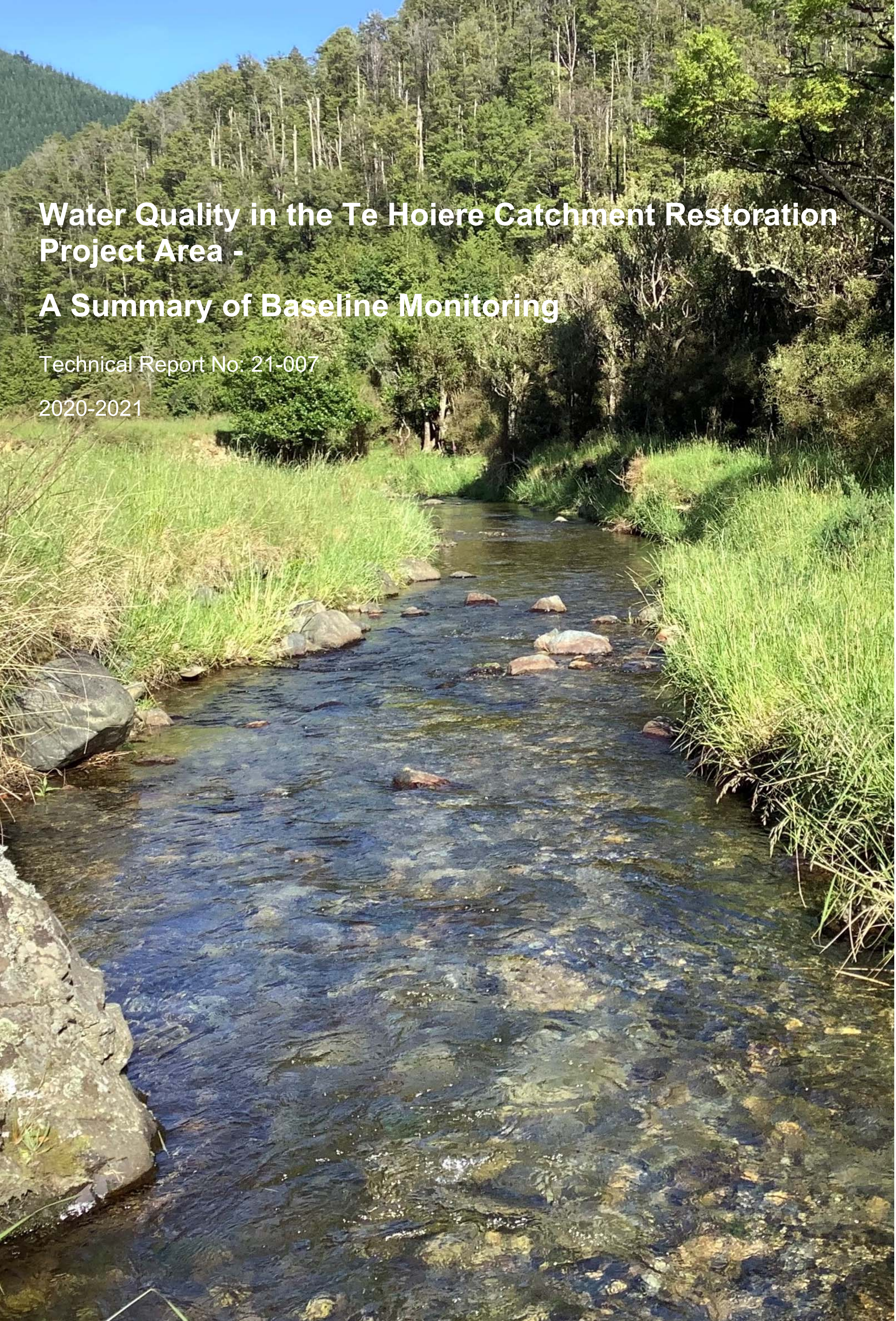
Water Quality in the Te Hoiere Catchment Restoration Project Area -

A Summary of Baseline Monitoring

Technical Report No. 21-007

2020-2021



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MDC Report No: 21-007

ISSN 1179-8119X (Online)
ISBN 978-1-99-115020-2 (Online)

File Reference/Record No: E355-021-02

November 2021

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Executive Summary

The Te Hoiere area is a Ministry of the Environment "At Risk Catchment" as well as one of the 14 Department of Conservation Ngā Awa rivers systems. It consists of several sub catchments, which drain into the lower part of the Pelorus Sound/Te Hoiere.

To gain a better understanding of baseline water quality, an extensive network of stream and river locations were monitored between August 2020 and July 2021. Monthly water samples and field observations were collected from 113 monitoring sites. Samples were analysed for Ammoniacal N, Nitrate N, DRP, E.coli, turbidity and pH. Field observations included streambank estimates of deposited fine sediment and algae cover.

Of the sub catchments monitored, the Linkwater area had generally the poorest water quality, followed by the Rai catchment. The best water quality was observed in waterways in the Tunakino and Wakamarina catchments.

The main land cover types in the Te Hoiere area are native vegetation, production forestry and pasture. The pasture was divided into two types: Te Hoiere/Pelorus pasture, which is grazed predominantly by dairy cattle and Kaituna pasture, which consists of a mixture of livestock grazing, dominated by sheep and beef. Water quality in the two pasture types differed significantly with Te Hoiere/Pelorus pasture having generally poorer water quality.

Waterways in native vegetation had low or optimal levels for most parameters monitored. The exception was elevated DRP concentrations. This points to natural sources of higher phosphorus in waterways within some parts of the Te Hoiere area. Streams in forestry dominated catchments had elevated levels for all parameters monitored, however, water quality was better than in waterways flowing through Te Hoiere/Pelorus pasture.

Rainfall generally caused increased concentrations for most contaminants.

Comparison of water quality in different sized streams revealed that smaller streams generally had the poorest water quality and should therefore be a focus for improvement actions.

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1. Introduction

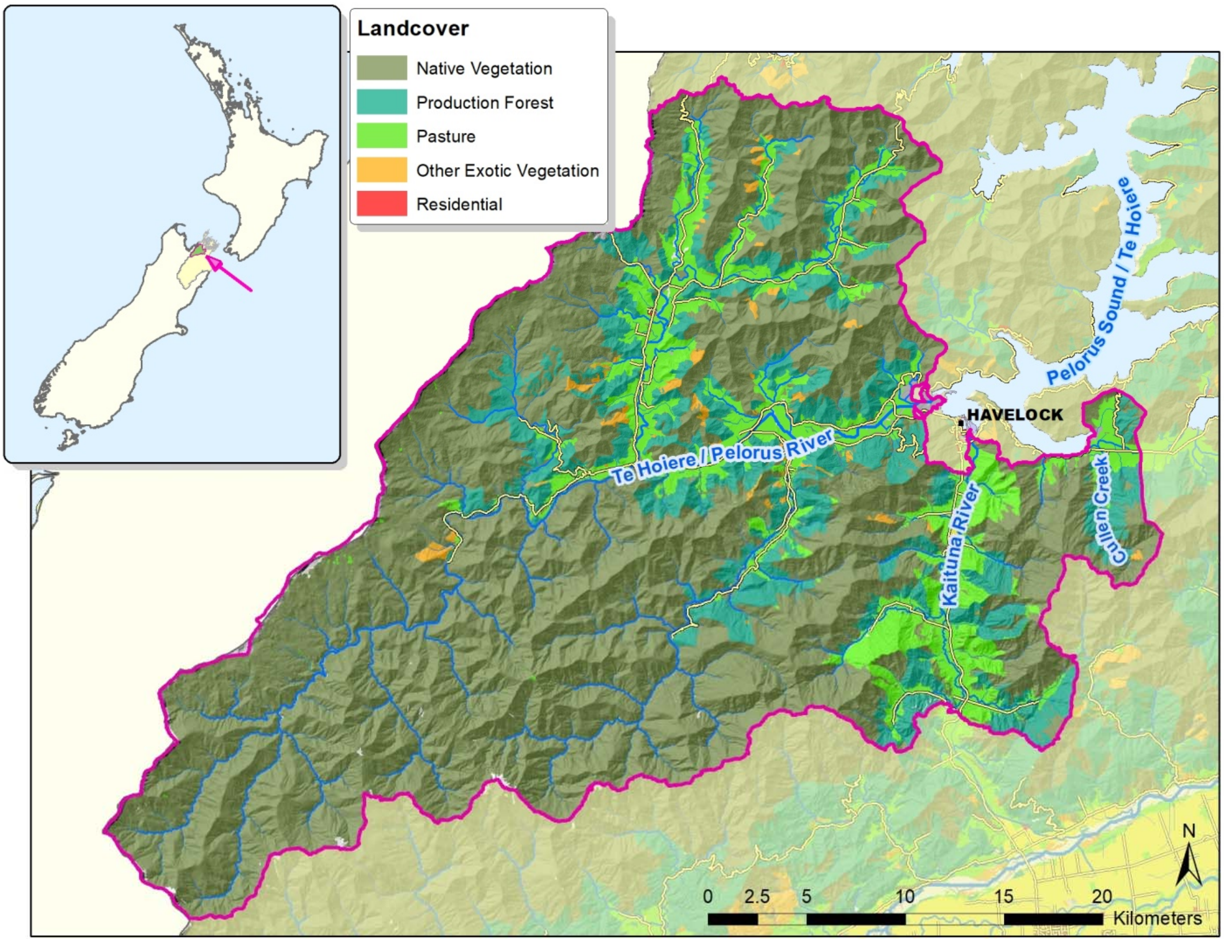


Figure 1: Location and Landover of the Te Hoiere/Pelorus Catchment Restoration Project area.

The area of the Te Hoiere Catchment Restoration Project (hereafter referred to as 'Te Hoiere Project') is located in the Northwest of the South Island's Marlborough region. It contains the catchments of several rivers, including the Te Hoiere/Pelorus River, Kaituna River and Cullen Creek. All catchments drain into the lower part of the Pelorus Sound/Te Hoiere.

The area receives between 1,500 and 2,650mm of rain annually, which represents some of the highest rainfall in the Marlborough region.

Large parts of the Te Hoiere Project area remain in native vegetation, particularly in the Ranges of the Southwest. As a result, water quality is generally good. Yet, State of the Environment monitoring has shown, that anthropogenic activities, such as pastoral land use and production forestry have caused water quality in some catchments to degrade. Subsequently, the Te Hoiere area was included in the "At Risk Catchment" programme of the Ministry of the Environment (MfE) and due to high biodiversity values, was designated as one of the 14 Ngā Awa rivers by the Department of Conservation (DoC).

In mid-2020, MfE approved funding for extensive stream water quality monitoring to provide baseline information and identify priority areas for water quality improvements. This report provides a summary of the results from this monitoring[1] .

[1] Monitoring results for individual sites are available for landowners and catchment groups.

2. Sampling Methodology

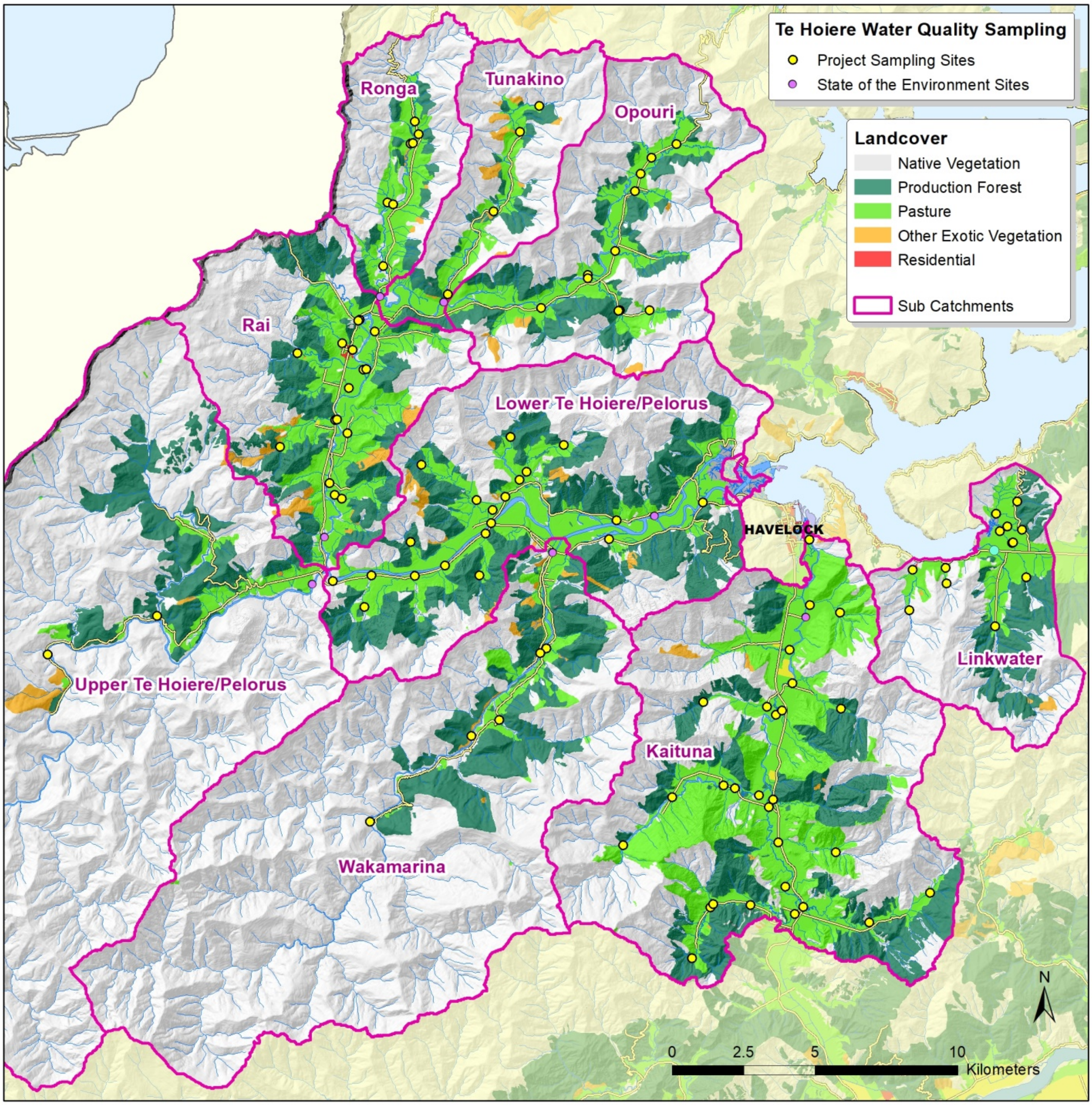


Figure 2: Te Hoiere Project and State of the Environment monitoring sites.

Over the course of a year, between August 2020 and July 2021, streams and rivers were sampled monthly at 105 sites. The number of observations per site varied between 5 and 12. The variability was caused by the addition of sites later in the programme, occasional limited access and drying out of stream reaches during the summer months.

The Te Hoiere Project area was divided into nine sub catchments. Sites within sub catchments were sampled on the same day. Samples were collected by SWE and analysed by Hill Laboratories. Field observations were recorded using Survey 123 and included stream bank estimates of algae cover and deposited fine sediment.

MDC's monthly State of the Environment water quality programme includes eight river sites located within the Te Hoiere Project area. Monitoring results from these sites collected during the project period were included in the data analysis for this report.

3. Summary or monitoring results

The following sections present a summary of the results for the different parameters monitored. The results are displayed using simplified Box and Whiskers Plots. These types of plots are ideal for showing the distribution of data for several sites in one graph. Figure 3 illustrates how Box and Whiskers Plots are created and shows examples for some of the most common data distributions.

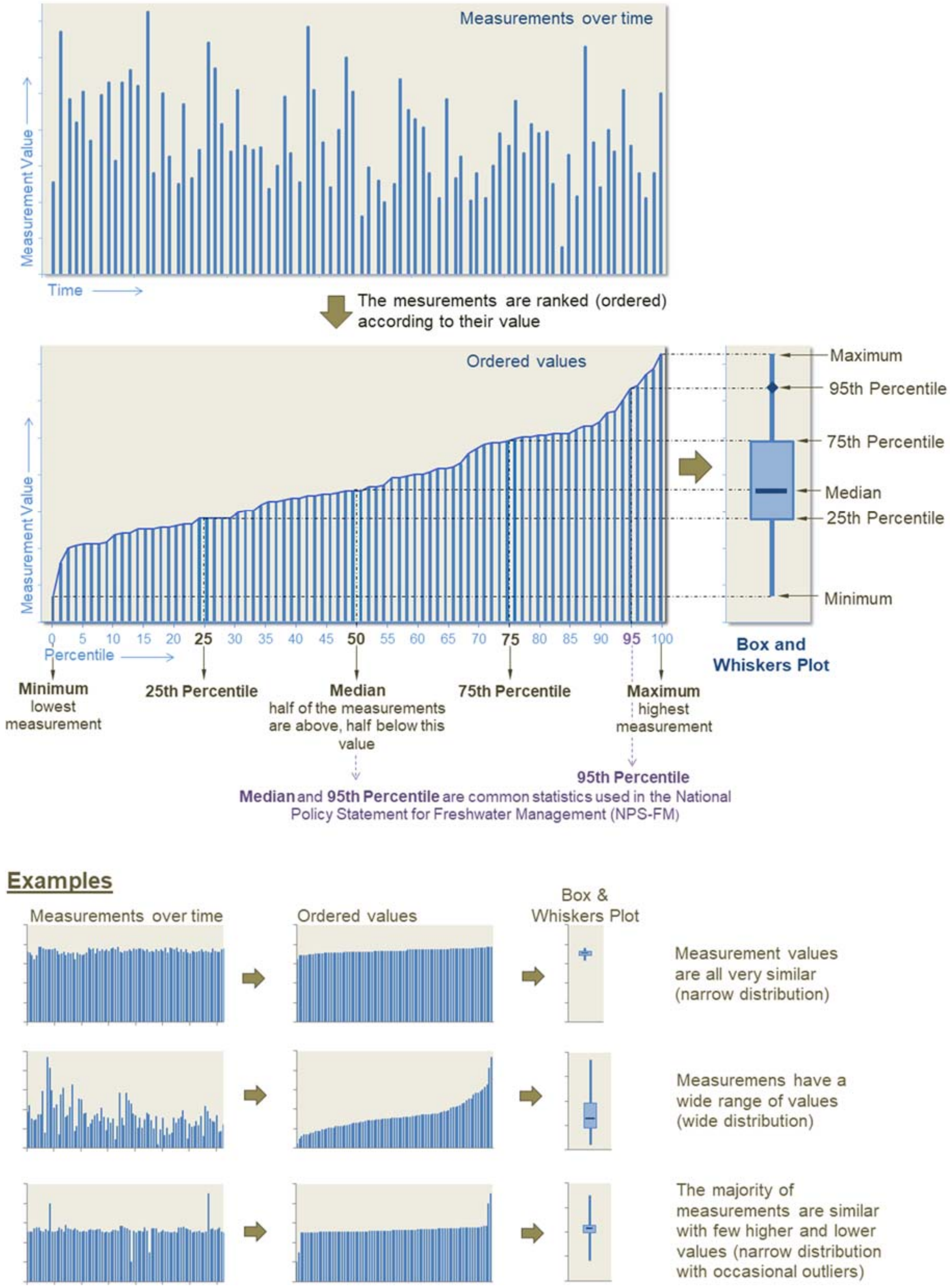


Figure 3: Creation of Box and Whiskers Plots and examples of different data distributions.

The initial summary graph in each section shows the monitoring results for each sub catchment. This can be used as a foundation for large-scale prioritisation of remediation work. The sub catchments used are based on hydrological boundaries and are shown in Figure 2.

Results are then presented for different Land cover classes. The monitoring network was designed with the purpose to identify areas where mitigation measures would provide the most benefit for water quality. Although, this included some land use based site selection, not all monitoring sites could be included in the analysis. The main land cover classes for the Te Hoiere area are native vegetation, production forestry and pasture.

The number of monitoring sites solely influenced by one land cover was very small, particularly, for non-native vegetation. The majority of streams in the Te Hoiere area have headwaters in native vegetation, flow through production forestry in the lower hills and pasture on the river-flats. This means that water quality of almost all sites was influenced by native vegetation and streams that exclusively flow through pasture were particularly rare.

Monitoring sites representative of native vegetation were comparatively easy to specify and were defined as sites with a minimum of 90% native vegetation cover. Monitoring site for the other land cover classes had to be based on the dominant anthropogenic vegetation cover, ignoring the proportion of native vegetation. The dominant land cover was defined as having to cover at least 10% of the catchment area and more than double the area of other anthropogenic land uses.

There was insufficient public information available to distinguish between different pasture types, such as dairy, beef/sheep or deer. However, initial analysis showed significant differences in water quality for pasture streams in the Kaituna catchment and the rest of the Te Hoiere area. This is due to the larger proportion of sheep and beef pasture in the Kaituna catchment. Pasture in most other sub catchments is dominated by dairy. In the Linkwater area, only one site could be classed as pasture dominated. This could not be considered representative for the area and the site was therefore excluded from the land cover analysis. Pasture was subsequently separated into two land cover classes,' Kaituna Pasture' and 'Te Hoiere/Pelorus Pasture' (Pelorus Pasture).

Unfortunately, the influence of Gorse and Broom on water quality could not be investigated. Although, areas overgrown with these invasive plants are often visible from roads, the size of these areas is comparatively small and is often intertwined with other land use types, such as production forestry and pasture.

Rainfall plays an important role in determining water quality. It causes surface run-off, which carries soil and contaminants from adjacent land areas into waterways. The higher flows also result in increased erosion of stream and river banks. Initial run-off often carries the largest amount of contaminants into rivers and streams. Therefore, relatively recent rainfall has the greatest influence on water quality. Monitoring of recreational water quality at river swimming sites in the Te Hoiere area has shown that E. coli concentrations increase during the initial rainfall, but usually return to lower levels within two days. Analysis of the influence of rainfall on water quality for the Te Hoiere Project data was therefore based on rainfall that had fallen in the 48 hours before samples were taken. Rainfall events were categorised into three classes: no rainfall, light to median rainfall (less than 10mm) and heavier rainfall events (more than 10mm). Rainfall data was taken from stations either within the sub catchment or from the nearest rainfall recorder.

Water quality was also analysed in relation to stream size. The size of a stream or river at the sampling location was based on the catchment area upstream of that point. Catchment size categories were chosen to allow a sufficient number of samples within each category for representative results. Due to the limited number of sites with larger catchments covered in native vegetation, the 'Native' land use category could not be included in this analysis.

In this report, results are generally compared against limits in the National Policy Statement for Freshwater Management (NPS-FM). Although, this provides valuable context, it is important to note that the results should not be used to determine the NPS-FM state. Monitoring of water quality as part, this project was limited to one year and many sites were not sampled every month. This does not fulfil the minimum data requirement for calculation of NPS-FM states. The exceptions are the eight sites monitored as part of the State of the Environment monitoring programme. NPS-FM states for these sites can be found in the latest Surface Water Quality SoE monitoring report on the MDC website.

3.1. Total Ammoniacal Nitrogen

Ammoniacal Nitrogen is the main form of reduced dissolved nitrogen and is one of the initial breakdown products of organic material, such as animal droppings and dead plant and animal matter. It is also the main form of nitrogen in urea fertiliser. In well-oxygenated water, bacteria quickly convert Ammoniacal Nitrogen into Nitrate Nitrogen. Elevated Ammoniacal Nitrogen concentrations are therefore an indication for large amounts of organic material or low dissolved oxygen concentrations.

High concentrations of Ammoniacal Nitrogen are toxic to aquatic organisms and the limits in the NPS-FM and proposed Marlborough Environment Plan (pMEP) are based on this toxicity. Ammoniacal Nitrogen consists of two components, only one of them, Ammonia, is toxic. The proportion of Ammonia and therefore toxicity increases with temperature and pH. For this reason, the NPS-FM requires temperature and pH adjustment of monitoring data. This adjustment could not be done for project data as water temperature was not collected. The assessment of the data against the limits is therefore only indicative.

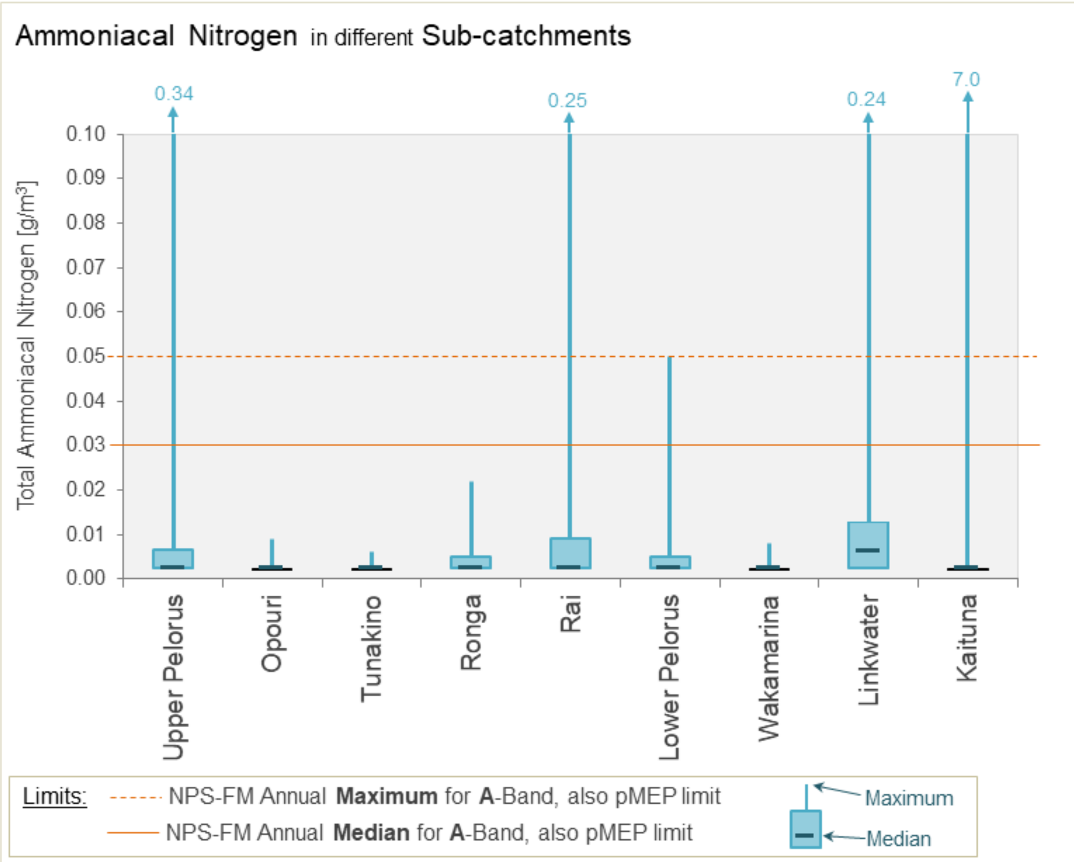


Figure 4: Total Ammoniacal Nitrogen concentrations in the sub catchments of the Te Hoiere Project area.

Figure 4 shows the Ammoniacal Nitrogen concentrations in the different sub catchments of the Te Hoiere Project area. Concentrations were generally low. The highest median concentration was measured in streams in the Linkwater catchment, but median concentrations in all sub catchments were well below the NPS-FM and pMEP limit.

The limit for maximum concentrations, however, was exceeded in waterways in a number of sub catchments, including the Upper Te Hoiere/Pelorus and Rai. Although, concentrations in the Kaituna catchment were generally very low, on one occasion, the overall highest level of Ammoniacal Nitrogen was measured in one of the tributaries of the Kaituna River. The concentration was several orders of magnitude above the limit.

The lowest levels of Ammoniacal Nitrogen were observed in streams and rivers in the Opouri, Tunakino and Wakamarina catchments.

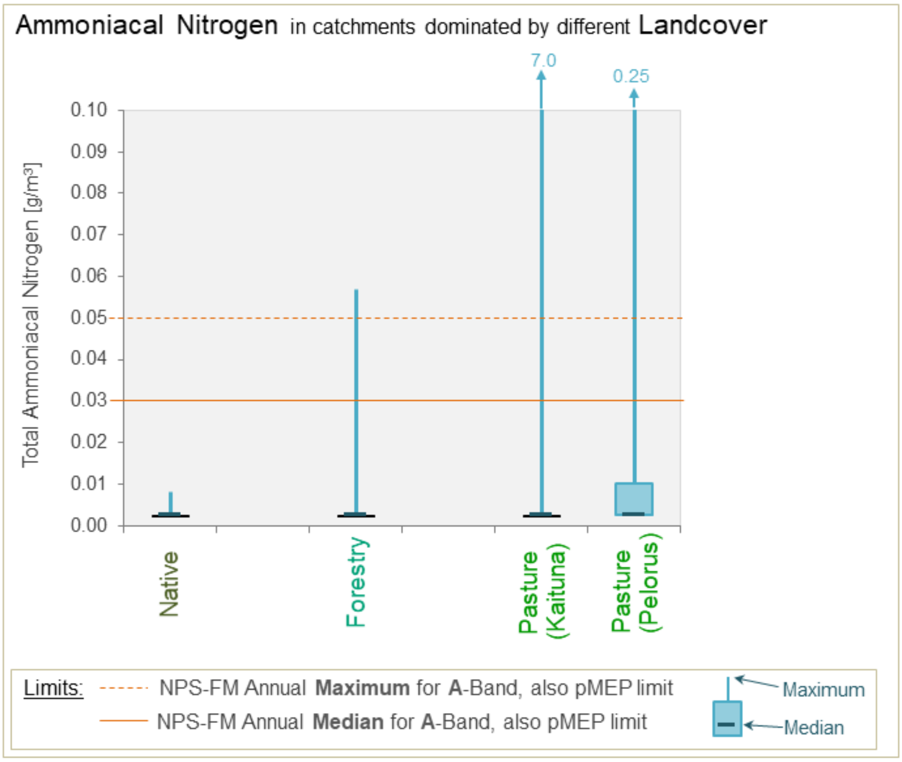


Figure 5: Total Ammoniacal Nitrogen concentrations in rivers and streams with catchments dominated by different land cover.

The Ammoniacal Nitrogen concentrations in catchments dominated by different land uses are shown in Figure 5. Streams and rivers flowing through native vegetation had consistently low concentrations. Within other land uses, Ammoniacal Nitrogen concentrations exceeded the limit for the maximum, but median concentrations stayed below toxic levels. The highest Ammoniacal Nitrogen concentrations were observed in waterways flowing through pasture dominated catchments in the Te Hoiere/Pelorus.

Figure 6 displays the influences of rainfall on Ammoniacal Nitrogen concentrations, while Figure 7 shows Ammoniacal Nitrogen concentrations in streams of different sizes (determined by catchment area).

For all land cover categories, concentrations were generally highest during heavier rainfall. This indicates that the majority of Ammoniacal Nitrogen originates from surface run-off carrying organic material, such as animal faeces and dead plant matter into waterways.

Concentrations were also consistently higher in smaller waterways. These streams carry less water and contaminants therefore have a greater effect due to a lack of sufficient dilution.

In Te Hoiere/Pelorus pasture streams, Ammoniacal Nitrogen concentrations are also elevated during dry weather conditions. A likely reason is livestock access, particularly to smaller streams.

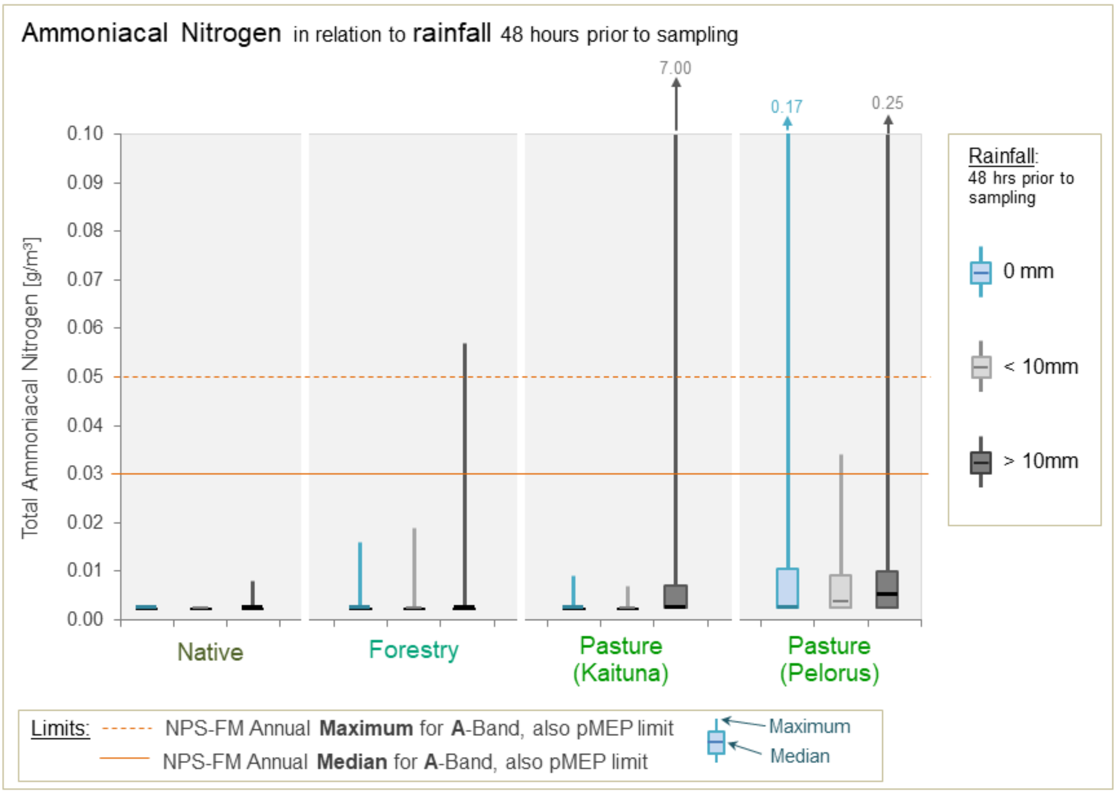


Figure 6: Total Ammoniacal Nitrogen concentrations at different rainfall totals 48hrs prior to sampling.

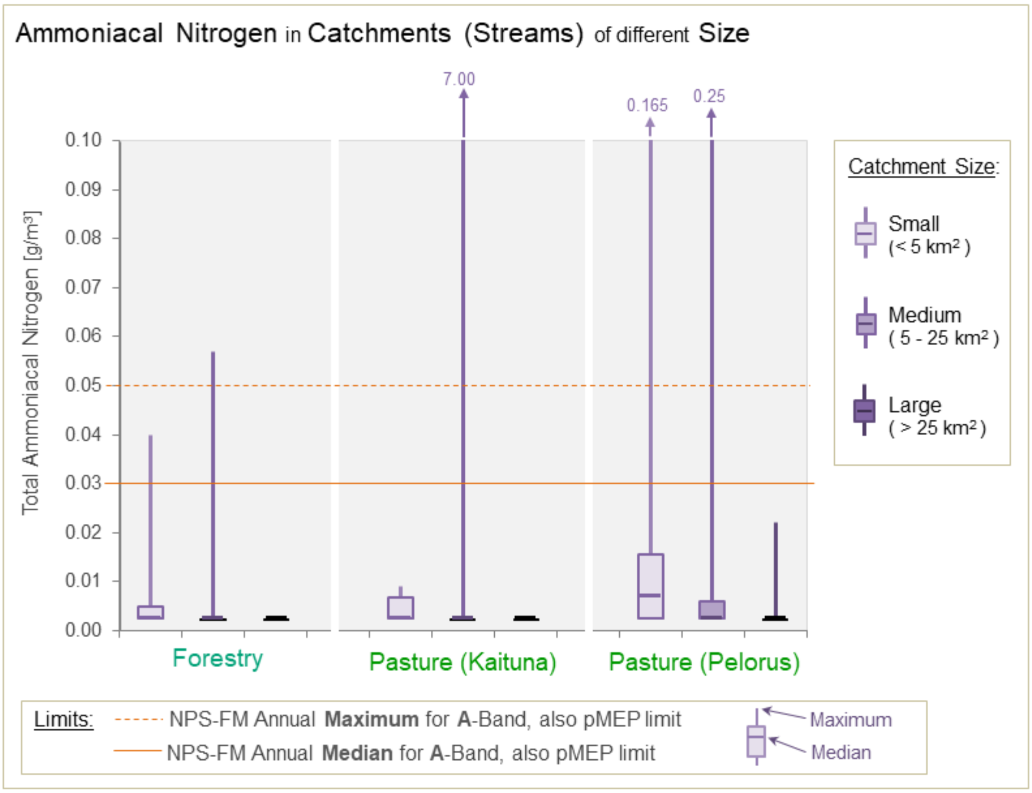


Figure 7: Total Ammoniacal Nitrogen concentrations in streams and rivers with different catchment sizes.

3.2. Nitrate Nitrogen

Nitrate is the main form of dissolved nitrogen in most waterways. It reaches rivers and streams primarily through leaching. Nitrogen fertiliser and organic nitrogen can leach into the soil and past the root zone of plants during rainfall and irrigation. Direct inputs of animal and plant matter also contribute to the Nitrate concentration in the water.

The NPS-FM and pMEP contain limits to protect aquatic animals from Nitrate toxicity[2]. However, elevated nitrogen levels impact on the aquatic ecology at concentrations well below those limits. As a main plant nutrient, nitrogen fuels the growth of algae. Currently the NPS-FM does not provide limits based on this effect.

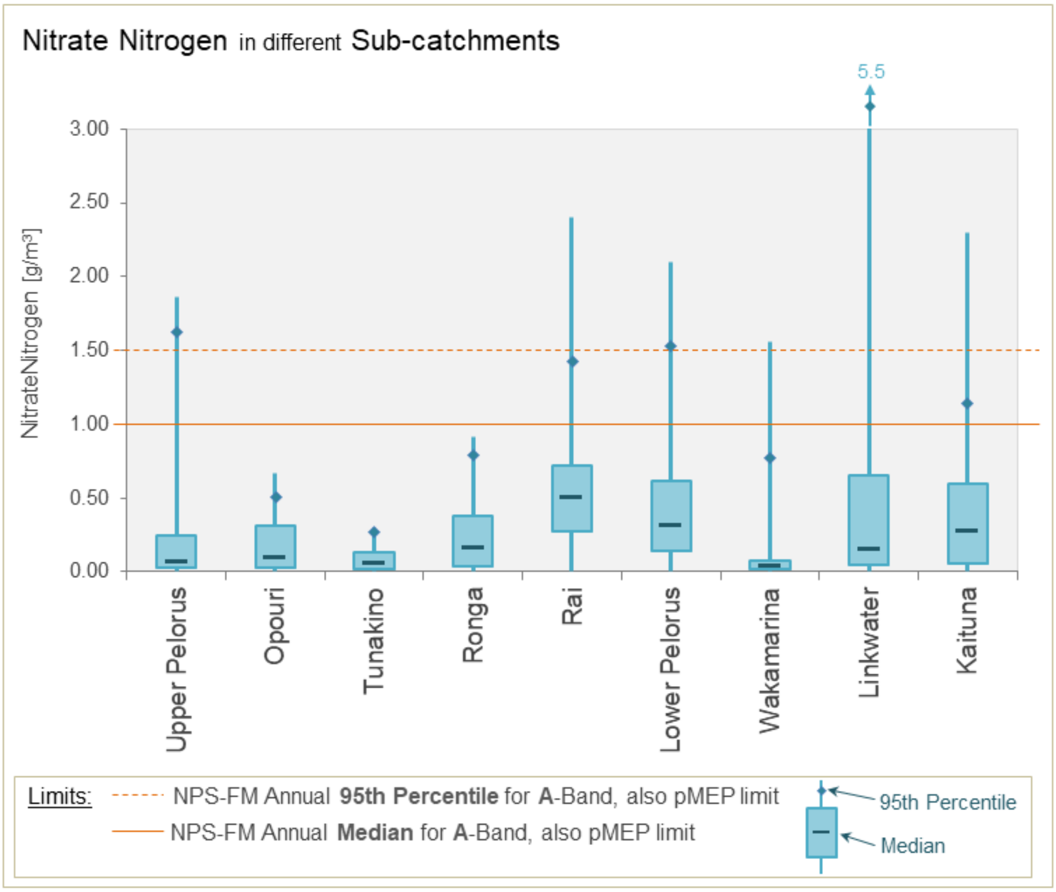


Figure 8: Nitrate Nitrogen concentrations in the sub catchments of the Te Hoiere Project area.

Median concentrations of Nitrate were highest in the Rai, Lower Te Hoiere/Pelorus and Kaituna sub catchments (Figure 8), but median levels in all sub catchments remained well below the toxicity limit.

The highest Nitrate Nitrogen concentrations were measured in samples taken from a stream in the Linkwater sub catchment. This caused the 95^{th} percentile of Nitrate concentrations for this sub catchment to exceed the NPS-FM and pMEP limit of 1.5 g/m^3 by a large margin. The 95^{th} percentile limit was also exceeded in two other sub catchments, the Upper and Lower Te Hoiere/Pelorus, but values were very close to the limit.

The lowest Nitrate concentrations were observed in streams and rivers in the Wakamarina and Tunakino catchments.

[2] Nitrate is also toxic to humans, particularly infants, but human health limits for drinking water are significantly higher.

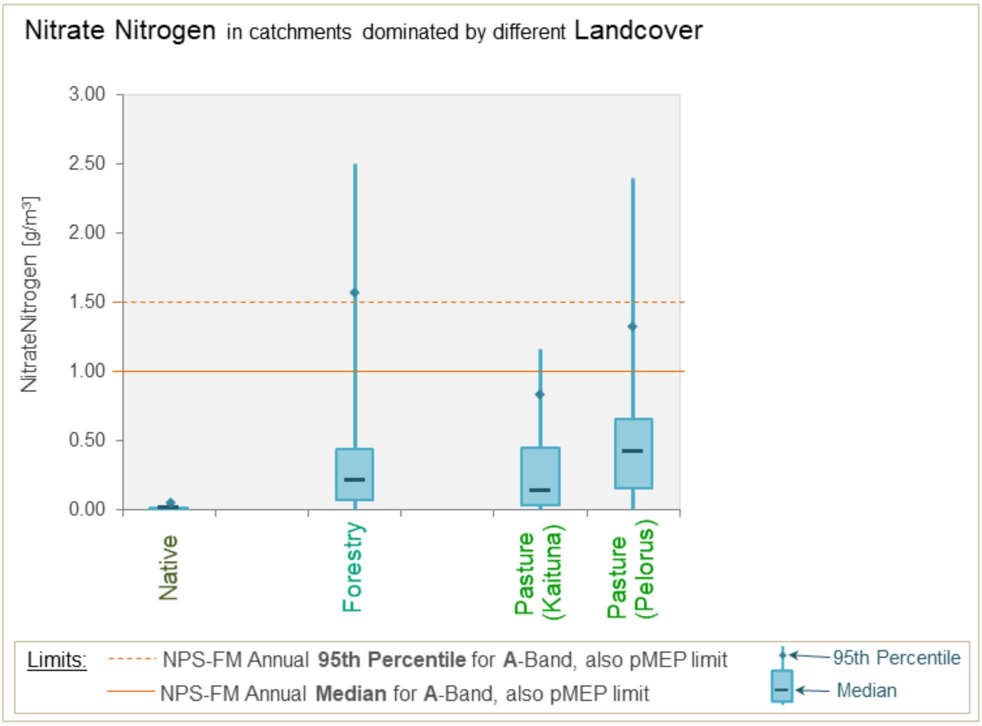


Figure 9: Nitrate Nitrogen concentrations in rivers and streams with catchments dominated by different land cover.

Comparison of Nitrate concentrations in waterways influenced by different land cover types, shows that streams flowing through native vegetation had consistently very low Nitrate levels (Figure 9). The overall highest concentrations were observed in Te Hoiere/Pelorus pasture streams. Cattle urine is a major source of nitrate leaching from pasture, but fertilisers and other sources, including direct inputs are likely to contribute.

Nitrate levels were also elevated in catchments dominated by production forestry. Further analysis showed that the highest concentrations were observed in catchments which contained some pasture (10-15%), but Nitrate Nitrogen concentrations also reached levels of 0.4 g/m^3 and higher in catchments with less than 1% or no pasture cover. Decaying slash left in and near stream channels can be a significant source of nitrogen. A possible additional source is the application of fertilizers as the majority of forestry is now in the second rotation. Nitrate inputs from natural needle litter are likely to be minor. Monitoring of streams in undisturbed mature pine forest has shown that Nitrate concentrations were similar to those in native vegetation.

Of the three anthropogenic land use types, Kaituna pasture had the lowest median Nitrate concentration. A possible reason is the dominance of sheep pasture within the Kaituna catchment. Sheep do not tend to enter waterways and nitrogen leaching from sheep pasture is generally comparatively low.

Figure 10 shows the influence of rainfall on Nitrate concentrations. Rainfall had a different effect on forestry streams, compared to streams flowing through pasture. In pasture-dominated catchments, particularly in the Te Hoiere/Pelorus, Nitrate concentrations decreased with increased rainfall due to dilution of leaching inputs at higher flows. In forestry catchments, Nitrate Nitrogen concentrations increase slightly with rainfall, pointing to direct inputs from surface run-off. Nevertheless, Nitrate concentrations were already elevated during dry weather, which point to additional nitrogen sources within the stream channel and/or leaching inputs.

Nitrate concentrations in different stream (catchment) sizes for the three anthropogenic land use types are illustrated in Figure 11. As for rainfall, there are differences between pasture and forestry. In forestry, concentrations are highest in small and medium sized streams. Again, pointing to direct inputs as the main source of nitrogen.

In pasture streams, particularly in the Te Hoiere/Pelorus, Nitrate concentrations increased with stream size. Further analysis showed that the larger waterways tended to have a greater proportion of pasture covering the catchment.

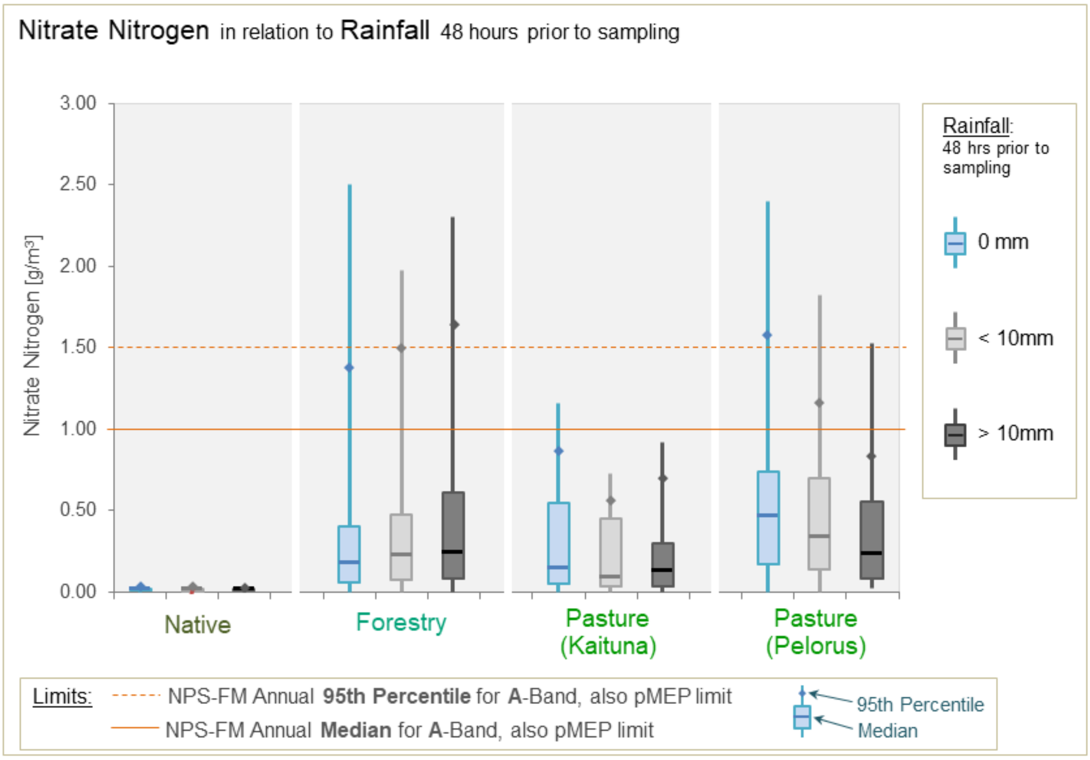


Figure 10: Nitrate Nitrogen concentrations at different rainfall totals 48hrs prior to sampling.

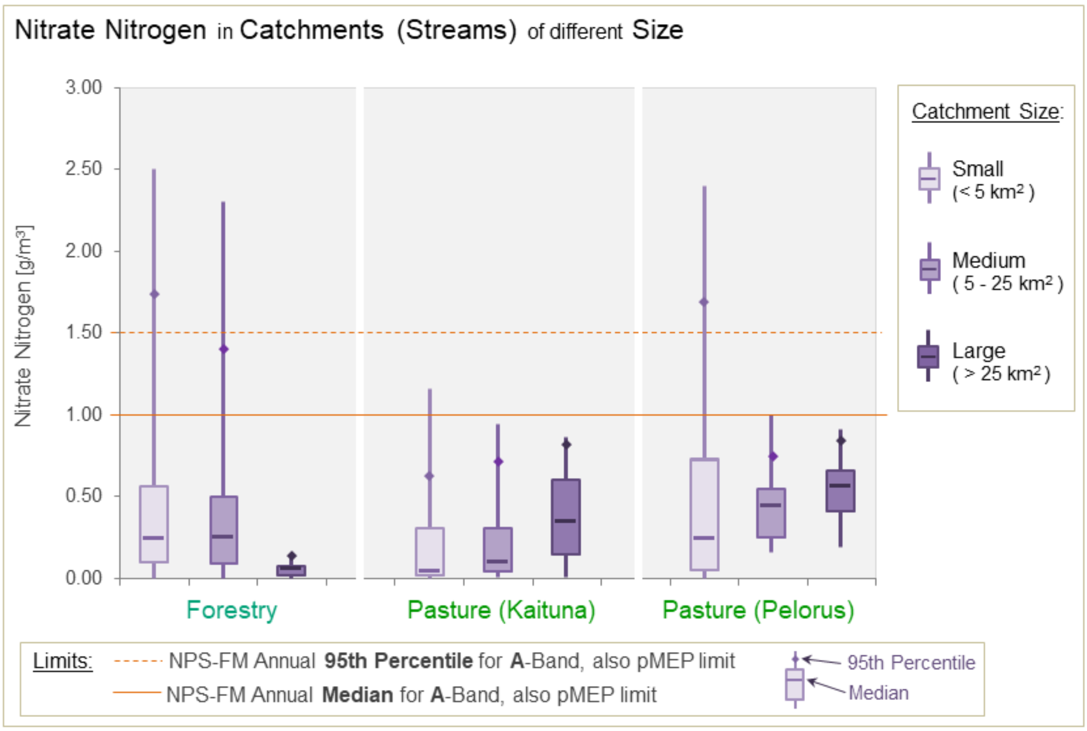


Figure 11: Nitrate Nitrogen concentrations in streams and rivers with different catchment sizes.

3.3. Dissolved Reactive Phosphorus (DRP)

Dissolved Reactive Phosphorus (DRP) is a measure for the form of phosphorus that can easily be taken up by plants. Together with elevated nitrogen concentrations, high levels of DRP can therefore result in excessive growth of algae. These algae can smother the stream bed, which results in the reduction of suitable habitat for fish and aquatic insects. Algae also cause changes in pH and dissolved oxygen that can impact on aquatic animals. From a human use perspective, excessive algae cover mainly affects amenity and recreational values of waterways.

Phosphorus is easily absorbed onto soil particles and therefore is generally less mobile than nitrogen. As a result, phosphorus concentrations in streams are often significantly lower than nitrogen concentrations and phosphorus becomes the controlling nutrient for algae growth. However, leaching of phosphorus can occur if the soil becomes saturated with nutrients due to frequent application of fertilizer.

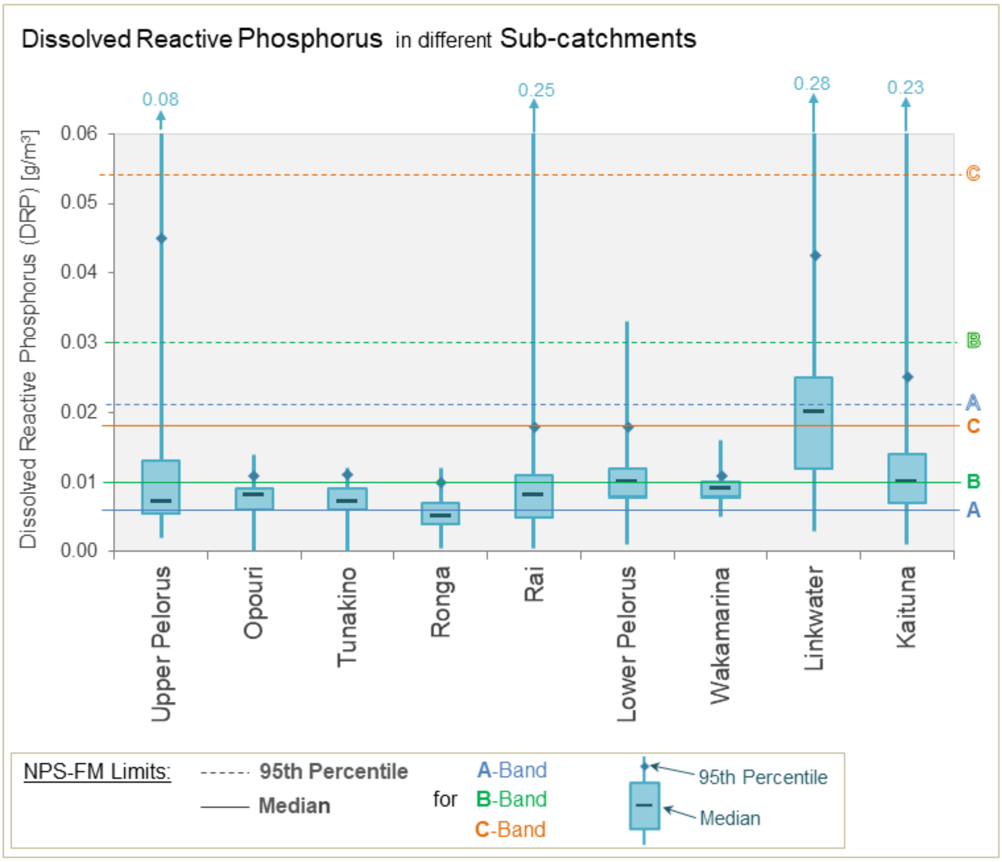


Figure 12: DRP concentrations in the sub catchments of the Te Hoiere Project area.

Figure 12 shows DRP concentrations for the individual Te Hoiere sub catchments. In relation to the measurement values, the NPS-FM limit bands are relatively narrow. This required the display of all band limits (distinguishable by different colours).

The highest DRP concentrations were observed in the Linkwater catchment. It was the only catchment with a median DRP concentration above the C-band limit. Most other sub catchments had median DRP concentrations within the B-band. Median concentrations in the lower Te Hoiere/Pelorus and Kaituna exceeded the B-band limit, but only marginally. Waterways in the Ronga catchment had the lowest DRP concentrations.

Although the median DRP concentration in the Wakamarina catchment was within the B-band, the narrow distribution of values suggests that elevated DRP levels were due to natural conditions, such as underlying geology. A large range of DRP concentrations, on the other hand, is caused by differences in land management. The catchments with the greatest range in DRP levels were Linkwater, the Upper Te Hoiere/Pelorus, Rai and Kaituna. Apart from the Rai, these are also the only catchments exceeding the 95th Percentile B-band limit.

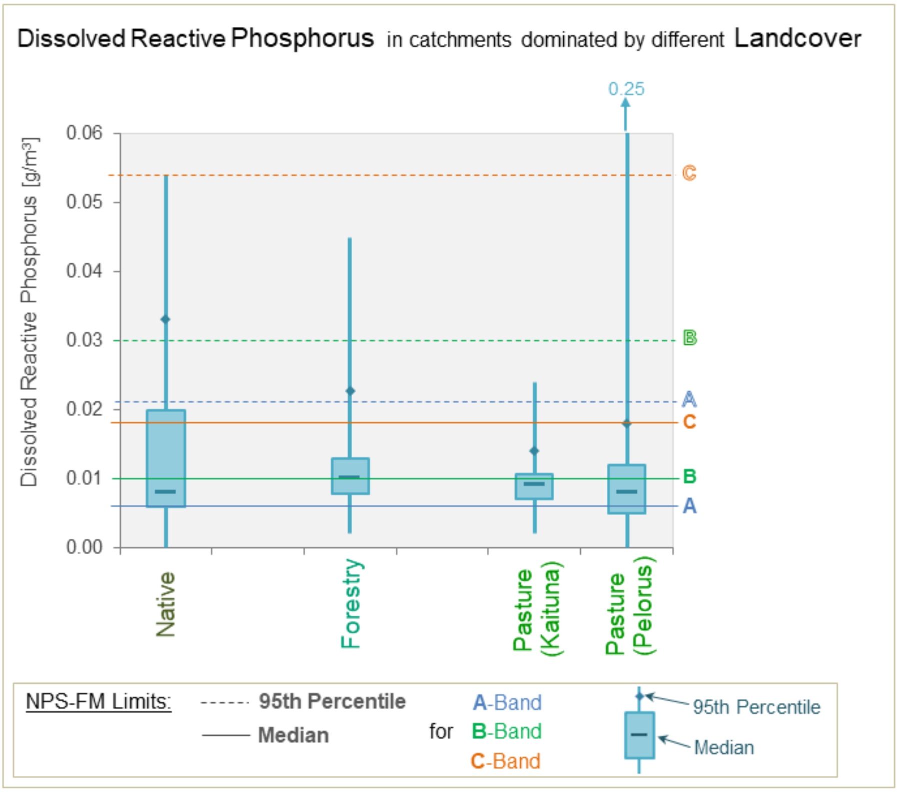


Figure 13: DRP concentrations in rivers and streams with catchments dominated by different land cover.

DRP concentrations in catchments dominated by different land cover are illustrated in Figure 13. Median concentrations are highest in forestry catchments. Of the two pasture classes, the Kaituna pasture had a higher median concentration, but streams flowing through Te Hoiere/Pelorus pasture had a greater variability in DRP, with higher extremes. However, streams in native vegetation showed the greatest variability in DRP concentrations of all land cover types. This suggests that a comparatively large proportion of DRP might originate from natural sources.

Because phosphorus binds well to soil, elevated DRP concentrations in streams are often associated with higher sediment loads. Although maximum DRP concentrations within the different land cover types were observed after heavier rainfall, median concentrations were not significantly influenced by rainfall (Figure 14). Further analysis of the Te Hoiere Project data showed a general increase in DRP with turbidity (a surrogate for suspended sediment covered in a later section)[3]. However, the correlation was statistically significant only for the Kaituna and the Lower Te Hoiere/Pelorus. In the Kaituna catchment, turbidity explained 26% of the DRP concentration, while in the Lower Te Hoiere/Pelorus 58% of DRP was associated with turbidity.

The large variation in native catchments during dry weather conditions is likely a result of differences in geology within individual sites catchments. Leaf litter and input from native and feral animals are possible contributing sources.

Figure 15 shows the DRP concentrations in different stream sizes for the three anthropogenic land cover classes. In forestry catchments, small streams had the highest DRP concentration. A possible cause is DRP released from slash, needles and/or fertiliser that is less diluted in smaller waterways.

In Kaituna pasture, DRP concentrations were similar in all stream size classes, while in Te Hoiere/Pelorus pasture medium sized streams had the highest concentrations. A possible explanation is a temporary increase in erosion of recently fenced and planted streams as the waterways revert back to naturally

[3] Separating data for the different sub catchments and using site medians provided the best results for Pearson correlation and linear regression analysis; Significance of correlation was tested using 2-tailed t-test. Log transformation did not improve the correlation.

wider stream beds. However, it is important to note that despite the temporary increase in DRP, riparian buffer zones result in better water quality in the long term.

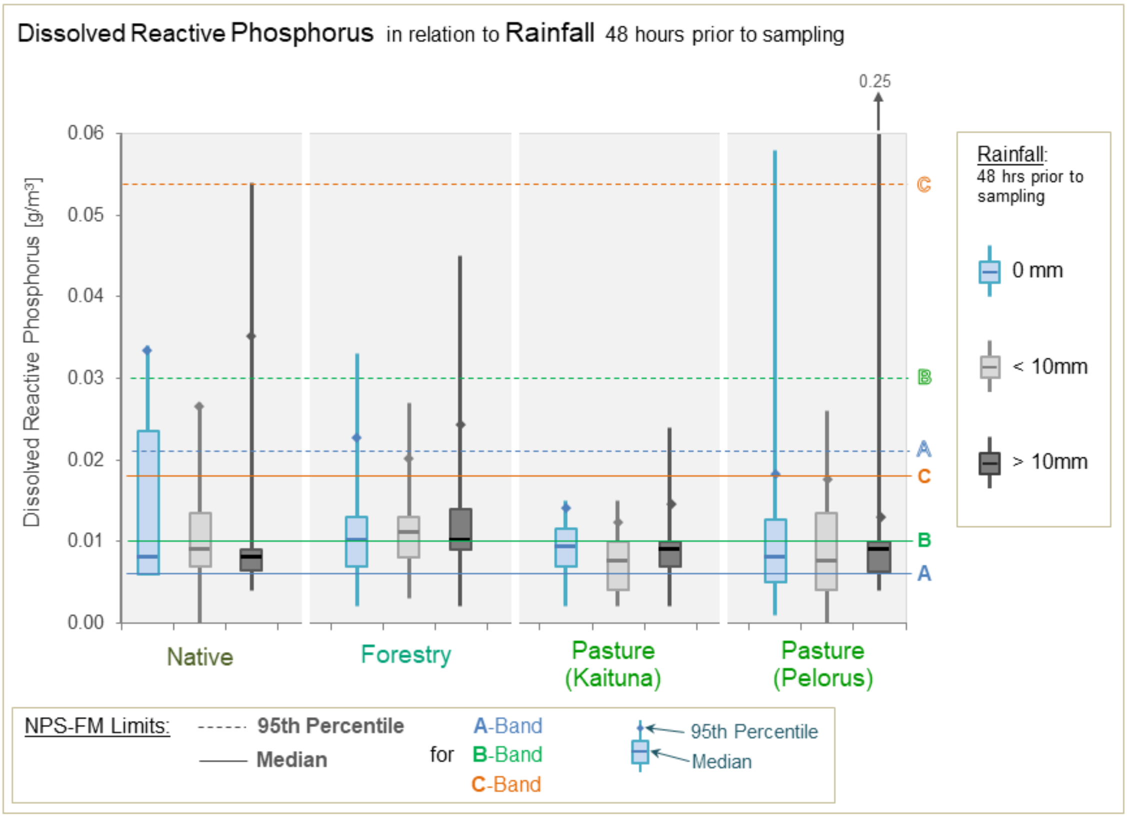


Figure 14: DRP concentrations at different rainfall totals 48hrs prior to sampling.

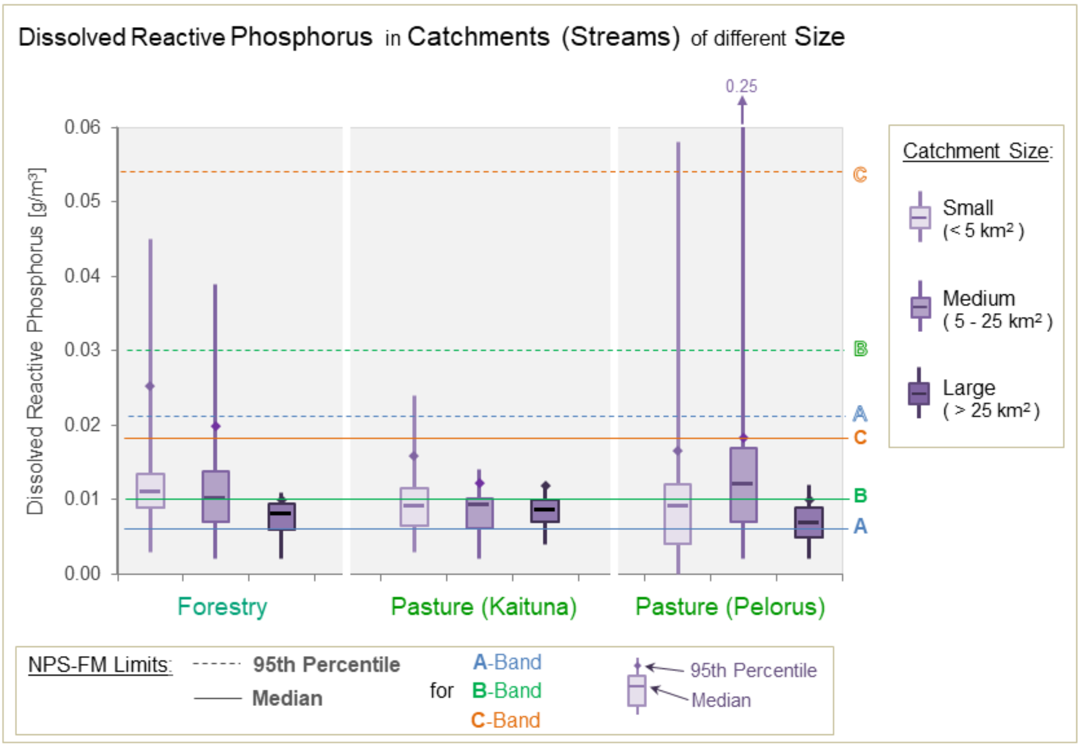


Figure 15: DRP concentrations in streams and rivers with different catchment sizes.

3.4. Turbidity

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

The NPS-FM includes limits for another surrogate measure of suspended sediment, visual clarity. Measuring visual clarity takes considerably more time than the measurement of turbidity. Due to the large number of sites sampled as part of the Te Hoiere Project, measurement of visual clarity was not feasible to be carried out at all sites and measurement of turbidity was chosen instead.

Generally, there is a good correlation between turbidity and visual clarity. Unfortunately, due to a lack of visual clarity data for the Te Hoiere area, catchment-specific conversion factors could not be determined. However, a 2019 Draft of the NPS-FM did contain turbidity limits. Analysis of visual clarity data from other parts of the region indicate that these proposed turbidity limits were equivalent to the visual clarity limits in the current NPS-FM. In this report, turbidity measurements are therefore compared against an equivalent turbidity limit based on the Draft NPS-FM.

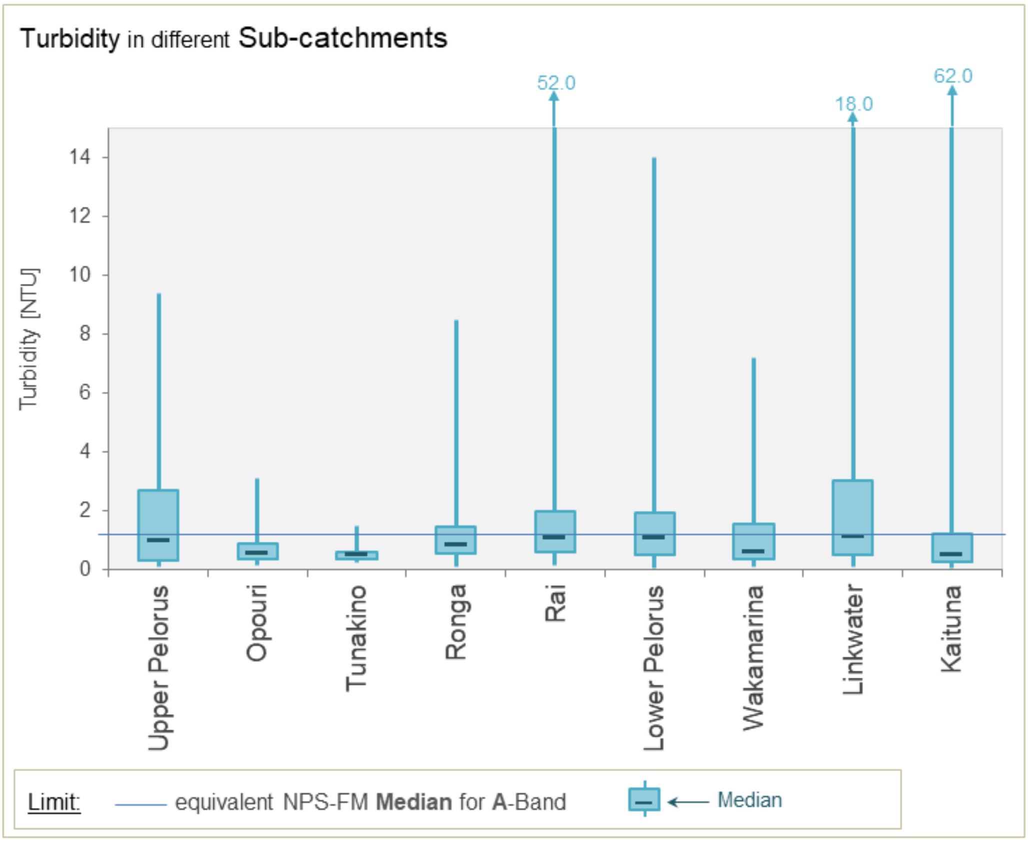


Figure 16: Turbidity in waterways in the sub catchments of the Te Hoiere Project area.

Water in the streams and rivers of the Te Hoiere Project area was generally very clear with only small amounts of suspended sediment. Turbidity was highest in the Linkwater, Rai and Lower Te Hoiere/Pelorus catchments, but none of the catchments exceeded the equivalent median turbidity limit for the A-Band. The waterways in the Tunakino catchment had particularly low turbidity values. The reason is likely the mature riparian buffer along most of the length of the Tunakino River, which stabilises banks and filters surface run-off.

Turbidity was also comparatively low in the Opouri catchment. Waterways in this catchment were most prone to drying up during the warmer months. This means that the surface flow at monitoring locations was at times disconnected from the upstream catchment by sections of subsurface flow. The stream gravels in these dry sections filter out suspended sediment and re-surfacing water is very clear.

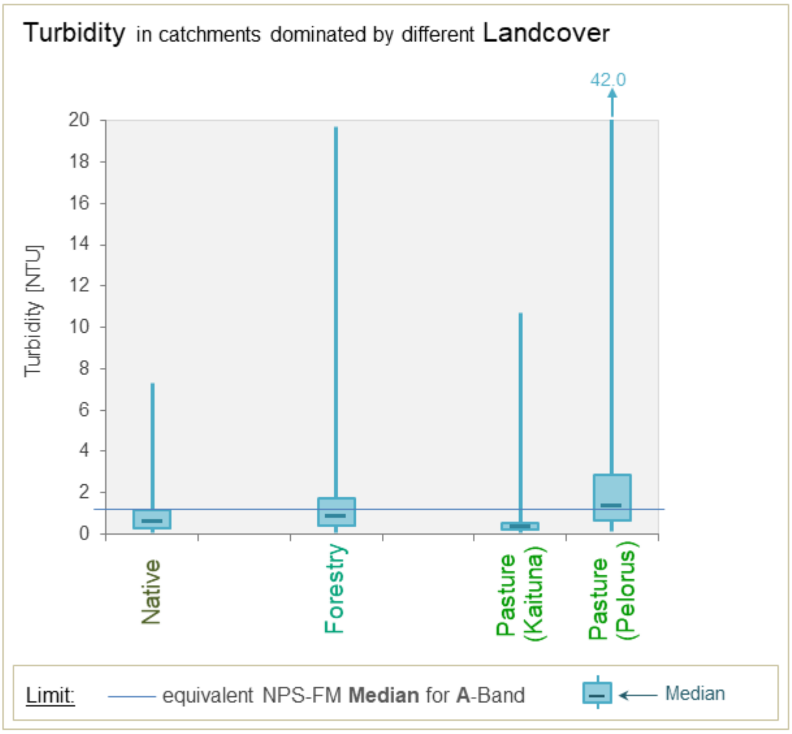


Figure 17: Turbidity in waterways in catchments dominated by different land cover

Within the four land cover classes, streams flowing through Te Hoiere/Pelorus pasture had the highest turbidity (Figure 17). Both, median and maximum values were above those of waterways influenced by other land uses. Pasture streams in the Kaituna catchment had the lowest turbidity. The difference between the two pasture classes was substantial.

Not surprisingly, turbidity was highest during heavier rainfall for all land cover classes (Figure 18). The cause is soil that is carried from bare areas of land by surface run-off and erosion of stream banks due to higher flows and water velocities. The most significant differences in turbidity due to rainfall were observed in the anthropogenic land use classes, forestry and pasture.

Turbidity in streams flowing through forestry-dominated catchments was overall slightly higher compared to waterways in native bush, but the difference was not significant. However, forestry streams had significantly higher turbidity during heavier rainfall. This suggests that in forestry catchments, land and/or streams banks are more prone to erosion.

In Te Hoiere/Pelorus pasture streams, turbidity was already elevated during dry weather. The reason could be found in the comparison of turbidity in different stream (catchment) sizes. This showed that smaller streams generally had higher sediment concentrations (Figure 19). The difference was particularly pronounced in the two pasture classes. The most likely cause is animal access. Dairy and beef cattle as well as other livestock are often not fenced off from smaller waterways. The animals can easily walk across small streams and cause substantial damage to the streambanks and stream bed, dislodging sediment that is carried downstream.

In forestry, slightly higher turbidity in smaller streams is likely due to damage by logging operations and feral animals. Although small areas of pasture were also present in some of the forestry dominated catchments, there was no correlation between turbidity and the percentage pasture for these catchments.[4]

[4] The 2-tailed t-test indicated that the correlation between median turbidity and proportion of pasture in forestry catchments was not statistical significant.

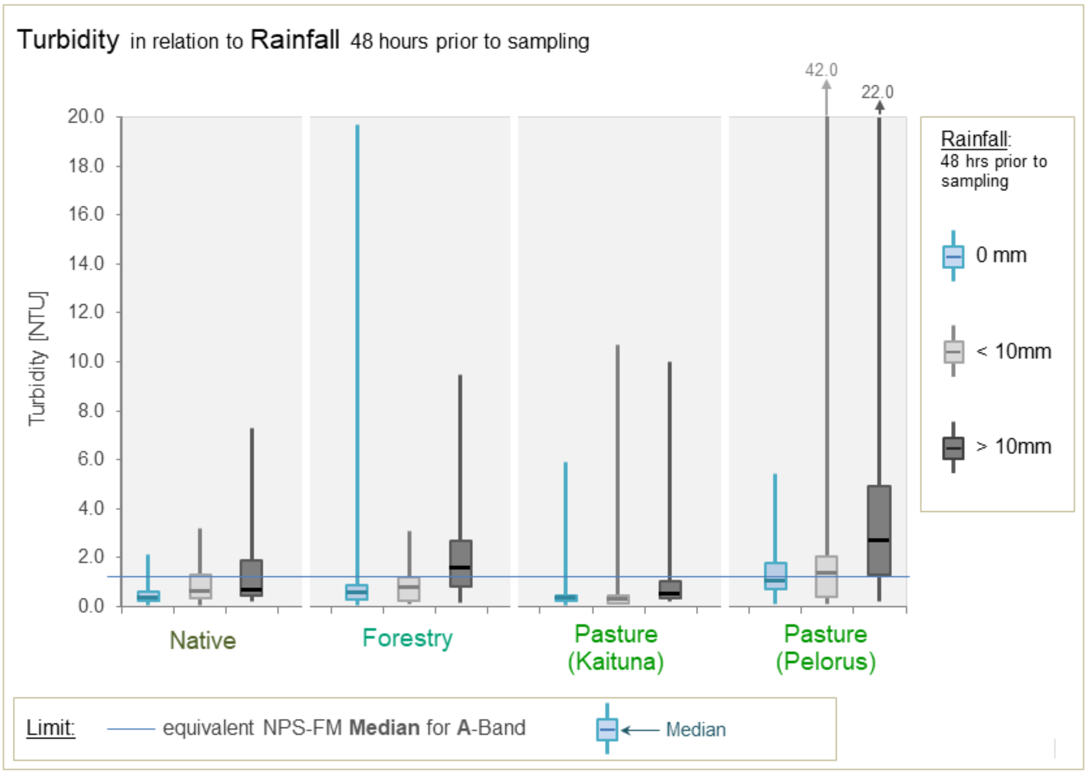


Figure 18: Turbidity at different rainfall totals 48hrs prior to sampling.

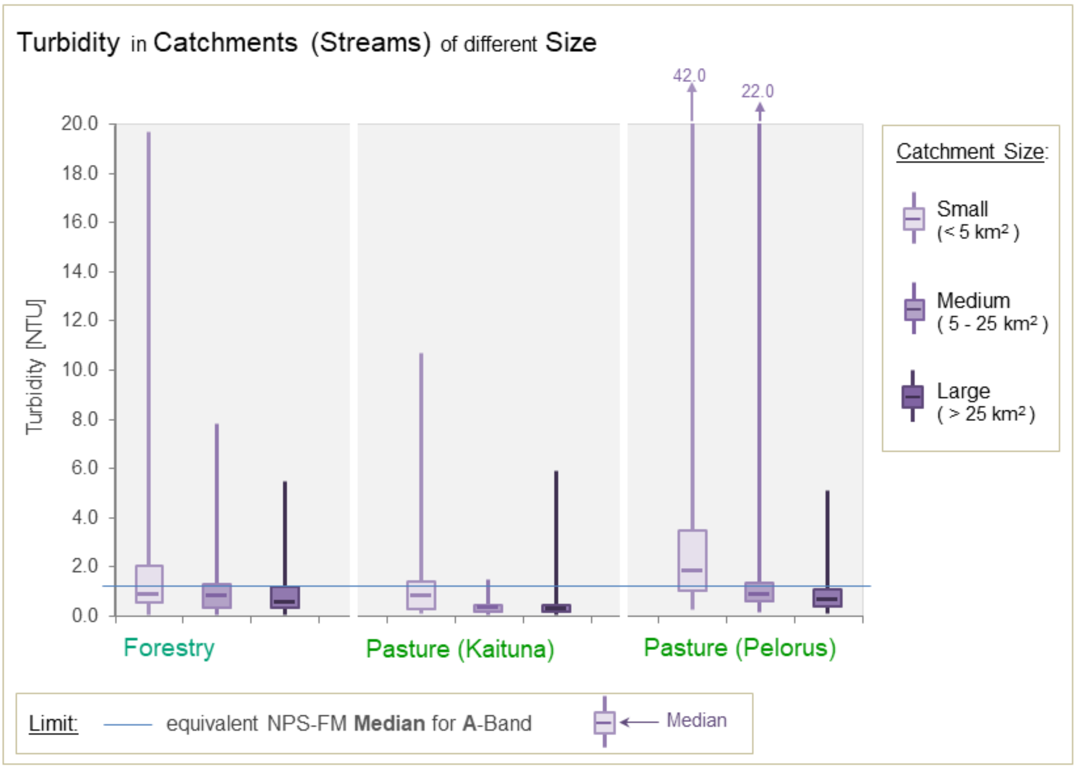


Figure 19: Turbidity in streams and rivers with different catchment sizes.

3.5. E. coli

E.coli are bacteria found in the gut of warm-blooded animals and humans. Most E. coli strains are not harmful to human health, but their presence indicates contamination with faecal matter, which might contain harmful organisms such as Campylobacter or Cryptosporidium.

The main sources of E. coli in rural streams are animal droppings, which are either deposited directly into waterways or carried there by surface run-off during rainfall or irrigation.

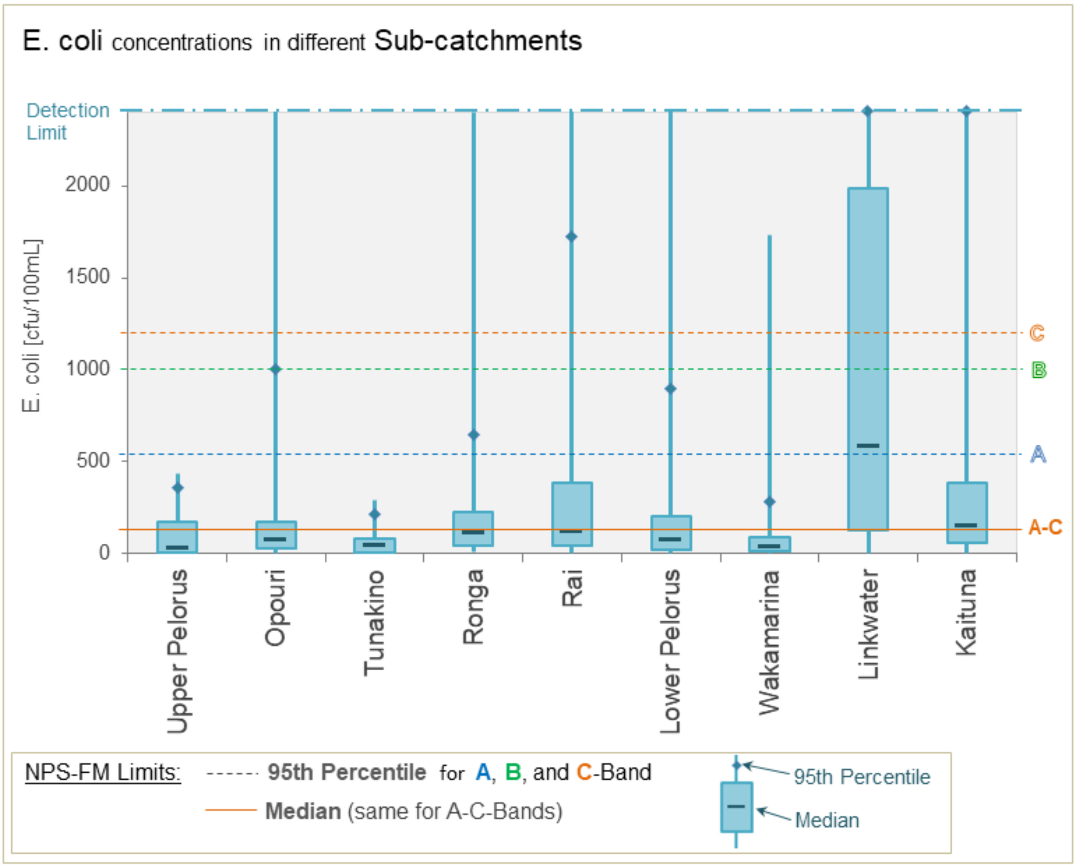


Figure 20: E. coli concentrations in the sub catchments of the Te Hoiere Project area.

E. coli concentrations in waterways within the different sub catchments are shown in Figure 20. For a number of samples with high E. coli concentrations, the laboratory was unable to provide bacteria counts above 2,420 cfu/100mL[5]. Although E. coli concentrations in other samples were measured to be up to a magnitude higher, results were cut off at the detection limit of 2,420 cfu/100mL to allow comparison of all results.

Uniquely for this parameter, NPS-FM bands A to C have the same median limit. Median E. coli concentrations in streams within the Linkwater and Kaituna catchments exceeded the limit for the A-C band. However, while Kaituna streams exceeded the median limit only marginally, the median E. coli concentration in Linkwater was more than four times that of the limit. Median E. coli concentrations in other sub catchments were within the A-C band, but came close the limit in the Rai and Ronga catchments.

The 95th percentile concentration limit for the C-band was exceeded by waterways in the Rai, Linkwater and Kaituna catchments. Rivers and streams in the Upper Te Hoiere/Pelorus, Tunakino and Wakamarina

[5] The Laboratory is required to estimate E. coli concentrations to determine an appropriate dilution series. A low estimate results in a low upper Detection Limit; (cfu = colony forming units).

catchments had the lowest E. coli concentrations. All three sub catchments had E. coli levels within the A-band.

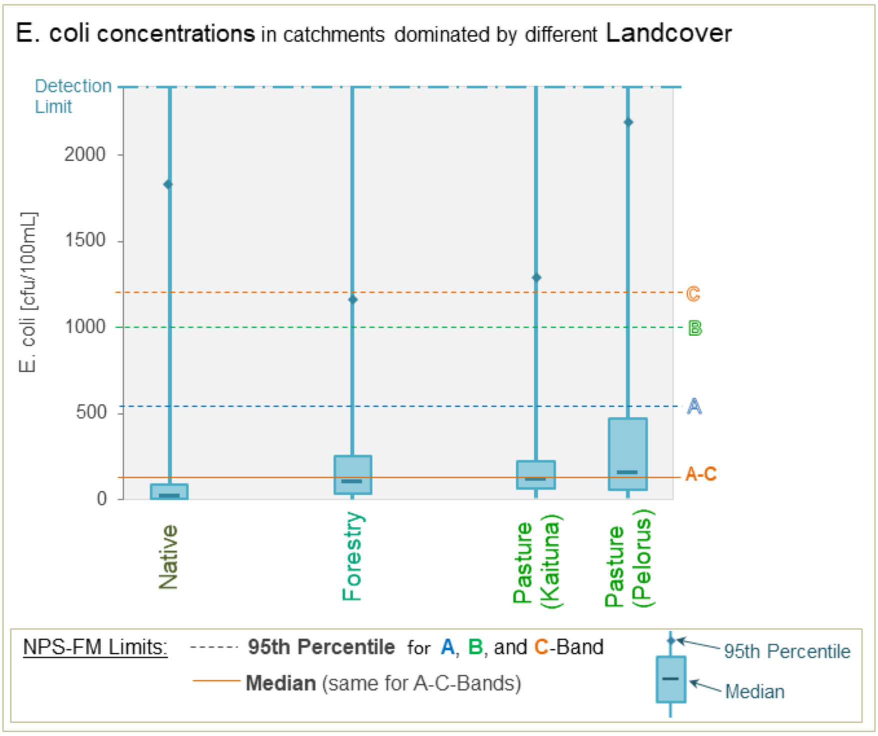


Figure 21: E. coli concentrations in rivers and streams with catchments dominated by different land cover.

E. coli concentrations were generally lowest in catchments covered by native vegetation, but occasional higher values resulted in the exceedance of the 95th percentile limit for the C-band (Figure 21). The highest E. coli levels were measured in streams and rivers flowing through pasture in the Te Hoiere Pelorus. E. coli concentrations in Kaituna pasture were slightly higher compared to forestry, but the difference was not significant. Sources of E. coli in forestry catchments include feral and native animals. Although some catchments dominated by forestry cover also included small areas of pasture, percentage pasture cover in the catchment was not the main determining factor for E. coli concentrations in the streams[6].

Figure 22 illustrates the influence of rainfall on E. coli concentrations within different land uses. There was a clear increase in E. coli concentrations with higher rainfall in streams flowing through forestry and Te Hoiere/Pelorus pasture. The lower E. coli concentrations during heavier rainfall in the Kaituna pasture are a result of dilution and 'cleaner' surface run-off following prolonged rainfall. The number of rainfall events during which sampling took place was limited and timing of sampling plays in important role as E. coli concentrations change significantly during the course of a rainfall event. The two pasture classes were not sampled on the same days and differences in rainfall data for the two pasture types could therefore be an artefact of the sampling.

Occasional high E. coli levels during dry weather in all land use classes indicate access by livestock and feral animals. Of the waterways flowing through pasture, small streams generally had the highest E. coli concentrations, particularly in the Te Hoiere/Pelorus catchment. In forestry, small and medium sized streams had similar E. coli concentrations, but as in the other two land use classes, concentrations were lowest in the larger rivers. The fact that all larger rivers had E. coli levels below the NPS-FM limits is positive, as these are the waterways used for swimming. However, other activities with a potential risk to human health, such as the harvest of Mahinga Kai, do occur in the smaller streams. Additionally,

[6] Pearson correlations showed an increase in median E. coli concentrations with an increase in the proportion of pasture in the catchment , with the 2-tailed t-test indicating statistical significance (P=0.03) for that correlation, but linear regression analysis revealed that percent pasture only explained 15% of the E. coli concentrations. Despite that, localised sources near the sampling site cannot be ruled out.

elevated E. coli concentrations indicate the presence of other contaminants and associated impacts on the ecological health of waterways. Smaller streams are often important refuges for aquatic animals.

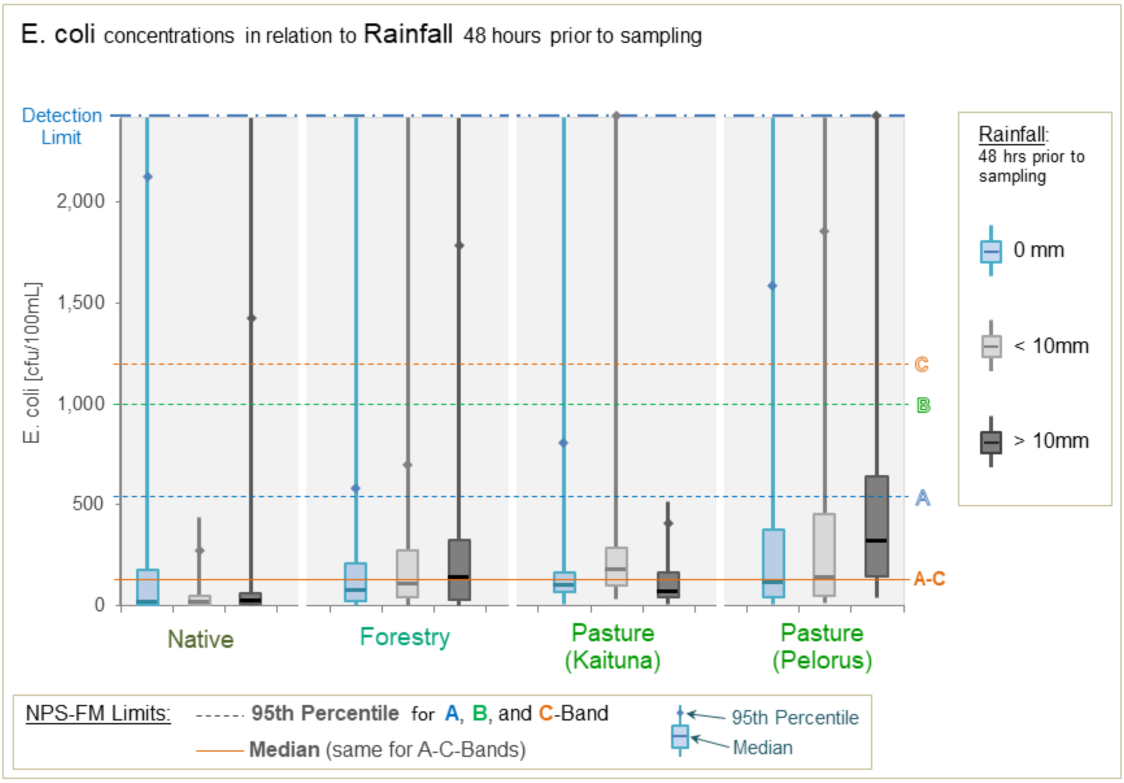


Figure 22: E. coli concentrations at different rainfall totals 48hrs prior to sampling.

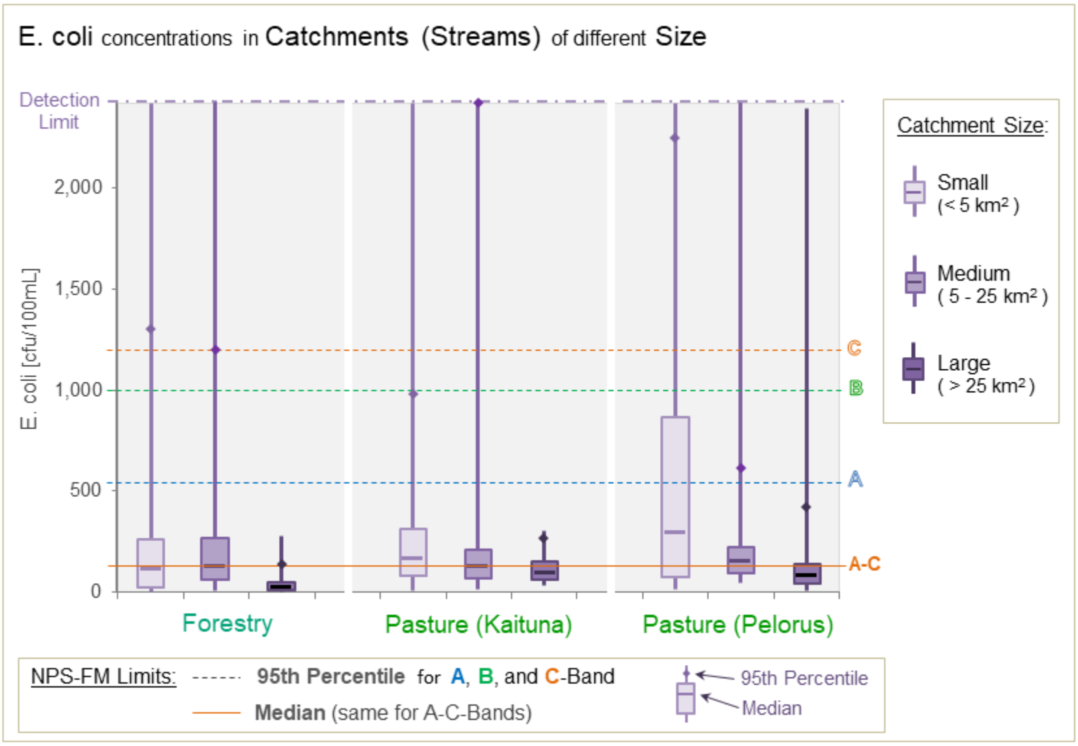


Figure 23: E. coli concentrations in streams and rivers with different catchment sizes.

3.6. pH

The pH is a measure for the acidity or alkalinity of water. It ranges between zero, indicating strong acidity and 14, representing strong alkalinity. Pure water has a neutral pH of 7.0. Photosynthetic activity by aquatic plants increases the pH of water, resulting in daily variations. Discharges of decomposing organic material can lower the pH and many heavy metals are more toxic at a lower pH. Geology can also influence the pH of waterways.

There are no limits in the current NPS-FM for pH values; however, a 2013 NIWA report prepared for the development of the NPS-FM suggested limits for this parameter. To allow assessment of the pH measurements from the Te Hoiere Project data, the following graphs show the suggested A-band limits from that NIWA report.

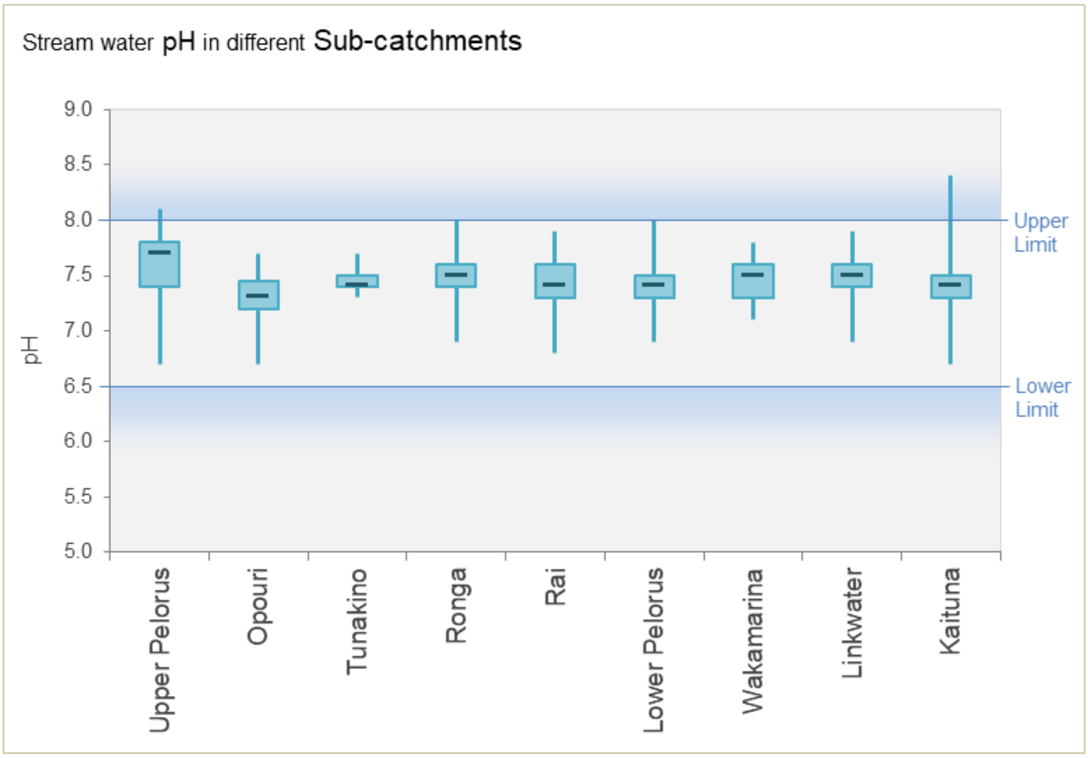


Figure 24: PH in waterways within the sub catchments of the Te Hoiere Project area.

Figure 24 shows pH values of waterways within the different sub catchments. PH was generally within the optimal range for aquatic organisms (between 6.5 and 8.0). The highest pH values were measured in waterways in the Upper Te Hoiere/Pelorus, while streams in the Opouri and Kaituna catchments had the lowest pH. Waterways in the Upper Te Hoiere/Pelorus had the greatest variability in pH, while the greatest range in values was observed in streams within the Kaituna catchment. Waterways in the Tunakino catchment had the most stable pH values.

PH values within the different land cover classes are displayed in Figure 25. Differences were only marginal with slightly lower median values in the two pasture classes. The median pH values in forestry streams were comparable to the median pH in native bush catchments, but pH values in forestry had a greater variability and range leading to occasional exceedances of the upper limit. PH values above 8.0 were also observed in a small number of samples from streams flowing through Kaituna pasture.

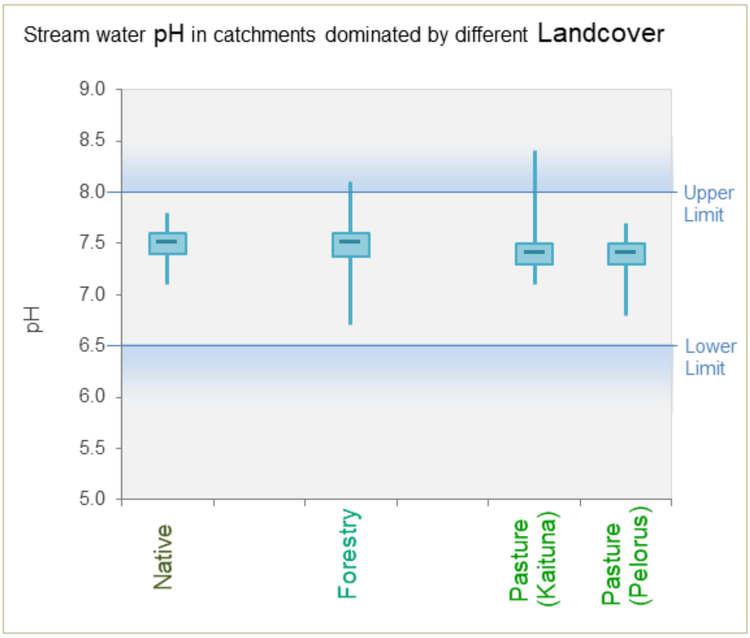


Figure 25: PH in waterways within catchments dominated by different land cover.

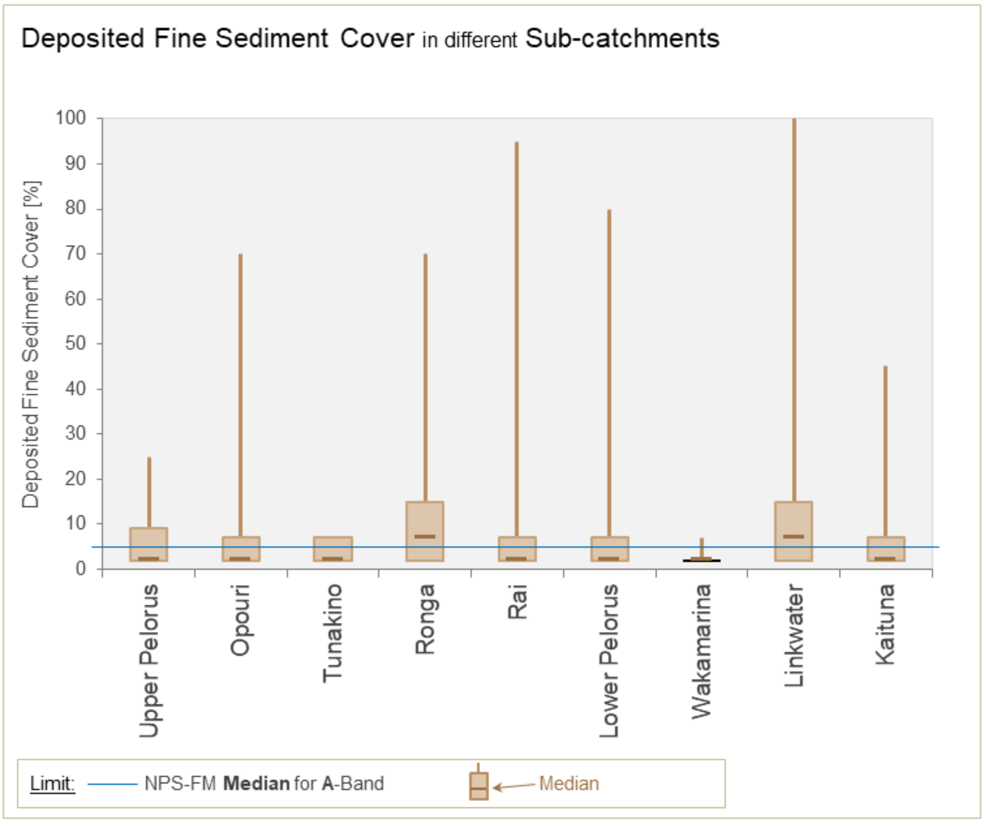
3.7. Deposited Fine Sediment and Algae Cover

Excessive quantities of fine sediment, filamentous algae and thick algae mats affect the ecological health and recreational values of waterways. The methodologies for the measurement of deposited fine sediment and algae cover required by the NPS-FM are both very time consuming, which made it unfeasible to include them in the Te Hoiere Project monitoring. However, bank side estimates of streambed cover can allow indicative assessments. Therefore, percentage cover with fine sediment and algae was recorded as part of the sampling.

Algae cover was divided into three types: thin mats, thick mats and filamentous algae. Only thick mats and filamentous algae can become problematic to ecological health, as excessive growth can result in the smothering of stream habitat and increased variability in dissolved oxygen concentrations and pH values. NPS-FM limits for algae cover are based on the measurement of the chlorophyll-a content within the algae. The amount of chlorophyll-a found within algae differs between algae species, but also varies within the same species with changing environmental conditions. The chlorophyll-a limits of the NPS-FM can therefore not be applied to visual assessments of algae cover.

For deposited fine sediment, however, NPS-FM limits can be applied to data from visual assessments. Yet, it is important to remember that these limits only provide indicative guidance as the data has not been collected using the required methodology.

The NPS-FM limits for deposited fine sediment vary with stream class. Streams and rivers in the Te Hoiere area belong to the ‘Cold Wet, Hard Sediment, Hill and Lowland’ River Environment Classification classes. These are equivalent to the Deposited Sediment Class 4 of the NPS-FM.



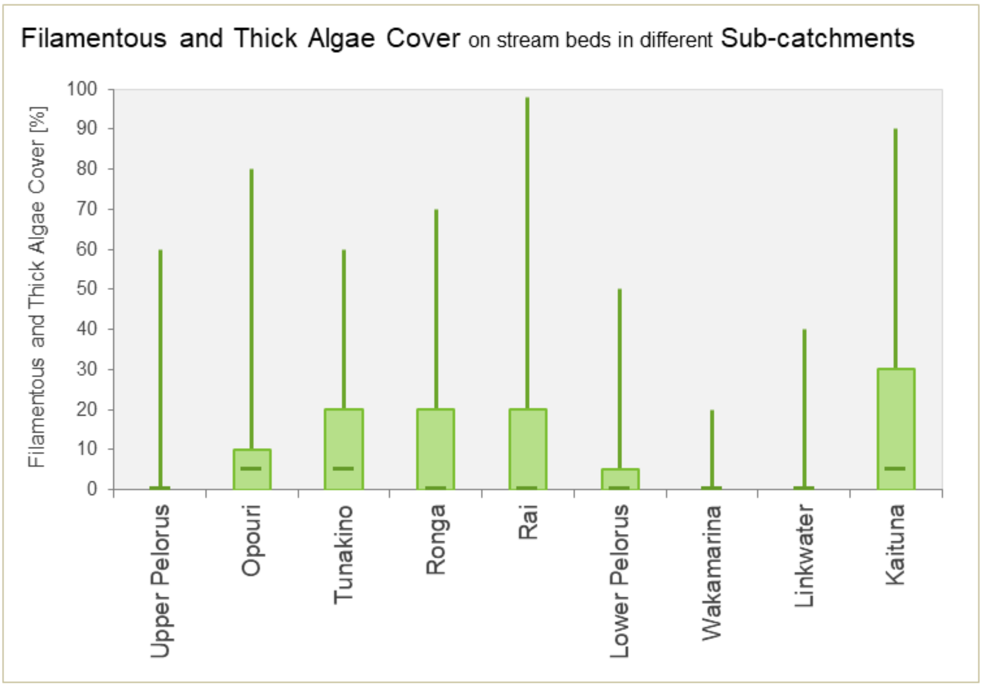


Figure 26: Deposited Fine Sediment Cover (top graph) and Algae Cover of stream and river beds in the sub catchments of the Te Hoiere Project area

The percentage of streambed covered with fine sediment and nuisance algae within the different sub catchments is shown in Figure 26. Deposited fine sediment cover in the Ronga and Linkwater catchments exceeded the NPS-FM A-band limit. The median cover in other catchments was low, however, in some streams in the Rai, Ronga, Opouri and Lower Te Hoiere/Pelorus, fine sediment covered more than half of the streambed. The lowest fine sediment cover was observed in the

Wakamarina catchment, but streambeds in the Tunakino catchment were also relatively free of fine sediment.

Further analysis of the data showed that in most sub catchments, there was no correlation between median turbidity and median deposited fine sediment cover[7]. The exceptions were the Rai and the Lower Te Hoiere/Pelorus. In these two catchments, turbidity explained 42% and 31% of deposited fine sediment, respectively.

Filamentous and thick algae mats occurred in waterways in all sub catchments, but generally only occupied a relatively small part of the streambed. The high rainfall in the Te Hoiere area means that floods and freshes are relatively common. Algae are often removed during increased flows as the higher velocity of the water causes streambed material to move downstream, scraping off algae in the process.

The highest median streambed cover with nuisance algae was observed in the Opouri, Tunakino and Kaituna catchments. Nuisance algae cover in the Upper Te Hoiere/Pelorus, Wakamarina and Linkwater catchments was very low.

There are a number of factors influencing the growth of algae. These include animal access, streambed shading and nutrient concentrations. The NPS-FM requires the setting of nutrient limits to control algae growth on streambeds. However, for the Te Hoiere Project data, there was no significant correlation between dissolved nutrient concentrations and percentage streambed cover with nuisance algae[8].

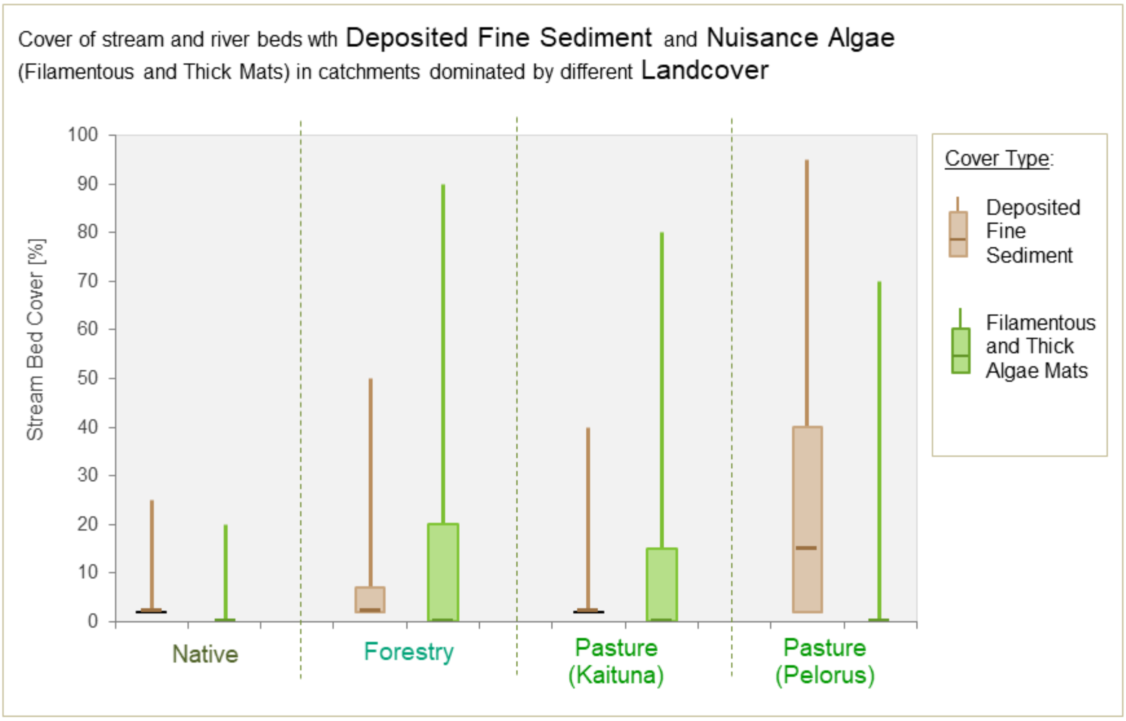


Figure 27: Deposited Fine Sediment and Nuisance Algae cover in catchments dominated by different land cover.

Streambed cover for the different land cover classes is displayed in Figure 27. In native catchments, streambeds were relatively free of fine sediment and nuisance algae cover. The highest amount of

[7] Pearson correlation with 2-tailed t-t test for significance. Log transformation did no improve the correlation.

[8] Correlation analysis was carried out for individual sampling results, as well as site medians for nutrient concentrations (DRP and Dissolved Inorganic Nitrogen) and median and 92nd percentile algae cover (92^{nd} percentile is based on 8% exceedance allowance of NPS-FM); the correlation was generally considerably better for the 92^{nd} percentile algae cover, but remained statistically not significant .

deposited fine sediment cover was found in waterways flowing through Te Hoiere/Pelorus pasture, while cover with nuisance algae was mostly low. The opposite was found in streams in Kaituna pasture, with significantly less deposited fine sediment, but higher algae cover. Forestry streams had the highest cover with nuisance algae and elevated amounts of deposited fine sediment.

During sampling, an assessment of stream bed cover was sometimes not possible (i.e. due to high turbidity or large stream size). Subsequently, there was insufficient data for further analysis, such as dependency on catchment size.

3.8. Summary

Of the sub catchments in the Te Hoiere Project area, Linkwater generally had the poorest water quality. Streams in the Linkwater area generally had the highest Ammoniacal Nitrogen, DRP and E. coli concentrations. Water quality in waterways in the Rai catchment was also comparatively poor.

The catchments with the best water quality were the Tunakino and Wakamarina.

Apart from elevated DRP concentrations, waterways in native vegetation catchment had good water quality with streambeds relatively free of fine sediment and nuisance algae. It is likely that a large part of DRP in the Te Hoiere waterways originates from natural sources.

Waterways flowing through pasture in the Te Hoiere/Pelorus had the poorest water quality, with the highest concentrations of Ammoniacal and Nitrate Nitrogen as well as E. coli and turbidity. Deposited fine sediment cover was also high. However, stream bed cover with filamentous and thick algae mats was comparatively low. Waterways within the other pasture class, Kaituna pasture, had generally better water quality, but Nitrate Nitrogen and E. coli concentrations were elevated and streambeds had higher nuisance algae cover. Unfortunately, Linkwater pasture could not be included as a land cover class in the analysis of land use impacts on water quality.

Streams flowing through catchments dominated by production forestry had elevated concentrations for all parameters monitored.

In all land cover classes, rainfall caused an increase in the concentrations for most contaminants. This increase was often most significant in the Te Hoiere/Pelorus pasture streams, with the exception of Nitrate Nitrogen, which decreased in this land cover class.

In most waterways, DRP concentrations showed the smallest and most inconsistent changes with rainfall. The exceptions were forestry streams, where DRP notably increased with higher rainfall.

Smaller streams had generally poorer water quality, with higher Ammoniacal Nitrogen and E. coli concentrations and higher turbidity compared to larger waterways. The difference was particularly noticeable in Te Hoiere/Pelorus pasture. The most likely reason is animal access to the waterways. The poorer state of smaller waterways means that actions to improve water quality should have a focus on the smaller streams.

4. Acknowledgements

We would like to thank the Ministry for the Environment for providing the funding, which presented us with this great opportunity to improve our understanding of water quality in the Te Hoiere area. We are also grateful to all the landowners that allowed and facilitated access to monitoring sites on their property and for their patience for the delays in the completion of this report.

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