The Whatawhata Integrated Catchment Management Project - Summary of environmental impact

Prepared for AgResearch

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Executive summary

The Whatawhata Integrated Catchment Management (ICM) Project is the longest continuously monitored before-after-control-impact (BACI) catchment-scale study in New Zealand. The study assessed the impact of catchment-wide land use changes on stream water quality/quantity and ecosystem health within several headwater catchments within and adjacent to the former-Whatawhata Research Station (WRS). Land use changes were implemented in 2001 and stream monitoring at ICM and pasture and native forest control (unimpacted) sites was conducted between 1995 and 2020 (the long-term environmental monitoring programme ended in June 2020). The long-term monitoring captured the before-and-after response of the catchment-scale land use changes, including timescales of responses and dynamics in response to natural events (e.g., severe weather).

The WRS has been the focus of over 100 environment-related publications, including international scientific journal articles, conference presentations, magazine, and internet articles. Many of these articles are not accessible to the general public and there is also no one summary document that describes the research and the key findings for the entire 1995 – 2020 study period. This report provides an accessible summary of the research that has been conducted that demonstrates the impact of the ICM at the WRS.

Within the WRS there are two experimental sub-catchments (Mangaotama (2.7 km^2) and Kiripaka (2.7 km^2)). The 'control' Whakakai catchment (3.1 km^2), which is located within a forest reserve immediately adjacent to the WRS, is entirely indigenous regrowth forest (broadleaf/podocarp). The most significant ICM-related land use changes took place in the Mangaotama catchment; hence this catchment is the focus of this report. As the Whakakai catchment remained unchanged over the entire study period it, provides base information that we can compare the Mangaotama catchment results to.

Here we present summary data of the impact of the ICM land use changes on:

- Stream water quality.
- Instream macro-invertebrate (e.g. aquatic insects and snails) communities.
- Stream shade and stream temperature.
- Stream hydrology.
- Hillslope stability.
- Suspended sediment loads.
- Fish communities.

One of the main 'take home' lessons from this project is that the impact of implementing sustainable land management practices (e.g., riparian planting, cattle exclusion from streams, large-scale afforestation, etc.,) within catchments is complex. Here we show that some measures of ecosystem health and/or water quality have improved at some sites (e.g., stream temperature, macro-invertebrate populations, and water clarity) while others have remained unchanged (e.g., suspended sediment loads) or even appear to have degraded (e.g., nitrate concentrations within a catchment planted entirely in pine).

It is intuitive that when sustainable land management changes are implemented that there will be positive environmental outcomes. However, there are likely to be site-specific factors that mean that some measures of ecosystem health and water quality are likely to be responsive to land use changes, but others are not. Land use history is also likely to play a role. In the case of the Mangaotama catchment (and also typical of many New Zealand catchments), it was cleared of its indigenous land cover over 100 years ago and agricultural land uses were implemented. Although these changes were relatively abrupt, the actual impacts of these changes are likely to have had an ongoing effect as the catchment adjusted to the new agricultural regime. It is therefore likely that any changes in land use back towards a more natural system will also take time to take effect or be detectable.

1 Introduction

In the 1950s The NZ Department of Agriculture set up the Whatawhata Hill Country Research station to assess means of lifting hill country farming to gain better production while ensuring soil conservation. The station grew to having 65 staff on site during the 1980s undertaking animal, plant, farm system and farm component research on the property. Whatawhata was one of the many outposts of the Ruakura Research Centre alongside Rukuhia and Te Kauwhata and was a major focus for the sheep and beef sector.

In the 1990s new challenges beyond production-based research emerged, with subsidies having come off agriculture in the 1980s and the profitability of hill country farming under threat. A new focus saw AgResearch start looking more into the implementation of "sustainable agriculture" that arose through the emergence of international sustainable development goals and the implementation of the Resource Management Act 1991. At Whatawhata this led to a partnership between AgResearch and NIWA to inform a multi-stakeholder hill-country catchment management group. The aim of this group was to oversee investigations into improving the economic, environmental, and social performance of North Island hill-country pastoral farming. An inter-disciplinary catchment management group was formed in 1996 to establish an integrated catchment management (ICM) project at a farm in the North Island hill-country. The Whatawhata Research Station (WRS) farm was selected as the project location. The catchment management group had representation from four broad groups: science (agricultural and environmental) policy (district and regional government, conservation), farming and Māori (Ngāti Māhanga). The overall goal of the ICM Project was to implement land use changes to achieve and demonstrate a well-managed rural hill country farm that was both economically viable and environmentally sustainable.

Land use changes were implemented in 2001 and stream monitoring at ICM and pasture and native forest control (unimpacted) sites was conducted between 1995 and 2020 (the long-term environmental monitoring programme ended in June 2020) to capture the before-and-after response of catchment-scale land use changes, including timescales of responses and dynamics in response to natural events (e.g., severe weather).

The Whatawhata Integrated Catchment Management (ICM) Project is the longest continuously monitored before-after-control-impact (BACI) catchment-scale study in New Zealand. The site has been the focus of over 100 environment-related publications, including international scientific journal articles, conference presentations, magazine, and internet articles. Many of these articles are not accessible to the public and there is also no one summary document that describes the research and the key findings for the entire 1995 – 2020 study period. The goal of this report is to provide an accessible summary of the research that demonstrates the impact of the ICM at the WRS.

2 Study catchments

The Whatawhata Research Station (WRS) is located approximately 20 km west of Hamilton (Figure 2-1). Within the WRS there are two experimental sub-catchments (Mangaotama (2.7 km^2) and Kiripaka (2.7 km^2)) (Figure 2-2). The 'control' Whakakai catchment (3.1 km^2), which is located within a forest reserve immediately adjacent to the WRS, is entirely indigenous regrowth forest (broadleaf/podocarp) and has been largely undisturbed by human activities for over 80 years since selective logging in the lower catchment ceased. The catchments are dominated by steep, hilly terrain, comprised of sedimentary sandstones and siltstones (greywacke and argillite) with strongly weathered thin yellow brown earth soils (Kaawa hill soil, an Ochreptic Hapludult, and the Waingaro steepland soil, an Umbric Dystrochrept)(Quinn & Stroud 2002). The climate is humid-temperate with a mean annual rainfall of 1663mm.

The most significant ICM-related land use changes took place in the Mangaotama catchment; hence this catchment is the main focus of this report. The land use changes in the Kiripaka catchment were minor (i.e. small areas of pasture were converted to pine and the beef cattle enterprise was modified) and therefore are not discussed in this report. As the Whakakai catchment has remained unchanged over the entire study period it provides base information that we can compare the Mangaotama catchment results to. As such, the Whakakai catchment can be considered to be a 'control' or 'reference' site.

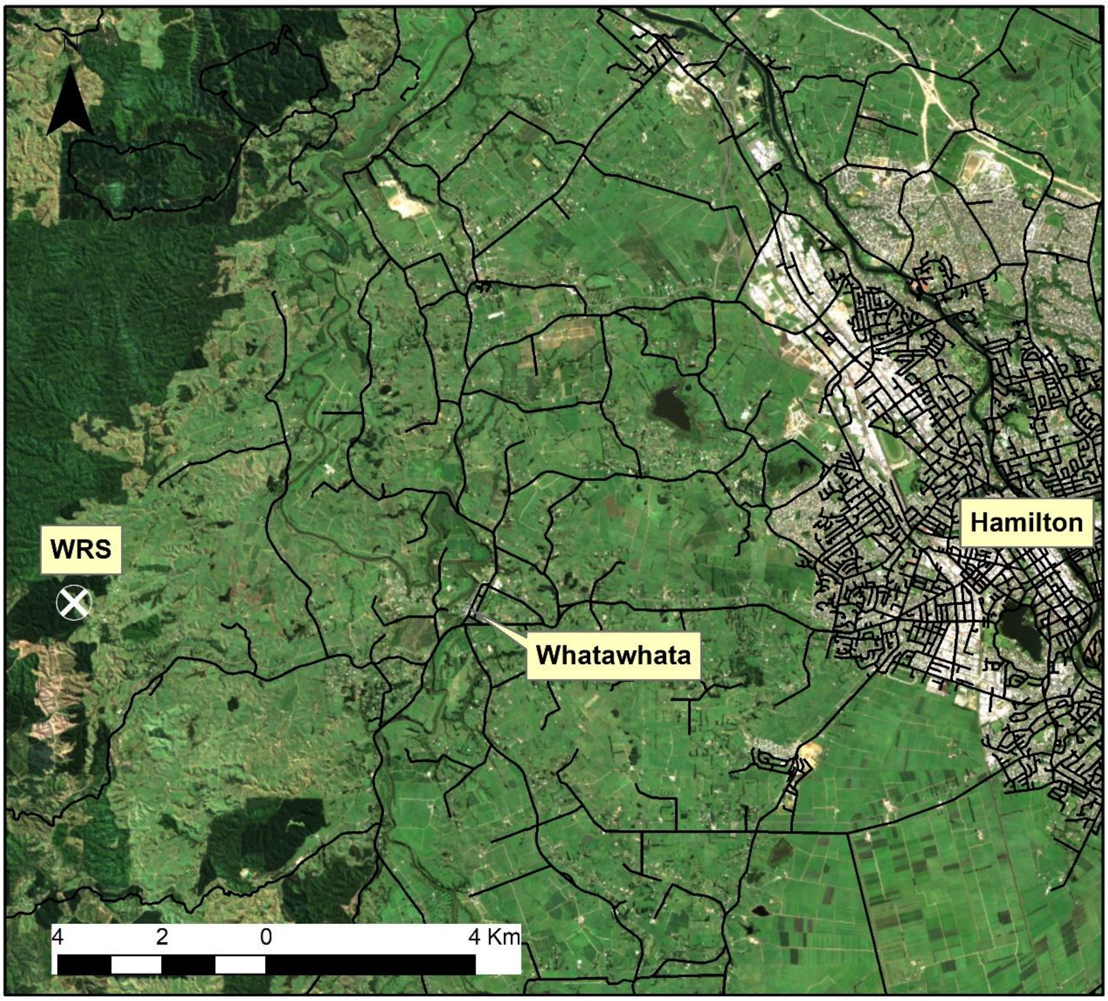

Figure 2-1: Location of Whatawhata Research Station.

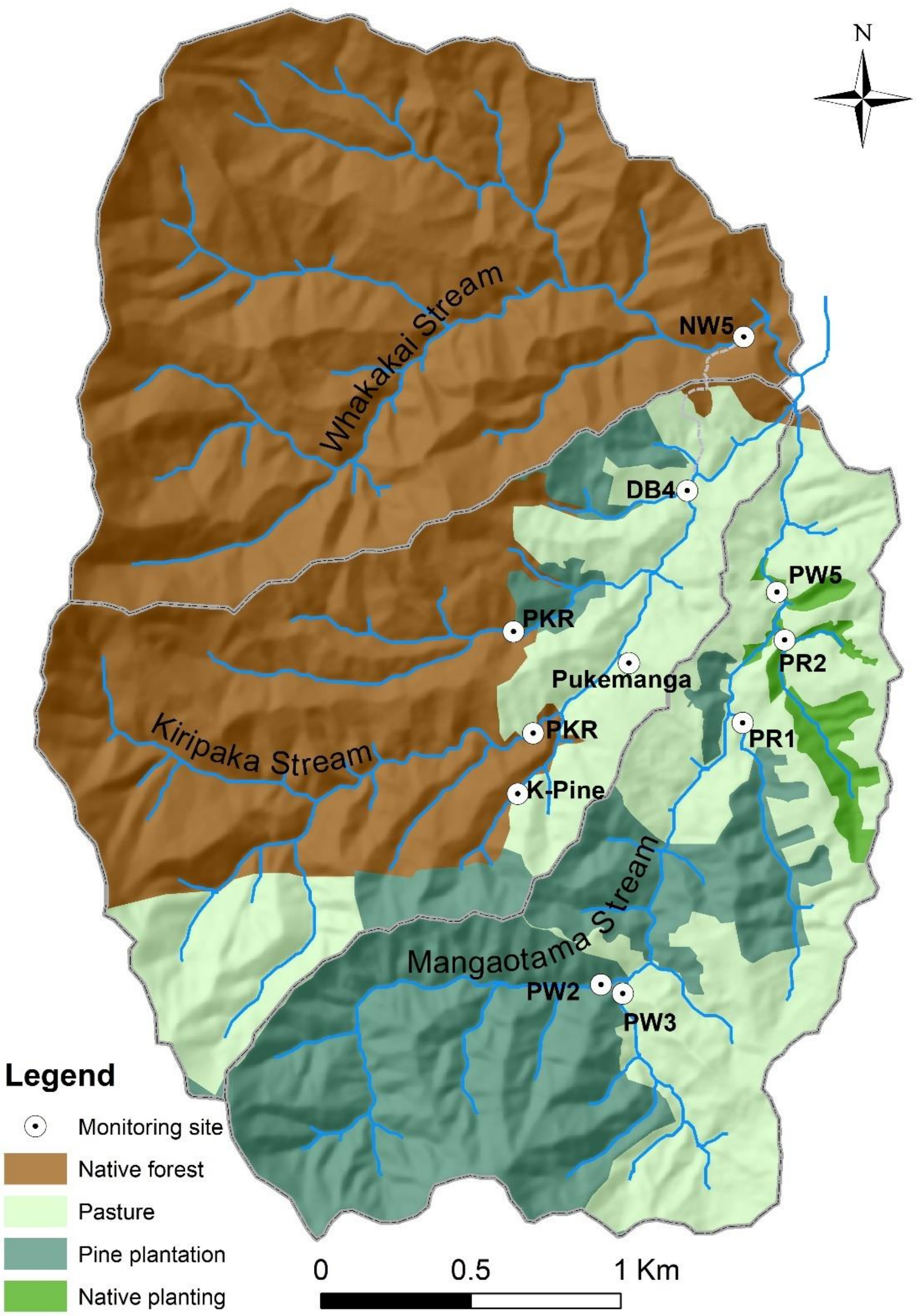

Figure 2-2: Whatawahata Research Station catchments, land use, and location of water quality and stream flow monitoring sites.

3 Integrated Catchment Management Plan

Prior to the implementation of the integrated catchment management plan the Mangaotama catchment was a mixed sheep and beef cattle enterprise stocked at about nine stock units (SU) per hectare with a sheep to cattle SU ratio of 60:40. Apart from some remnant indigenous trees, the riparian areas were devoid of trees and livestock had unrestricted access to streams (Figure 3-1). In 2000–2001 the ICM plan was implemented in the catchment. Poplar trees (*Populus deltoides*) were planted for erosion control during 2000 in erosion prone parts (mainly stream banks) of the area that remained in pasture. During August 2001, 153 ha were planted in *Pinus radiata*, with the exception of a 10 m unplanted buffer on each side of the stream channels. In the lower reaches of the catchment, indigenous tree and shrub species were planted across 7 ha of the existing pastoral land, surrounding and linking an existing 5 ha of indigenous riparian forest patches (Figure 2-2). Exclusion of all livestock from waterways was achieved for areas converted to pine forestry and areas of indigenous tree planting. Cattle, but not sheep, were excluded from riparian areas within the remaining pasture areas. Although all livestock have been excluded from pine afforested areas, feral pigs use forested areas as cover and stream bank/wetland disturbance caused by wallowing and rooting has been observed in the pine forest areas. Additionally, the beef herd was changed from Angus beef breeding to a Friesian-cross bull beef enterprise with animals brought in during autumn at 6 months old and sold at 18 months. The significance of this change is that it resulted in the smaller cattle being present in the catchment over the wetter winter period when rainfall is high and grass growth is limited.

In summary, the main land use changes implemented by the ICM plan were:

1. riparian native tree planting – a 7 ha pastoral area adjacent to a main channel was planted (the area upstream of site 'PR2' on Figure 2-2),
2. exclusion of livestock from channels – this was achieved through conversion to pine forestry (without fencing), native forest establishment (with fencing) or fencing of the stream sides in pastoral areas,
3. planting poplar trees adjacent to eroding stream banks,
4. planting *Pinus radiata* on the most unproductive grazing land and degraded parts of the catchment (total of 153 ha) (indicated as 'pine plantation' on Figure 2-2), and
5. Angus beef herd was replaced with a Freisian bull beef enterprise.

3.1 Methods for monitoring of effects of ICM land use changes

The monitoring site locations within the three sub-catchments are shown in Figure 2-2. A list of variables measured for each stie is presented in Table A-1. Within the Mangaotama catchment there are 5 monitoring sites (PR1, PR2, PW2, PW3, PW5). The Kiripaka catchment has five monitoring sites also (DB4, PKR, PINE, Pukemanga Seep and Pukemanga Weir). These sites were established prior to the establishment of the ICM (see Quinn & Stroud 2002). While there were some very minor land use changes in the Kiripaka catchment (i.e., some small areas of pine plantation and a change to the beef cattle enterprise), it was not part of the ICM study. Furthermore, the minor land use changes means that monitoring sites within the catchment do not provide useful reference data. Therefore there are no pre- and post- treatment type results to present from the Kiripaka monitoring sites. There is one monitoring site (NW5) within the Whakakai catchment.

For the purpose of keeping this report succinct we have only presented data from the Mangaotama catchment (which was the focus of the ICM plan) and the Whakakai catchment (which was used as a control or reference catchment where the land use remained unchanged). The pre- and post-ICM treatments for the key Mangaotama and Whakakai sites are presented in Table 3-1.

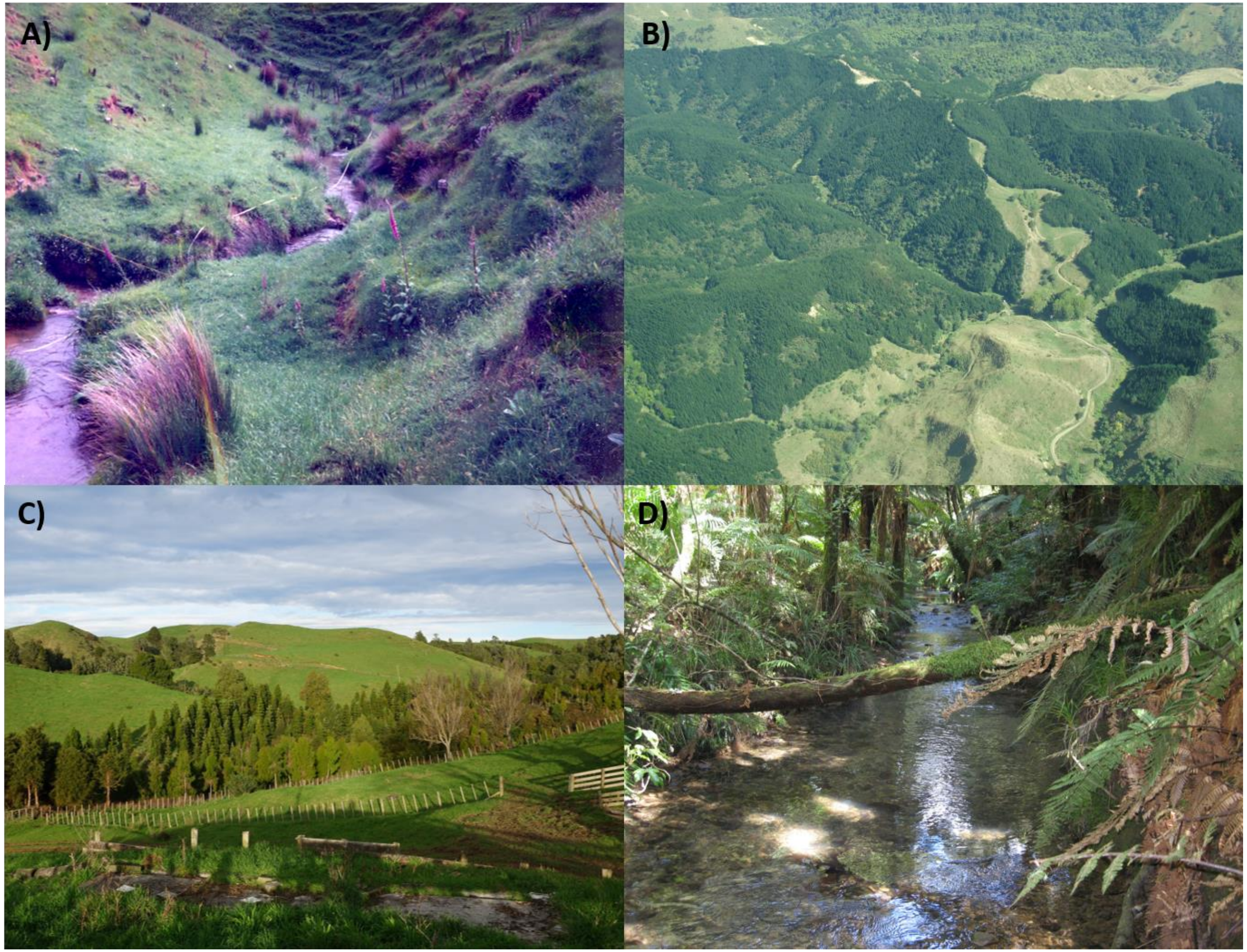

Figure 3-1: Whatawhata Research Station images. A) typical pre-ICM pasture stream conditions, B) upper Mangaotama catchment pine plantation, C) riparian areas planted in native trees (20 years after planting), D) stream reach within the native forest Whakakai catchment.

Table 3-1: Key monitoring sites within the Whatawhata Research Station.

Site	Catchment	Catchment area (ha)	Pre-ICM land cover %pasture:%pine: %native	Post-ICM land cover %pasture:%pine: %native	Main ICM changes
PW2	Mangaotama	95	100:0:0	0:100:0	Pine plantation (100%); all livestock excluded
PW3	Mangaotama	49	100:0:0	63:36:1	Cattle (not sheep) excluded from riparian areas; pine plantation (36%)
PR1	Mangaotama	34	100:0:0	58:42:0	Pine planation (42%); limited livestock exclusion
PR2	Mangaotama	27	93:2*:5	70:0:30	Large area of native riparian planting; all livestock excluded from planted riparian area
PW5	Mangaotama	268	99:0:1	38:58:4	Pine plantation (58%); Cattle (not sheep) excluded from riparian areas This site is the most downstream catchment site – therefore it encompasses all the land use changes described for PW2, PW3 and PR2
NW5	Whakakai	311	0:0:100	0:0:100	Native forest control site - No land use change

*Eucalypt and pine

3.1.1 Water quality

Monitoring of a number of water quality variables occurred continuously from 1995 to 2020. With the exception of sites PR1 and PR2 (where sampling commenced in September 2000) water quality samples were collected from each site on a monthly basis beginning in April 1995. Sampling took place regardless of flow/weather conditions and occurred at approximately the same time of day during each visit. This type of sampling tends to mostly intercept baseflow conditions, particularly in small catchments where the duration of most storm flow events is short and the probability of a monthly visit intercepting high flows is low.

Once collected, water samples were promptly place out of light and chilled in an insulated storage bin containing an ice slurry. Samples were delivered to the NIWA—Hamilton Water Quality Laboratory on the day of collection. Samples were analysed for a number of measures of water quality, including forms of nitrogen and phosphorus, turbidity, suspended sediment and dissolved organic carbon. During monthly site visits stream temperature measurements were taken and water clarity was measured using the black disc visibility method. A full list of the variables measured is presented in Table A-1.

3.1.2 Invertebrate community data

Benthic macroinvertebrates were collected with a Surber sampler (0.04 m^2, 250 µm mesh net) from 10 randomly selected points within each designated study reach (100–120 m). The ten samples were composited and preserved in 70% isopropyl alcohol.

The samples were sorted and identified in the laboratory. Invertebrate sampling was conducted twice annually, in the spring and autumn. The species abundance counts from the two samplings were averaged to obtain a yearly measurement.

Here we used the macroinvertebrate data to determine: i) species richness, and ii) the quantitative macroinvertebrate community index (QMCI). Species richness is the number of species present at a site. The QMCI is an index is a measure of ecosystem health based off what macroinvertebrates are present. The QMCI assigns a number to each macroinvertebrate species based on its sensitivity to organic pollution. Species are graded a number between 1 (extremely tolerant) and 10 (highly intolerant). The index calculates an average score weighted by abundance of each species. Higher QMCI scores generally indicates healthier streams.

3.1.3 Stream shade measurements

Shading of streams, particularly by riparian trees, strongly influences stream ecology, notably by limiting the growth of aquatic plants and algae and limiting solar heating of the stream water (reducing the high temperatures that stress fish and stream insects) (Davies-Colley & Rutherford 2005, Hughes et al. 2020). Shading of stream reaches was measured at both bank and stream-water level during 2 yearly surveys using a LI-COR LAI-2000 canopy analyser sensor which captures light from the whole upper hemisphere via a fish-eye lens. The canopy analyser sensor was used to measure diffuse light exposure at 20 pseudo-random points over the stream reach while an identical reference sensor logged incident diffuse lighting on a nearby hilltop. The ratio of stream lighting to incident lighting, over the upper hemisphere, was used to calculate the proportion of completely diffuse incident lighting so as to provide an index of time-averaged total lighting and the complement of shade (Davies-Colley & Payne 1998).

Unfortunately, the canopy analyser measurements did not start until 2007, so development of riparian shade during the first 5 years of ICM was not characterised. However, initial shade levels of study stream reaches in 2001, just prior to ICM, were assumed (reasonably) to be the same as those measured by Rob Davies-Colley at the stream sites within the WRS in *ca.* 1994.

3.1.4 Stream hydrology

Stage height has been recorded since February 1994 at Whakakai and since December 1992 at Mangaotama (NW5 and PW5, respectively on Figure 2-2). Stage height was measured by NIWA Hydrologger water level recorders (1 mm resolution). Mangaotama has a composite rectangular weir at its outlet while Whakakai has a bedrock control immediately upstream of a small waterfall. Both sites have stage/discharge ratings that have been determined by manual gaugings over a good range of water levels. More detailed information on measurement of stream hydrology can be found in Hughes et al. (2020).

3.1.5 Suspended sediment loads

At both the Mangaotama and Whakakai end-of-catchment monitoring sites (i.e. PW5 and NW5, respectively) turbidity was recorded continuously (at 15-minute intervals) between 1998 and 2010 by Greenspan TS300 turbidity sensors (nominal range 0 – 1000 NTU). Storm event suspended sediment samples were obtained at irregular intervals between March 1999 and January 2011 at Mangaotama and during 2010 at Whakakai. Site-specific regression relationships between field turbidity and total suspended solids (TSS) concentration were used to convert the turbidity time series to a TSS time series. The continuous flow record for the sites and these TSS data were used together determine total suspended sediment loads. More detailed information can be found in Hughes et al. (2012).

3.1.6 Fish data

Fresh water fish surveys were carried out at 14 sites (within the three sub-catchments) on seven occasions (2000, 2001, 2002, 2007, 2008, 2012, and 2021). The surveys were carried out at a number of the water quality sampling sites but supplemented by other sites to better reflect other factors that can influence fish distributions (Figure 3-2).

Multi-pass electric fishing was used to sample the fish in order to estimate population densities. Where sampling was restricted to a single pass, the total number of fish captured per species was taken as the population. This may have underestimated true population size at these sites/times. Common bullies and Cran's bully were treated as a single group of fish for density analysis as their ecological role and habitat requirements in these streams will be almost indistinguishable.

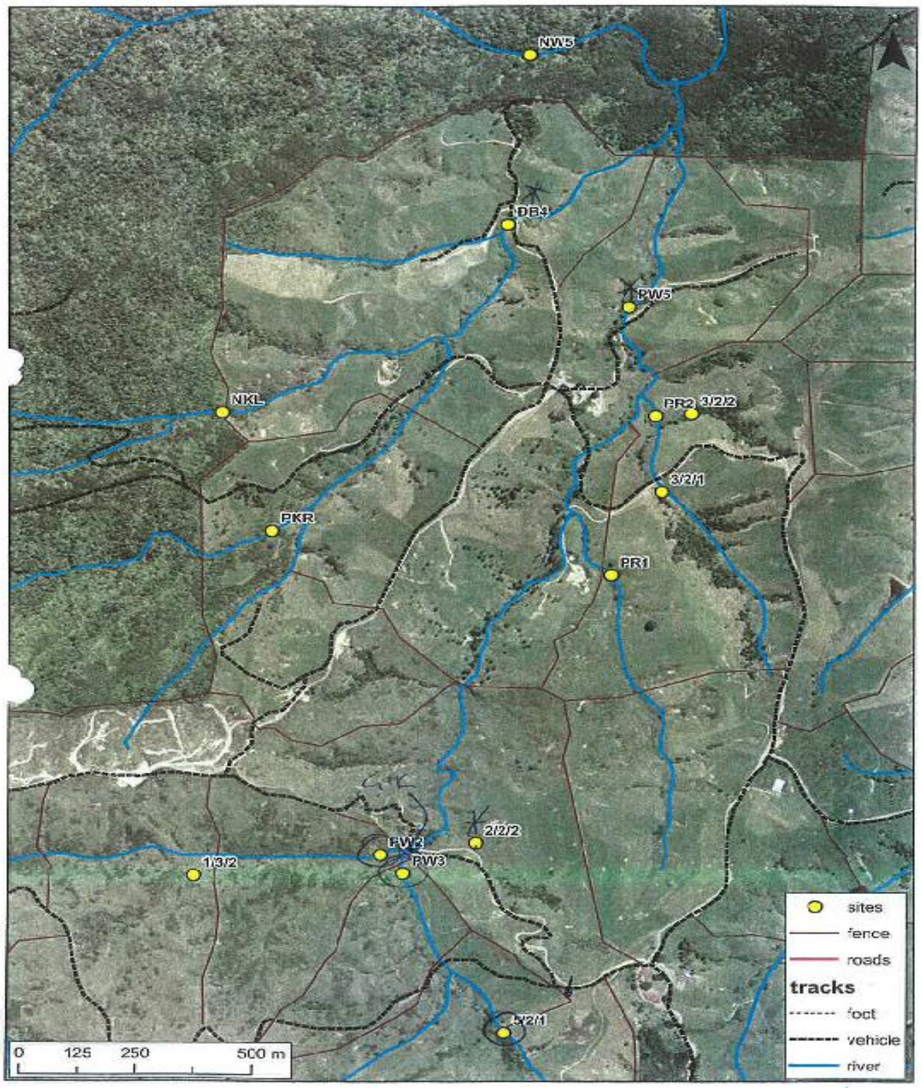

Figure 3-2: Whatawhata fish sampling sites.

4 Key findings

There are over 25 years of data from multiple monitoring sites within the three sub-catchments at the Whatawhata Research Station. Because of the volume of these data, it is not practical or desirable to present every finding in this report. Here we will present some key findings from the main monitoring variables. Where there are other publications that contain more detailed information on a topic they are referred to in relevant sub-sections

4.1 Water quality

Table 4-1 provides a summary of median concentrations of each of the measured forms of nitrogen (N)and phosphorus (P) for the before and after- ICM periods for the entire study period. The difference in median concentration between the pre-ICM and post-ICM periods is colour coded (see the figure caption). It is not the purpose of this report to describe in detail what all these data mean. Detailed accounts of the water quality response to the ICM changes can be found in previous publications (e.g., Quinn & Stroud 2002, Quinn et al. 2009, Hughes & Quinn 2014). The important thing to note is that some things have 'improved' (indicated by decreases in concentration) while other things have 'degraded' (indicated by an increase in concentration) while others have remained the same. It is also worth noting that while a statistically significant difference has been detected between the pre-ICM and post-ICM median concentrations, in many cases the actual change is very small. Many of these changes are so small that in reality it makes very little difference and would most probably have no measurable ecological effect. Evidence of this is that all but one of the median values for ammonium and nitrate are better than the A attribute band (a healthy and resilient state with minimal toxicity on aquatic species) indicated in the National Policy Statement for Freshwater Management (NPS-FM) (Table 4-1). Furthermore, all the median concentrations are well within the national bottom lines[1] indicated in the NPS-FM.

Our findings illustrate that the water quality response to catchment land use changes is complex, with some measures of water quality appearing to improve in response to the land use changes while others appear to have remained static or even degraded. This is sort of response is something that has also been noted in overseas studies (e.g., McKergow et al. 2003, Muller et al. 2015). The take home lesson here is that the response of water quality to catchment restoration measures is complex, and we cannot necessarily expect all measures of water quality to improve immediately.

[1] National bottom lines are the nationally set (by the NPS-FM) minimum acceptable states for ecosystem health and human health for recreation

Table 4-1: Median concentrations of various water quality variables during the pre- and post-ICM periods. Change (%) indicates the percentage difference between the pre- and post-ICM periods. All concentration data are reported in micrograms per litre (µg/l). Green indicates a statistically significant decrease in median concentration between the pre-and post-ICM periods. Red indicates a statistically significant increase in median concentration between the pre-and post-ICM periods. Blue indicates no statistically significant change in median concentration between the pre-and post-ICM periods.

Site	Ammonium (NH4-N)	Nitrate (NO3-N)	Total organic nitrogen (TON)	Total nitrogen (TN)	Dissolved reactive phosphorus (DRP)	Total phosphorus (TP)
PR1						
Pre-ICM	8	54	177	286	5	17
Post-ICM	13	258	171	453	5	25
Change (µg/l)	5	204	-5.5	167.5	0	8
Change (%)	63	378	-3	59	0	47
PR2						
Pre-ICM	9	101	153	264	11	32
Post-ICM	8	273	127	404	14	39
Change (µg/l)	-1	172	-26	140	3	7
Change (%)	-11	170	-17	53	27	22
PW2						
Pre-ICM	13	450	192	658	20	47
Post-ICM	10	1350	140	1515	40	68
Change (µg/l)	-3	900	-52	857	20	21
Change (%)	-23	200	-27	130	100	45
PW3						
Pre-ICM	16	753	210	1113	29	61
Post-ICM	11	919	136	1070	30	58
Change (µg/l)	-5	166	-74	-43	1	-3
Change (%)	-31	22	-35	-4	3	-5
PW5						
Pre-ICM	11	399	195	584	14	38
Post-ICM	10	793	135	958	17	44
Change (µg/l)	-1	394	-60	374	3	6
Change (%)	-9	99	-31	64	21	16
NW5						
Pre-ICM	3	102	70	188	41	52
Post-ICM	3	94	52	149	43	54
Change (µg/l)	0	-8	-18	-39	2	2
Change (%)	0	-8	-26	-21	5	4

Table 4-2: The National Policy Statement for Freshwater Management A band attribute state and national bottom line concentrations for ammonium and nitrate in New Zealand rivers.

NPS-FW attribute state	Ammonium (µg/l)	Nitrate (µg/l)
'A' band	<30	<1000
National bottom line	240	2400

A couple of particularly interesting water quality findings are the response of both nitrate and ammonium (both forms of nitrogen that are undesirable if present in excessive levels) at the PW2 site. In 2001 the land upstream of the PW2 site was planted completely in pine and all livestock were removed from the area. Figure 4-1 shows the ammonium response at the PW2 site (A) and the NW5 native forest site (B). In the pre-ICM period at PW2, the ammonium concentrations are quite variable with some high concentrations recorded. We interpret this to be due to the unrestricted access of cattle to the streams and the high ammonium is derived from cattle urinating directly in (or near) the stream channels. In contrast, ammonium concentrations during the post-ICM period for PW2 and the entire record for the native forest site (NW5) are less variable and there were no high concentrations as there are no cattle present.

Figure 4-2 shows the nitrate response at the PW2 site (A) and the NW5 native forest site (B). In the pre-ICM period at PW2, the nitrate concentrations are stable and low. However, after the ICM changes (stock removal and planting pines) the nitrate concentrations began to trend upward. The nitrate concentrations at the native forest site (NW5) over the same period were consistently low with no trend either up or down. The increased nitrate concentrations at PW2 were attributed to several factors:

i) the concentrating effect of less water making it to the stream due to interception of rainfall by growing pine forest,

ii) the reduction of instream nutrient uptake by macrophytes and periphyton due to increased riparian shading,

iii) uncontrolled growth of a nitrogen fixing weed (gorse) in some parts of the catchment, and

iv) the reduction in the nutrient attenuation capacity of seepage wetlands due to the decrease in areal coverage of seepage wetlands in response to afforestation.

This increase in nitrate concentrations observed at this site is a good example of how the water quality response of land use changes can be complex. In some circumstances (because of site specific conditions) mitigation measures may not result in an immediate and positive impact.

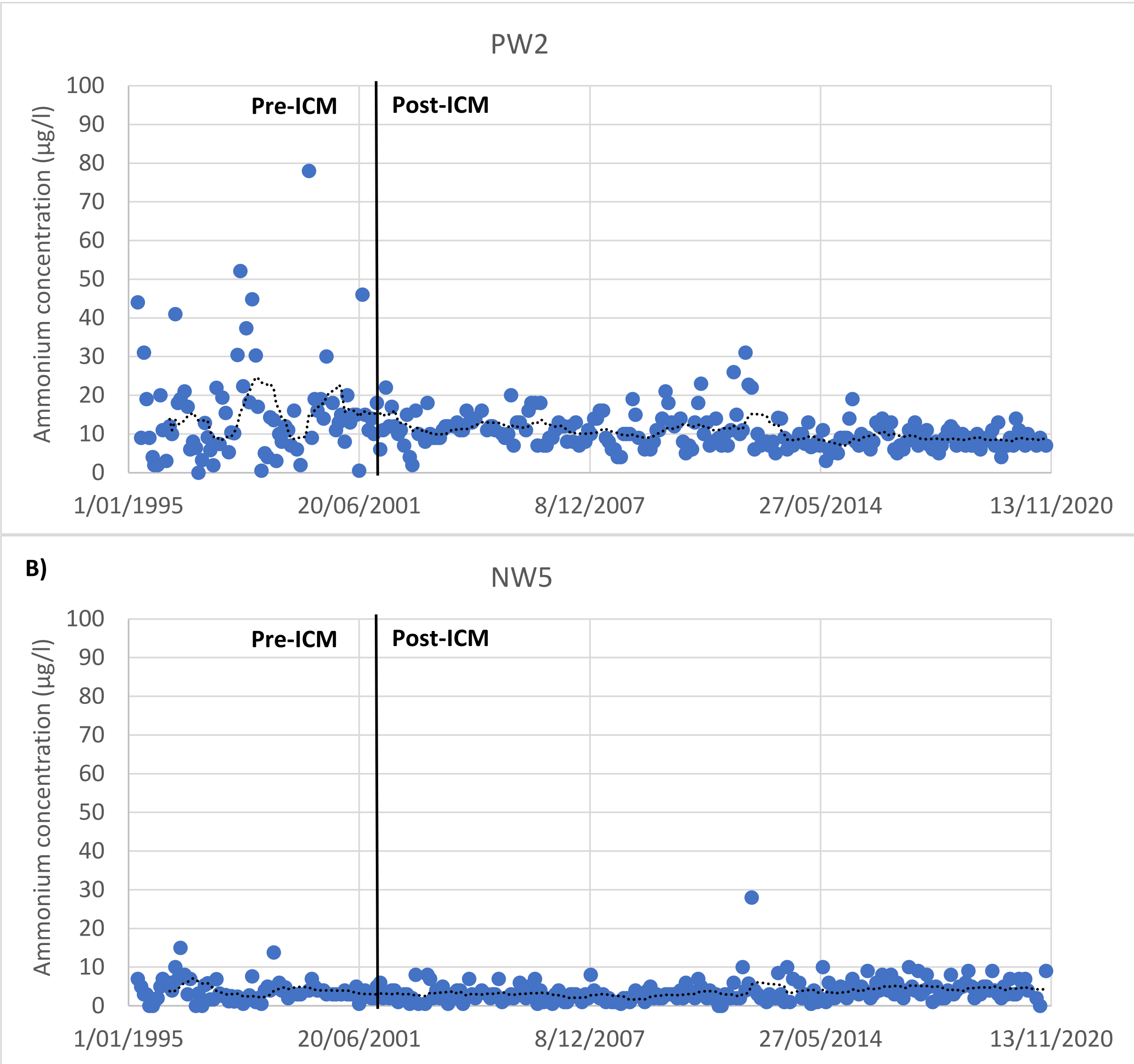

Figure 4-1: Monthly ammonium concentration data for a) the PW2 site, and B) the NW5 (native forest) site.

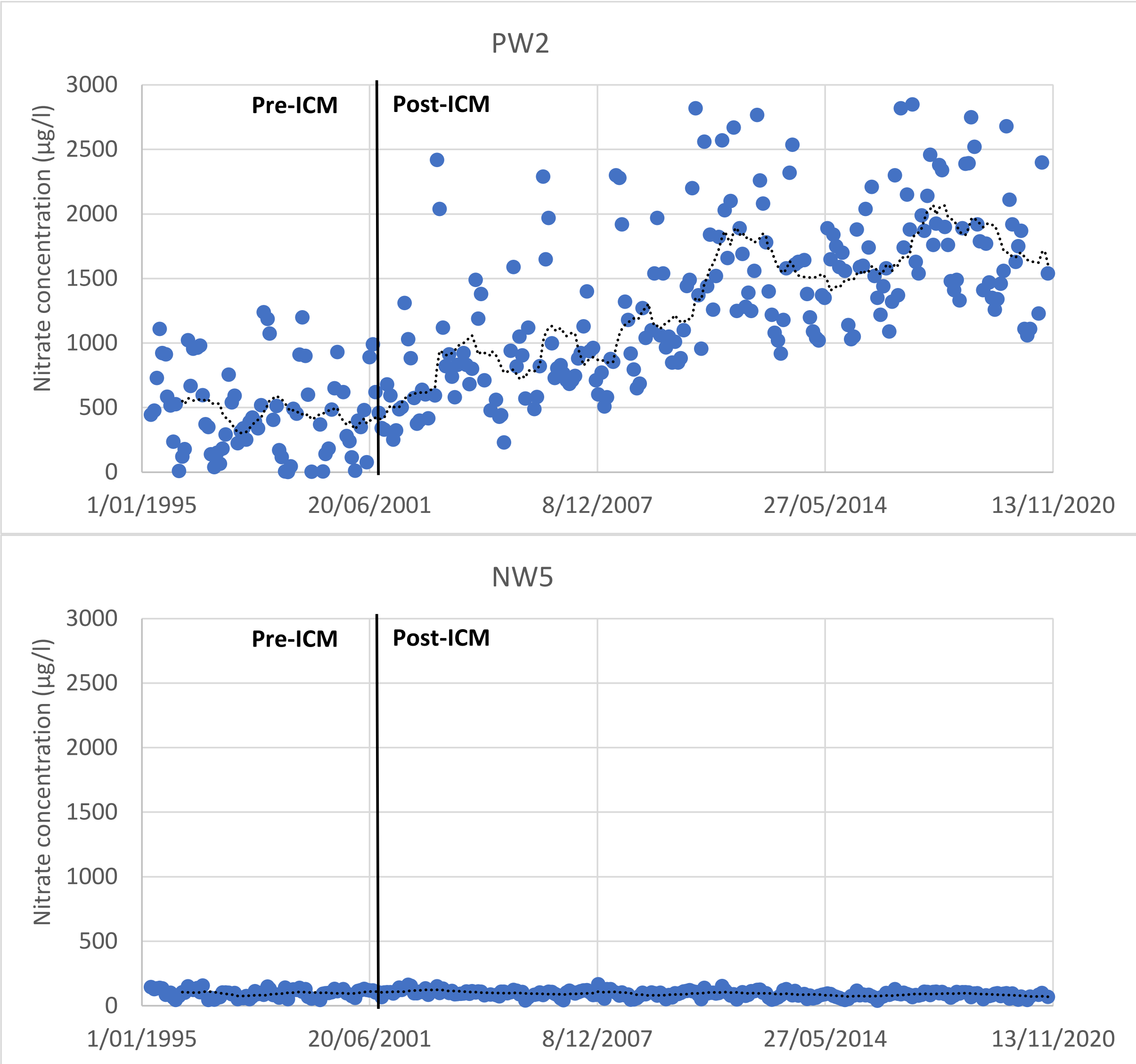

Figure 4-2: Monthly nitrate concentration data for a) the PW2 site, and B) the NW5 (native forest) site.

Visual clarity of stream water

Visual clarity (VC) is the attribute used by the National Policy Statement for Freshwater Management to describe the suspended matter content of water. This measure is used as it is both easily and precisely measured. The water VC at many of the key sites has not improved as much as may have been expected (Table 4-3) (NB: an increase in VC indicates and improvement). At two of the experimental sites, PW3 (with cattle exclusion and poplar planting in its sub-catchment) and possibly PW5 (with a mix of catchment treatments), improvements in VC occurred after ICM, although the changes were rather modest. However, at PW2 (pine plantation), VC seems to have changed little following ICM, while at PR1 (42% pine) and PR2 (native plantings) VC seems to have worsened after ICM. Visual clarity also appeared to have improved at the native reference site (NW5).

Table 4-3: Pre- and post-ICM median visual clarity at monitoring sites.

ICM period	PW2	PW3	PR1	PR2	PW5	NW5
Pre-ICM clarity (m)	0.54	0.63	1.67	0.94	0.75	1.00
Post-ICM clarity (m)	0.60	0.91	1.21	0.82	0.90	1.34

There are a number of factors that may have contributed to this lack of improvement in the VC of the streams within the Mangaotama catchment (Davies-Colley & Hughes 2020). Reduced livestock, particularly cattle, disturbance of soils and channels is expected to improve VC immediately after ICM treatment – consistent with the improvement seen at PW3. However, this improvement seems to have been negated to a greater or lesser at other sites by reduced pasture ground cover under the developing shade of riparian tree planting, permitting increased generation of suspended particular matter (e.g., sediment and organic material) until 'forest' (shaded) ground cover and soil conditions slowly develop over many decades. Visual clarity is expected to further worsen in the Mangaotama ICM catchment for the next several decades as stream banks erode and channels widen in response to increased shade, before rehabilitated streams finally approach riparian soil, ground cover, channel morphology and water quality regimes characteristic of mature forest (Davies-Colley & Hughes 2020). But even in the long-term, VC may improve rather 'unspectacularly' considering that a nearby native forested control stream (NW5) is not markedly clearer than at formerly pasture ICM experimental sites (Table 4-3).

More detailed information on the impact of the ICM land uses changes on stream visual clarity are available in Davies-Colley and Hughes (2020).

4.2 Stream shade and temperature

Figure 4-3 shows the progressive development of vegetative shade over streams (at bank level) at key monitoring sites. In 2018, 16 years after ICM, the shade of 'treatment' reaches was already quite high, approaching that characteristic of native forest (about 97% as measured along the Whakakai Stream upstream of NW5). Heavy shade by native plantings rapidly established over the small stream upstream of PR2, but shade developed more slowly over the larger channel in the PW5-native reach. Even the spaced poplar plantings in the study reach above PW3 provided appreciable shade by 2018 (~90% when in leaf). The fairly slow development of shade under pines upstream of PW2 reflects the 10 m unplanted setback either side of the channel, and the dip in shade measured in 2011 is attributed to pine thinning in two phases about 9 years after ICM planting.

The significance of stream shading is that it creates conditions that are closer to that of undisturbed (forested) streams and hence provide conditions that are more suitable to native instream aquatic organisms (such as macro-invertebrates and fish). Shade creates more cover for instream fauna and also lowers the stream temperature. A study of stream characteristics and the invertebrate populations of paired reaches in Waikato pasture and riparian restored reaches found that a change in invertebrate populations toward native forest communities was strongly linked to reductions in stream temperature and associated high canopy cover (Parkyn et al. 2003). In the longer-term, the presence of riparian vegetation also provides a source of wood and other material that will fall into the streams and create more diverse aquatic habitats. Our measurements of stream temperature at the key monitoring sites show the impact of riparian planting on stream temperature at the key monitoring sites (Figure 4-4). All the key monitoring sites (Figure 4-4) have recorded reductions in stream temperature, with site PR2 and PW5 now experiencing stream temperatures close to that of the Whakakai native forest reference site.

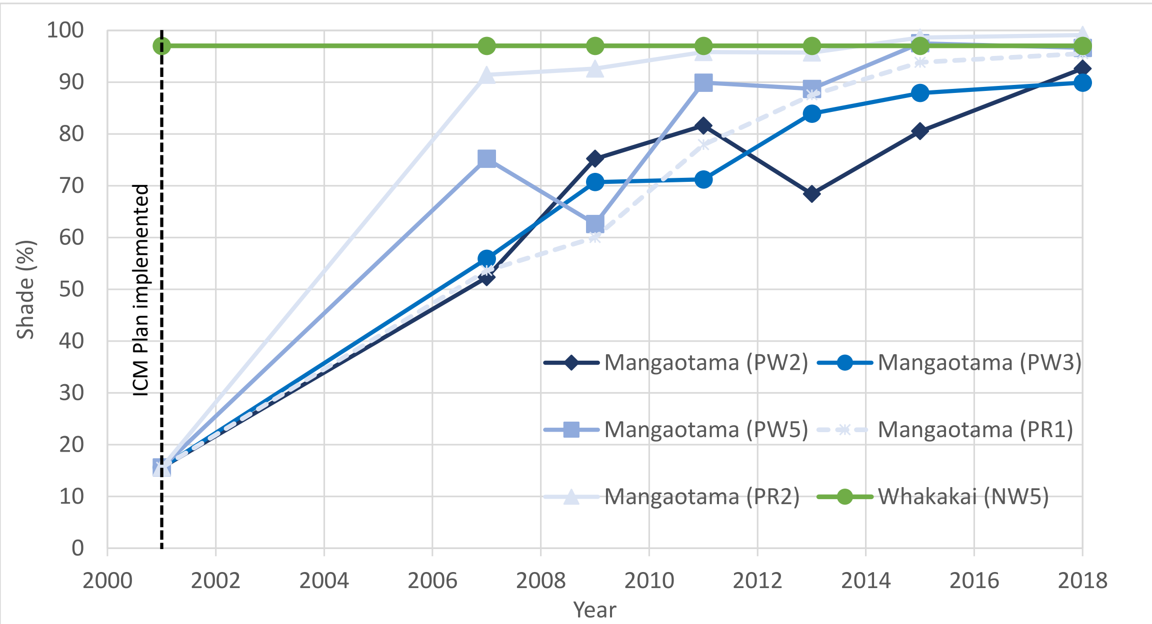

Figure 4-3: Change in channel shade at key Whatawhata monitoring sites over the post-ICM period.

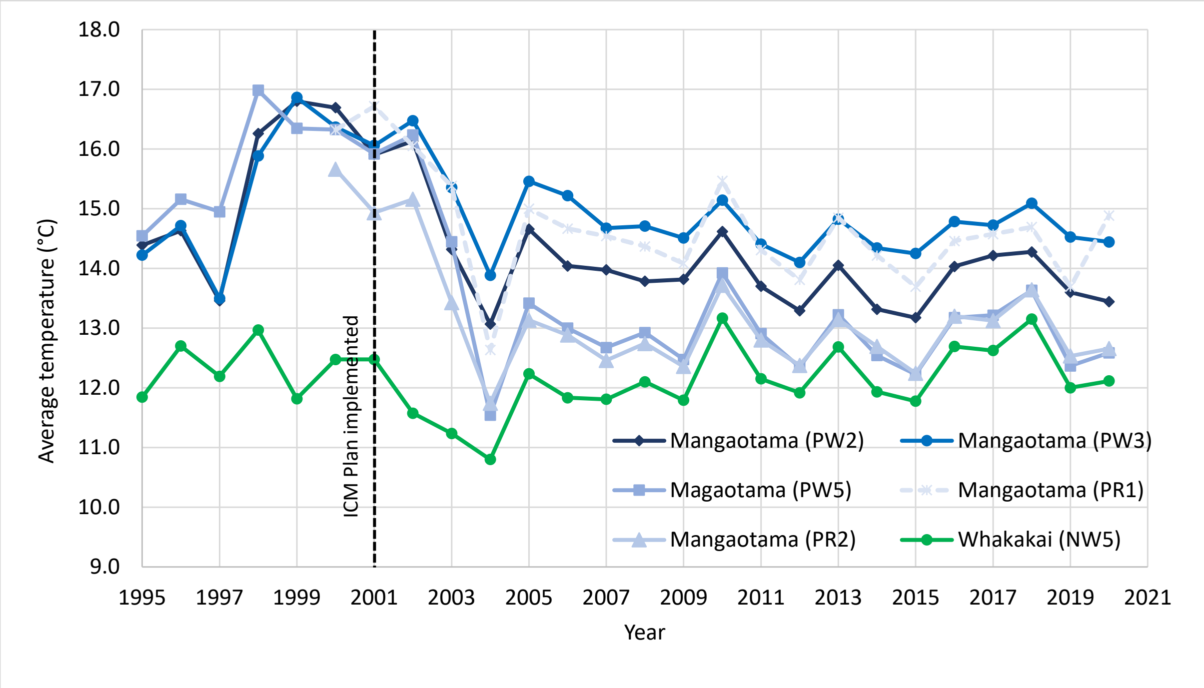

Figure 4-4: Average annual stream temperature for key Whatawhata monitoring sites (1995-2020).

4.3 Suspended sediment loads

Figure 4-5 shows the specific suspended sediment yield (mass of sediment (tonnes) exported from the catchment per unit of area (km^2)) for the Mangaotama and Whakakai catchments. The ICM-related land use changes took place in the Mangaotama catchment in 2001 while the Whakakai catchment is the native forest catchment where the land use has remained unchanged. There are two notable features of the data in Figure 4-5. Firstly, there was no apparent decrease in sediment yield at Mangaotama after the catchment wide land use changes - the average yield for the pre-ICM period (1999-2000) was 94 t/km^2/y while it was 101 t/km^2/y for the post-ICM period. Secondly, the yield from the Whakakai catchment is consistently lower than the Mangaotama catchment. The specific sediment yield from Mangaotama (97 ±39 t/km^2/year) was around 60% higher than Whakakai (60 ±22 t/km^2/year).

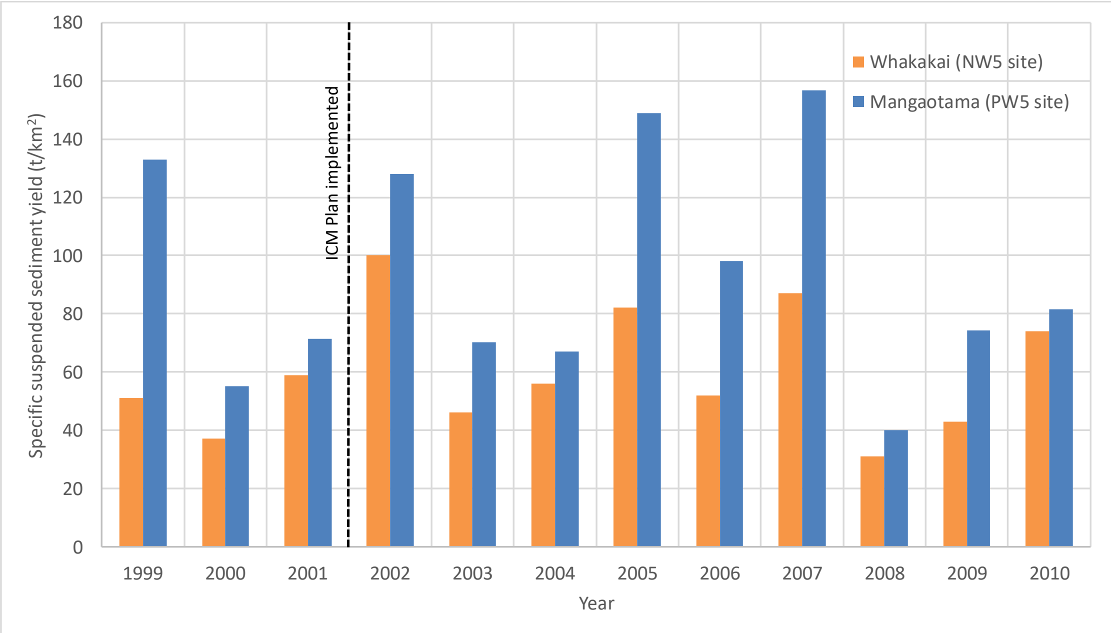

Figure 4-5: Annual specific suspended sediment yield for the Mangaotama and Whakakai catchments (1999-2010).

The absence of a detectable reduction is sediment yield at the Mangaotama catchment is perhaps surprising given the large-scale catchment changes that took place, many of which were aimed at reducing sediment delivery to streams (e.g., poplar planting, pine planting on steep degraded land and exclusion of cattle from riparian areas). However, the lack of much pre-ICM sediment yield data makes it problematic to assess the effects on sediment yield of the ICM changes. There are only two pre-ICM years of data (1999 and 2000) and both of these years had below average rainfall. Furthermore, there were no sizeable flow events at either site during 2000. There is typically a close relationship between the magnitude of the largest event occurring during a year and annual sediment yield. Accordingly, the fact that the average yield calculated for the pre-ICM period is about the same as that calculated for the post-ICM period should not necessarily be interpreted as the ICM changes having no impact on sediment yield. As previously noted by Hicks (1994), what it does demonstrate is the need to treat average annual yields calculated over short time periods with some caution, because inter-annual variability in sediment yields can be high. Further suspended sediment load data can be found in Hughes et al. (2012).

Previous limited research in New Zealand that used a paired catchment approach has found that pasture catchments typically export c. 2-5 times more sediment than an equivalent catchment under mature forest (Dons 1987, Fahey & Marden 2000). The relatively small contrast in the annual specific sediment yields between our two study catchments (Mangaotama vs Whakakai) compared to previous studies can probably be attributed to the fact that for most of the study period the Mangaotama catchment was a mixed land use catchment with almost 60% of its catchment area under first rotation pine plantation or native plantings. Low average yields within Mangaotama maybe partially attributed to the fact that only one event exceeding the 5- year return period occurred during the study period. It is during large events that the greatest difference in sediment yields between the two catchments occurs, possibly due to the initiation of mass movement on the pasture hillslopes (see slope stabilisation section below).

4.4 Slope stabilisation

It is widely accepted that the presence of trees on steep hillslopes can provide protection from some forms of erosion. The pines within the Mangaotama catchment were planted on hillslopes that were known to be subject to excessive erosion. The actual measurement of how effective trees can be at preventing erosion can be difficult and in fact has rarely been done in New Zealand catchments. A storm on 6 February 2007 provided a test of the effectiveness of the ICM tree planting. A rainfall gauge in the middle of the study area recorded 110 mm of rainfall over 8 hours, with 97 mm falling in a four hour period within this event. Farm staff reported significant land-slipping in some steep areas in pasture at the bottom of the Mangaotama catchment and in areas of an adjacent catchment. A reconnaissance flight in March 2007 showed the benefits of pine planting in preventing landslips.

- Thirty landslips were recorded in 203ha of pasture in the Mangaotama and Kiripaka catchments (Figure 4-6).
- No landslips were observed in 126 ha of established native forest within the Kiripaka catchment or in adjacent fully forested catchments.
- Only 2 slips were observed in 180 ha of 6 year old pine planted in the Mangaotama catchment, with 1 further slip in an area of gorse within a pine-planted area.
- There were 4 significant slips an area of 6 year old native shrubs and trees (area above PR2 site).

This demonstrates the benefits of planting pine for rapidly enhancing the stability of rolling-to-steep hill lands.

Figure 4-6: Pasture-based landslips as a result of the February 2007 storm event. (Photo: John Quinn).

Further details on this semi-quantitative assessment of the role pine forest in stabilising hillslopes at the WRS are presented in Quinn and Basher (2007).

4.5 Stream flow

To determine the effect of afforestation on annual runoff, runoff for the Mangaotama catchment, if it had remained in pasture, was predicted. This was done by developing a regression relationship between annual runoff at Mangaotama and Whakakai for the pre-planting period (1994–2001; Figure 4-7). This relationship was then applied to the post-2001 annual runoff data from Whakakai to provide predictions of pasture-based runoff.

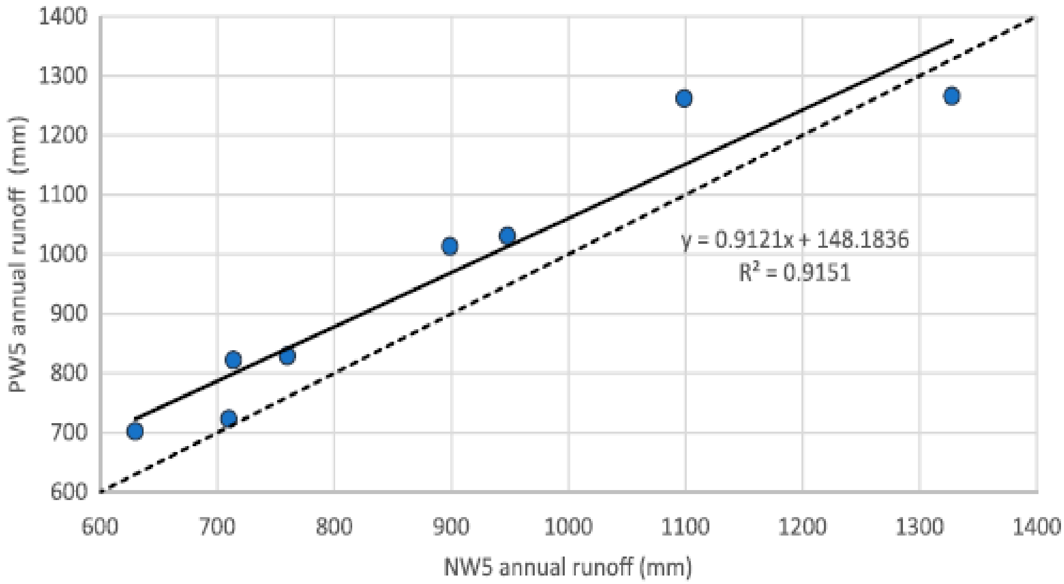

Figure 4-7: Relationship between annual runoff at Mangaotama (PW5) and Whakakai (NW5) for the 8-year pre-planting period (1994–2001). The dashed line is a 1:1 curve for reference.

Figure 4-8 shows the difference between in annual runoff (stream flow) between the actual post-ICM runoff and that predicted should it have remained totally in pasture. It shows that from 2003 the measured runoff at Mangaotama was consistently lower than the predicted pasture-equivalent runoff. Between 2003 and 2008, when the pine trees were growing vigorously there was a gradual increase in the difference between measured and predicted runoff, with a peak at 380 mm in 2008 (seven years after forest planting). As the average runoff within the Mangaotama catchment during the pre-ICM period was around 1000 mm, the 380 mm reduction equates to around a 38% reduction in the total amount of water flowing in the stream. The removal of trees during two phases of pine thinning (a common forestry practice aimed producing high quality timber) resulted in more runoff being generated. As noted in other New Zealand studies, the reduction in flow is likely to be largely the result of interception of rainfall by the dense forest canopy. This intercepted flow is largely lost to evaporation.

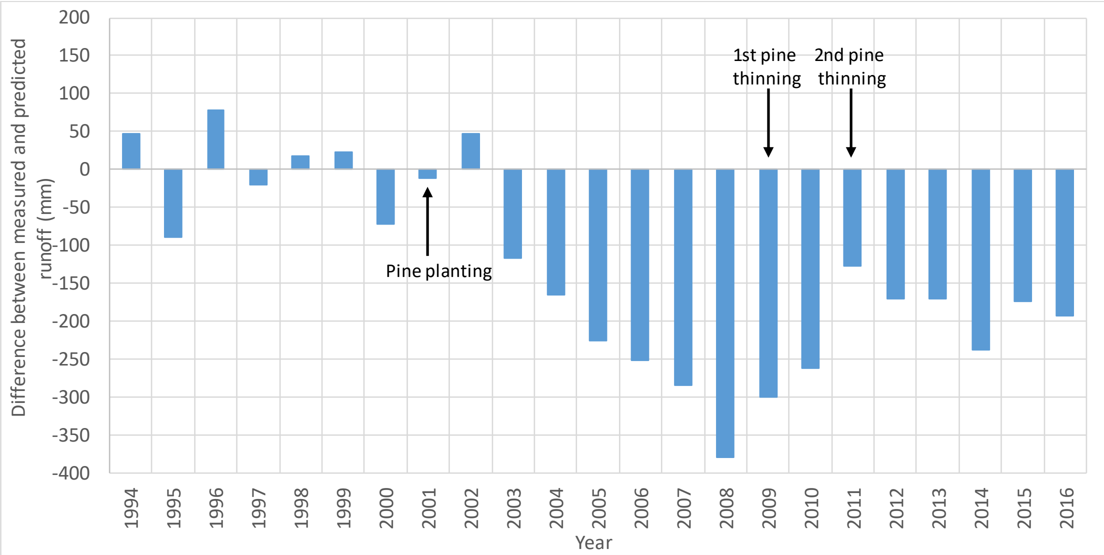

Figure 4-8: **Difference between measured and predicted annual runoff for the Mangaotama catchment.**

The impact of afforestation on peak flows was assessed by comparing mean peak flows for the pre-planting period (1994–2001) with a post-canopy closure period (2009 to 2016) (Figure 4-9). Details of this analysis are presented in (Hughes et al. 2020).

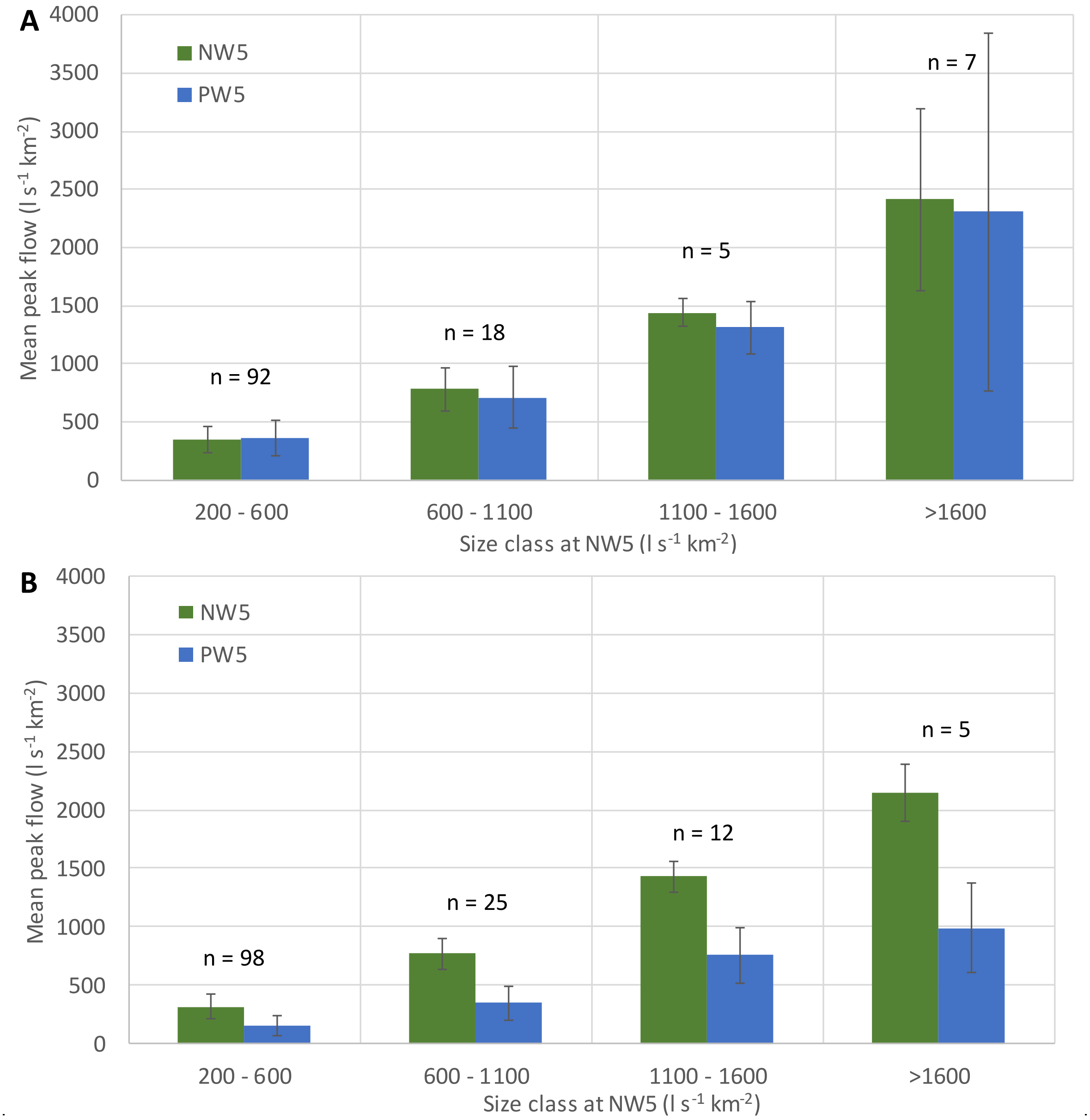

Figure 4-9: Event peak flows (mean ±1 standard deviation) for four event size classes for A) the 8-year pre-planting period (1994–2001) and B) for the 8-year post-planting period after 8 years of plantation forest growth (2009–16) for Mangaotama (PW5) and Whakakai (NW5).

For all flood event sizes, the afforestation reduced peak flows by about half. This is a significant change in the stream's hydrology with it resulting in fewer large damaging flood events. The main observed outcome of this is the less damage experience to farm infrastructure (e.g. fencing, culverts) during this time.

As found in other New Zealand studies (e.g., Duncan 1995, Fahey & Payne 2017) afforestation within the Mangaotama catchment has also reduced the amount of water flowing in the river during low flows (i.e. extended periods with no flood events). The pattern for the change in low flow is less certain than for the reduction in total flow and peak flows but the afforestation appears to have reduced low flow volumes by about 25%. This is similar to the reductions in low flow noted in the other New Zealand studies.

More detailed information on the hydrological impact of the ICM land uses changes are available in (Hughes et al. 2020).

4.6 Aquatic Macroinvertebrates (instream animals, excluding fish)

Figure 4-10 and Figure 4-11, respectively, show how species richness and QMCI values have changed in each site over time, both before and after implementation of the ICM in 2001. Species richness initially increased over the first five years of sampling (before implementation of the ICM); this was likely due to additional rare taxa being caught each year as more samples were collected over time until a plateau was reached (e.g., species accumulation curve, Ugland et al. (2003)). Richness declined in all but one site in 2001, when the ICM plan was implemented. In the Mangaotama sites, this could be partly attributable to disturbance associated with restoration activities. However, a similar decline in species richness also occurred in the undisturbed native forest site (NW5) in that year, suggesting that unfavourable climatic conditions and/or hydraulic conditions (i.e. extremely warm temperatures and low flows, or high floods) were likely also a factor. After the ICM was implemented in 2001, species richness values in both Mangaotama and Whakakai remained generally lower than pre-ICM for about 10 years and then began to increase to similar to pre-ICM levels.

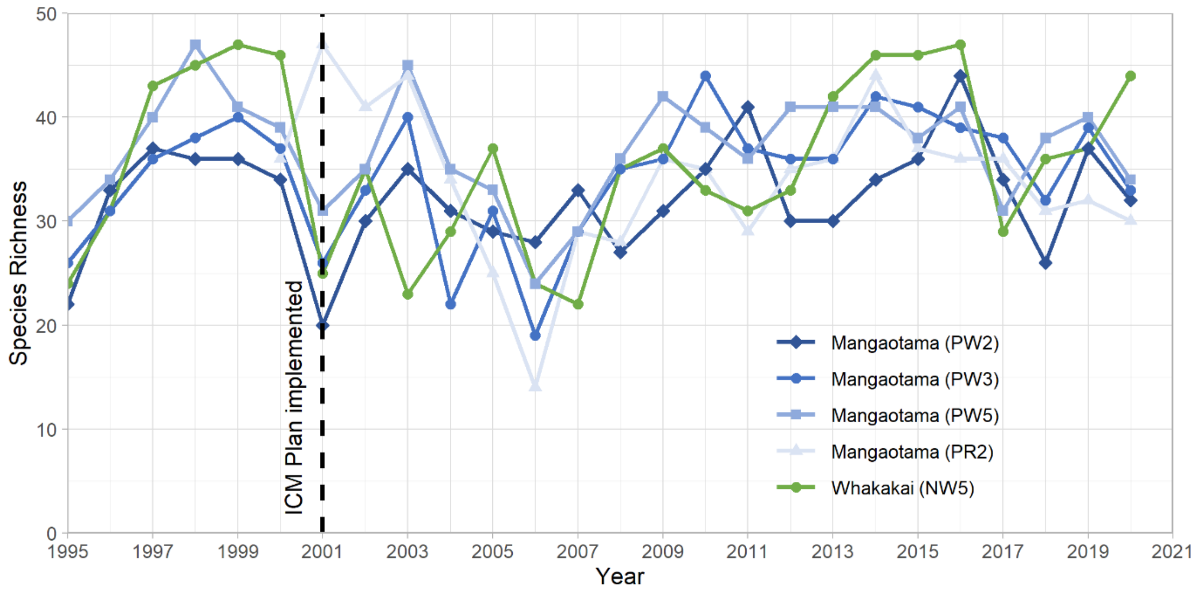

Figure 4-10: Species richness at five key Whatawhata monitoring sites between 1995 and 2020

QMCI scores were lower in the Mangaotama sites than the Whakakai site prior to ICM implementation, but have increased since then (Figure 4-11). Unlike species richness, there was no decline in QMCI scores in 2001 around the time of ICM implementation. This suggests the declines in species richness at the time was due to fewer rare taxa, which would have little impact on QMCI. Following implementation of the ICM, QMCI scores in Mangaotama streams PW2 and PW3 have increased to values similar to the Whakakai site (NW5). The interannual variability in QMCI scores in PW2 and PW3 has also declined over time. QMCI scores in the remaining Mangaotama streams PW5 and PR2, on the other hand, have remained lower and more variable year to year, though still higher than pre-ICM values.

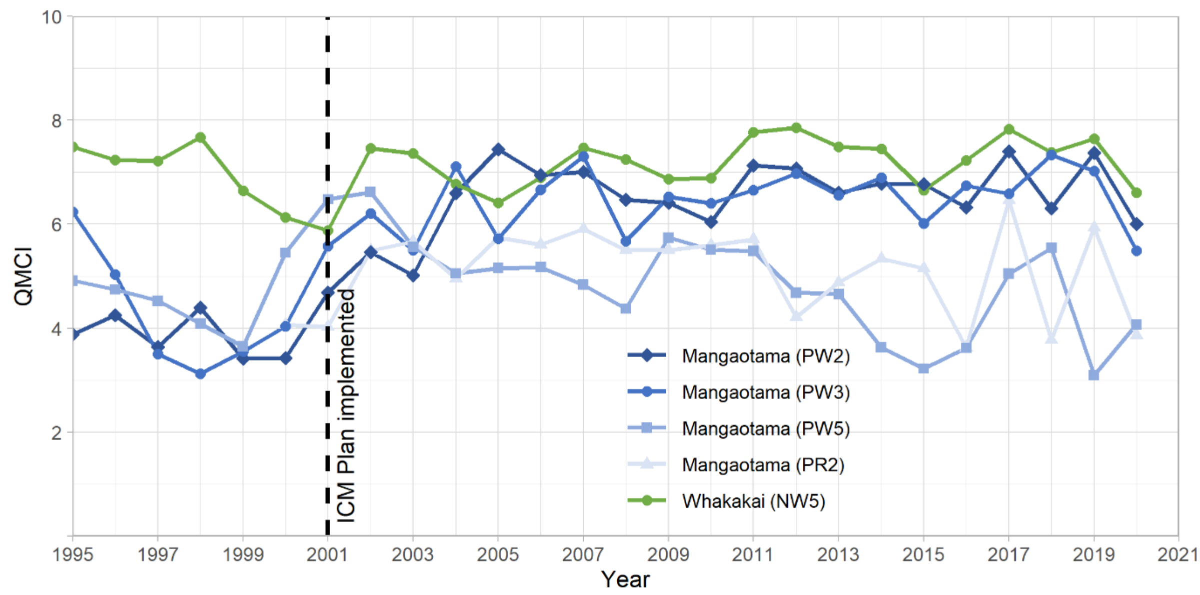

Figure 4-11: QMCI values at five key Whatawhata monitoring sites between 1995 and 2020

More detailed information on the impact of the ICM land uses changes on instream macro-invertebrate communities are available in Graham and Quinn (2020).

4.7 Fish

A total of eight fish species were recorded from the 14 sites over the period 2000 to 2012 (Table 4-4). The shortfin eel (*Anguilla australis*) was the most prevalent species being found at all sites, followed by longfin eel (*Anguilla dieffenbachii*), which were also found at the majority of sites. Three kokopu species (banded (*Galaxias fasciatus*), giant (*Galaxias argenteus*) and shortjaw (*Galaxias postvectis*)) and three bully species (redfin bully (*Gobiomorphus huttoni*), Cran's bully (*Gobiomorphus basilis*) and common bully (*Gobiomorphus cotidianus*)) were also present.

Table 4-4: Species occurrence for the 14 sites and overall occurrence for all 82 sampling events.

Species expected	No. sites where present	Overall frequency of occurrence
Longfin eel	10	0.46
Shortfin eel	14	0.78
Cran's bully	5	0.16
Common bully	4	0.10
Redfin bully	2	0.06
Banded kokopu	5	0.10
Giant kokopu	1	0.01
Shortjaw kokopu	1	0.02

Native species that could potentially be present, but that have not yet been found at these sites, include koaro (*Galaxias brevipinnis*), lamprey (*Geotria australis*), smelt (*Retropinna retropinna*), inanga (*Galaxias maculatus*) and torrentfish (*Cheimarrichthys fosteri*). At least some of the monitoring sites are within the natural range (in terms of altitude and distance upriver) for upstream migration by these species. It is likely that the absence of smelt and inanga to date reflects the presence of downstream migration barriers that prevent recruitment of these weak swimming, non-climbing species to the catchment.

The failure to detect the other species likely reflects naturally low recruitment of these species in the wider Waipa catchment and/or limited availability of suitable habitat in the sampled reaches.

No introduced fish species were found at any of the sample sites. Whereas the sites are all above the expected distributions for koi carp (*Cyprinus carpio*), catfish (*Ameiurus nebulosus*), goldfish (*Carassius auratus*), gambusia (*Gambusia affinis*) and other warm-water fish species, they are within the distributional limits for trout. The absence of trout is, therefore, unusual because rainbow trout (*Oncorhynchus mykiss*) have been recorded in the Mangaotama Stream less than 1 km below the monitoring area and are able to penetrate well upstream even in small, high gradient streams. The occurrence of natural falls below the monitoring sites, but above instream culverts can be expected to limit upstream penetration by trout.

Figure 4-12 illustrates the total fish density at the key monitoring sites between 2000 and 2012. Statistical tests carried out by Rowe and Franklin (2013) determined that total fish densities only increased significantly at PW5. Total fish densities either remained unchanged or decreased slightly at the other key sites identified in Figure 4-12. Interestingly, total fish densities were consistently lowest at the native forest site (NW5). A further fish survey that took place in December 2021. The data associated with this survey have not been analysed in detail, but it will be used (in association with the previous survey data) to assess if there has been any long-term change (i.e. 20 years since land use changes) in fish populations.

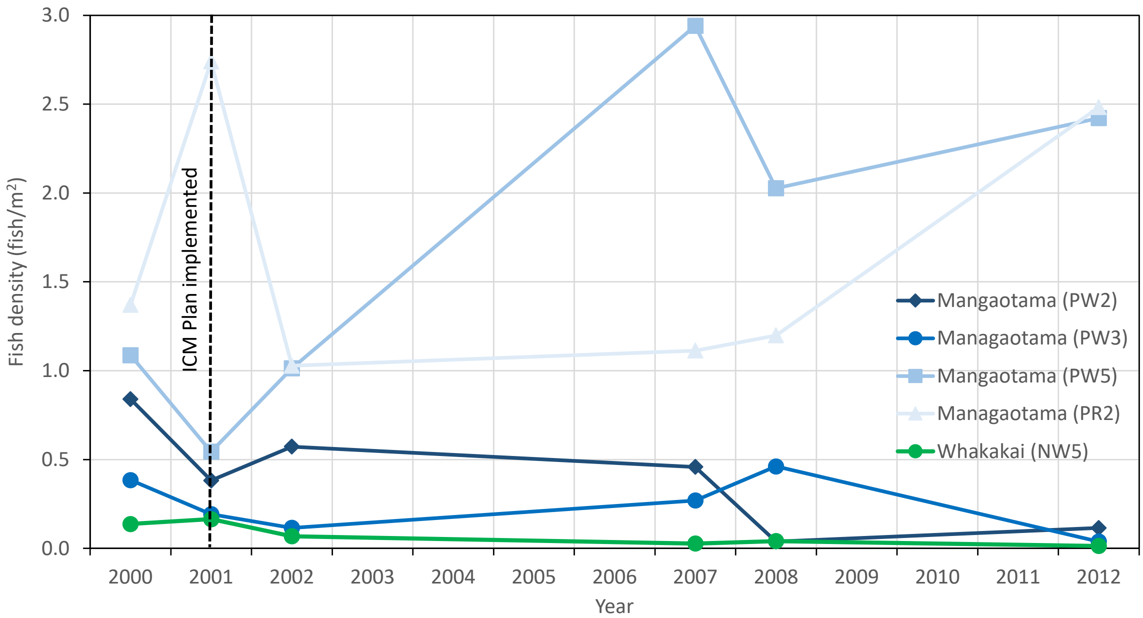

Figure 4-12: Fish density at key Whatatwhata monitoring sites (2000-2012).

5 Conclusions

The Whatawhata Integrated Catchment Management (ICM) Project is the longest continuously monitored before-after-control-impact (BACI) catchment-scale study in New Zealand. Indeed, it is probably the only such study from any location that has monitored the environmental impacts of catchment-scale land use changes over such a long period.

This report provides a brief summary of the environmental response of the ICM land use changes within the Mangaotama, within the Whatawhata Research Station. Multi-variable monitoring took place in the catchment between 1995 and 2020. Large scale land use changes occurred in 2001 when an integrated catchment management plan was implemented. With 25 years of water quality, hydrology and ecosystem health data from multiple sites within three sub-catchments there is a vast amount of information available. The purpose of this report was to present an accessible summary of the key results. More detailed information is available in the publications referred to in the text.

Perhaps the main 'take home' lesson to that has been learnt from this project is that the impact of implementing sustainable land management practices (e.g., riparian planting, cattle exclusion from streams, large-scale afforestation, etc.,) within catchments is complex. Here we show that some measures of ecosystem health and/or water quality have improved at some sites (e.g., stream temperature, macro-invertebrate populations, and water clarity) while others have remained unchanged (e.g., suspended sediment loads) or even appear to have degraded (e.g., nitrate concentrations within a catchment panted entirely in pine).

It is intuitive that when sustainable land management changes are implemented that there will be positive environmental outcomes. However, there are likely to be site-specific factors that mean that some measures of ecosystem health and water quality are likely to be responsive to some land use changes, but others are not. Land use history is also likely to play a role. In the case of the Mangaotama catchment (and also typical of many New Zealand catchments), it was cleared of its indigenous land cover over 100 years ago and agricultural land uses were implemented. Although these changes were relatively abrupt, the actual impacts of these changes are likely to have had an ongoing effect as the catchment adjusted to the new agricultural regime. It is therefore likely that any changes in land use back towards a more natural system will also take time to take affect or be detectable.

Much of the environmental monitoring within the Whatawhata Research Station has now ended. However, re-establishing monitoring in the future would be easily done. There are some land use change-related areas of research that the WRS may still be able provide valuable information on. In particular, the Station has the potential to provide information on the impact of forest harvest on stream water quality and instream ecosystem health. Determining the environmental impacts from harvesting large forest plantations has previously received little attention in New Zealand. Clearly, the clearance of forest and exposure of bare soils increases the potential for erosion, degraded water quality and ecosystem health. The historical data, site infrastructure and detailed land use history data make the WRS an ideal location to monitor the impact of forest harvest activities.

6 Acknowledgements

Many people and organisations have been involved the Whatawhata Integrated Catchment Management Project the 25 years of its existence. However, special mention needs to made of the late Dr John Quinn (former Chief Scientist of NIWA's Freshwater and Estuaries Centre). John led the establishment of an environmental study site network within the WRS in the early 1990s. John was also instrumental in ensuring that comprehensive environmental monitoring (including hydrometric sites) was maintained for ~25 years. The Mangaotama ICM plan was originally conceived and established by a catchment management group (named in Dodd et al. (2008), comprising over 20 individuals from science, policy and farming groups and Ngāti Māhanga iwi. Many NIWA staff member have been involved in data collection from the site, special mention is made here to Kerry Costley, Ralph Morse and Brian Smith. AgResearch and Tainui Group Holdings staff provided site access and cooperation throughout the study. Special acknowledgement goes to the Ngāti Māhanga as kaitiaki of the land which lies within the WRS.

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Appendix A Summary of long-term monitoring at the Whatawhata Research Station

Table A-1: Variables measured at the WRS long-term monitoring sites. The symbol ✓ indicates that monitoring for that variable took place (time period covered is indicated in the "temporal coverage" column). The **X** symbol indicates no monitoring of that variable took place.

Variable measured (unit)	Frequency	Mangaotama sites					Kiripaka sites					Whakakai	Temporal coverage
		PW2	PW3	PW5	PR1	PR2	PKR	K-Pine	Puke Seep	Puke Weir	DB4	NW5	
Hydrology (l/s)	Continuous	✓	✓	✓	X	X	X	X	X	X	✓	✓	PW5 & DB4 (1993-present); NW5 (1994-present); PW2 and PW3 (2012-2020)
Nephelometric turbidity (NTU)	Continuous	X	X	✓	X	X	X	X	X	X	X	✓	1998-2010
Acidity/basicity (pH)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Electrical conductivity (µS)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Lab nephelometric turbidity (NTU)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Total suspended solids (mg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2019
Volatile suspended solids (mg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2019
Inorganic suspended solids (mg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2019
Dissolved reactive phosphorus (µg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Total phosphorus (µg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Ammonium-N (µg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Nitrate-N (µg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Total Kjeldahl nitrogen (µg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2006
Total nitrogen (µg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2006-2020
Dissolved organic carbon (µg/l)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020
Temperature (°C)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1995-2020

Variable measured (unit)	Frequency	Mangaotama sites					Kiripaka sites					Whakakai	Temporal coverage
		PW2	PW3	PW5	PR1	PR2	PKR	K-Pine	Puke Seep	Puke Weir	DB4	NW5	
Visual clarity (m)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓	1995-2020
Coliforms (MPN/100 ml)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2001-2002, 2004-2005, 2017-2020
E.coli (MPN/100 ml)	Monthly grab	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	2001-2002, 2004-2005, 2017-2020
Invertebrate surveys	Sept & March	✓	✓	✓	✓	✓	✓	X	X	X	✓	✓	1995-2020
Water and channel width surveys	Sept & March	✓	✓	✓	✓	✓	✓	X	X	X	✓	✓	1995-2020
Water depth surveys	Sept & March	✓	✓	✓	✓	✓	✓	X	X	X	✓	✓	1995-2020
Macrophyte abundance surveys	Sept & March	✓	✓	✓	✓	✓	✓	X	X	X	✓	✓	1995-2020
Benthic sediment composition	Sept & March	✓	✓	✓	✓	✓	✓	X	X	X	✓	✓	1995-2020
Bed sediment samples (Quorer)	Sept & March	✓	✓	✓	✓	✓	✓	X	X	X	✓	✓	1995-2020
Algal stone scrub surveys	Sept & March	✓	✓	✓	✓	✓	✓	X	X	X	✓	✓	1995-2020
Channel cross-section surveys	Various	✓	✓	✓	✓	✓	X	X	X	X	X	X	Annually from 1998 to 2007, then biannually 2008 to 2016, and 2017
Channel shade measurements	Various	✓	✓	✓	✓	✓	X	X	X	X	X	X	Annually from 1998 to 2007, then biannually 2007 to 2015, and 2018
Fish Population Surveys	Various	✓	✓	✓	✓	✓	X	X	X	X	✓	✓	2000, 2001, 2002, 2007, 2008, 2012, 2021