MARLBOROUGH DISTRICT COUNCIL

Water Quality in the Are Are Creek Catchment

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Executive Summary

Are Are Creek flows through the Kaituna valley and is a tributary of the Wairau River. Large pine production forest covers the hills of the catchment, while the valley floor is dominated by pastoral land use. Monthly State of the Environment monitoring at the bottom of the catchment has shown that water quality is poor. In order to find the causes, a total of 24 sites located throughout the catchment were sampled on 6 occasions in 2013 and 2014. A number of physical and chemical parameters were measured at each site including E. coli, nutrient concentrations, turbidity, water temperature, pH and Dissolved Oxygen saturation. Parameters exceeded guideline values for the protection of ecological and recreational values at the majority of sites monitored. The site with the worst water quality was located on a small tributary in the mid catchment. Further investigations revealed direct discharge of sewage, together with effluent discharges and silage leachate was causing the deterioration in water quality. Remediation works were initiated and are on-going. At the majority of the other sites direct livestock access and lack of shading by tall bank vegetation were key contributors to poor water quality. Additionally, nitrate leachate from pastoral landuse into subsurface flow and groundwater entering Are Are Creek in the mid and lower reaches caused elevated Soluble Inorganic Nitrogen concentrations.

Figure 1: Arial view of the Are Are Creek catchment.

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1. Introduction

Are Are Creek is a northbank tributary of the Wairau River. Its headwaters originate in Okaramio and its mainstem flows alongside State Highway 6, through the Kaituna valley, before joining the Wairau River downstream of the SH6 Bridge. The Are Are Creek catchment has an area of 31.4 km^2. Production pine forest dominants land cover in the elevated parts of the catchment (47%), and pasture dominants land cover in the lower elevations (27%). Smaller areas of the catchment are covered by native forest and shrubs (18%) and vineyards (6%).

Monitoring data collected as part of the State of the Environment (SoE) program from the lower reaches of Are Are Creek have shown that the river has poor water quality. Concentrations of Soluble Inorganic Nitrogen (SIN) consistently exceed guideline levels for prevention of nuisance algal growth and concentrations of Dissolved Reactive Phosphorus (DRP) and E. coli frequently exceed guideline levels for nuisance algal growth and contact recreation, respectively [1, 2].

The aim of this study is to examine water quality throughout the Are Are Creek catchment, in order to determine the origin of contaminant inputs, and to provide insight as to the reasons for the river's poor water quality.

2. Methods

2.1. Sites

Sampling was undertaken at 24 sites throughout the catchment; 11 sites on the mainstem of Are Are Creek and 13 sites from eight tributary streams (Figure 2).

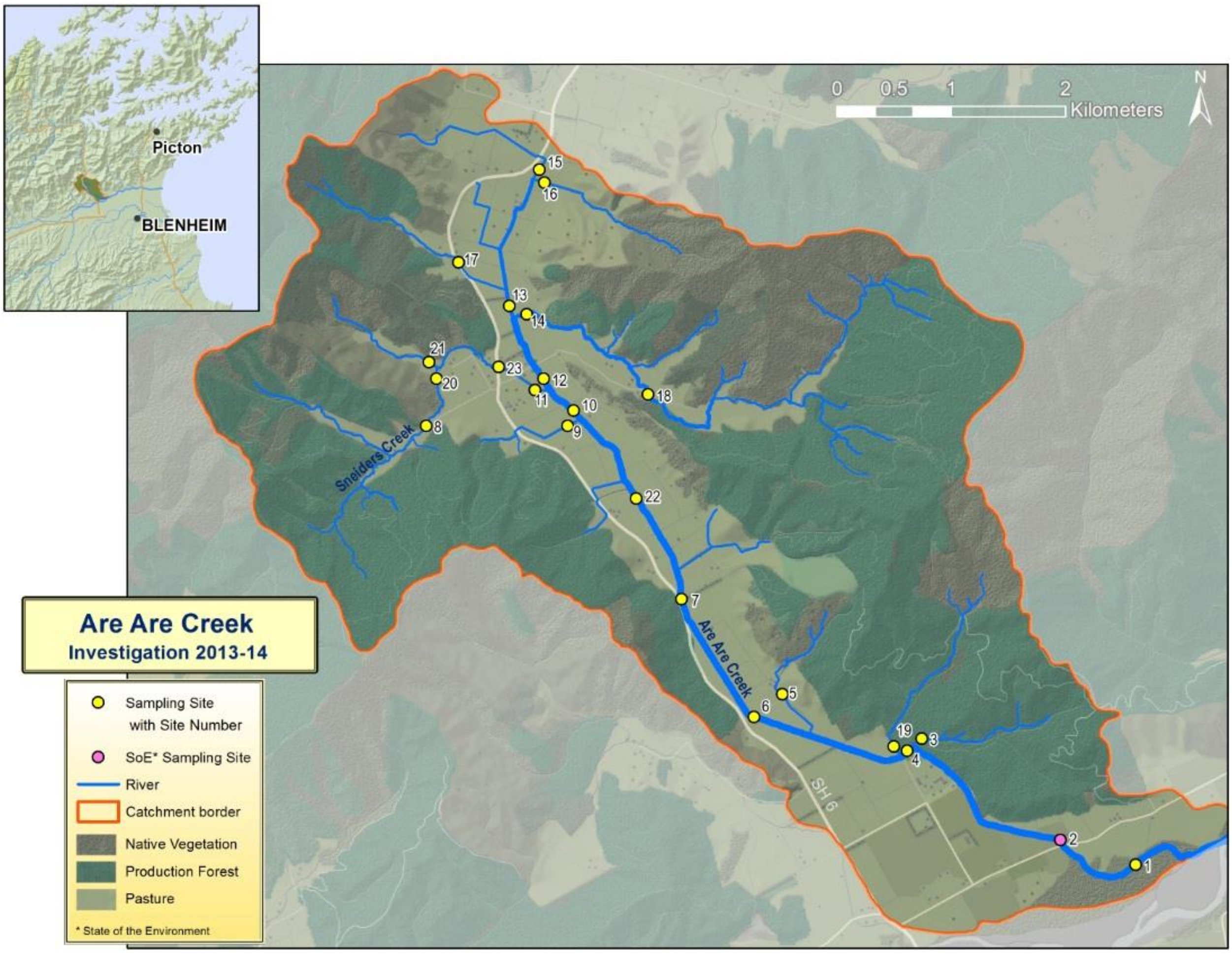


Figure 2: Location of Study sites.

Sites were sampled on up to six occasions between November 2013 and September 2014 (Table 1). In addition, Site 2 (Are Are Creek at Kaituna-Tuamarina Track) has been sampled monthly as part of the State of the Environment (SoE) sampling since July 2009. This site is also the location of a permanent flow recorder. Additional flow measurements were taken at four of the mainstem sites on 7 March 2014.

	Site	21-Nov-13	6-Mar-14	15-May-14	6-Jun-14	24-Jul-14	8-Sep-14
Are Are Creek sites	15	x		x	x	x	x
	13	x	x	x	x	x	x
	12	x	x	x	x		
	10	x	x	x	x		
	22				x		x
	7	x	x	x	x	x	x
	6	x	x	x	x		x
	4	x	x	x	x	x	x
	2	x	x	x	x	x	x
	1	x	x	x	x	x	x
Tributary stream sites	16	x		x	x	x	x
	17	x		x	x	x	x
	18					x	
	14	x		x	x	x	x
	8	x		x		x	
	20			x	x	x	
	21			x		x	
	23				x	x	x
	11	x	x	x	x		
	9	x		x	x		
	5	x		x			x
	19		x	x	x	x	x
	3	x		x	x	x	x

Table 1: Dates individual study sites were sampled.

2.2. Physical characteristics

Physical characteristics of each site were recorded by taking photographs of the sites and undertaking visual assessments for parameters including water clarity, organic bed cover, inorganic bed cover, stock access, adjacent land use and riparian vegetation.

2.3. Water quality

At each site, water samples were collected for analysis of turbidity, pH, nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N) and total ammonical nitrogen (NHx-N), dissolved reactive phosphorus (DRP) and indicator bacteria (E. coli). Analyses were undertaken by Hill Laboratories in their IANZ accredited water testing laboratory using appropriate standard methods. On two occasions, when very high concentrations of indicator bacteria were found, further laboratory analyses were undertaken for detection of molecular markers to provide insight into the origin of faecal matter in the sample. These analyses were undertaken by Cawthron Institute. Dissolved oxygen, water temperature and conductivity were measured in the field using standard equipment and techniques.

A detailed description of the various water quality parameters and the rationale for the guideline levels used in Marlborough can be found in the Marlborough District Council's recent State of the Environment Surface Water Quality Monitoring Reports (1, 2). Information about water quality parameters is also available on the Marlborough District Council's website at wwwmarlborough.govt.nz/Environment/Rivers-and-Wetlands/River-Water-Quality/Quality.

Sampling was carried out during base flows, which ranged from 0.2 to 0.36 m^3/s (Figure 3). Base flow conditions represent the predominant situation. The limited timeframe of the study did not allow representative sampling of flood flows.

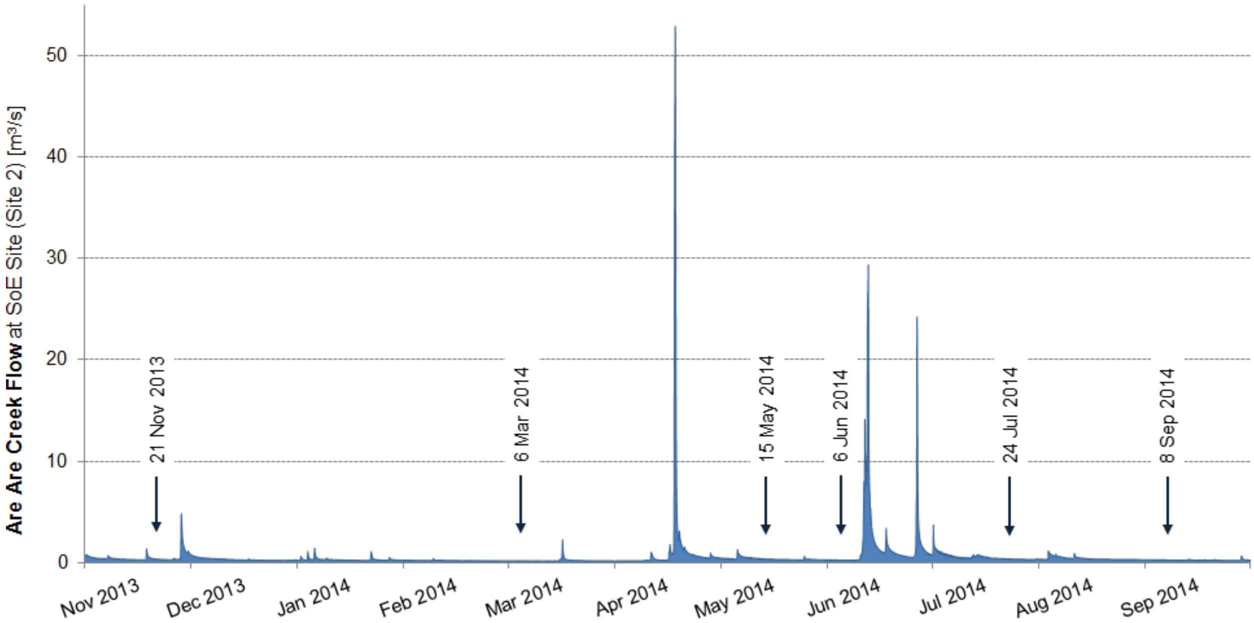


Figure 3: Flow in m^3/s at Are Are Creek (Site 2) from 1 November 2013 to 30 September 2014. Sampling dates are shown with arrows.

3. Results

3.1. Flow

Flow gaugings at four mainstem sites during very low flows in March 2014 showed a gradual increase in flow volume with distance downstream. The flow increased from 0.08 m^3/s at Site 12 (immediately upstream of the confluence with Sneider's Creek) to 0.09 m^3/s at Site 10 (downstream of Sneider's Creek, and upstream of Site 9 tributary), indicating that Sneider's Creek was contributing around 0.01 m^3/s to the mainstem flow. At Site 6, flow had increased to 0.12 m^3/s (an increase of 0.03 m^3/s), despite very little flow entering the river from the small tributaries between Sites 10 and 6. Flow in the Site 9 tributary was too low for samples to be taken. This suggests that upwelling from the groundwater contributes to the increase in flow that occurs in the mid-reaches of the mainstem, between Sites 10 and 6. At Site 2, flow increased by another 0.05 m^3/s to 0.17 m^3/s indicating even greater groundwater inflow in the lower reaches, which most likely originats from the Wairau aquifer.

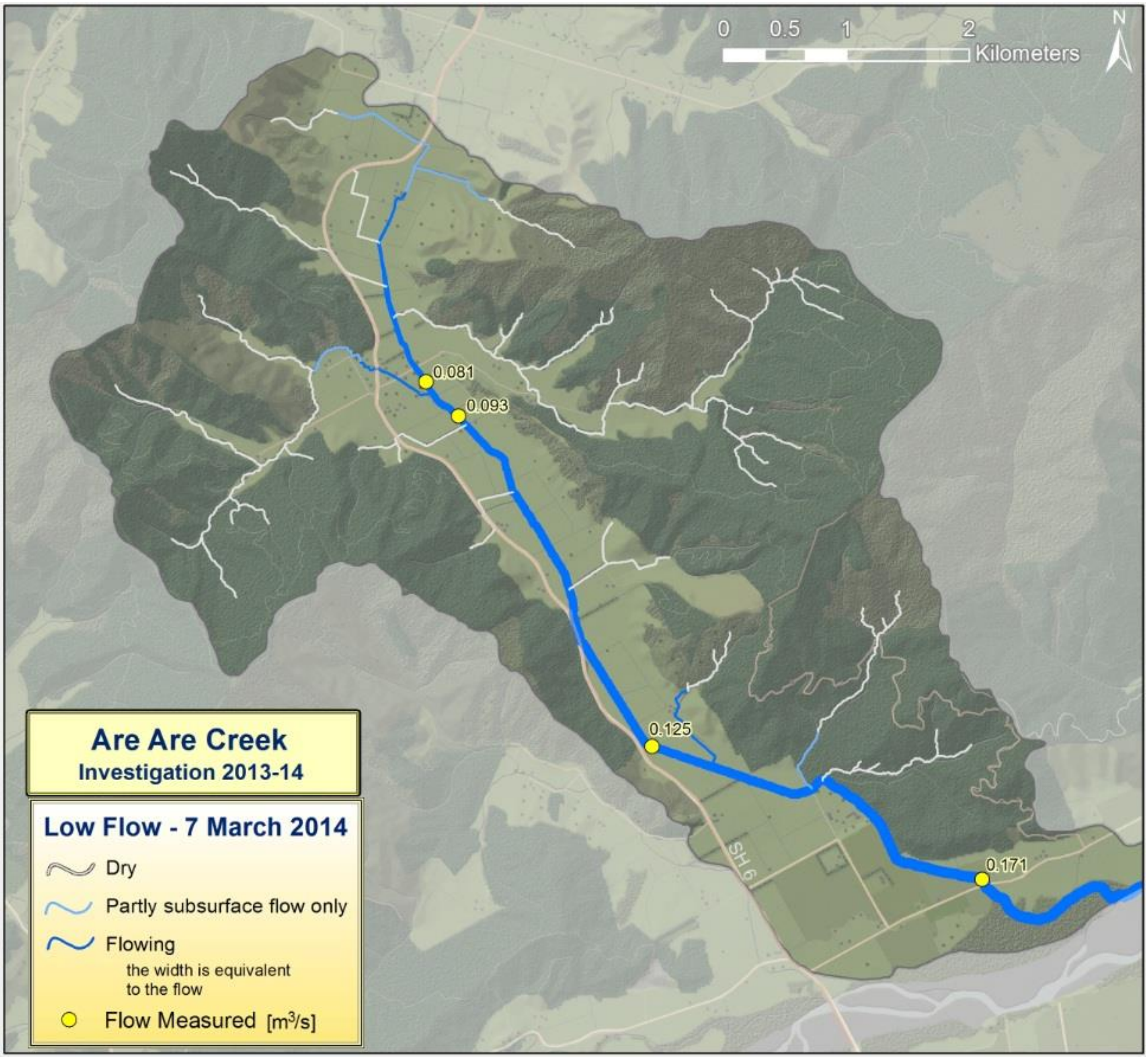
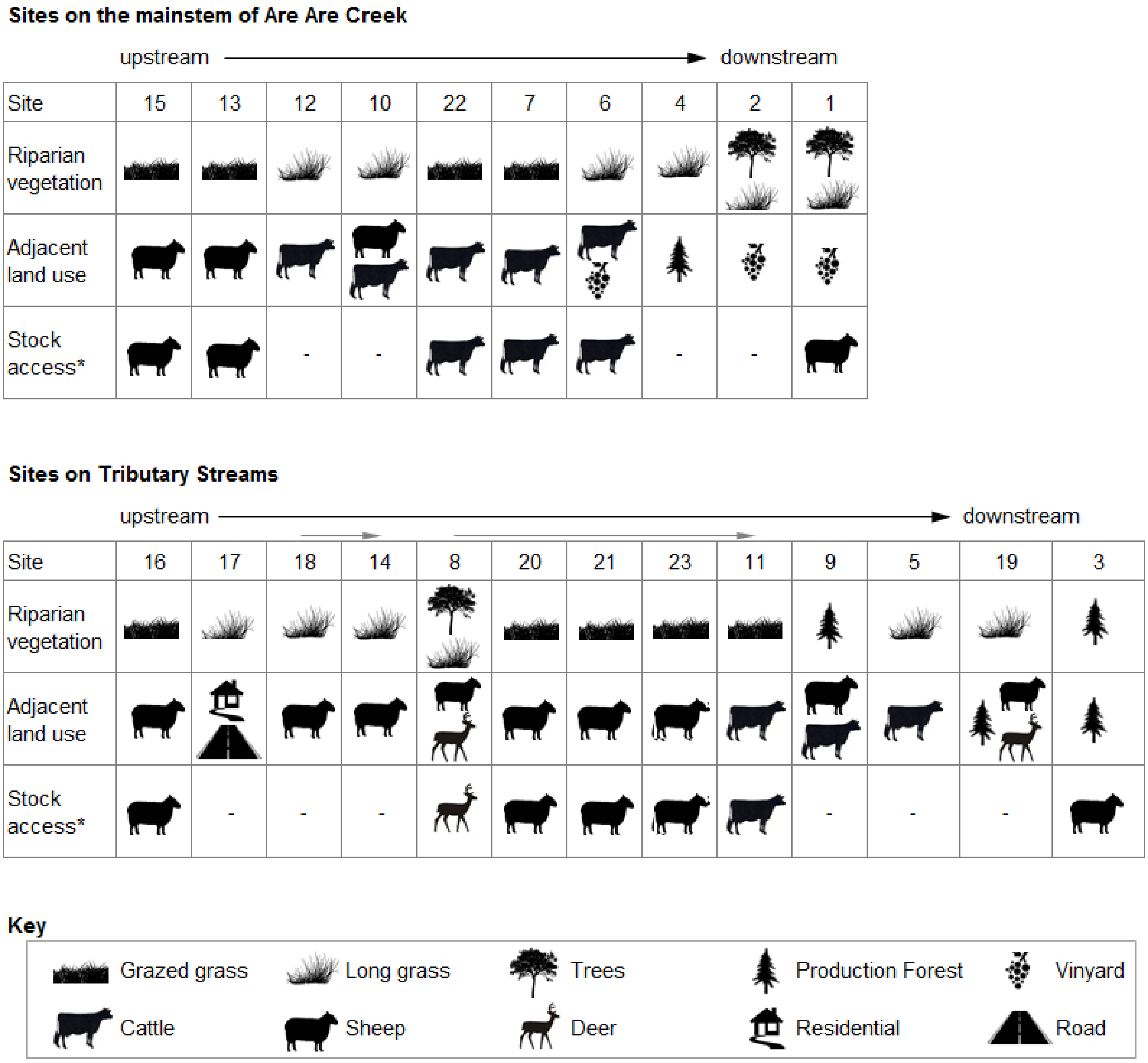


Figure 4: Summer low flow gaugings on 7 March 2014.

3.2. Physical characteristics

Observational data relating to riparian plantings, adjacent land use and stock access to the channel are summarised in Table 2.

With the exception of Sites 2 and 1 in the lower reaches of Are Are Creek, riparian zones at all of the mainstem sites were planted with grasses. Sites in the upper and mid-reaches of Are Are Creek were surrounded by pasture, with sheep observed grazing adjacent to the three upper-catchment sites (Sites 15 and 13), and beef or dairy cattle observed adjacent to the mid-reach sites (Sites 12, 10, 22, 7 and 6). In the lower reaches of the mainstem, Are Are Creek flowed through vineyard and forestry land (Sites 6, 4, 2 and 1). Stock access to the channel was evident at just over half of the sites on Are Are Creek: at both sites in the upper catchment (Sites 15 and 13: sheep); at half of the mid-catchment sites (Sites 22, 7 and 6: cattle); and at Site 1 in the lower catchment (sheep).



* Direct Livestock access to the waterway or signs of recent livestock access
(Absence of a descriptor indicates that stock access was not evident at the site on any of the sampling occasions. However, it is possible that stock access may have occurred upstream, without being observed during sampling.)

Table 2: Summary of physical characteristics relating to riparian plantings, adjacent land use and stock access. Sites are arranged in order from upstream to downstream. The descriptors that best represented each site over all of the sampling occasions were chosen. More detailed descriptions can be found in the appendices.

Riparian zones at most of the sites on tributary streams were planted with grasses. Exceptions were Site 8 (upstream site on Sneider's Creek), which was shaded by riparian trees, and Sites 9 and 3, which were bordered by established conifers. Most of the tributary sites were surrounded by pasture, with sheep (at Sites 16, 14, 18, 23, 21, 20, 8, 9 and 19), cattle (at Sites 11, 8, 9, 5 and 19) and deer (at Site 8) observed. Site 17 (small tributary in the upper-catchment) was located alongside SH6 and residential properties, and Sites 19 and 3 (both lower-catchment tributaries) were located on streams running through plantation pine forests. Stock access to the channel was evident at sites on three tributary streams: Site 16 in the upper catchment (sheep); all five sites in Sneider's Creek (cattle, sheep, deer); and at the forested Site 3 (sheep).

3.3. Indicator Bacteria (E.coli)

E. coli is a bacterium commonly found in the guts of warm-blooded animals (including humans), and is used as an indicator of faecal contamination. State of the Environment monitoring at Site 2 had shown that E. coli concentrations regularly exceeded the recreational guidelines (Figure 5). Exceedances were not limited to rainfall events, when animal droppings from adjacent land are washed into the waterway. High E. coli concentrations were also observed during fine weather conditions, which suggest direct inputs as a result of livestock access and/or effluent discharges.

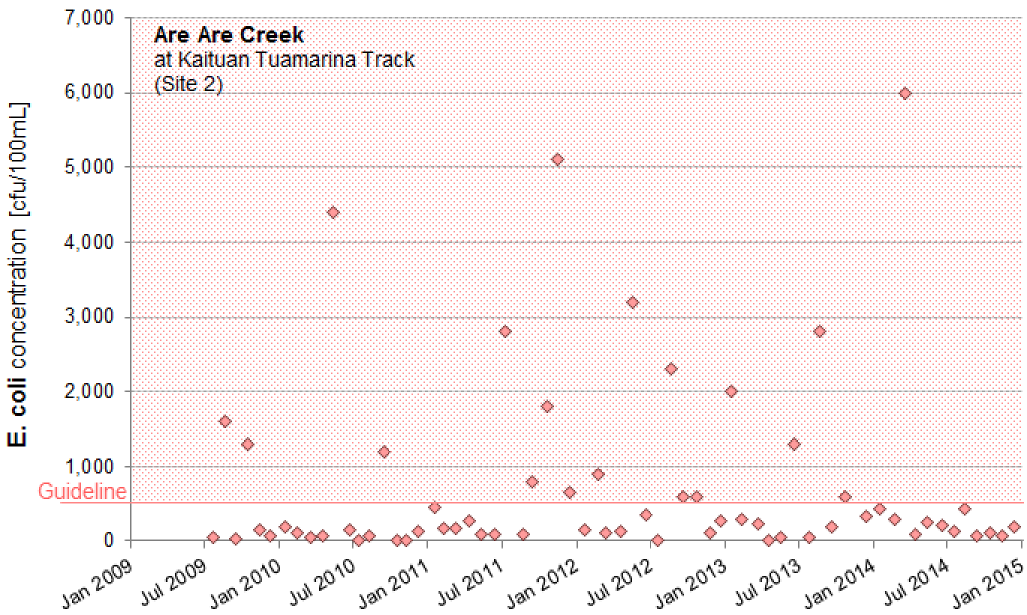


Figure 5: E. coli concentrations measured as part of the monthly State of the Environment sampling at Are Are Creek, Site 2.

The E. coli concentrations found throughout the Are Are Creek catchment are shown in Figure 6. Concentrations of E. coli frequently exceeded guideline levels for contact recreation in the upper catchment (mainstem sites 15 and 13), and in the lower catchment (mainstem sites 4 and 2), with almost all sites in the mid-catchment (Sites 12, 10, 22 and 6) consistently having E. coli concentrations below the guideline level of 550 E.coli/100 mL[1]. Concentrations at Site 4 and Site 2 were occasionally very high, with 13,000 E.coli/100 mL occurring at Site 4 in July 2014, and concentrations of 6,700 and >6,000 E.coli/100 mL occurring at Site 2 in November 2013 and March 2014, respectively. Faecal-source tracking of a Site 4 sample indicated that the faecal bacteria were from a variety of sources, with bovine, ruminant, wildfowl, dog and faint human markers detected.

[1] The actual unit for E. coli concentrations based on the analytical method used is 'cfu/100mL', but for better clarity 'E.coli/100mL' is used in the text.

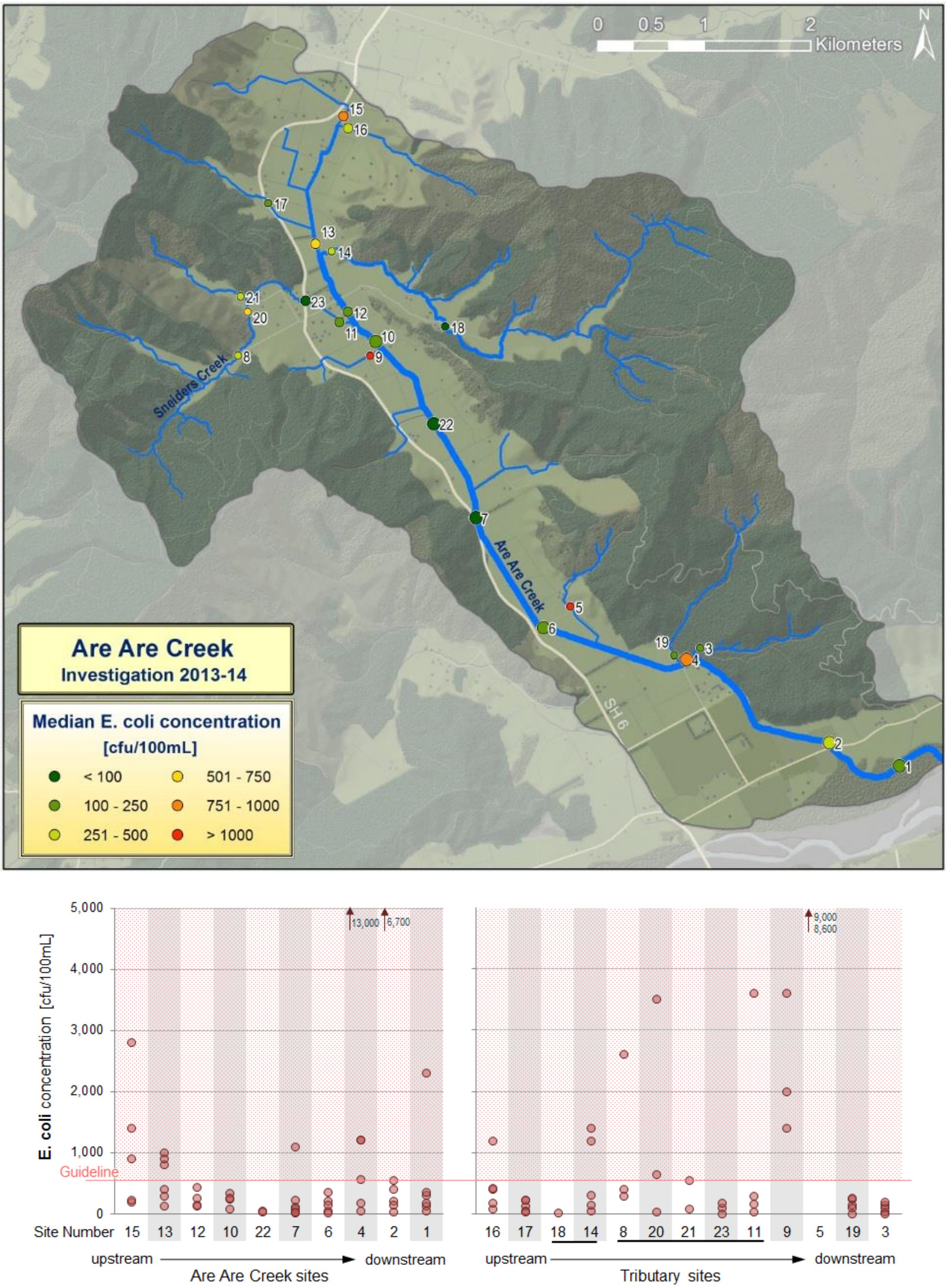


Figure 6: E. coli concentrations measured during the study. The map shows the median concentrations and site numbers, while the graphs show all measurements for the sites along Are Are Creek and its tributary streams in a downstream direction. Underlined sites are located on the same tributary stream.

With the exceptions of Site 17 in the upper catchment, and Sites 19 and 3 in the lower catchment, the tributary sites commonly had high E. coli concentrations. Sneider's Creek at Site 11 (just upstream of its confluence with Are Are Creek) had concentrations above the guideline level on one of four sampling occasions (3,600 E.coli/100 mL in March 2014); the only time cattle had direct access to the creek at the site. Faecal-source tracking confirmed that faecal contamination was of bovine/ruminant origin. The left bank tributary sampled at Site 14 exceeded guideline levels on two of five occasions (1,400 and 1,200 E.coli/100 mL in November and June, respectively). At the Site 9 and Site 5 tributaries, guideline concentrations were consistently exceeded on all occasions that they were sampled, with very high concentrations found at Site 5 in particular (November: 9,000 E.coli/100 mL; May: 8,600 E.coli/100 mL).

3.4. Soluble Inorganic Nitrogen (SIN)

Soluble Inorganic Nitrogen (SIN) is the sum of the three forms of nitrogen that are most easily taken up by plants: nitrate-N (NO_3-N), nitrite-N (NO_2-N) and ammonical-N (NH_x-N). State of the Environment monitoring has shown that SIN concentrations are almost exclusive above the guideline level of 0.165 mg/L for nuisance algae growth at the bottom of the catchment (Figure 7). Concentrations are usually higher during the cooler months when less SIN is removed due to reduced algae growth. Nitrate Nitrogen is the predominant form of SIN; consistently contributing more than 90% of the concentration.

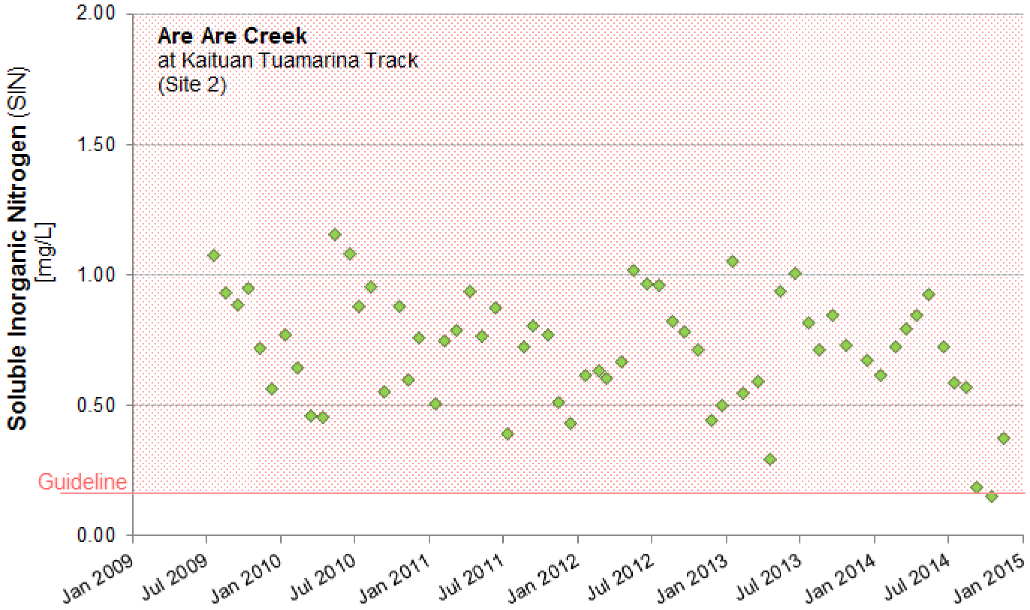


Figure 7: Soluble Inorganic Nitrogen concentrations measured as part of the monthly State of the Environment sampling at Are Are Creek, Site 2.

The results of the study show concentrations of SIN consistently exceeded the guideline level for nuisance algal growth at all but the two uppermost sites (Sites 15 and 13) along the mainstem of Are Are Creek (Figure 8).

At the tributary sites, SIN concentrations were more variable. Concentrations in the upper-catchment tributaries (Sites 16 and 17) were below guideline levels on most occasions. At the largest left bank[2] tributary concentrations exceeded guideline levels on two of the five sampling occasions just upstream of its confluence with Are Are Creek and once upstream on the same tributary at Site 18. At the Sneider's Creek tributary, at Site 11 (just upstream of its confluence with Are Are Creek), SIN concentrations exceeded guideline levels on all four sampling occasions: a pattern consistent with samples from the other sites in this tributary (Sites 23, 21, 20 and 8). Site 23, in particular, had some very high concentrations (1.426 mg/L and 0.956 mg/L in September 2014 and July 2014, respectively).

[2] True left and right banks are designated, facing in a downstream direction.

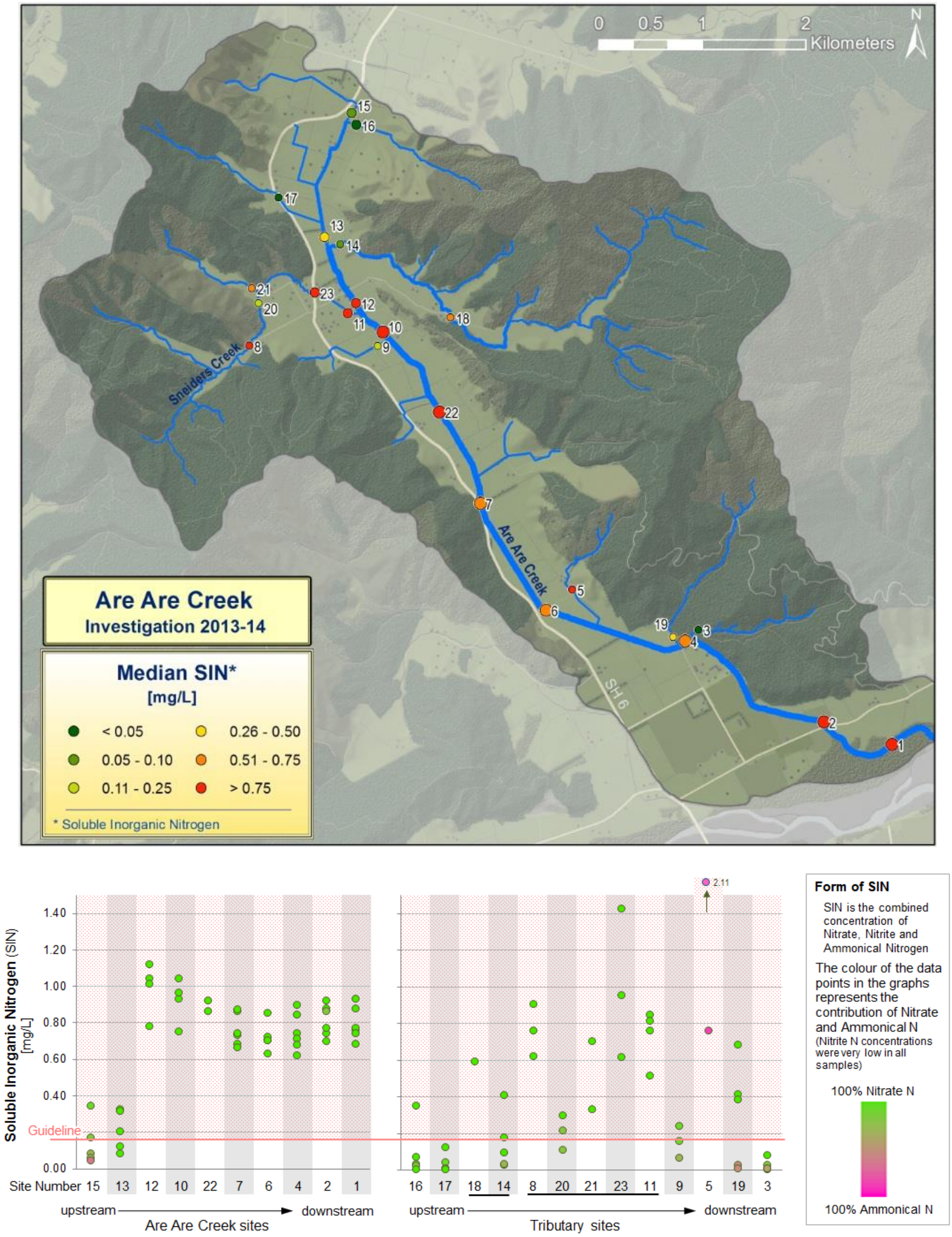


Figure 8: SIN concentrations measured during the study. The map shows the median concentrations and site numbers, while the graphs show all measurements for sites along Are Are Creek and its tributary streams in a downstream direction. Underlined sites are located on the same tributary stream.

At the small Site 9 tributary, concentrations were relatively low, below guideline levels on two of the three occasions sampled. In contrast, SIN concentrations in the Site 5 tributary exceeded the guideline level on both occasions sampled, with an extremely high concentration of 2.106 mg/L found in May 2014. While the majority of SIN in most of the other samples was in the form of nitrate-N, the Site 5 samples were unusual in that the majority of the SIN was ammonical nitrogen reaching levels toxic to aquatic life. At other sites the proportion of ammonical nitrogen was high only in samples with very low concentrations of SIN. At the Site 19 tributary, SIN guideline levels were exceeded on three of five occasions, whereas, at the Site 3 tributary, SIN concentrations were consistently below the guideline level.

3.5. Dissolved Reactive Phosphorus (DRP)

DRP is the form of phosphorus that is most easily taken up by plants, so high concentrations can contribute to excessive growth of algae and/or aquatic plants. Phosphorus commonly enters rivers bound to sediment, and then dissolves into water, becoming available for plant and algal growth. This means that bank erosion, along with fertilizer use in surrounding pasture, and point source discharges such as those from sewage treatment plants and septic systems, all contribute to DRP levels.

Figure 9 shows the Dissolved Reactive Phosphorus (DRP) concentrations measured as part of the State of the Environment sampling at Site 2. The DRP concentration varies significantly, exceeding the guideline more than 50% of the time. Similar to SIN concentrations, values are generally higher during the colder months; however the seasonal pattern is not as distinct.

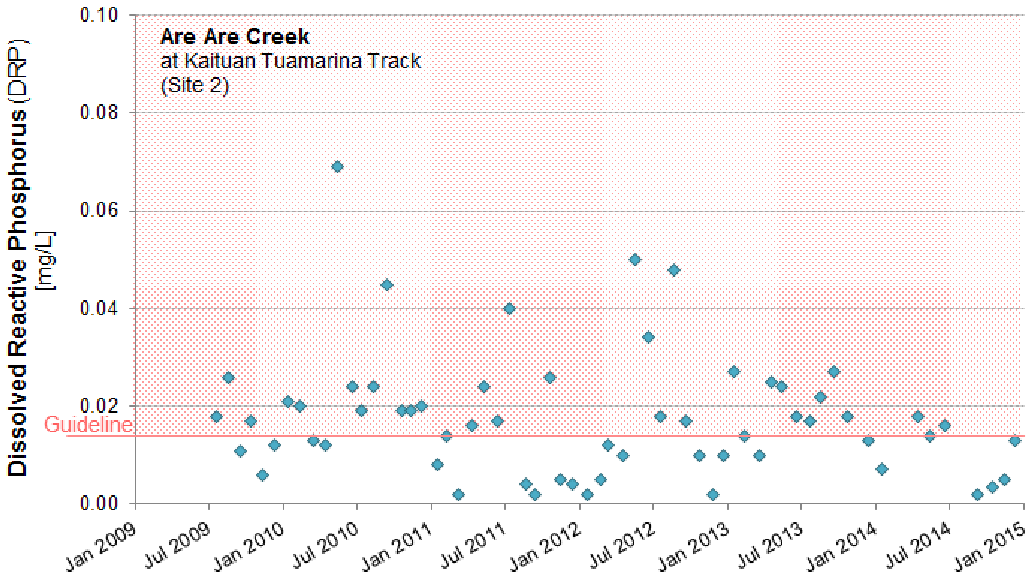


Figure 9: Dissolved Reactive Phosphorus concentrations measured as part of the monthly State of the Environment sampling at Are Are Creek, Site 2.

The results of the study are shown in Figure 10. Accept for the mid reaches (Sites 22, 7 and 6) DRP concentrations in the mainstem of Are Are Creek commonly exceeded guideline levels for prevention of nuisance algae growth.

Of the tributary sites, Site 5 had exponentially higher DRP concentrations than any other site. The highest concentration of 2.9 mg/L was almost 200 times the guideline level of 0.015 mg/L. Although not at the same scale, sites on the large left bank tributary (Sites 14 and 18) and on Sneider's Creek (Sites 11, 23, 21, 20 and 8) commonly had DRP concentrations that were at or above the guideline level, as did the small Site 9 tributary. Concentrations at the upper (Sites 16 and 17) and lower (Sites 19 and 3) catchment tributaries were consistently below guideline levels.

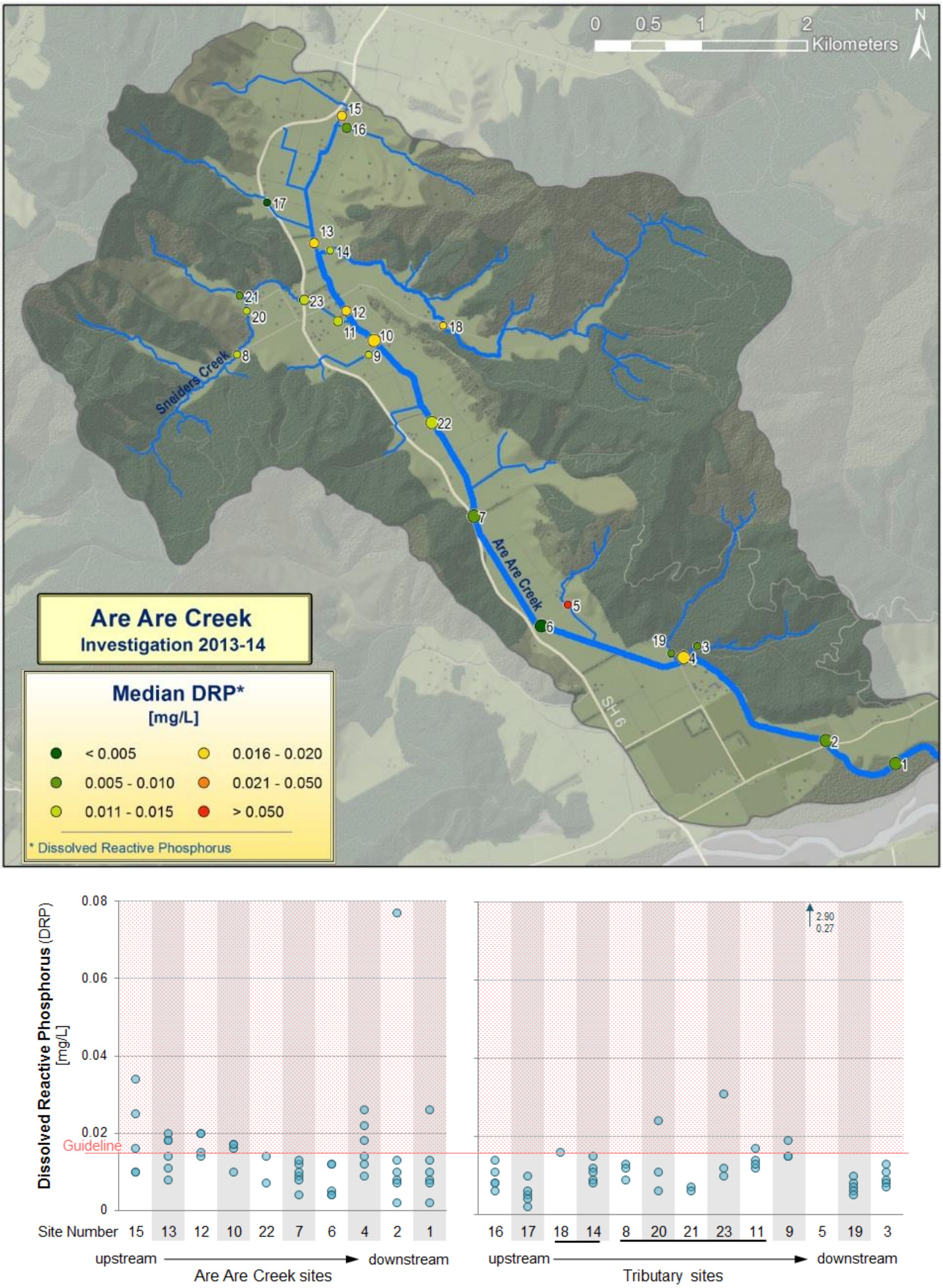


Figure 10: DRP concentrations measured during the study. The map shows the median concentrations and site numbers, while the graphs show all measurements for sites along Are Are Creek and its tributary streams in a downstream direction. Underlined sites are located on the same tributary stream.

3.6. Turbidity

Turbidity at the State of the Environment site (Site 2) is generally below the guideline of 5.6 NTU, indicating that the water is typically reasonably clear (Figure 11). Very high turbidity is associated with flood flows, but occasional values slightly above the guideline were observed during dry weather conditions.

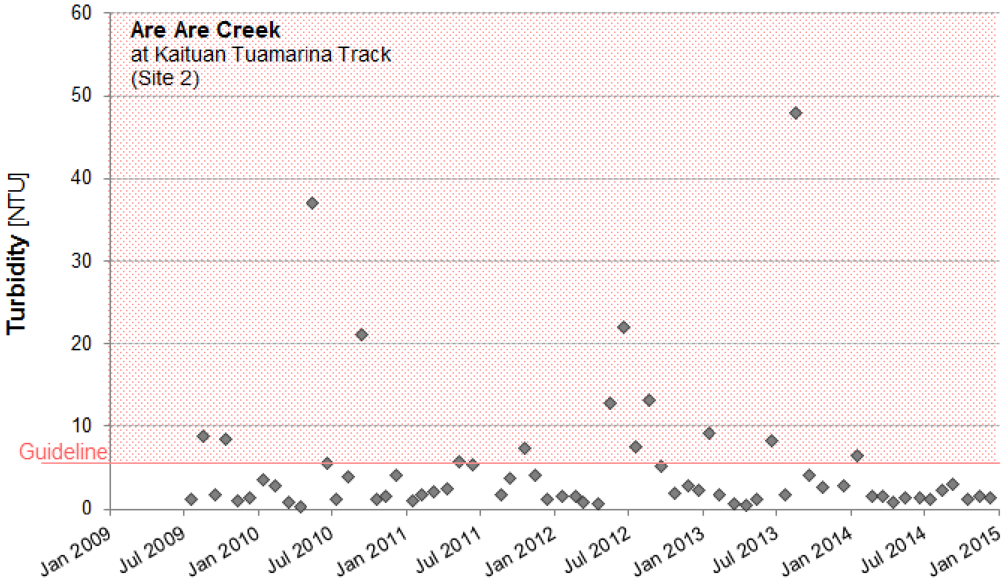
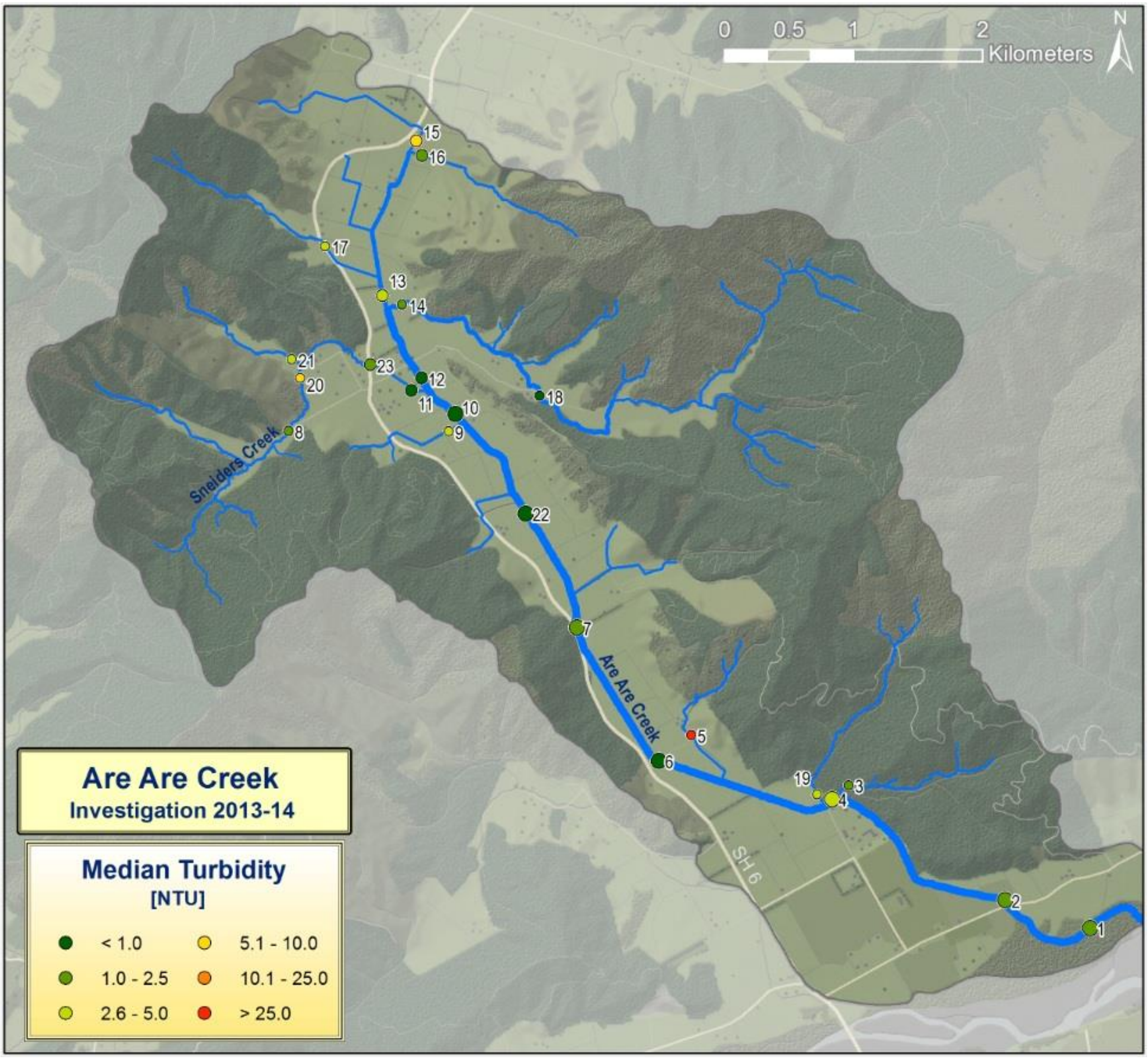


Figure 11: Turbidity measured as part of the monthly State of the Environment sampling at Are Are Creek, Site 2.

Figure 12 shows turbidity measurements from throughout the catchment observed as part of the study. Turbidity measurements at Sites 15 and 13 (upper mainstem) were normally higher than those at the mid-mainstem sites, and turbidity at Site 15 exceeded the guideline level of 5.6 NTU on two of the five occasions sampled. In the mid-reaches of the mainstem (Sites 12, 10, 22, 7 and 6), turbidity was relatively low (below 2 NTU) on all occasions sampled. In the lower reaches of Are Are Creek (Sites 4, 2 and 1), turbidity was commonly higher than that in the mid-reaches, and, on occasions, it exceeded the guideline level.

Most of the sites on the tributaries of Are Are Creek had turbidities at or below 4 NTU on most occasions. Site 20 (Sneider's Creek) and Site 5 were exceptions, with elevated turbidity measurements on all of the occasions sampled. At Site 20, all three measurements exceeded the guideline level by a relatively small amount (6.2, 5.8 and 6.5 NTU in May, June and July 2014, respectively). At Site 5, both measurements were extremely high (22 and 61 NTU in November 2013 and May 2014, respectively), well above the guideline level and levels at other sites.



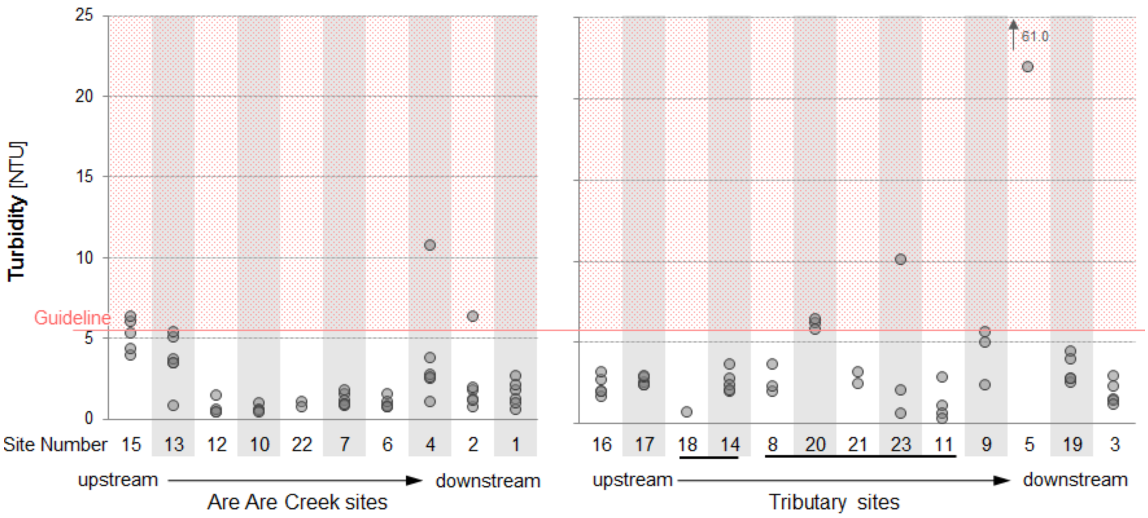


Figure 12: Turbidity measured during the study. The map shows the median Turbidity and site numbers, while the graphs show all measurements for sites along Are Are Creek and its tributary streams in a downstream direction. Underlined sites are located on the same tributary stream.

3.7. Water Temperature

Water temperature has a strong seasonal and diurnal pattern with highest values during midday in summer and lower values at night and during the colder months. In the absence of point discharges, the variation in water temperature is strongly dependant on shading of the waterway by riparian vegetation. When tall vegetation is growing on stream banks, less sunlight can reach the water. This lowers water temperatures and results in greater ecological diversity of aquatic life. High water temperatures have negative impacts on survival of stream invertebrates and fish, increasing their oxygen requirements, while simultaneously causing a decrease in the availability of dissolved oxygen. High temperatures also contribute to accelerated growth of aquatic plants and algae that can lead to nuisance algal growth and a reduction in dissolved oxygen at night.

The State of the Environment monitoring showed that water temperatures are occasionally exceeding the guideline value of 21.5°C for protection of aquatic life at Site 2 (Figure 13). However these results are spot measurements only and are rarely measured during the time when values are at their highest. Still, they can be useful to provide an indication of streams that are likely to have very high summer maximum temperatures. The occasional guideline exceedances observed in Are Are Creek possibly indicate, that high water temperatures are a regular occurrence during the summer months.

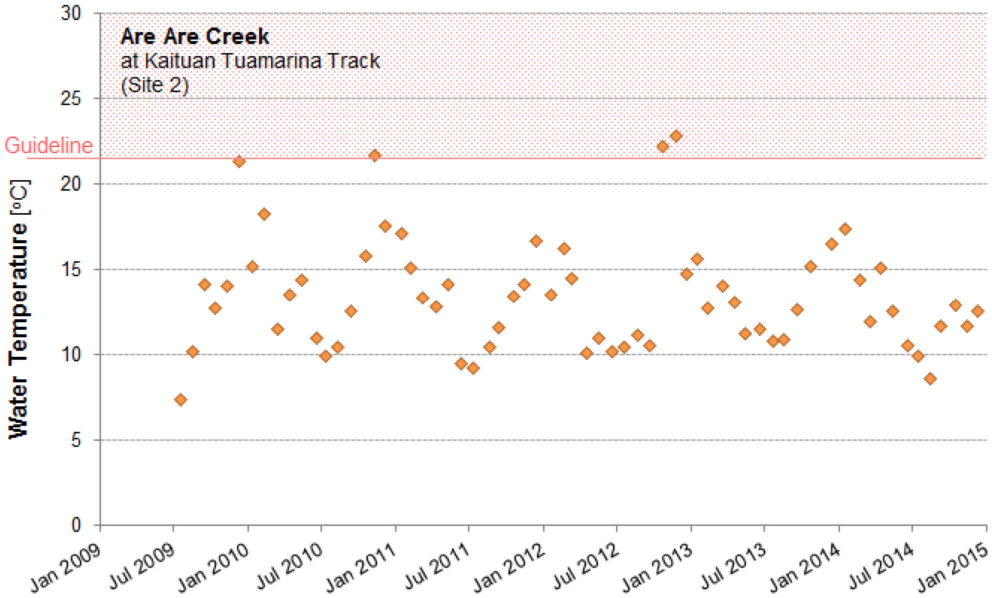


Figure 13: Water Temperatures measured as part of the monthly State of the Environment sampling at Are Are Creek, Site 2.

Water temperatures were also measured on four occasions during the study. Of the mainstem sites, Sites 15 and 13 (both in the upper-reaches), and Sites 7 and 6 (both in the mid-reaches) had spot temperatures approaching the guideline. Similarly, several of the tributary sites had spot temperatures that approached or reached the guideline level: Sites 16 and 17 (upper-catchment) and Sites 8 and 9 (mid-catchment). As the majority of Are Are Creek is unshaded by riparian vegetation, it is likely the water temperature frequently exceeds the maximum guideline temperature during the summer months.

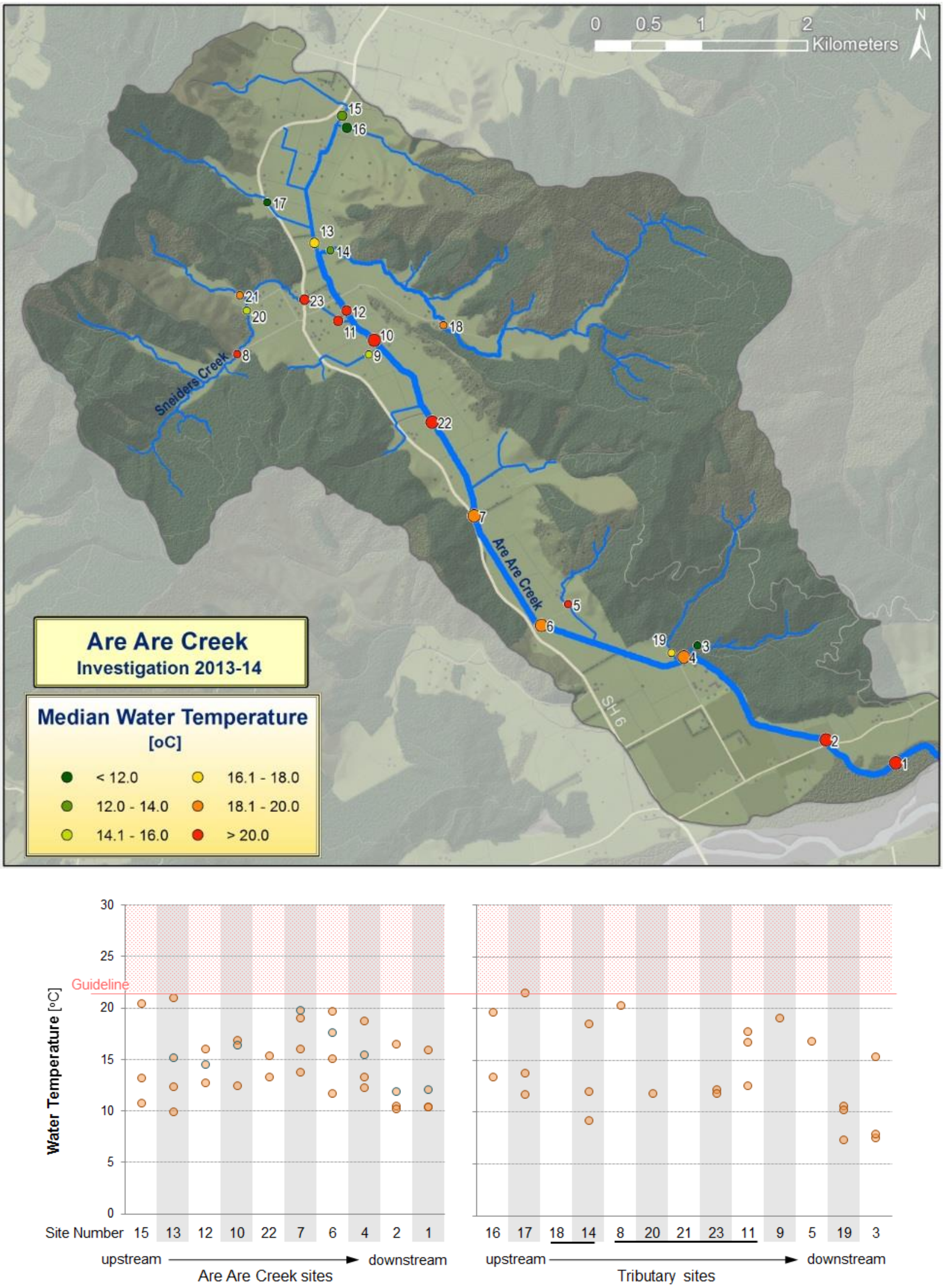


Figure 14: Water temperatures measured during the study. The map shows the median water temperature and site numbers, while the graphs show all measurements for sites along Are Are Creek and its tributary streams in a downstream direction. Underlined sites are located on the same tributary stream.

3.8. Dissolved Oxygen (DO)

Dissolved Oxygen (DO) saturations vary cyclically over a 24 hour period, usually rising throughout the day as aquatic plants and algae release oxygen during photosynthesis, and peak around mid-afternoon. At this time of the day it is common for water to become supersaturated (DO saturation over 100%). From early evening and overnight, DO saturation decreases as photosynthesis ceases and the biological processes that consume oxygen (such as respiration by aquatic animals, plants and bacteria) continue. Thus, it is usual for DO saturations to reach a minimum just before dawn. This diurnal variation needs to be kept in mind when interpreting spot measurement data.

Apart from one measurement taken during a flood event in May 2009, DO saturation at the State of the Environment site has been above the guideline of 70% for the protection aquatic life. For this reason, during the study DO saturation was measured at different sites in catchment on only two sampling runs (Figure 15).

Spot measurements of DO saturations at the mainstem sites showed considerable variation. While a number of sites in the mid-reaches had single records of very high DO (Sites 22, 7 and 6 all had DO saturations over 140% when sampled between 11 am and 2:30 pm on 8 September 2014), Site 15 in the upper-reaches had very low DO saturation (70.2%) when sampled at 3:35 pm on 21 November 2013.

For the tributary sites, with the exception of a single measurement for Site 5, all spot DO saturations were between 80 and 120%. The one measurement taken from Site 5 (at 12:05 pm on 21 November 2013), gave a DO saturation of 62.7%. As values are usually at a maximum around midday this measurement indicates that DO saturation at Site 5 is likely to be permanently below the guideline value.

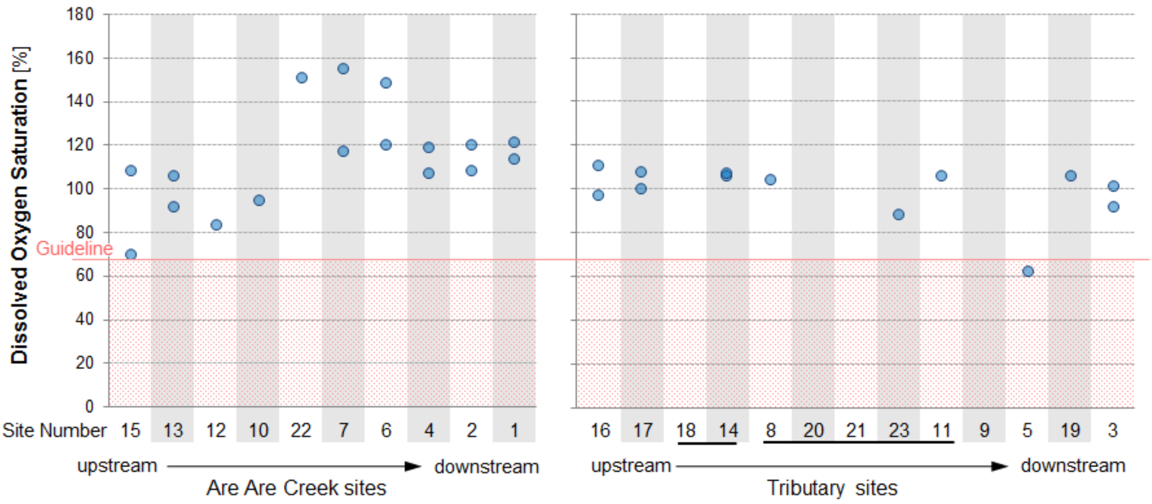


Figure 15: Dissolved Oxygen saturation measured during the study. The graphs show all measurements for sites along Are Are Creek and its tributary streams in a downstream direction. Underlined sites are located on the same tributary stream.

3.9. pH

The pH of river water has a diurnal pattern similar to DO as it is linked to the photosynthetic activity of aquatic plants. The highest pH values are usually observed around midday when DO saturation and water temperature are also at their maximum. The monthly State of the Environment sampling at Site 2 did not show exceedances of the pH guidelines at Site 2.

During the additional monitoring, as part of the study, pH measurements at sites on the mainstem and tributaries ranged widely between the upper and lower guideline levels of 7.8 and 6.7. Nevertheless, only one pH measurement fell below the lower guideline level: that taken at Site 23 (Sneider's Creek beside SH6) with a pH of 6.5. Given the natural variability in pH, both spatially (due to geology and soils) and temporally, it is difficult to identify trends using spot data, but the measurements for Site 23 did seem unusually low (6.5, 6.7 and 6.8), given the higher pH levels at the sites immediately upstream (Site 21) and downstream (Site 11) on Sneider's Creek. pH measurements of 6.7 were also recorded at Sites 12 (on three of four occasions sampled). Although this site is on the mainstem, it is geographically close to Site 23.

Downstream of Site 12 the pH increases along the mainstem. This is most likely the result of increased photosynthetic activity of aquatic plants as Are Are Creek widens and more sunlight reaches the stream bed. Some of the highest pH levels were observed in the lower tributaries, particularly Site 3.

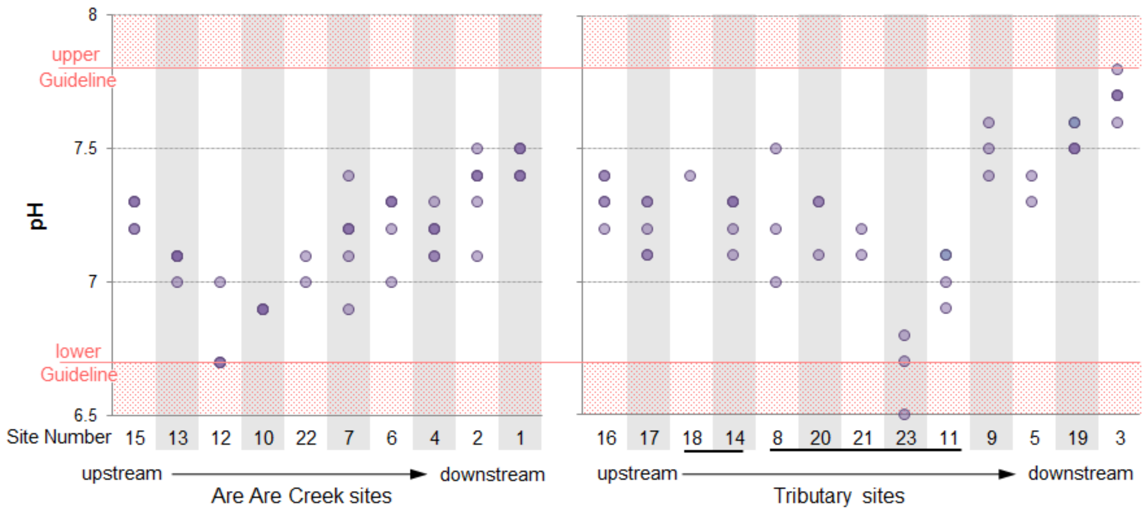


Figure 16: pH measurements at the study sites. The graphs show all measurements for sites along Are Are Creek and its tributary streams in a downstream direction. Underlined sites are located on the same tributary stream.

4. Summary and Discussion

An overview of the occurrence of elevated levels of indicator bacteria, nutrient concentrations and turbidity at the individual study sites is given in Table 3.

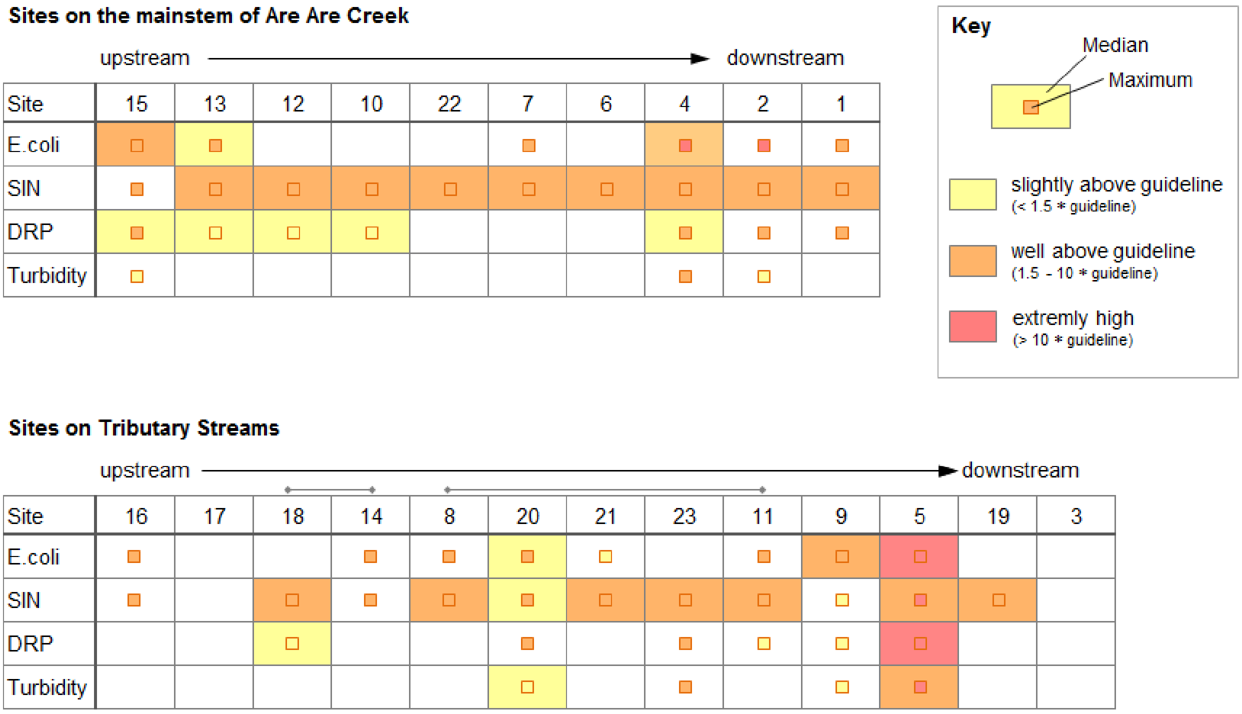


Table 3: Guideline exceedances of median and maximum values at the individual study sites.

E.coli concentrations were generally lowest in the mid reaches of Are Are Creek. The consistently very high E. coli levels in tributary Site 5 caused elevated levels in Are Are Creek downstream (Sites 4 and 2), despite the considerably lower tributary flow compared to Are Are Creek. Overall Site 5 had the worst water quality of all sites monitored as part of the study. DRP and SIN concentrations were exceptionally high and the water was very turbid. This sparked further investigations into the causes. With the help of the land owner it was discovered that sewage from a septic tank was flowing into the stream. Animal effluent and leachate from a silage pad were found to be additional sources. The sewage system is currently being replaced and works to eliminate the other sources are also being carried out. Once these works are complete, the area will be sampled again in order to monitor the effectiveness of the remedies. With the elimination of these sources, water quality in the lower Are Are Creek is likely to improve significantly.

Upstream of the Site 5 tributary elevated E. coli concentrations were mostly the result of livestock with direct access to the waterways, either at the sampling site or in reaches upstream. There are several factors influencing the impact stock access has on the water quality of the stream. These include the type of livestock; the stock density and the amount of time stock have been on a particular paddock. For example when a comparatively large number of sheep is confined to a relatively small paddock, the impact on water quality can be substantial, particularly for smaller waterways. An example is Site 15, when sampled on the 15 May 2014 (Figure 17). High E. coli concentrations at Site 20 on the 5 June 2014, on the other hand, are a result of a prolonged period of grazing by a similar number of sheep on a larger paddock. The number of sheep with access to the waterway upstream of Site 3 was very small (10 sheep) resulting in negligible impacts on water quality.

Direct livestock access might also explain the slightly higher DRP concentrations in the upper catchment and occasionally high DRP levels in some of the tributaries. The relationship between stock access and DRP concentrations is less clear, however, when compared to the impact of stock access on E. coli concentrations. Some of the DRP is likely to originate from inflowing groundwater or subsurface flow. The flow data provide an indication of upwelling groundwater, particularly in the mid and lower reaches.

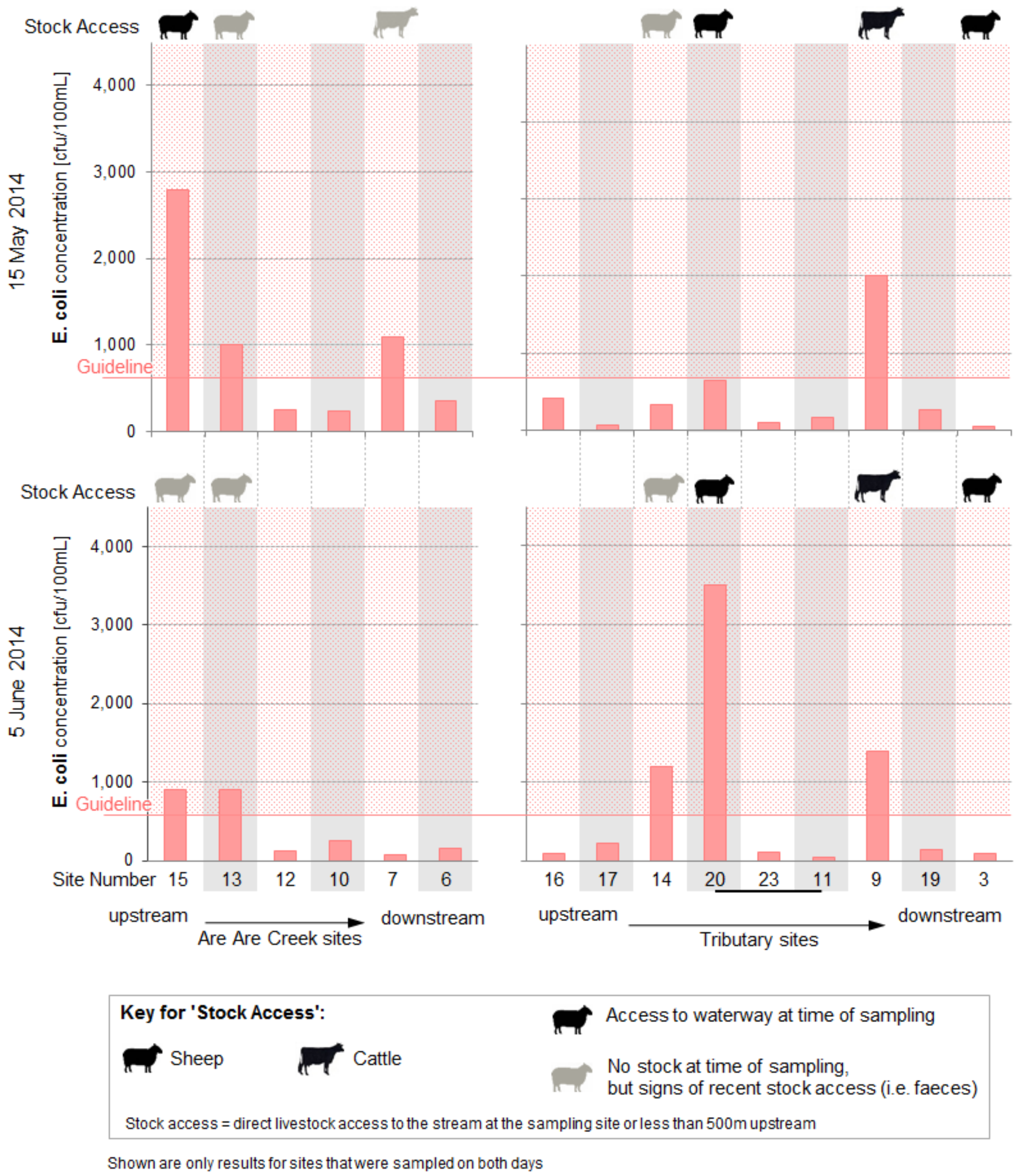


Figure 17: E. coli concentrations and direct livestock access to the waterways at sites sampled on two sampling occasions.

SIN concentrations in the mainstem of Are Are Creek were generally quite high; except for the uppermost reach (Site 15) all sites had SIN levels above the guideline value. The consistently elevated SIN concentrations observed in Are Are Creek in the mid and lower reaches (Figure 8) indicate that the source was leachate from the surrounding pastoral land entering the creek as subsurface and groundwater inflow, rather than direct inputs. This is a common occurrence for waterways with substantial areas of pastoral land cover in the catchment and can be observed throughout the region [2]. In the tributary streams SIN concentrations were significantly more variable, which suggests that at least in some of the streams, direct inputs (i.e. in the form of animal faeces) played a greater role.

The high nutrient concentrations in Are Are Creek caused substantial growth of algae on the stream bed. Photosynthetic activity of these aquatic plants caused water in the mid-reaches to become supersaturated with dissolved oxygen on some occasions. These afternoon maxima are likely to be followed by low night-time saturations which can be detrimental to fish and aquatic insects. Processes such as the breakdown of organic material (i.e. animal droppings) will further reduce dissolved oxygen concentrations. However, 24-hour sampling to plot diurnal highs and lows would be required to confirm this. The lack of shading from tall riparian vegetation aids the growth of aquatic plants as more sunlight reaches the stream bed. This is also contributing to high summer water temperatures observed at some of the sites.

The water in Are Are Creek and its tributaries was generally clear with only occasionally high turbidy at the majority of sites. Only Sites 5 and 20 had turbidites consistently above the guideline. As mentioned above sewage was causing the water to be very turbid at Site 5. The slightly elevated turbidity of Site 20 was most likely linked to a ford crossing less than 500m upstream, just downstream of Site 8.

The sites with the best water quality were Site 3 and Site 17. The entire catchment of the Site 3 tributary is covered in mature pine forest and a small number of sheep have access to the waterway upstream of the sampling location. None of the parameters analysed as part of this study were exceeding guideline values at this site, but the water did have an unusually high pH. Similarly elevated pH could be observed at Site 19 located on a tributary largely draining the same pine forest and it is possible that lime application to this production forest might be responsible. The Site 17 tributary also has large parts of the catchment planted in pine forest, but lowland areas are dominated by pasture. The only guideline exceedance observed at Site 17 was a high water temperature in November, most likely the result of a lack of shading vegetation on the stream banks in the reaches dominated by pastoral landuse.

At the majority of the other sites monitored in the Are Are Creek catchment guideline values for at least two parameters were exceeded. The main factors contributing to deterioration in water quality were direct livestock access, nutrient leaching into subsurface flow and groundwater, and the lack of tall riparian vegetation.

5. Acknowledgements

We would like to thank the landowners in the Are Are Creek catchment that provided access to their properties and allowed the investigation to take place. Special thanks to Bryan Phillips of Nelson Forest Ltd. for his outstanding service.

6. References

1. Marlborough District Council (2013) State of the Environment Surface Water Quality Monitoring Report, 2013. MDC Technical Report No: 13-011.

2. Marlborough District Council (2014) State of the Environment Surface Water Quality Monitoring Report, 2014. MDC Technical Report No: 14-006.

7. Appendix (Site Details)

7.1. Mainstem of Are Are Creek

Site 15

Upper mainstem, upstream of first tributary; E: 1664245, N: 5414986

Stream runs through pasture, with no riparian buffer zone. Although fenced on one side, stock (sheep) access, or evidence of stock access (trampled banks, grazed riparian grass) was noted on most sampling occasions, with high stock densities observed during the May 2014 sampling trip.

Water was usually slightly turbid, with a high proportion of the bed covered with fine sediment. The channel was narrow and relatively deep.

Figure 18: Site 15 on 21 November 2013 (left) and looking upstream on the same day (right).

Site 13

Upper mainstem, upstream of largest left-bank tributary; E: 1664065, N: 5413758

Stream runs through pasture, and although it is fenced on both sides, sheep access to the banks and channel was observed on two occasions, and evidence of recent sheep access (faeces and hoof-prints) was present on a further two occasions. The riparian zone was grazed or long grass on both banks, with significant bank erosion occurring over the winter months.

The stream channel supported large growths of aquatic plants or algae during the warmer summer months, and on several occasions a large proportion of the bed was covered by fine sediments. The water was observed to be clear or slightly turbid on all six occasions.

Figure 19: Site 13 on 6 March 2014 (left) and looking upstream on 8 September 2014 (right).

Site 12

Mid-mainstem, downstream of largest left bank tributary, but upstream of Sneider's Creek (largest right bank tributary); E: 1664385, N: 5413128

No stock access observed. Adjacent land use is pasture (beef). The riparian zones on both banks contain long grasses, predominantly. At least 50% of the bed was covered by algae on all four sampling occasions, with a small amount of fine sediment (5% cover) observed on three occasions. Some emergent aquatic plants were present in March 2014 (10% cover). The water was clear on all four occasions.

Figure 20: Site 12, looking upstream on 6 March 2014.

Site 10

Mid-mainstem, downstream of Sneider's Creek tributary; E: 1664644, N: 5412883

No stock access observed. Adjacent land use is pasture (beef and sheep). The riparian zones on both banks contain long grasses, predominantly. 80 to 90% of the bed was covered by algae on all four sampling occasions, with some fine sediment (5 – 30% cover) also observed.

Figure 21: Site 10 on 6 March 2014

Site 22

Mid-mainstem; E: 1665142, N: 5412170

No stock access was observed at the times of sampling, but there was evidence of stock access on previous occasions. The adjacent land use was pasture (beef cattle), and the riparian zones of both banks comprised short grasses. Long brown filamentous algae covered approximately 95% and 60% of the bed in June and September, respectively. In September 2014, fine sediment covered 70% of the bed.

Figure 22: Site 22, erosion on left bank (left) and looking downstream (right) on 8 September 2014

Site 7

Mid-mainstem; E: 1665539, N: 5411287

Stock were not observed on the river banks or in the river on any of the six sampling occasions, but the presence of hoof-prints on the banks and bed, and dried cattle faeces, suggested that recent access by cattle had occurred prior to sampling in November 2013 and March, May and September 2014. The adjacent land use was pasture (beef cattle), and the riparian zones of both banks comprised grazed grasses. Coverage of the river bed by algal mats and filamentous algae ranged from 50% to 95%, and submerged aquatic plants covered around 5, 20 and 50% of the bed in November 2013, March and June 2014, respectively. Fine sediment covered a proportion of the bed on each sampling occasion, with percentage cover ranging from 5% in November 2013 to 60% in March 2014.


Figure 23: Site 7 on 6 March 2014 (left - note stock trampling) and 8 September 2014.

Site 6

Mid-mainstem; E: 1666173, N: 5410253

The adjacent land use was mainly pasture (dairy), with some vineyards. The riparian zone on both banks comprised medium to long grasses (grazed), with some patches of bare earth. No stock access to the channel was observed, but evidence of prior access by cows was noted in November 2013. It was also noted that some run-off from adjacent paddocks is likely to have occurred via the old stock crossing upstream of the bridge (see photograph below). Periphyton was estimated to cover at least 70% of the bed on all five occasions (predominantly filamentous algae on three occasions, and algal mats on two), with 10% cover by submerged macrophytes also recorded in March 2014. Coverage by fine sediments ranged from 10 to 40%.


Figure 24: Site 6, looking upstream on 21 November 2013 (left) and looking downstream on 6 March 2014.

Site 4

Lower mainstem, behind Kaituna sawmill; E: 1667541, N: 5409979

The land use surrounding the site was predominantly plantation pine forest, with no stock access or evidence of previous stock access on any of the sampling occasions. The riparian zone comprised long grasses, with some patches of bare earth. The bed was completely covered with periphyton in November 2013 (70% algal mats; 30% filamentous algae), with cover ranging from 40 to 85% on the five subsequent sampling occasions. Macrophytes covered around 20% of the bed in March 2014 (see photograph below). Coverage by fine sediment ranged from 10 to 40%, and the water was observed to be slightly turbid on three of the six sampling occasions, in one instance due to eel activity upstream!


Figure 25: Site 4 on 6 March 2014 (left) and looking upstream on 8 September 2014 (right).

Site 2

Lower mainstem, at regular 'State of the Environment' monitoring site; E: 1668856, N: 5409173

Adjacent land use was vineyards, with the riparian zones comprising long grasses, shrubs and tall trees (3 m wide) on the true left bank, and long grasses, shrubs and small trees (3 - 5 m wide) on the true right bank. No stock access to the site was observed. A high proportion of the bed was covered with periphyton on all six occasions (80% to 100% cover; most commonly filamentous algae, but also brown algal mats). Around 5% of the bed was covered with aquatic plants in November 2013 and March 2014. 10% to 20% of the bed was estimated to be covered with fine sediments on all six occasions, however, a more extensive thin layer of fine sediment was observed to cover all or most of the bed in November and June and was incorporated into the periphyton.

Figure 26: Site 2 on 6 March 2014 and looking upstream on 21 November 2013.

Site 1

Lower mainstem, upstream of confluence with Wairau River; E: 1669515, N: 5408957

The land use adjacent to Site 1 was vineyards (with sheep-grazing at times) and reserve land. The riparian zone comprised tall trees on both banks, with some long grasses also present. Stock access (sheep) was observed in May, June and September 2014, and evidence of recent stock access was found in July 2014. No stock access was observed during the November 2013 or March 2014 sampling occasions. Periphyton was estimated to cover between 60% and 90% of the bed on all six occasions, with the dominant kind of algae varying between thin algal mats and short brown filamentous algae. A small amount of the bed (2%) was covered by cyanobacteria mats in September 2014. Aquatic plants covered a small proportion of the bed (5%) in November 2013 and March 2014. Fine sediment was observed to cover between 5% and 30% of the bed on all six occasions.

Figure 27: Site 1 on 21 November 2013 and 6 March 2014.

7.2. **Tributaries**

Site 16

Small tributary on the true left bank in the upper catchment. Site is located just upstream of the confluence with Are Are Creek. E: 1664249, N: 5414969

Flows through pasture (sheep), with no riparian buffer zone: pasture is grazed right to the edge of the stream. Has permanent fencing on true left bank, and at times, temporary fencing on true right bank. Stock access to the stream was observed in July 2014, and evidence of stock access was found in November 2013. On the other three sampling occasions, stock were excluded from the stream. Observations of periphyton and sediment cover of the bed were made in November 2013, July 2014 and September 2014: in November, 70% of the bed was covered with fine sediment, and 10% with algal mats, whereas in July and September, algae covered 80% to 100% of the bed, with 10% to 20% cover by fine sediment.

Figure 28: Site 16, looking upstream on 8 September 2014.

Site 17

Small tributary on the true right bank in the upper catchment; E: 1663588, N: 5414242

Flows through roadside reserve / residential land (beside old Okaramio Tavern), with long grasses growing in the riparian zones of both banks. No stock access was observed. The bed was commonly observed to have 5 – 10% coverage by fine sediments, and coverage by periphyton (mainly algal mats) on the five occasions varied between 20% and 80%.

Figure 29: Site 17, looking downstream on 8 September 2014.

Site 14

Largest tributary on the true left bank of the catchment. Site is located just upstream of the confluence with Are Are Creek; E: 1664080, N: 5413755

In its lower reaches, this tributary flows through pasture (sheep), with the riparian zones of both banks comprising grasses and bare earth (especially from the June 2014 sampling, onwards, when bank erosion was noted). Stock access to the stream was not observed. Sampling was not carried out at this site in March 2014, due to very low flow. Flow was also low in June 2014. Periphyton cover at the site varied, ranging from 20% to 80%, and estimates of cover by fine sediment ranged from less than 5% (July) to 40% (November).

Figure 30: Site 14, looking downstream on 6 March 2014 and looking upstream on 21 November 2013.

Site 18

Largest tributary on the true left bank of the catchment. Site is located upstream of a farm bridge.
E: 1665248, N: 5413083

The adjacent land use is pasture (sheep), with long grasses and shrubs growing in the riparian zones on both banks. No stock access was observed. Flow at the site was comparable to that in Sneider's Creek, and was higher than that observed at Site 14 (downstream, where the tributary joins with Are Are Creek). Thin brown algal mats covered approximately 90% of the bed, and fine sediments covered 10%.

Site 8

Sneider's Creek is the largest tributary on the true right bank of the catchment. This site is located 5m upstream of Cameron's Road at the ford. E: 1663304, N: 5412809

The surrounding land use is pasture (deer, sheep, cattle) and a gravel road, with a riparian buffer of long grasses and trees (2 m wide) on the true left bank, and long grasses (1 m wide) on the true right bank. Stock access to the creek was observed in November, when deer had access upstream of the site. No stock access was observed in May or July. Periphyton covered at least 80% of the bed on all three occasions, with algal mats dominant in November (90% cover) and July (80% cover), and short filamentous algae in May (90% cover). Fine sediment covered around 60% of the bed in November, but only 10% and 20% in May and July, respectively.

Figure 31: Site 8, looking downstream toward the ford (left) and looking upstream on 21 November 2013.

Site 20

Site is located on Sneider's Creek just upstream of the confluence with the Site 21 tributary. E: 1663397, N: 5413306

The adjacent land use is pasture, with grazed grass extending right down to the channel. Sheep access to the channel was observed on all three sampling occasions. Filamentous algae covered 70, 80 and 90% of the bed in May, June and July, respectively. Percentage cover by fine sediments ranged from 5 to 30%.

Site 21

This site is located on a small tributary of Sneider's Creek, just upstream of the confluence of the two.
E: 1663398, N: 5413317

The adjacent land use is pasture, with grazed grass extending right down to (and into) the channel. Sheep access to the channel was observed on both sampling occasions. Thin brown algal mats covered around 30% of the bed on both occasions, and fine sediment was present at around 5% and 40% cover of the bed in May and July, respectively.

Site 23

Site is located on Sneider's Creek (the largest tributary on the true right bank of the catchment), at the Sneider's Creek bridge on SH6. E: 1663939, N: 5413324

Adjacent and upstream land use is pasture (sheep). There is no riparian buffer zone, with grazed grass extending right down to the channel edge. On two of the three sampling occasions, sheep were observed with access to the channel upstream. High coverage by filamentous algae (90%) and fine sediment (80%) were observed in June. In July, 40% of the bed was covered with submerged macrophytes, and fine sediment covered 20% of the bed. In September, filamentous algae covered only 20% of the bed, and fine sediment was less apparent, covering only 5%.

Figure 32: Site 23, looking downstream on 8 September 2014.

Site 11

Sneider's Creek is the largest tributary on the true right bank of the catchment. Site is located just upstream of the confluence with Are Are Creek. E: 1664370, N: 5413123

At its lower end, this tributary flows through pasture (beef cattle), and there is no riparian buffer zone, with grazed grass extending right down to the channel edge. Stock access, or evidence of recent access, was observed on three of the four sampling occasions. Fine sediment covered around 80% of the bed in November, but was less evident in March, May and June 2014, when coverage was estimated at 10% or lower. In March, the channel was full of emergent macrophytes (60% cover) and filamentous algae (40% cover); in May, 60% of the channel was covered with thin brown algal mats; and in June, short brown filamentous algae covered 80% of the bed.

Figure 33: Site 11, looking upstream on 21 November 2013 and looking downstream towards the confluence with Are Are Creek on 6 March 2014.

Site 9

Small tributary on the true right bank in the mid-catchment. This site is just upstream of the confluence with Are Are Creek. E: 1664651, N: 5412866

This small tributary flows through pasture, but the riparian zones on both banks at this site support large conifers. No stock access to the channel could be seen from the site. A high proportion of the bed was covered with fine sediments on all three sampling occasions: 100% in November, 95% in May and 50% in June. Extensive periphyton cover was not observed in November or May, but around 90% of the bed was covered by filamentous algae in June.

Figure 34: Site 9, downstream of the culvert just upstream of the confluence with Are Are Creek (left) and upstream of the culvert (right) on 21 November 2014.

Site 5

Site is located on a small tributary on the true left bank that enters Are Are Creek downstream of Site 6 and upstream of Site 4. E: 1666422, N: 5410452

The adjacent land use at this site is pasture. The riparian zones on both banks contain long grasses. No stock access was observed at the site. A high proportion of the bed was covered with fine sediment on both sampling occasions: 80% in November and 100% in May. In November some filamentous algae were also present (around 30% cover). On both occasions, the water was observed to be turbid with a yellowish colouration. The site had a strong odour of cattle faeces on both occasions, which may have been coming from the yard. In May, the yard was observed to be very boggy and paddocks on the farm had large ponds on them.

Figure 35: Site 5 on 21 November 2013. The tributary a few meters downstream from Site 5 (middle) and at the confluence with Are Are Creek (right) during the investigation on 14 January 2015.

Site 19

Small tributary on the true left bank that enters Are Are Creek just upstream of Site 4. This site is located at the lower end of the tributary, just before it enters Are Are Creek. E: 1667461, N: 5409925

The land adjacent to, and just upstream of this site is pasture and plantation pine forest. The riparian zones on both banks are predominantly covered with long grasses, with some trees also present on the true left bank. The grasses obscured the channel in March and May (see photograph below), but the channel was noted to be more open in July and September as the grasses had been flattened. Stock access was not observed on any of the sampling occasions. At times, the bed had a high proportion of fine sediment (May: 50% cover; July: 50% cover; September: 80% cover). Emergent macrophytes covered almost all (95%) of the bed in March. Some periphyton cover was observed in June (30% thin mats), July (30% thin mats) and September (20% filamentous algae).


Figure 36: Site 19, looking upstream on 6 March 2014 and downstream of the road culvert on 8 September 2014.

Site 3

Small tributary on the true left bank that enters Are Are Creek just downstream of Site 4. This site is located at the lower end of the tributary, just before it enters Are Are Creek. E: 1667556, N: 5409990

This tributary flows through plantation pine forest, and both riparian zones are planted with tall trees (mainly pine). At its lower end, it flows into Are Are Creek through a culvert which directs the water down a rocky bank (see photograph below). Stock access was observed on four of the five sampling occasions, with around 10 sheep on the land upstream of the culvert. The bed was covered with fine sediment, and abundant leaf litter was also observed, probably due, at least in part, to the pool that had formed upstream of the culvert. The water was observed to be a yellowish or tannin brown colour on several occasions.


Figure 37: Site 3, looking downstream at the confluence with Are Are Creek on 8 September 2014 (left) and looking upstream of the culvert (right) on 21 November 2013.