Factsheet 3: Cost-effectiveness of farm system changes for improving water quality, greenhouse gas mitigation and biodiversity. Whatawhata case study.

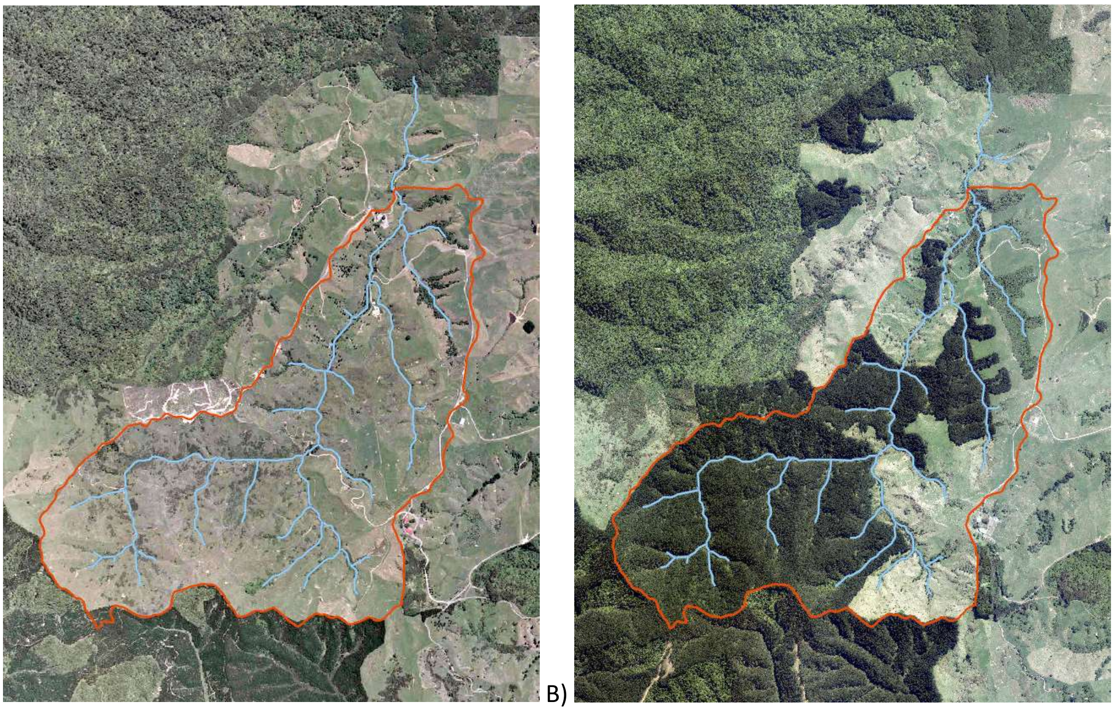
Mike Dodd (AgResearch) and Andrew Hughes (NIWA)

Background

In 2001, a number of land use and land management changes were implemented within the 260 ha Mangaotama catchment on the then Whatawhata Research Centre (Fig. 1). These changes were made under the direction of a multi-stakeholder advisory group, for the purpose of investigating ways of improving the economic and environmental performance of a hill country mixed livestock farm (Dodd et al. 2008).

- Pine forestry plantation 140 ha (54% of whole catchment and 77% of LUC VI and VII land)*.
- Indigenous vegetation restoration 12 ha (5% of whole catchment)* surrounding and connecting 7 ha of indigenous forest remnants around a first order stream.
- Poplar pole spaced planting on erodible land remaining in pasture (1000 stems).
- Exclusion of all livestock from 16.5 km of streams (85% of total stream length) and of cattle from all streams.
- Transition of the cattle enterprise from beef breeding (Angus) to bull finishing (Holstein-Friesian).
- Transition of the sheep breeding enterprise (Romney) genetics to a high-fecundity facial eczema resistant flock (Texel × Romney).

*also leading to increased shading of 14.7 km of streams (75% of total stream length).



A) B)

Figure 1. Aerial photo of the 260 ha Mangaotama catchment block in a) 2001 prior to land use changes and b) 2019, with catchment boundary marked in red and streams in blue.

In 2016 AgResearch surrendered their lease of the Whatawhata Research Station land (880 ha) and Tainui Group Holdings assumed management of the whole station, including the Mangaotama catchment. The animal enterprises across the block have largely remained the same since, with some years carrying dairy grazers in addition to the breeding ewes and bulls.

Long-term measurements

In the Mangaotama block NIWA established five stream monitoring sites in 1995 (Fig. 2): PW2, PW3, PR1, PR2 and PW5 (which is an end-of-catchment site where stream flow has been measured since 1993). Two other key monitoring sites are DB4 and NW5 which are near end-of-catchment sites in the Kiripaka and Whakakai catchments, respectively (Fig. 2). The Kiripaka catchment is a mixed land use (34% pasture, 9% pine, 57% native) catchment and the Whakakai catchment is entirely in native forest, including the Karakariki Scenic Reserve. Flow has been measured at DB4 and NW5 since 1993 and 1994, respectively. Monthly measurements of water quality were made until September 2020. These measurements included pH, electrical conductivity, turbidity, total suspended solids (TSS), volatile suspended solids (VSS), temperature, dissolved reactive phosphorus (DRP), total phosphorus (TP), nitrate (NO_3^-), ammonium (NH_4^+), organic carbon and visual clarity (VC) (Hughes & Quinn 2014). Samples of the faecal indicator bacteria, *E.coli,* were taken from four sites in the upper catchment in 2001-2 and 2004-5 and from the PW5 site in 2017-20. Spring and autumn surveys of water width and depth, macrophytes, benthic sediment, bed sediment and algae were conducted. Channel cross-section surveys were conducted annually from 1998-2007 and biannually from 2008-17. Channel shade measurements were conducted annually from 1998-2007 and biannually from 2008-15. Fish population surveys were conducted on seven occasions between 2000 and 2021.

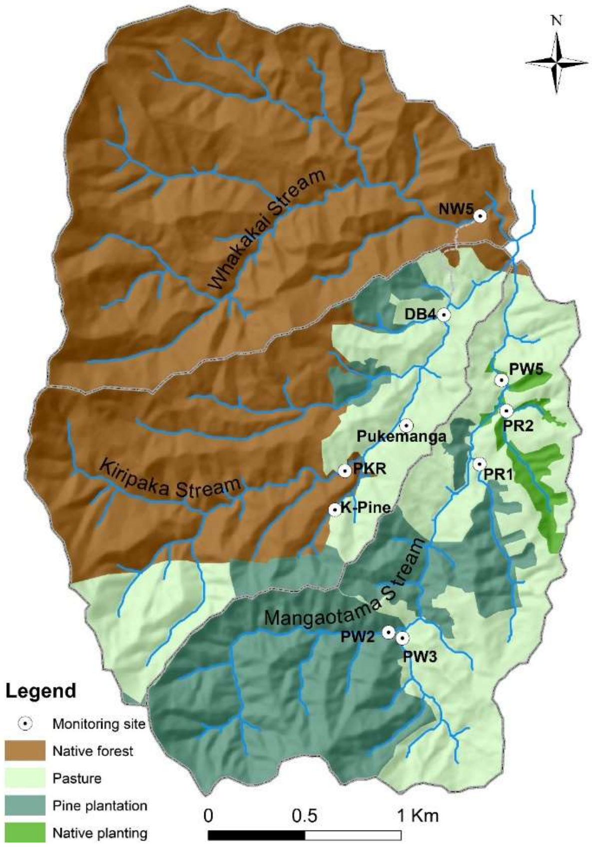


Figure 2. Whatawhata catchments, land use, and location of key water quality and stream flow monitoring sites.

In 2000, 17 permanent vegetation sample plots (each 50 m^2) were established in three forest remnants within the Mangaotama, with a further 30 plots established in larger native forest areas in the Whakakai (Smale et al. 2008). Measurements in 2000, 2002, 2004, 2008, 2012 and 2019 included plant species identification, vegetation cover across five height tiers, sapling and seedling numbers, tree stem densities, diameters and heights, and woody debris on the forest floor. A further 19 permanent vegetation sample plots (each 50 m^2) were established in 2002 in the native shrub riparian planted areas around the largest bush remnant. Measurements in 2019 included tree survival, root collar diameters, tree heights and canopy widths.

Published allometric relationships between shrub and tree measurements of stem diameter and height were used to calculate tree biomass and carbon stocks (Beets et al. 2012).

The whole Whatawhata farm was entered in the Emissions Trading Scheme in 2017. Eighteen circular mensuration plots (28 m diameter) have been established in the pine forestry area of the Mangaotama and measured in 2022 for stem density, diameter and tree height.

Thirty-four soil sampling sites were established in the native riparian planted areas in 2001 and re-measured in 2019 (0-300 mm). Thirteen soil sampling sites were established in native remnant, pasture, native planted and pine areas in 2001 and re-measured in 2011 (0-200 mm). Measurements included dry bulk density, soil organic carbon and soil organic nitrogen content at in either three or two layers respectively.

Costs of transition

Costs associated with land use and management change over the 2000-2010 decade are shown in Table 1 (Dodd et al. 2014). Not included are the opportunity cost of the reduction in grazing area and associated revenue, the reduction in costs associated with not maintaining those areas for grazing (i.e., fertiliser, weed control), or the costs of measuring the changes in water quality, vegetation and soils. The initial costs within the first two years were ~$423k, with the full cost of transition over 10 years being ~$940k. The block was assessed by a registered valuer in 2004 as having a market value of $750k.

Table 1: Actual costs of land use changes within the 260 ha Mangaotama catchment block at Whatawhata.

Item	Detail	Period (Years)	Total cost ($)
Native riparian restoration	Establishment	Y1	142 400
	Maintenance	Y2-10	53 100
Pine forest plantation	Establishment	Y1	178 200
	Maintenance	Y2-20	305 300
	Silviculture	Y7-11	464 000
Poplar planting		Y1	3 600
Fencing alterations		Y1-2	18 000
Capital livestock changes		Y1-2	80 000
Total			**1244 600**

Benefits: catchment hydrology

Stream flow measurements over the seven years prior to land use change can be used as a benchmark for total runoff, by comparing catchment runoff in the Mangaotama (PW5) with the Whakakai (NW5) and applying the relationship to the subsequent period. This indicates that measured annual runoff since 2001 was between 120-380% lower than would be expected if the Mangaotama had remained in pasture. In addition, peak flows across the range of stormflow events have not changed between the 1994-2001 and 2002-2010 periods in the Whakakai, but diminished by 50-60% in the Mangaotama, while base flows have diminished by ~25%. This represents a decline in damage risk for infrastructure but also the potential for reduced dilution of contaminants from land.

Benefits: slope stabilisation

While tree planting on slopes is generally expected to provide protection from mass erosion, the only semi-quantitative assessment of this at Whatawhata comes from observations after a storm event in February 2007 (110 mm per 4 hours). The abundance of landslips was ~1 per 7 ha in pasture, ~1 per 70 ha in the 6-year old pine plantations, ~1 per 2 ha in the 6-year old native plantations above PR2 and none in the adjacent native forest above NW5.

Benefits: water quality

Changes in water quality in the fourth-order stream draining the Mangaotama catchment block are shown in Table 5. These are based on regular monthly grab sampling for the period 1995-2001, prior to land use change and 2002-2019 following land use change.

Table 2: Changes in median measures of stream water quality at PW5 (Mangaotama near end-of-catchment site) and NW5 (Whakakai native forest catchment), for the 6-year period prior to land use changes and the 19-year period after. National Objectives Framework (NOF) bands and national bottom lines (NBL) for rivers are noted where relevant (MfE 2023).

Item	Units	NBL	Site	1995-2001	NOF band	2002-2020	NOF band
Visual clarity	Black disc (m)	0.61[1]	PW5	0.71	C	0.90	B
			NW5	1.00	A	1.34	A
Dissolved reactive P	$\mu g\ L^{-1}$	n.a.	PW5	14	C	17	C
			NW5	41	D	43	D
Total P	$\mu g\ L^{-1}$	n.a.	PW5	38		44	
			NW5	52		54	
Nitrate-N	$\mu g\ L^{-1}$	2400	PW5	399	A	793	A
			NW5	102	A	94	A
Ammonium-N	$\mu g\ L^{-1}$	240	PW5	11	A	10	A
			NW5	3	A	3	A
Total N	$\mu g\ L^{-1}$	n.a.	PW5	584		958	
			NW5	188		149	
Temperature	°C	n.a.	PW5	15.8		13.2	
			NW5	12.4		12.1	
Macroinvertebrates	QMCI	4.5	PW5	4.7	D	5.0	C
			NW5	7.2	A	7.4	A
E. coli	MPN 100 ml^{-1}	n.a.	PW5	398[2]	E	496[3]	E

[1]Suspended sediment class 2 for river environment classification group Warm Wet Hill
[2]MPN = most probable number, measured over two years at multiple pastoral sites (Donnison et al. 2004)
[3]measured at PW5 for one year from July 2018.

Indications are that water quality has improved at the catchment outlet in terms of visual clarity and temperature. Visual clarity is correlated with suspended sediment loads and this implies a reduction in sediment export consistent with observations of reduced erosion. However, there was no clear evidence of a reduction in annual specific sediment yield, calculated as 94 $t/km^2/y$ for 1999-2000 vs. 101 $t/km^2/y$ for 2002-2010. Statistical analysis of the nutrient concentration data indicated that the small decrease in ammonium-N concentration was significant, but that the *increases* in concentrations of DRP, nitrate-N and total N were also significant. Note that nitrate-N is approaching the 1000 $\mu g\ L^{-1}$L threshold for band B. The *E. coli* data for before and after land use change do not align spatially but do suggest that there has been little overall improvement in this measure.

It is apparent (and perhaps surprising) that the concentrations of DRP, nitrate-N and Total N have all increased since the implementation of the land use changes. However, over the same period total stream flow has also decreased by ~30%. This is largely because of the interception of rainfall and evapo-transpiration by the large and growing new plantation forest cover. Therefore, a reverse-dilution effect has occurred where the increased concentrations can be partially attributed to the reduced flow. Flow modelling to account for this effect indicates that the total amount nitrate-N discharged from the Mangaotama stream approximately doubled in the period after 2001.

Benefits: greenhouse gas (GHG) mitigation

There are a number of impacts on GHG emissions and mitigations as a result of the land use changes, including C sequestration in tree planting (native, poplar and pine) and in recovering native bush remnants, as well as the reduction in biogenic methane and nitrous oxide emissions associated with changes in livestock enterprises.

Survival of native shrubs and trees in the planted areas was approx. 75% after 18 years. While most plants established well in the first 3 years, the increase in canopy cover has suppressed some, along with natural death of short-lived shrub species and some early losses of kauri due to frost, which were not replaced at the time. Increases in carbon stocks also occurred in the forest remnants and small areas of regenerating scrub over 18 years (Dodd et al. 2020). Overall, the system has been transformed from a net source to a net sink over the 18-year period (Table 3).

Table 3: Measured vegetation carbon stock changes and modelled farm system emissions.

Item	**Rates of C stock change ($tC\ ha^{-1}y^{-1}$)**	**Net emissions in 2000 ($t\ CO_2$-e)**	**Net emissions in 2019 ($t\ CO_2$-e)**
Tree planting – pines	+17.6	-62	-9505
Tree planting – native shrubs	+4.8		-100
Scrub regeneration	+4.4		-88
Tree planting – native trees	+2.1		-17
Forest remnant regeneration	+1.4	-26	-42
Tree planting – poplars	+0.4		-15
Livestock CH_4 emissions		+891	+398
Soil N_2O emissions		+230	+91
Energy use emissions		+47	+22
Total		+1080	-9256

Considering the vegetation carbon sequestration alone, the cost:benefit of the forest restoration and planting works out to $76 per tonne of CO_2-e. For comparison, the vegetation carbon accumulation predicted for 18 years from other generic tools is shown in Table 4. Growth at this site appears to have been about 30-50% greater than the MPI lookup table estimates for native forest.

Table 4: Comparative CO_2-e sequestration rates over 18 years

Item	**Source**	**CO_2-e ($t\ ha^{-1}$)**
Whatawhata native shrub carbon	Measured	316
Native shrub carbon	Tane's Tree Trust (mixed species) [2]	155
Whatawhata native tree carbon	Measured	139
Native tree carbon	Tane's Tree Trust (native trees) [2]	105
Native forest ETS carbon	MPI lookup tables (national)[1]	155
Pine ETS carbon	MPI lookup tables (Waikato region) [1]	428

[1] MPI (2017); [2]Tane's Tree Trust https://www.tanestrees.org.nz/resources/carbon-calculator/

Carbon stocks also occur in soil, with a depth of 300 mm being a conventional benchmark (IPCC 2003). Table 5 shows the changes in soil carbon stocks for the two studies using repeat measurements at the same sites, across a range of vegetation types. Both data sets indicate that soil carbon stocks under pasture are declining over time at this site. This also occurred where native shrubs were planted into pasture, but not in the one pine planted site. In grazed bush remnant sites, soil carbon accumulated, but declined with exclusion of livestock.

Table 5: Soil carbon (C) stocks under areas of permanent pasture, permanent native bush, pine and native shrub planted into pasture.

Study	Initial vegetation (# sites)	Initial C ($tC\ ha^{-1}$)	Current vegetation	Final C ($tC\ ha^{-1}$)	Rate of change ($tC\ ha^{-1}\ y^{-1}$)
2002-2021 (0-300 mm)	Pasture	121.9	Pasture	94.1	-1.46
	Pasture	116.6	Planted shrub	104.9	-0.62
2001-2011 (0-200 mm)	Pasture (2)	110.4	Pasture	83.1	-2.73
	Pasture (4)	123.6	Native shrub	105.6	-1.80
	Pasture (1)	76.3	Pine	90.0	1.37
	Grazed native bush (2)	53.2	Grazed native bush	71.2	1.80
	Grazed native bush (4)	88.2	Fenced native bush	72.6	-1.56

Benefits: aquatic biodiversity

Two key aquatic faunal groups are of interest in reflecting aquatic habitat, macroinvertebrates (i.e. aquatic insects, snails, worms, etc.) and fish. Fish densities at PW5 had apparently increased from 1.0 to 2.5 individuals per m^2 over the first 10 years but have declined again in the most recent survey. The macroinvertebrate community index has improved at the PW2 and PW3 sites, but has been highly variable at the PW5 site, with no clear trend following the land use changes.

Benefits: indigenous forest biodiversity

The third major category of benefit is the improvement in forest remnant condition as a result of fencing, pest control and planting. Before and after differences can be included here, along with a comparison against un-restored fragments in never-grazed areas within the nearby Karakariki Scenic Reserve (Table 6). While these measurements were made in a 3-ha area in the lower catchment above PR2, a further 5 ha of forest remnants occur in the wider catchment, all of which were surrounded by pine plantations. As such, improvements in native understorey growth and cover are likely to have been similar in these areas, which were also excluded from livestock access. In addition, approx. 13 ha of riparian area left unplanted among pine forestry across the whole catchment represents an opportunity for native regeneration and indications are that tree ferns are now abundant in these areas. While there has also been substantial growth of native shrubs and trees under the pine canopy, it is inevitable that these will be removed upon pine harvesting.

Table 6: Changes in native bush fragment structure from 2000-2019 following fencing and pest control.

Item	Units	2000	2019	Reserve forest
Species richness	Species per $50m^2$ plot	24	24	33
Sapling regeneration	Stems ha^{-1}	20	10 600	6800
Foliage cover 0.3-2.0 m	%	11	24	32
Foliage cover 2.0-5.0 m	%	34	31	37
Bare ground cover	%	15	3	4
Litter ground cover	%	46	69	78
Tree basal area	$m^2\ ha^{-1}$	51	64	61
Woody debris	$m^2\ ha^{-1}$	8	10	22

While native plant species richness in this fragment has not changed over 19 years, other indicators of structure have improved towards the levels seen in ungrazed forest. These include a reduction in bare ground cover in favour of litter cover, an indication of less livestock disturbance, and an increase in woody biomass through tree growth and death. This increase in biomass is also reflected in the carbon stock change of 1.4 tC $ha^{-1}y^{-1}$ in Table 3. By comparison, the carbon stock change in nearby grazed bush fragments over this period was much lower, at 0.85 tC $ha^{-1}y^{-1}$ (Dodd et al. 2020) Most striking is the increase in sapling regeneration and vegetation cover in the 0.3-2.0 m forest tier, as these fragments are no longer browsed by cattle.

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Images


Figure 2. View of the Mangaotama catchment block from Northeast end, including gully bush remnants, kauri and totara plantings, spaced poplars and pine forest at the southwestern skyline boundary. Barkers block woolshed on right.