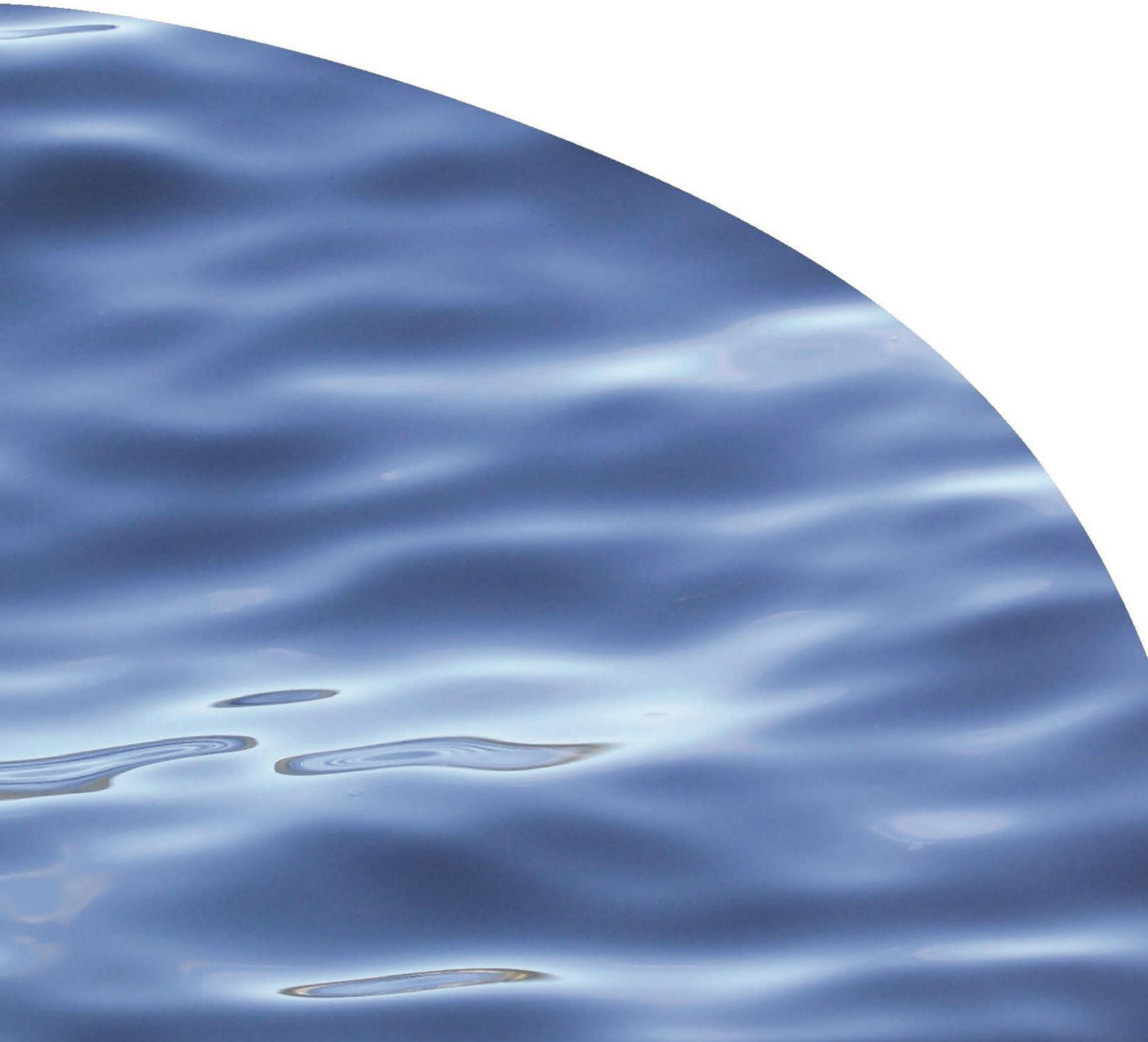
REPORT NO. 3429

FARM MITIGATION PACKAGES FOR TRANSITIONING TO COMPLIANCE UNDER THE TUKITUKI PLAN CHANGE 6 TO HAWKE'S BAY REGIONAL RESOURCE MANAGEMENT PLAN



FARM MITIGATION PACKAGES FOR TRANSITIONING TO COMPLIANCE UNDER THE TUKITUKI PLAN CHANGE 6 TO HAWKE'S BAY REGIONAL RESOURCE MANAGEMENT PLAN

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EXECUTIVE SUMMARY

This report suggests two mitigation packages (or bundles) that will enable Hawke's Bay Regional Council and farmers to improve aquatic ecosystem health in the Tukituki catchment. Hawke's Bay Regional Council (HBRC) intends for the mitigation packages to be considered by landowners as a means to negotiate interim consent conditions for operating farms that exceed Natural Capital Nitrogen leaching rate allocations, while they transition to lower nitrogen-loss farm systems that adhere to the Tukituki Plan Change 6 rules. In addition, the mitigation packages can be used by landowners within 'nitrogen exceeding' catchments as listed in the Tukituki Plan. The mitigation packages are for landowners who have exhausted practical measures to reduce nitrogen leaching to allowable rates—the extent of what are considered practical nitrogen loss mitigation measures is to be decided by HBRC in discussion with landowners.

For landowners who wish to use aquatic ecosystem health improvements for consenting purposes, HBRC has proposed that the intensity (and cost) of ecosystem health mitigation packages should be scaled by how much a landowner is likely to be contributing to nitrogen problems in the catchment. HBRC has proposed that landowners are grouped into three nitrogen leaching rate categories to determine the level (or intensity) of mitigation actions required. Categories are as follows:

- Level 1: Contributing nitrogen concentration less than 0.8 mg/l
- Level 2: Contributing nitrogen concentration between 0.8 mg/l and 2.4 mg/l
- Level 3: Contributing nitrogen concentration over 2.4 mg/l.

The 'contributing nitrogen' concentration will be calculated by multiplying the nitrogen loss concentration or the 'N in drainage' value (determined using the latest version of OVERSEER) by a catchment-specific nitrogen assimilation factor that will be provided by HBRC. Landowners grouped into Level 1 will be required to adhere to industry good practice and follow the Plan rules, whereas, landowners in the Level 2 and Level 3 categories will need to do additional work to improve aquatic ecosystem health.

The proposed mitigation packages for Level 2 and Level 3 categories are described below. The 'rule-of-thumb' values for the extent of the mitigations are put forward as a starting point for HBRC and landowners to consider how potential environmental improvements can be bedded into a farm landscape. Justifications for the proposed mitigation actions and a review of relevant literature are presented in the body of this report.

Suggested Level 2 mitigations (contributing concentration 0.8-2.4 mg/l)

1. Install managed riparian areas *averaging* at least 5 m wide from the low-flow wetted edge along all permanently wetted waterbodies (drains, streams, lakes and wetlands). Fenced areas should be of variable widths, with wider sections to accommodate relatively steep areas, depressions in the stream banks, ephemeral drains and other features that concentrate overland flow through the riparian area.

2. For a minimum of 1 km or at least 5% of waterbody length on a farm (i.e. stream length and / or wetland / lake perimeter) undertake riparian planting. Planted segments should occur for continuous kilometre-long segments. Priority should be given to permanently flowing streams that have an active channel width of less than 8 m wide. Where possible, plant species and planting densities should be sufficient to provide 60–80% shade of the low-flow channel.
3. Install fencing to protect stream gully heads from stock where stream-side riparian fencing is impractical due to steepness of land. Provide alternative water sources (e.g. reticulation or solar powered troughs) so stock are not forced to go to waterways to drink. Provide shade trees or other forms of shelter away from waterways so steep banks and riparian vegetation are not the only shade / shelter option for stock.
4. Create constructed wetlands, fenced seepage wetlands and / or sediment traps equating to 0.5% of catchment areas within the farm boundaries.
5. Identify critical source areas for fine sediment and phosphorus and install fencing, grass swales and detention bunds to manage runoff during moderate rainfall events.
6. Identify potential fish passage barriers and improve fish passage around any unnatural barrier under 4 m high; for example, by retrofitting fish passes or upgrading pipe culverts to box culverts.

Suggested Level 3 mitigations (contributing concentration > 2.4mg/l)

1. Install managed riparian areas *averaging* at least 10 m wide from the low-flow wetted edge along all permanently wetted waterbodies (drains, streams lakes and wetlands). Fenced areas should be of variable widths, with wider sections to accommodate for relatively steep banks, depressions in the stream banks, ephemeral drains and other features that concentrate overland flow through the riparian area.
2. For a minimum of 2 km or at least 10% of waterbody length on a farm (i.e. stream length and / or wetland / lake perimeter), undertake riparian planting. Planted segments should occur for continuous kilometre-long segments. Priority should be given to permanently flowing streams that have an active channel width that is less than 8 m wide. Where possible, plant species and planting densities should be sufficient to provide 60–80% shade of the low-flow channel.
3. Install fencing to protect stream gully heads from stock where fencing is impractical due to steepness of land. Provide alternative water sources (e.g. reticulation or solar powered troughs) so stock are not forced to go to waterways to drink. Provide shade trees or other forms of shelter away from waterways so steep banks and riparian vegetation are not the only shade / shelter option for stock.
4. Create constructed wetlands, fenced seepage wetlands and / or sediment traps equating to 1% of catchment areas within the farm boundaries.

5. Undertake a native planting and weed control programme on any natural wetland areas on the farm.
6. Identify critical source areas for fine sediment and phosphorus and install fencing, grass swales and detention bunds to manage runoff during moderate rainfall events.
7. Identify potential fish passage barriers and improve fish passage around any unnatural barrier under 4 m high; for example, by retrofitting fish passes or upgrading pipe culverts to box culverts.

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1. INTRODUCTION

The Tukituki Plan Change 6 (the Plan) to Hawke’s Bay Regional Council’s (HBRC) Regional Resource Management Plan has been operative since 1 October 2015. Among other high-level objectives, the Plan aims to maintain or enhance aquatic ecosystem health while providing for sustainable water and land use (Appendix 1). To this end, the Plan now has Dissolved Inorganic Nitrogen (nitrogen) leaching rate limits in place for all high intensity farms over 4 ha and low intensity farms over 10 ha. The nitrogen leaching rate limits are derived from the Land Use Capability (LUC) classification system, which categorises the suitability of an area for different land use types based on variables such as: susceptibility to erosion, steepness of slope, susceptibility to flooding and liability to wetness or drought (Lynn et al. 2009; McDowell 2018b).

Some landowners in the Tukituki catchment are currently exceeding their prescribed nitrogen leaching rates, in some cases by more than 60% (based on modelled results from the farm nutrient budgeting model OVERSEER). Under the Plan, these landowners require a resource consent to continue to farm. A few sub-catchments have exceeded the Plan’s instream nitrogen concentration target of 0.8 mg/l, which means that most farms in these catchments will also require a consent to continue farming. Although the need for a resource consent is often triggered by nitrogen, an ultimate objective in the Plan relates to improved ecosystem health, with nitrogen reductions being one way of achieving improved ecosystem health outcomes. HBRC is proposing to consider a broad range of potential mitigation options for consenting purposes (i.e. not just nitrogen mitigations)—if it can be demonstrated that those mitigations will contribute to an overall improvement in aquatic ecosystem health.

Hawke’s Bay Regional Council has proposed that the intensity (and cost) of ecosystem health mitigation packages should be scaled by how much a landowner is likely to be contributing to nitrogen exceedances in the catchment. A relatively higher nitrogen contribution will require landowners to implement more intensive and / or widespread mitigation actions than those with more moderate contributions. HBRC has suggested that landowners will be grouped into three categories to determine the level (or intensity) of mitigation actions required for consideration of granting a consent (Dr Andy Hicks, pers. comm.). The proposed categories supplied by HBRC are as follows:

- Level 1: Contributing nitrogen concentration less than 0.8 mg/l
- Level 2: Contributing nitrogen concentration between 0.8 mg/l and 2.4 mg/l
- Level 3: Contributing nitrogen concentration over 2.4 mg/l.

The ‘contributing nitrogen concentration’ is calculated by multiplying the overall OVERSEER output ‘N in drainage’ value, which indicates the Dissolved Inorganic Nitrogen loss from a farm, by a catchment-specific nitrogen assimilation factor. The nitrogen assimilation factor accounts for the ability of receiving waterbodies to assimilate nitrogen loading and will be determined by HBRC environmental staff.

Landowners grouped into Level 1 will only be required to follow industry good practice and adhere to the Plan rules, whereas, landowners in the Level 2 and Level 3 categories will need to implement additional mitigations to improve aquatic ecosystem health.

1.1. Project scope

This report suggests two mitigation packages (or bundles) that can be used by HBRC and farmers to negotiate consent conditions for farms in the Level 2 or Level 3 nitrogen contribution categories. It is important to note that mitigation actions that specifically target nitrogen leaching are *excluded* from this report—the mitigation packages described here are for landowners who have exhausted all practical measures to reduce nitrogen leaching to allowable rates under the Plan. The farm environmental planning process and the OVERSEER farm management tool already provide support for farmers to implement good management practices to mitigate nitrogen loss (Low et al. 2019a). Instead, this report focuses on potential mitigations for improving aquatic ecosystem health that are not directly related to reducing nitrogen loss. The intention is to take a broader view of aquatic ecosystem health and enable a wider range of management options to be included in farm environment plans. For example, shading streams or reducing fine sediment and particulate-bound phosphorus loss, in a manner that is over and above what the Plan requires, may result in net gains for ecosystem health—even if high nitrogen leaching rates continue in the short to medium term. For the purpose of this report I have taken the definition of aquatic ecosystem health to be broadly representative of the Plan's high-level objectives (Appendix 1). That is, *healthy* aquatic ecosystems support close to naturally occurring populations of macroinvertebrates and native fish, are free from excessive periphyton growths and support mahinga kai and trout fisheries.

Below I first outline the relevant environmental rules under the Plan. I then review aquatic ecosystem health in the Tukituki catchment to determine key issues that could be targeted by farm mitigation practices. Following this, I review potential land use mitigation options. Finally, I describe mitigation actions that are likely to improve aquatic ecosystem health that are 'over and above' what is already required by the Plan. These are matched to the Level 2 and Level 3 nitrogen 'contributing concentration' categories.

1.2. Nitrogen leaching allocation rules under the Plan

The LUC-based nitrogen leaching allocation rates are shown in Table 1. Landowners must use OVERSEER (version 5 or 6) to produce modelled estimates of nitrogen leaching rates for their farm system. They can determine if they are over their nitrogen leaching rates by comparing the modelled estimates with the allowable leaching rates allocated to the LUC classes attached to their land parcel(s). The LUC classes have been mapped at the farm-scale for the entire Tukituki catchment and can be seen at https://hbmaps.hbrc.govt.nz/mapviewer/?map=67686b47a9dc4def9987143ded8c6f60

Table 1. Table excerpt from a Tukituki Plan Change 6 information booklet showing the different nitrogen leaching rate allowances based on Land Use Capability (LUC) classes.

LUC LEACHING ALLOWANCES

LUC[7] Class	1	2	3	4	5	6	7	8
Rate (kgN/ ha/ year)	30.1	27.1	24.8	20.7	20	17	11.6	3

1.3. Plan rules summary

If a landowner is over their nitrogen allocation and wishes to use ecosystem health improvements to gain consent, then the mitigation actions must be ‘over and above’ what is already required by the Plan in terms of environmental protection. Below, Table 2 shows a summary of the key environmental actions that are already required of landowners as part of the Plan. Also shown are the key dates by which these new measures are to be put in place. The actions listed in Table 2 cannot be used to further offset nitrogen leaching exceedances to gain consent because they are already required by the Plan.

Table 2. Table excerpt from the Tukituki Plan Change 6 information booklet showing the key aquatic environmental protection actions that landowners are required to undertake and the dates by which they are to be implemented (TTP 2016).

WHEN BY	ACTION TO BE TAKEN
NOW	Keep copies of your nutrient budget input and output files OR Keep all of the records specified in Schedule XXI of the Tukituki Plan so you can prepare a nutrient budget
31 May 2018	Submit a Farm Plan
31 May 2019 (and annually thereafter)	Check if your farm plan needs to be updated. If your farm system has changed[2] in the last 12 months, your plan will need to be updated
31 May 2020	Implement your Farm Plan
	Ensure nitrogen leaching from your property complies with the LUC leaching rates set in the Tukituki Plan
	Exclude stock from rivers, lakes and wetlands[3] : If you live in a priority sub-catchment[4] (shown in the map over the page) you must exclude all stock (except sheep) on land with a slope of less than 15° AND land with a slope greater than 15° if the stocking rate of the paddock exceeds 18 su[5]/ha If you are outside a priority sub-catchment: • On land with a slope of 15° or less, you must exclude all livestock (except sheep) • On land with a slope greater than 15° with a stocking rate of more than 18 su/ha you must exclude all livestock (except sheep) OR, if stock exclusion it is not practicable you will need to do other things in an effort to minimise sediment and other sources of P entering streams
	Bridge or culvert all rivers crossed by formed stock races
31 May 2021 (then 3 yearly)	Submit an updated farm plan to HBRC

1.4. The Tukituki catchment ecosystem health summary

1.4.1. Geology, land use and river morphology

The Tukituki catchment is the third largest watershed in the Hawke's Bay region, covering approximately 2,500 km^2. For management purposes the catchment is split into 17 sub-catchment units (Figure 1). Land use in the catchment is shown in Figure 2. The catchment has varied topography, with about half of the land surface having a steep slope (21–42°) and a quarter with a flat to gentle slope (0–3°) (Newsome & Wilde 2008). The dominant geology is about equal parts soft sedimentary, alluvial and hard sedimentary rock. River morphology is characterised by steep erodible headwater streams flowing from the Ruahine Ranges into the major tributaries (including the Waipawa and Makaroro rivers). Rivers within the Tukituki and Waipawa system are typically partially braided but confined to a managed flood channel within stopbanks. Gravel is extracted from the Waipawa and lower and middle Tukituki to manage flood risk.

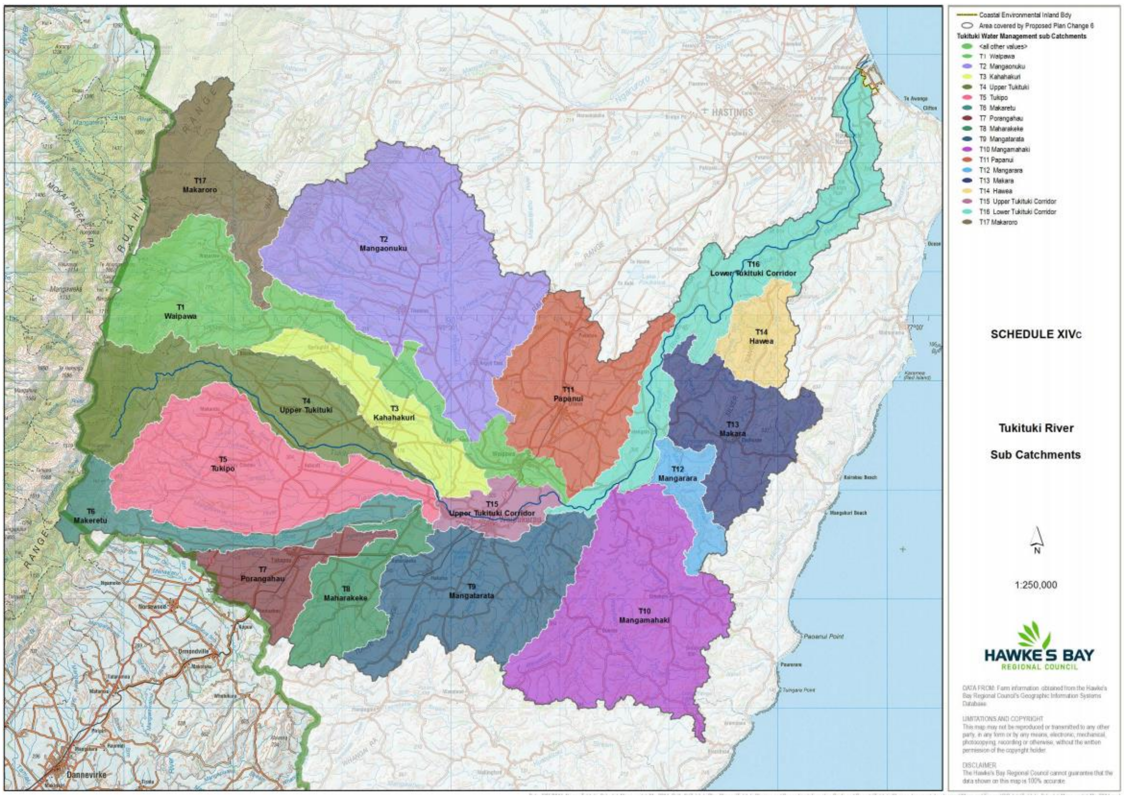

Figure 1. The Tukituki sub-catchments figure reproduced from the Tukituki Plan Change 6 to HBRC Regional Resource Management Plan (HBRC 2015).

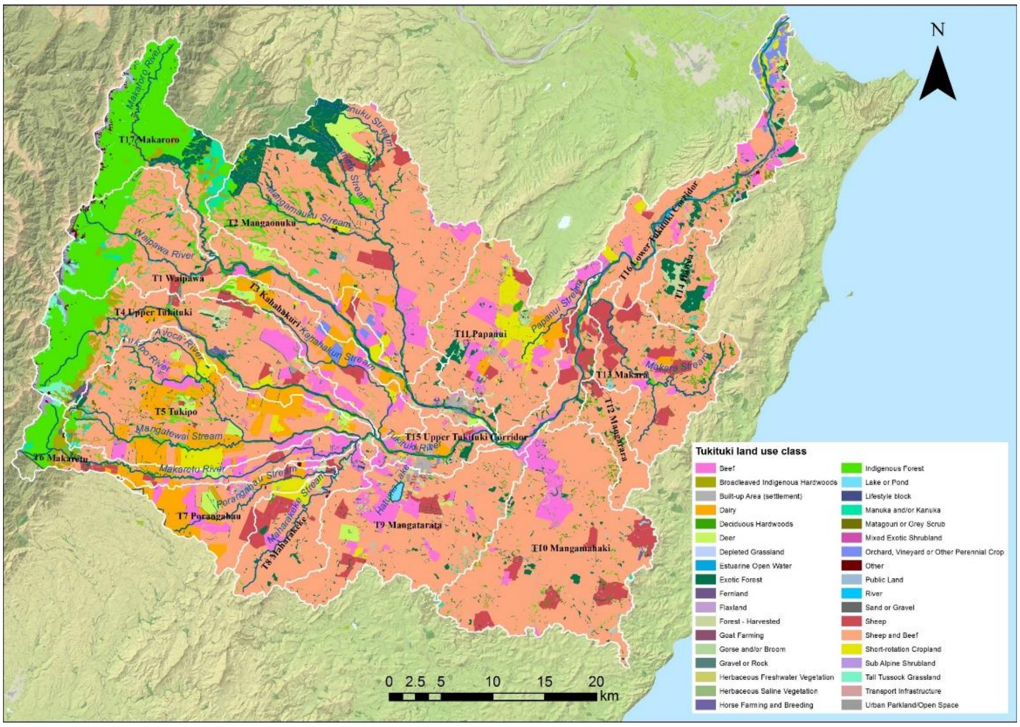

Figure 2. Land use in the Tukituki catchment. Data were sourced from HBRC Land Science GIS database that amalgamates LCDB5, AgriBase and local knowledge.

1.4.2. Stressor dynamics in the Tukituki catchment

A substantial review of water and habitat quality in the Tukituki catchment was undertaken as part of the Assessment of Environmental Effects for the proposed Ruataniwha Water Storage Scheme (Young et al. 2012). This information is highly relevant for determining overall ecosystem health in the catchment and is summarised below.

Water quality in the upper Tukituki catchment is excellent but generally declines downstream. The mid-reaches of the river are enriched with nitrogen and some tributaries have high concentrations of dissolved reactive phosphorus (DRP), including include the Mangatarata, Porangahau and Papanui rivers. Ratios of nitrogen to phosphorus in the water indicate that algal growth at most sites in the middle and lower reaches of the Tukituki mainstem is likely to be limited by phosphorus concentrations. Co-limitation of algal growth, by both nitrogen and phosphorus, is thought to occur in the upper catchment above State Highway 50, and nitrogen limitation occurs in the upper Tukipo River. Accordingly, decreases in phosphorus concentrations in the middle and lower reaches of the Tukituki River ought to result in slower benthic algal growth rates—leading to longer periods between flood events (flushing flows) before benthic algae accrues to high biomasses. Periphyton guidelines for the protection of recreational and trout fishery values have been breached occasionally at almost all routine sampling sites in the Tukituki catchment. However, periphyton proliferations are more common in the middle and lower reaches of the Tukituki River, and in some tributaries (e.g. Porangahau and Mangaonuku) (Young et al. 2012).

Like many other large, wide and open-channelled lowland rivers, the lower Tukituki River reaches high summer water temperatures. Temperatures have been recorded in excess of 25 °C which can stress sensitive aquatic life (Young et al. 2012). For example, brown trout will cease feeding once temperatures climb above 19 °C (Elliott 1994) and temperatures in excess of 25 °C can kill *Deleatidium* sp. mayflies. *Deleatidium* mayflies are New Zealand's most common mayfly (genus) and are an important food source for a range of higher trophic-level invertebrates, fish and river birds (Quinn et al. 1994). Temperatures in many of the tributary streams across the plains will also reach levels that will stress aquatic life during mid-late summer. Within the wider catchment, cool refuge areas may benefit mobile fish species because they can seek out these areas during summer. For example, anecdotally, brown trout in the lower mainstem river are thought to move into the cooler spring-fed tributary streams during summer. Eels may also optimise their growth and survival by moving throughout the catchment on a seasonal basis. Therefore, measures that address high summer temperatures, such as plantings for stream shade, are likely to improve stream health in these tributaries and potentially the wider catchment through providing better habitat conditions for fish.

Minimum dissolved oxygen (DO) concentrations are well below guideline levels in some tributaries that are affected by groundwater inputs (that have naturally low DO), as well as excessive macrophyte and algal growths that have been caused by increased light and nutrients from development of the land for agriculture. For example, DO levels at 37% saturation have been recorded in the Papanui Stream. Within the Tukituki mainstem, the lowest DO concentrations occur at the Shag Rock monitoring site (75% saturation). In some areas, low DO is probably excluding sensitive fish and macroinvertebrate species from persisting year-round. Measures that will increase minimum DO concentrations, particularly in the spring-fed tributaries, for example by reducing excessive algal and macrophyte growths, ought to improve ecosystem health within the catchment (Young et al. 2012).

The composition of macroinvertebrate communities within the mainstem river indicate that health in the upper reaches is excellent, while the middle and lower reaches are generally considered to be in ‘fair’ health. The macroinvertebrate community present in the Mangatarata and Papanui streams are typical of systems in a state of poor ecological health (Young et al. 2012).

The Tukituki catchment supports a relatively diverse range of native fish with few introduced pest fish relative to other large North Island catchments (Table 3). According to the latest Department of Conservation national threat classification (Dunn et al*.* 2017), eight of the 19 native fish species found in the catchment are considered to be ‘At Risk–Declining’, or ‘Nationally Vulnerable’ in the case of lamprey (Table 3). Most fish present have migratory life histories that require (or benefit from) access to the estuary and ocean, with dwarf galaxias and upland bullies being the exceptions. Therefore, measures that improve fish passage for upstream migrating juvenile fish have the potential to improve ecosystem health by increasing fish densities in potentially underutilised habitat.

Both brown and rainbow trout occur in the Tukituki catchment, but rainbow trout are more widespread. During the most recent National Angler Survey the Tukituki River was rated as the most popular angling river in the Hawke’s Bay region (Unwin 2016).

Table 3. Fish species recorded (using all records from 1980 – 2015) in the Tukituki catchment (Jellyman & Sinton 2015) and their national threat classification from Dunn et al. (2017).

Common Name	**Scientific name**	**Threat classification**
Lamprey	*Geotria australis*	Nationally Vulnerable
Redfin bully	*Gobiomorphus huttoni*	At Risk, Declining
Longfin eel	*Anguilla dieffenbachii*	At Risk, Declining
Torrentfish	*Cheimarrichthys fosteri*	At Risk, Declining
Bluegill bully	*Gobiomorphus hubbsi*	At Risk, Declining
Inanga	*Galaxias maculatus*	At Risk, Declining
Koaro	*Galaxias brevipinnis*	At Risk, Declining
Dwarf galaxias	*Galaxias divergens*	At Risk, Declining
Giant bully	*Gobiomorphus gobioides*	Not Threatened
Black flounder	*Rhombosolea retiaria*	Not Threatened
Cran's bully	*Gobiomorphus basalis*	Not Threatened
Upland bully	*Gobiomorphus breviceps*	Not Threatened
Common smelt	*Retropinna retropinna*	Not Threatened
Common bully	*Gobiomorphus cotidianus*	Not Threatened
Shortfin eel	*Anguilla australis*	Not Threatened
Yellow-eyed mullet	*Aldrichetta forsteri*	Not Threatened
Grey mullet	*Mugil cephalus*	Not Threatened
Estuarine triplefin	*Grahamina* sp.	Not Threatened
Rainbow trout	*Oncorhynchus mykiss*	Introduced and Naturalised
Brown trout	*Salmo trutta*	Introduced and Naturalised
Gambusia	*Gambusia affinis*	Introduced and Naturalised
Goldfish	*Carassius auratus*	Introduced and Naturalised

2. MITIGATION ACTIONS TO IMPROVE AQUATIC ECOSYSTEM HEALTH IN THE TUKITUKI CATCHMENT

2.1. Nutrient management

2.1.1. Nitrogen loss mitigation

As stated earlier, addressing nitrogen loss from farms is not the main focus of this report. Nevertheless, it is important to point out that some land use mitigations to reduce nitrogen loss are captured within OVERSEER. The algorithms within OVERSEER assume that a range of practical industry-standard nitrogen loss mitigations are implemented on a farm. The nitrogen leaching rate values that are used to assess compliance with the Plan are based on OVERSEER predictions. Because most practical nitrogen mitigation practices are already (assumed to be) in place, these actions are not available to further reduce the nitrogen leaching to achieve compliance. However, there are some promising nitrogen mitigation practices available that are not considered within operational versions of OVERSEER.

Nitrogen loss mitigations that are not currently part of OVERSEER include: reducing storage and leachate from silage stacks, improved crop management that includes installing swales, strategic grazing, improved strategies to reduce pugging and soil compaction and improved effluent management practices. Seepage wetlands, and alternative forages are also not included and are considered to have high nitrogen management potential (Low et al. 2019a). This is because these later mitigations address the most common nitrogen loss pathways to the environment—via effluent or nitrate-nitrogen (NO3-N) leaching through the soil profile. However, the effectiveness of these mitigations is highly variable due to the complex biological systems involved (Low et al. 2019a). Landowners that are exceeding their nitrogen leaching rate allocation should consider adopting some of these practices, despite the science being incomplete regarding estimates of their effectiveness.

2.1.2. Phosphorus loss mitigation

In many areas of the catchment, including the lower mainstem Tukituki River, phosphorus concentrations during periods of relatively stable flow may limit algal growth. Therefore, any reduction in phosphorus loading ought to improve ecosystem health by reducing the amount of time the mid- and lower river experiences the declines in habitat quality that are associated with high benthic algal biomasses (Matheson et al. 2012; Snelder et al. 2013).

Key practices that are effective at reducing the amount of phosphorus-laden runoff (and fine sediment) include: fencing off waterways and leaving ungrazed grass filter strips, avoiding pugging of soils (especially in paddocks close to waterways), avoiding overgrazing and bare soil, controlling runoff from tracks, races and feedpads, applying effluent to land and following good practice fertiliser application guidelines (McDowall et al. 2018).

Phosphorus loss from agricultural systems can be modelled in OVERSEER using the phosphorus sub-model. Terms within the model's algorithms are included for soil loss, fertiliser application, dairy farm effluent disposal, plant loss, animal dung, infrastructure, stock exclusion, riparian buffer area, stock wallows, fence line pacing, drainage type, storm events, irrigation and natural phosphorus loss. As with nitrogen loss, OVERSEER assumes that industry standard good land management practices are already implemented with respect to these variables.

In general, it is more cost effective to mitigate the loss of diffuse contaminants, such as phosphorus-laden runoff, at the source rather than further down the catchment (Turner et al. 1999). McDowell et al. (2012) found that strategies to mitigate phosphorus losses in Otago catchments were 6–7 times more cost-effective when applied to critical source areas than if they were applied across entire paddocks. Critical source areas are the parts of a farm that account for most of contaminant loss but make up a small amount of the area. More recently, based on a targeted case study in the Lake Hayes catchment (Central Otago), McDowall et al. (2018) confirmed that managing runoff around critical source areas during small storm events is highly cost-effective. These areas typically include, paddock depressions, gateways, water troughs, bridges and stock laneways near streams (Figure 3). Runoff can be mitigated by installing bunds and / or grassed filter strips between critical source areas and waterbodies (Figure 4). McDowall et al. (2018) note that mitigating phosphorus loss during 'large' flood events is not practically achievable.

I suggest that all the good management practices to reduce phosphorus that are included in the OVERSEER sub-model should be expected from any landowner exceeding their nitrogen allocation by any amount. In addition, landowners should identify critical source areas on a farm and targeting mitigations to these areas. Extra emphasis on reporting the implementation of these measures is suggested within farm plans. Making this information available to the HBRC compliance team is a critical part of the process to ensure that good phosphorus management practices are implemented.

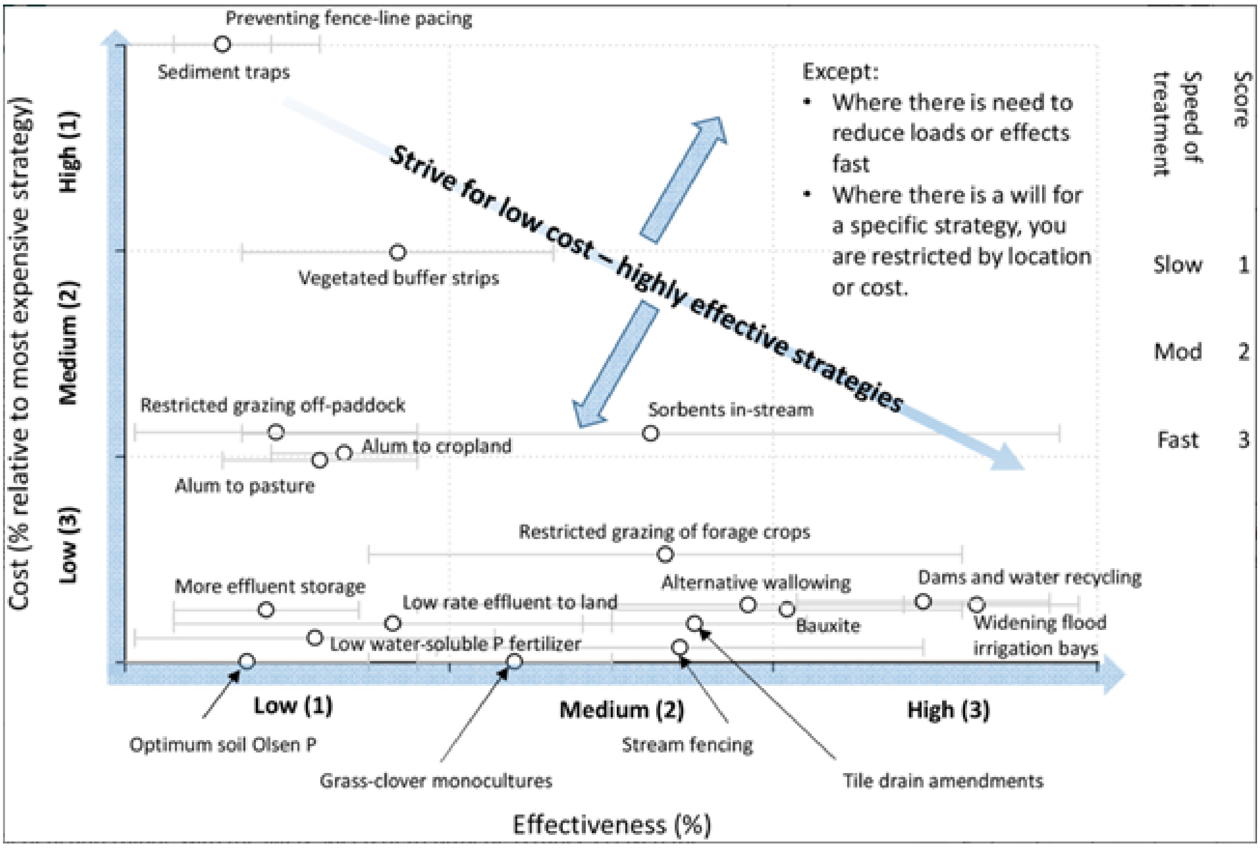

Figure 3. An analysis of the cost effectiveness of mitigation measures to improve water quality in receiving environments by reducing nitrogen, phosphorus and fine sediment loading in the Lake Hayes catchment (McDowall et al. 2018).

Figure 4. An example of a critical source area on a paddock that could benefit from a grassed filter area (swale) and / or bund near the point of entry to a waterbody. See photo source and associated information about critical source areas at: https://www.dairynz.co.nz/environment/land-management/critical-source-areas/.

Constructed wetlands and sediment traps have great potential to mitigate for phosphorus loss and these mitigation options are *not* included within OVERSEER. This is because their performance can be mixed and is highly site-specific, and wetland performance is influenced by complex biological systems. In some situations, wetlands can become phosphorus sources over time (Land et al. 2016). Nevertheless, collectively, when implemented in many locations throughout a catchment, wetlands and sediment traps are likely to provide a sink for phosphorus on average (Land et al. 2016). In addition, wetlands and sediment traps can be viewed as appropriate for mitigating fine sediment loss from farms.

To remain effective, sediment traps need to be engineered in such a way that they can be easily emptied, and a plan needs to be in place to dispose of the material. McDowall et al. (2018) consider sediment traps to be one of the least cost-effective options to reduce phosphorus and fine sediment within farmed catchments (Figure 3). Nevertheless, if they are appropriately designed with enough capacity, they can trap large volumes of sediment. In some cases, they may be the only option if it is not practical to implement riparian fencing, or, riparian fencing has already been put in place.

On balance I suggest that wetlands and sediment traps are an appropriate mitigation option to improve ecosystem health given their ability to trap fine sediment, their potential to decrease phosphorus loads downstream and their potential biodiversity values in a landscape. Restoration or creating wetlands is an active area of research in terms of mitigating land use effects. For example, seepage wetlands and constructed wetlands are likely to form part of ‘standard’ good management practices in the near future for mitigating nutrient loss (Low 2019a). Guidelines for constructing wetlands to treat tile-drain discharges are currently available (Tanner et. al. 2010) and work is underway to quantify wetlands’ abilities to reduce various contaminants so this can be included in OVERSEER (Wright-Stow 2019). In the meantime, however, the quantification of wetland performance would need to be done on a more subjective basis. Additionally, guidelines on wetland restoration are available in the Wetland Restoration Handbook (Peters & Clarkson 2010). Perhaps one of the easiest ways to improve biodiversity and ecosystem health values on a farm is by undertaking invasive weed and predator control in existing wetlands (Peters & Clarkson 2010).

2.2. Riparian area management

There are no requirements within the Plan for riparian planting or for minimum fence setback widths around waterbodies. A setback width defines the size of the managed riparian area or riparian buffer zone. In addition, cattle and deer on steep land (> 15 degrees slope) and sheep (on any slope) are excluded from the stock exclusion rules. Therefore, there is considerable scope for landowners to improve aquatic ecological health by:

1. implementing a riparian planting plan
2. increasing the width of managed riparian areas (by increasing fenced stock exclusion setback widths)
3. by excluding sheep from riparian areas or cattle and deer from streams on steep land.

There is a large body of literature demonstrating the range of aquatic ecosystem health benefits that are supported by stock exclusion and well managed vegetated riparian management areas. These benefits are summarised in Table 4.

Table 4. Riparian functions and ecosystem health benefits of well managed riparian areas, table adapted from Quinn (2009).

Riparian function	Ecosystem health benefit
1/ Control of livestock excreta and damage	Reduced fine sediment and nutrients (N+P)
2/ Bank stabilisation	Reduced fine sediment
3/ Overland flow filtering	Reduced fine sediment and nutrients
4/ Nutrient uptake by plants	Reduced nutrients (N+P)
5/ Denitrification	Reduced nutrients (N)
6/ Shading	Reduced benthic algae, reduced temperatures
9/ Enhancing in-stream fish habitat	Increase instream hiding cover along bank edges, supply of vegetative material for small fish cover
7/ Aesthetics	Improved perception of waterbody value fosters greater environmental care for the waterbody
8/ Shading	Reduced instream temperatures, Lower light levels discourage algae and macrophyte growths
9/ Leaf litter input	Increased macroinvertebrate diversity
10/ Wood, vegetative debris input	Increased macroinvertebrate and fish habitat quality

2.2.1. Riparian stock exclusion setbacks widths

Riparian zones intercept fine-sediment and particulate-bound phosphorus by slowing surface runoff, allowing particles to settle and / or infiltrate into the soil. There are numerous factors that can affect the ability of the riparian zone to intercept contaminants; for example, slope length, slope angle, soil porosity and clay content (Collier et al*.* 1995). However, the key variable that is most easily manipulated by landowners is the width of the riparian management area.

With increasing fenced riparian management area width there are diminishing returns in sediment and phosphorus removal (Figure 5) (Parkyn 2004; Dymond et al. 2010). Gharabaghi et al*.* (2006) found that sediment removal efficiency increased from 50 to 98% as the width of riparian filter strip increased from 2.5 to 20 m. Similarly, Smith (1989) found 80% removal of suspended sediment in 10–13 m-wide riparian buffer strips. In a catchment-scale study on a spring creek in South Canterbury, Holmes et al. (2016) found that riparian strips with an average width of 5 m (or more) were associated with relatively low levels of deposited fine sediment in reaches downstream (< 20% cover on the stream bed). In keeping with these results, Zhang et al. (2010) estimates that mitigation effectiveness for fine sediment declines steeply for riparian buffers wider than about 6 m (Figure 5). Moreover, recent proposed stock exclusion rules under Central Government's Essential Freshwater initiative propose that *minimum* fenced setbacks of 5 m (on average) are put in place for all heavy stock farms (MFE, MPI 2018), although this has been reduced to three metres in the final version following consultation.

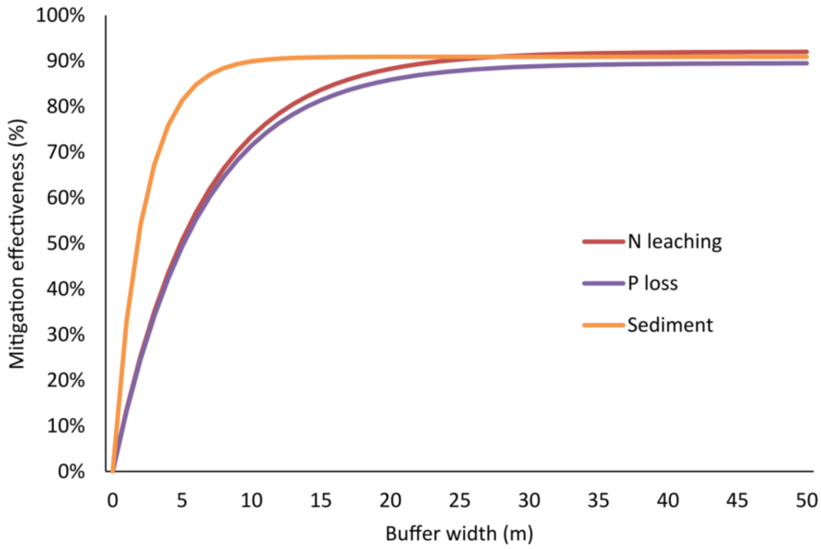

Figure 5. A conceptual model of riparian buffer mitigation effectiveness (from Zhang et al. 2010).

I suggest that using fenced setbacks that are a minimum of 5 m (average width) around all waterbodies on farms with livestock is an appropriate component of any mitigation package for landowners that are exceeding their nitrogen leaching allocation rate.

It is important to stress that variable riparian widths, which account for changes in local topography, are more effective than set-width buffers. For example, riparian areas should be wider and encompass depressions along a stream bank where runoff from adjacent paddocks will get directed and channelised during a rain event. In addition, riparian areas should be wider in sections of stream with steeper bank profiles. Riparian grassed filter strips are relatively ineffective at filtering overland flow on steeply inclined banks of many small headwater streams, e.g. > 15 degrees (Parkyn 2004). In this instance, fencing to retire or partially exclude stock from stream gully heads may be the best or only practical option to protect riparian areas.

2.2.2. Riparian vegetation type and effective lengths of management areas

Riparian vegetation *type* has a major influence on aquatic ecosystem health. Densely matted grasses are generally considered to provide the best filtering strips because they provide the most torturous pathway for sediment-laden runoff from adjacent pasture (Collier et al. 1995; Lyons et al. 2000; Gharabaghi et al. 2006). Native grasses, sedges, shrubs and trees can all overhang and drape into the stream, providing cover and shade for fish and macroinvertebrates (Raleigh et al. 1986;

Allouche 2002). Furthermore, in small degraded lowland streams, overhanging grasses and emergent vegetation can narrow a stream, which eventually increases the diversity of velocities and depths. In turn, this can increase habitat quality (Summers 2010).

The riparian vegetation community can also influence nutrient uptake (primarily nitrogen and phosphorus) by recovering nutrients from shallow groundwater and storing them in plant tissue. In general, the capacity for nutrient removal is related to the size of plants in the riparian zone. Large plants and trees will tend to have deeper root masses, allowing deeper ground water to be intercepted. They also have the ability to store more nutrients in plant tissue (Lyons et al. 2000; Quinn 2009). Large trees perform many other ecological functions in the riparian zone. These include the supply of instream shade, leaf litter, woody debris, terrestrial invertebrates and shade for adult stages of aquatic macroinvertebrates. All these functions are influenced by the tree type, density and proximity to the river (Quinn 2009).

Shade is one of the most important functions that riparian trees provide a stream ecosystem. This is particularly important in Hawke's Bay which is well known for its high sunshine hours and summer temperatures. For 'naturalness' to be achieved, 80% shade of a stream bed could be considered appropriate. This is about the amount of shade that a mature native forest would provide to a small to medium-sized stream with an active channel that is less than 7 m wide (Rutherford et al. 1997; Harding et al. 2009). Shading of 60–80% may limit periphyton proliferation and nuisance algal growths (Quinn et al. 1997). Recently, Collins et al. (2019) found that a minimum of 80% shading was required to effectively control instream and emergent macrophytes, which is achievable in small streams and drains but not achievable in medium to large rivers (e.g. streams wider that 8 m).

On the other hand, high amounts of stream shading within a catchment may reduce algal, macrophyte and invertebrate production. In turn, this could reduce the instream uptake and assimilation of nutrients (Matheson et al. 2012) and production of some fish species. Excessive shading in the riparian area also has the potential to shade out groundcover vegetation and increase stream bank erosion until a new stable channel width is established (Lyons et al. 2000; Quinn 2009). Nevertheless, on balance, I consider it unlikely that streams will be excessively shaded at the segment to sub-catchment scale within the agricultural landscape of the Tukituki catchment. Moreover, the potentially negative effects of shading of ground cover can be managed for by provided adequate riparian management area widths, about 10 m wide (minimum average width), that include some grassed filter strip area along the paddock edge. Given the loss of productive land and expense of planting and weed control for planted riparian areas, these mitigations can be considered a more costly option relative to grassed filter strips. Consequently, then extent of expected riparian planting is less for landowners in the level 2 nitrogen loss exceedance category than for those in Level 3.

The *lengths* of riparian management areas required to produce measurable ecological benefits within agricultural landscapes will be vary greatly between waterbodies. Doehring et al. (2019) found largely equivocal results when they assessed the effect of short riparian areas (i.e. less than 200 m or 2% of the total upstream catchment area) on a variety of ecosystem health indicators. They concluded that small-scale efforts to fence and plant the riparian zones of streams appear to have little effect on ecosystem function. In contrast, Jowett et al. (2009) found native fish habitat improved in a two-kilometre section of restored riparian habitat. Holmes et al. (2016) identified that 300 m lengths of well managed riparian areas (i.e. > 5 m wide with rank grass and some riparian plantings) were associated with reduced deposited sediment downstream in a spring fed stream. Based on these data, I suggest that if implemented, riparian planting should occur along waterbody segments for at least 1000-m lengths, or the equivalent of > 5% of the upstream catchment's wetted channel area.

2.2.3. Deterring stock from waterways in steep catchments

Under the Tukituki Plan, stock are not required to be excluded from waterways in areas where the land slope is above 15 degrees, and sheep are not required to be excluded from any waterways. High rates of bank erosion can occur in these steeper areas, and efforts to reduce *E. coli* and meet swimmability targets, as well as phosphorus and fine sediment targets in the Tukituki River may be undermined if a large proportion of waterways are still accessed by stock in areas where fencing is impractical and not obligatory (i.e. waterways flowing through all of the steeper country). Methods other than fencing can be utilised to *deter* stock from waterways, rather than physically excluding them. One approach is to provide alternative water supplies for stock via reticulation (Journeaux & van Reenen 2016), or by providing shade trees mid-paddock rather than there only being shade along waterways (Betteridge et al. 2012). A strategic approach to keeping stock out of waterways, including stock water reticulation and shade trees, is promoted by Greater Wellington Regional Council (GWRC 2012), and could be considered as part of a mitigation package to improve water quality along waterways in the Tukituki where stock exclusion is not a requirement.

2.2.4. Prioritising riparian management at the landscape scale

In principle, the greatest localised ecosystem benefit of riparian planting will be realised in smaller waterbodies and in relatively narrow streams with stable hydrology. Therefore, any riparian enhancement should be targeted first at the smaller waterbodies on a farm. Small streams (1st and 2nd Strahler order) make up the majority of the stream network, therefore, they receive a disproportionate amount of farm-derived pollutants from overland flow and in shallow ground water (Wohl 2017; McDowall et al. 2017). Smaller waterbodies also have a disproportionately large amount of 'edge habitat' that is in contact with the riparian area, relative to open water habitat, when compared with larger waterbodies. This means the potential of riparian areas to affect the ecosystem health of smaller waterbodies is proportionally greater. For example, small stream ecosystems derive a greater proportion of their energy base from terrestrial resources, such as leaf litter and / or terrestrial insects (Vannote et al. 1980). So, if the riparian areas of small streams or ponds are degraded then their ecosystems will deviate further from their natural 'reference' condition relative to larger waterways—where the food base is driven primarily by benthic algae produced from the mid-channel habitat (even in pristine systems). In addition, small waterbodies can be effectively shaded by riparian vegetation. As mentioned above, as a stream gets wider than 7 m the ability of riparian vegetation to reduce water temperature and limit algal and macrophyte growth is likewise reduced. Nevertheless, riparian vegetation will still be beneficial in larger rivers for other reasons, such as supplying vegetative material to the stream and overhanging edge cover for fish. Based on the reasoning above we suggest that any riparian management actions are prioritised for small streams that have an active channel < 8 m wide.

2.3. Stream and channel manipulation

Stream bank recontouring and drain realigning is routinely undertaken in some areas to improve drainage, reduce bank erosion or manage flood risk. These activities can have negative impacts on ecosystem health by disturbing biota and simplifying the structural habitat template of a stream (Blann et al. 2009). However, in principle, there are some situations where stream bank reshaping or realigning could be used to improve ecosystem health, for example, when excessive bank erosion is occurring and leading to large amounts of fine sediment entering a stream. In this instance, using machinery to shallow the angle of stream banks in areas where erosion is problematic can be beneficial for downstream environments—provided it is targeted to where it is needed (Hudson & Harding 2004). This process is typically referred to as 'rebattering' or bank reshaping. In New Zealand, bank reshaping typically results in a uniform trapezoid channel shape which may reduce stream and riparian habitat quality (Blann et al. 2009). Undertaking mechanical erosion protection using a 'two-stage' channel approach is widely accepted globally as a more ecologically sensitive method. Two stage channels allow room for streams to create some mesohabitat diversity within the 'first stage' or low flow channel (Powell et al. 2007).

If a stream has been mechanically straightened or lowered in the past, then redirecting / restructuring the channel could (conceivably) increase habitat complexity and ecosystem health. Any potential channel engineering ought to incorporate modern concepts of stream restoration; for example, instating a two-stage channel with stream meanders and habitat structures. However, assessing the set of circumstances that would result in a net improvement to ecosystem health from engineering works would need specialist input (e.g. from stream ecologists with a sound understanding of fluvial geomorphology). Therefore, I do not think channel engineering should be a standard method to improve stream health in order to gain consents related to nitrogen exceedances. Nevertheless, regional council staff could assess the potential to improve ecosystem health through channel engineering on a case by case basis with a site visit and further input from specialists. Such a project is likely to be expensive and may need some resourcing from the regional council, a farming industry body or equivalent institution.

2.4. Native fish passage remediation

Most native fish in the Tukituki catchment require access to the estuary and ocean to complete their life cycle. This means that upstream fish passage for juvenile native fish is critical for making habitat available to them. Knowledge of the locations of upstream fish passage barriers is typically very limited within agricultural areas. This is particularly true in small streams and drains on private land, which can provide highly productive habitat for a range of native fish species. Small headwater streams and drains can also provide native fish with refuge areas that are free from persistent trout predation pressure (Franklin et al. 2018).

Fish passage to areas upstream of a culvert can be limited if the culvert is 'perched' (i.e. there is a vertical drop to the stream below the downstream end of the culvert pipe that is not in contact with the stream bed). Alternatively, velocities may be too fast if the diameter of the pipe used in the culvert constricts water flow so that velocities exceed the maximum swimming speed of upstream migrating fish. In these instances, fish passage can be rectified by installing box culverts at crossings or by retrofitting passage enhancements. Franklin et al. (2018) has produced a recent guide for identifying and rectifying fish passage barriers.

Providing for fish passage is not a requirement of the Plan and so could be an appropriate and highly effective way to improve ecosystem health—provided it is targeted to areas where it its needed. This will require some specialist knowledge and should be done in partnership with HBRC as part of the consenting process. Maintaining connectivity of waterways and fish passage is likely to receive increasing focus as regional councils implement the recommendations in the National Policy Statement for Freshwater Management (Franklin et al. 2018).

3. SUGGESTED MITIGATION PACKAGES FOR NITROGEN EXCEEDANCE CATEGORIES

In common with HBRC, other regional councils are adopting tiered approaches for the use of land use mitigations, with the general principle being that more costly mitigations are allocated to catchments or sub-catchments with high instream values or high sensitivity to pollution. For example, the Horizons Regional Council recently reviewed land use mitigation options as a function of cost (Low et al. 2019b). Similarly, Matheson et al. (2018) prepared a report for Bay of Plenty Regional Council which suggests three levels of land use mitigation 'bundles' to reduce the four main land use derived pollutants (nitrogen, phosphorus, fine sediment and *Escherichia coli*). These were prepared for the sub-catchments of the Rangitāiki and Kaituna-Pongakawa-Waitahanui Water Management Areas. The mitigation bundles are ranked in terms of cost to apply and are summarised in Appendix 2. Daigneault and Elliot (2017) also present mitigation bundles to manage nutrient pollution that use much the same list of individual management actions as Matheson et al. (2018) (Appendix 3). In the present report, the extent and degree of how the suggested mitigations should be applied is modelled on the work of the authors cited above. The point of difference is that the mitigation actions proposed here focus on improving ecosystem health, rather than mitigating nitrogen loss.

There is no single land use mitigation strategy that can meet all ecological objectives, i.e. there is no 'silver bullet' for managing freshwater ecosystem health. In addition, there will always be tension between relatively blunt and fixed policy instruments and the bespoke and adaptive nature of an optimised land use mitigation plan. With this in mind, below I describe a list of potential mitigation options for the two levels of nitrogen leaching exceedance rates (i.e. Levels 2 and 3). These suggestions are not intended to be entirely prescriptive. I have attempted to provide 'rule-of-thumb' values to guide the degree and / or extent that these mitigation measures should be applied. The values are put forward as a starting point to consider how potential environmental improvements can be bedded into a farm landscape.

The degree of effort described below should be amended if regional council staff consider it appropriate after an on-site assessment of a farm and its aquatic ecosystem(s). This could be done as part of the farm planning process for landowners that are exceeding their nitrogen leaching rate allocations. For some landowners the suggested mitigation measures may not be practical or even feasible. For example, landowners without waterbodies on their farm cannot undertake riparian fencing. Landowners in this situation could consider implementing actions to improve ecosystem health in their wider sub-catchment (i.e. outside their land boundary, see Section 4).

3.1. Level 1: Under nitrogen leaching allocation rate

For landowners that are currently under their allocated nitrogen leaching rates there are no specific actions required—other than industry standard good management practices and any additional measures deemed necessary by the Plan (Table 2).

3.2. Suggested Level 2 mitigations (contributing concentration 0.8-2.4mg/l)

1. Install managed riparian areas *averaging* at least 5 m wide from the low-flow wetted edge along all permanently wetted waterbodies (drains, streams, lakes and wetlands). Fenced areas should be of variable widths, with wider sections to accommodate for relatively steep areas, depressions in the stream banks, ephemeral drains and other features that concentrate overland flow through the riparian area.
2. For a minimum of 1 km or at least 5% of waterbody length on a farm (i.e. stream length and / or wetland / lake perimeter) undertake riparian planting. Planted segments should occur for continuous kilometre-long segments. Priority should be given to permanently flowing streams that have an active channel width of less than 8 m wide. Where possible, plant species and planting densities should be sufficient to provide 60–80% shade of the low-flow channel.
3. Install fencing to protect stream gully heads from stock where stream-side riparian fencing is impractical due to steepness of land. Provide alternative water sources (e.g. reticulation or solar powered troughs) so stock are not forced to go to waterways to drink. Provide shade trees or other forms of shelter away from waterways so steep banks and riparian vegetation are not the only shade / shelter option for stock.
4. Create constructed wetlands, fenced seepage wetlands and / or sediment traps equating to 0.5% of catchment areas within the farm boundaries.
5. Identify critical source areas for fine sediment and phosphorus and install fencing, grassed swales and detention bunds to manage runoff during moderate rainfall events.
6. Identify potential fish passage barriers and improve fish passage around any unnatural barrier under 4 m high; for example, by retrofitting fish passes or upgrading pipe culverts to box culverts.

3.3. Suggested Level 3 mitigations (contributing concentration > 2.4mg/l)

1. Install managed riparian areas *averaging* at least 10 m wide from the low-flow wetted edge along all permanently wetted waterbodies (drains, streams lakes and wetlands). Fenced areas should be of variable widths, with wider sections to

accommodate for relatively steep banks, depressions in the stream banks, ephemeral drains and other features that concentrate overland flow through the riparian area.

2. For a minimum of 2 km or at least 10% of waterbody length on a farm (i.e. stream length and / or wetland / lake perimeter), undertake riparian planting. Planted segments should occur for continuous kilometre-long segments. Priority should be given to permanently flowing streams that have an active channel width that is less than 8 m wide. Where possible, plant species and planting densities should be sufficient to provide 60–80% shade of the low-flow channel.
3. Install fencing to protect stream gully heads from stock where fencing is impractical due to steepness of land. Provide alternative water sources (e.g. reticulation or solar powered troughs) so stock are not forced to go to waterways to drink. Provide shade trees or other forms of shelter away from waterways so steep banks and riparian vegetation are not the only shade / shelter option for stock.
4. Create constructed wetlands, fenced seepage wetlands and / or sediment traps equating to 1% of catchment areas within the farm boundaries.
5. Undertake a native planting and weed control programme on any natural wetland areas on the farm.
6. Identify critical source areas for fine sediment and phosphorus and install fencing, grassed swales and detention bunds to manage runoff during moderate rainfall events.
7. Identify potential fish passage barriers and improve fish passage around any unnatural barrier under 4 m high; for example, by retrofitting fish passes or upgrading pipe culverts to box culverts.

4. 'OFFSITE' MITIGATION

All of the above options for improving aquatic ecosystem health could conceivably be applied outside the boundaries of a landowner's farm—where the action could result in greater ecological gains. For example, sheep farmers are not required to fence under the Plan. Yet substantial ecosystem gains could be achieved by fencing sheep from the margins of streams to install grassed filter strips and stabilise the banks (Holmes et al. 2016; Hughes 2016). Because of the diminishing returns in fine sediment reduction with increasing fencing width, in theory, excluding sheep from a stream may be more effective than widening the riparian area in a stream that already has stock exclusion fencing. Likewise, improving fish passage or planting for shade could also be more effective at improving ecosystem health, if implemented in areas other than the land parcel that exceeds a nitrogen leaching rate allowance. For example, there is little environmental gain by improving fish passage in the headwaters of a stream if there are no plans to enable fish passage past barriers present on downstream farms.

In short, if landowners do not find it practical or possible to implement any of the suggested ecosystem improvements on their own land, they could look to their wider sub-catchment for opportunities to improve ecosystem health. This approach may benefit from setting up sub-catchment groups as collectives to negotiate where mitigations will occur and who will resource and implement them. This approach would also require involvement of Regional Council staff for help with identifying potential areas that could benefit from any 'offsite' mitigations and to ensure that any actions taken are formally recognised as part of the consenting process.

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6. APPENDICES

Appendix 1. Freshwater objectives under the Tukituki Plan Change 6 to Hawke's Bay Regional Council's Resource Management Plan: Tukituki River Catchment (HBRC 2015).

5.9 TUKITUKI RIVER CATCHMENT

5.9.1 Fresh Water Objectives

OBJ TT1 To sustainably manage the use and development of land, the discharge of contaminants including nutrients, and the taking, using, damming, or diverting of fresh water in the Tukituki River catchment so that:

(a) Groundwater levels, river flows, lake and wetland levels and water quality maintain or enhance the habitat and health of aquatic ecosystems, macroinvertebrates, native fish and trout;

(b) Water quality enables safe contact recreation and food gathering;

(ba) Water quality and quantity enables safe and reliable human drinking water supplies;

(c) The frequency and duration of excessive periphyton growths[1] that adversely affect recreational and cultural uses and amenity are reduced;

(d) The significant values of wetlands are protected;

(e) The mauri of surface water bodies and groundwater is recognised and adverse effects on aspects of water quality and quantity that contribute to healthy mauri are avoided, remedied or mitigated; and

(f) The taking and use of water for primary production and the processing of beverages, food and fibre is provided for.

OBJ TT2 Where the quality of fresh water has been degraded by human activities to such an extent that Objective TT1 is not being achieved, water quality shall not be allowed to degrade further and it shall be improved progressively over time so that OBJ TT1 is achieved by 2030.

OBJ TT4 To manage the abstraction of surface water and groundwater within a minimum flow regime and allocation limits that achieve OBJ TT1 while recognising that existing takes support significant investment.

OBJ TT4A To recognise that industry good practice for land and water management can assist with achieving Objectives TT1, TT2 and TT4.

OBJ TT5 Subject to Objectives TT1, TT2 and TT4, to enable the development of on-farm storage and Community Irrigation Schemes[2] that improve and maximise the efficient allocation and efficient use of water.

Appendix 2. The three mitigation bundles for developed by Matheson et al. (2018) for application in the Rangitāiki and Kaituna-Pongakawa-Waitahanui water management areas in the Bay of Plenty. Bundles are rated by cost to apply on farm from M1 (low cost) through to M3 (high cost). Bundles are intended to be applied cumulatively (i.e. M3 includes applying mitigations in M1 and M2) and assume existing good management practices are already in place.

Mitigation bundle	Land use type				
	Dairy pastoral	Non-dairy pastoral	Arable	Horticulture	Forestry
M1	▪ Placement of feeding equipment ▪ Timing of effluent application in line with soil moisture levels (assumes sufficient storage) ▪ Reduced tillage practices ▪ Improved nutrient budgeting and maintenance of optimal Olsen P ▪ Laneway run-off diversion ▪ Grow maize on effluent blocks (if already growing maize) ▪ Elimination of summer cropping ▪ Reductions in seasonal stocking rate ▪ Efficient fertiliser use technology ▪ Efficient irrigation practices (soil moisture monitoring) ▪ Use of plant growth regulators [to replace N] ▪ Adoption of low N leaching forages ▪ Relocation of troughs ▪ Slow release phosphorus fertiliser RPR ▪ Reduce autumn N application - replace with appropriate low(er) N feed ▪ 3m average vegetated and managed buffer around rivers, streams, lakes and wetlands subject to the Dairy Accord; 1m around drains; 5m average buffer on slopes between 8 and 16 degrees, 10m average buffer on slopes above 16 degrees	▪ Improved nutrient budgeting and maintenance of optimal Olsen P ▪ Efficient fertiliser use technology ▪ Stock class management within landscape ▪ Adopt M1 arable cultivation practices for winter cropping ▪ Laneway run-off diversion ▪ Relocation of troughs ▪ Appropriate gate, track and race placement, design (where possible) ▪ Targeted space planting of poles ▪ Slow release phosphorus fertiliser RPR ▪ Adoption of low N leaching forages ▪ Full stock exclusion from all waterbodies greater than 1m wide at any point adjacent to farm (including drains) and wetlands. 2m average vegetated and managed buffer around rivers, streams, lakes and wetlands; 1m around drains; 3m average buffer on slopes greater than 8 degrees; 5m average buffer on slopes greater than 16 degrees.	▪ Grass or planted buffer strips ▪ Complete protection of existing wetlands ▪ Maintain optimal Olsen P ▪ Efficient fertiliser use and technology ▪ Cover crops between cultivation cycles ▪ Manage risk from contouring ▪ Reduced tillage practices	▪ Complete protection of existing wetlands ▪ Maintain optimal Olsen P ▪ Laneway run-off diversion ▪ Efficient fertiliser use and technology ▪ Efficient irrigation practices (soil moisture monitoring, not following fertiliser application) ▪ Grass swards under canopy, minimise bare ground and vegetated buffers around waterways.	▪ Management of gorse ▪ Complete protection of existing wetlands

Mitigation bundle	Land use type				
	Dairy pastoral	Non-dairy pastoral	Arable	Horticulture	Forestry
M2	▪ Increase effluent application area ▪ Develop a detention bund ▪ Controlled grazing with stand-off pads (16 hours per day on pad in autumn), if they already have a stand-off pad ▪ Installing variable rate irrigators on existing pivot irrigators ▪ Reduce imported autumn supplement fed by 20% ▪ Reducing fertiliser N use (to 100kg N/ha) ▪ Full stock exclusion from permanently flowing waterbodies less than 1m wide (REC Order 2 and above) and average 2m vegetated and managed buffer; 3m average buffer on slopes between 8 and 16 degrees, 7m average buffer on slopes above 16 degrees	▪ Eliminate N that supports capital livestock ▪ Detention bunds ▪ Complete protection of gully heads ▪ Management of gorse ▪ Whole paddock space planting of poles ▪ Full stock exclusion from permanently flowing waterbodies less than 1m wide (REC Order 2 and above) and 1m average vegetated and managed buffer; 2m average buffer on slopes greater than 8 degrees, 3m average buffer on slopes greater than 16 degrees [with associated stock water reticulation, if any]. ▪ Convert steep land (e.g. LUC class 7-8, >26 degrees) into forestry/mānuka and fenced ▪ Changing stock ratios to reflect lower N leaching potential	▪ Use of silt fencing ▪ Complete protection of gully heads -N/A ▪ Reducing fertiliser N use ▪ Strip tillage	▪ Detention bunds in gullies (where they exist in amongst orchard properties)	

Mitigation bundle	Land use type				
	Dairy pastoral	Non-dairy pastoral	Arable	Horticulture	Forestry
M3	▪ Afforestation of erosion prone land (e.g. >26 degrees) ▪ Stock excluded from REC Order 1 watercourses less than 1m wide and 1m wide average vegetated buffer ▪ Impervious effluent storage and sufficient capacity to comply with soil moisture guidelines and low rate effluent application ▪ Restricted grazing in covered stand-off pad, with use extended to winter as well ▪ Put in standoff pad if they haven't got one and use for 16 hours per day in autumn ▪ Switching from manual (e.g. K-line) to pivot irrigators with variable rate irrigators – irrigated dairy farms with manual irrigation systems only ▪ Creation of new wetlands ▪ Reducing stocking rates down by 0.3 cows/ha	▪ Full stock exclusion from REC Order 1 watercourses less than 1m wide and 1m wide average vegetated buffer. ▪ Creation of new wetlands ▪ Eliminate N that supports trading livestock ▪ Reducing stocking rates	▪ Creation of new wetlands ▪ Sediment traps		▪ Creation of new wetlands

Appendix 3. Three mitigation bundles were developed by Daigneault and Elliot (2017) for managing land use derived pollutants in New Zealand. Bundles are rated by cost to apply on farm from M1 (low cost) through to M3 (high cost). Bundles are intended to be applied cumulatively (i.e. M3 includes applying mitigations in M1 and M2) and assume existing good management practices are already in place.

Mitigation Bundle	Management Option
M1	Installation of soil moisture monitoring gear and VRI on existing centre pivots. Adjust cropping fertiliser rates and types to best suit plant requirements and timings Limit each urea application Variable Rate Fertiliser Gibberellic Acid to substitute some spring and autumn nitrogen on pastures Apply nitrate inhibitors Optimise Stocking Rates Implement best management practices for infrastructure use and maintenance Optimum Olsen P Low solubility P fertiliser Laneway runoff diversion Effluent management Stock exclusion/fencing
M2	Modify irrigated area to include centre pivots/laterals fitted with Variable Rate Irrigation technology Variable Rate application of liquid urea Wetlands and/or sediment traps Tile drain amendments Reduce nitrogen fertiliser applications Riparian planting Enhance animal productivity via introducing cows with greater genetic merit Dairy farms to install covered feed pads and required effluent systems
M3	Further reduce nitrogen fertiliser applications Reduce stocking rates All cows wintered off paddock, possibly in barns Restricted grazing of pasture and cropland Apply alum to pastures and crops Increase effluent area No winter feed crop yields over 14 t/ha.