Water quality information for farmer decision-making in the Nguturoa catchment, Manawatū

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Abstract
In 2021 a group of farmers and landowners along the Nguturoa Stream in the Manawatū-Whanganui Region began a study into water quality. The farmers felt that they needed precise information to establish their farming priorities for improving the waterway, and for monitoring the effects of making management changes. Monthly sampling and laboratory testing were carried out across the catchment and field tests were also undertaken at the time of sampling. The results were compared to those in the Manawatū River, the ultimate receiving environment for the catchment. The results highlighted that throughout the year the water in the Nguturoa Stream had lower dissolved inorganic nitrogen concentrations than the Manawatū River, but it had higher organic nitrogen concentrations in most months. Almost all the phosphorus results were above those measured in the Manawatū River as were the turbidity results. On seven occasions the Nguturoa Stream had *E.coli* results above the standard in the National Policy Statement for Freshwater Management 2020.

Compared to the laboratory test results, the field tests that were used were found to be inconsistent and unreliable for catchment and farm management decision making. The results highlighted for the farmers that overland flow was a more important source of in-stream contamination than they expected, for nitrogen, phosphorus and *E.coli* as well as sediment.

Keywords farm planning, catchment planning, Manawatū River, field test, aquatic monitoring

Background
Many New Zealand farmers are making management changes to improve the quality of freshwater associated with their farm properties. Generally this is occurring without farmers obtaining specific data for understanding how their on-farm activities influence water quality, or receiving feedback on how much difference they are actually making. When water quality information is collected and provided to farmers they may not have the means to interpret the results and apply them to their own circumstances (Tomer 2014). This makes farmer decision-making around the adoption of new practices for water quality improvement more difficult (Leeuwis 2004). Feedback is considered to be a vital component of stimulating and guiding farmer learning (Leeuwis 2004). A study on the adoption of water management practices in five intensively farmed catchments found that farmers wanted to know more about the link between their farming practices and water quality, but it was difficult for them to access that information (Bewsell, Kaine, Higson 2005). Monitoring waterway condition was one of the most-reported needs for making future progress in community-run catchment groups (Sinner et al. 2022). Although computer modelling and simulation has been used by scientists to understand the relationship between water quality and landuse practices (Monaghan et al. 2021), direct measurement remains an important part of landowner decision-making (Barnes et al. 2009).

In this paper the authors describe the concentrations of a range of freshwater contaminants in the Nguturoa Stream, a subcatchment of the Manawatū River, and how these changed along the length of the catchment over the course of a year. The authors have used this information to begin working with landowners in exploring the relationship between water quality information and their decision-making.

Approach
Introduction to Nguturoa Catchment
The Nguturoa Stream arises in the Manawatū Region, below Te Mata peak in the Tararua Range, near to the city of Palmerston North and Linton Military Camp. It flows about 7 km to the west dropping from 100 metres to 20 metres above sea level, before it becomes part of the Linton Drain and then, via the Tokomaru River, it flows into the Manawatū River. Most of the land (about 1,500ha) surrounding the Nguturoa Stream is rolling country that has been cleared for farming since about 1870 (Lauridson 1989). The average rainfall in the catchment is about 1200mm (Overseer News 2021), and the soils are generally imperfectly drained silt loams. Between the first sampling site at the top of the catchment, just below a spring, and the last sampling site near the bottom of the catchment, below the bridge along State Highway 57, the stream passes through eight farming properties.

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Water Quality in the Receiving Environment and in Nearby Catchments

A catchment group was established in 2020, comprising about 20 landowners, including seven farming families. Three of these families (two dairy farm operations and one sheep and beef farm) initiated the water quality project in late 2020, to provide practical methods for farmers to monitor waterway condition and ecological health, and to integrate the results of the monitoring with strategic farm and catchment planning. The project was not designed or intended to provide information for regulatory or compliance purposes.

There have been no long-term monitoring sites in the Nguturoa Catchment although an ecological assessment of the Catchment was carried out by Richard Storey (Storey 2014). Three nearby waterways have been monitored for water quality by Horizons Regional Council for several years.

1. The Manawatū River has been monitored at the Opiki Bridge (40°44´S 175°45´E) up-stream of the confluence with this catchment, for flow and water quality for over five years and this provided the "receiving environment" measures in this project (LAWA 2014). Compared to other lowland rural rivers, the Manawatū River at this site is in the best 50% for *E.coli*, the worst 25% for suspended fine sediment, the worst 50% for all forms of nitrogen and the worst 50% for all forms of phosphorus.
2. The Kahuterawa Stream (40°50´S 175°59´E) to the north of and running parallel with this catchment flows directly into the Manawatū River above the Opiki Bridge. It drains a lowland forest catchment. Compared with other similar sites across New Zealand, the Kahuterawa Stream is in the worst 50% for *E.coli* and fine sediment. It is in the worst 50% for all forms of nitrogen. Although it is in the best 25% for dissolved reactive phosphorus it is in the worst 50% for total phosphorus (LAWA 2014). The Kahuterawa Stream has hydrological similarity with the Nguturoa Stream. It has about the same sized catchment and arises in the same set of hills with a similar rainfall, and so the known flow rates of the Kahuterawa Stream were used as an approximation of Nguturoa Stream flow rates in calculations of nutrient loads (Figure 1).
3. The Tokomaru River (40°47´S 175°51´E) to the south joins the Nguturoa Stream just before it flows into the Manawatū River below Opiki Bridge. Compared with other lowland forest sites the Tokomaru River is in the worst 50% for *E.coli* and the best 50% for fine sediment. The Tokomaru river is in the best 50% for all forms of nitrogen except for ammoniacal nitrogen where it is in the worst 50%. It was also in the best 50% for both forms of phosphorus.

For comparison purposes Table 1 has median results for the Lower Manawatū River over the time period that the Nguturoa Stream was being sampled and tested. Also in Table 1 are the attributes required by the National Environmental Standard for those water quality standards that have been of general concern across New Zealand.

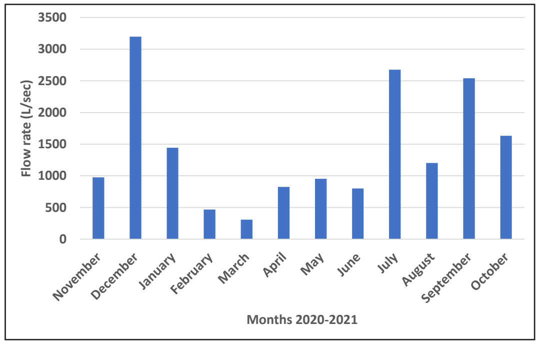

Figure 1 Average monthly flow rates for the Kahuterawa Stream for the period of Nguturoa Stream sampling

Catchment Water Quality Assessments

The project incorporated two reference sites – the first was in the hills close to its origin (40°27´S 175°35´E) and the second was below the bridge (40°26´S 175°33´E) near its exit into the Linton Drain. The first and highest sampling site in the catchment was situated just below a spring on Te Mata peak, it's results provided an initial base line for all subsequent waterway results from sampling sites within the catchment. The Manawatū River at Opiki bridge provided an indicator of how

Table 1 Median water quality in results the Manawatū River and the National Policy Statement attributes for freshwater when measured over five years or more.

Water quality attributes (mg/L)	Lower Manawatū River at Opiki (2021)	National Policy Statement
Nitrate-N	0.65	<=2.4
Nitrite-N	0.01	
Ammoniacal-N	0.06	<=1.3
Organic-N	0.2	
DIN	0.72	
Total-N	0.88	
DRP	0.03	<0.02*
Total-P	0.07	
Turbidity (NTU)	22.1	<3.0
E.coli (per 100ml)	260	<540*

*These standards for DRP and E.coli (measured at bathing areas during the swimming season), require Regional Council action plans to address them. The C-band for E.coli is: median <=130, <20% samples over 540, <34% samples over 260, 95th percentile <1200 the Nguturoa Stream results were affecting subsequent receiving waterways. For this, LAWA results provided benchmarking over the long term (5 years plus).

The project focussed on addressing four topics:

1. An assessment of overall waterway health in the catchment by sampling monthly through 2021 and laboratory testing (at the Central Environmental Laboratories, Palmerston North):
   a. Nitrate nitrogen
   b. Nitrite nitrogen
   c. Ammoniacal nitrogen
   d. Total nitrogen
   e. Dissolved reactive phosphorus (DRP)
   f. Total phosphorus
   g. Turbidity
   h. Escherichia coli (*E.coli*).
2. An evaluation of the effects on the waterway of three individual farms. Each farm owner suggested a waterway within their farm that had a catchment mainly within the farm boundaries; along with a part of the Nguturoa Stream below their farm, and before it became influenced by subsequent farms.
3. Field tests were carried out on-farm to provide the farm owners with immediate results of: nitrate-N, reactive phosphorus, and water clarity. A comparison of the field tests was made with the equivalent laboratory tests using simple correlations and regression analyses. Missing results have been excluded.
4. The development of farm plans that incorporated farmer goals and learning about farm management and waterway health. This topic is being addressed in Parminter 2023 (forth coming).

At the same time that the laboratory samples were collected, field tests were carried out for nitrate nitrogen, reactive phosphorus, and water clarity. The nitrate field test used a micro-colorimetric test produced by Aquaspex (Shinn 1941). The test was suitable for nitrate concentrations between 0.05 and 0.8 mg/L and it had five colour bands: 0.05–0.1–0.2–0.4–0.8 mg/L. Through the year 30 test samples were collected for nitrate nitrogen and field tested.

The reactive phosphorus field test used a hand-held colorimeter (Hanna Instruments: Smithfield, Rhode Island, USA) for checking the colour change associated with the ascorbic acid method of analysing water concentrations in water (Watanabe and Olsen 1965). It had a range of 0.0 to 2.5 mg/L and a resolution of 0.01 mg/L. Through the year, 30 test samples were collected and field tested, however only 14 of these fully followed protocol and were suitable for further analysis.

The clarity field test required a hand-held tube one metre long with moveable aquarium magnets (Valois et al. 2019). Through the year 18 test samples were collected and field tested, two samples were high in tannins making the field observations difficult.

Results and Discussion

Laboratory Testing and Overall Waterway Health

The 2021 laboratory results for the upper catchment sampling site below the spring, and the lower catchment sampling site beneath the bridge on Highway 57, are shown in Table 2 and Table 3. The two sets of results can be compared in Figures 2 to 7. The following information is taken from Factsheets on the website for Land Air Water Aotearoa (LAWA 2014).

Table 2 Monthly results for the upper catchment sampling site.

	Dissolved Inorganic Nitrogen[1] (mg/L)	Organic Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Bound and Organic Phosphorus (mg/L)	Turbidity (NTU)	*E.coli* (MPN/100mL)
November	0.034	0.136	0.014	0.036	3.34	10
December	0.079	0.261	0.022	0.028	4.04	109
January	0.032	0.128	0.009	0.021	2.98	146
February	0.029	0.181	0.008	0.032	1.92	135
March	0.022	0.108	0.013	0.007	2.02	31
April	0.09	0.17	0.012	0.038	3.35	256
May	0.023	0.277	0.01	0.03	6.31	85
June	0.033	0.087	0.016	0.014	2.00	10
July	0.212	0.088	0.018	0.022	3.02	10
August	0.089	0.101	0.014	0.016	3.12	20
September	0.128	0.182	0.016	0.014	4.15	10
October	0.021	0.129	0.01	0.02	3.05	10

[1] Dissolved inorganic nitrogen includes nitrate (NO_3-N), nitrite (NO_2-N), and ammoniacal nitrogen (NH_3-N)

Nitrogen

The nitrogen results in Tables 2 and 3, increased between the upper and lower parts of the catchment for all months of the year, except for organic nitrogen in February, and dissolved inorganic nitrogen (DIN) results in March. Rainfall and flow rates in the Nguturoa Catchment and the nearby Kahuterawa Stream were at their lowest in February and March and this may have contributed towards the low nitrogen figures then.

Nitrogen in waterways encourages the growth of nuisance plants and algae. It can also be toxic to fish and other forms of stream life. DIN comprises nitrogen as nitrate, nitrite, and ammonia. Nitrate is easily leached through the soil into ground water where it can then flow into waterways; it is particularly generated by animal urine. Nitrite is generally found at very low levels in New Zealand waterways but can be oxidised from ammonia and present in streams characterised by very low oxygen levels. Ammoniacal forms of nitrogen enter waterways primarily through point-source discharges, such as dairy shed effluent - overflowing storage ponds or effluent spreader runoff.

The other form of nitrogen reported here is organic nitrogen (calculated by subtracting DIN from the total nitrogen measurement). Organic nitrogen is washed off the surface of nearby grazing land into waterways. Organic nitrogen breaks down into more available forms of nitrogen (e.g. nitrate), but consumes oxygen in the process, and the reduced oxygen can reduce fish-life.

There were large absolute increases between the sampling sites for DIN in February and May (Figure 2 and Figure 3) and these months were also when the relative differences were greatest. Most of the relative increases were due to increases in nitrate nitrogen. The Manawatū River sampled by the Regional Council as part of their State of the Environment reporting, over July to September 2021 had DIN readings of over 1.0mg/L and organic nitrogen over 0.11mg/L. Over all months of the year, the Nguturoa Stream had lower DIN concentrations than its ultimate receiving environment in the Manawatū River, but it had higher organic nitrogen concentrations in all months except February.

Phosphorus

Phosphorus encourages plant and algal growth in waterways. Dissolved reactive phosphorus (DRP) is the most plant available form of phosphorus and is mainly dissolved from sediment when this has been washed into a waterway. Comparing figures 4 and 5, the largest absolute increase in DRP between the upper and lower sampling sites was in March when the lower result was over eight times the source concentration. March was the month when flow rates in the catchment were at their lowest.

All the Nguturoa Catchment monthly results for DRP and bound and organic phosphorus were above those measured in the Manawatū River except for July to September (inclusive). The Manawatū River had highly variable results from month to month through the year, but a median monthly result of 0.02 mg/L. For most of the year water from the Nguturoa Stream can be considered to be generally increasing phosphorus concentrations in its receiving environment.

Table 3 Monthly results for the lower catchment sampling site.

	Dissolved Inorganic Nitrogen[1] (mg/L)	Organic Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Bound and Organic Phosphorus (mg/L)	Turbidity (NTU)	*E.coli* (MPN/100mL)
November	0.138	0.362	0.051	0.029	4.46	10
December	0.395	0.605	0.058	0.052	5.24	118
January	0.109	0.531	0.055	0.075	5.52	3870
February	0.652	0.108	0.055	0.085	5.48	1785
March	0.021	0.949	0.116	0.134	3.54	1119
April	0.298	0.372	0.039	0.061	4.43	2198
May	0.474	0.396	0.028	0.052	4.13	245
June	0.221	0.149	0.026	0.014	2.52	20
July	0.856	0.244	0.031	0.029	3.53	697
August	0.856	0.344	0.024	0.036	5.52	327
September	0.699	0.601	0.03	0.09	26.9	4880
October	0.235	0.385	0.03	0.05	6.03	906

[1] Dissolved inorganic nitrogen includes nitrate (NO_3-N), nitrite (NO_2-N), and ammoniacal nitrogen (NH_3-N)

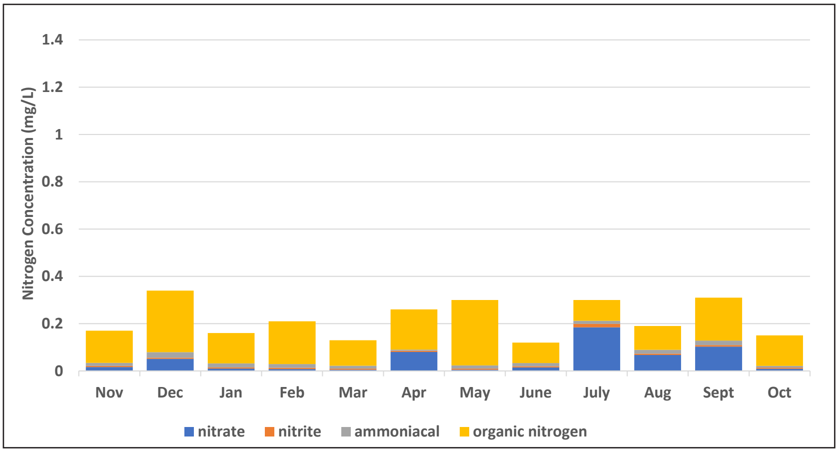

Figure 2

Monthly nitrogen results for the top of the Nguturoa Catchment at the sample site below the spring, for 2020-21.

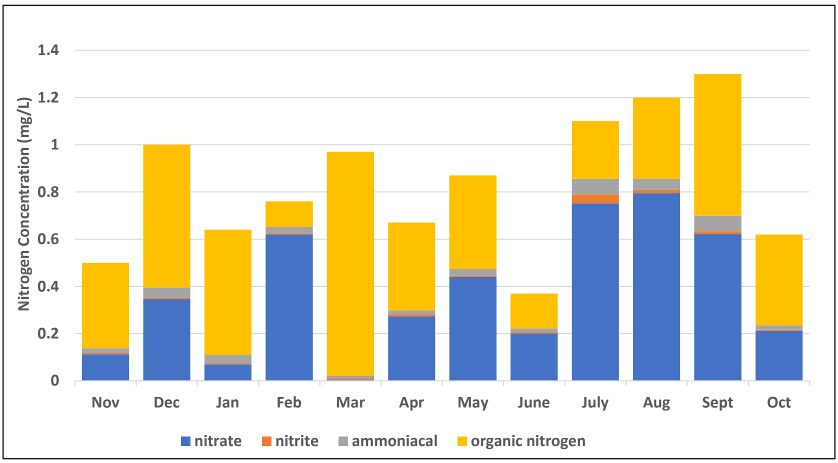

Figure 3

Monthly nitrogen results for the lower Nguturoa Catchment at the sample site below the bridge on Highway 57, for 2020-21.

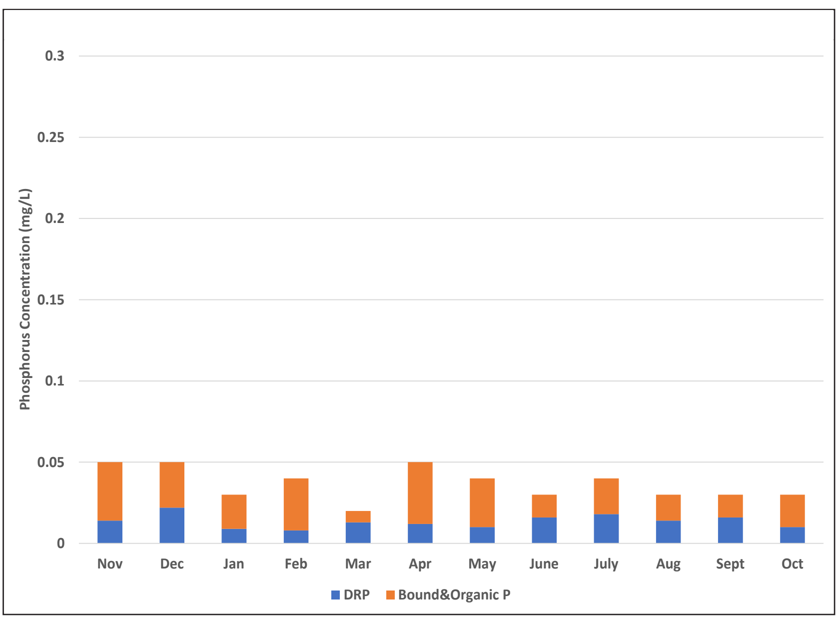

Figure 4

Monthly phosphorus results for the top of the Nguturoa Catchment just below the spring, for 2020-21.

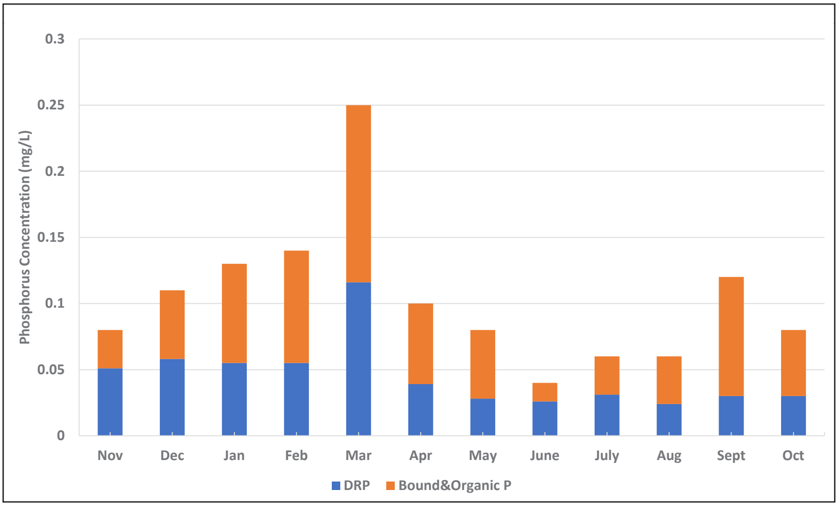

Figure 5

Monthly phosphorus results for the lower Nguturoa Catchment sample site below the State Highway 57 bridge, for 2020-21.

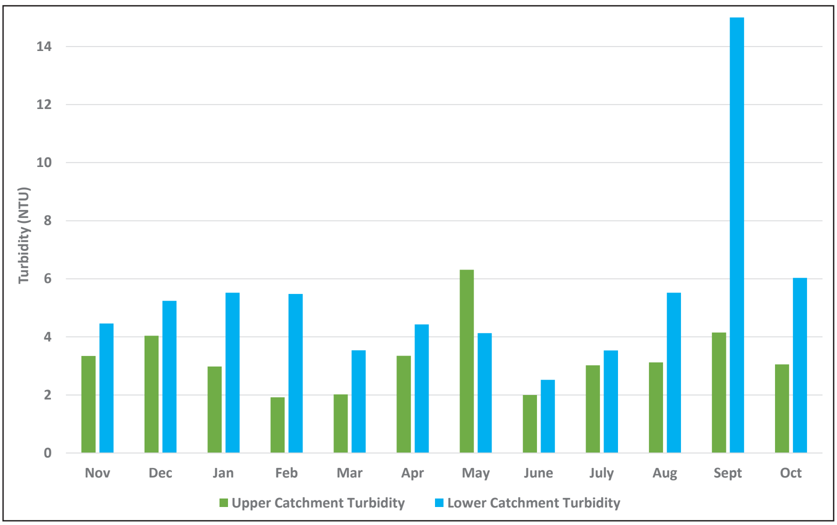

Figure 6

Monthly turbidity results for the Nguturoa Catchment comparing results for the upper and lower sampling sites, for 2020-21.

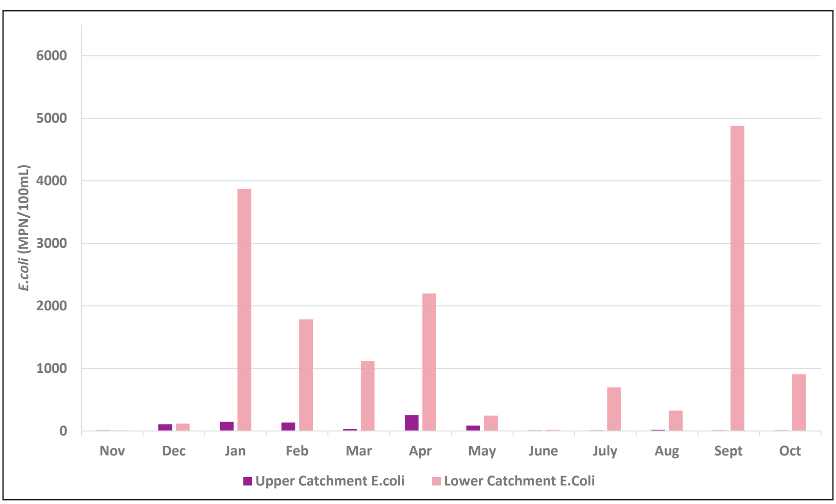

Figure 7

Monthly *E.coli* results for the Nguturoa Catchment comparing results for the upper and lower sampling sites, for 2020-21.

Turbidity (an indicator of fine sediment)

Turbidity is a measure of the cloudiness of water, generally resulting from suspended fine sediment. Turbidity levels had their greatest absolute increase in the Nguturoa Catchment in September after heavy rain in the catchment (Figure 6). Turbidity was also high that month in the Manawatū River (above 50 nephelometric turbidity units; NTU). Over the whole year the Manawatū River had a median result of 6.2NTU and the median result for the Nguturoa Stream was 4.9NTU. From February to April (inclusive) the Manawatū River has lower turbidity than the Nguturoa Stream. At other times of the year the Nguturoa Stream can be expected to be decreasing sediment levels in the Manawatū River receiving environment.

Escherichia coli

Escherichia coli (*E.coli*) is a type of bacteria commonly found in the intestines of animals and people. Low concentrations of *E.coli* can be found naturally, however high concentrations generally indicate faecal contamination that may be harmful to humans. The month with the greatest increase in *E.coli* concentrations in the Nguturoa Catchment was September after heavy spring rain (Figure 7). The National Policy Statement for Freshwater Management (New Zealand Government 2020; NPS-FM) has a national water contact bottom line that requires waterways to have an annual median *E.coli* count under 260MPN/100ml (where MPN means the 'most probable number'), and for regional councils to notify the public of any single-occasion-results that might be over 540MPN/100ml (at recognised primary contact sites). The Nguturoa Stream had seven months of the year when *E.coli* results were over 540MPN/100ml. The Manawatū had four months of the year with *E.coli* readings above 540MPN/100ml.

Summary of Laboratory Results for the Catchment

In comparison with LAWA results for the Manawatū River (LAWA 2014); the Nguturoa Stream had better than expected DIN results over much of the year. In contrast, the Nguturoa Stream had unexpectedly high results for organic nitrogen. DRP and total phosphorus concentrations were higher than the Lower Manawatū River results all year round. Turbidity results indicated sediment loss over much of the year similar to or higher than the Lower Manawatū River. The levels of sediment washing into the stream may be associated with a loss of phosphorus attached to the sediment particles and organic nitrogen.

Elevated *E.coli* levels on repeated occasions may be associated with surface runoff from grazed paddocks along waterways in the catchment.

Results from Individual Farm Businesses

The annual median results from three individual farms within the catchment are shown in Table 4. All three farms were running livestock. Farm A was higher up in the catchment and separated by three small properties from Farm B which was above and alongside Farm C. The in-stream results tended to increase as they were collected further away from the source of the stream (Figure 8). The exception is the nitrate results that tended to be lower in samples collected from farms further downstream. In the table the column for 'stream' results is the main Nguturoa Stream, the column for 'drain' is for waterways draining from catchments wholly within each farm.

In the farm drains the concentrations of nutrients were generally higher than the in-stream results. The exceptions were Farms A & B having lower nitrate concentrations, and Farms A & C having lower *E.coli* counts.

Farm A was a mixed livestock farm, and used temporary fencing to keep cattle out of waterways. The livestock class and grazing management appeared to reduce its contribution towards waterway nitrates and *E.coli*. The main contaminant for Farm A was likely to be sediment (turbidity) and soil-bound phosphorus.

Farm B was a dairy farm on flat to rolling topography. It had a relatively low stocking rate with pasture-based feeding and winter and summer crops. Nitrogen was the

Table 4 Annual median results (October, March, June, October).

	Farm A		Farm B		Farm C	
	Stream	Drain	Stream	Drain	Stream	Drain
Nitrate-N (mg/L)	0.25	0.02	0.125	0.005	0.074	0.081
Organic Nitrogen-N (mg/L)	0.172	0.378	0.419	5.073	0.859	1.074
DRP (mg/L)	0.01	0.02	0.05	0.15	0.10	0.06
Total Phosphorus-P (mg/L)	0.045	0.09	0.095	0.07	0.115	0.13
Turbidity NTU	5	17	4	18	12	7
E.coli (MPN/100mL)	384	52	295	292	2012	1103

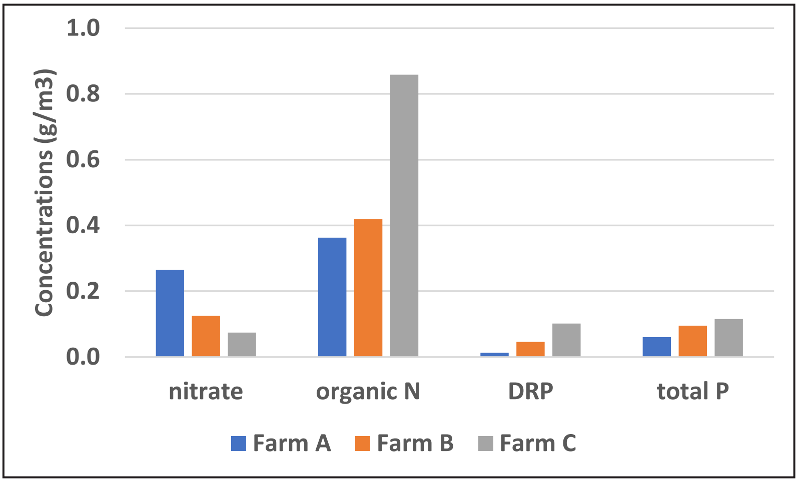

Figure 8

Median in-stream nutrient concentrations from waterways associated with three farms in the catchment based on monthly sampling 2020-21.

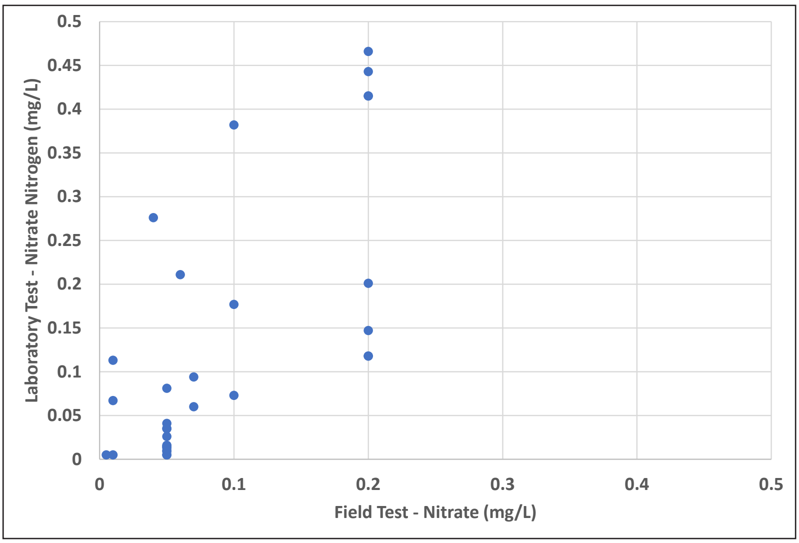

Figure 9

Comparison of the field test for nitrate nitrogen and the laboratory test for nitrate nitrogen

main nutrient waterway contaminant associated with this farm, as both nitrate and organic nitrogen. *E.coli* levels in the drain on Farm B were much higher than the nearby Nguturoa waterway.

Farm C was another dairy farm on flat to easy hill topography. This farm also had nitrogen being lost to the nearby waterway as nitrate and as organic nitrogen. *E.coli* levels were raised but lower than the nearby Nguturoa Stream.

Comparison with Field Tests

Through the year 32 nitrate-N test samples were collected and field tested (Figure 9). The median of the nitrate field tests in Table 5, was significantly lower than the median of the laboratory tests ($P<0.05$), and the standard deviation of the laboratory results was larger. The field tests were not observed to go over 0.2mg/L although they are read from a five point scale with a maximum of 0.8mg/L.

The nitrate test results between the field test and the laboratory test, had a correlation of 0.5 ($R^2 = 0.25$). The regression equation in Table 6 had a significant F-test ($P>0.95$). This is not a particularly strong relationship and indicates that the nitrate field test has low predictive ability.

The reactive phosphorus field test results are shown in Table 5 and Figure 10. Dissolved reactive phosphorus results for the laboratory are for the phosphorus component only, whereas the field test measures orthophosphate. To convert orthophosphate (PO_4^{3-}) to phosphate (PO_4-P) the field test result needs to be multiplied by 0.3261. The means for the raw data is shown in Table 5.

The reactive phosphorus test results had a correlation

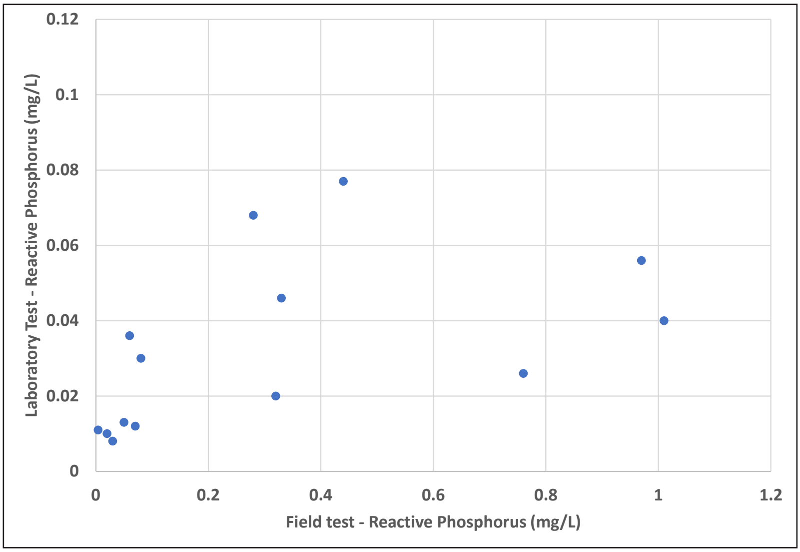

Figure 10

Comparison between the field test for reactive phosphorus and the laboratory test for dissolved reactive phosphorus as phosphorus.

of 0.5 ($R^2 = 0.25$), and the regression equation in Table 6 had a significant F-test (P>0.95). Again, this is not a particularly strong relationship and indicates that the phosphorus field test has low predictive ability.

The clarity field test results are shown in Table 5 and Figure 11. The clarity tube results had a correlation with turbidity of 0.66 ($R^2 = 0.44$). The regression equation results for the clarity tube, in Table 6 had a significant F-test (P>0.95). Although similar, turbidity and water clarity are not measures of the same water quality attribute. Water clarity responds to the presence of suspended solids and colour in the water column, whereas turbidity is considered an indicative measure that depends on the physical characteristics of the fine sediments as well as their concentration (Franklin, Booker and Stoffels 2020). Although this was our best relationship, these differences may have contributed towards the variability of the results.

Table 5 Median results for the nitrogen and phosphorus field tests.

Type of Test	Number of Samples	Median	Standard Deviation	Standard Error
Nitrate Field Test	32	0.05	0.07	0.012
Nitrate Laboratory Test	32	0.07	0.15	0.026
Phosphorus Field Test	17	0.18	0.36	0.095
Phosphorus Laboratory Test	17	0.026	0.04	0.009
Water Clarity field Test	16	0.66	0.16	0.039
Turbidity Laboratory Test	16	6.8	8.6	2.155

Table 6

	Regression Coefficient	Standard Error	P-value
Nitrate Intercept	0.097	0.025	<0.001
Nitrate Field Test	0.213	0.067	<0.001
Phosphorus Intercept	0.002	0.007	0.011
Phosphorus Field Test	0.032	0.016	0.067
Water Clarity Intercept	0.76	0.05	<0.001
Water Clarity Field Test	-0.01	0.004	0.005

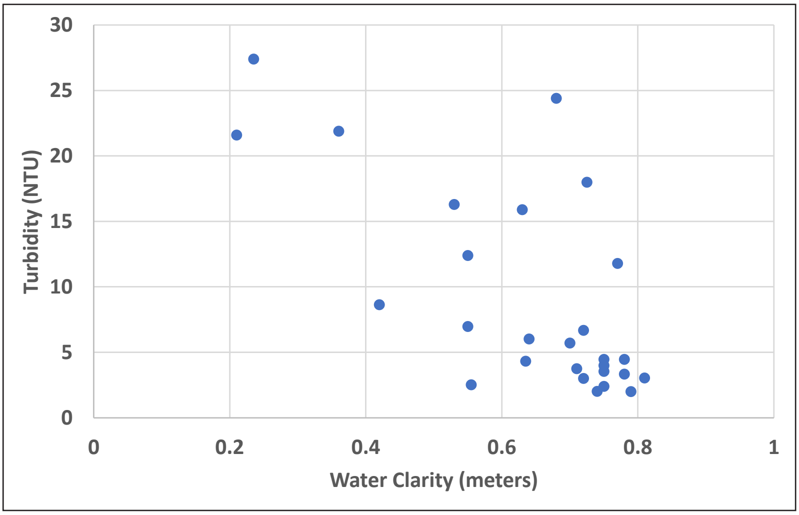

Figure 11

Comparison between clarity tube field test results and the laboratory test for turbidity.

Conclusions and Application

In comparison with the ultimate receiving environment (the Manawatū River), the Nguturoa Stream had generally low levels of nitrogen contamination, but relatively high levels of organic nitrogen. Phosphorus levels were higher than the Manawatū River, as was *E.coli*. Compared to much of the lower Manawatū River catchment, which is relatively flat the Nguturoa Stream catchment is largely rolling to easy hill country. It's water quality results can be associated with the additional amounts of runoff created by overland flow from rain falling on the hill country.

The farmers and other landowners in the catchment received a monthly newsletter with the laboratory test results and an interpretation of their significance. These results enabled landowners to identify the priority contaminants associated with their properties at different seasons of the year. The results from this project generated on-farm and catchment community discussions about the best way of addressing their concerns and these strategies were incorporated into their farm plans. The results highlighted to the farmers that overland sediment and nutrient flows were a more important source of in-stream contamination than they expected, for nitrogen, phosphorus and *E.coli* as well as sediment.

The newsletters were discussed at catchment community meetings and consequently a plan was formed to fence and plant riparian areas along the Nguturoa Stream and its tributaries.

Having real data on the instream conditions and their seasonal variation assisted the farmers and the other landowners with decision-making, setting priorities and strategic planning.

The field tests had only moderate success. The farmers had hoped that they could be used to replace laboratory testing, but the field test results have been demonstrated to be unreliable as a means of monitoring waterway contamination and the results of taking remedial action.

It is going to take a number of years before the benefits of all the management changes can be observed in the Nguturoa Catchment. The community is continuing its monitoring programme and expanding it further down the catchment to include more farmers and other landowners.

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