monitoring at Speeds Road (done as part of the Picton Drinking water supply monitoring).
- Investigate possible point-sources in Koromiko Stream and Unnamed Creek.
- Carry out an investigation into sediment sources should turbidity levels increase again.

8.1.2. Improvement of water quality

- Planting of tall (preferably native) riparian vegetation along the lower parts of the Tuamarina River to reduce the growth and productivity of aquatic plants and with it the large variability in dissolved oxygen levels.
- Fencing off of livestock (particularly beef cattle) in the upper parts of the catchment to reduce E. coli concentrations in the waterways.
- Leaving unharvested buffers along streams during forestry harvest to minimise the loss of soil to waterways during rainfall in the years following the harvest.
- Remove cattle access to swales and small drains in the mid catchment to reduce E. coli concentrations in waterways.
- Discourage the dumping of animal carcasses into waterways.
- Planting of riparian vegetation (preferably native) along pasture streams to filter run-off during rainfall.

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10. References

1. ANZECC (2000) Australia and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council. Agriculture and Resource Management Council of Australia and New Zealand

2. Allison RA, Craft CB, Stevens CJ, Barry MJ and Bach LB (2007) Soil phosphorus release from a restoration wetland, Upper Klamath Lake, Oregon. Wetlands 27(4), 1025-1035

3. Ausseil O and Clark M (2007) Recommended Water Quality Standards for the Manawatu-Wanganui Region: Technical Report to Support Policy Development. Report No. 2007/EXT/806 Horizons Regional Council

4. Biggs B (2000) New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams. Prepared for Ministry for the Environment

5. Croke JC and Hairsine PB (2006) Sediment delivery in managed forests: a review, Environ. Rev., 14, 59–87, doi:10.1139/a05-016

6. Davidson P, Wilson S (2011) Groundwaters of Marlborough. Marlborough District Council. Caxton Press, Christchurch, New Zealand

7. Dean T and Richardson J (1999) Responses of seven species of native freshwater fish and shrimp to low levels of dissolved oxygen. New Zealand Journal of Marine and Freshwater Research. Vol. 33:99-106

8. Drizo A, Comeau Y, Forget C and Chapuis RP (2002) Substratum phosphorus accumulation during maturation of gravel-bed constructed wetlands. Environ. Sci. Technol. 36 (21), 4642-4648

9. Environment Canterbury (2007) Erosion and sediment control guidelines for the Canterbury region. Report No. R06/23, Canterbury Regional Council, Christchurch

10. Fahey BD, Marden M, and Phillips CJ (2003) Sediment yields from plantation forestry and pastoral farming, coastal Hawke’s Bay, North Island, New Zealand, J. Hydrol., 42, 27–38.

11. GNS Online Maps http://data.gns.cri.nz/geology/

12. Goodman JM et. al (2013) Conservation status of New Zealand freshwater fish, 2013. Department of Conservation, http://doc.org.nz/documents/science-and-technical/nztcs7entire.pdf

13. Hay J, Hayes J and Young R (2006) Water Quality Guidelines to Protect Trout Fishery Values. Cawthron Report No. 1205 for Horizons Regional Council

14. Henkel S (2013) State of the Environment Surface Water Quality Monitoring Report, 2013. Marlborough District Council – Technical Report No. 13-011

15. Henkel S (2017) State of the Environment Surface Water Quality Monitoring Report Card 2017. Marlborough District Council

16. Jones C (1998) Vegetation Survey of Para Wetland. Report by Department of Conservation for Nelson/Marlborough Fish & Game

17. Julian JP, de Beurs KM, Owsley B, Davies-Colley RJ, and Ausseil AE (2016) River water quality changes in New Zealand over 26 years: response to land use intensity, Hydrol. Earth Syst. Sci., 21, 1149–1171

18. Kensington L (2016) Dairyshed Effluent and Stream Crossing Survey 2015/2016. Marlborough District Council. Report No.: 16-001

19. Landcare Research SINDI – Soil Quality Indicators https://soils.landcareresearch.co.nz/soil-data/sindi-soil-quality-indicators/

20. Lark M (1999) A Species List of Birds and comments on a Survey of the Para Swamp 9-10 October 1999

21. Lilburne L, Webb T, Robson M and Watkins N (2013) Estimating nitrate-nitrogen leaching rates under rural land use in Canterbury (updated). Environment Canterbury Regional Council, Report No. R14/19

22. Marlborough Catchment & Regional Water Board (1978) Tuamarina River Catchment - Water Quality Survey and suggested Management Strategy

23. McCormick PV and Laing JA (2003) Effects of increased phosphorus loading on dissolved oxygen in a subtropical wetland, the Florida Everglades. Wetlands Ecology and Management (2003) 11: 199-216

24. McDowell RW, Cox N, Daughney CJ, Wheeler D and Moreau M (2014) A national assessment of the potential linkage between soil, and surface and groundwater concentrations of phosphorus. 2014 Water Symposium, Blenheim, New Zealand

25. MfE (2003) Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment.

26. Neame L (2002) Tuamarina River and Catchment Water Quality Survey 29 May 2002. Marlborough District Council

27. NZ Government (2017) National Policy Statement for Freshwater Management 2014 (updated 2017).

28. NZWWA (2003) Guidelines for the safe application of biosolids to land in New Zealand. New Zealand Water and Waste Association, Wellington

29. Nelson/Marlborough Fish & Game (2006) Application for Resource Consent. U060969

30. Nelson/Marlborough Fish & Game (2014) Application for Resource Consent. U140927

31. Nelson/Marlborough Fish & Game and the New Zealand Game Bird Habitat Trust (2012) Para Wetland Restoration and Development Plan.

32. Norman E (2016) Eel deaths blamed on aphid invasion. News article on nzherald.com (http://www.nzherald.co.nz/wairarapa-times-age/news/article.cfm?c_id=1503414&objectid=11627218)

33. Peters M, Clarkson B (ed.) (2012) Wetland Restoration – A Handbook for New Zealand Freshwater Systems. Manaaki Whenua Press, Lincoln

34. Quinn J and Hickey C (1990) Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. New Zealand Journal of Marine and Freshwater Research, Vol. 24:387-409

35. Rait R, Campbell I (2014) Soil Properties in the Koromiko Area. Marlborough District Council, Technical Report No. 14-007

36. Smart J (2009) Dairyshed Effluent and Stream Crossing Surveys – 2008/2009 Report. Marlborough District Council

37. Tanner CC, Sukias JPS and Upsdell MP (1999) Substratum phosphorus accumulation during maturation of gravel-bed constructed wetlands. Water Science and Technology, 40 (3), 147-154

38. Tait A (2017) Interpolation of Mean Annual Rainfall for Marlborough District. Report prepared by National Institute of Water & Atmospheric Research Ltd for Marlborough District Council. Report No: 2017004WN

39. Williams H (2005) Issues related to groundwater and surface water takes in the MDC Speeds Road well field area. Report prepared by Pattle Delamore Parners Ltd for Marlborough District Council

11. Appendix

Results of the 2015/2016 water quality investigation (one to two samples were taken in 2014)

11.1. Main River sites

Site 1

Tuamarina River at State Highway One (1680588E, 5412144N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.625	0.61	0.005	0.012	20	2.4	7.5
9/12/2014	0.366	0.35	0.016	0.02	110	2.1	7.3
22/01/2015	0.006	< 0.002	0.005	0.004	60	1.07	7.2
25/02/2015	0.02	0.014	0.005	0.012	38	1.1	7.4
26/03/2015	0.094	0.087	0.005	0.006	29	3.5	7.4
5/05/2015	0.335	0.33	0.005	0.049	22	0.92	7.2
16/06/2015	0.615	0.61	0.005	0.033	24	1.12	7.1
10/08/2015	0.635	0.63	0.005	0.016	30	1.29	7.2
14/09/2015	0.595	0.59	0.005	0.012	60	1.42	7.2
20/10/2015	0.665	0.66	0.005	0.022	31	1.52	7.2
14/01/2016	0.009	0.001	0.005	0.058	90	1.33	7.5

Site 2

Tuamarina River at Bush Road (1680171E, 5413325N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.692	0.66	0.022	0.012	29	3.4	7.5
9/12/2014	0.405	0.4	0.005	0.02	270	2.9	7.7
22/01/2015	0.064	0.052	0.005	0.007	90	3	7.3
25/02/2015	0.108	0.097	0.01	0.02	73	1.9	7.3
26/03/2015	0.225	0.21	0.005	0.014	35	0.82	7.4
5/05/2015	0.391	0.37	0.011	0.056	15	0.8	7.2
16/06/2015	0.655	0.64	0.005	0.033	30	1.17	7.1
10/08/2015	0.705	0.7	0.005	0.016	24	1.38	7.1
14/09/2015	0.645	0.64	0.005	0.012	70	1.06	7.1
20/10/2015	0.715	0.71	0.005	0.022	49	1.12	7.1
10/11/2015	0.595	0.58	0.005	0.024	110	1.3	7.4
14/01/2016	0.064	0.055	0.005	0.061	39	1.12	7.4

Site 3

Tuamarina River at Boat Point (1679492E, 5416702N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
22/01/2015	0.345	0.34	0.005	0.004	210	1.76	7.4
25/02/2015	0.281	0.22	0.061	0.014	2400	3.1	7.4
26/03/2015	0.378	0.35	0.018	0.012	190	1.65	7.5
5/05/2015	0.543	0.53	0.013	0.014	70	0.77	7.5
16/06/2015	0.898	0.88	0.018	0.013	240	1.45	7.2
10/08/2015	1.005	1	0.005	0.01	160	1.24	7.2
14/09/2015	0.975	0.96	0.005	0.008	120	1.12	7.2
20/10/2015	0.915	0.91	0.005	0.006	43	0.69	7.2
10/11/2015	0.805	0.8	0.005	0.008	21	0.7	7.4
14/01/2016	0.463	0.44	0.013	0.009	60	0.96	7.5

Site 4

Tuamarina River at Para Road (1679212E, 5419497N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.955	0.95	0.005	0.008	30	1.28	7.5
9/12/2014	0.721	0.7	0.011	0.008	490	0.76	7.1
22/01/2015	0.515	0.5	0.005	0.002	390	1.58	7.1
25/02/2015	0.475	0.47	0.005	0.004	280	1.58	7.1
26/03/2015	0.555	0.54	0.005	0.008	230	1	7.2
5/05/2015	0.632	0.62	0.012	0.014	370	0.73	7.3
16/06/2015	1.005	1	0.005	0.013	170	0.88	7.1
10/08/2015	1.195	1.19	0.005	0.01	110	2.4	7.1
14/09/2015	1.175	1.17	0.005	0.01	120	0.97	7.1
20/10/2015	1.145	1.14	0.005	0.008	220	0.55	7
10/11/2015	1.095	1.08	0.005	0.008	110	0.43	7.2
14/01/2016	0.685	0.68	0.005	0.007	230	0.67	7.3

Site 5

Tuamarina River at Speeds Road (1679679E, 5421265N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.805	0.8	0.005	0.01	400	1.5	7.6
9/12/2014	0.465	0.46	0.005	0.008	350	0.46	7.2
22/01/2015	0.355	0.34	0.005	0.002	190	0.47	7.1
25/02/2015	0.205	0.2	0.005	0.006	300	2.2	7.3
26/03/2015	0.395	0.39	0.005	0.011	250	1.22	7.2
5/05/2015	0.65	0.61	0.03	0.024	280	0.56	7.4
16/06/2015	1.195	1.19	0.005	0.015	510	1.15	7.2
10/08/2015	1.355	1.35	0.005	0.01	90	1.24	7.2
14/09/2015	1.164	1.14	0.014	0.01	210	1.17	7.2
20/10/2015	1.005	0.99	0.005	0.01	430	0.68	7.2
10/11/2015	0.875	0.87	0.005	0.013	510	0.84	7.3
14/01/2016	0.465	0.45	0.005	0.012	320	0.64	7.4

Site 7

Tuamarina River at Lindens Road (1681141E, 5424485N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.415	0.41	0.005	0.006	440	2	7.8
9/12/2014	0.395	0.39	0.005	0.004	180	0.64	7.4
22/01/2015	0.295	0.29	0.005	0.002	380	0.87	7.3
25/02/2015	0.375	0.36	0.005	0.006	470	2.1	7.2
26/03/2015	0.385	0.38	0.005	0.008	300	2.7	7.3
5/05/2015	0.435	0.43	0.005	0.01	440	0.68	7.4
16/06/2015	0.855	0.84	0.005	0.01	520	1.08	7.1
14/09/2015	0.585	0.58	0.005	0.006	260	1.57	7.3
20/10/2015	0.605	0.59	0.005	0.004	300	0.88	7.3
10/11/2015	0.625	0.61	0.005	0.007	100	0.69	7.4
14/01/2016	0.615	0.61	0.005	0.006	1000	1.17	7.4

11.2. Tributaries

Site K

Koromiko Stream at State Highway One (1679895E, 5421628N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.305	0.3	0.005	0.002	14	2.8	7.6
9/12/2014	1.167	1.11	0.047	0.006	190	1.51	6.9
22/01/2015	3.615	3.6	0.015	0.002	110	1.56	6.8
5/05/2015	1.405	1.4	0.005	0.006	160	0.88	7.3
16/06/2015	3.205	3.2	0.005	0.009	100	1.08	7.1
10/08/2015	1.945	1.94	0.005	0.002	50	2.1	7
14/09/2015	0.475	0.47	0.005	0.004	47	0.99	7.2
20/10/2015	0.753	0.74	0.013	0.004	20	1.29	7
10/11/2015	0.556	0.53	0.016	0.002	140	0.67	7.2
14/01/2016	1.077	1.05	0.017	0.002	90	0.93	7.2

Site B

Bragg Creek at Speed Road South Ford (1677909E, 5421275N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.475	0.47	0.005	0.012	60	0.12	7.2
5/05/2015	0.545	0.54	0.005	0.013	42	0.05	7.1
16/06/2015	0.605	0.6	0.005	0.014	42	0.57	6.9
10/08/2015	0.635	0.63	0.005	0.012	11	0.31	6.9
14/09/2015	0.625	0.62	0.005	0.012	15	0.54	6.9
20/10/2015	0.595	0.59	0.005	0.014	7	0.15	6.9
10/11/2015	0.465	0.45	0.005	0.01	23	0.12	7.2
14/01/2016	0.355	0.35	0.005	0.014	80	0.2	7.3

Site U

Tuamarina River Study - Site 04 (Unnamed Creek) (1679723E, 5420557N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.974	0.89	0.074	0.038	2700	2.1	7.7
16/06/2015	1.245	1.24	0.005	0.013	190	0.97	7.2
10/08/2015	1.585	1.58	0.005	0.006	300	1.21	7.3
14/09/2015	1.875	1.87	0.005	0.009	19	1	7.3
20/10/2015	1.465	1.46	0.005	0.006	1900	0.96	7.2
10/11/2015	1.421	1.4	0.011	0.01	230	0.66	7.4
14/01/2016	0.426	0.37	0.046	0.024	1200	0.75	7.6

Site P

Para Stream at Para Road (1678722E, 5419548N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/09/2014	0.009	0.004	0.005	0.002	100	0.78	7.9
16/06/2015	0.062	0.056	0.005	0.012	54	0.5	7.5
10/08/2015	0.042	0.037	0.005	0.006	31	0.89	8
14/09/2015	0.024	0.018	0.005	0.007	50	1.76	8.3
20/10/2015	0.019	0.014	0.005	0.006	140	0.75	7.6

Site L

Tuamarina Lagoon at Howard St Outlet (1680093E, 5413272N)

Date	Soluble Inorganic Nitrogen mg/L	Nitrate-Nitrogen mg/L	Ammonical Nitrogen mg/L	Dissolved Reactive Phosphorus mg/L	E. coli concentration n/100mL	Turbidity NTU	pH
10/11/2015	0.006	0.001	0.005	0.019	480	4.6	7.9
14/01/2016	0.006	0.001	0.005	0.056	2000	7.2	8
30/09/2016	0.059	0.8	0.059	0.033	280	2.6	7.5
11/10/2016	0.705	0.69	0.005	0.02	210	2	7.5