

Water quality in New Zealand: Land use and nutrient pollution

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Parliamentary Commissioner
for the **Environment**
Te Kaitiaki Taiao a Te Whare Pāremata

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Photography

Cover: Manawatū region

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Contents

Commissioner's overview	5
1 Introduction	9
1.1 Purpose of the report	10
1.2 Background	11
1.3 Modelling the future	12
1.4 What this report does not cover	13
1.5 What comes next	14
2 The nutrient problem	15
2.1 How nitrogen and phosphorus end up in water	16
2.2 How do nitrogen and phosphorus affect water quality?	18
2.3 Water quality science is complicated	22
2.4 In conclusion	24
3 Rural land use in New Zealand is changing	25
3.1 LURNZ – A model of how land is used	27
3.2 How land use has changed in recent years	29
3.3 How the model predicts future land use	31
3.4 Modelled land uses in 2020	32
3.5 Conclusion	34
4 Nutrient losses from different land uses	35
4.1 A sheep/beef farm in Gisborne reverting to scrub	36
4.2 A sheep/beef farm in Canterbury converting to a dairy farm	37
4.3 A plantation forest on the Volcanic Plateau converting to a dairy farm	38
4.4 Changes in land use can lead to very different nutrient losses	39

5	Changes in farm productivity and mitigation	41
5.1	Productivity	42
5.2	Mitigation	44
5.3	The net effect of increasing both productivity and mitigation	48
6	Nutrient loads into water are changing	51
6.1	CLUES – modelling nutrient loads in catchments	52
6.2	The results	54
6.3	Two contrasting catchments	57
6.4	What do changing nutrient loads mean for water quality?	62
7	Summary and conclusion	65
	Notes	69
	References	77
	Appendix - Land use definitions	81

Commissioner's overview

I still think of Canterbury as home. For a hundred years, farmers grew crops and ran sheep on the patchwork plains. But over the last twenty years, water has transformed much of this long-familiar landscape into bright green pasture grazed by dairy cows. Often the first sign of such change has been the felling of macrocarpa shelter belts to make way for irrigators up to a kilometre long travelling across paddocks. In parts of the North Island too, large-scale and rapid land use change has been taking place. For instance, north of Taupō, tens of thousands of hectares of pine forests have been felled and replaced by dairy farms.

These land use changes reflect the changing economics of farming. In 1982, the number of sheep in New Zealand peaked at 70 million; now there is less than half that number. Beef cattle numbers have also fallen. Changing how we use land in response to market signals is not new.

How ever we use our land, the quality of the water in our rivers and streams, lakes, estuaries and aquifers is affected. This report is focused on how current changes in land use are affecting the amounts of nitrogen and phosphorus that end up in fresh water. As explained in my 2012 report, *Water quality in New Zealand: understanding the science*, too much nitrogen and phosphorus in water lower its quality by causing excessive growth of weeds, slime and algae, affecting populations of insects, fish and waterbirds. On land, nitrogen and phosphorus are valuable nutrients; above certain concentrations in water, they are pollutants.

The analysis that underlies this report has been undertaken by linking two models together – one a model of land use change and the other a model that can be used to estimate the nutrient loads in water. Both are models that are used by government agencies to inform policy development.

The outcome of the modelling exercise is not good news. I had hoped it would be otherwise. It is almost inevitable that without significantly more intervention, we will continue to see an on-going deterioration in water quality in many catchments across the country, particularly in Canterbury and Southland.

This is not the fault of any one industry alone nor the fault of a single generation. Industrial wastes and town sewage have, until relatively recently, been significant sources of water pollutants and continue to be in some places. Much, if not most, of the phosphorus that has accumulated, and continues to accumulate, in waterways is the result of the erosion that has followed many decades of forest clearance for sheep farming. But the influx of nitrogen in highly soluble form that has accompanied the dairy boom has joined with the phosphorus to foster unwanted plant growth in much of our fresh water.

Dairy farming is not the only land use that has high nutrient loss rates. But the land area used by others – like horticulture – is scarcely changing.

Where declining water quality is attributed to dairy farming, the cause is generally given as 'intensification' – defined as putting more cows on each hectare of land. What the modelling has shown is that the bigger cause is the scale of the expansion of dairy farming – putting cows on more hectares.

The land use model forecasts that, by 2020, dairy farms will cover over 650,000 more hectares of land than in 1996 when the dairy boom was just beginning, with 70% of the increase in Canterbury, Otago and Southland.

Certainly, a great deal of effort is being put into mitigation – reducing the amounts of nitrogen and phosphorus that end up in fresh water. Both central and local government have committed to spending many millions of dollars seeking to protect vulnerable iconic lakes. Other important initiatives have been the Dairying and Clean Streams Accord, the Land and Water Forum, and the many catchment zone committees using a collaborative approach to managing water. On a personal level, I am regularly heartened by reading Jon Morgan's newspaper columns about the innovation and stewardship displayed by individual farmers.

The majority of dairy farmers now spread their dairy shed effluent on to land, recycling the nutrients it contains. Increasingly, stream banks are being fenced off and planted. But shed effluent accounts for only a small proportion of the urine and dung excreted by cows, and riparian strips are much better at stopping phosphorus than the very soluble and elusive nitrogen.

The results of the modelling exercise show that the amount of nitrogen entering fresh water every year in virtually every region of the country will continue to rise. This is especially so in regions where dairy farming is expanding and is occurring despite concurrent increases in forestry.

While the rate at which phosphorus is added to water is relatively steady in most regions, significant increases are occurring in Canterbury and Southland. And the amount of phosphorus present in many water bodies keeps rising as it accumulates in sediment.

The impact of this on-going and increasing stress will generally be worsening water quality – more blooms of algae and cyanobacteria, more streams trailing metres of brown slime, fewer stream insects and fish, and more wells and waterways exceeding nitrate toxicity limits.

All of us as New Zealanders face a difficult dilemma.

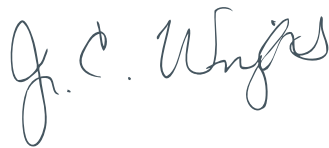
Our small country is a major supplier of protein in the form of milk powder to developing countries, and the dairy sector is now the biggest single earner of export dollars. It is entirely understandable that many of those that make a living off the land seek the greatest economic return. Rising farm costs without corresponding price increases for wool and meat are continuing to incentivise dairy farm conversions.

Unfortunately, this investigation has shown the clear link between expanding dairy farming and increasing stress on water quality. Even with best practice mitigation, the large-scale conversion of more land to dairy farming will generally result in more degraded fresh water. However, in some cases, enhanced mitigation may create some room for dairy conversions. The nature of the catchment and the waterbodies within it are all-important. For instance, on the West Coast, nitrogen loads on rivers are very high, but this does not affect water quality because the nitrogen is rapidly carried out to sea.

New Zealand is richly endowed with rivers and streams, with lakes and estuaries and aquifers. Their beauty and variety is important to us in many ways, including another major driver of our economy, tourism – an industry that has been built on a ‘clean green’ brand. Recreational use of our waterways has a strong local characteristic – people expect to be able to swim, fish and gather mahinga kai close to where they live, and certainly without needing to travel to a national park.

When this investigation began, I hoped the modelling would provide happier news. In much of my work, I actively seek out ‘win-wins’ for the economy and the environment. But in this case, New Zealand does face a classic economy versus environment dilemma. Despite the thousands of academic papers that have been written about ‘internalising’ environmental costs into the economy, its practice largely eludes us. While ‘polluter pays’ is a logical extension of ‘user pays’, its implementation is fraught with many challenges.

To its credit, the Government has embarked on a programme of reforming the management of fresh water. One of the milestones in that programme has been the development of the 2011 National Policy Statement for Freshwater Management. This requires that the *‘overall quality of fresh water’* in all regions of the country be maintained or improved. We cannot achieve this goal unless decision makers more actively address the link between land use change and water quality.



Dr Jan Wright

Parliamentary Commissioner for the Environment



1

Introduction

'What in Europe took twenty centuries and in North America four, has been accomplished in New Zealand within a single century.'

Geographer Kenneth Cumberland, 1941¹

New Zealand is a young country – young in geological time and young in terms of human settlement. Before humans arrived, the country was almost entirely clothed in green with primordial forests growing from the mountains to the coast. Yet in a relatively short time, the land has seen many changes.

At the same time that humans changed the land, they also changed the multitude of rivers, lakes, streams, and aquifers that contain New Zealand's fresh water. One huge change came from the felling and burning of forests to provide pasture for millions of sheep greatly increasing the rate of soil erosion. In much of the country this has resulted in stony riverbeds being covered with layers of sediment and clear water becoming murky.

Over the past decade, the quality of the country's fresh water has become the most important environmental issue in the eyes of many New Zealanders. The current and previous Government, along with regional councils, have responded in a variety of ways. But water quality is a complex matter and water pollutants are many and varied.

In the last few years, concern has been particularly focused on the two major nutrients – nitrogen and phosphorus. These two elements are essential for plant growth, and so are valuable fertilisers on land. But in water, they can also cause the growth of choking invasive weeds, riverbed slime and (sometimes toxic) algal blooms.

This report looks into the future, specifically the year 2020. The most up-to-date modelling available has been used to estimate the annual amount of nitrogen and phosphorus that will be added to the country's fresh water in that year.

The modelling is focused on changes in 'diffuse sources' of nutrient pollution. Diffuse sources now account for more than 95% of the nutrients that end up in fresh water, although discharge from 'point sources' – such as factories and town sewage – can be locally significant.²

Looking into the future is always looking '*through a glass darkly*' and all models are subject to numerous caveats and criticisms. But this does not mean that they are valueless. Modelling the future is everywhere in public policy – predicting trends in GDP, estimating the workforce required to deal with an ageing population, deciding where to build new schools.

1.1 Purpose of the report

The Parliamentary Commissioner for the Environment is an independent Officer of Parliament, with functions and powers granted by the Environment Act 1986. Her role allows a unique opportunity to provide Members of Parliament with independent advice in their consideration of matters that may have impacts on the quality of the environment.

Water quality is a subject of high public concern and vigorous debate. In March 2012 the Commissioner published *Water quality in New Zealand: understanding the science*, written to provide an accessible guide to the science of water quality. This report follows on from that first report. It delves into one critical aspect of water quality – the relationship between land use and the two nutrient pollutants: nitrogen and phosphorus. The purpose is to give decision makers a deeper understanding of how changes in land use affect water quality.

This report has been produced pursuant to ss 16(1)(a), (b) and (c) of the Environment Act 1986.



Source: Brian High

Figure 1.1 An algal bloom at Washdyke Lagoon, near Timaru.

1.2 Background

New Zealand is a country that from time to time has undergone periods of very rapid land use change, largely driven by the heavy reliance of the economy on exports of commodities.

In the 18th century, European settlers burned tussock in the high country to create grazing for the Merino sheep that produced valuable fine wool. The great kauri forests of the north fell victim to the demand for the resin (gum), with most exported to make varnish. The timber was used to provide spars for ships in the British Navy and to build houses in Sydney and San Francisco.³ After the first refrigerated ship sailed for Britain with a cargo of frozen lamb carcasses in 1882, the demand for pasture soared. Butter and cheese, as well as meat, could now be exported – more forests were burned and swamps were drained. A forestry boom in the 1920s and 1930s led to the first large plantings of radiata pine.

Such changes in how land was used inevitably changed the natural environment, including the quality of the fresh water in many rivers, streams and lakes.

Today the country is experiencing another very rapid change in the way much of our rural land is used. The demand from middle classes of Asia for protein in the form of milk powder is fuelling a boom in dairy farming. Some land formerly used for sheep/beef farming and for forestry has been converted to dairy farms.

In 2002, the 'Dirty Dairying' campaign pointed to dairying as the major cause of deteriorating water quality. The campaign spurred animated debates about just how bad water quality is in different parts of the country and how much dairying is to blame. But it has also led to both policy development and on-the-ground actions aimed at improving water quality, or at least slowing the deterioration.

In 2003, Fonterra, government agencies and regional councils signed the Dairying and Clean Streams Accord, which was replaced by the Sustainable Dairying: Water Accord in 2013. In 2009, the Land and Water Forum was established, based on the model of collaborative decision making used in some Scandinavian countries. In 2013, the Ministry for the Environment released a discussion document titled *Freshwater reform 2013 and beyond*, proposing the setting of limits on water pollutants.

Councils have also been increasingly active. For instance, nutrient loss limits have been placed on some farms in some catchments in Waikato, Bay of Plenty and Manawatū. In several regions, resource consents are now required for converting land to dairy farming. Some regional and district councils have partnered with Government and others to fund protection of a number of lakes and two rivers. Another initiative is the Hill Country Erosion Fund for reducing sediment loss from hill country farms.

The discharge of nutrient-rich effluent from dairy sheds directly into waterways is now relatively rare, and many streams have been fenced and crossings bridged to keep cattle out of water. Riparian planting – stabilising banks with vegetation that absorbs some nutrients – is increasingly encouraged.

At the same time, greater production from agriculture is anticipated. The Government has set a target of doubling the value of agricultural exports by 2025. Increases in dairy production have come from increasing both the stocking rate on dairy farms (cows per hectare) and the milk yield from each cow. The Government has also allocated funding to support new irrigation schemes and this will enable further expansion of dairy farming and other types of intensive farming.

On the one hand, there are initiatives aimed at reducing the impact of agriculture on water quality. On the other hand, there are initiatives aimed at obtaining more value from agriculture that may well exacerbate its impact on water quality. The Government has a policy that requires that the *'overall quality of fresh water within a region is maintained or improved'* by 2030.⁴

The modelling commissioned for this report begins the task of looking into the future. Its purpose is to shed some light on the direction in which the quality of our fresh water might be heading in different parts of the country. It is far from painting a complete picture, but should still be useful. As the noted statistician, George E. P. Box, famously said *'All models are wrong, but some are useful'*.

1.3 Modelling the future

The results in this report are derived from a major modelling exercise commissioned from Motu Economic and Public Policy Research (Motu) and the National Institute of Water and Atmospheric Research (NIWA).

The work commissioned required that two existing models be joined together – a model of land use change developed by Motu, and a model of nutrient losses from land into water developed by NIWA, AgResearch and others.

The land use model is known as LURNZ – *Land Use in Rural New Zealand*. It can be used to predict how uses of rural land in different parts of the country will change over time. These predictions are based on economic variables such as commodity prices and physical variables such as slope of the land.

The nutrient loss model is known as CLUES – *Catchment Land Use for Environmental Sustainability*. It can be used to predict the nutrient loads entering fresh water across the country. These predictions are based on land uses and physical variables such as soil type, climate and rainfall.

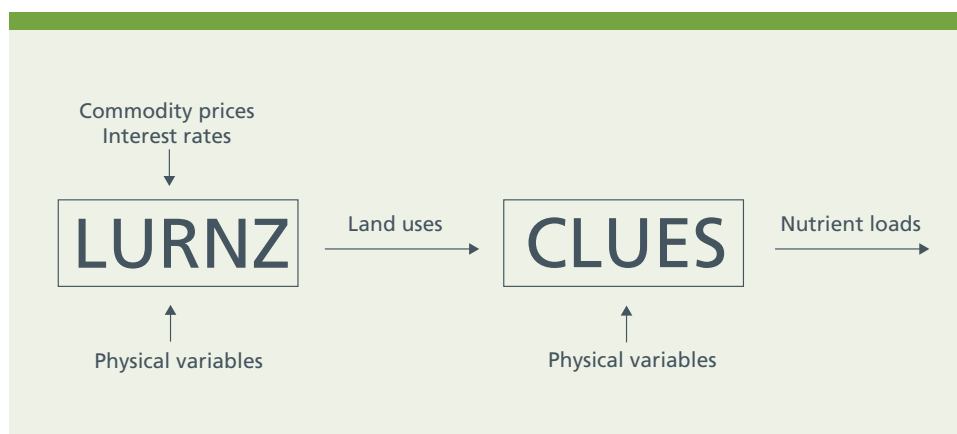


Figure 1.2 A high-level schematic depiction of the modelling exercise on which this report is based.

The joined LURNZ–CLUES model has been used to predict the total annual amounts of nitrogen and phosphorus that will be lost from the land into water in different parts of the country in the year 2020.⁵

All models are, of course, approximations of reality and some are better than others. There are a number of land use and water quality models that have been developed in New Zealand. As part of this investigation, Motu convened two workshops – one to describe and assess the different land use models available, and the other to describe and assess the different nutrient loss models available. LURNZ and CLUES are the models that have been designed to answer questions at the national level.⁶

1.4 What this report does not cover

- Water pollutants other than nitrogen and phosphorus
- Analysis of values placed on fresh water, including Māori spiritual values
- Water scarcity and allocation including storage for irrigation.
- The quality of the water in any particular water body.
- Standards, guidelines, limits and targets for water quality
- Governance, legislation, policy or regulation.

1.5 What comes next

Chapter 2 describes some basic science of nutrient pollution, highlighting the differences between nitrogen and phosphorus and their effect on water quality.

Chapter 3 describes how the LURNZ model has been used to predict land use changes and presents the results.

Chapter 4 demonstrates how nutrient losses from land change when the use of the land changes.

Chapter 5 deals with two major changes underway in farming – increasing productivity and increasing environmental mitigation.

Chapter 6 describes how the CLUES model has been used to predict nutrient loads entering fresh water and presents the results.

Chapter 7 summarises the findings of the investigation.

The following documents are available at www.pce.parliament.nz.

- Regional maps of rural land use in 1996, 2008 and 2020.
- The technical report by Motu entitled '*Land use and farming intensity: for 1996, 2008 and 2020*' that underlies Chapter 3.
- The technical report by NIWA entitled '*National nutrient mapping using the CLUES model*' that underlies Chapter 6.
- Workshop reports by Motu '*Understanding the practice of water quality modelling*', '*Understanding the practice of land use modelling*' and '*The mitigation of nutrient loss from New Zealand agriculture: separating the probable from the possible.*'



Source: Brian High

Figure 1.3 A bloom of the cyanobacteria, *Phormidium*, on the Ōpihi River near State Highway 1 in South Canterbury.

An aerial photograph showing a river with several meanders flowing through a landscape of agricultural fields. The fields are divided into various sized plots, some appearing darker (possibly wet or planted) and others lighter (possibly bare or harvested). The river is a dark, winding line through the landscape.

2

The nutrient problem

To understand the relationship between land use and the two nutrient pollutants – nitrogen and phosphorus – it is first necessary to understand key aspects of the science. This chapter highlights the differences between nitrogen and phosphorus and describes the effects they have on fresh water.

All plants and animals need nitrogen and phosphorus to grow – they are essential nutrients. But when excess nitrogen and phosphorus end up in fresh water, they can cause problems.

There are, of course, many types of water pollutants – heavy metals, toxic chemicals, pesticides, and the pathogens that can make people and animals sick.⁷ Those that come from *point* sources – such as the effluent from a factory – are relatively easy to control. *Diffuse* sources of pollutants generally come from a large number of small sources that are hard to pinpoint – such as urine patches and eroding stream banks – and pose a much greater challenge.

In New Zealand there are three major water quality problems that primarily come from diffuse sources. One is sediment – the mud and silt that continues to build up on the beds of rivers, streams, lakes and estuaries, making water murky and smothering aquatic life. The second is bacterial contamination from water running over land and into waterways. The third is the two nutrients, nitrogen and phosphorus. These nutrient pollutants are the focus of this report.

There are three sections in this chapter:

- The first focuses on how nitrogen and phosphorus get into fresh water.
- The second describes how excessive amounts of these two nutrients degrade water quality.
- The third deals briefly with some of the complexity of water quality science.

2.1 How nitrogen and phosphorus end up in water

There is a fundamental distinction between nitrogen and phosphorus that not only affects how they get into water and how easy they are to control, but how they 'behave' in water.⁸

Nitrogen – in the forms in which it generally gets into water – is very soluble. This means that it can flow relatively easily across land, and leach down through soil into groundwater, and make its way into rivers, streams and lakes, and down into aquifers.

In contrast, phosphorus tends to stick to soil and is not as easily washed away by water. Much of the phosphorus in waterways originated as naturally occurring phosphorus in soil. As soil is washed into water, it not only builds up as layers of sediment, but takes phosphorus in with it. Some phosphorus is dissolved in water and can be taken up by aquatic plants, but most phosphorus in waterways is trapped and accumulates in the sediment. This trapped phosphorus can later be released again under the right conditions and thus be available for plant growth.

For this reason, it is useful to think of nitrogen as the 'elusive one' and phosphorus as the 'sticky one'.

Nitrogen

The main source of nitrogen in New Zealand's waterways is urine from farm animals.

Urine contains urea, which is rich in nitrogen. Urine thus acts as a nitrogen fertiliser, but urine patches in paddocks are too much of a good thing when the grass cannot grow fast enough to take up all the nitrogen. When paddocks are waterlogged, the nitrogen can wash straight through the soil before plants can use it. This occurs particularly in winter.

The weight of stock on the soil surface can cause waterlogged soils to become 'pugged', and so nutrients are more likely to be washed off across the surface directly into waterways. And compacted soil is difficult for plant roots to penetrate, further slowing plant growth and take-up of nitrogen.

Over the last twenty years, sales of nitrogen fertiliser have increased steeply. But while some nitrogen entering waterways will have come from nitrogen fertiliser, this fertiliser is a much smaller source of nitrogen than animal urine. However, the increased use of urea fertiliser has, along with irrigation and supplementary feed, enabled higher stocking rates, and more animals mean more urine.⁹



Source: C. Davidson

Figure 2.1 Leaching rates of nitrogen are particularly high when cattle are break-fed in winter on forage crops such as swedes.

On a per hectare basis, the highest losses of nitrogen come from land used for market gardening, in part because vegetables do not take up nitrogen efficiently.¹⁰ The lowest nitrogen loss per hectare comes from forested land and scrub. Losses from livestock farming lie in between.

Most of the nitrogen that enters fresh water is available for plant growth in the water, fertilising weeds, algae and other pest plants. This is not the case for phosphorus.

Phosphorus

The main way that phosphorus gets into water is through being carried into waterways stuck to soil particles. However, some phosphorus is also dissolved in water and can leach into waterways in the same way as nitrogen does.

Historically, phosphorus has accumulated in waterways where land has been cleared, with the highest rates occurring where rainfall is high, slopes are steep and soils are prone to erosion. Phosphorus occurs naturally in soil, but the use of superphosphate fertiliser on hill country, which began in the 1950s, increased the phosphorus in soil and thus the losses into water.

Sewage and animal effluent are rich in phosphorus. Wastewater from towns, dairy factories, freezing works, and pulp and paper plants can be large point sources of phosphorus. But although these point sources can be significant at specific places and times of year, they are much less significant at a national level than the diffuse sources of phosphorus.



Source: Peter Scott

Figure 2.2 Much of the hill country of New Zealand should never have been cleared for sheep farming. Storms have washed away topsoil on many steep slopes carrying phosphorus along with the sediment into rivers and streams. Denis Glover's poem 'The Magpies' evokes the heartbreak of a failed hill country farm.

2.2 How do nitrogen and phosphorus affect water quality?

There are two ways in which nutrients affect water quality. The first is nitrate and ammonia toxicity and the second is unwanted growth of plants.

Too much nitrogen (in the form of nitrate) can kill sensitive organisms, and affect humans and animals that drink the water.¹¹ Young bottle-fed babies can develop a kind of 'blue baby syndrome', when the nitrate interferes with the ability of the blood to carry oxygen; once recognised, this condition is readily treatable.¹²

Too much nitrogen (in the form of ammonia or nitrate) is highly toxic to fish and some other aquatic organisms. Both raw sewage and dairy shed effluent are rich in ammonia.

The much more common and widespread impact of nutrient pollution – excessive growth of unwanted plants – occurs at lower nitrogen levels. Excessive growth of unwanted plants, such as slime, algae and choking weeds, degrades swimming and fishing spots and depletes oxygen in the water, sometimes to the point of suffocating aquatic life.

Most of these plants are native and part of natural stream ecosystems.¹³ They can be put into four groups (see Figure 2.3).

- *Periphyton* form layers of slime over stones, submerged logs, and can smother other plants. Thick mats trailing tendrils of brown slime can be seen in many lowland streams and rivers in summer.¹⁴
- *Macrophytes* are larger plants that generally root into the sediment and grow up toward the light. Invasive exotic weeds like hornwort grow prolifically in response to excess nutrients.
- *Phytoplankton* that float in the water are tiny plants that can multiply extremely rapidly, particularly in summer, covering large water surfaces with bright green algal blooms.
- *Cyanobacteria* are often called blue-green algae, although they are not actually algae. Nor are they usually blue-green, but can be many colours such as dark brown or red. They are much more likely than algae to form toxic blooms. In lakes cyanobacteria generally float; in rivers, they form part of the periphyton covering stones on the bottom.

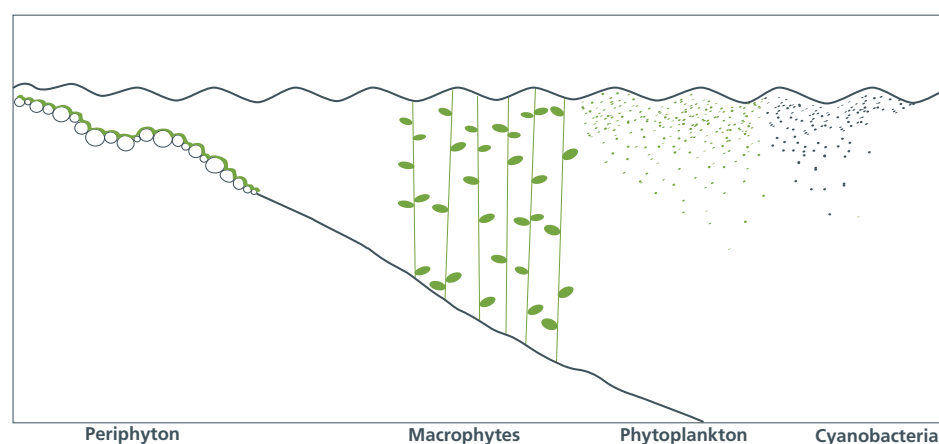


Figure 2.3 Periphyton tend to grow in shallow water forming slime on submerged stones. Macrophytes grow in deeper water – they are rooted in the sediment and reach up toward sunlight. Phytoplankton and cyanobacteria can form mats that cover large surfaces when they ‘bloom’.

When these plants grow in excess, they change the composition of fresh water insect communities (see Figure 2.4).

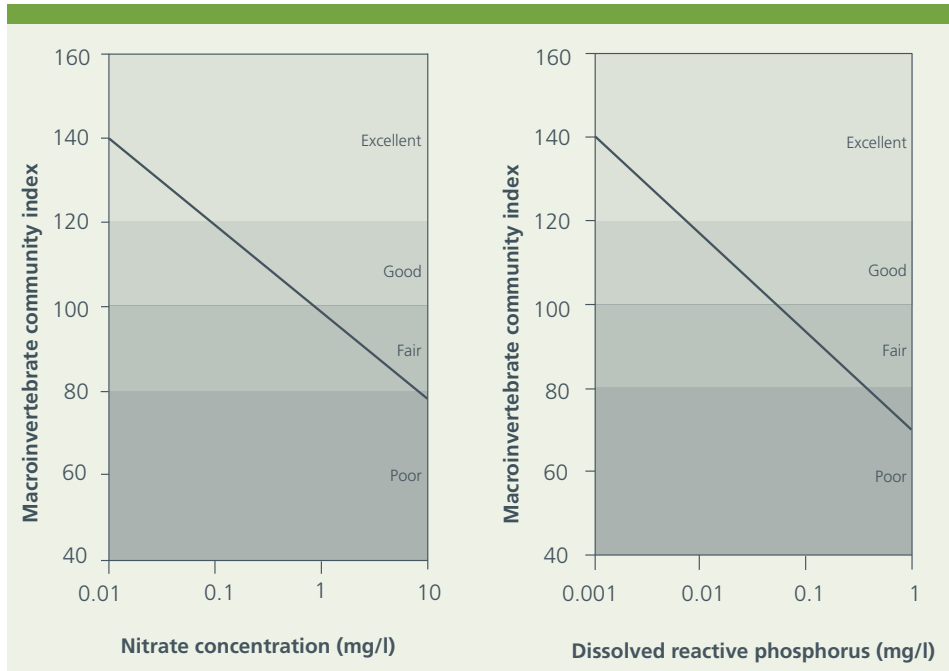


Figure 2.4 The health of communities of insects and other invertebrates in water can be measured using an index called the Macroinvertebrate Community Index (MCI). The graphs above show how MCI falls with increasing concentrations of nitrogen and phosphorus in water. A high MCI score indicates good water quality.¹⁵

Because these insects and invertebrates form the basis of the food chain in water bodies, any changes affect other species like fish and waterbirds (see Figure 2.5).



Source: J. Kappley

Figure 2.5 When fresh water is enriched by nutrients, the composition of invertebrate communities changes. Snails and worms that thrive in a muddy slimy environment proliferate, but stoneflies, mayflies, and caddisflies become scarce. The larvae of these insects provide food for fish and waterbirds like the blue duck (whio) shown here.

2.3 Water quality science is complicated

When quantities of the nutrients nitrogen and phosphorus end up in a particular water body the impact on the quality of the water varies greatly. Intuitively we tend to think that halving the nutrients entering water would make its quality twice as good (and vice versa), but the relationship is far more complex than this. Some of this complexity is described in this section.

22

Varying vulnerability

A host of natural factors – the ‘receiving environment’ – affects the vulnerability of a water body to nutrient pollution.¹⁶

Lakes (and some aquifers) are generally more vulnerable than rivers because they act like sinks accumulating pollutants, especially sediment and the phosphorus trapped within it. But pest plants will grow more readily in a shallow warm lake than in a deep cold lake. Similarly, a river that meanders on a winding course to the sea is generally more vulnerable than a river that flows swiftly straight to the sea.

Another aspect of varying vulnerability is the time of year. Winter rain deepens rivers and speeds up flow rates, so although nutrient loads can be high, they are diluted more and washed further downriver. In summer, water levels are lower and more stable, water temperature is higher and more sunlight reaches the water. Algal blooms and trailing mats of periphyton occur more frequently in summer – the time of year when people are most likely to be out swimming, fishing and appreciating the beauty of rivers and lakes.

A lack of nitrogen or phosphorus can limit the growth of unwanted plants

An excess of nitrogen or of phosphorus alone will not lead to exorbitant growth of pest plants – there needs to be enough of both nutrients. If plant growth in a water body is curbed by a lack of nitrogen, it is said to be *nitrogen-limited*. Similarly, when plant growth is curbed by a lack of phosphorus, it is said to be *phosphorus-limited*. These terms are abbreviated to N-limited and P-limited respectively.¹⁷

It appears N-limitation is less common in New Zealand water bodies than P-limitation – this is certainly the case for lakes.¹⁸ However, the estuaries in New Zealand are more likely to be N-limited than P-limited.¹⁹ In rivers, whether nitrogen or phosphorus is limiting, often varies from time to time or place to place.²⁰ Nitrogen may limit plant growth at one site, and phosphorus at another.

Understanding nutrient levels and limitation is critically important for developing plans and actions for protecting water quality. It also raises the possibility of only having to control one nutrient in some situations. If the water quality is, for instance, P-limited, it may be that controlling phosphorus inputs will be sufficient to limit the growth of algae and other plants.

So is it enough to control either nitrogen or phosphorus?

In situations where inputs of only one nutrient need to be limited, protecting water quality may well be easier and cheaper. This is particularly so if the nutrient that needs to be limited is phosphorus, because it is much easier to control than the 'elusive' nitrogen.

Unfortunately, this approach will usually be risky for several reasons, including the following:²¹

- Different species of plants need different amounts of the two nutrients. So for instance, limiting phosphorus might stop one plant from growing, but favour another that needs less phosphorus.²² *Phormidium*, a cyanobacterium that rapidly multiplied into dark brown toxic mats in the Hutt River last summer, will only grow in water low in phosphorus.²³
- The limiting nutrient can change both daily and seasonally. The water in the Manawatū River changes back and forth between being N-limited and P-limited.²⁴
- The limiting nutrient might be nitrogen in one part of a river and phosphorus in another. This may be the case in the Tukituki River in Hawke's Bay, where it is thought that the limiting nutrient varies in the upper catchment, while the lower reaches of the river are generally P-limited.²⁵

More complexity

The complex way in which phosphorus 'behaves' in water is particularly important.

Most phosphorus is stuck to the sediment, but some is dissolved in the water. It is this 'dissolved reactive phosphorus' that fuels plant growth. As water quality worsens, the level of oxygen dissolved in the water falls and the water becomes more alkaline. The effect is to pull more phosphorus out of the sediment and make it available for plant growth. This 'positive feedback' leads to the deterioration in water quality accelerating.

Another concern is that cyanobacteria, which are relatively likely to become toxic, will generally tolerate a wider pH range than other aquatic plants. So when water becomes more alkaline, cyanobacteria may replace other plants such as periphyton.²⁶

2.4 In conclusion

Most of the nitrogen and phosphorus in fresh water originates from diffuse sources on land. The nature and scale of these diffuse sources depend to a large extent on how the land is used. When land uses in a catchment change, the nutrient loads on the streams in that catchment are also likely to change. While the impact of nutrients on water quality can vary, it is clear that if nutrient loads increase significantly, so does the pressure on water quality.

The next chapter deals with how land is used in New Zealand and how it is changing over time. Examining this is a necessary step in gaining understanding of what the future might hold for nutrient pollution and water quality.

An aerial photograph of a rural landscape. A dark, winding river flows through the left side of the image. The rest of the landscape is a patchwork of various shades of green and brown, representing different types of agricultural land use. A large white number '3' is overlaid on the left side of the image.

3

Rural land use in New Zealand is changing

When the way in which land in a catchment is used changes, the nitrogen and phosphorus that is lost off the land is also likely to change. This in turn changes the amounts of nitrogen and phosphorus that get into the water in the catchment, and is likely to affect the quality of that water.

In just a few generations, as recounted in Chapter 1, much of New Zealand was converted from native forest and tussock to pasture. In many places that change has left eroded hillsides and layers of sediment (containing phosphorus) in rivers and streams.

This chapter is about the rapid change in the use of rural land that began about twenty years ago. It is now many years since New Zealand was Britain's farm, sending lamb, butter and wool back to the home country. In responding to today's export markets, greater use of fertiliser and irrigation has led not only to rural land being used to produce a different mix of commodities, but in many cases to more intensive use of that land.

Changes to the way in which land is used have environmental consequences – not just to the immediate environment, but also beyond. For instance, changing use of land *upstream* will change water quality *downstream*. Some changes will benefit the natural environment, while others will not.

The core of this report is the use of modelling to gain a sense of where the quality of the fresh water in different parts of the country is headed. Chapter 1 contains a high-level description of how this has been done by linking together two models – a model of land use change and a model of nutrient losses from land into water.

The first, the model of land use change, is described in more detail in this chapter, and the modelling results that forecast land use change to 2020 are presented.²⁷



Source: New Zealand Journal of Agriculture, 1946

Figure 3.1 It is many years since New Zealand was Britain's farm, sending lamb, butter and wool back to the home country.

3.1 LURNZ - A model of how land is used

The ability to forecast land use change in New Zealand is comparatively new, and the development of the first model suited to this task began only ten years ago. The model – called Land Use in Rural New Zealand (or LURNZ) – has been developed by researchers at Motu.²⁸

LURNZ is used to give insight into how different policy decisions and market conditions influence changes in land use. For example, the model has been used by the Ministry for Primary Industries to look at how changes in climate are likely to affect pastoral production in the future.²⁹

LURNZ can be used to construct maps of land use. It does this by dividing the country into millions of one hectare squares – ‘pixels’ – each with one of eleven land uses. This is analogous to the way an image on a TV screen is built up of many tiny pixels, each of a different colour.

At the heart of LURNZ is a set of high-resolution satellite photographs taken in three different years, showing land cover in the different pixels. This information is supplemented by data from a number of sources.³⁰



Source: LUCAS Programme, Ministry for the Environment

Figure 3.2 At the heart of LURNZ is a set of satellite photographs taken in three different years. This multi-spectral image shows green grass as orange, exotic forest as red, and so on, and gives much more information than a ‘natural colour’ image would. The town of Hanmer Springs is near the centre of the image.

The eleven different types of land use in LURNZ are depicted below in Figure 3.3.³¹



Sheep/Beef



Dairy



Plantation Forestry



Scrub



Horticulture



Urban



Lifestyle



Conservation Land



Pasture on public land



Privately owned indigenous forest



Non-productive land

Figure 3.3 The land use types used in the LURNZ model.³²

3.2 How land use has changed in recent years

In order to look to the future – in this report, the year 2020 – it is necessary to be grounded in the past. For this report, data in the LURNZ model was used to create two maps of historic land use – one in 1996 and the other in 2008.³³

In 1996, just under a third of New Zealand was used for sheep/beef farming.³⁴ Over the following twelve years, as milk prices rose and dairy farming became increasingly profitable, nearly 300,000 hectares of land used for sheep/beef farming was converted to dairy farming, mostly in the traditional sheep farming regions of Canterbury and Southland. In Canterbury, the area of land used for dairy farming tripled, and more than quadrupled in Southland.

Over the same time period, about 200,000 hectares of plantation forestry was planted, mostly on steeper hill country land previously used for sheep/beef farming. This occurred across the country, with the largest increases occurring in Otago, Gisborne and Manawatū-Whanganui.

The fourth land use shown as changing is scrub. Land used for hill country sheep/beef farming increases when scrub is cleared, and decreases when pasture is left to revert to scrub.³⁵

These changes are shown at the national level in Figure 3.4 and at the regional level in Table 3.1.

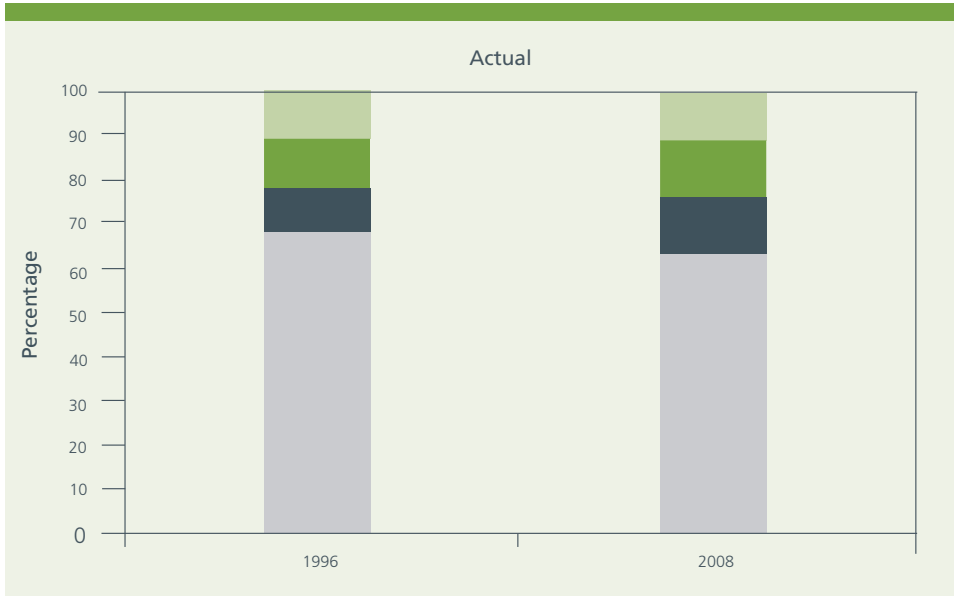


Figure 3.4 Proportions (by area) of sheep/beef, dairy, forestry and scrub land in 1996 and in 2008. The light grey represents sheep/beef farms, the dark grey represents dairy farms, the dark green represents plantation forests, and the light green represents scrubland.

Region	Sheep/ Beef	Dairy	Plantation Forestry	Scrub
Northland	16,000	-29,500	14,700	-2,300
Auckland	8,800	-16,200	4,300	100
Waikato	-42,800	35,500	2,900	200
Bay of Plenty	-10,900	4,100	2,200	1,800
Gisborne	-27,200	300	28,100	-1,400
Hawke's Bay	-27,700	8,300	19,100	-3,500
Taranaki	7,600	-11,800	4,700	-500
Manawatū- Whanganui	-38,700	12,000	26,500	-1,200
Wellington	-13,400	-1,000	14,600	-1,000
Nelson and Tasman	-4,600	1,000	5,600	-2,600
Marlborough	-27,200	-1,700	15,000	-6,800
West Coast	-18,400	22,100	5,100	-6,300
Canterbury	-140,100	122,500	15,700	-4,200
Otago	-53,100	26,300	28,200	-3,100
Southland	-128,400	111,900	17,400	-1,600
New Zealand	-499,900	283,700	204,100	-32,400

Table 3.1 Change in land use between 1996 and 2008 (rounded to the nearest 100 hectares).

3.3 How the model predicts future land use

The LURNZ model can be used to predict how land will be used for different purposes in the future. Such predictions are, of course, not set in stone, but rather scenarios that can be used to explore how the future might unfold.

The scenario of land uses in 2020 presented in this report is one of 'business as usual'. It does not include national or regional policies that will influence future land uses, either actual or potential. For instance, impacts of the Accelerated Irrigation Fund, the Hill Country Erosion Fund, the nitrogen cap in the Taupō catchment, the Rotorua Te Arawa Lakes Programme, and the Horizons One Plan are not modelled.

31

The 2020 scenario is modelled in two stages:

- Predicting how land uses will change at a national level.
- Predicting where in the country those land use changes will occur.

The first stage predicts how land uses will change in response to projected prices of commodities (wool, lamb, beef, milk solids, logs, carbon), and projected interest rates.³⁶ For instance, high prices for milk solids and low prices for wool and lamb will incentivise switching from sheep/beef farming to dairy farming.

The second stage uses the physical characteristics of different areas of land, such as soil type and slope, to model where the changes in land use will take place.³⁷ For instance, some land may be too steep for dairy cows, and it is unlikely that plantation forests would be planted on flat, highly fertile soils where returns for other land uses are likely to be higher.

Only four different land uses are modelled as changing between 2008 and 2020 – sheep/beef farming, dairy farming, plantation forestry, and scrub (see Figure 3.5).



Figure 3.5 The conceptual model that underlies the allocation of the land use changes driven by economic variables across different catchments.

3.4 Modelled land uses in 2020

The decline in sheep/beef farming looks set to continue for the foreseeable future (see Figure 3.6). In the twelve years to 2020, the model predicts that the land used for sheep/beef farming will decline even faster than it did in the previous twelve years. Much of this land is shown as converting to dairy farming, with some planted in forest, and the remainder being left to revert to scrub.

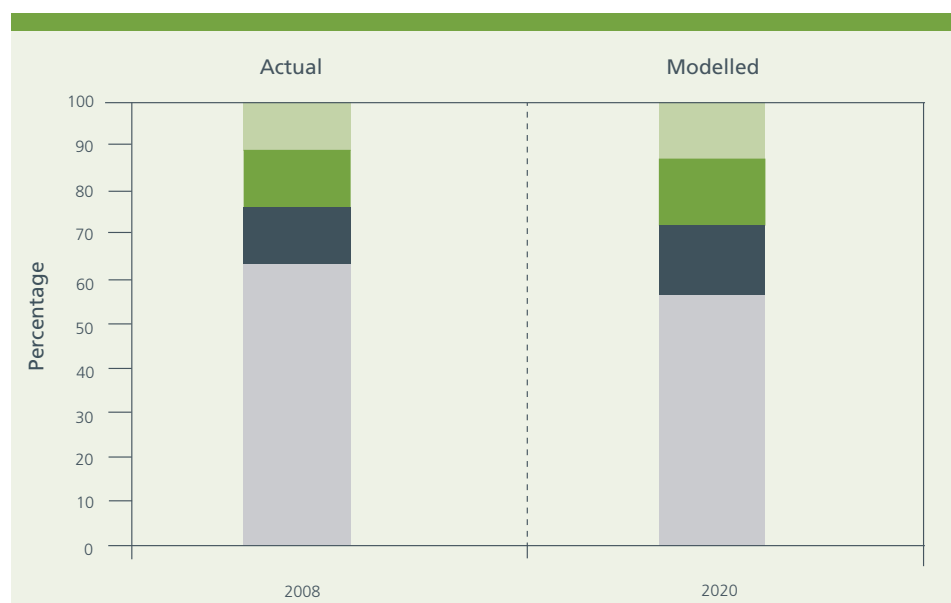


Figure 3.6 Proportions (by area) of sheep/beef, dairy, forestry and scrub land in 2008 and forecast for 2020. The light grey represents sheep/beef farms, the dark grey represents dairy farms, the dark green represents plantation forest, and the light represents scrub land.

These changes are expected to take place in virtually every region across the country, as can be seen in Table 3.2. The model predicts that relatively flat and fertile land converts to dairy farming, some land is planted in trees, and low productivity hill country is left to revert to scrub.

Region	Sheep/ Beef	Dairy	Plantation Forestry	Scrub
Northland	-26,100	16,900	24,900	-15,600
Auckland	-8,200	7,700	300	200
Waikato	-56,700	26,100	17,700	12,900
Bay of Plenty	-18,100	4,700	18,200	-4,900
Gisborne	-73,600	4,200	62,400	6,900
Hawke's Bay	-71,900	20,900	40,900	10,200
Taranaki	-32,000	17,700	14,900	-600
Manawatū- Whanganui	-136,900	32,200	10,100	94,600
Wellington	-42,400	25,600	16,200	600
Nelson and Tasman	-13,500	10,000	11,100	-7,600
Marlborough	-39,700	4,900	13,200	20,600
West Coast	5,700	-2,300	0	-3,400
Canterbury	-202,800	99,600	5,600	93,400
Otago	-121,200	49,300	6,900	64,000
Southland	-54,300	52,800	2,900	-1,400
New Zealand	-891,600	370,300	245,200	269,800

Table 3.2 Modelling results for changes in land use between 2008 and 2020 (rounded to the nearest 100 hectares.

This report is being written nearly half way through the twelve years from 2008 to 2020. Are the land use changes that have taken place since 2008 consistent with what LURNZ has forecast?³⁸

By 2011, a quarter of the way through the twelve-year period, the land used for dairy farming had actually increased by 120,000 hectares.³⁹ This is a third of what the model predicts for the whole twelve-year period. This indicates that conversion to dairying is consistent with the model's prediction.⁴⁰

In contrast, the scale of the increase in forestry land predicted by the model may not be eventuating. Data from the Ministry for Primary Industries shows the total area of plantation forest has declined slightly over the last decade. However, the amount of land being converted to forestry has started to pick up again, associated with a rise in the timber price.⁴¹

3.5 Conclusion

The way in which rural land is used is changing. The last three decades have seen a large reduction in the land area used for sheep/beef across the country, with conversion to dairy farming, plantation forestry, and reversion of hill country to scrub. The LURNZ model forecasts this to continue.

Figure 3.7 summarises the changes that have taken place in the twelve years from 1996 to 2008 and those expected to take place in the twelve years from 2008 to 2020.

Maps showing the land uses in 1996 and 2008, and the forecast land uses in 2020 in each region of the country are on the website www.pce.parliament.nz.

How land is used influences the rates at which nitrogen and phosphorus is lost from land. In the next chapter, three examples are used to illustrate what happens to nutrient losses when the land use is changed.

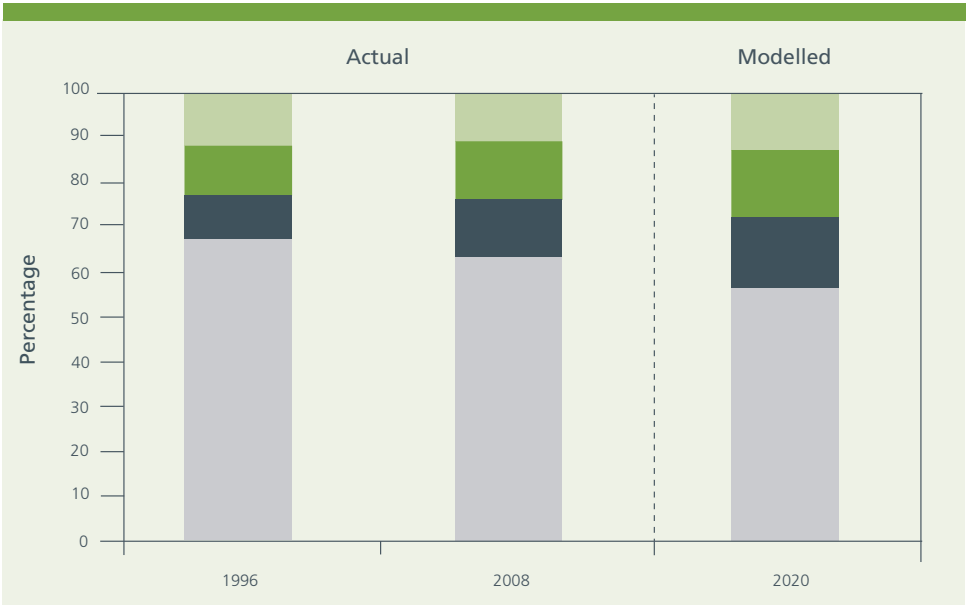


Figure 3.7 Proportions (by area) of sheep/beef, dairy, forestry and scrub land in 1996, 2008 and forecast for 2020. The light grey represents sheep/beef farms, the dark grey represents dairy farms, the dark green represents plantation forests, and the light green represents scrubland.



4

Nutrient losses from different land uses

Chapter 3 described how the land area used for sheep/beef farming can be expected to further decline by 2020, with relatively flat and fertile land converting to dairy farming, some land planted in trees, and low productivity hill country left to revert to scrub.

The quality of the water in different catchments across the country is heavily influenced by the way in which land in these catchments is used and, indeed, has been used in the past. The nitrogen that runs off and leaches through land used for dairy farming is attracting increasing attention (and research effort). Less well known is that much of the phosphorus in river and lake sediments has its origin in the erosion of hill country sheep pasture that has occurred over many decades.

Loss rates from urban areas on a per-hectare basis can also be high, but towns and cities cover relatively small areas – less than one percent of New Zealand.⁴² And, as noted in Chapter 2, loss rates from horticulture can be very high, but the area of land used in this way is scarcely changing and has been modelled as fixed.

This chapter begins to address the relationship between land use and the nutrients lost off land into fresh water. It does this using three illustrative examples of land use change that are occurring in New Zealand. These three are:

- An extensive sheep/beef farm on hilly clay soil in Gisborne reverting to scrub.
- An intensive sheep/beef farm on alluvial soil in Canterbury converting to a dairy farm.
- A plantation forest on pumice soil in the Volcanic Plateau converting to a dairy farm.

For each, the annual nitrogen and phosphorus losses are shown before and after the land use change. These nutrient loss rates have been provided by NIWA and are based on a mix of measurements and modelling using the industry standard model for estimating farm nutrient losses (OVERSEER).^{43,44}

While nutrient losses are heavily influenced by land uses, they depend on many other factors, such as rainfall, soil type, fertiliser use, number of stock, stock type, whether they are kept on the farm over winter, and so on. The loss rates in this chapter are ‘conservative averages’, based on the best available information.

4.1 A sheep/beef farm in Gisborne reverting to scrub

36



Source: Brian Robinson

Figure 4.1 Sheep/beef farmland on poor hilly soil may be left to revert to scrub.

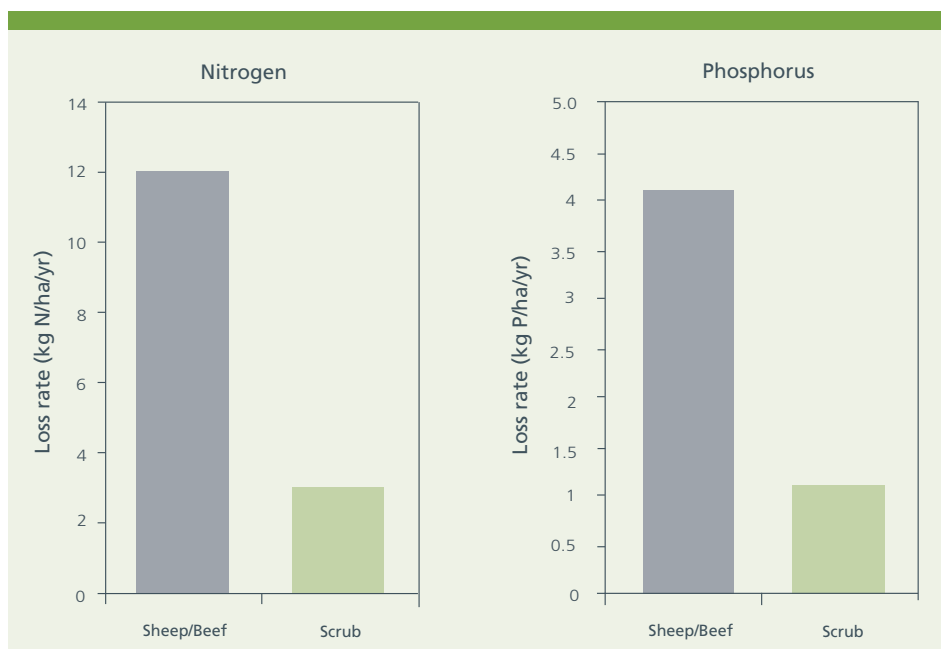


Figure 4.2 Nitrogen and phosphorus loss rates on an extensive sheep/beef farm on hilly clay soil in Gisborne reverting to scrub.⁴⁵ When sheep/beef farmland of this type reverts to scrub, loss rates of both nutrients fall by a factor of 4.

4.2 A sheep/beef farm in Canterbury converting to a dairy farm



Source: D. Pastor

Figure 4.3 Sheep and dairy cows on the Canterbury plains.

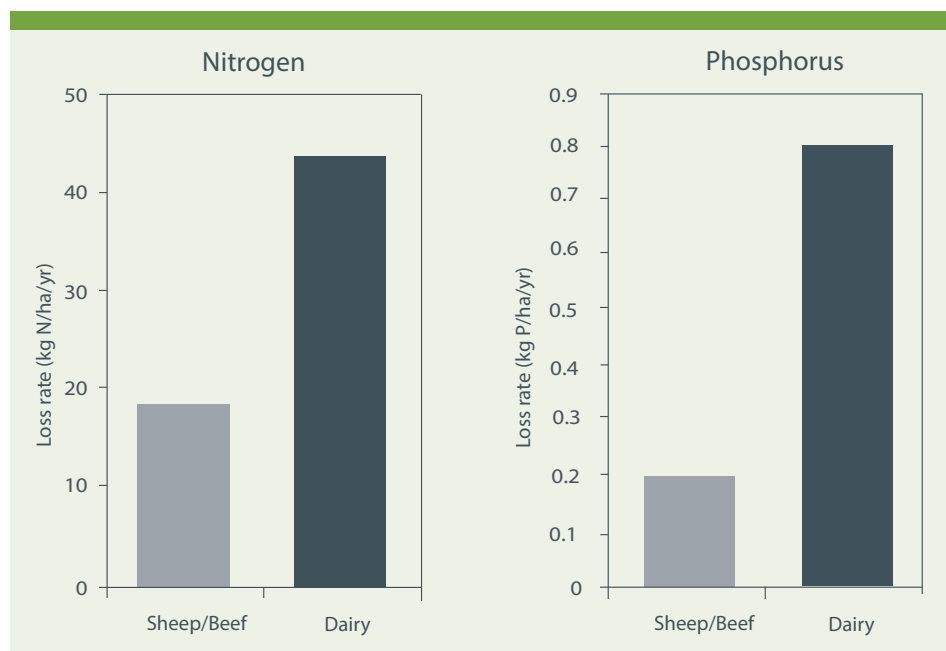


Figure 4.4 Nitrogen and phosphorus loss rates on an intensive sheep/beef farm on alluvial soil in Canterbury converting to an intensive dairy farm. The impact of such a farm conversion on nutrient losses varies, but the change shown above is 'conservative'.⁴⁶

4.3 A plantation forest on the Volcanic Plateau converting to a dairy farm

38



Source: Parliamentary Commissioner for the Environment Archives

Figure 4.5 A plantation forest on the Volcanic Plateau being felled so pasture can be sown for a dairy farm.

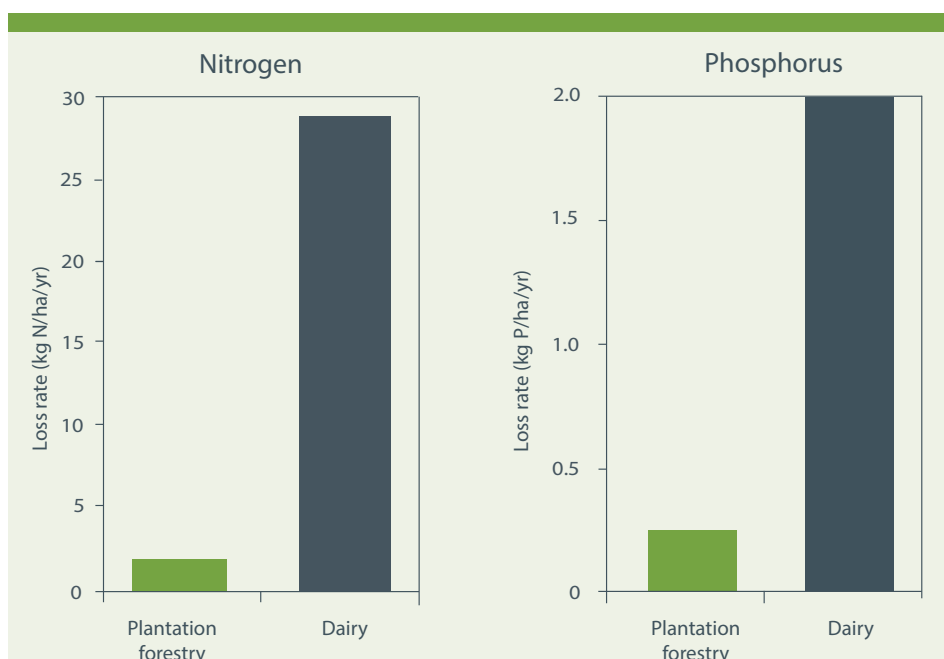


Figure 4.6 Nitrogen and phosphorus loss rates from a plantation forest on pumice soil in the Volcanic Plateau converting to a dairy farm. ⁴⁷ In this type of land conversion, loss rates of both nutrients increase by an order of magnitude.

4.4 Changes in land use can lead to very different nutrient losses

The preceding sections depict three kinds of rural land use changes that are taking place in New Zealand. The three examples used to illustrate these changes are located in particular parts of the country – Gisborne, Canterbury, and the Volcanic Plateau. But the general impact on nutrient losses from these changes does not depend on location.

39

- When a sheep/beef farm is replaced by forest or scrub, annual losses of both nitrogen and phosphorus *decrease*.
- When a sheep/beef farm is converted to a dairy farm, annual losses of both nitrogen and phosphorus *increase*.
- When a forest is felled and converted to a dairy farm, annual losses of both nitrogen and phosphorus *increase greatly*.

There are, of course, variations in nutrient losses that depend on many factors. For instance, nitrogen loss rates from dairy farms in Canterbury vary widely. At one extreme, a farm on very stony soil with border dyke irrigation and running four cows per hectare ‘wintered on’ can lose as much as 195 kilograms of nitrogen from each hectare every year. At the other extreme, a farm on medium to heavy soils running three cows per hectare ‘wintered off’ can lose as little as 14 kilograms of nitrogen from each hectare every year.⁴⁸

The changes away from sheep/beef farming – whether on relatively fertile land to dairy farming, or on poorer land to scrub and forest – are taking place on hundreds of thousands of hectares across the country. The change from forestry to dairy farming is occurring on a lesser scale – tens of thousands of hectares – but is very significant in the catchments where it is occurring.⁴⁹

In areas where changes in land use are occurring on a large scale there are likely to be significant changes in nutrient loads entering waters.

But changes in farming practices – whether for improving productivity or mitigating environmental impacts – can also alter nutrient loss rates. Such changes in farming practices are considered in the next chapter.



5

Changes in farm productivity and mitigation

The farming practices that were imported by settlers – both from Polynesia and later Great Britain – bear little resemblance to the way New Zealanders farm today. The need to adapt and innovate came first in response to the challenging climate, later to keep a step ahead of international competitors, and later still to protect the environment.

Farming practices have changed, and continue to change, in two ways that affect nutrient losses into waterways. The first – increasing *productivity* – is often accompanied by greater nutrient loss. The second – increasing *mitigation* – reduces nutrient loss.

For instance, in a catchment dominated by dairy farming, increases in *productivity* (defined as milk solids per hectare) may well be accompanied by increases in nutrient loss and poorer water quality.⁵⁰ On the other hand, a great deal of effort is going into *mitigation* on dairy farms – decreasing the loss of nitrogen and phosphorus by such measures as keeping cattle out of streams and planting riparian strips.

The modelling exercise that forms the basis of this report estimates nutrient loads in waterways in the future – specifically, the year 2020. To do this requires, among other things, an assessment of the impact that changing productivity and mitigation have had, and are likely to have, on nutrient losses from different land uses.

There are three sections in this chapter – the first dealing with productivity, the second dealing with mitigation, and the third, dealing with the combined effect of both on nutrient losses and nutrient loads in waterways.

5.1 Productivity

There are two ways to improve productivity – getting more meat, milk, wool and wood off a hectare of land:

- Increasing inputs, such as fertiliser, supplementary feed, and water.
- Using inputs more efficiently by, for instance, improving animal and plant genetics, and 'precision' application of water and fertiliser.

The first approach – increasing inputs – generally leads to greater nutrient losses. The second approach – increasing the efficiency with which inputs are used – can reduce nutrient losses.

Increased use of inputs has been the major driver of the extraordinary gain in productivity in dairy farming. The productivity of **dairy** farming has risen by 60% in the last twenty years (see Figure 5.1).⁵¹



Source: LIC and DairyNZ, 2012

Figure 5.1 The productivity of dairy farming and the annual amount of urea fertiliser used in New Zealand over the last twenty years.

Increased use of inputs has been the major driver of this extraordinary gain in productivity. More water, more supplementary feed and, in particular, the use of urea fertiliser to extend the grass growing season has enabled many dairy farmers to produce more milk from each cow and put more cows on each hectare.⁵² Figure 5.1 also shows the huge increase in the amount of urea fertiliser used over the last 30 years in New Zealand.⁵³

The productivity of **sheep/beef** farming has improved by about 20% over the last twenty years (see Figure 5.2). This increase may be more attributable to efficiency gains such as advances in animal genetics than to increased inputs.⁵⁴ Fertiliser use in the sector has grown from a historic low in the 1990s to a peak in 2002.⁵⁵

Earlier increases in sheep/beef productivity were due to increasing inputs – for example, aerial topdressing of superphosphate fertiliser. The recent dip in productivity shown in Figure 5.2 may be in part due to the more productive land being converted to dairy farms.

The productivity of plantation pine **forestry** has not significantly changed in the last two decades.⁵⁶

The Government has set a goal of doubling the value of exports from primary production by 2025, and industry groups have all set goals for increasing productivity.⁵⁷

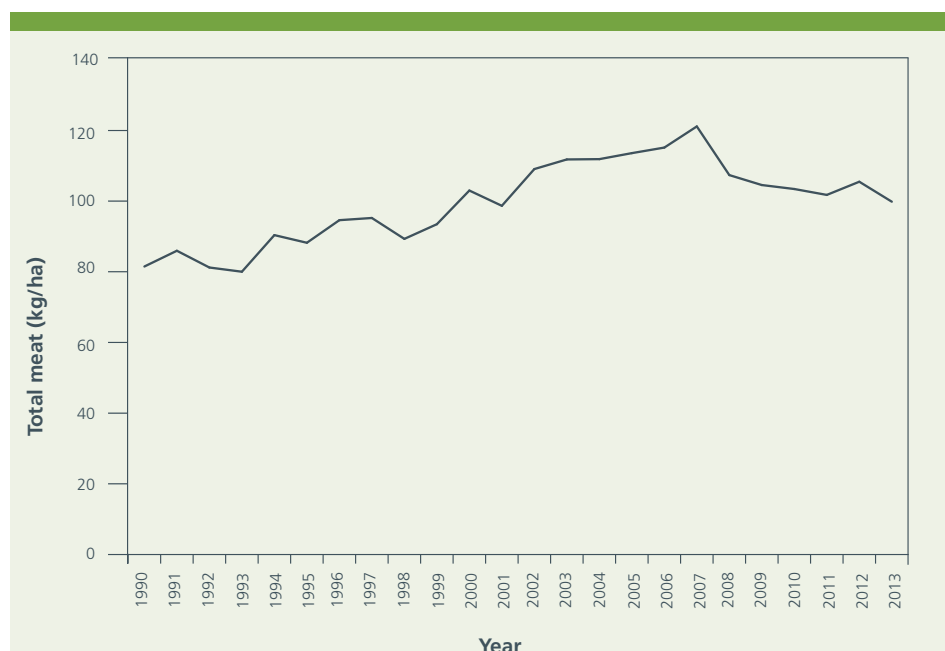


Figure 5.2 The average change in productivity of sheep/beef farming in New Zealand over the last twenty years.

5.2 Mitigation

Over recent years, concern has grown about the impact of excess nutrients on water quality. For many decades, phosphorus has accumulated in sediment in waterways as soil has eroded off the land, effluent and town sewage has been discharged into water, and manure and superphosphate have been washed off pasture. In recent years, the rapid growth in dairy farming has led to a big increase in the concentration of nitrogen in waterways in many parts of the country.⁵⁸

There are many ways in which nutrient losses can be mitigated. These include:

- Disposing of town sewage and dairy shed effluent on to land, thus using it as a fertiliser.
- Planting poplars, willows and other trees to hold the soil on erosion-prone hill country.
- Fencing gullies and letting them revert to native bush.
- Nutrient budgeting to avoid using excess fertiliser.
- Fencing streams and bridging crossings to exclude cattle thus reducing both direct deposition of dung and urine and erosion of banks.
- Planting riparian strips along stream banks so that nutrients will be absorbed by growing plants before they reach the water.
- Keeping cattle off pasture at critical times using concrete stand-off pads and wintering barns.
- Constructing wetlands in low-lying areas.

As described in Chapter 2, it is generally harder and more expensive to prevent 'elusive' nitrogen from reaching waterways than 'sticky' phosphorus.

For instance, keeping stock out of waterways through fences and bridges reduces phosphorus loads significantly, but has virtually no impact on nitrogen loads. This is because only a small proportion of nitrogen gets into water through 'direct deposition' of urine. Whereas direct deposition of dung and the breaking down of banks by stock are important pathways for phosphorus.

Riparian strips are more effective in stopping phosphorus, because most of the phosphorus is tightly bound to soil and the plant roots stop the banks from eroding and carrying sediment into the water. In contrast, much of the nitrogen is dissolved in ground water and travels through the soil without coming into contact with the plant roots.

Diffuse nitrogen – mostly originating from animal urine – is the greatest technical and economic challenge for nutrient mitigation. Constructing large wetlands on low-lying areas can remove significant amounts of nitrogen as well as phosphorus, but is expensive.⁵⁹ Keeping cows on stand-off pads or inside wintering barns can also be effective in reducing nitrogen leaching.⁶⁰

Good management practices such as targeted use of irrigation water and fertiliser, shed effluent management, and stock exclusion from waterways generally reduce losses of nitrogen by up to 20%.⁶¹

The addition of large capital-intensive mitigation methods, such as stand-off pads, wintering barns and artificial wetlands as well as good management practices can reduce losses of nitrogen by up to 50%.⁶²

Over recent years the farming sector, research institutes, and central and local government have put increasing effort into mitigation – reducing the loss of nutrients into water, particularly from dairy farms. Creative mitigation innovations are also coming from individual farmers (see Boxes 5.1 and 5.2).

Box 5.1 Farm sector organisations working to mitigate nutrient pollution

In May 2003, Fonterra, the Minister for the Environment, Minister of Agriculture and Forestry, and Regional Councils signed a voluntary agreement to start to address the impacts of the dairy sector on waterways. The **Dairying and Clean Streams Accord** focused on excluding stock from streams and wetlands, bridging or culverting stock crossings, managing nutrient losses, and ensuring dairy shed effluent discharges complied with resource consents and regional plans. By 2012, it had achieved some of its targets, but fell short on others.⁶³

An extension of these mitigation efforts, called the **Sustainable Dairying: Water Accord**, was announced in 2013.⁶⁴ The new accord sets an expectation that all dairy farmers adopt good management practices – riparian planting, management of nitrogen and phosphorus losses, and monitoring of water use. It also commits to new dairy conversions meeting the expectations set out in the Accord prior to milk collection commencing. It has been reported that some dairy companies will make compliance with the Accord a condition for collecting milk.⁶⁵

The **Red Meat Sector Strategy** released in 2011 includes improved nutrient management initiatives focused on managing costs and increasing productivity. A core initiative is to develop nutrient management systems so that animal feed is converted efficiently to protein.⁶⁶

In 2007, the Government set up a research consortium known as **Pastoral 21**, in collaboration with farm sector organisations. They are researching ways to increase productivity and profitability from pastoral farming, while reducing nitrogen and phosphorus losses to water.⁶⁷

Since 2004, the last two Governments, along with councils and other organisations, have committed to expenditure of many millions of dollars for improving the water quality of a number of lakes and rivers polluted by nutrients.⁶⁸

Box 5.2 A win-win for economy and environment

Mike and Sharon Barton own a beef finishing farm in the Lake Taupō catchment. Under Waikato Regional Council's nitrogen cap, the number of animals on the farm is effectively restricted.⁶⁹ The Bartons set out to increase the dollar value and the environmental value of their beef.

Most cattle on this farm are finished at less than 22 months old, and this reduces the nitrogen loss from urine in several ways. Young cattle convert grass into protein efficiently, so more nitrogen ends up in meat and less in groundwater. Young cattle urinate little and often, spreading the nitrogen around the pasture more evenly than older cattle. Nitrogen leaching is particularly high in winter when rainfall is high and grass is growing too slowly to absorb it, so cattle are sent to the meatworks before spending a second winter in this sensitive catchment. No nitrogen fertiliser is used on the farm; instead clover is used to fix nitrogen.

Taupo Beef (as it is marketed) is of particularly high quality due in large part to grass feeding of the cattle, and specialised processing and aging of the meat. It sells for a high price that includes an environmental premium. Waikato Regional Council has developed an environmental tick that uses the auditing of farms in the Taupō catchment to verify brand claims around water quality.



Source: Parliamentary Commissioner for the Environment Archives

Figure 5.3 A herd from the Barton farm only a few weeks away from processing. The business is 'predicated upon dollars profit per kilogram of nitrogen leached'.⁷⁰

5.3 The net effect of increasing both productivity and mitigation

The modelling exercise to predict changes in nitrogen and phosphorus loads entering waterways must extend beyond just the changes in land use type discussed in the previous sections. The modelling must also take into account two opposing trends in farm practices.

- Increasing productivity – when it involves increasing inputs – is likely to *increase* the annual nutrient losses per hectare from land into water.
- Increasing mitigation *reduces* nutrient losses from land into water.

A productivity database was compiled based on trends in different regions and different land classes between 1996 and 2008. These trends were then projected forward to 2020.⁷¹

Projecting the effectiveness of mitigation is much more problematic. Recent trends in mitigation and industry commitments were used as a starting point.

As part of this investigation, the Parliamentary Commissioner for the Environment convened a group of experts from AgResearch, Motu and Horizons Regional Council to provide an assessment of likely nutrient mitigation on dairy and sheep/beef farms in the next few years. The group concluded that widespread adoption of large capital-intensive mitigation in the dairy sector, such as stand-off pads, wintering barns and artificial wetlands, was unlikely by 2020.⁷²

Instead, the group concluded that, by 2020, increased mitigation of nutrient losses would come primarily from more efficient use of nitrogen fertiliser, lower nitrogen loss per animal due to improved genetics, the adoption of good environmental practices in new dairy conversions, and compliance of all dairy farms with the *Sustainable Dairying: Water Accord* nutrient goals.

Quantifying the impact on nutrient losses of this stepped-up mitigation is challenging. It was decided to assume that for the purposes of modelling, farmers would be 'holding the line' by 2020, increasing productivity while holding nutrient losses steady. This assumption was applied to both dairy and sheep/beef farming.

This assumption is optimistic. As one of the co-leaders of Pastoral 21 has commented:

*'Thanks to science, better farm management practices and other tools, we have found amazing ways to increase farm production over the years... We've also found ways to reduce environmental footprint – but not at the same pace.'*¹⁷³

The next chapter presents the second part of the modelling exercise that forms the basis of this report.



6

Nutrient loads into water are changing

The modelling exercise on which this report is based involved joining together two models – a model of land use change and a model of nutrient losses from land into water.

Chapter 3 dealt with the first model – LURNZ – *Land Use in Rural New Zealand*. The modelling results show how the area of land used for sheep/beef farming has declined markedly in recent years, with some land converted to dairy farming and some planted in forest. The incorporation of forecasted commodity prices and interest rates into the model enabled future land use change to be predicted, and showed the decrease in land used for sheep/beef farming looks set to continue.

Chapter 4 showed how losses of nitrogen and phosphorus from land vary with how the land is used.

Chapter 5 dealt with changing farm practices and the effect they are having on nutrient losses from land into water. This information has been incorporated into the modelling.

This chapter is focused on the second model. This – a model of nutrient losses from land into water – is known as CLUES – *Catchment Land Use for Environmental Sustainability*.⁷⁴ There are four sections in this chapter.

- The first describes the CLUES model.
- The second presents the modelled nutrient loads for different regions.
- The third shows changing land use and changing nutrient loads for two contrasting catchments, one in Southland and one in Gisborne.
- The fourth discusses the variable impact of changing nutrient loads on water quality.

6.1 CLUES - modelling nutrient loads in catchments

Understanding the flow of nutrients on farms is very important. Nitrogen and phosphorus are vital for plant growth. Nutrient that ends up in water is lost from production, so managing nutrients efficiently can boost productivity and reduce fertiliser costs. An example of such an efficiency gain that has become common practice in much of the country is spraying dairy shed effluent on to pasture, transforming it from water pollutant to soil fertiliser (see Figure 6.1).

Ideally, nutrient flows on farms would be measured directly. To do this, instruments called lysimeters can be placed in the soil to measure flows of nutrients that are dissolved in water at particular places (see Figure 6.2). In practice however, direct measurement of nutrient flows is usually impractical and expensive, so modelling is the only option.



Source: Taranaki Regional Council

Figure 6.1 Many dairy farms now dispose of their shed effluent by spraying it on to land, reducing the need for fertiliser. However, it is important that effluent is not sprayed on to waterlogged soil, so farms must have storage ponds large enough that spraying can be delayed until conditions are right.



Source: Parliamentary Commissioner for the Environment Archives

Figure 6.2 Lysimeters being used to measure nitrate flowing through soil in the Taupō catchment.

To guide fertiliser use on farms, the model called OVERSEER was developed more than a decade ago. Over the years it has been expanded to include most flows of nutrients on farms, including the nitrogen and phosphorus that ‘flows’ off land into water.⁷⁵

CLUES – *Catchment Land Use for Environmental Sustainability* – is a model that predicts the effect of land use change and intensification on the major water pollutants *E. coli*, and sediment, as well as nutrients, in each stream reach in New Zealand.⁷⁶

CLUES incorporates a version of OVERSEER to estimate the nitrogen and phosphorus in water coming from diffuse sources. The effects of physical variables such as slope, rainfall and soil type are all modelled. Point sources such as town waste water treatment plants and freezing works are added in.⁷⁷ CLUES has been calibrated to ensure it provides realistic results by comparing the nutrient loads it predicts with those derived from regional and national water quality datasets.

For this investigation, CLUES has been ‘run’ with the land use results from Chapter 3 as inputs. Thus, the two models – LURNZ and CLUES – are linked together.

Catchment *nutrient loads* have thus been modelled for the three key years of 1996, 2008, and 2020; that is, tonnes of nitrogen and phosphorus entering the streams of different catchments over the course of each of the three years.^{78,79} The nutrient loads for individual catchments are added together to give nutrient loads for the different regions of New Zealand.

6.2 The results

The results in this section are expressed as percentage changes in modelled nutrient loads in different regions over the two twelve-year periods – 1996 to 2008, and 2008 to 2020.

For instance, in Taranaki:

- During 1996, 10,400 tonnes of nitrogen leached into the streams of Taranaki.
- During 2008, 10,800 tonnes of nitrogen leached into the streams of Taranaki – an increase of 4% over the load in 1996.
- During 2020, over 11,300 tonnes of nitrogen is expected to leach into the streams of Taranaki – an increase of 5% over the load in 2008.

Changing nitrogen loads

When nitrogen load changes are compared with the land use changes in Tables 3.1 and 3.2, one correlation is strikingly clear. Regions with significant increases in dairy farming also have large increases in nitrogen loads (see Figure 7.1).

The relationship between changes in other land uses and nitrogen loads are not as clear at the regional level. Changing from sheep/beef farming to forestry (or scrub) decreases nitrogen loads because the main source of nitrogen – animal urine – has gone. However, these decreases in nitrogen load, as a result of increases in forestry and scrub, are generally outweighed by the increases in nitrogen load from dairy conversions.⁸⁰

Region	% change 1996 to 2008	% change 2008 to 2020
Northland	-2	4
Auckland	-5	6
Waikato	8	5
Bay of Plenty	6	0
Gisborne	0	-3
Hawke's Bay	6	4
Taranaki	4	5
Manawatū-Whanganui	7	5
Wellington	3	14
Nelson and Tasman	4	7
Marlborough	0	2
West Coast	8	-1
Canterbury	27	15
Otago	10	13
Southland	19	8
New Zealand	9	6

Table 6.1 Percentage change in nitrogen loads over two twelve-year time periods.

Region	% change 1996 to 2008	% change 2008 - 2020
Northland	-3	0
Auckland	-5	1
Waikato	1	0
Bay of Plenty	-1	-2
Gisborne	-1	-2
Hawke's Bay	-1	-3
Taranaki	-2	-1
Manawatū- Whanganui	-1	-4
Wellington	-2	1
Nelson and Tasman	1	3
Marlborough	-2	-3
West Coast	1	0
Canterbury	5	3
Otago	1	2
Southland	6	3
New Zealand	0	-1

Table 6.2 Percentage change in phosphorus loads over two twelve-year time periods.

Changing phosphorus loads

In general, predicted phosphorus loads undergo little change. The greatest increases are in the regions with the most significant dairy conversion – Southland and Canterbury.

There are two main reasons why phosphorus loads decrease when land cover changes from pasture to forest or scrub. The first is because animals – and animal manure – are taken off the land. The second is because land covered in forestry or scrub is more resilient – the risk of soil slipping and bringing sediment and the associated phosphorus into the water is reduced. CLUES does not model the latter, and so underestimates the reduction in phosphorus load that accompanies land cover changing from pasture to forest.

6.3 Two contrasting catchments

The changing nutrient loads reported above are at the regional level, but consideration of their impact on water quality needs to begin at the catchment level. This section shows the modelled changes between the past and the future – between 1996 and 2020 – for two very different catchments.

The Ōreti catchment in Southland

The Ōreti catchment is one of four major river catchments in Southland. The Ōreti River rises in the Mavora Lakes area and runs through a fertile valley to its mouth at the New River Estuary at Invercargill. Large areas of flat land in this catchment have traditionally been used for sheep/beef farming, but many of the farms have been converted to dairy farms with more conversions expected (see Figures 6.3 and 6.4).

Nitrogen and phosphorus loads in the Ōreti catchment are predicted to increase by nearly 90% and more than 30% respectively above 1996 levels by 2020.⁸¹ Between 1989 and 2007 measured concentrations of dissolved reactive phosphorus, nitrate/nitrite and total nitrogen in the lower Ōreti all increased significantly.⁸²

Two other major catchments in Southland – Maitai and Aparima – are undergoing similar land use and nutrient load change.

The Waiapu catchment in Gisborne

The tributaries of the Waiapu River on the East Cape rise in the rugged forested Raukūmara Range, and run through steep, erosion-prone hills, before joining together as the Waiapu and passing by Ruatōria to the sea. The Waiapu carries an immense amount of sediment from its steep, eroding catchment, traditionally used for sheep/beef farming.⁸³

Large areas of this steep land have been, and are predicted to continue to be, converted to forestry (see Figures 6.5 and 6.6.) As a result, nitrogen and phosphorus loads in the Waiapu catchment are predicted to decrease by 10% and 2% respectively below 1996 levels by 2020.⁸⁴

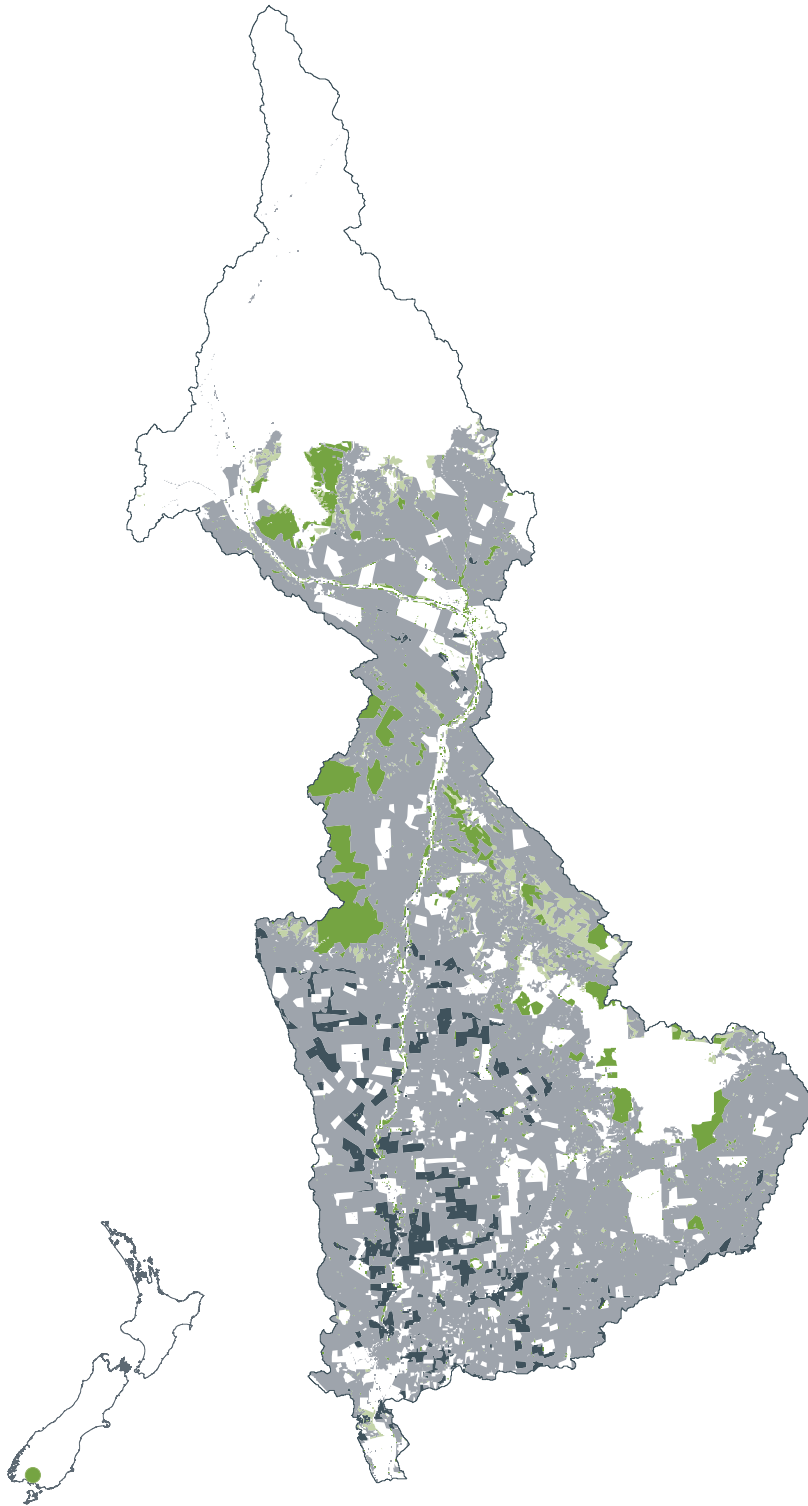


Figure 6.3 Land use change in the Ōreti catchment in Southland – 1996 (historical). Land used for sheep/beef farming is shown in light grey, land used for dairy farming is shown in dark grey, land used for forestry is shown in dark green and land covered in scrub is shown in light green.

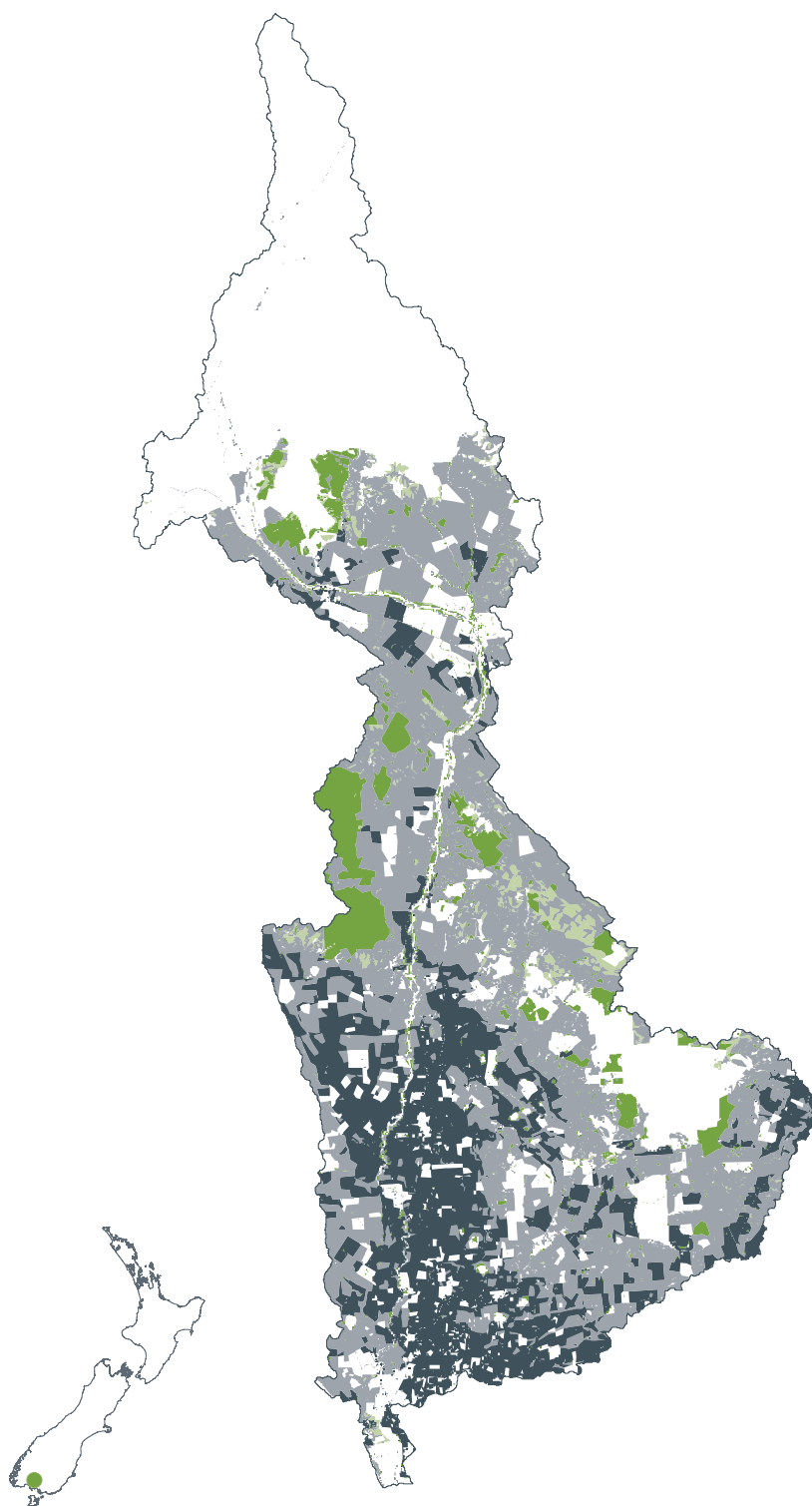


Figure 6.4 Land use change in the Ōreti catchment in Southland – 2020 (predicted). Land used for sheep/beef farming is shown in light grey, land used for dairy farming is shown in dark grey, land used for forestry is shown in dark green and land covered in scrub is shown in light green.

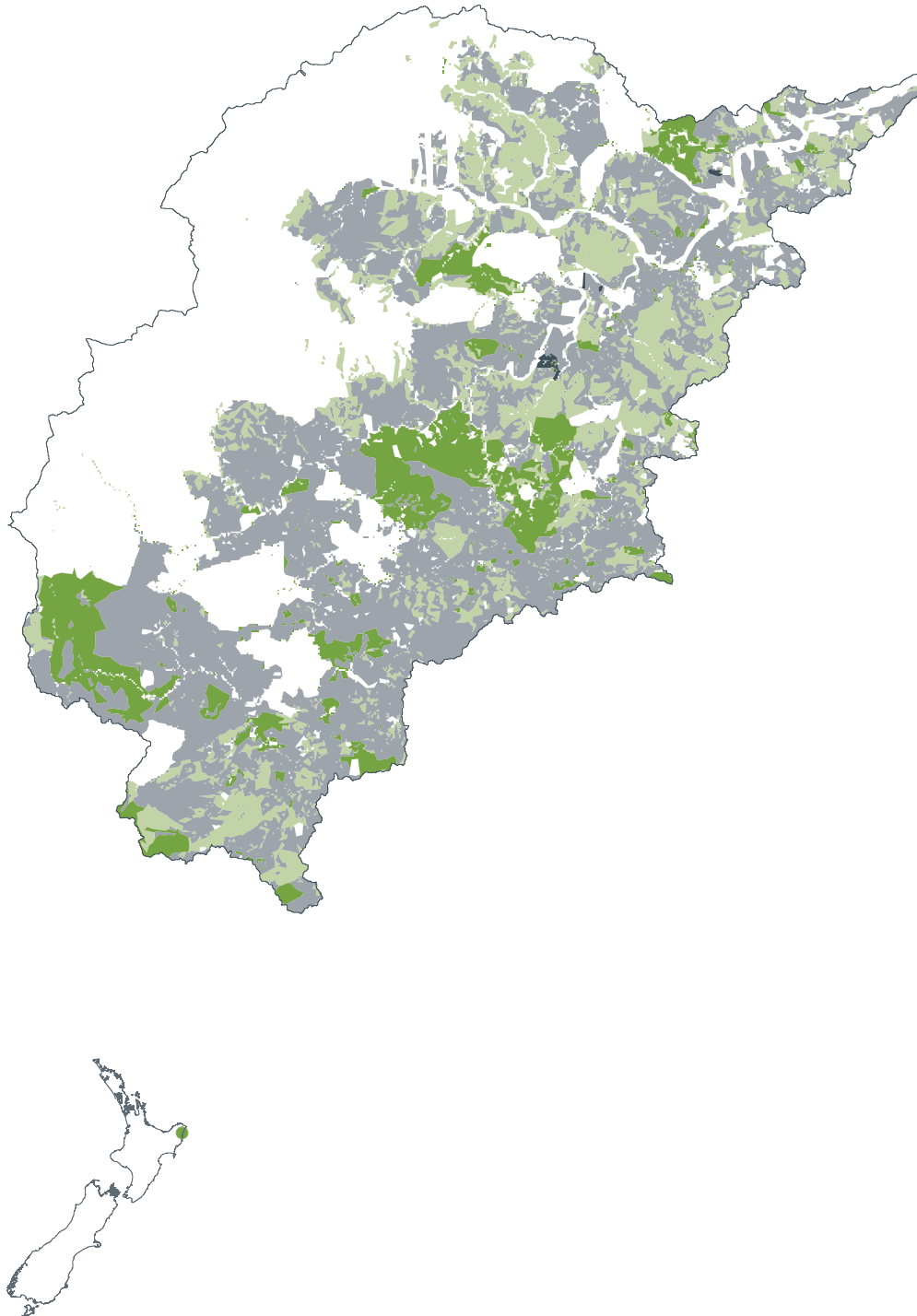


Figure 6.5 Land use change in the Waiapu catchment in Gisborne – 1996 (historical). Land used for sheep/beef farming is shown in light grey, land used for dairy farming is shown in dark grey, land used for forestry is shown in dark green and land covered in scrub is shown in light green.

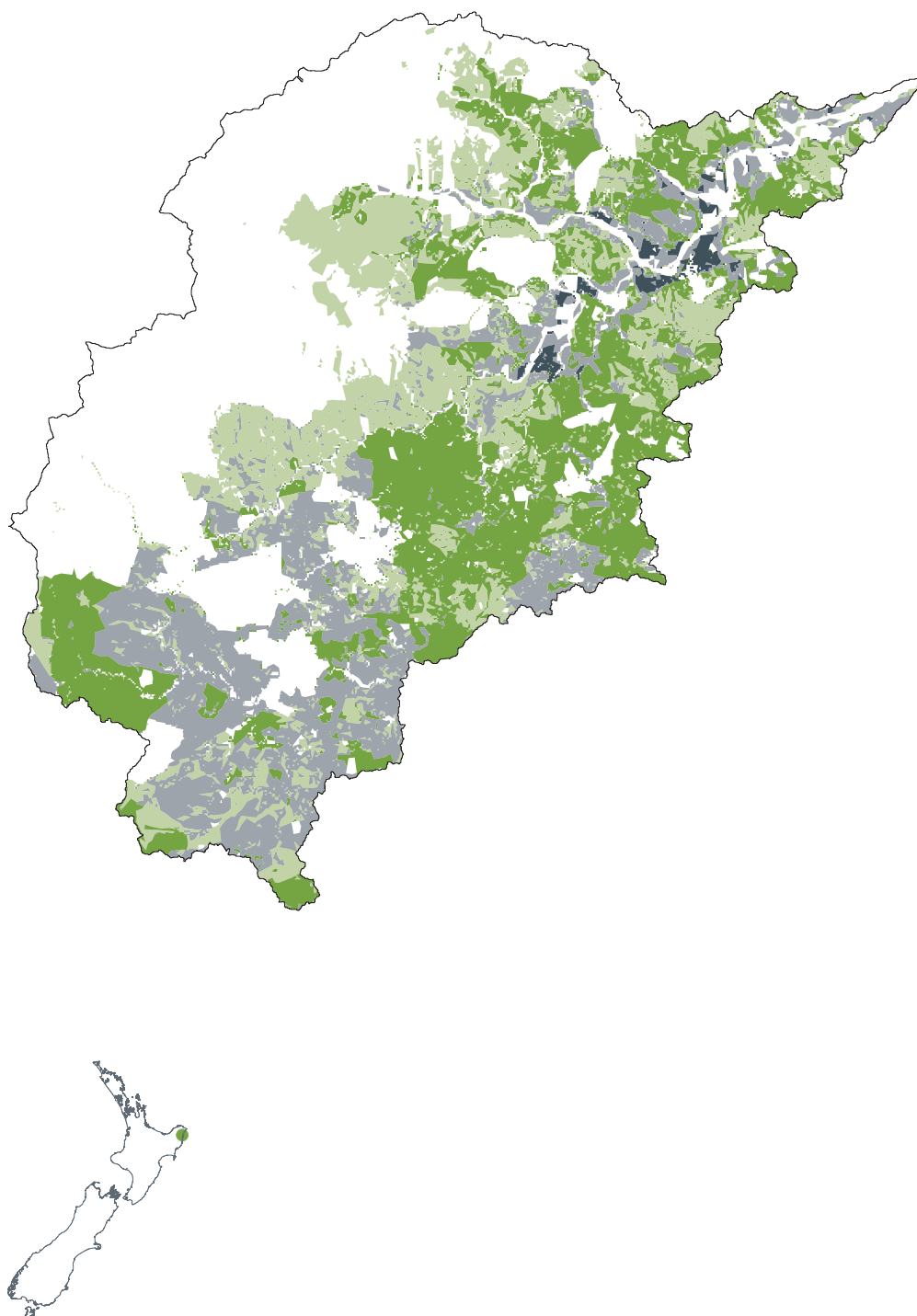


Figure 6.6 Land use change in the Waiapu catchment in Gisborne – 2020 (predicted). Land used for sheep/beef farming is shown in light grey, land used for dairy farming is shown in dark grey, land used for forestry is shown in dark green and land covered in scrub is shown in light green.

6.4 What do changing nutrient loads mean for water quality?

As discussed in Chapter 2, the relationship between nitrogen and phosphorus entering water – the nutrient load – and the effect on the quality of the water is complex. The greater the vulnerability of a body of fresh water, the greater the impact of the nutrient load will be.

To illustrate this, consider two stylised examples both subject to the same increasing nutrient load – the first, a vulnerable lake in which water quality deteriorates rapidly, and the second, a resilient river in which the water quality scarcely changes.

The lake is shallow and warm, with layers of sediment built up on the bottom due to decades of erosion from sheep farming on surrounding hills. The concentration of nitrogen in the water keeps rising because the nitrogen load has increased over recent years. Phosphorus has been accumulating in the sediment for as long as the hills have been grazed by stock and topsoil has been washed into the lake by heavy rain. In summer, the lake ‘stratifies’ and the lack of oxygen increases the release of phosphorus from the sediment into the water.⁸⁵

The river is cold, shaded, and flows swiftly to the sea. In the ranges where its headwaters rise, it rains heavily every few days. The nitrogen and dissolved phosphorus in the water stays low due to this frequent flushing. There is some sediment on the stony riverbed, but at times the river runs so fiercely that it lifts and carries the sediment out to sea. The river flows directly into the sea; there is no estuary to be smothered in sediment.

The nutrient loads – tonnes of nitrogen and phosphorus entering streams each year – are best interpreted as stresses on water quality.

The *nitrogen stress* is rising year on year in nearly all regions of the country, especially in Canterbury, Southland and Otago. While regions like Manawatū and Waikato are predicted to have a lesser increase in nitrogen load, many rivers and lakes in these regions already have high nutrient loads and poor water quality.⁸⁶

The *phosphorus stress* is relatively constant, but keeps accumulating in the sediment in most water bodies, particularly lakes.

Ongoing and increasing nutrient loads will generally lead to worsening water quality – more degraded lakes, more turbid (cloudy) estuaries, greater frequency and duration of algal blooms at swimming spots and elsewhere, declines in the insects, fish and birds that rely on these ecosystems, and more water wells and surface water that exceed nitrate toxicity limits for drinking.⁸⁷

Indeed, this is supported by the Ministry for the Environment's most recent report card on water quality. It shows those areas that have the greatest increases in nutrient concentrations – particularly nitrate – are the same areas with the greatest deterioration in water quality.⁸⁸



Source: Horizons Regional Council

Figure 6.7 Periphyton in the lower Rangitīkei River in 2013.



7

Summary and conclusion

“The health of our waters is the principal measure of how we live on the land”⁸⁹

Over recent years, water quality has become a subject of high public concern and vigorous debate in New Zealand. This investigation has explored the relationship between land use and the two nutrient pollutants that cause water quality problems – nitrogen and phosphorus.

Most of the nitrogen that ends up in fresh water has its origin in animal urine. Nitrogen is ‘elusive’; it exists in highly soluble forms that readily leach through soil into groundwater. This makes it difficult to mitigate – to keep out of water.

Much of the phosphorus that ends up in water began as naturally occurring phosphorus in soil, and has been carried into water over many decades through erosion. Phosphorus is ‘sticky’; most of it is attached to soil and sediment. On the one hand, this makes it relatively easy to mitigate. On the other hand, when it gets into water it accumulates in the sediment on riverbeds and lakebeds, although some will be flushed out in rapidly flowing rivers.

This report is based on results obtained by linking two models. The first, known as LURNZ, is a simulation model of land use change. The second, known as CLUES, can be used to estimate the nutrients lost from land to fresh water at a catchment scale.

Over recent years, shifting commodity prices have led to many sheep/beef farms on relatively flat and fertile land being converted to dairy farms. At the same time, large areas of hill country sheep/beef land have been planted in forest, and some have been left to revert to unproductive scrubland. The LURNZ model predicts that these trends will continue.

The amounts of nitrogen and phosphorus travelling off land into water depend to a large extent on how the land is used. For instance, in a heavily forested catchment, there are few animals producing nitrogen-rich urine and phosphorus-rich dung, and the tree roots hold the soil (and the phosphorus it contains) on the land. In catchments dominated by pasture, especially dairy pasture, nutrient loss rates are much higher.

Consequently, when land uses change, the amount of nitrogen and phosphorus that is lost from the land into water also changes.

The land use change results from LURNZ have been ‘fed in’ to the second model – CLUES – to estimate their impact on the tonnes of nitrogen and phosphorus being added every year into the streams, rivers, lakes, aquifers and estuaries in different regions of the country.

The modelling shows annual nitrogen loads on fresh water continuing to rise in virtually every region. Figure 7.1 shows how these increasing nitrogen loads correlate with the expansion of dairy farming. Canterbury, Southland, and to a lesser extent, Otago, stand out. Other regions have lesser increases, although some, such as Waikato and Manawātū, already have high nitrogen loads and existing water quality problems.

The increases in nitrogen loads shown in Figure 7.1 are regional averages. In some catchments, they will be much greater, and in other catchments much smaller.

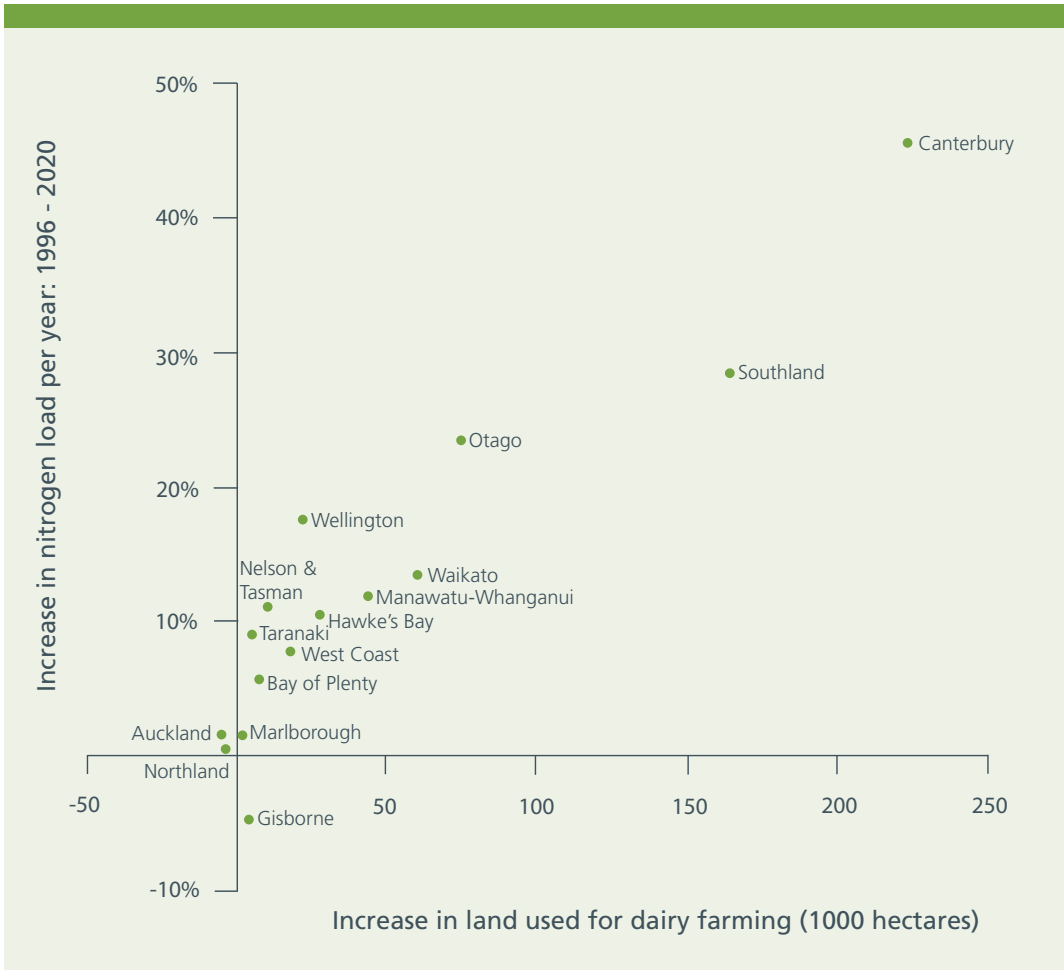


Figure 7.1 Large-scale land use change to dairy farming leads to an increase in the amount of nitrogen that gets into fresh water. The graph shows the differences between 1996 and 2020.

The modelling shows much smaller changes in the annual phosphorus loads. The only significant increases between 1996 and 2020 are in Canterbury and Southland: 9% and 10% respectively. In some regions, annual phosphorus loads are decreasing. Nevertheless, much of the phosphorus entering fresh water will continue to accumulate in sediment.

Because dairy farming has expanded so quickly and is known to have high nutrient loss rates, mitigation has become a major focus of changing farm practices. The modelling for this report has been done assuming that by 2020 reductions in nutrient losses from mitigation will offset increases from more intensive use of the land. This assumption is optimistic.

Mitigation may be able to 'hold the line' or even reduce nutrient losses in some cases. But mitigation cannot offset the increase in nutrients that comes from large-scale change to more intensive land uses. While new dairy farms converted from exotic forests in the central North Island may employ extensive mitigation techniques, the nutrient losses are still at least ten times higher than they were when the land was covered in trees.

In catchments where there has been large-scale land use change to dairy farming the gains made by increased mitigation are swamped.

Excessive levels of nitrogen and phosphorus in fresh water make it too fertile, leading to accelerated plant growth and algal blooms, degrading swimming and fishing spots, and damaging fresh water ecosystems. At very high levels, too much nitrogen is toxic to fish and other aquatic life.

While water quality is complex, the science has established clear relationships, and these are well understood and accepted. Although much depends on natural factors like flow rate, water quality tends to be worst in areas where nutrient loads are highest.

It has been theorised that in some cases nitrogen loads are less important, because the growth of excessive plant growth could be controlled by focussing on managing phosphorus. This may be possible under the right conditions, but relies on many factors being in alignment. Such an approach would not, for example, protect the many nitrogen-limited estuaries which are already especially vulnerable because they lie at the bottom of catchments.

The passage of time may reveal a different land use future to the one forecast by the modelling. If, for instance, dairy farming expands more slowly and forestry expands more quickly, then nitrogen and phosphorus loads will be lower than predicted. But the opposite, if anything, appears to be the case.

Unfortunately, if we continue to see large-scale conversion of land to more intensive uses, it is difficult to see how water quality will not continue to decline in the next few years. This is despite the best efforts of many and some undoubted successes.

Understanding the links between land use, on-farm practices and water quality is essential for developing policies that achieve good outcomes – healthy rivers, lakes, estuaries and aquifers. Hopefully, this report has clarified and deepened that understanding.

Notes

- 1 Cumberland, 1941, p.529.
- 2 (Elliott, et al., 2005). As part of this investigation all councils were surveyed about point sources in their regions. All of the regional councils indicated that they considered point sources in their regions to be sufficiently dealt with under the RMA.
- 3 Te Ara – the Encyclopedia of New Zealand, <http://www.teara.govt.nz/en/kauri-forest/page-3> [Accessed October 2013]
- 4 National Policy Statement for Freshwater Management 2011.
- 5 The joined up model has also been ‘run’ for the years 1996 and 2008. Because the land uses in different parts of the country are known for these two years, these runs have served to calibrate the model, as well as to show changes over time. Two technical reports – one on the LURNZ modelling by Motu and the other on the CLUES modelling by NIWA – are available on www.pce.parliament.nz. The LURNZ report is ‘*Land use and farming intensity for 1996, 2008 and 2020*’. The CLUES report is ‘*National nutrient mapping using the CLUES model*’.
- 6 The reports on these workshops – ‘*Understanding the practice of land use modelling*’ and ‘*Understanding the practice of water quality modelling*’ are available on www.pce.parliament.nz.
- 7 Pathogens are invisible disease-causing microbes such as bacteria and viruses. Town sewage and animal manure are the main source of pathogens.
- 8 Nitrogen and phosphorus do not exist in water or soil in their elemental forms, but as ions – nitrate, nitrite, ammonium, and phosphates. However, for simplicity, they are referred to as nitrogen and phosphorus in this report.
- 9 Dairy farms generally produce more urine and dung per hectare than beef farms. The main reason for this is that stocking rates on dairy farms are generally higher and use more fertiliser than on farms running beef cattle (Clothier, et al., 2007, pp.7-8).
- 10 Menneer, et al., 2004, pp.12-13; Clothier, et al., 2007, pp.6-8.
- 11 Hickey and Martin, 2009.
- 12 A recently released survey of Canterbury groundwater shows nitrate concentrations increasing over time. As of 2012, 11% of groundwater wells in the region exceed the Ministry of Health maximum acceptable value (MAV). Most of the wells that exceed MAV are located near Ashburton, where nitrate levels have been high since at least 2004. (Environment Canterbury, 2013, pp.7-9; Hanson and Abraham, 2010). Nitrate levels have also been found to be above the Ministry of Health guidelines in 25% of wells near Balfour in Southland. (Environment Southland, 2009).
- 13 Some pest plants are exotic. The most serious – hornwort – is widely established in the North Island, and capable of growing taller than a three-storey building (Matheson, et al., 2005).
- 14 Didymo is a type of periphyton that blooms only in very low nutrient rivers. This is because the bloom, of carbohydrate stalks, is actually the organism’s reaction to low nutrient water (Kilroy and Bothwell, 2011).

- 15 Adapted from Death, 2012, p.23.
- 16 See PCE, 2012, Chapter 6.
- 17 Similarly, the growth of plants in a waterway may be limited by other factors such as light or temperature.
- 18 In a study of 121 New Zealand lakes, ratios of nitrogen and phosphorus suggested that 14% were N-limited and 53% were P-limited. However, nutrient addition experiments showed that addition of nitrogen and phosphorus often caused growth responses in phytoplankton. The main conclusion of the study was that in most cases, management of both nitrogen and phosphorus may be required to control phytoplankton growth (Abell et al. 2010).
- 19 Larned, et al., 2011.
- 20 See Larned, et al., 2011 and McArthur, et al., 2010.
- 21 See Wilcock, et al., 2007 and Larned, et al., 2011.
- 22 Some plants can store nutrients to use later when that nutrient becomes limited. For example, some cyanobacteria store nitrogen. If there is a short-term addition of that nutrient, the plant will replenish its stores and continue to grow later on when the nutrient becomes limited again (Oliver, et al., 2012, pp.166,172).
- 23 Heath, et al., 2012, pp.i-ii; Wood and Young, 2012, p.iii.
- 24 McArthur, et al., 2010.
- 25 Uytendaal and Ausseil, 2013, pp.33-35.
- 26 Summerfield and Sherman, 2008.
- 27 The description of the land use modelling and the data in this chapter are taken from '*Land use and farming intensity for 1996, 2008 and 2020*' (Anastasiadis and Kerr, 2013), and is available on www.pce.parliament.nz.
- 28 The development of LURNZ began in 2002. For more information refer to Hendy and Kerr, 2006.
- 29 Wratt, et al., 2008.
- 30 The model uses satellite data taken in 1996, 2002 and 2008 from the Land Cover Database (version 3), which differentiates between pasture, forestry and scrub. The satellite photographs alone are not sufficient for a number of reasons. For instance, while they can accurately distinguish between pasture and forest, they cannot distinguish between pasture used for sheep/beef farming and pasture used for dairy farming. Nor can they identify land that has just been planted in pine tree seedlings. Therefore the Agribase Enhanced Land Cover Database is used to identify pasture used for sheep/beef farming from pasture used for dairy farming. Supplementary sources of information include New Zealand Dairy Statistics collected by DairyNZ and the Livestock Improvement Corporation (LIC), the Agricultural Production Survey and Census data collected by Statistics New Zealand, and the National Exotic Forest Description data collected by the Ministry for Primary Industries.
- 31 See the Appendix to this report which contains detailed definitions of the eleven land uses. The term 'land use' is a misnomer for some, such as scrub and non-productive land. However, it is the term used in LURNZ.

- 32 Sources: Sheep/Beef - JR Photography, Dairy - David Hollander Lincoln University, Plantation forestry - PCE archives, Scrub - All About Earth Moving, Horticulture - John Steadman, Urban - Robert Brienza, Lifestyle - RB Glasson, Conservation land - PCE archives, Pasture on public land - Middle Rock, Privately owned indigenous forest - Te Motu Kairangi, Non-productive land - PCE archives.
- 33 1996 was the first year in which comprehensive satellite photographs became available. Satellite photographs were also taken in 2002 and 2008.
- 34 In 1996 sheep/beef farm land covered 8,260,000 hectares, dairy farm land 1,236,000 hectares, plantation forestry 1,313,000 hectares, and scrub land 1,338,000 hectares. The remaining land came to 14,556,000 hectares.
- 35 Changes in areas of the other land uses in LURNZ between 1996 and 2008 were all small. Between 1996 and 2008, the area of land categorised as horticulture grew by only 40,000 hectares in total. This category includes arable cropping, orchards and vineyards, as well as market gardens. Over half the increase was in Marlborough, presumably due to the expansion of vineyards. In the same 12-year period, urban land grew by 12,000 hectares, and changes in other land uses were very small.
- 36 Estimates of future commodity prices and future interest rates are taken from Ministry of Agriculture and Forestry, 2011b, and are assumed to be constant after 2015. In the results presented in this report the carbon price is assumed to be \$5 per tonne. Modelling runs incorporating a \$25 carbon price predicted more land being planted in forest, and less reverting to scrub.
- 37 LURNZ contains three datasets of relevant physical characteristics. The LUC (Land-Use Capability) map has information on the underlying bedrock, soil type, slope, vegetation cover and climate. The Land Environments of New Zealand dataset has information on the slope of the land. The CCAV (Average Carrying Capacity) map is used to define unproductive land.
- 38 Another set of satellite images of land cover across New Zealand was taken in 2012, but these have not yet been processed into the Land Cover Database.
- 39 LIC and DairyNZ, 2012, p.7.
- 40 As this report was finalised a spike in resource consent applications for dairy conversion occurred in Southland after Fonterra announced its record forecast payout of \$8.30 per kilogram. Environment Southland consents manager was reported as saying 'there had been more dairy farm conversion applications in the past four months than there had been in almost two years'. *Southland Times*, 1 November 2013, 'More Southland dairy farms expected.'
- 41 Ministry for Primary Industries, 2012, pp.20-21; Levack, 2013.
- 42 In certain circumstances, nutrients from urban and industrial point sources can have a significant impact on water quality. For instance, about half the phosphorus entering the upper Manawatū River from spring to autumn comes from point sources. See PCE, 2012, pp.63-65. However, the scale of nutrient loss from diffuse sources should not be underestimated. For instance, the conversion to dairy and drystock farms of a 36,500 hectare pine forest in the upper Waikato catchment is expected to lead to a 17-fold increase in nitrogen lost from this land, more than offsetting the reduction in nitrogen from the \$15 million upgrade to Hamilton's sewage treatment plant (Environment Waikato, 2008a, p.34).

- 43 Estimates of phosphorus losses from diffuse sources are more uncertain than estimates of nitrogen losses. See Menneer, et al., 2004, p.4.
- 44 OVERSEER was initially developed by the Ministry of Agriculture and Forestry as a tool to guide users of fertilisers like urea. However, in 2003 it was expanded to include most nutrient movements around a farm and model the nutrient losses. In recent years the model has been developed by AgResearch with funding support from the Ministry for Primary Industries and the Fertiliser Association of New Zealand.
- 45 The nutrient losses shown in this figure have been estimated by running OVERSEER 6.0 for an 'easy slope' sheep/beef farm running 5 sheep and 3 beef cattle per hectare. The modelled farm is on brown soil and clay loam with medium subsoil drainage. Annual rainfall is 1800 mm and phosphorus fertiliser is applied at a rate of 15 kg/ha each year. The nitrogen loss rates that are used for scrub and pine forest are the same everywhere in New Zealand. The phosphorus loss rates include the impact of erosion because of the slope of the land.
- 46 The nitrogen loss rates shown in this figure are based on 'look-up' tables developed for Environment Canterbury. The nitrogen loss rate for sheep/beef land is for non-irrigated '50/50' sheep/beef farms. The nitrogen loss rate for dairy land is for irrigated farms running 3 cows per hectare, 'wintered on'. Both are averages for very light soils in three locations – Lincoln, Darfield and Hororata (Lilburne, et al., 2010, pp.17,21). The phosphorus values are based on the conversion of a sheep/beef farm in the Hurunui catchment to an irrigated dairy farm (Brown, et al., 2011, p.12).
- 47 The nitrogen loss rates in this figure have been taken from Vant, et al., 2008 and are attenuated values. The phosphorus loss rate for dairy for this figure (2.0 kg N/ha/yr) was based on attenuated Rotorua values from Park and MacCormick, 2011, p.1 (3.3 kg N/ha/yr) and McIntosh, 2012, p.3 (1.1 kg N/ha/yr). The loss rate for exotic forest is an average from Cooper and Thomsen, 1988, p.284 (0.095 kg P/ha/yr) and McIntosh, 2012, pp.3-4 (0.4 kg P/ha/yr). The loss rate from the latter has been taken from '*the high end of the range*' because of the enhanced nutrient loss that occurs when forest is harvested.
- 48 Nitrogen loss rates from a sheep/beef farm depend largely on how intensively the farm is run. At one extreme, a dryland farm with 10% beef and 90% sheep on medium to heavy soil only has a loss rate of about 10 kgN/ha/yr. At the other extreme, a 100% beef farm with border dyke irrigation on extremely light soil will have a loss rate of about 150 kgN/ha/yr (Lilburne, et al., 2010, p.30). The value in Figure 4.4 is representative.
- 49 While the example in this chapter is in the upper Waikato catchment, it is not the only place where this change is occurring – for instance, Balmoral Forest in Canterbury is being converted to dairy farms.
- 50 The word 'productivity' is used to mean many different things. In this report, it is taken to mean yield (meat, wool, milk solids, wood) per hectare.
- 51 In 1993, 653 kg of milk solids were produced each year on average from each hectare of dairy land. By 2012, this had risen to 1,028 kg (LIC and DairyNZ, 2012, p.8). These increases in productivity that vary across the country have been incorporated into the modelling (Anastasiadis and Kerr, 2013). Urea fertiliser data comes from Statistics New Zealand Infoshare.

- 52 The average cow produced 26% more milk, 28% more milkfat, 33% more protein and 30% more milksolids in 2012 than it did in 1996. The average dairy farm stocking rate increased from 2.43 cows per hectare in 1996 to 2.83 cows per hectare in 2012. In 2012, stocking rates varied from 2.18 cows per hectare on the West Coast to 3.44 cows per hectare in South Canterbury (LIC and DairyNZ, 2012, pp.7,14,23).
- 53 The amounts of urea fertiliser used in New Zealand in the years 1991, 1994 and 1997-2001 were not recorded.
- 54 MacKay, et al., 2012, pp.11,13.
- 55 Total fertiliser use in the sheep/beef industry peaked at 171 kg/ha in 2002, up 51% on the historic average of 113 kg/ha. Pers. comm. to PCE, Rob Gibson, Agricultural Analyst, Beef + Lamb NZ Economic Service. 4 November 2013.
- 56 Pers. comm. to PCE, Warren Parker, CEO, Scion, 10 September 2013.
- 57 Ministry for Primary Industries, 2013, p.3.
- 58 Ballantine and Davies-Colley, 2010, p.iv.
- 59 Wetlands are generally low lying, so more of the nitrogen dissolved in groundwater passes through them and can be absorbed by the wetland plants (Wilcock, et al., 2010. pp.2-3). See also McDowell, et al., 2013, p.23. Note that the cost of constructing a wetland includes the loss of pasture.
- 60 (McDowell, et al., 2013). Note that this approach requires more 'cut and carry' feeding.
- 61 McCall, 2013, p.6.
- 62 McDowell, et al., 2013. The effect of a 50% reduction in nitrogen and phosphorus losses depends on the intensity of the farming operation. For example, if a farm is losing nitrogen at an annual rate of 70 kg per hectare, a 50% reduction will lower it to 35 kg per hectare. But if a farm is losing nitrogen at an annual rate of 40 kg per hectare, a 50% reduction will lower it to 20 kg per hectare.
- 63 Dairying and Clean Streams Accord (between Fonterra Co-operative Group, Regional Councils, Ministry for the Environment, and Ministry of Agriculture and Forestry), 2003, pp.2-3.
- 64 All dairy companies have signed up as partners to the Accord, with the exception of Westland Milk Products.
- 65 See *Nelson Mail*, 26 February 2013, 'New accord takes tougher stance', and DairyNZ and DCANZ media release, 20 February 2013, *Dairy industry steps up with new water quality agreement*. Farmers with contracts with Fonterra are required to provide accurate information that allows Fonterra to calculate their nitrogen loss and nitrogen conversion efficiency, using the OVERSEER nutrient management programme.
- 66 Deloitte, 2011, pp.87,104.
- 67 Pastoral 21 is a collaborative research venture among DairyNZ, Fonterra, Dairy Companies Association of New Zealand, Beef and Lamb New Zealand and the Ministry of Science and Innovation. AgResearch, 2011, p.12.

- 68 These include Waikato River, several of the Rotorua lakes, Lake Taupō, Te Waihora/Lake Ellesmere, Manawatū River, Wairarapa Moana, Wainono Lagoon and Waituna Lagoon.
- 69 In 2011, Waikato Regional Council imposed a nitrogen cap (Variation 5) on the Lake Taupō catchment to reduce the amount of nitrogen entering this iconic lake.
- 70 *Rural News*, 23 October 2012, 'Barton's branded beef initiative.'
- 71 For detail on how this was done, see Anastasiadis and Kerr, 2013, pp.10-16.
- 72 Anastasiadis, et al., 2012.
- 73 Brent Barrett, co-leader of Pastoral 21, quoted in AgResearch, 2011, p.12.
- 74 The description of nutrient modelling using CLUES and the data in this chapter are taken from '*National nutrient mapping using the CLUES model*' (Parshotam, et al., 2013), and is available on www.pce.parliament.nz.
- 75 OVERSEER is used by pastoral and arable farmers to create nutrient budgets and nutrient management plans. A 2011 update of progress towards the Dairying and Clean Streams Accord reported that almost all dairy farms now have nutrient budgets and about half have nutrient management plans (Ministry of Agriculture and Forestry, 2011a, p.3). OVERSEER was used to provide much of the data for the figures in Chapter 4.
- 76 CLUES has been developed by scientists at NIWA, the Ministry for the Environment, AgResearch, Landcare Research, Plant and Food Research and Harris Consulting for the Ministry for Primary Industries. See Woods, et al., 2006, p.iv. The model has been used by regional councils in Waikato, Bay of Plenty, Manawatū-Whanganui, Canterbury and Southland. It has also been used by the Ministry for the Environment for policy development.
- 77 For this modelling exercise, point source inputs are taken to be constant. This will probably underestimate some of the locally significant reductions, but will have little effect on the results in this report because point sources are now a small component (less than 5%) of total nutrient loads entering waterways (Elliot, et al., 2005).
- 78 There are 'real world' complexities that are not captured in CLUES. For instance, some of the nitrogen and (soluble) phosphorus that leaches into the ground is absorbed through natural processes (known as attenuation) and does not end up in waterways. Another process not modelled in CLUES is the 'load to come'. The groundwaters in some catchments move very slowly and contain nutrient leached through soil many years ago. For example, the time it takes for nutrients to travel through groundwater and into Lake Taupō ranges from 2 to 10 years on the western side of the lake and from 40 to 85 years on the northern side of the lake (Morgenstern, 2007. p.ii-iii).
- 79 For the purposes of modelling nutrient loads in the year 2020, it is assumed increasing mitigation between 2008 and 2020 offsets increases in productivity (Parshotam, et al., 2013, p.9).
- 80 In Canterbury, for instance, the increase in the area of land covered by plantation forest and scrub between 2008 and 2020 is predicted to be about the same as the increase in dairy land (approximately 100,000 hectares), yet the nitrogen load is modelled as rising by 18%.

- 81 Nitrogen loads in the Ōreti catchment are predicted to increase from 2,500 tonnes per year in 1996 to 4,680 tonnes per year in 2020, and phosphorus loads are predicted to increase from 290 tonnes per year in 1996 to 390 tonnes per year in 2020.
- 82 Ballantine and Davies-Colley, 2010, p.35.
- 83 The Waiapu catchment has one of the highest annual sediment yield rates in the world. Scion, 2012, p.4.
- 84 Nitrogen loads in the Waiapu catchment are predicted to decrease from 1,110 tonnes per year in 1996 to 1,000 tonnes per year in 2020, and phosphorus loads are predicted to decrease from 5,480 tonnes per year in 1996 to 5,370 tonnes per year in 2020.
- 85 For a description of lake stratification, see PCE 2012, p.36.
- 86 See Ballantine and Davies-Colley, 2009 and Environment Waikato, 2008b.
- 87 High levels of some forms of nitrogen can be directly toxic to aquatic life such as fish and invertebrates, or their eggs and larvae. The most toxic form is ammonia but nitrate can also be toxic to aquatic life. The increases in nitrogen predicted in this modelling are based on Total Nitrogen, most of which occurs in the form of nitrate.
- 88 As described in Chapter 2, the health of communities of insects and other invertebrates in water can be measured using an index called the Macroinvertebrate Community Index (MCI). MCI falls with increasing concentrations of nitrogen and phosphorus in water. A high MCI score indicates good water quality. See Ministry for the Environment, *Macroinvertebrate Community Composition (MCI)*, <http://www.mfe.govt.nz/environmental-reporting/fresh-water/river-condition-indicator/macroinvertebrates.html> [Accessed November 2013]. The report card draws on data from over 300 sites collected by NIWA and regional councils, and provides information on the current state and recent trends in nutrient concentrations, stream invertebrates and bacteria (*E. coli*). The summary figures can, and have been, interpreted in a number of ways. However, the detailed maps and information on trends clearly show the relationship between increasing nutrient stress and declining water quality.
- 89 Attributed to geomorphologist, Luna Leopold.

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Appendix

Land use definitions

LURNZ produces data for 11 different land use types, however only four of these land uses – those known to be changing significantly in area – are shown on the maps found on-line at www.pce.parliament.nz.

The four land use classifications that are shown on the maps, and show modelled changes to the year 2020 are:

- **Sheep/Beef:** Beef cattle farming, sheep farming and mixed sheep/beef farming.
- **Dairy:** Dairy milk production, dairy dry-stock rearing and grazing other people's stock.
- **Plantation Forestry:** Exotic forestry, forest harvested and deciduous hardwoods.
- **Scrub:** Fernland, flaxland, gorse and/or broom, broadleaved indigenous hardwoods, manuka and/or kanuka, matagouri or grey scrub, mixed exotic scrubland and sub-alpine scrubland.

The other seven land use categories that are not modelled to the year 2020 are:

- **Urban:** Built-up area, urban parkland/open space and transport infrastructure.
- **Horticulture:** Arable cropping/short-rotation cropland, orchard, vineyards and other perennial crops.
- **Other animals and lifestyle properties:** For example, honey production, horses, deer, kennels/catteries, ostrich farming, lifestyle blocks and homestays.
- **Department of Conservation land and public land (not pasture):** Includes Department of Conservation land or local government land as well as privately owned land that may have some use restrictions, for example Māori land or private reserves. Excludes pasture on public land.
- **Pasture on public land:** The South Island high country pastoral leases are an example of pasture on public land. For this land, the lease agreement controls how it may be used. This land is typically sheep/beef farming and is unlikely to change land use while under a pastoral lease agreement.
- **Privately owned indigenous forest:** Native forest areas on privately owned properties.
- **Non-productive land:** For example, gravel and rock, sand, dumps, permanent ice and snow, mangroves, rivers, lakes, estuaries and alpine grass/herb field.

Mapping of LURNZ land use data to CLUES land use types

The LURNZ land use data is reclassified for use in CLUES. It is reclassified according to the following:

82

LURNZ	CLUES
Sheep/beef	Sheep/Beef high country, hill country or intensive
Dairy	Dairy
Plantation forestry	Plantation forest
Scrub	Scrub
Horticulture	Horticulture e.g. market gardening
Other animal and lifestyle	Substituted with other land uses from CLUES e.g. other animals, goat, and pigs.
Non-productive	Other e.g. bare soil, rivers and lakes
Indigenous forest	Native forest
Urban	Urban
Pasture on public land DoC and other public land	Substituted with corresponding land uses from CLUES e.g. native forest, sheep/beef hill, tussock, and scrub.

Above information is taken from Anastasiadis and Kerr, 2013 and Parshotam, et al., 2013 unless otherwise referenced.