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New Zealand's fresh waters:
Values, state, trends and human impacts

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FOREWORD

Fresh water provides us with considerable natural advantage. It is abundant and supports our economy, our environment, our recreation and our national identity. There are many values associated with fresh water for all New Zealanders, and particularly for Māori. Moreover, the state of our fresh water is the environmental issue of highest public concern.

In recent years there has been an increasingly complex and at times confusing public discourse about fresh water. It is clear that fresh water is an issue on the minds of many New Zealanders. Accordingly, following discussion with Prime Minister Key, I undertook to produce a paper explaining the issues surrounding the state of fresh water in New Zealand, and this is something that my Office has been working on independently for some time.

Until relatively recently the issues of conservation and issues of economic development have been largely seen in isolation. We have been proud of our environment as reflected in our extensive portfolio of national parks and the conservation estate. However, waters outside these areas have been seen primarily through the lens of development. Now, the need for more holistic and integrated practices of ecosystem management – something long-recognised by Māori – is more generally understood. But such management practices do create challenges in dealing with legacy issues: to ensure the quality of our freshwater estate on one hand, while balancing development interests on the other. These scientific and policy challenges are compounded by the inherent complexities of freshwater-associated ecosystem maintenance and enhancement. It is these complexities and challenges that the reports that follow are intended to elucidate.

The recent release of the Government’s ‘Clean Water’ discussion document and proposed new standards for the swimmability of our fresh waters has brought some of the issues to the fore. Therefore I have accelerated completion of this paper so that it might assist those who wish to engage in the consultation on those proposals.

The report is in two sections. The first is a summary report written from my Office with the assistance of the Departmental Science Advisors from the Department of Conservation and the Ministry for the Environment. This overview avoids technical detail but tries to explain the core issues of public concern that have implications for policy development. The main body of the report is a more technical and scientifically referenced document that reviews the state of fresh water in New Zealand and issues related to restoration. The initial draft of the technical report was prepared by the Freshwater Group from NIWA, and was then subjected to iterative review assisted by a number of academics, the Departmental Science Advisors and my Office. The final draft has also undergone external peer review. I want to acknowledge the extraordinary amount of work done by Dr Bryce Cooper and his team at NIWA. We are lucky that New Zealand has a large number of world-class scientists in both the CRI and university sectors who have extensive knowledge from diverse perspectives on the challenges presented by our diverse catchments, lakes, rivers, estuaries and wetlands. These issues extend from geomorphology and hydrology to understanding the ecology of our native plants, fish, insects and birds, and consideration of our pastoral agricultural system and the impact of urbanisation and industrialisation. The likely impacts of climate change are a further and critical concern.

It has been inevitable since humans and their accompanying animals and plants came to New Zealand and altered land use that there would be impacts on the quality of fresh water. This has been particularly so since the arrival of Pakeha and the rapid expansion of pastoral farming. The latter, and particularly its very rapid intensification in recent years, creates enormous challenges. On one hand it is at the core of our economy, on the other it has led to rapid changes in land use, particularly through dairy expansion, with concomitant major and adverse impacts on the quality of our fresh water estate. Agriculture and horticulture are also creating some supply-side issues in some catchments – that is, there are places and times where there simply is not enough water to meet everyone's needs. The urbanisation of New Zealand is a further source of reduced water quality. Accompanying issues are created by the impact of hydroelectric and geothermal power, industrialisation and the arrival of exotic invasive species that have all had further impacts on our fresh water and its associated biota.

There are many measures of water quality – reflecting its physical, chemical and biological characteristics. However, no single measure is sufficient to understand the state of fresh water and the analysis is further complicated by gaps and inconsistency in the monitoring regimes. This is reflected in the current confusion over the proposed new water standards, which this paper seeks to explain. There is an inherent and pragmatic logic in having nuanced definitions that take into account what is an acceptable risk, consideration of the seasonal changes, the relationship to extreme weather events etc., but the impacts of such complexity must be interpreted and communicated clearly.

Water monitoring in New Zealand is imperfect, with sampling site distribution not fully representative of the environmental variation that occurs, sub-optimal site density in places, and variable quality of sampling and analysis protocols. Despite these challenges, the data very clearly shows that water quality and quantity is being adversely affected primarily by changes in land use and the diffuse contamination arising from pastoral farming and urbanisation.

While the public understandably might hope for rapid restoration of water quality across all rivers and lakes in New Zealand, this is unrealistic and scientifically impossible. In some cases we are dealing with contamination that occurred decades ago, and the legacy effects may take a similar time to flush from the system. Moreover there are no silver bullets in water restoration – multiple actions are needed, requiring partnerships between central and local authorities, iwi, citizens and businesses including farmers.

Climate change can only put additional pressures on our freshwater ecosystems. In a number of regions drought will become more common requiring either better water management and/or changes in land-use. Considerable research is needed to pre-emptively identify the strategies to employ.

Freshwater research has certainly been accelerated by the National Science Challenge processes, and water issues have been highlighted further in the recently released *Conservation and Environment Science Roadmap*. These issues will also be referenced in the soon-to-be-released *Primary Sector Science Roadmap*. The linkage between these two roadmaps highlights the intertwined nature of the challenges ahead.

The brief Q&A section and the two papers that follow are intended primarily to inform the public and policy makers regarding the associated science rather than to point to specific policy initiatives. There are clearly very complicated trade-offs between public expectations, economic drivers and recreational considerations in protecting our fresh water. This will require sustained commitment by governments, industry, local authorities and community groups, and an ongoing commitment to monitoring and research across multiple modalities.

I hope that this report will be of value in enhancing public and policy understandings of the opportunities and challenges ahead.

PD Gluckman

12 April 2017

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FRESH WATER Q&A[1]

Why is freshwater management such a complex issue?

Fresh water is obviously vital to life – for humans to drink and to support the natural ecosystems we rely on for survival. But beyond the physical need for fresh water, it is valued for many diverse reasons by a wide range of stakeholders, and some of these interests are inherently competing.

We value water for:

- Its cultural and aesthetic values
- As a source of mahinga kai;
- Potable water supply and household use (bathing, laundry, toilets, cooking, gardening, etc.);
- Economic uses, including agriculture (irrigation and stock use), industrial use, hydroelectric energy generation, fisheries, and tourism;
- Recreation and social amenity; and
- Sustaining our indigenous biodiversity, which in turn delivers its own set of ecosystem services that enable the uses listed above.

Many of the services provided by freshwater systems, and the values they support, can only be maintained so long as the health of the ecosystem as a whole is maintained. Yet many of our uses of fresh water diminish those very values by degrading ecosystem health and water quality. This creates an inherent conflict of stakeholder interests and values, which makes policy in this space complex.

With increasing use and demand for fresh water, it becomes harder to reconcile the varying interests of households, agriculture and industry, with the other values we hold to be important, including those of conservation, recreation, tourism and of iwi.

What does the science say about the overall state of New Zealand's freshwater domain?

New Zealand's freshwater resources, in terms of quantity and quality, are in variable states. Some water bodies are in a good state but others have been significantly compromised by agricultural intensification, urban expansion and industrial pollution, hydroelectric development, or the effects of drought. Our wetlands have been greatly reduced and many river catchments are significantly affected by dam systems. Over recent decades, flows of foothill catchment or spring-fed rivers and streams have declined substantially, particularly in lowland areas on the eastern sides of both islands.

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[1] These Q&As are intended to provide a rapid insight into the matters of highest public interest. Each of these are expanded indepth in the papers that follow.

New Zealand has a very diverse range of freshwater systems, which means that the baseline or 'reference' conditions for measuring aspects of water quality vary between systems (rivers, lakes, aquifers, wetlands) and between regions, depending on factors such as climate, hydrogeology, vegetation, soil composition and land use. The general patterns observed for river and lake water quality and ecosystem health are strongly related to the catchment environment – they vary depending on the topography and land cover of catchments. Catchments with predominantly urban and pastoral land-cover are typically associated with the poorest water quality, and those with natural land cover (e.g. indigenous forest or tussock) typically have the best water quality.

For both rivers and lakes, nutrient (nitrogen and phosphorus) concentrations, and the levels of microbial contamination, increase with increasing proportions of high-intensity agricultural and urban land cover in their catchments. The fundamental ecosystem health issue is whether these nutrients trigger excessive phytoplankton growth, which varies considerably between catchments but is clearly related to human activities on land.

The science is clear - New Zealand's fresh waters are under stress because of what we do in and around them.

How did it get to this state?

The state of our fresh water is largely a consequence of human habitation, which has changed the native landscape dramatically. Humans have impacted the freshwater environment through deforestation, draining wetlands, and establishing settlements around freshwater rivers and lakes. The natural flow regimes of many New Zealand rivers have long been altered by human activities. Humans influenced river hydrology and hence flow regimes by large-scale clearing of scrub or forest, markedly increasing runoff from the land and thus increasing floods and low flows. Dams, weirs and industrial uses further changed our freshwater systems. Incursions of non-indigenous plants, animals and fish have affected our ecosystems. But of particular import has been the rapid intensification of agriculture and expansion of urban areas, which has had a significant impact on water quality. There are inherent lag effects of some land-use practices, such that in some areas we are now seeing effects of inputs into waterways that occurred years and even decades ago.

What are the specific pressures on our freshwater systems?

The major pressures of growing concern have been rural land use practices, industrial use (power generation and discharges) and urban development. Pest invasions, (for example, the incursion of didymo into South Island rivers or koi carp into Waikato wetlands) have also been a cause for concern.

Specifically, our fresh water is under pressure from:

- Agriculture - surface run-off depositing nitrogen, phosphate, and sediment into streams; faecal contamination due to livestock access to waterways; irrigation pressures
- Hydropower - water diversion and changing flow regimes; barriers to fish migration
- Urban development - pollution from urban stormwater and industrial sources
- Pest invasions – altering ecological processes and displacing native species
- Climate change - impacts on flow regimes, groundwater levels, water temperatures, biotic invasions, and consequences for freshwater ecosystems.

What are the expected impacts of climate change on fresh water in New Zealand?

Climate change is expected to result in:

- greater variability over time in river flows, with increased frequency of extreme floods and prolonged droughts. The degree of this variation will be different across the country due to New Zealand's complex geography.
- intensified stratification in deep lakes, and possibly intensified wind-driven mixing in shallow lakes.
- changes in the distributions of native species, valued introduced species, and invasive pests, and in the timing and severity of phytoplankton blooms. Warmer habitats are likely to favour the colonisation and spread of invasive species.
- increased need for water storage in eastern areas to meet irrigation demands that increase due to projected warming and drying.
- salinisation of coastal wetlands as sea level rises and seawater reaches further inland.

Are things improving or getting worse?

Many freshwater systems continue to be under increasing stress. Overall, there is a mix of both positive and negative trends, but there is evidence that restoration activities are having some positive effects. There is a recent prevalence of improving trends in urban and pastoral areas with regard to phosphate and ammonia, but degrading trends outnumber improving trends for nitrate and total nitrogen. There are also improvements in visual clarity and median *E. coli* concentrations in some areas, but others show progressive deterioration.

Who monitors freshwater quality, and where can the information be found?

Freshwater monitoring in New Zealand is undertaken mostly by Regional Councils and by NIWA, but also by universities, the Department of Conservation, Fish and Game Councils and numerous others. Individual catchment reports can be found on the Land Air Water Aotearoa (LAWA) website (https://www.lawa.org.nz). The Ministry for the Environment, in association with Statistics New Zealand (Stats NZ), is now tasked under the Environmental Reporting Act 2015 to report regularly on the state of the New Zealand environment. Fresh water is among five environmental domains subject to regular monitoring, and will be reported in late April 2017.

Despite an enormous effort there is a lack of systematic monitoring of river and lake fish, wetland ecology and water quality, and groundwater macro-fauna, and no overall nationally integrated water quality monitoring programme that deals with the need for representativeness and other design criteria. Thus there is a risk of bias in reporting, and the gaps place some limits on the conclusions that can be drawn about freshwater state and trends. The recent 'Clean Water' proposals will assist by creating a regime of sustained and repeated monitoring.

How is freshwater quality (or 'health') measured?

Many different variables are measured to assess water quality and the health of a freshwater system. These include:

- Physical-chemical variables – measures of stress on the system such as temperature, pH, dissolved oxygen, salinity, nutrients (nitrate-nitrogen, ammonium-nitrogen, total nitrogen, dissolved reactive phosphorus, total phosphorus), and visual clarity
- Measures of ecosystem health – biological variables influenced by nutrient inputs, including periphyton biomass (rivers), phytoplankton biomass (lakes), composition of the

macroinvertebrate community (macroinvertebrate community index, or MCI), and trophic state (trophic level index, or TLI)
- Measures effecting human health for recreational use – indicators of microbial contamination and the presence of toxic algae.
    - The test used to assess the presence of microbial pathogens in New Zealand freshwater systems is detection of *Escherichia coli* (*E. coli*), which signals the presence of animal or human faeces in the water, and the likelihood that other harmful water-borne pathogens such as *Campylobacter*, *Cryptosporidium*, *Giardia*, hepatitis A viruses, and Salmonella may also be present.
    - In lakes, the criteria for swimmability consider the potential for toxins from cyanobacteria (often called blue-green algae) to be present. Assessments of lake state for toxic algae are based on total cyanobacterial biovolume.

What do the recent proposed changes to assessing swimmability mean?

The biggest change suggested in the new 'Clean Water' proposal is the aim for more rivers and lakes to be 'swimmable' rather than having 'wadeability' as the minimum acceptable state for recreation. There are two distinct components to assessing the suitability of a site for swimming – grading and surveillance. Grading assesses the general suitability of a site for swimming over the long term (and uses long term monitoring to determine that) whilst surveillance assesses the suitability of a site for swimming in the short-term (is it OK to swim today?). Guidelines established by the Ministry for the Environment and the Ministry of Health in 2003 included both grading and surveillance, whilst the National Policy Statement for Freshwater Management (NPS-FM) 2014 considered only grading. The proposed changes to the NPS-FM included in the 2017 'Clean Water' consultation package brings both grading and surveillance together again.

For the *surveillance* criteria, ≤540 *E. coli* /100ml is the 'threshold' for swimmability. Swimming is not recommended if the *E. coli* concentration is at or above this level because the risk of infection from full immersion can be more than 5%. To ensure that risk remains low, the surveillance criteria also specify that if *E. coli* concentration on a given day exceeds 260 per 100 ml, daily sampling is required until the concentration falls below 260 (when risk of infection is under 1%, or 1 in 100 exposures). Because storm events in particular can lead to a temporarily high count due to faecal runoff and/or wastewater overload, it is logical to have a rating system that considers the possibility of such extreme measures and focuses on the anticipated range of measurements when people are likely to be swimming.

The proposed *grading* criteria are based around the annual median *E. coli* concentration, as well as how often the above thresholds are exceeded. Swimmable water bodies would need to have a median *E. coli* concentration of no more than 130 per 100ml (meaning half the measures are below this) – at this level the estimated risk of infection is extremely low (at most 0.1% or 1 in 1000 exposures). Having this as a required median means that at least 50% of the time, there is a very low risk to swimmers. This is true even for the lowest swimmable grade (C/yellow, or 'fair' for swimming). This measure would have critical impact on how a catchment is managed.

Grading also takes into account the percentage of time the threshold of 540 *E. coli* /100ml is exceeded at a particular site. To achieve the highest (A/blue, or 'excellent') grade this can occur no more than 5% of the time, and the intermediate threshold of 260 *E. coli* /100ml cannot be exceeded more than 20% of the time. For the lowest swimmable grade, the 540 threshold cannot be exceeded more than 20% of the time, and exceedance of the 260 threshold must be no more than 34% of the time.

These criteria are derived to ensure that the overall risk to swimmers remains low, even considering sampling during times when contamination is likely and swimming is not. Based on these criteria, an A-grade river would have an overall infection risk of ~1%, a B-grade river would have an overall risk of less than 2%, and a C-grade river would have an overall risk of <3.5%. But in practice these risks would be much lower, as higher counts would most often occur when the river is unswimmable for other reasons (e.g., during or after heavy storms)

Maps, information on the swimmability ratings and surveillance for specific recreational sites are available on the LAWA website (https://www.lawa.org.nz) to help inform the public about conditions and risks.

Will the new proposed standards on monitoring for swimmability assist in improving water quality?

In the proposed amendments to the National Policy Statement for Freshwater Management 2014 (NPS-FM), contained in the 2017 Clean Water package, there is a move to *require councils to identify where the quality of lakes and rivers will be improved so they are suitable for swimming more often*, and an associated target to make 90% of rivers swimmable by 2040. To enable enactment of these amendments, and to overcome the deficiencies in the current NPS-FM, the Clean Water package proposes the more nuanced grading system described above.

The effect of the changes from the current NPS-FM to now include surveillance monitoring, and the requirement for a very low median value for all swimmable rivers, is to ensure management that ameliorates continual or repeatable sources of contamination and to force overall and progressive improvements in the safety of the fresh water estate for swimming, with co-benefits for general water quality.

Is our aquifer-sourced groundwater safe? Are different types of aquifer more vulnerable to contamination than others?

Municipal drinking water supplies in New Zealand meet the required bacteriological, protozoal and chemical standards most of the time, whether sourced from surface water or groundwater aquifers. Aquifers are underground reservoirs that are formed by layers of porous rock or sand, through which water can flow. Water enters aquifers from precipitation or by seepage from rivers, lakes, and reservoirs. Groundwater in aquifers eventually flows naturally to the surface through springs and seeps, or it can be extracted through wells for agricultural, municipal, and industrial use.

Most municipal supplies that are sourced from groundwater come from 'confined' or 'secure' aquifers – those that are covered by a layer of rock sediment that inhibits leaching of surface contaminants into the water.

Unconfined aquifers lack this top layer, so there is very little physical filtration or temporal slowing of contaminant movement into water. This type of aquifer is not considered to be much safer than surface water, and if used to supply drinking water, the water should be treated for contamination in the same way that surface water supplies are.

How might aquifers be contaminated?

There has been a general assumption in New Zealand that 'secure' groundwater sources of public water supply are not affected by microbial contamination. Although soil layers above confined aquifers provide a barrier to the contamination from human and animal activity on the surface, groundwater can still be contaminated by microbial pathogens from poorly constructed wells, septic tanks or offal pits.

Pathogens can be transported through soils but they die off over time and distance. Contamination is most likely if there is a direct connection between surface water and groundwater (e.g. shallow wells near streams).

What is being done to improve freshwater quality?

Solutions to freshwater issues created by stressors are often complex but typically require three components – the availability of appropriate technologies and procedures (e.g., upgraded wastewater treatment, changes to urban or farm management, and mitigation systems); some form of policy intervention (e.g., rules and incentives); and societal pressure and commitment for change.

There are proven methods and technologies for reducing stresses imposed on fresh waters, including:

- Protecting and restoring riparian zones and wetlands, and prioritising their protection in regional planning rules. This includes riparian planting and fencing to keep livestock out of waterways.
- Ensuring water allocation does not exceed requirements for sustainable flow regimes in rivers.
- Longitudinal monitoring regimes with the monitoring sites appropriate to the nature of the catchment and its likely issues.
- Improving treatment of point source and diffuse source discharges and applying on-site and off-site mitigation tools to ensure that contaminant inputs do not exceed critical thresholds.
- Using pest control technologies to reduce the abundance and spread of pest populations.
- Retrofitting migration barriers to allow fish passage and developing alternative transfer methods.
- Developing and expanding fisheries management for both native and exotic species.
- Ensuring management and restoration efforts consider all stressors so that bottlenecks to improved ecosystem health are removed.

Restoration activities are being undertaken in many catchments all over the country, including riparian planting, fencing waterways, developing and operating within-farm environment plans involving calculating nutrient budgets, and other approaches. But in some cases it may take over 50 years to reach the desired outcomes because of the residence time of existing high nutrient levels in the water (groundwater around Lake Rotorua being but one example). We are often dealing with legacy effects and cumulative effects, exacerbated by new urban or agricultural developments. Even where restoration has occurred, this is generally not to the original state, nor can it generally be, given the fact that humans and terrestrial mammals are only recent arrivals in Aoteoroa. As New Zealanders, we want a vibrant economy, a quality environment, and preserved natural heritage – and there are no simple solutions.

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Summary report

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Summary report

INTRODUCTION

Fresh water[2] in Aotearoa/New Zealand is a taonga – a treasure of great cultural, environmental, social and economic significance. Having healthy freshwater systems is absolutely vital to our wellbeing. Despite this status, the quality of our fresh water in many places has become a significant concern for many stakeholders. Demands on our freshwater systems continue to increase.

Less than 800 years ago Aotearoa/New Zealand had no terrestrial mammalian inhabitants. Today 4.5 million humans and many millions of terrestrial mammals make this land their home: the impact of this transition on our waterways has been profound.

The drivers of change are complex and inter-related, and the impacts are cumulative over many decades. Human involvement through changed land-use, the development and then recent intensification of pastoral agriculture and progressive urbanisation and industrialisation have all played their role. The state of our fresh water is a consequence of this social and economic history. Preventing further degradation, protecting and enhancing water quality and ecosystem health, and addressing the likely impact of climate change are priorities for New Zealanders. The required management responses are complex, time-dependent, sometimes uncertain, and will be costly.

Because of its all-encompassing nature and wide range of stakeholders, debates over water use and quality are inevitable. The issues around using and protecting our water resources are ‘post-normal’ in nature, also referred to as ‘wicked problems’ involving complex science intertwined with a range of stakeholder values and interests that can never be fully aligned. National and regional standard setting, regulation and consenting must take the science into account while finding a point of equilibrium between these very diverse perspectives and interests.

To ensure better informed debate and policy discussion in this contentious area, it is helpful to assess the current state of fresh water, the scientific understandings of the factors underlying changes to water quality, and the approaches to remediation that policy makers and the public might consider. With better and broadly based understandings, more informed decisions on freshwater issues can be made – decisions that will be widely understood and supported, and that will be underpinned by good science. We have an opportunity and an obligation to make things better, but doing so isn’t easy.

This summary report draws out the core points from the extensive data and commentary provided in the accompanying technical report.[3] It is not the purpose of this paper to enter into political debate, but rather to assist New Zealanders through what is a complex and often contentious set of issues involving inevitable scientific uncertainties and unknowns that can create reasons to avoid addressing the necessary solutions.

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[2] For the purpose of both this summary report and the full technical report, fresh water is defined as ‘all water except coastal and geothermal water’, in accordance with its definition in the Resource Management Act 1991.

[3] New Zealand’s fresh waters: Values, state, trends and human impacts. Technical report (this volume, pp.1-67)

This set of reports has had a long gestation and has been developed independently of work that has led to the recent release of a consultation document on the 'Clean Water: 90% of rivers and lakes swimmable by 2040' goal[4]. However given that the 'Clean Water' package is out for consultation, the Office of the Prime Minister's Chief Science Advisor (OPMCSA) has given priority to accelerating completion of this report before that consultation period is complete. The attached technical report was prepared in early draft form by freshwater scientists at the National Institute of Water and Atmospheric Research (NIWA), but since then has been subject to extensive review and rewriting by the OPMCSA, informed by a number of freshwater academics and the relevant departmental science advisors. It was also subject to independent peer review. The technical report has been intentionally written in a form to be fully accessible with extensive referencing.

This paper is independent of, but complements the "Our Fresh water" report to be published at the end of April 2017, within the regular series of reports produced by the Ministry for the Environment and Stats NZ under the Environmental Reporting Act 2015.[5] That report will follow the specific requirements of the Act, and will report on the state of our freshwater environment, the pressures that affect the state, and how this state influences aspects of the environment and our well-being. The present paper and underlying technical report take a broader and more explanatory approach, presenting the science relevant to the condition of our fresh waters and to restoration of water quality.

FRESHWATER VALUES

Fresh water contributes greatly to our economy, and is highly valued by New Zealanders for cultural, social and recreational reasons. Indeed it is an inherent part of our national identity. The provision and benefits of fresh water to meet economic, social, cultural and environmental needs are referred to as 'ecosystem services', and include water for:

- intrinsic cultural value and a source of mahinga kai;
- potable water supply and household use (bathing, toilets, cooking, gardening, etc.);
- economic uses (agriculture (irrigation and stock use); industrial use; hydroelectric energy generation; fisheries; tourism);
- recreation and social amenity; and
- sustaining our indigenous biodiversity, which in turn delivers its own set of ecosystem services.

All consumptive uses of water have some impact on the freshwater environment, even where water recycling is involved. Some non-consumptive uses have serious impacts through introduced biota, changing water chemistry or hydrology, and other effects on ecosystem services. With increasing use and demand for fresh water, it becomes harder to reconcile varying interests of households, agriculture and industry, and of communities that require other values be catered for, including those of conservation, recreation, tourism and of iwi.

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[4] Ministry for the Environment; Clean Water package 2017. http://www.mfe.govt.nz/fresh-water/freshwater-management-reforms/clean-water-package-2017

[5] New Zealand Legislation: Environmental Reporting Act 2015 http://www.legislation.govt.nz/act/public/2015/0087/latest/DLM5941105.html?search=ta_act_E_ac%40ainf%40anif_an%40bn%40rn_25_a&p=2

CULTURAL VALUES

The national significance of fresh water for all New Zealanders is recognised in the National Policy Statement for Freshwater Management (NPS-FM), as is *Te Mana o te Wai*. Safeguarding the health of the water (*te hauora o te wai*), the health of the environment (*te hauora o te taiao*) and the health of people who come in contact with the water (*te hauora o te tāngata*) are essential objectives of the NPS-FM that support high-level 'national values' for fresh water – they are fundamental to meeting the needs of the nation and of all its citizens.

Water is a taonga to Māori; it is a source of mahinga kai[6] and it carries a life force (*mauri*). This is reflected in the concept of *Te Mana o te Wai* - the innate relationship between *te hauora o te wai* (the health and mauri of water) and *te hauora o te taiao* (the health and mauri of the environment), and their ability to sustain *te hauora o te tāngata* (the health and mauri of the people).

The mauri of water is now being embodied in Treaty of Waitangi settlements; for example the Whanganui River Deed of Settlement of 2014 and the recent Te Awa Tupua (Whanganui River Claims Settlement) Bill (2017)[7], which focuses on the river and recognises the river as a being. Water is viewed, with land, as a total system - *Ki uta ki tai* (mountains to sea) which should be managed within this framework. However, current management practices are not necessarily aligned to such a framework, so it is not surprising that many within the Māori community continue to express concerns about the state of fresh water generally, about mahinga kai, and about important places like the Whanganui River and Te Waihora/Lake Ellesmere, which to them are a major concern.

POTABLE WATER SUPPLY AND URBAN USE

Potability, or suitability and safety for drinking is an expectation New Zealanders have of the water that comes out of their taps. Some towns and cities get their potable water from surface water (reservoirs and rivers) and others use a groundwater (aquifer) source. Of the water allocated for consumptive use, 8% is allocated to potable supply. The reliability of this supply is generally high, but it faces increasing pressure from rising demand as the population grows (which puts pressure both on supply and on the treatment and distribution infrastructure), and from insufficient storage capacity to cope with droughts.

Municipal supplies sourced from surface waters are invariably chlorinated to treat for pathogens, whereas those sourced from groundwater aquifers may not necessarily be treated, because where groundwater is overlain by layers of materials of low permeability, such as clay, the risk of contamination is considered to be extremely low. However, the 2016 contamination of groundwater-sourced water in Havelock North (possibly via contaminated surface water entering through bores) highlights the importance of careful monitoring and management of all aspects of the water supply system. The event raised questions about whether the expectation of potability is being met adequately throughout New Zealand. Even Christchurch, generally perceived to be home to New Zealand's highest quality drinking water, is now having to chlorinate some of its water, in the face of earthquake-related infrastructure issues.

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[6] Mahinga kai refers to the production and gathering of all foods and other natural resources, as well as the areas from which they are sourced.

[7] New Zealand Legislation http://www.legislation.govt.nz/bill/government/2016/0129/latest/DLM6830851.html?src=qs

Urban use extends to household, gardening and commercial use, and council use for irrigation of sports fields, etc. Even though not all of this needs to be treated water, in general the same supply and distribution system is used; only a few individual organisations and dwellings have separate rainwater collection and storage for non-potable use.

ECONOMIC VALUES

Water for agriculture

Water is vital to our primary industries-based economy. In regions like Canterbury, Hawkes Bay, Tasman, Marlborough and Central Otago, water is relied on for irrigation purposes, sourced from both underground and surface supplies. But water is not just used by agriculture, viticulture and horticulture for irrigation – since the 19th century it has also been used for stock watering, and is used extensively in dairy farming for activities other than just growing grass (e.g. cleaning of milking sheds and equipment). Demand for irrigation water is high in spring and autumn for cropping farmers, but also in summer for dairy farmers as they seek to extend the 'spring flush' of grass growth.

Water for industrial use

Industrial use of water for some industries (e.g., steel, horticulture, dairy and meat processing, manufacturing) has high value returns, often with relatively low commercial costs as the water is of sufficient quality to be used without treatment prior to use. However, there are potential environmental costs in terms of water quality impacts from industrial discharge.

Water for energy production

Fresh water is used in hydro-power operations that generate over half of New Zealand's total electricity supply. Water for hydroelectric power is of high economic value for meeting energy needs while reducing carbon emissions, and although this is considered to be non-consumptive use, it is not without environmental impact. For example, impoundments (e.g. dams) turn rivers into lakes that slow the movement of water and facilitate the growth of phytoplankton[8]. In some large New Zealand rivers the natural flow regime has been altered, with impacts on natural ecosystems and aquatic and terrestrial habitats both upstream and downstream of hydro dams. Birds that rely on braided rivers (e.g., wrybill, black stilt, black-fronted terns and black-billed gulls) are particularly vulnerable to the effects of flow alteration by hydropower operations, and dams often impede the passage of fish that require access to the sea. Our beloved beaches and coastlines rely on a constant supply of sand that is generated from rocks and gravel that move from mountains to sea through our rivers. Interrupting the natural supply can result in coastal erosion effects, which in turn may require engineering interventions. All hydropower schemes in New Zealand operate under resource consents generally aimed at both minimum flow protection and the maintenance of some flow variability. Some schemes (e.g., in the Mackenzie Basin), however, are not necessarily bound by such conditions, but are instead subject to complementary mitigation agreements.

Freshwater fisheries

Lakes and rivers (and their associated estuarine systems) are important for freshwater-based fisheries in New Zealand. Native fisheries include customary iwi fisheries, and recreational and

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[8] Phytoplankton are microscopic algae and cyanobacteria suspended in the water column and are able to produce oxygen through photosynthesis.

commercial fisheries for whitebait and eels. There is mounting concern about the state of some whitebait species and long-finned eels. Habitat loss, often a function of alteration of river flows and drainage of wetlands, is a particular concern for whitebait in the lower spawning reaches of many systems.

New Zealand is world renowned for its introduced trout, and to a lesser extent its salmon fisheries. These fisheries are recreational but also have an important international and domestic economic value for tourism. In recent times there have been declines in lowland trout fisheries in particular, associated with land use intensification and water loss.

There are many native fish species that have no recreational or commercial value, but they have high conservation value. Many of these are at risk, especially those found in Central Otago and the Mackenzie Basin. Once again habitat loss is an important threat, but so too are predation and competition from introduced trout and other predatory fish.

Tourism

Healthy waterways are critically important economically for tourism, which was New Zealand’s largest export industry in 2015. A substantial proportion of domestic and international tourist activities in New Zealand occur in or adjacent to fresh water, especially in places like the central North Island, Mackenzie Basin and southern New Zealand including Queenstown – where wild and scenic rivers and streams are used for ‘adventure’ tourism – but there is also tourism values associated with some urban rivers like the Avon in Christchurch.

RECREATIONAL/SOCIAL AMENITY

Socially, our water bodies and their physical diversity provide a resource for many different (mainly recreational) users. It is hard to know what the most popular use of fresh water for recreation is, but clearly swimming, boating (jet-boating, kayaking and canoeing), fishing (for trout and salmon and whitebait mainly), and picnicking are the main uses. All of these values have been impacted over time, negatively in many places, by water and land resource development. This is most notable in lowland streams used for angling, in many lowland rivers and streams used for swimming, and in some rivers used for jet-boating and whitewater kayaking. Dams have created new resources for some activities, but at a cost to other activities: e.g., whitewater kayaking needs rapids and gorges; flatwater kayaking typically occurs on lakes and downstream sections of rivers.

Of these activities, perhaps the one that garners most attention is swimming, with freshwater quality often becoming synonymous with “swimmability” (see **Box i**). Unfortunately because of the multiple dimensions to measuring water quality, this is a complex concept. Several factors are relevant to considering whether a particular location is suitable for swimming, including depth, temperature, current strength, visual appeal (clarity and colour), the absence of nuisance weeds or algae, and human health risks from microbial pathogens or toxic algae.

It is important to understand that the swimmability measures in Box i do not include all the measures of water quality that regulators must take into account in managing the fresh-water domain. The swimmability measures are defined around human health considerations with activities likely to involve full immersion into the water. A much broader range of considerations and measures is needed to manage for potability, extraction for agricultural, industrial and urban uses, and ecological and aesthetic considerations. These other measures assess the ecological health of the river or lake and whether, for example, the concentrations of nutrients (nitrogen and phosphorus) are within acceptable levels.

Box i. What is meant by "Swimmability"?

A range of characteristics need to be considered when assessing a water body's suitability for swimming, including depth, temperature, current strength, visual appeal (clarity and colour), the absence of nuisance weeds or algae, and human health risks from microbial pathogens or toxic algae. Microbial pathogens in the water can enter the body by ingestion, or through the ears, nasal passages, mucous membranes or cuts in the skin, and can cause gastrointestinal illness, respiratory symptoms, or more harmful diseases like hepatitis A. Microbial contamination is a concern in in both rivers and lakes, whilst the presence of toxic cyanobacteria is primarily a concern of lakes.

Suitability for swimming – assessing microbial contamination

The test used to assess the presence of pathogens in New Zealand freshwater systems is detection of *Escherichia coli* (*E. coli*). Detecting *E. coli* signals the presence of animal or human faeces in the water, and the likelihood that other harmful water-borne pathogens such as *Campylobacter*, *Cryptosporidium*, *Giardia*, hepatitis A viruses, and Salmonellae may also be present. Faecal contamination from animals can occur via runoff from farms during rainfall events, or if animals have direct access to waterways. Human faecal contamination of waterways can occur via poorly treated sewage or septic tank systems, or during heavy rain when sewerage systems cannot cope and they overflow into stormwater systems. Because of these heightened health risks from runoff and stormwater, people are often advised to avoid swimming for 48 hours after prolonged or heavy rain.

There are two distinct components to assessing the suitability of a site for swimming – grading and surveillance. Grading assesses the general suitability of a site for swimming over the long term (and uses long term monitoring to determine that) whilst surveillance assesses the suitability of a site for swimming in the short-term (is it OK to swim today?). Surveillance also reduces the risk of selective assessments and allows for long-term trend assessment to ensure that there is progressive improvement at sites that are not optimal. Guidelines established by the Ministry for the Environment and the Ministry of Health in 2003 included both grading and surveillance, whilst the National Policy Statement for Freshwater Management (NPS-FM) 2014 considered only grading. The proposed changes to the NPS-FM included in the 2017 'Clean Water' consultation package brings both grading and surveillance together again, with proposed surveillance criteria being numerically identical to the 2003 guidelines for microbial water quality.

Under the surveillance criteria, during the swimming season authorities should warn against swimming when *E. coli* levels in rivers and lakes are detected at a concentration at or above 540 counts per 100 millilitres (ml). Such a sampling result indicates that the water, at that time, has exceeded the upper level of contamination that is considered acceptable for swimming – beyond this threshold the risk of infection from full immersion can be more than 5%. To ensure that risk remains low, the surveillance criteria also specify that if *E. coli* concentration on a given day exceeds 260 per 100 ml, daily sampling is required until the concentration falls below 260. Because storm events in particular can lead to a transient high count due to faecal runoff and/or wastewater overload, it is logical to have a rating system that considers the possibility of such extreme measures and focuses on the anticipated range of measurements when swimming is likely.

In order to ensure an overall low level of risk for swimming in a particular water body, standards have been established that require the level of *E. coli* to be well below the 540 /100ml swimmability threshold most of the time. This is one aspect of the grading criteria. Importantly, the use of a guideline that includes a low median value (which means that half of measurements made at a site must be below that level) is an effective way of putting an obligation on waterway management to reduce continual or repeatable sources of contamination to generally very low levels. The 2017 'Clean Water' package proposes that all 'swimmable' water bodies should have a median *E. coli* concentration of no more than 130 /100ml. The risk of infection at this level is extremely low (approximately 0.1%, or 1 in 1000 exposures). This means that at least 50% of the time, even in rivers that are only graded as 'fair' (yellow or C grade category in the NPS-FM), there is very low risk to swimmers.

Rivers are also graded on how often they exceed a level of 260 *E. coli* per 100 ml – a level conferring between 0.1 and 1% risk. For the proposed gradings the *E. coli* level must be lower than 260 /100ml at least 70% of the time and below the 540 /100ml threshold at least 90% of the time for a 'good' (green or B grade) rating. An 'excellent' (blue or A grade) rating requires 80% below 260 and 95% below 540 /100ml. Overall, this proposed grading would mean that the risk across all time (disregarding weather events or other risk factors which would reduce the likelihood of swimming in any case), the risk of infection from contact in rivers graded as 'swimmable' is very low. For example, the risk would be approximately 1% for an A grade river, and if one knew nothing else and could swim at any time, but in practice the risk will be much lower because the highest risk would be at times when swimming is least likely.

Box i. (continued)

Swimming in lakes – assessing toxic cyanobacteria
Councils monitor lakes, with a focus on popular recreational sites, for presence and amount of the planktonic cyanobacteria, which can produce a variety of toxins. For a lake to be considered safe for swimming, in addition to meeting the requirements for *E. coli* as for rivers, potentially toxic cyanobacteria cannot be present in quantities that could harm people's health.

Assessments of lake state and trend for toxic algae are based on total cyanobacterial biovolume. If potentially toxic cyanobacteria are present, the threshold level for contact recreation (e.g. swimming) is a cyanobacterial biovolume >1.8 mm^3/L. These guidelines are based on the assumption that all species of cyanobacteria in the lake are toxic, which might not be the case. This is precautionary and is likely to suggest a higher risk in some situations than actually exists. If no known toxin-producing species are detected on further investigation, the upper limit is 10 mm^3/L biovolume.

When cyanobacterial biovolume exceeds guideline levels, the lake is more actively monitored and warnings are put in place. If an algal bloom is suspected, swimming is not advised, and dogs should be kept on a lead – accidental consumption or exposure to the water could be harmful.

Another concern about water quality regards the safety of domestic animals, including dogs, because *Phormidium*, a potentially toxic cyanobacterium that is generally associated with low-flow conditions in streams with compromised water quality, appears to be becoming more widespread.

INTRINSIC ENVIRONMENTAL AND CONSERVATION VALUES

At a more fundamental level of ecosystem services (i.e., not just the services of direct benefit only to water users), freshwater systems perform filtration, flood control, nutrient cycling[9] and carbon sequestration[10] functions.

New Zealand freshwater systems are naturally diverse, reflecting the diversity of the landscapes they are located within. High proportions of our freshwater invertebrate, fish and bird species are not found elsewhere in the world (endemic), including many species that are classified as threatened or at risk[11] (notably 28% of native fish species).[12] This uniqueness brings with it both conservation responsibilities and the need for application of local research and knowledge to protect them. Many of these endemic species are vulnerable to changes in environmental conditions, and concerns exist about their resilience to current and future pressures.

From a conservation perspective, many of New Zealand's rivers (especially the eastern South Island's large braided rivers) are biodiversity hotspots for endemic and threatened species of birds (e.g., black-billed gull, black stilt and wrybill – the only bird in the world with a beak curved to the side) and for many species of plants and terrestrial invertebrates (e.g., the robust grasshopper). They also play an important role as hosts for migratory birds globally. Some of these rivers and many others around the country are important native fisheries habitats,

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[9] Nutrient cycling is the movement and exchange of nutrients (elements) from organic and inorganic matter back into the production of living matter.

[10] Carbon sequestration is a natural process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form. For example, freshwater wetlands act as 'carbon sinks' because their plants absorb carbon dioxide from the atmosphere through photosynthesis, and standing water reduces respiration of that carbon dioxide back to the atmosphere.

[11] The conservation status of native species is assessed by the Department of Conservation according to the risk of extinction they face within New Zealand. http://www.doc.govt.nz/nature/conservation-status/

[12] Conservation status of New Zealand freshwater fish. Allibone, R., et al. (2010). *New Zealand Journal of Marine and Freshwater Research*, 44, 271-287.

including the culturally important whitebait and eel fisheries. Lowland lakes, notably Te Waihora (despite its hypertrophic state[13]), are also important for birdlife.[14] Even our groundwater resources contain life – over 100 invertebrate species live in aquifers, and are believed to play an important cleansing role for the water in those aquifers.

For all of the species and communities in rivers, lakes, wetlands and groundwater, their habitat is being affected in ways that impact conservation efforts. We know this because we can count birds (and they are declining in many places), we can measure the health of the aquatic invertebrate community in rivers via the Macroinvertebrate Community Index (MCI),[15] and we have long term records of the distribution and populations of some fish species.

MONITORING NEW ZEALAND'S FRESHWATER SYSTEMS

Water quality can be defined in a number of ways. For New Zealanders, the issue of 'swimmability' is an important measure of the quality of a freshwater body (see Box i). But for freshwater systems, 'quality' relates not only to the state of the water itself; it encompasses the biological health of the system as a whole, and multiple measures are needed to provide a full picture (see Box ii).

Box ii. What is water quality?

Water quality as defined in this report refers to the physical, chemical and biological characteristics of a water body. These characteristics determine how and for what purpose water can be used and the species and ecosystem processes it can support. It includes such characteristics as pH (acidity), dissolved oxygen, suspended sediment, nutrients, *E. coli*, heavy metals and pesticides. It can also include key biological and biochemical variables, such as aquatic plant, invertebrate and fish composition, the abundance of algae, and oxygen demand. Multiple measurement variables are used in virtually all assessments of water quality, leading to a 'rich picture' of the state of the water body, describing those characteristics that are within 'healthy' ranges and those that are outside of these. In an attempt to rank sites and simplify communication, composite indices of water quality have been developed. While such indices provide a useful aggregate snapshot, they can also inadvertently disguise specific problems within a waterbody that need acting upon.

A number of 'variables', or indicators, are monitored to determine freshwater quality and ecosystem health. The 'trophic state' of a freshwater body is an important proxy for health relating to the levels of nutrients and plant growth (or plant *biomass*). A 'eutrophic' lake has high nutrients and high plant growth; 'hypertophic' is a more extreme state of nutrient enrichment. The trophic state is primarily determined by the concentration of nitrogen and phosphorus in the water, so these nutrients are key monitoring variables to determine water quality.

The major monitoring variables used to assess freshwater states and trends for rivers, lakes and groundwater are listed below. These variables are assessed against a scale of values ranging

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[13] A hypertrophic state is a state of excessive productivity, with a high concentration of nutrients and very high primary producer biomass.

[14] Te Waihora has the most bird species of any habitat in New Zealand, with 169 species recorded.

[15] The Macroinvertebrate Community Index (MCI) is a community-level biological indicator of general river health based on the presence or lack of macroinvertebrates such as insects, worms and snails in a river or stream. The MCI assigns a score to each species or taxon based on its tolerance or sensitivity to organic pollution, then calculates the average score of all taxa present at a site.

from those indicative of a healthy state (conditions of little or no stress to aquatic life) to those indicative of an unacceptable state (conditions of significant, persistent stress exceeding tolerance levels). When one or more variables have values nearing the unacceptable end of the scale, there is a risk of species loss and other negative ecological effects.

The list of measures is considerable, reflecting the multiplicity of factors that can affect water quality and the multiple uses that water is put to. The most common measures include:

- **Physical-chemical variables**: temperature, acidity (pH), dissolved oxygen, nitrate-nitrogen (NO_3-N), ammoniacal-nitrogen (NH_4-N), total nitrogen (TN), dissolved reactive phosphorus (DRP), total phosphorus (TP), lake-bottom dissolved oxygen (DObottom), visual clarity, and for groundwater, dissolved iron and manganese, electrical conductivity and total dissolved solids
- **Biological variables for rivers**: abundance and composition of periphyton (algae and associated organisms attached to rocks, fine sediment and plants), and a river health index based on benthic (bottom dwelling) invertebrates, which is known as the 'macroinvertebrate community index' (MCI)
- **Biological variables for lakes**: phytoplankton biomass (as chlorophyll-*a* concentration), the trophic level index (TLI) based on integrating chlorophyll-*a*, water clarity, total nitrogen and total phosphorus concentrations, and the lake submerged plant indicator (LakeSPI)
- **Wetland monitoring**: Where wetland monitoring occurs, itis mostly based on the Wetland Condition Index (WCI) which incorporates five ecological indicators: hydrological integrity, physiochemical parameters, ecosystem intactness, animal impacts, and dominance of native plants.
- **Public health risk**: Concentration of the faecal indicator bacterium *Escherichia coli* (abbreviated *E. coli*) is used as an indicator to assess risks of contamination by pathogens such as *Campylobacter*, *Cryptosporidium*, *Giardia*, Salmonellae and hepatitis A – and *E.coli* is therefore a standard measure for drinking water supplies, including groundwater.[16] River-bed periphyton mats are monitored in most river monitoring programmes because they can include the cyanobacterium *Phormidium*, which can produce neuro-muscular toxins (anatoxins). Levels of toxic planktonic cyanobacteria (often called blue-green algae even though they are not actually algae) are monitored in popular recreational lakes as the main criteria for determining their safety for swimming (see **Box i**).

Water quality monitoring is complicated further by what standards should be set, and how and where monitoring is to occur. For example, determining acceptable levels of nitrogen and phosphorus is complex because different situations (e.g., light/shading, river flow regimes, river bed type, lake type) influence the response of algae and lead to one or the other nutrient being the limiting factor for the growth of plants and determining the trophic state.

The science highlights a clear need to ensure long-term, repeated measurements through time at the same sites, and that the sites chosen need to be informative. Irrespective of any global goal that is set, most people want to know whether at any monitored site the water quality

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[16] Ministry of Health. (2008). Drinking-water standards for New Zealand 2005 (Revised 2008).

meets requirements for human and ecosystem health, and if it does not, that there is evidence of improvement over time. Given that any such goal can only be a reflection of the sum of sites monitored, the issue is to ensure a logic to where, when and how often monitoring is performed. This is complex in itself. Monitoring at the downstream-most point in a catchment can give an overall view of the catchment, but monitoring upstream can point to sites of potential contamination to allow for more targeted allocation of mitigation activities. It is not a matter of choosing a balance of upstream and downstream sites, rather it is a matter of considering the priorities for monitoring, the values placed on the resource, the geography of the catchment and the activities that occur within it, in planning a robust monitoring regime.

FRESH WATER IN NEW ZEALAND – PLENTIFUL BUT CAPRICIOUS

New Zealand's freshwater supply is driven primarily by the predominant westerly weather systems and the underlying physical geography of the country – these systems typically wet the West Coast with rain year round,[17] and dump snow in the mountains in winter. At the same time they leave much of the agriculturally and horticulturally productive east subject to highly variable rainfall, typically leading to drought conditions somewhere every year. But the topography of New Zealand, with its northeast-southwest oriented mountain ranges, also provides opportunity. As the West Coast gets very wet, especially in the South Island, so do the mountain catchments draining to the east. It is these catchments that supply over half of NZ's electricity needs and also provide for the irrigation needs of agricultural development. But these same rivers also deliver other services – for recreation and for conservation of endangered species of birds and fish. It is these rivers, along with rainfall and occasional snowfalls (on the plains) that help recharge the groundwater resources of the Canterbury Plains. There are lakes in many of the headwater catchments of the Southern Alps that are vital to the New Zealand tourism industry, but which also act as storage buffers for the downstream river flows; and downstream there are lowland lakes and wetlands, much reduced in area but vital for Māori cultural use and for conservation. The North Island has river systems that primarily have their origin either in the mountain chain that extends from Wellington to the East Cape, or in the volcanic plateau that is the origin of the Waikato and Whanganui – rivers of great importance across multiple domains.

Clearly New Zealand has abundant water resources, but not always in the right places at the right times for our needs. The eastern sides of both islands are far drier than the west, and the northern portion of the North Island can also be very dry (on occasion). As noted, especially in the South Island, large snow and rain-fed rivers flow to the east, but even these rivers have low-flow periods when they cannot meet all natural and human demands. Mid- to late summer (when peak snow melt is over and the country is in a more stable, sunnier weather pattern) and autumn are often particularly water-scarce times.

Despite the above challenges, on a per capita basis New Zealand has the second highest volume of renewable fresh water of all countries in the OECD[18] (107,527 m3/yr – around 43 times the amount of water in one Olympic swimming pool per head). We have 3800 large lakes (area >1ha) and more than 413,000km of streams and rivers (around 10-times the circumference of the earth). However the total per capita water use in New Zealand is also significantly higher than in

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[17] Drought does occur occasionally on the West Coast, and fire restrictions have been implemented.

[18] Organisation for Economic Cooperation and Development http://www.oecd.org/about/

most other OECD countries, partly because it is used in hydro-electricity generation, supplying approximately 60% of our electricity requirements, and from extensive use in irrigation.

We have extensive groundwater systems and aquifers, especially along the eastern sides of both islands and in the central North Island. Aquifers are "recharged" with water from rainfall soaking through ground overlying the aquifer, and from river water that flows from riverbeds into aquifers. A key feature of aquifers is residence time – the average amount of time that water stays in the system. Groundwater residence time assessments are useful for determining the amount of time it will take for a contaminant to reach a groundwater drinking water source or a surface water body, and will assist in calculating its likely concentration when it arrives. Depending on the depth, structure and location of the aquifer, this can vary from 5-10 years (e.g. Canterbury shallow aquifers) to 100 years or more (e.g. Lake Rotorua catchment), and there are implications for restoration from these variable residence times.

New Zealand's hydrological system also includes glaciers and snowpack, as well as significant wetlands, albeit only around 10% remain intact. Within this system, it is important to note the great diversity of catchment geographies, the types of river and their relatively short length, and a number of key rivers interrupted by dams. Our four largest river catchments (Clutha, Waikato, Waitaki and Waiau) are all significantly affected by dam systems for power generation.

THE IMPACT OF CLIMATE CHANGE

Further pressure on our freshwater systems can be expected to arise as a result of climate change. The most likely scenarios arising from climate change will impact significantly on both where and when rain falls, and thus on river flows and the regional availability of fresh water. There are likely to be increased flows on the west coast of the South Island and in rivers draining the eastern flank of the Southern Alps, and decreased flows rivers on the east coasts of both islands, and in Waikato and Northland.

Other expected impacts on New Zealand's fresh water include:

- Greater variability over time in river flows, with increased frequency of extreme floods and prolonged droughts. The degree of this variation will be different across the country due to New Zealand's complex geography.
- Intensified stratification in deep lakes, and possibly intensified wind-driven mixing in shallow lakes.
- Changes in the distributions of native species, valued introduced species, and invasive pests, and in the timing and severity of phytoplankton blooms. Warmer habitats are likely to favour the colonisation and spread of invasive species.
- Increased need for water storage in eastern areas to meet irrigation demands that increase due to projected warming and drying.
- Salinisation of coastal wetlands as sea level rises and seawater reaches further inland.

THE STATE OF OUR FRESH WATER

New Zealand's freshwater resources, in terms of 'quantity' and quality, are in variable states, as summarised in **Table i**. We know about these states and these trends, and other states and trends reported here because of the monitoring undertaken in New Zealand, mainly by Regional Councils and by NIWA, but also by universities, the Department of Conservation, Fish and Game Councils and numerous others. The results of much of this monitoring are reported in Environment Aotearoa 2015[19] and can be found in individual catchment reports on the Land Air Water Aotearoa (LAWA) website (https://www.lawa.org.nz). The reliability of this information is ensured by a variety of quality assurance processes and by the public availability of most of the monitoring data. The Ministry for the Environment and Stats NZ will be releasing their freshwater domain report at the end of April 2017, which will include the latest data on states and trends.

Table i. State of freshwater resources in New Zealand (qualitative assessment)

Resource type	Current state and trend		Major pressures	Secondary pressures
	Quantity/ Area	**Quality**		
Snow and ice	• Declining	• Very good	• Climate change	
Lakes	• Lowland lakes – wetland edges drained, reducing in area	• Lowland lakes – severely degraded	• Agricultural intensification	• Farming • Urban development (for urban lakes)
	• Upland lakes – many modified by level control	• Upland lakes – very good	• Hydro-electric power	• Forestry • Invasive plants and fish
Rivers	• Large rivers – very mixed with some excellent and some very degraded and/or experiencing allocation impacts	• Large rivers – very mixed with some excellent and some very degraded (especially in the North island)	• Agricultural intensification • Urban development • Loss of connectivity	• Hydro power • Artificial barriers affecting fish migration • Flow regime changes
	• Lowland rivers and streams – many over allocated	• Lowland rivers and streams – many very degraded	• Agricultural intensification • Loss of riparian vegetation • Channelisation, loss of connectivity	• Urban development • Artificial fish migration barriers
Wetlands	• Over 90% of original wetlands lost	• Many in very degraded condition	• Agricultural intensification	• Urban development • Invasive weeds • Water level decline
Groundwater	• Increasing rates of depletion and reduced recharge in some regions	• Overall good but declining in many areas	• Agricultural intensification – extraction and water quality effects • Horticulture	• Urban development; • Climate change

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[19] Ministry for the Environment & Statistics New Zealand. Environment Aotearoa 2015 http://www.mfe.govt.nz/publications/environmental-reporting/environment-aotearoa-2015

The current, compromised state of some water bodies in New Zealand may be linked to agricultural development, to urban expansion or pollution, to hydroelectric development, or to the effects of drought. Major lakes in mountain catchment areas of the South Island, including Manapouri, Tekapo, Pukaki and Coleridge, have been negatively impacted from hydro-electric development. Most rivers, lakes and wetlands elsewhere have experienced some degree of negative impact by development, mostly agricultural in origin.

Associated with these resources are their linked values, often diverse and sometimes conflicting in terms of competing requirements. From a resource management and decision-making perspective, we need to think about what the various values and demands are, why they are important, what their current state is and how they might be changing, and what is driving the changes. These are big societal questions that can be informed by the science of water quality and assessments of trends.

TRENDS AND PRESSURES

The current state of our fresh water reflects the fact that all of the values that we ascribe to it have been compromised to varying degrees (see **Table ii**). The science is clear - New Zealand's fresh waters are under stress because of what we do in and around them. The impacts of our activities include:

- Modification and destruction of riparian habitats and wetlands due to drainage, flood control, and land development and intensification;
- Reductions in suitable habitat due to altered flow regimes caused by takes for irrigation, impoundment for hydropower, flood control, and water diversion for all of these;
- Effects on sensitive species and ecological processes due to river channelization and flood control works, elevated inputs of sediment, nutrients, bacteria and toxicants from point sources and diffuse runoff from land, particularly agricultural and urban land;
- Contamination by urban, industrial and agricultural activities;
- Introductions of invasive plants, invertebrates and fish that alter ecological processes and displace native species;
- Creation of barriers to native fish migration such as dams, culverts and flood control gates;
- Depletion of native fish populations due to habitat loss and fishing pressures;
- Cumulative effects of multiple stressors that can push ecosystems towards tipping points and increase resistance to recovery;
- Climate change impacts on flow regimes, groundwater levels, water temperatures, biotic invasions, and consequences for freshwater ecosystems.

Among this long list, it is clear that the major drivers of growing concern have been rural land use practices, industrialisation (power generation and discharges) and urban development. Pest invasions, (for example, the incursion of didymo into South Island rivers or koi carp into Waikato wetlands) have also had major impacts.

The real question we face is whether or not it is possible to sustain the economic gains New Zealand has enjoyed, but which are associated with increased water use, together with the cultural, conservation, recreation and other services our freshwater resources have historically afforded us.

Table ii. State and trend of freshwater values in New Zealand (qualitative assessment)

Value	Current state	Trend	Major driver of change	Secondary drivers
Conservation values				
Native birds	Mixed to good in mountain-fed rivers; poor elsewhere	Declining for braided river birds	Predators and weeds, habitat loss	Water abstraction[20] and hydropower
Native fish	Mixed to good in mountain-fed rivers; poor in pastoral and urban rivers. Canterbury galaxias at risk.	'At risk – declining' for galaxias, declining for whitebait and longfin eel, increasing for shortfin eel, torrentfish	Habitat loss – flows, access (migration barriers), water quality	Introduced fish
Aquatic invertebrates	Mixed to good in mountain-fed rivers; poor in many places elsewhere		Hydropower development	Land use/sedimentation
Wetlands	Estimated 10% remaining, many of degraded quality	Continuing net decline	Agricultural and urban development	Pests and weeds; hydrological modifications
Recreation values				
Swimming		Declining in places; static in others	Agricultural intensification/water abstraction Urban development	
Fishing		Declining of much of country, particularly in lowland areas	Agricultural intensification/water abstraction	Didymo in the South Island Continued expansion of invasive aquatic weeds in many areas
Jetboating	Good in most places		Hydro power and water abstraction	
Kayaking	Excellent in most places		Hydro power and water abstraction	
Drinking water values				
Potable, drinking, water	Mixed – good in many areas but moderate to degraded in parts of eastern SI and NI		Agricultural intensification Poor well-head management	Urban land use
Maori cultural expectations				
Mahinga kai; mana kaitiaki; taonga species	Depending on comparative historical measure, often very degraded, e.g., Te Waihora	Likely worsening in many places	Habitat destruction via multiple causes – farming and urban development mainly	Drainage, channelization and hydrological modification generally

Urban development

Although agriculture is the major driver of change in the state of our freshwater resources and values nationally, the urban environment is an important driver in some places. Urban pressure issues are not limited to the provision of adequate drinking water (e.g., the current debate over a water treatment plant in west Auckland), but also over the adequacy of sewerage and

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[20] Abstraction is the process of taking water from a river, groundwater or other source, either temporarily or permanently, for irrigation, industry, recreation, flood control or treatment to produce drinking water.

stormwater systems. Even generally adequate systems can be overloaded under extreme weather conditions, and deciding the capacity such systems need to have in order to cope with intermittent or rare events is complex, and the solutions expensive. Septic tanks in some recreational areas are another source of potential contamination if they are not maintained.

In Auckland historically, wetlands were drained and freshwater streams have been affected by activities such as infilling and loss of riparian vegetation, discharges of contaminants, sediment runoff and abstraction of water. Some of the most notable impacts have been observed in the city of Christchurch, where urbanisation has impacted its rivers for more than 100 years. The swamps of Christchurch are largely gone (although some are now being restored), the Avon and Heathcote rivers are heavily polluted by heavy metals and sediment, and there is an added issue of reduced flows due to groundwater level declines. Contact recreation guidelines in these rivers are almost always breached. Heavy metals, which also affect the Avon-Heathcote estuary, require considerable remediation. Heavy metal contamination in rivers is the result of both historical industrial practices (e.g. mining and smelting), weathering of roofs, and vehicle components such as brake linings (copper) and tyre fillers (zinc), that collect on impermeable surfaces and wash off during rainfall and runoff processes. These and other pressures create habitat and recreational issues. In time and with effort and community commitment, contact recreation standards should be achievable.

Agricultural intensification

Table ii indicates that the main drivers of change (typically decline) in values are linked primarily to agriculture and to its recent intensification (mainly dairying). First, and perhaps most obvious, are the detrimental changes to water quality. Livestock farming impacts on water quality are both direct and indirect, both of which are important in considering mitigation strategies.

Direct impacts occur through:

- Trampling and pugging of stream edges and wetlands, leading to increasing sedimentation and habitat loss;
- Defecation directly into water, contributing to high *E. coli* concentrations that can breach contact recreation guidelines. Management strategies are to fence off streams and/or build stream crossings.

Indirect impacts occur through:

- Application of fertilisers on land, which release phosphorus and nitrogen into water bodies via surface runoff and leaching. Phosphorus can be managed by planting at edges of streams, lakes, and wetlands [called riparian management], contour cultivation to avoid direct runoff of sediment which has phosphorus attached, and careful management of areas within farms that contribute or concentrate most of the runoff (called critical cource areas). Nitrogen losses from fertilizer can be managed by carefully matching application rates to plant requirements.
- Nitrogen entry into waterways from livestock urine. When cows and cattle urinate, they create nitrogen-rich ‘urine patches’, and when it rains or when the ground is irrigated the water in which the nitrogen is dissolved flows downward through the soil into the groundwater system, often finding its way into surface water further down the catchment. Nitrogen is also present in surface runoff.
- Sediment - pastoral erosion produces more sediment in waterways than forested areas, affecting downstream coastal and estuarine areas by reducing water clarity. Harvesting of plantation forests also produces very high sediment run-off.

Nitrogen and phosphorus in water, in combination with other environmental factors such as light, flow, temperature and stream bed condition, contribute to growth of periphyton[21] or algae (including cyanobacteria). This growth is often prolific in summer in nutrient-rich environments – it can negatively affect swimming, angling and other recreation at times when it is present. Some algae, including several cyanobacteria species, can be toxic.

We know that faecal deposition, and phosphorus and nitrogen input, are problematic. However, *E. coli* contamination can be reduced through appropriate farm management practices and wastewater and stormwater treatment. And we also know that at low concentrations of phosphorus and/or nitrogen, we can limit algal growth to within acceptable levels most of the time.

The complications of maintaining acceptable levels of nitrogen and phosphorus are multiple and often interacting and cumulative – small amounts leaching from multiple properties add up to significant issues when they accumulate in downstream waterbodies. We measure these nutrient losses from farmland by the amount lost in kilograms per hectare per year. Low-intensity agricultural properties typically lose around 10 kg or less of nitrogen per hectare per year. High-intensity properties (e.g., some types of horticulture or an irrigated dairy farm on free-draining soils) can be lose more than 80 kg of nitrogen per hectare per year. We can measure these losses directly,[22] and we have models – most commonly known as nutrient budget models – that calculate estimates of nutrient losses at the root zone, and can also be used to identify potential environmental impacts. These models combine knowledge about soils, pasture or other vegetation type, land use, rainfall, and fertiliser input and work out a nutrient balance sheet of nutrient inputs and outputs. Any nitrogen or phosphorus loss can be thought of as a loss of a resource for the farmer, and ultimately as a potential loss of water quality in the receiving environment for all of us. Achieving a low nutrient-loss farming system requires careful land use and management practices, increasingly following industry-recommended 'good management practices'[23]. These include a variety of farm-specific tools and strategies that can be used to keep a farm within its nutrient budget. Some of these strategies are relatively cheap (e.g., matching fertiliser inputs to plant uptake requirements), whereas some can be very capital intensive (e.g., herd homes[24] for dairy cows).

There is obviously a critical relationship between the entry of nutrients from farms and other sources in a catchment into rivers, streams and groundwater, and the attenuation processes operating beyond the farm (e.g. uptake and transfer of nutrients in the riparian environment or in groundwater with low oxygen concentrations), affecting rivers and lakes downstream. The sum of nutrient losses from land can ultimately exceed the level at which the river or lake can cope before it becomes unacceptably affected by algal growth or nitrogen toxicity. For rivers another critical variable is the flow or amount of water in the river or lake, which influences dilution or the frequency of flushing flows. In general, the more water, the lower the

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[21] Periphyton are freshwater organisms including algae, fungi, and bacteria that cling to plants and other objects on beds of rivers, lakes and streams (usually in shallow water) and turn dissolved nutrients into food for invertebrates.

[22] Nutrient losses can be measured using lysimeters – cylindrical devices buried upright in the soil that collect water moving through the soil column, which can then be analysed for its nutrient content.

[23] The Matrix of Good Management: defining good management practices and associated nutrient losses across primary industries http://www.massey.ac.nz/~flrc/workshops/14/Manuscripts/Paper_Williams_2014.pdf;
Dairy NZ Good management practices;
www.dairynz.co.nz/media/4106341/Good_management_practices_April_2016.pdf;

[24] Herd homes are shelters for housing animals, where effluent is managed to reduce environmental impacts by applying it to pastures to fertilise feed crops for the animals.

concentration of nutrients, and therefore the lower the likelihood of severely detrimental effects – support the idea that 'the solution to pollution is dilution' (see **Box iii**). But flow and water level are affected by water use; for example, water taken from a river for irrigation reduces the ability of that river to dilute nutrients. In lakes, however, it is the total mass of nutrients flowing into the lake that is as important or more important than the inflow concentration because lakes have long residence times, allowing contaminants to accumulate.

Other local geographical factors also play a role. Consider two neighbouring lakes in Canterbury. Te Wairewa/Lake Forsyth is in a narrow valley, it has surrounding hills which shelter it to some degree from the winds that help oxygenate the waters, and the hills and their soils are volcanic and naturally rich in phosphorus, and nitrogen inputs are high. In addition, the lake rarely opens to the sea for flushing. All these circumstances contribute to the lake's hyper-eutrophic state. But in Te Waihora/Lake Ellesmere, the wind plays a greater role in keeping the water well-oxygenated, and most of the existing values of the lake are retained, albeit at sub-optimal levels. The differences between these two lakes highlights the importance of thinking about the diversity of drivers of water quality when considering how to address the challenges ahead.

Box iii. Is "dilution the solution to pollution"?

The concept of dilution as the solution to pollution revolves around the idea that the concentrations of pollutants in wastewater discharges or agricultural runoff can be reduced to below harmful levels if they enter water bodies that have sufficiently high flow or volume to dilute them. This is a relatively simple premise that, unfortunately, is not quite so straightforward in practice.

Historically, consenting processes for point source discharges have sought to ensure that the receiving waterway could assimilate the discharge without unacceptable effects beyond a "mixing zone" immediately downstream. However, this approach often ignores the cumulative effects of multiple discharges on waterways, something that now needs to be explicitly taken into account when operating within the limits required by the National Policy Statement for Freshwater Management. Additionally, some pollutants bio-accumulate – they persist and are transferred through the food chain.

A new approach is emerging in Canterbury. The large mountain catchment braided rivers are being carefully 'mined' for their plentiful supplies of fresh clean water. This water is being used to recharge groundwater, thus diluting the pollutant and improving reliability of supply – a process known as Managed Aquifer Recharge (MAR). There is a relatively small environmental cost to the large rivers (provided sufficient flow is retained to support their values) but a relatively large gain then to the lowland streams where this cleaner groundwater then later emerges.

WHERE TO FROM HERE?

There is a lot of fresh water in New Zealand and that water is highly valued by New Zealanders. It is greatly valued when it is in the rivers and lakes and wetlands and in groundwater for a wide variety of generally passive, or "in stream" uses (tourism, maintaining biodiversity, recreation). It is also greatly valued when it is abstracted, or actively used – whether for irrigation, industry or for drinking, bathing, gardening etc. Yet there is tension between all of the passive uses and some of the active ones – especially irrigation, industry, potable water supply and hydropower. So we must ask the question – is it really possible to have our cake and eat it too? As a nation, do we have the scientific understanding, the management tools, the policy solutions, and the resolve to do it? In theory we do, but in practice this is a real challenge because of the way costs and benefits are distributed among those who value the water; this challenge is made greater if the decision-making framework appears to create winners and losers. This in turn raises a number of policy dilemmas. These issues have been highlighted recently in the 2017 OECD review of New Zealand's environmental performance.[25]

Despite the challenges outlined above, there are important choices that New Zealand has to make. No single strategy will be enough. Major changes will be needed in some sectors of the economy, and in planning and consent activity. These changes will be neither instantaneous nor cost-free. The lag effects associated with flushing contaminated groundwater, for example, means that it will be decades or longer before results are noticeable in many places, even with immediate management interventions. Investment over time will be needed. The collaborative Land and Water Forum[26] and regional initiatives such as the Canterbury Water Management Strategy[27] are important in addressing these tensions. Many policy decisions will be needed, supported by land-use planning and commercial decisions both by large companies and by farming businesses. Whatever policy settings are chosen there are costs to some stakeholders. On the other hand there are high expectations for prevention of further degradation and progress to restoration, and in many catchments that restoration will take time. Catchments that are small, with simple geomorphology and land-use characteristics, and with socially coherent and motivated communities, will generally be easier to manage or remediate than large and complex catchments.

Despite these challenges we are seeing improvements – indeed the recent data indicate that improving trends are underway in the urban and pastoral land-cover classes with regard to phosphorus and ammonia, although the reverse is true for nitrate and total nitrogen. Across all classes, many rivers now show improving trends with regards to visual clarity and median *E. coli* concentrations, but others still show progressive deterioration. There is still much to be done by government, regional councils, NGOs, farmers and businesses, and indeed all New Zealanders.

Thus far only a few major catchments in New Zealand, for example the Hurunui in North Canterbury and Lake Taupo, provide examples of multi-stakeholder agreement and progress. Many catchments all over the country are undertaking restoration activities that include riparian planting, fencing waterways, developing and operating within farm environment plans involving calculating nutrient budgets, and other approaches. But in some cases it may take over 100 years to reach the desired outcomes because of the residence time of existing high nutrient levels in the water (groundwater around Lake Rotorua being but one example). We are often dealing with legacy effects and cumulative effects, exacerbated by new urban or agricultural developments. Even where restoration has occurred, this is generally not to the original state, nor can it be, given the fact that humans and terrestrial mammals are only recent arrivals. Some systems have gone beyond deleterious tipping points. As New Zealanders, we want a vibrant economy, a quality environment, and preserved natural heritage – and there are no simple solutions.

The technical report that follows details the science of our freshwater system – what we know of its state, and the challenges that need to be addressed. Continued, expanded and scientifically determined monitoring, reporting and learning will be essential so that policy settings and decisions by all stakeholders are appropriate as we strive to enhance the quality and sustainability of fresh water across all of New Zealand

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[25] OECD Environmental Performance Reviews: New Zealand 2017. http://www.oecd.org/newzealand/oecd-environmental-performance-reviews-new-zealand-2017-9789264268203-en.htm

[26] Land & Water Forum http://www.landandwater.org.nz

[27] Canterbury Water Management Strategy http://www.cwms.org.nz/

New Zealand's fresh waters:
Values, state, trends and human impacts

Technical report

New Zealand’s fresh waters:

Values, state, trends and human impacts

Technical report

INTRODUCTION

The primary purpose of this report is to present a summary of the knowledge scientists have about New Zealand’s fresh water estate, and to discuss the complexities and challenges of applying this knowledge to inform management initiatives that support all values we have for this essential resource.

Fresh water is critical to the many needs of our nation and its citizens; indeed we cannot live without it. But beyond providing potable water for human consumption and ecosystem services that sustain life, our natural waterways have immense cultural and aesthetic value, and spiritual value to Māori. We depend on healthy freshwater systems to provide for domestic, recreational, tourism, industrial and agricultural uses and for generation of hydroelectric energy. But there is growing concern over the state of our freshwater resources.

Since humans first arrived in New Zealand there have been inevitable impacts on the freshwater estate. The natural landscape changed dramatically with deforestation, wetland drainage, the introduction of pastoral agriculture, and the emergence and spread of towns and cities around rivers and lakes, some developing into sprawling conurbations. Industrialisation often relied on water and in turn impacted on its quality. Dams built for power generation inundated rivers, impeded fish passage and changed water flows, and land-use changes brought altered patterns of run-off and erosion. The expanding agricultural sector brought impacts of increasing fertilizer use, and growing numbers of farm animals led to further contamination of fresh water. The recent and very rapid expansion of dairying, particularly using irrigation into formerly dryland areas, is of particular note. Irrigation schemes to support primary production, and increasing population needs for potable and domestic water put pressure on water resources and have led in some cases to allocations beyond supply. The irrigation demands will be aggravated further by climate change. Imported invasive species have affected many of our larger lakes, rivers and streams and the chemical and biological profile of our fresh waters have changed considerably.

Clearly then, the human-created burdens of agriculture, urbanisation and industrialisation have impacted on the quality of our freshwater estate and this has become an increasingly contentious concern to New Zealanders. Preserving the quality of our waterways and indeed seeking to improve their quality where possible involves very difficult tradeoffs, and different groups of stakeholders will weigh the options differently.

To help inform the national dialogue about what options are available to improve the state of our fresh water (a debate that includes considerations beyond this paper regarding costs which would be incurred and who should bear them), this report attempts to summarise what scientists know (and do not know) about freshwater states and trends, and the pressures that are driving the most concerning changes. The report also aims to explain why different waterways (and types of waterways) may be in different states of health, and why some will be easier to improve than others. This knowledge should help support realistic expectations about what can be done, given the context of a country that has a very different human, animal and land-use profile to what existed 200 years ago.

This report is not a policy document and its genesis predates the current government's recent policy proposal on freshwater quality targets. However, it is hoped it will assist New Zealand to better understand the need for a number of policy decisions at both central and local levels of government, and the challenges any choice will have for various groups of stakeholders. There is a need for a long-term strategy that has broad acceptance by New Zealanders if the freshwater estate is to be protected from further degradation, and enhanced wherever possible.

SECTION 1. WHY NEW ZEALANDERS VALUE THEIR FRESH WATERS

Key messages:

Our fresh waters are fundamental to meeting the needs of the nation and its citizens. They are valued for a range of reasons that include:

- Cultural values: Most New Zealanders value the quality of our environment, which is heavily shaped by rivers, lakes and streams. Fresh waters have particular values to Māori, expressed in part through the concept of Te Mana o te Wai - the 'Mana' of the water. Fresh water is also a source of mahinga kai.
- Potable water supply and household use: Surface water and groundwater provide for the drinking water and household needs of urban and rural communities.
- Economy: New Zealand's economy is supported by our freshwater resources including clean and healthy waterways for tourist experience, hydro-power for energy supply, irrigation for primary production, stock water supply and water for processing industries.
- Recreational/social amenity: Our springs, wetlands, streams, rivers and lakes are valued highly by the public and tourists for their resources and the places they provide to walk, swim, boat, fish, and recreate and refresh by connecting with natural environments.
- Intrinsic environmental values (supporting and regulating functions): Freshwater systems perform filtration, flood control, nutrient cycling and carbon sequestration functions. The rich biodiversity of healthy freshwater systems offers opportunity for greater adaptive responses to new challenges such as climate change. Estuaries and wetlands are particularly important in this regard.

It is inevitable that fresh water quality has changed since humans arrived in New Zealand, and, over time, by our progressive changes in land use by agriculture, urbanisation and industrialization. This pattern has become increasingly acute in recent decades and there is a strong and growing public concern that these freshwater values are under threat, and in some cases are being compromised beyond acceptable limits. But the tradeoffs relating to water quality and quantity, and to stakeholder expectations, are complex and difficult. Different groups of stakeholders will have different perspectives on these tradeoffs based on how they weigh and perceive the different dimensions of values versus the cost of protection and remediation. These are important and critical issues for all New Zealanders.

Our nation's abundant fresh water provides a natural advantage that can only be the envy of many other countries. New Zealand has the second highest per-capita volume of renewable fresh water (107,527 m^3/yr) in the OECD behind Iceland.[28] Our 3820 lakes[29] and over 413,000 km of streams and rivers,[30] wetlands and aquifers provide for our well-being in many ways. Fresh water contributes greatly to our economy, is an inherent part of our national identity, and is highly valued by New Zealanders for cultural, social and recreational reasons.

The multiple and sometimes conflicting values we hold for fresh water make its management complex and often contentious. Water has high economic value when used for industry, hydropower and irrigation, but the current consent process for allocating water for these purposes is based on a high level of supply reliability, which is not always available and becomes less so when over-allocated. Sometimes catchments are over-allocated, and this has flow-on effects on the ability of the waterways to provide other ecosystem services.[31] Balancing supply with demand while also minimizing adverse effects on both surface and groundwater resources is an ongoing dilemma that is becoming increasingly difficult to resolve as demand grows and communities increasingly require that other values are adequately catered for, including those of iwi.

Surveys of New Zealanders show that while the majority of us hold the view that we live in a cleaner and greener environment than those in other countries, we do have particularly strong concerns about our fresh waters (Hughey et al., 2016) – in repeated surveys the state of our rivers and lakes has consistently rated as the environmental issue of highest public concern (Fig. 1). This is a reflection of both the prominence of the issue in the media and the perceived environmental change and degradation that has occurred in the recent past.

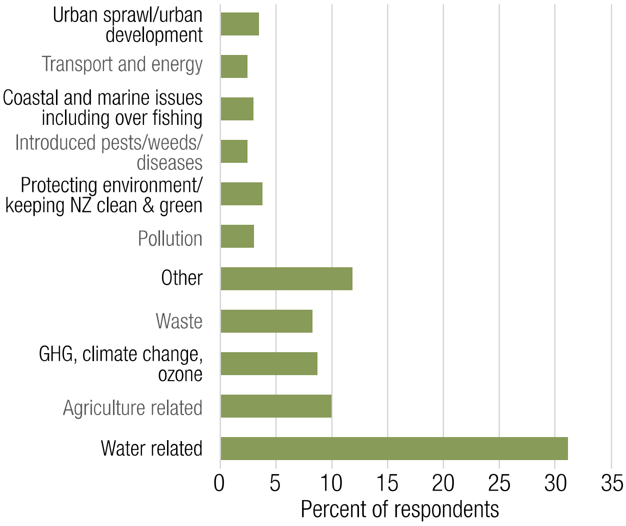

Figure 1: Results of a public survey of the most important environmental issues facing New Zealand. Reproduced from Hughey et al., 2016 (© Lincoln University)

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[28] Organisation for Economic Co-operation and Development. Freshwater resources. http://stats.oecd.org

[29] Based on lakes greater than 1 hectare in size

[30] All streams and rivers in the Digital Network underpinning the River Environment Classification Version 2.0 (REC v2) https://www.niwa.co.nz/freshwater-and-estuaries/management-tools/river-environment-classification-0

[31] The Millennium Ecosystem Assessment defines ecosystem services as the goods and benefits provided to people by ecosystems. These include: a) provision services, such as the provision of food, fuelwood and water; b) regulating services, such as flood and erosion control; c) supporting services, such as soil formation and nutrient cycling; and d) cultural services, such as opportunities for recreation and spiritual experience (Millennium Ecosystem Assessment, 2005a).

The provision and benefits of freshwater systems to meet economic, social, cultural, ecological and environmental needs are referred to as ecosystem services (Dymond, 2013; Roberts, 2015) and include water for: (1) cultural value – including as a source of mahinga kai; (2) potable supply and household use; (3) economic uses – including agriculture (irrigation and stock use), industrial use, hydroelectric energy generation, fisheries and tourism; (4) recreational and social amenity; and (5) intrinsic environmental and conservation value – including maintaining ecosystem functions and sustaining our indigenous biodiversity. These values and uses for fresh water are summarized below, with indigenous biodiversity covered more fully in Section 2.

1.1 CULTURAL VALUES FOR WATER

For all New Zealanders, waterways are a core part of a wider cultural setting within our natural landscapes and are often sites of national significance (Fig. 2).

Māori use the concept of *Te Mana o te Wai* - the 'Mana' of the water - to recognise the intrinsic values associated with a water body's visual appeal and knowing that it is 'healthy' and supports a diverse ecology (Harmsworth, 2016). Māori view water as a taonga (treasure) which carries a life force, or mauri, which needs to be protected. A healthy mauri is critical for a freshwater body to sustain traditional food species and habitats, and to support a range of cultural uses including gathering of mahinga kai. This has important cultural value as it is part of the traditional way of life for Māori and provides a means of holding the tribe together.

Figure 2: Examples of iconic freshwater bodies: Lake Taupo (photo Dave Allen, NIWA), Whanganui River (Photo John Quinn, NIWA), O Tu Wharekai wetlands (Photo Chris Tanner, NIWA) and Hamurana Springs (Photo Erika MacKay, ©NIWA).

1.2 POTABLE SUPPLY AND HOUSEHOLD USE

Around 95% of New Zealanders are supplied with potable water from municipal water treatment and distribution systems. New Zealand has strict guidelines designed to ensure the public safety of its reticulated drinking water (Ministry of Health, 2008), and New Zealanders have high expectations with respect to the reliability and quality of the water that is supplied to them. Municipal drinking water supplies in New Zealand meet the required bacteriological, protozoal and chemical standards most of the time, particularly in areas of larger supply (serving more than 10,000 people) (Ministry of Health, 2016). Supplies sourced from surface waters are invariably chlorinated to treat for pathogens, whereas those sourced from groundwater may not be, on the presumption that the risk of contamination is extremely low. However, the 2016 outbreak of campylobacteriosis in Havelock North and reports of contaminated groundwater in Christchurch provide contemporary evidence that such a presumption is questionable and needs to be revisited.

Of the water allocated for consumptive use, 8% is allocated to potable supply (Aqualinc Research Ltd, 2011), the remainder primarily being for industrial and agricultural use. The reliability of supply is generally high but can be limited by excessive allocations, treatment and distribution infrastructure, by rising use due to population growth, and by source limitations brought about by insufficient storage to cope with droughts (a constraint that can be expected to increase with climate change). Periodic water restrictions have been necessary in many urban areas due to drought.

These supply limitations have been brought into sharp focus in Auckland, where a projected population increase of around 1 million in the next 30 years poses critical concerns for the future with respect to water supply infrastructure to match this growth.[32] The city already relies on a take of 150,000 m^3/day (1.73 m^3/s) from the Waikato River to augment its reservoir supplies, and further consents are being sought by Watercare to increase this by 200,000 m^3/day[33]). In contrast, Christchurch is almost completely reliant on groundwater supplies from aquifers, but here too security of supply is an issue, with water restrictions having been enforced in dry years due to insufficient groundwater recharge.[34] Additionally, earthquakes pose a risk to aquifer security, increasing the potential for contamination.

To relieve pressure on supply for domestic purposes (and because of increasing water charges), there is a growing interest in various towns and cities in the storage and use of rainwater and greywater for non-potable household and commercial use. While there are perception issues to be overcome with individual landowners with respect to safety and cost (Bint, 2015), at the community-wide scale it seems economically inefficient to supply high quality potable water for non-potable uses where on-site solutions exist. The capture of roof runoff for later use on-site and the reuse of greywater both offer environmental benefits for downstream fresh waters and estuaries (Lewis, 2015). This is as much about resilience in the face of emergencies when there may be complete cessation of supply as it is about drought relief.

1.3 ECONOMIC VALUES FOR WATER

Water for agriculture

Of the allocated water in New Zealand, 81% is allocated to agricultural use, with nearly all of that being allocated to irrigation. In spite of New Zealand's relatively high water stocks, there are places and times where water shortages occur and the water resource is over-allocated.

Irrigated land in New Zealand in 2012 totalled 720,000 ha, having increased by over 50% in the decade from 2002 (Statistics New Zealand, 2013). Within New Zealand's current economic context, the economic benefits of irrigation are significant (NZIER, 2014) – from 6% of farmed area, irrigation produces 20% of agricultural GDP, there is approximately a 3-fold economic flow-on effect, and irrigation and its halo businesses can be important employers in local

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[32] Auckland Council. The Auckland Plan. http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/plansstrategies/theaucklandplan/Pages/theaucklandplan.aspx?utm_source=shorturl&utm_medium=print&utm_campaign=Auckland%2BPlan

[33] Watercare. Waikato River water: www.watercare.co.nz/about-watercare/our-services/waikato-river-water/Pages/default.aspx

[34] Christchurch City Council. Water Supply Strategy (drinking water) 2009: https://www.ccc.govt.nz/the-council/plans-strategies-policies-and-bylaws/strategies/water-supply-strategy-drinking-water-2009/

communities. Regions that dominate the irrigation statistics are Canterbury (429,000 ha) and Otago (102,000 ha), with significant areas (≥20,000 ha each) in Marlborough, Southland, Hawkes Bay and Waikato. Irrigated land is used for a variety of productive uses but nationally is dominated by dairy farming and grazing (448,000 ha) and other pastoral farming (122,000 ha), although this shows strong regional variations with, for example, viticulture being important in Marlborough and fruit and vegetables being important in Hawkes Bay.[35]

The expansion of irrigation has led to conflicts as water resources become fully-allocated. Full allocation is a function both of ensuring sustainable flows or water levels in natural waters, and also the reliability of supply given the number of other water users, as noted above. Full- or over-allocation occurs predominantly in Canterbury and Otago, but does occur in some catchments of other regions (e.g., Hawkes Bay, Waikato). The prolonged debates about the Central Plains Irrigation scheme in Canterbury and the Ruataniwha Dam project in Hawkes Bay are examples of the conflicts in use that arise from differing community values and stakeholder interests.

The increasing constraints on water availability are being addressed through efforts to increase water-use efficiency within irrigation schemes and using off-river reservoirs to harvest water during relatively high flows for use during low flows. The pressure on water resources at critical summer low-flow periods, exacerbated by overallocation in the absence of limits on takes and the intensifying effects of climate change, have prompted this interest in the use of water harvesting and storage to lower water supply risk (Aqualinc Research Ltd, 2011).

Water for livestock consumption makes up a small proportion of agricultural water use, and typically does not require consent for abstraction. It is the responsibility of regional councils to manage the use of surface and groundwater resources for livestock use in their regions. A review of water physical data from 1995-2010 found that livestock drinking-water and dairy-shed requirements increased by just under 15% (a volume increase of 35.8 million cubic metres) over this period. (Statistics New Zealand, 2010)

Water for industrial use

Industrial uses of water for processing and manufacturing either directly source water themselves through individual takes (60%), or are supplied through urban water supply systems (40%) (Robb & Bright, 2004). Industrial use of water for some industries (e.g., steel, dairy and meat processing, manufacturing) has high value returns per unit of water, with relatively low costs as the water is of sufficient quality to not require treatment prior to use (Statistics New Zealand, 2010). However, this does not consider the possible environmental costs in terms of water quality impacts and/or clean-up costs after use (also known as ‘externalities’ of industry).

Water for energy generation

Hydroelectric power is the largest source of renewable energy in New Zealand, providing close to 60% of our electricity needs (MBIE, 2016). The average annual use of river flow for hydropower between 1995 and 2010 was 159,600 x 10^6 m^3 per year or 32% of river outflow to the sea. Such use is of high economic value and is non-consumptive, though not necessarily environmentally benign (see section 4.2). Adverse environmental effects need to be minimised and, given the long-term nature of the investments in hydropower infrastructure, there is also a need to plan for the projected impacts of climate change on the reliability of the upstream water resource (Gluckman, 2013).

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[35] Irrigation statistics are based on unpublished 2014 Agricultural Production Survey data provided by Stats NZ.

Freshwater fisheries

New Zealand’s freshwater fisheries include both sport fisheries and native fisheries, some of which are commercial (Deans et al., 2016). Freshwater sports fishing (trout and salmon species) is an important feature of the New Zealand lifestyle and a significant contributor to international tourism revenues.

Long-term data on angling and usage compiled by Fish and Game NZ and the Department of Conservation Taupo fishery indicate that there are about 150,000 active fishing licenses sold each year, which represents some 1.2 million angler days (Unwin, 2009). New Zealand has an international reputation for trout and salmon sport fisheries; trout streams and lakes occur in all regions, while salmon are concentrated in the large alpine rivers of the eastern South Island. Few estimates of the economic value of sports fisheries have been undertaken, but their value can be deduced by the $54-305M economic impact estimated for the incursion of the invasive alga *Didymosphenia geminata* (“rock snot” or didymo) in rivers of the South Island (Branson, 2006).

The native fishery is centred on eels, flounder, mullet, lamprey, koura and whitebait, all of which have high cultural significance for Māori, and whitebaiting is also very popular among New Zealanders generally. There are substantial commercial fisheries for native whitebait (juvenile *Galaxias* spp.) and shortfin eel (*Anguilla australis*) and smaller fisheries for longfin eel (*Anguilla dieffenbachii*) and flounder (*Rhombosolea* spp.). The Ministry for Primary Industries (MPI) manages the eel fishery under the fisheries quota system and it has an annual export value exceeding $6M. The Department of Conservation manages the whitebait fishery, but MPI has a role in food safety. Despite the commercial market, whitebait are considered a recreational fishery and catch, and therefore the market value statistics are not available.

Freshwater aquaculture involves two main species – an export-based Pacific salmon industry based on the hydropower canals of the Mackenzie Basin, and a few small-medium koura (freshwater crayfish) farms in the North and South Islands. Trials are continuing to establish the viability of whitebait farming.

There are public, iwi and fisher concerns about the state of the freshwater fishery, the effects of habitat loss and barriers to fish migration such as dams, farm culverts and water diversion races. Eels and whitebait in particular have been showing signs of decline in some areas, with the decline in longfin eels detected at a national level. The scientific evidence related to these concerns and how to address them are described in Section 4.2 and Section 5.4 of this report.

Tourism

New Zealand’s fresh waters feature prominently in the promotional media, being used to convey New Zealand’s image and it’s desirability as a place to visit and recreate. Our largest lakes (e.g., Taupo, Wanaka, and Wakatipu) are iconic parts of the landscape and support local tourism-based economies. Our many wild and scenic rivers and streams are a draw card for tourists, with trout fishing and adventure tourism (jet boating, bungee jumping, whitewater rafting) representing part of the Pure NZ ‘kiwi experience’ (Simmons, 2013).

In fact, a substantial proportion of domestic and international tourist activities in New Zealand occur in or adjacent to fresh water (Booth & McCay, 2007). Of the 30 highest-rated ecotourism activities among international visitors in 2008, more than half are directly or indirectly dependent on freshwater ecosystems (Simmons, 2013).

Estimates of the economic value of freshwater activities by international and domestic tourists include $140M per year for river activities and $188M per year for lake activities (Patterson & Cole, 2013). These estimates were based on a limited range of activities and thus may underestimate the true value of freshwater-based tourism. In addition, extracting the value of freshwater-based activities from the total economic value of tourism to the national economy is difficult (Simmons, 2013) as it includes a large number of subsidiary contributions (e.g., recreational equipment sales and rentals, guiding services which may not be solely for us in the freshwater environment). Additional values are associated with visits to hot springs, glaciers and waterfalls.

1.4 RECREATIONAL AND SOCIAL VALUES FOR WATER

As New Zealanders, we value fresh water as an integral part of our lifestyle for swimming, boating, kayaking, rafting and fishing, and simply the scenic experience. Just as tourism thrives on our freshwater lakes and wild rivers, New Zealanders also value these for their recreation and social amenities. Rivers are central features of a number of New Zealand cities such as Whanganui (the 'river city'), Hamilton (the Waikato River) and Christchurch (the Avon), and these provide local social amenities. Hydro-lakes also provide considerable amenity value (for example, the international rowing facilities at Lake Karapiro), where our venerated Olympic athletes train.

Swimming is one of the most popular recreational activities among New Zealanders, with over a third of all adults participating at least once a year. Freshwater fishing, canoeing and kayaking together attract over 850 000 participants annually (Statistics New Zealand, 2009).

Swimming in the freshwater environment is a particularly important issue for New Zealanders, as we have become increasingly aware of the decline in quality of some of the water bodies that are valued for this purpose. A 'swimmable' water body is a place where people want to swim – a place with clear and clean water where the risk of getting sick from contaminants in the water is low.

Several factors are relevant to considering whether a particular location is suitable for swimming, including depth, temperature, current strength, visual appeal (clarity and colour), the absence of nuisance weeds or algae, and human health risks from microbial pathogens or toxic algae. The criteria relating to human health risks are the main concern for setting standards for swimmability, which unfortunately are not met for some of our rivers. This will be discussed further in Section 3 and Box 1.

1.5 INTRINSIC ENVIRONMENTAL VALUES FOR WATER

Freshwater systems have intrinsic value for their supporting and regulating functions and their capacity to sustain life. They act to filter waste, control flooding,[36] cycle critical nutrients, regulate climate and help mitigate greenhouse gas emissions through carbon sequestration. Estuaries and wetlands are particularly important in this regard, but despite the high value of these ecosystem services, only 10% of original wetlands remain in New Zealand, and many that remain require urgent remediation (Dymond, 2013).

When healthy, freshwater systems support a wide variety of living organisms (fish species, macroinvertebrates, plants). High biodiversity allows for greater adaptive responses to new challenges such as climate change (Dymond, 2013).

New Zealand's unique freshwater biodiversity has significant conservation value in the global context, and will be discussed further in Section 2.

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[36] Wetlands in particular are important for flood control. They act as natural sponges that trap and slowly release surface water, including flood waters. Vegetation in and around wetlands slows the speed of flood waters.

SECTION 2. NEW ZEALAND'S FRESH WATERS ARE UNIQUE AND VARIED

Key messages:

- New Zealand freshwater systems are naturally diverse, reflecting the range of landscapes they are located within. New Zealand rivers have a unique geomorphology and have moulded the physical landscape. For example, meandering rivers moved and deposited fertile soil in the Waikato, while the large, unstable and highly braided rivers of Canterbury created layered gravel aquifers.
- High proportions of our freshwater invertebrate, fish and bird species are not found elsewhere in the world (i.e. they are endemic), including many species that are considered threatened (notably 28% of native fish species).
- This uniqueness brings with it both international conservation responsibilities and the need for application of local research and knowledge to protect them.
- Many of these endemic species are vulnerable to changes in environmental conditions, and concerns exist about their resilience to current and future pressures.

2.1 DIVERSITY OF FRESHWATER TYPES

New Zealand's main islands span 13 degrees of latitude on the boundary of the Pacific and Australian tectonic plates, resulting in a highly diverse climate, geology and landform. This diversity in physical setting also results in a great diversity in catchments, and the waterbodies that they feed. New Zealand has 70 major river catchments – 40 in the South Island and 30 in the North Island (Biggs et al., 1990), forming 3820 lakes (Schallenberg et al., 2013), more than 413,000 km of streams and rivers (Young, 2013); geothermal and cold-water springs (Death, 2004; Scarsbrook et al., 2007), karst systems[37] (Williams, 2004), groundwaters (Fenwick, 2016); and wetlands (Johnson, 2004).

Different catchment types have different ecological, biological and physical characteristics, influenced by their climate, topography, geology and land cover (Snelder & Biggs, 2002). They differ in their vegetation– from native forest, to high-country tussock (grazing lands), to productive pasture. They differ in geology, from hard (greywacke) sediments to soft mudstones, ash and igneous rock, which impacts their water chemistry (Close & Davies-Colley, 1990). They differ in their size and their flow variability, and in the habitats that all of these factors help to create.

Our rivers provide an example of this diversity. New Zealand's rivers are generally short (the 20 longest range from 154 – 425km), so that travel times from source to the sea are often measured in days rather than months, in contrast to most continental rivers. Despite their relatively short lengths, individual rivers show considerable variability in form, processes and biota along the river continuum (Vannote et al., 1980) from typically small, shaded, cool headwater streams to larger unshaded, warmer, lowland river reaches. Land use change, mainly agricultural and urban development that removes riparian shade, tends to reduce this diversity relative to the natural state (Collier et al., 2000; Quinn, 2000).

Different rivers vary widely in flow and have correspondingly diverse morphologies, even within a region (Jowett & Duncan, 1990). For example, differences across the Waikato Region in rainfall patterns, geology and soils, produce marked differences in stream hydrology, channel form and

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[37] Karst systems are landscapes formed by the dissolution of soluble rocks, including limestone and dolomite. Karst regions contain aquifers that are capable of providing large supplies of water.

ecology over short distances. The average annual flood flows in catchments vary widely over a distance of 150 km from the Central North Island to Coromandel Peninsula (from 0·3 to 8 $m^3/s/km^2$) (McKerchar & Pearson, 1989), and this has flow-on effects for ecological processes.

Our diversity of landform, soils, climate, and land use also result in a wide range of suspended sediment and nutrient concentrations in rivers (Biggs et al., 1990). This variability means that the baseline or 'reference' conditions for measuring several aspects of water quality and biodiversity vary between rivers both within and between regions. For example, rivers and lakes associated with glaciers have a creamy look that comes from glacial sediments carried from the mountains into the water – they will always have a different appearance to rivers and lakes in non-glaciated regions and baseline sediment measures will differ. In response to the complexity of interpretation that this introduces, researchers have developed classification tools (Snelder & Biggs, 2002; Leathwick et al., 2010) that help resource managers and policy makers establish locally-relevant objectives for water quality and ecosystem health. The differences in waterbody character greatly influence management actions and their outcomes.

2.2 FRESHWATER FLORA AND FAUNA AND ASSOCIATED VULNERABILITIES

The diversity of freshwater fish species in New Zealand is low relative to other parts of the world, possibly due to the relatively short geological history of our waterways. However, 92% of our 50 genetically distinct native fish species are found nowhere else in the world (they are endemic to New Zealand) (Joy & Death, 2013) (Fig. 3). Of these species, 28% are ranked as threatened, with the majority of these occurring in the Canterbury and Otago regions where a suite of rare non-migratory galaxiids exist (Allibone et al., 2010).

Figure 3: Examples of endemic native fish: the giant kokopu and torrentfish (photos the late Bob McDowall, ©NIWA).

Native fish

Our fish fauna includes a high proportion of species that migrate between fresh water and the sea (or sometimes a downstream lake) during their life cycle (McDowall, 1998), making them vulnerable to effects of artificial barriers such as dams, flood and tide gates, and poorly installed road culverts (see Section 4.2).

Many fish species spend much of their time on the bed of rivers, and are therefore sensitive to increased siltation caused by land practices that accelerate soil erosion (Joy & Death, 2013). Several whitebait species spawn in riparian vegetation, making them vulnerable to damage to these areas (e.g., from urbanization and livestock grazing) (Hickford & Schiel, 2011).

Macroinvertebrates

Macroinvertebrates (e.g., insects, crustacea, snails, clams, worms) play a pivotal role in aquatic food webs, being consumers of primary producers (algae, aquatic plants) and being preyed upon by fish, making the measurement of their density important for assessing aquatic ecosystem health (Stark, 1993). Different macroinvertebrate taxa and species have different sensitivities to pollution, and their presence or absence also provides a qualitative biological indicator of the health of the waterway, known as the ‘macroinvertebrate community index’ (MCI) (see Section 3.1). The exact number of species is unknown, but there are around 800 described freshwater insects alone in New Zealand, of which 61 species are considered nationally vulnerable, endangered or critical (Joy & Death, 2013). A small sample of New Zealand’s freshwater macroinvertebrate diversity is shown in Figure 4.

Figure 4: Examples of native freshwater invertebrates – larvae of the mayfly *Zephlebia* (photo Brian Smith), freshwater mussel (kākahi/kāeo) *Hyridella* (photo Brian Smith), freshwater crayfish *Paranephrops planifrons* (kōura), (photo Rohan Wells, NIWA), and hydrobiid snail *Potamopyrgus* (photo Kevin Collier, ©NIWA).

The macroinvertebrates of our groundwater are very poorly known, even though this fauna appears to have a major role in maintaining groundwater quality and aquifer ecosystem functioning within the country’s huge alluvial aquifers (Boulton et al., 2008; Fenwick, 2016). Over one hundred macro-faunal species have been described, but it is likely that several hundred remain undescribed. The most abundant taxa, crustaceans, do not actively move between water systems, making them vulnerable to human activities that stress the ecosystem (e.g. deoxygenation due to excessive carbon load) because there are few or no outlying populations available for reversing or restoring biodiversity (Fenwick, 2016). Furthermore, human activities such as inter-basin transfers of water (e.g., for irrigation) may reduce biodiversity and resilience by facilitating interbreeding of otherwise genetically isolated populations and species, and initiating competitive displacement of endemic species by species arriving from newly connected catchments (Boulton et al., 2008).

Aquatic plants

Thirty-five of the 113 species of our native aquatic plants are endemic (Fig. 5). The remaining two thirds are also found in Australia, indicating natural introductions from seed transfer by migratory waterfowl or wind dispersal (Champion, 2000).

Figure 5: Examples of native charophyte plants (Photos Tracey Edwards, ©NIWA).

Braided-river birds

New Zealand's rivers provide habitat for over 80 bird species, many of which are endemic to New Zealand. Most species are migratory and only utilise the river at specific times in their life cycle, typically in their spring to early summer breeding seasons. A number of species have developed specialised adaptations that allow survival in the New Zealand river environment, including unique morphologies, and foraging and breeding behaviours (Keedwell, 2005; Hughey, 1985; Veltman, 1995).

Many of New Zealand's riverine bird species are threatened, with predation by introduced mammalian predators, loss of habitat and human, livestock and domestic pet disturbance all contributing factors (Sanders & Maloney, 2002; Whitehead, 2008; Cruz, 2013). Many braided river bird species nest on bare-gravel islands (Hughey, 1985, 1998), with higher breeding success on islands separated from river banks by wide, fast-flowing braids that act as barriers to mammalian predators (Duncan, 2008; Pickerell, 2015). Stabilized or lowered flows lead to channelization and weed encroachment (Brummer), which reduces the available nesting habitat and increases the risk of predation (Hicks, 2007).

SECTION 3. ASSESSMENT OF STATE AND TRENDS IN NEW ZEALAND FRESHWATER QUALITY

Key messages:

Freshwater monitoring in New Zealand involves regular assessments of chemical, physical and/or biological conditions at approximately 1000 river sites and 100 lake sites, as well as standardized groundwater monitoring at around 1000 bores. Despite the enormous effort in freshwater monitoring there is a lack of systematic monitoring of river and lake fish, wetland ecology and water quality, and groundwater macro-fauna.

Data from 2009-2013 indicate the following about the state of New Zealand rivers:

- Water quality and ecosystem health (as indicated by measurements of nutrients, *E. coli* and macroinvertebrate (MCI) scores) generally worsen across land-cover classes in the following order: natural, exotic forest, pastoral, urban.[38]
- Ecosystem health (as measured by median MCI scores) is generally designated as 'excellent' at sites in the natural class, 'good' in the pastoral and exotic forest classes; and 'poor' in urban class.
- Median water clarity in the natural land class was almost twice that in other land-cover classes.
- The minimum acceptable state for *E. coli,* as defined by the current National Policy Statement grading for primary contact (i.e., swimming) was exceeded at times at all urban sites and the majority of pastoral sites.

Analyses of 10-year trends from 2004-2013 indicate improvements for many rivers in median concentrations of total phosphorus, dissolved reactive phosphorus, and ammonium nitrogen (NH_4-N), and in visual clarity and *E. coli*, but others still show progressive deterioration. There were more sites showing degrading trends in MCI scores (indicating declining ecological health) than the number showing improvement, and many sites showed degrading trends in nitrate-nitrogen (NO_3-N).

3.1 MONITORING PROGRAMMES

The Ministry for the Environment (MfE), in association with Statistics New Zealand, is tasked under the Environmental Reporting Act 2015 to report regularly on the state of the New Zealand environment. This includes reporting on the pressures (human activities and natural factors) that create the environmental state, and the impacts of the state (and changes to it) for New Zealand's environment, economy and society. Fresh water is among five environmental domains subject to regular monitoring and reporting. The next freshwater domain report ("Our fresh water") is due for release in late April 2017 and will contain the latest data on states and trends. The information provided here draws upon the same base data.

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[38] Land-cover classes are based on the New Zealand River Environment Classification (Snelder et al., 2004). The 'natural' class includes indigenous forest, tussock and scrub, and bare ground in mountainous catchments, 'exotic' means non-native planted forestry, and 'pastoral' refers to all intensive agricultural use and includes pasture, cropping and horticulture. A river segment is classified as exotic forest or natural if those categories account for the largest proportion of the upstream catchment area, unless pastoral land exceeds 25% of the catchment, in which case the segment is classified as pastoral, or urban land exceeds 15 % of the catchment, in which case the segment is classified as urban.

Data on the freshwater domain comes from a variety of sources. All of NZ's Regional and Unitary councils, complemented by NIWA and GNS Science, are involved in monitoring water quality in rivers (over 1000 reaches), lakes (around 100) and groundwater (around 1000 bores). Some councils also monitor wetlands, but seldom for their water quality. Despite an enormous effort there is a lack of systematic monitoring of river and lake fish, wetland ecology and water quality, and groundwater macro-fauna, and no overall nationally integrated water quality monitoring programme that deals with the need for representativeness and other design criteria. Thus there is a risk of bias in reporting, and the gaps place some limits on the conclusions that can be drawn about freshwater state and trends.

Monitoring variables

Nationally there is no agreed complete set of monitoring variables covering all national and regional monitoring and reporting requirements that all councils are committed to undertaking. However the National Objectives Framework (NOF) for the National Policy Statement for Freshwater Management 2014 (NPS-FM) (Ministry for the Environment, 2014) lists some attributes that should be monitored, and there is a suite of physical-chemical (and where appropriate biological) variables that are typically monitored and reported. The most important of these variables are described in Table 1. The complex topic of assessing 'swimmability', including threshold levels for monitoring *E. coli* and toxic algae, are discussed in Section 3.2 and Box1.

Table 1. Common monitoring variables used to assess freshwater quality and ecosystem health

Monitoring variable	Comment
Physical-chemical variables – measures of water quality/stress on system	
Temperature	Affects many physical, biological and chemical processes, e.g. the amount of oxygen that can be dissolved in water, the rate of photosynthesis of plants, metabolic rates of animals, and the sensitivity of organisms to toxic wastes, parasites and diseases.
Acidity measured by pH	Aquatic life protection; pollution indicator; acidification. pH level can be affected by industrial waste, agricultural runoff or drainage from unmanaged mining operations, and natural levels of humic acids from decomposing plant material.
Dissolved oxygen	Essential for respiration of aquatic life. Decomposition of organic matter consumes dissolved oxygen that is needed by fish and other animals Low oxygen results in asphyxiation of respiring organisms.
Salinity	Unnatural change in salinity can alter the biotic composition and biodiversity of a water body.
Nitrate-nitrogen (NO_3-N)	Nitrogen source used by algae, cyanobacteria and macrophytes. At high concentrations, nitrate be toxic to aquatic life and degrade potable supplies. Sources include runoff containing animal wastes and fertilizers.
Ammonium-nitrogen (NH_4-N)	Nitrogen source used by algae, cyanobacteria and macrophytes. At high concentrations, ammonia can be toxic to aquatic life and degrade potable water supplies. Generally present at lower concentrations than nitrate-nitrogen.
Total nitrogen (TN)	Nitrogen source used by algae, cyanobacteria and macrophytes. TN includes NO_3-N and NH_4-N, which are highly bioavailable, and organic and particulate forms that are converted to NO_3-N and NH_4-N by bacteria and animals.
Dissolved reactive phosphorus (DRP)	Phosphorus source used by algae, cyanobacteria and macrophytes. Principal pathways to water bodies are surface runoff and sediment erosion.
Total phosphorus (TP)	Phosphorus source used by algae, cyanobacteria and macrophytes. TP includes dissolved inorganic forms that are highly bioavailable, and organic and particulate forms that are converted to dissolve inorganic forms by bacteria and animals.
Lake-bottom dissolved oxygen (DObottom)	A measure of the trophic state of lakes that stratify during summer; low DObottom concentrations is generally associated with high primary production and ecosystem respiration.
Visual clarity	Visual clarity is closely correlated to light penetration and suspended sediment concentration. Reduced light penetration and elevated suspended sediment reduce plant growth rates, inhibit fish feeding, and degrade, aesthetic quality and recreational values.
Electrical conductivity	Surrogate for total dissolved solids or salinity – an indicator of saltwater intrusion in coastal aquifers, and the degree of geochemical weathering, and/or the level of inorganic contaminants.

Table 1 (continued). Common monitoring variables used to assess freshwater quality and ecosystem health

Monitoring variable	Comment
Biological variables – measures of ecological health	
Periphyton biomass in rivers	A measure of abundance and composition of benthic river algae (includes didymo); affected by nutrient inputs. Assessed based on chlorophyll-*a* concentration
Phytoplankton biomass in lakes	The abundance of planktonic algae and cyanobacteria in a lake water column; affected by nutrient inputs, light, temperature, circulation and grazing. Assessed based on chlorophyll-*a* concentration
Macroinvertebrate community index (MCI)	A measure of the composition of the invertebrate animal community on the river bed, providing an overall indication of general river health. MCI scores are calculated using tolerance values for the macroinvertebrate taxa that are present in benthic samples.
Trophic level index (TLI)	Used to classify lakes into trophic classes (e.g. oligotrophic, eutrophic) based on chlorophyll-*a*, total nitrogen and total phosphorus concentrations, and visual clarity. TLI increases with increasing eutrophication. Serves as a measure of the overall health of NZ lakes.
Lake submerged plant indicator (LakeSPI)	A simple assessment tool based on native and invasive plant presence and the depths at which these plants occur, reflecting environmental conditions of a lake over time. Captures the status of native vegetation, the impact from invasive weeds, and overall ecological condition of the lake.
Public health risk indicators	
E. coli	Indicator of faecal microbial pollution and thus risk of exposure to faecal pathogens and associated risk of infectious disease for people swimming in or drinking the water
Cyanobacterial mats	Can include the cyanobacterium *Phormidium*, which can produce neuro-muscular toxins (anatoxins), mainly in rivers
Planktonic cyanobacteria	Photosynthetic bacteria. Some species produce toxins
Pesticides	Potentially toxic pesticides are monitored in groundwater and concentrations assessed against maximum allowable values (MAVs)

3.2. ASSESSMENTS OF RIVER STATE AND TRENDS

The most recent national-scale assessment of river water quality and ecological state and trends was carried out in 2015, using data for the period 2009-2013 for state analyses and 2004-2013 for analyses of 10 year trends (Larned et al., 2016). The data came from several hundred monitoring sites, which were grouped by climate class and catchment land cover class. Four predominant land cover classes were used: urban, pastoral (livestock grazing lands), exotic forest (e.g., pine plantations) and natural (a composite of native forest, scrub, tussock and wetland). Land-cover classes are based on the New Zealand River Environment Classification (Snelder & Biggs, 2002).

The state analyses revealed that the *general patterns* of river water quality were strongly related to the catchment environment – water quality and ecosystem health vary with the topography and land cover of catchments; urban and pastoral land-cover are typically associated with the poorest water quality, and natural land cover is typically associated with the best water quality.

Concentrations of nutrients and *E. coli* increased, and macroinvertebrate community index (MCI) scores and visual clarity decreased, with increasing proportions of high-intensity agricultural and urban land cover in the upstream catchment (Larned et al., 2016). Generally, sites in catchments dominated by native vegetation had better scores on *all metrics* (i.e. better water quality) compared with exotic forests, pasture, and at the other end of the spectrum, in urban areas. In the discussion below, these general patterns are assessed within the context of ecosystem health guidelines and measures of human health risk.

Measures of ecological health

Ecological health in water bodies is partially a function of inputs into them, such as nutrients from soils and contaminants and from agricultural, urban and industrial activities. Thus ecological health varies widely depending on human activities on land within the catchments that feed the water bodies.

In a recent national assessment (Larned et al., 2016), median concentrations of nutrients (NO_3-N, NH_4-N, TN and TP) increased across land-cover classes in the following order: natural, exotic forest, pastoral, urban. Median *E. coli* concentrations also increased across land-cover classes in the same order, and median MCI scores decreased in the same order. The median visual clarity was best in the natural class and uniformly lower in the other land-cover classes. ANZECC trigger values,[39] which are intended to alert water managers to concerns about potential adverse ecological effects (ANZECC, 2000), were exceeded in the urban land-cover class for all nutrients (based on median concentrations). In the pastoral and exotic forest classes, median dissolved reactive phosphorus (DRP) concentrations exceeded the ANZECC trigger values in some upland and some lowland sites. Median NO_3-N concentrations rarely (less than 1% of sites) exceeded toxic levels as defined in the NPS-FM, (Ministry for the Environment, 2014) whilst those for NH_4-N were always below toxic levels. The fundamental ecosystem health issue is whether the periphyton/phytoplankton growth is excessive based on elevated DIN and/or DRP – such growth occurs at levels much lower than the toxicity limits, and varies considerably between catchments. This presents difficulties for ensuring appropriate local/regional responses, and in setting national limits.

Measures of human health risk

The main concern for human health relating to water quality in freshwater systems is microbial contamination. In some waterbodies, toxins produced by cyanobacteria can also pose a health risk from contact or ingestion of toxins (see below – *Toxic algae*).

Microbial contaminants

The microbial test used to assess possible pathogen presence in New Zealand freshwater systems is detection of *Escherichia coli* (*E.coli*), which serves as a cost-effective indicator of contamination from animal or human faecal sources. Quantitative risk assessments have been used to determine levels of *E. coli* that correspond to a given risk level for infection by pathogens such as *Campylobacter*, *Cryptosporidium*, *Giardia*, Salmonellae and hepatitis A that are likely to be present if the water is contaminated with faecal matter.

In a nation-wide study of faecal pathogens and faecal indicators at 25 recreational freshwater sites in 1998–2000, *Campylobacter* was the most widely occurring pathogen, being present in two-thirds of all samples and sometimes at high concentrations (Till et al., 2008). The New Zealand microbiological water quality guidelines (Ministry for the Environment, 2003) were derived from this study and are based on the risk of *Campylobacter* infection, the relationship between *Campylobacter* and the more easily measured indicator *E. coli*, and the degree of statistical precaution deemed appropriate to apply. The guidelines in relation to the suitability of a waterbody for swimming or other immersive activities are discussed below.

Toxic algae

Cyanobacteria are a natural feature of aquatic ecosystems. However excessive nutrient enrichment can cause proliferations of planktonic (floating) cyanobacteria in lakes (Wood et al., 2016) and benthic (bottom covering) cyanobacterial mats in rivers (McAllister et al., 2016). Cyanobacterial blooms have ecological effects (including reduction of dissolved oxygen in the water), and when widespread can make the waterbody unappealing for swimming. But most

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[39] **ANZECC trigger values** are values for water monitoring indicators that denote marginal water quality for ecosystem health. If the median value of an indicator for a particular site exceeds the trigger value, then it is intended to "trigger" a response on the part of water managers, which might be to initiate special sampling or carry out an investigation of reasons for the degraded water quality.

importantly, they can produce toxins (poisons) that are dangerous to humans and animals (Puddick et al., 2014).

There has been an increase in the reported distribution, intensity and frequency of proliferations of some toxic species of the mat-forming toxic cyanobacteria *Phormidium* in some New Zealand rivers over the last decade. *Phormidium* proliferations have been observed in over 100 North and South Island rivers since 2009, primarily rivers on the east coast (McAllister et al., 2016). These proliferations have been associated with reductions in river flows, increases in dissolved inorganic nitrogen concentrations and decreasing concentrations of dissolved reactive phosphorus. Blooms also occur in association with higher loads of phosphorus-enriched fine sediment, and there is evidence that *Phormidium* can access biologically available phosphorus from suspended sediment in rivers otherwise low in this nutrient (Wood et al., 2015). Periodic high-flow events are thought to be needed to clear periphyton proliferations, including *Phormidium* mats (Clausen & Biggs, 1997; Heath et al., 2014), but more research is needed to fully understand the dynamic interactions that influence toxic algal proliferation.

Assessing suitability for swimming

A range of characteristics needs to be considered when assessing a water body's suitability for swimming – e.g., depth, temperature, current strength, visual appeal (clarity and colour), the absence of nuisance weeds or algae, and human health risks from microbial pathogens or toxic algae. Detection of *E. coli* in a water body signals the likelihood that harmful water-borne pathogens such as *Campylobacter*, *Cryptosporidium* oocysts, *Giardia* cysts, hepatitis A viruses and Salmonellae may also be present. Such pathogens in the water can enter the body by ingestion, or through ears, nasal passages, mucous membranes or cuts in the skin, and can cause gastrointestinal illness, respiratory symptoms, or more harmful diseases like hepatitis A. Microbial pathogen contamination is a concern in both rivers and lakes, whilst the presence of toxic cyanobacteria is primarily of concern in lakes.

There are two distinct components to assessing the suitability of a site for swimming – grading and surveillance. Grading assesses the general suitability of a site for swimming over the long term (and uses long term monitoring to determine that) whilst surveillance assesses the suitability of a site for swimming in the short-term (is it OK to swim today?). The *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*, established by the Ministry for the Environment (MfE) and the Ministry of Health (MoH) in 2003 (Ministry for the Environment, 2003) included both grading and surveillance, whilst the NPS-FM 2014 considered only grading. The proposed changes to the NPS-FM included in the consultative 2017 Clean Water package (Ministry for the Environment, 2017) brings both grading and surveillance (in its Appendix 5) together again. The surveillance criteria in the MfE/MoH 2003 guidelines and the Clean Water 2017 proposal are numerically identical. The proposed changes to how grading is assessed are described in Box 1.

Under the surveillance criteria (e.g., see Clean Water, Appendix 5), during the bathing season sampling should occur at least weekly, and authorities should warn against swimming if the *E.coli* concentration in rivers and lakes reaches or exceeds 540 per 100 ml. Such a sampling result indicates that the water, at that time, has exceeded the upper level of contamination that is considered acceptable for swimming – when the risk of infection from full immersion may be more than 5% (Till et al., 2008; McBride, 2011, 2016). To ensure that risk remains low, the surveillance criteria also specify that if *E.coli* concentration on any given day exceeds 260 per 100 ml, daily sampling is required until the concentration falls below 260.

Under the grading criteria, whether a river is considered ‘swimmable’ depends on how often the 540 *E. coli* / 100mL threshold is exceeded, and what the average (median) *E. coli* level for that river is, which affects the overall level of risk. Setting a very low median value has major implications for ensuring management of the river, as it means that at least half of the time there can be only negligible risks of contamination and this requires attention to diffuse and focal points of potential contamination. Knowing these values allows a calculation of the percentage of time that the river presents a risk of infection with *Campylobacter*, as indicated in Table 2. Applying a threshold value of 540 *E.coli* /100mL is considered a precautionary approach to the inherent uncertainties in the calculations – allowing for a high margin of safety. Water bodies that are considered ‘swimmable’ have *E. coli* concentrations below this level most of the time, so the actual risk of infection averaged over a year in such water bodies is significantly lower than 5%, even in the worst case scenario (see Table 2).

Table 2. Suggested swimmability ratings in the proposed amendments to the National Policy Statement for Freshwater Management (http://www.mfe.govt.nz/fresh-water/national-policy-statement), based on *E. coli* threshold exceedance frequency and median concentration, as well as estimated risks

Category	Percentage of exceedances over 540 cfu/100mL	Percentage of exceedances over 260 cfu/100mL	Median concentration (cfu/100mL)	Description of swimmability – risk of *Campylobacter* infection (based on *E. coli* indicator)
Blue / Excellent	<5%	<20%	≤130	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk). Less than 5% of the time, the estimated risk is ≥50 in 1000 (>5% risk) **Overall risk across all time is (not taking season or weather into account) is approximately 1%**
Green / Good	5-10%	20-30%	≤130	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk). 5-10% of the time the estimated risk is ≥50 in 1000 (>5% risk) **Overall risk across all time is <2%**
Yellow / Fair	10-20%	20-34%	≤130	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk). 10-20% of the time the estimated risk is ≥50 in 1000 (>5% risk) **Overall risk across all time is <3.5%**
Orange / Poor	20-30%	>34%	>130	20-30% of the time the estimated risk is ≥50 in 1000 (>5% risk) **Swimming not recommended**
Red / Very poor	>30%	>50%	>260	For more than 30% of the time the estimated risk is ≥50 in 1000 (>5% risk) **Swimming strongly advised against**

In many rivers where monitoring occurs, the 540 *E. coli* / 100mL threshold is exceeded periodically, particularly at urban and pastoral sites. In recent assessments, all monitored urban sites and approximately 90% of pastoral sites exceeded this safety threshold at some times. In addition, close to half of exotic forest sites and a third of natural sites also exceed this value at times (Larned et al., 2016). High *E. coli* concentrations tend to occur during storm flows (McKergow, 2010), but can also be elevated during summer if animals have unrestricted access to streams (i.e., no fencing), because increased heat stress attracts animals to water, and reduced streamflow provides less dilution of faecal inputs (Donnison et al., 2004; Bagshaw, 2008). Human faecal contamination of water bodies can occur via poorly treated sewage or septic tank systems, or during prolonged or heavy rain when sewerage systems cannot cope and they overflow into stormwater systems. Guideline exceedance in streams classed as natural and exotic forest may be due to the influence of small areas of pastoral land use within the stream catchments or to faecal inputs from feral animals (e.g., pigs, deer, possums) and birds (Donnison et al., 2004). Because of the heightened health risks from runoff and stormwater, people are often advised to avoid swimming for 48 hours after prolonged or heavy rain.

According to the swimmability categories outlined in Table 2, currently 72% of New Zealand rivers and lakes meet at least 'fair' (yellow, or C grade) criteria, in that they pose a low overall risk to swimmers. The government announced its goal to improve this statistic to 90% in the recently released *Clean Water* package (Ministry for the Environment, 2017). Making rivers safe for swimming in intensively farmed areas that do not currently meet proposed swimmability guidelines will require a commitment to changing farming practices and implementing mitigations. After these changes are made, there may still be times (e.g., after rains) when it may not be wise to swim.

An update of the 1998-2000 national microbiological water quality study (Till et al., 2008) seems timely given recent changes in microbiological techniques (for source attribution and virulence), our understanding of *Campylobacter* dose-response, and changed land use practices. Additionally, it seems an opportune time to review the basis for designating a waterbody suitable for swimming. By fostering a more precise and accurate understanding of water quality beyond simply 'swimmable' or not, we are in a better position to manage and restore freshwater resources more effectively. It is important to assess the somewhat outdated binary swimmable/non-swimmable classification, and working towards a more nuanced approach that considers not only the levels of bacterial contamination (given new methodologies) but also the related issue around how often those levels are exceeded. The government's *Clean Water* package appears to take such an approach (see Box 1).

BOX 1 – Understanding the standards

Microbiological standards

The current NPS 2014 has an A to D grading for *E.coli*, with a National Bottom Line that requires waters to be suitable for wading (bottom of the C band), numerically defined as a median of 1,000 *E.coli* per 100 millilitres. While this is the mandatory National Bottom Line, the NPS 2014 also describes a minimum acceptable state for swimming as a 95th percentile of 540 *E. coli* per 100 ml (i.e., *E. coli* levels must be below 540 in 95% of the samples). Under the NPS, where regional councils, in consultation with their communities, choose to have waters suitable for swimming then this is the test that must be met. Unfortunately the NPS is deficient in that it provides no direction on sampling protocols and this is very important in determining grading – particularly whether *E.coli* levels during high flow events and/or in winter, when swimming is unlikely, should or should not be included in the analysis.

In the proposed amendments to the NPS, contained in the 2017 Clean Water package, there is a move to 'require councils to identify where the quality of lakes and rivers will be improved so they are suitable for swimming more often', and an associated target to make 90% of rivers swimmable by 2040. To enable enactment of these amendments, and to overcome the deficiencies in the current NPS, the Clean Water package proposes a more nuanced grading system.

A key feature of this more nuanced system is to describe the distribution of *E. coli* counts seen over time at a particular site. In all cases to be swimmable, half the measures must be below 130 per 100 ml – that is a level of *E. coli* where the risk of infection less than one chance in 1000. The effect of this requirement is to ensure management that ameliorates continual or repeatable sources of contamination. The standards then define the frequency and level to which any measures can exceed this median cut-off of 130. This means that at least 50% of the time, even in rivers only graded as 'fair' (minimum acceptable swimming grade), there is a very low risk to swimmers.

(*continued next page*)

BOX 1 (continued)

Two additional risk levels are identified in the proposed amendments: 260 per 100ml, where the risk of infection is estimated to be 1:100, and 540 per 100ml, where the estimated infection risk reaches the level of 1:20. The *E.coli* level must not exceed this concentration more than 5% of the time for A grade (blue), 10% of the time for B grade (green), and 20% of the time for C grade (yellow) swimmable ratings. Both the median criterion and the '540 exceedance' criterion must be met – so the poorest of these determines the grading. Usefully, the proposed amendment also provides direction on how the grading is to be determined - using a minimum of 100 samples, collected on a regular basis regardless of weather conditions, over a maximum of 10 years. The Clean Water Package proposes this 90% target will be applied to rivers that are deep enough to swim in, and lakes with perimeters larger than 1500m.

Direct comparison between the NPS-FM and the proposed amendments in the Clean Water package requires caution as the measures are different, but it seeks to:

- improve the minimum expectation for microbial quality, from an *E. coli* median of 1000 per 100ml in the current NPS to 130 per 100ml, for 90% of freshwaters.
- provide clear direction that requires grading for swimmability to be determined from samples collected on a regular basis regardless of weather conditions – i.e., it will include samples from high flows. Given that such samples may be expected to have transient high *E. coli* levels, this requirement introduces a stringency that is potentially absent from application of the NPS-FM (where no direction on sampling protocols is given).

A consequence of this change in protocol is that the Clean Water (2017) proposal might initially appear to be less stringent than the NPS-FM. However, because of the multiple criteria employed, comparability is more nuanced. Certainly there is a reduction in stringency for dealing with *extremes* – the high *E. coli* concentrations that tend to occur at times that would be unsuitable for swimming in the first instance (i.e. within 48 hours after heavy rains when swimming is not recommended). For example, the minimum acceptable state for swimmability (bottom of the C or yellow band) in the Clean Water proposal allows exceedance of 540 *E. coli* per 100ml for up to 20% of the time, whereas the NPS-FM allows that for only 5% of the time. For its highest grading, the Clean Water package also has requirements that appear less stringent than that in the NPS-FM: the Clean Water A grade (blue) allows 5% exceedance of 540 *E. coli* per 100ml, whereas the NPS-FM A band allows a 5% exceedance of less than half that value (260 per 100ml). Importantly, however, the Clean Water package has a median requirement for swimmable grading as well (all sites must be below 130 half of the time), which the NPS does not have. Depending on the distribution of the data at a particular site, this is likely to be the requirement that is most constraining to the site's swimmable grading under Clean Water (2017).

The overall effects of these changes, and in particular the proposed monitoring regime and median requirements, are designed to force overall and progressive improvements in the safety of the fresh water estate for swimming.

Toxic cyanobacteria standards

In lakes, the criteria for swimmability consider the potential for toxins from cyanobacteria (often called blue-green algae) to be present. Assessments of lake state and trend for toxic algae are based on total cyanobacterial biovolume. If potentially toxic cyanobacteria are present, the threshold level for contact recreation (e.g. swimming) is >1.8 mm^3/L. If no known toxin-producing species are detected, a level up to 10 mm^3/L is considered acceptable (Ministry for the Environment & Ministry of Health, 2009). This guideline is based on the assumption that all species of cyanobacteria in the lake are toxic, which might not be the case. This is precautionary and is likely to suggest a higher risk in some situations than actually exists. (Wood, S. et al., 2014).

These threshold values were designed to trigger a series of management actions (following a three tier 'alert-level framework') when there is a single measured exceedance at a monitored water body. However, as with *E. coli* measurements, lakes and lake-fed rivers are graded for 'swimmability' based on how often the levels are exceeded. A lake that is graded as 'fair' for swimming (state C in the NPS-FM) must have a cyanobacterial biovolume below 1.8 mm^3/L at least 80% of the time (using a minimum of 12 samples collected over three years). This level poses only a low risk of health effects from exposure during swimming or other recreational activities on and in the water. Lakes graded as 'A' (very good for swimming- corresponding to the 'blue' category in the NPS-FM) have levels ≤0.5 mm^3/L, a level posing no more risk than natural (pristine) conditions.

Invasive Algae

Proliferations of the invasive alga didymo currently occur in most of the major South Island catchments. Didymo blooms were first noted in New Zealand in 2004 (Kilroy & Unwin, 2011), initially spreading from the Mararoa and Buller Rivers using human vectors (e.g. on fishing gear, footwear, or boats taken to different rivers and catchments). Although eradication of didymo from the South Island is believed to be impossible, there have been no reports to date of didymo in North Island rivers. This has been helped by public awareness campaigns, but the different physico-chemical conditions in North Island rivers may also be an important factor (Vieglais, 2008; Bothwell et al., 2014).

Fish populations

National-scale trends in the occurrence of fish in New Zealand's rivers show decreasing trends in Canterbury galaxias, and increasing trends in shortfin eel. The decreasing trend in Canterbury galaxias is consistent with its conservation status of "at risk – declining" (Goodman, 2014). Increases in the occurrence of shortfin eels suggest that populations are stable and/or growing, which warrants their status of "not threatened". For half of the species assessed in trend analysis, the trend direction could not be inferred with confidence. In some cases, this may have indicated stable populations, but in most cases, the data were insufficient to make strong inferences. Updated trend data is expected in the upcoming freshwater domain report by MfE and Stats NZ, to be released at the end of April 2017.

An assessment of changes in fish communities in New Zealand rivers using data from the New Zealand Freshwater Database from 1970 to 2007 that included over 22,500 sites showed that on a national scale, the health of fish communities declined overall (and most rapidly since 2000), with the largest declines being in rivers in pastoral or urban catchments. Exotic forest sites showed no significant change and there was a significant improvement at native forest and scrub sites (Joy, 2009).

Flow trends

The natural flow regimes of many New Zealand rivers have long been altered by human activities. Both Māori and then particularly European settlers influenced river hydrology and hence flow regimes by large-scale clearing of scrub or forest, markedly increasing runoff from the land and thus increasing floods and low flows. Over recent decades, flows of foothill catchment or spring-fed rivers and streams have declined substantially, particularly in lowland areas on the eastern sides of both islands. These declines are due to a combination of factors, including over allocation of surface water (e.g. the Ashburton River) and groundwater (e.g. some aquifers in the Wellington region), wetland drainage and land cover change, as well as climate variability, and probably also climate change (McKerchar, 2010). In combination these conditions have devastating effects on some river flows; for example, Canterbury's Selwyn River is effectively now dry at a once popular swimming and fishing area, Coe's Ford. Larger mountain catchment rivers have sustained their flows, although impoundment for hydro-electricity generation has reduced small to medium flood flows on the Waitaki, Clutha and Waikato rivers, and irrigation abstraction has also modified flow regimes, for example on the Rangitata River (Duncan & Woods, 2013).

3.3. ASSESSMENTS OF LAKE STATE AND TRENDS

Lakes in New Zealand show a wide variation in water quality and ecosystem health, with alpine, glacial and volcanic lakes often pristine and most lowland lakes being in poor condition. It is important to note, however, that for all of the core water quality variables, a wide range of values have been measured in lakes across New Zealand (Larned et al., 2016). We have some very pure and stunningly clear lakes that support a diverse natural ecology but we also have lakes that are highly nutrient enriched (eutrophic), turbid, or ecologically-compromised. For example, the highest and lowest median visual clarities reported from regularly monitored lakes were 15 m in Lake Taupo and 0.1 m in Te Waihora/Lake Ellesmere (Larned et al., 2016). The highest visual clarity ever reported for natural fresh water in the world was in Blue Lake (Nelson Lakes National Park), with a maximum clarity of 82 m (Gall et al., 2013).

A national assessment of lake state and trends for the period 2009-2013[40] (Larned et al., 2016) found that riverine lakes, ICOLLS (intermittently closed and open lagoons and lakes) and dune lakes generally had elevated chlorophyll, nitrogen and phosphorus concentrations and low clarity, indicating an elevated trophic state. Invasive plants compromise the condition of one-third of monitored lakes. Although the number of lakes included in the assessment was small relative to the total number of lakes in New Zealand, the monitored lakes included those that warrant the most monitoring effort (e.g. Taupo, Rotorua, Ellesmere).

An analysis of national-scale relationships between lake water quality and catchment land cover (Abell et al., 2011) showed that, as for rivers, both total nitrogen and total phosphorus concentrations in lakes increased with increasing proportions of high intensity agricultural and urban land cover in their catchments. These national scale relationships between lake water quality and land cover have been corroborated by regional studies (e.g., (Paul, 2012)).

Lake water quality and trophic state

Eutrophication is the enrichment of natural waters with nutrients, leading to excess plant and algal growth. Gradual nutrient enrichment is a natural process of lake aging, whereas eutrophication is the same process greatly accelerated by increased nutrient inputs, usually from land development. While eutrophication degrades lakes for some purposes, some values can be sustained. For example, Te Waihora/Lake Ellesmere has undergone significant ecological transformation and has even been described as ‘biologically dead’, yet it sustains a particularly diverse, species-rich bird habitat and very important native flora, as well as New Zealand’s largest commercial eel fishery.

The Trophic Level Index (TLI) is a measure of a lake’s trophic state, calculated based on total nitrogen, total phosphorus, phytoplankton chlorophyll concentrations, and water clarity (see Table 3). The TLI has been used as an indicator of the overall water quality of New Zealand lakes. Not surprisingly, deep lakes in mountainous areas of New Zealand generally have lower TLI scores (better water quality) than those in lowland pastoral or urban catchments. An assessment of 65 lakes between 2009 and 2013 found a median TLI score of 3.6, and for those lakes where a trend could be detected, there were more lakes showing worsening conditions than showing improving conditions (Larned et al., 2015). TLI scores have been improved by restoration efforts in some lakes, such as Lake Brunner in the West Coast region of the South Island, which has been impacted by dairy intensification. Reduction of nutrient inputs has occurred through riparian planting, fencing of streams, and implementation of nutrient management plans on farms, which have contributed to reduced (improved) TLI scores (Hamilton, Collier, et al., 2016; Ministry for the Environment, 2016).

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[40] Based on data from between 20 and 84 lakes that met the analysis criteria.

Table 3. Lake water quality ratings based on Trophic Level Index (TLI)

Rating	TLI score	Description
Very good	>2	Microtrophic: very low levels of nutrients and algae; very high water clarity
Good	2-3	Oligotrophic: low levels of nutrients and algae; high water clarity
Average	3-4	Mesotrophic: moderate levels of nutrients and algae
Poor	4-5	Eutrophic: elevated levels of nutrient and algae. Water green and murky
Very poor	>5	Hypertrophic: saturated with nutrients, very high algal growth, very low water clarity

Lake submerged plant indicator (Lake SPI)

The ecological health of New Zealand lakes has also been assessed using the LakeSPI, which reflects habitat degradation for macrophytes (large submerged or floating water plants and algae) but also incorporates the degree of impact from alien weeds. A national assessment of submerged plants in 155 lakes surveyed between 2005 and 2013 indicated good to excellent ecological conditions in 33% of the lakes, and poor ecological conditions in 37% of the lakes (Schallenberg et al., 2013). Half of the lakes in agricultural catchments had poor ecological condition or were unvegetated.

Toxic cyanobacteria

The presence of cyanobacterial blooms in lakes poses a risk to people and animals who contact or consume the water, because they can produce harmful cyanotoxins with a range of different effects including neurotoxicy (anatoxins and saxitoxins), hepatotoxicy (microcystins, nodularins and cylindrospermopsins) and dermatoxicity (lipopolysaccharides and aplysiatoxins) (Codd et al., 2005).

Blooms are typically green in colour, and can form scums on the water surface, particularly at the lake edge. Growth of cyanobacteria is highest during periods of warm temperatures and sunlight – so they generally occur in the summer months.

Assessments of toxic algal state and trends in lakes are based on total cyanobacterial biovolumes. Although this is an important indicator of the safety of a lake for swimming and other contact recreation, comprehensive data are lacking on the extent of toxic algae proliferation in most New Zealand lakes (Wood et al., 2016). Councils monitor lakes with a focus on recreational sites, but many lakes are not routinely monitored for cyanobacterial blooms. Modelling has been used to some extent to predict algal-bloom promoting conditions, mainly in relation to lake trophic state (Snelder et al., 2016). It is desirable that cyanobacterial monitoring be included with other variables at all monitored sites.

3.4. ASSESSMENTS OF GROUNDWATER STATE AND TRENDS

Around 80% of the fresh water in New Zealand is groundwater, found in underground reservoirs known as aquifers. Aquifers are formed by layers of porous rock, sand or gravel through which groundwater flows, and from which water can be extracted in sufficient quantities for human use. There are aquifers underlying around a quarter of the land surface of New Zealand, predominantly in the North Island and in Canterbury.

Groundwater chemistry

Groundwater chemistry data for 2004-2013 from sites in the National Groundwater Monitoring Programme (NGMP) were used in a recent state and trend analysis (Moreau, 2015). The most common trends in groundwater contaminants were increasing concentrations (i.e., degrading conditions) in nitrate-nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), dissolved reactive phosphorus (DRP), iron, and manganese.

The state analysis indicated that gravel aquifers had higher NO_3-N concentrations and lower NH_4-N and DRP concentrations than sand aquifers. The ANZECC nutrient trigger values (levels that signal that a response from water managers is required) were exceeded for NO_3-N at over 60% of the NGMP sites. NH_4-N and DRP also increased at many sites. The maximum allowable values (MAV) under the *Drinking-water Standards for New Zealand* (Ministry of Health, 2008) were exceeded for NO_3-N at 2% of NGMP sites, and the guidelines were exceeded for NH_4-N at 5% of sites, iron at 23% of sites, and manganese at 41% of sites.

In approximately 40% of the NGMP monitoring sites, the groundwater was strongly affected by human activities. These 'impacted sites' had elevated NO_3-N concentrations, without the elevated iron and manganese concentrations associated with rock dissolution. Most of the impacted sites were in the Waikato, Wellington and Southland Regions.

Microbial contamination

There has been a general assumption in New Zealand that 'secure' groundwater sources of public water supply are not affected by microbial contamination. Although soil layers above contained aquifers provide a barrier to the contamination from human and animal activity on the surface, groundwater can still be contaminated by microbial pathogens from poorly constructed wells, septic tanks or offal pits.

Information is limited on the extent of microbial contamination in individual wells, but the recent campylobacteriosis outbreaks at Darfield and Havelock North, and earlier outbreaks (Ball & ESR, 2006) suggest that the preparation and implementation of water safety plans for drinking-water systems fed by subsurface groundwater sources need to be re-assessed. A clear understanding of the potential sources of contamination, separation distances and potential migration pathways to bores and wells is required to help identify increased risks to groundwater sources, and how they can be managed (e.g., through appropriate controls on land-use activities and discharges around water-supply bores) (Callander et al., 2014).

Pesticides

The latest survey of pesticides in groundwater, carried out in 2014-15 (Humphries & Close, 2015), showed that out of 165 wells, measurable pesticide concentrations were detected in 28 wells (17%), of which 10 were contained measurable levels of two or more pesticides. The 28 wells were found in Northland (2 of 11 wells sampled), Auckland (4 of 8), Waikato (9 of 40), Gisborne (2 of 6), Tasman (7 of 15) and Southland (4 of 4) regions. Pesticides were not detected in sampled wells from Hawkes Bay (12 wells), Taranaki (5 wells), Horizons (23 wells), Greater Wellington (11 wells), Marlborough (17 wells), Canterbury (5 wells), and Otago (8 wells). The Bay of Plenty and West Coast regions were not included in the survey.

A total of 22 different pesticides were detected (with triazine herbicides being the most common), but concentrations were generally acceptably low. A single exceedance of a pesticide Maximum Acceptable Value (MAV) for drinking water was observed, for the insecticide Dieldrin in a well in the Waikato (0.043 mg m^{-3} vs MAV of 0.04). Dieldrin is a potent and long-lasting insecticide, widely used until the 1960s for control of ecto-parasites on sheep. Sheep dips on farms were commonplace, and the chemicals used in them may persist in soils near disused dip sites (Ministry for the Environment, 2006).

Comparisons with earlier surveys indicate that a similar percentage of wells had detectable pesticide residues over the 12 year period to 2014 and that there were no overall trends in concentrations (Humphries & Close, 2015).

3.5. IMPROVING NATIONAL SCALE ASSESSMENTS – A COMMENT

National assessments of freshwater quality require information from a good geographical spread of sites in Regional Council monitoring networks, allowing separate assessments from river, lake and groundwater monitoring sites. Making a national-scale assessment does not imply averaging of measurements across all sites in the country, since it is important to be able to identify variations in water quality across the country, or between different types of land use. Ideally, utilising monitoring sites from council networks should result in large national networks with unbiased environmental coverage across New Zealand and with high statistical power (for statistical and inferential purposes), but these aims are not always achieved, often due to differences in the way the data is gathered. In practice, regional council sites are biased toward more impacted sites that require monitoring for environmental management.

The term representativeness refers to the degree to which monitoring networks achieve unbiased environmental coverage; in a highly representative network, monitoring sites are distributed among environmental classes in the same proportions that the environmental classes occur. Recent assessments of representativeness have identified several problems. In national aggregations of council river monitoring sites, some environmental classes are over-represented, particularly those in lowlands and hill country with pastoral land cover, and other classes are under-represented or entirely unrepresented, particularly those in mountainous areas with natural land cover (Larned & Unwin, 2012). In national collections of lake monitoring sites, low-elevation lakes in catchments with pastoral land cover are over-represented and lakes in alpine and native forest-dominated catchments are under-represented (Schallenberg et al., 2013). In reality most testing is done close to population centres, where both impacts and concerns about the state of water quality may be greatest. A consequence of non-representative site selection is that wider inference cannot be made, and caution is required in comparing across categories of land use.

There is also a risk of bias associated with the precise location of the monitoring site; for example, if they are located in shady parts of a generally exposed river they may not be telling the whole story. The relatively small number of river, lake and groundwater sites currently monitored in New Zealand limits statistical power for detecting interclass differences in water quality or for detecting trends. However, there are indirect approaches that can partially address these deficits through modelling.

The problems associated with poor representativeness and limited numbers of monitoring sites could be partially alleviated by greatly expanding existing monitoring networks, but high operating costs are impediments to expansion. As a partial alternative, model-based predictions of conditions at unmonitored sites can be used in lieu of direct measurements. The most common approach is to use statistical models and existing monitoring data to interpolate or extrapolate from monitored sites to unmonitored sites (Fig. 6). For example, monitoring data from New Zealand river monitoring sites were used with national scale environmental data in random forest regression models to predict chemical and physical water quality, faecal indicator bacteria, MCI scores, and periphyton cover at approximately 560,000 river reaches across the country (Unwin et al., 2010; Snelder et al., 2014; Booker, 2015). Similarly, monitoring data from 121 New Zealand lakes were used in regression tree models to estimate TN, TP and phytoplankton chlorophyll-*a* concentrations in 3820 lakes (Sorrell., 2006). For both river and groundwater monitoring, the shortage of reference sites has been addressed by using statistical models to infer reference conditions (Daughney et al., 2012; McDowell et al., 2013). In each case, predictive models do not eliminate the need for continued monitoring - rather they augment the current monitoring and can 'fill the gaps' in our understanding of the state of New Zealand's fresh waters. Minimally-disturbed reference sites are also needed in freshwater monitoring networks for comparison with impacted sites, for restoration targets, and for identifying the effects of global processes such as climate change, independent of local land-use and human-impact effects.

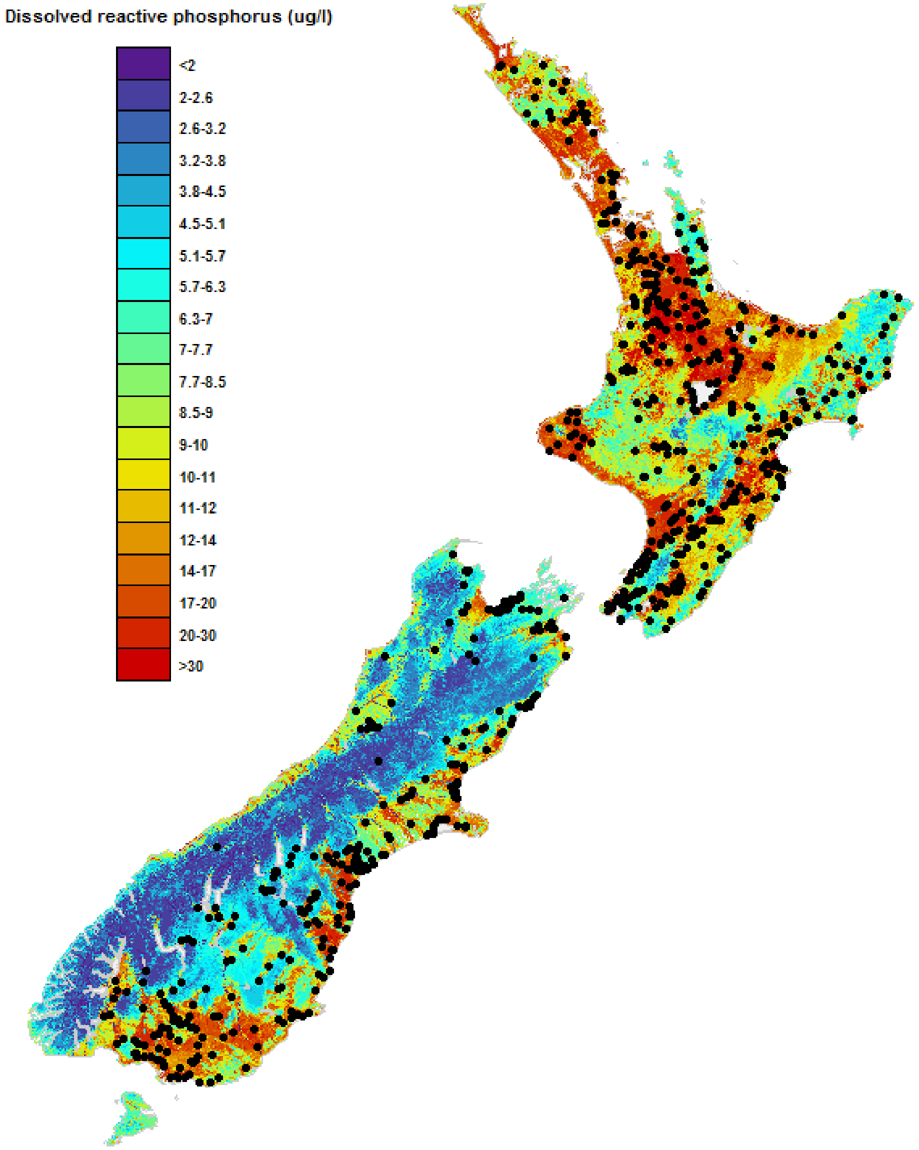

Figure 6: Mapped results from random forest regression model with estimated median concentrations of dissolved reactive phosphorus (DRP) in river reaches. Black circles represent monitoring sites with data from the 2003-2007 period used in the model. Reproduced from Unwin et al. (2010). ©Ministry for the Environment.

SECTION 4. HUMAN-INDUCED STRESSORS IN FRESH WATERS

Key messages:

The science is clear - New Zealand's fresh waters are under stress because of what we do in and around them. In particular, intensified agriculture, altered land use, industrialisation and urbanisation have created this stress. Impacts include:

- Modification and destruction of riparian zones and wetlands.
- Reductions in suitable habitat due to altered flow regimes caused by takes for irrigation, impoundment for hydropower, and water diversion for both.
- Effects on sensitive species and ecological processes due to elevated inputs of sediment, nutrients, bacteria and toxicants from point sources and diffuse runoff from land, particularly agricultural and urban land.
- Introductions of invasive plants, invertebrates and fish that alter ecological processes and displace native species.
- Creation of barriers to native fish migration such as dams, culverts and flood control gates.
- Depletion of native fish populations due to fishing pressures and predation by introduced fish.
- Predicted climate change impacts on flow regimes, groundwater levels, water temperatures, biotic invasions, and consequences for freshwater ecosystems.
- Cumulative effects of multiple stressors that push ecosystems towards tipping points.

The presence and effects of most stressors vary with local conditions, but some, such as climate change and diffuse-source pollution, are widespread. Although stressors are often studied in isolation, they generally occur in combination. Multiple stressors may have interactive effects – the weakening effect of one promoting the harmful effect of another.

4.1 MODIFICATION OF RIPARIAN ZONES AND LOSS OF WETLANDS

Approximately 85% of the land area of New Zealand was forested before humans arrived. It can be assumed that streams had shaded headwaters with faunas adapted to forest conditions. Land clearance has reduced forest cover from 85% to 29% (including 6% in plantation forests), with the remainder mainly in pasture. In the absence of forested riparian buffers, pastoral streams have distinctly different invertebrate faunas, reflecting changes in food resources (more algae and less leaf litter), habitat (less wood, more fine sediment, lack of suitable riparian vegetation for life cycle completion by adult phases of many insects) and water quality (higher temperature maxima and fluctuations, nutrient input) (Quinn, 2000). Replacement of native forest by pine plantations has much less impact on streams than conversion to pasture, but phosphorus export from plantations can still contribute to eutropication, (Abell et al., 2011) and logging and replanting can create periodic disturbances that alter stream habitats substantially (Quinn, 2005).

Riparian habitat loss

Streamside riparian areas occupy the interface between land and water and exert a disproportionately large influence on stream conditions in relation to the area they occupy (Fig. 7). For example, hydrological and biogeochemical processes in the riparian zone and stream channel modulate the concentration of contaminants such as nitrate passing through them.

Nitrate is very soluble and is not absorbed by soil, so any that is not taken up by vegetation or microbes will be transported into waterways. Vegetation and microbial communities in the riparian zone can therefore act as a sink for nitrate. (Ranalli & Macalady, 2010).

Riparian zones provide multiple benefits, including:

- Shading/low light conditions that prevent undesirable blooms of algae and keep water temperatures below levels that are lethal to sensitive aquatic invertebrates and fish (Boothroyd et al., 2004)
- Low air temperatures in the near-stream area used by the adult phases of aquatic insects (Meleason & Quinn, 2004)
- Reduced stream bank erosion (Boothroyd et al., 2004)
- Maintenance of aquatic invertebrate and native fish communities that are similar to those in mature pine and native forest streams (Rowe et al., 2002; Quinn et al., 2004)
- Reduced input of “logging slash” (waste and sediment) to stream channels (Fahey et al., 2004).

The management of vegetation and disturbance in riparian areas is therefore important to control impacts of land use on aquatic ecosystems.

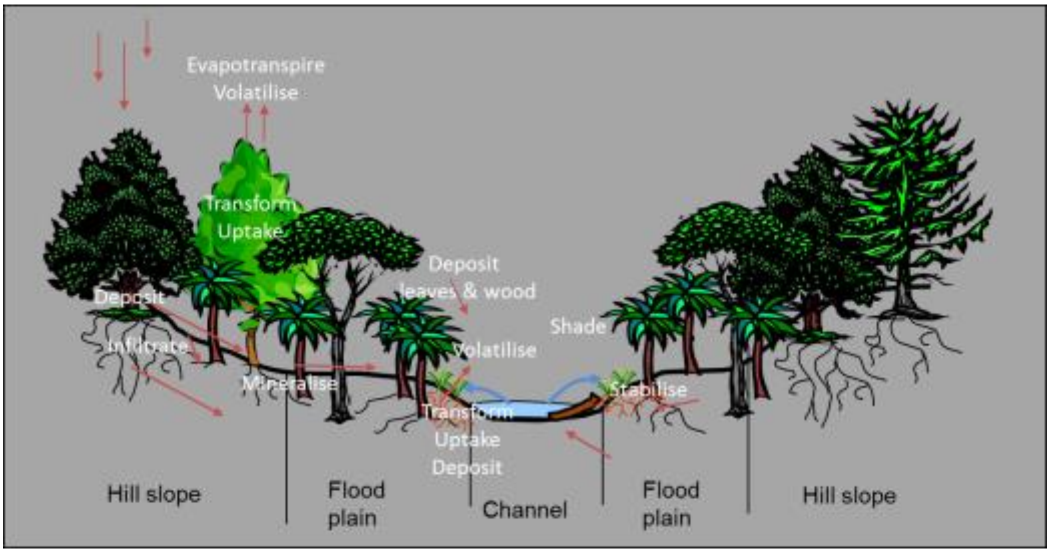

Figure 7: Summary of the protective functions of riparian vegetation for streams. Adapted from Parkyn & Davies-Colley (2003) ©NIWA

Wetlands

Wetlands are highly valued for their role in landscapes such as flood protection, water storage, erosion control and retention and transformation of nutrients (Campbell & Jackson, 2004). Wetlands act as ‘hot spots’ for biodiversity and are highly valued for the rare and threatened species often found there and as centres for bird migrations.

The Ramsar Convention, an international agreement recognising many of the world’s important wetlands, has six designated Ramsar Sites in New Zealand (Whangamarino swamp, Awarua/Waituna Lagoon, Manawatu Estuary, Kopuatai Peat Dome, the Firth of Thames and Farewell Spit) and a further six are being investigated for this status.[41] In spite of the recognised

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[41] Additional New Zealand sites being investigated for listing as internationally significant wetlands under the Ramsar convention include the Avon-Heathcote Estuary in Christchurch, Mangarakau near Farewell Spit, Okarito Lagoon in South Westland (home of a white heron colony), Lake Wairarapa near Wellington, Ohiwa Harbour in the Bay of Plenty and Kaipara Harbour north west of Auckland

importance of wetlands in landscape functioning and in biodiversity maintenance, ninety percent (or 3 million hectares) of New Zealand wetlands have been lost since 1850, due mainly to draining and conversion to agricultural land (McGlone, 2009; Clarkson et al., 2011). The loss has been disproportionately high in lowland and coastal areas. Wetlands continue to be lost in spite of recognition in the RMA of the values of wetlands and the requirement in the National Policy Statement for Freshwater Management for "protecting the significant value of wetlands". In addition to conversion to pasture, impacts on wetlands have been degraded through partial drainage, flooding, burning, nutrient enrichment from surrounding land and the introduction of pests (Clarkson et al., 2003). Climate change is likely to further impact wetlands, with sea-level rise leading to erosion and salt-water intrusion.

Drainage alters wetland species composition and biogeochemical cycles, reduces aquatic habitat area and increases access by terrestrial predators. Flooding of wetlands occurs when they are incorporated into wider flood control schemes (e.g., in the lower reaches of the Waikato River) or when ephemeral wetlands are dammed for water storage on farms. Burning has been a common method to remove wetland vegetation for conversion to pasture. Several important wetland plants such as *Carex* (sedge grass) and *Empodisma* (wire rush) are very sensitive to burning and recovery is slow. Nutrient enrichment and eutrophication creates hypoxic and anoxic conditions in wetlands[42] (Sorrell et al., 2004). New Zealand wetlands are highly susceptible to pest invasions. Non-native willows are among the most widespread and tenacious invaders; willows competitively exclude native wetland plants and alter wetland hydrology (Sorrell et al., 2004). In addition, pest fish such as koi carp disturb wetland sediment, reduce water quality and consume wetland vegetation.

4.2 HABITAT LOSS DUE TO ALTERED FLOW REGIMES AND WATER LEVELS

The human activities of abstraction, water diversion and water storage cause changes to lakes, wetlands and groundwater due to altered water levels, and changes to riverine habitats due to altered flows and loss of certain types of habitat, or loss of connectivity of habitats. Fresh water is abstracted from rivers or groundwater for irrigation, drinking water, household and industrial use, and hydropower generation. There are around 16,000 consents to take water in New Zealand. There are more consents to take groundwater than surface water, but more water is consented to be taken from surface waters than from groundwater. Most of the water consented for consumptive use is for irrigation and this use is growing rapidly.

There are also unconsented takes including some household and lifestyle block bores, and high water users such as schools and hospitals. Although these contribute only a small fraction of abstracted water, abstraction of water for household use and for livestock drinking water still occurs even when river flows are minimal, and the cumulative effect of these uses can have significant impacts, particularly in areas where urban and lifestyle block development is expanding.

For flowing water, water quantity limits for rivers (i.e., environmental flows), as required by the NPS-FM, are set such that flows and water levels in waterbodies provide for ecological, cultural, recreational, landscape and other values. Environmental flow limits must comprise at least a

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[42] Hypoxia refers to low-oxygen conditions, when dissolved oxygen is below the level necessary to sustain most animal life. Anoxia is a more severe condition of oxygen depletion.

minimum flow (the flow below which no further water is to be taken) and an allocation rate (the maximum rate of abstraction).

Box 2: Impoundments replace riverine ecosystems with lake ecosystems

Impounded rivers behind dams function like lake ecosystems, with water residence times far greater than the river. For example, the eight hydroelectric dams along the Waikato River are estimated to increase the travel time over the c. 180 km from Taupō to Karāpiro 13-fold (from 62 to 830 hours) under summer low flow conditions and 8-fold (from 48 to 375 hours) under winter high flow (Rutherford, 2001). Extended water residence times raise the risk of increased phytoplankton (Pridmore & McBride, 1984), which can adversely affect both the lake and downstream systems. Water quality impacts are especially noticeable within and downstream of hydropower where thermal stratification occurs. Toxic arsenic-3 may be released from the anoxic sediments (e.g. Lake Ohakuri (Webster-Brown, 2005)) and in some cases where reservoir deep water is released, low dissolved oxygen levels can affect downstream ecosystems (e.g., below Lake Waitaki; (Young et al., 2004)). Reduced scour, lowered current velocities and increased sedimentation within dams enhance conditions for aquatic weeds that often grow to nuisance levels (Champion & Clayton, 2010), affecting both power production and recreational activities.

Ecological requirements for minimum flows

Minimum river flows are set to ensure that water abstraction or damming does not deplete flows to the point where adverse ecological effects occur. Designated minimum flows are often called ecological flows; they are flows and water levels that are required to provide for the ecological integrity of the flora and fauna in waterbodies and at their margins (Beca, 2008).

The main ecological requirement used to define minimum flows is the provision of adequate physical habitat (i.e., adequate area in a flowing channel with the right combinations of water depth, water velocity and substrate for the most critical or sensitive species). This applies to all ecosystem components present at a minimum flow site, including algae, aquatic invertebrates, small and large fish, native plants, terrestrial invertebrates, and native river birds.

Different organisms respond in different ways to flow-related variables such as current velocity, water depth, channel width and river-bed substrate (Jowett & Duncan, 1990). Knowledge of these responses allows relationships to be developed to predict how changes in flow will affect available river habitat, referred to as 'Weighted Usable Area', (WUA). This habitat-based approach has been used to inform the setting of minimum flows at thresholds and has been shown to achieve retention of desired instream values such as indigenous fish and trout abundance, and suitability for angling (Jowett & Biggs, 2006). Refinements to this approach are the subject of current research – for example, Hayes et al.(2016) have developed a method that links flow to the provision of food resources for drift-feeding fish, and have shown that application of this approach can lead to higher minimum flow thresholds for salmonids than those derived using the WUA approach. The implications are significant for developing flow-regime plans that appropriately account for the flow-related needs of fish. Additional considerations in setting minimum flows include ensuring adequate flows to maintain suitable water temperatures, adequate dissolved oxygen levels and to enable up and down-river "connectivity" (e.g., minimum depths for fish passage).

Environmental requirements for mid- and high-range flows

River flows in the mid to-high range, occurring during freshes and floods, do 'geomorphic work' on river channels by moving gravel, controlling the encroachment of riparian vegetation, and maintaining channel size and form (Fig. 9). They also provide vital ecological services such as flushing mud and periphyton from stream beds, cueing fish migration, and facilitating migration to and from the sea by opening river mouths (Larned et al., 2012). Dams and 'flood-harvesting' to off-channel reservoirs (Fig. 8) reduce the size, frequency, and duration of mid- and high-flow events, and can reduce the provision of ecological services. Consequences of reduced mid-range and high flows include the cessation of braiding, loss of habitat for endangered braided-river birds through weed encroachment, impeded upstream migration of fish such as salmon and eels, and erosion of coasts adjacent to the river mouths.

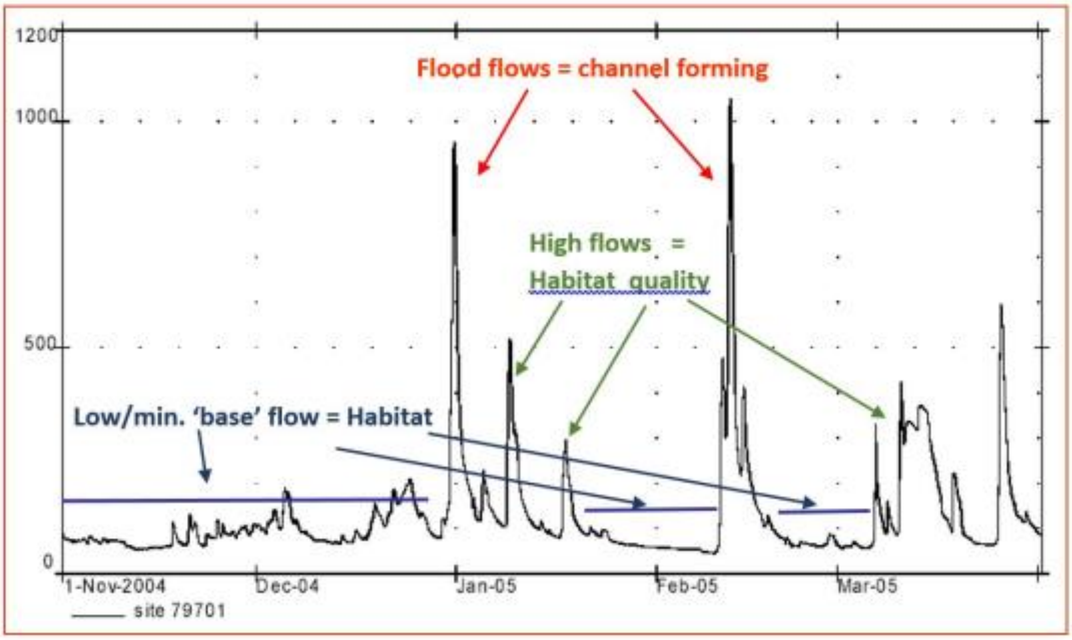

Figure 8: New Zealand river hydrograph showing flow variability and geomorphic and ecological functions of flows Large flood flows can change (or maintain) the morphology of river channels, Intermediate 'high flows' maintain habitat quality by flushing accumulated fine sediments and proliferations of algae, and base flows define the amount of habitat available for living communities. Flow magnitude on Y-axis is as m^3/s (note log-scale). (Adapted from Biggs et al. 2008 with permission, ©Elsevier)

Effects on downstream river flows and habitats

Hydropower or irrigation reservoirs can attenuate river flood peaks, reduce minimum flows (and therefore habitat availability) and alter patterns in river flow variability. A wide range of adverse effects of flow alterations have been observed. Hydroelectric development on the Waitaki River has reduced the sediment supply and flow variability through the lower reaches, resulting in vegetation encroachment on the river channel, which has in turn altered sediment transport and reduced wildlife habitat quality (Tal et al., 2004). Flow alteration by hydropower operations is an issue of particular concern for the native birds that rely on braided rivers (e.g., wrybill, black stilt, white-fronted and black-fronted terns, black-billed gulls; (Hughey et al., 2010)). These species are highly susceptible to habitat loss and terrestrial predators (see Section 2.2). Project River Recovery in the Waitaki River Basin is specifically aimed at reducing river bird predation in rivers (www.doc.govt.nz/our-work/project-river-recovery/).

Where accumulations of algae and sediment occur below dams there may be a requirement for "flushing flows", which are deliberate releases of small floods to restore riverbed health (Biggs et al., 2008; Lessard, 2013). All hydropower schemes in New Zealand operate under resource consents aimed at both minimum flow protection and the maintenance of some flow variability.

Inter-basin transfers and landscape changes

Hydropower production is frequently associated with inter-basin water transfers. For example, the Waikato hydropower system receives 33% of inflow from diversions in the Whanganui, Whangaehu and Rangitikei river catchments, with corresponding flow reductions in those three rivers. The Manapouri power scheme has diverted water from the Waiau River through the Fiordland Mountains to Deep Cove in Doubtful Sound. Ecological consequences for river and downstream ecosystems as a result of both augmented and reduced flows have been the topics of much environmental debate and court action over the last few decades, such as those on the Tongariro Power Development Scheme (TPD Hearings Committee, 2001). The Waitaki power scheme has altered the landscape across the Mackenzie Basin with canals that divert water from the major rivers of the basin. This has been the subject of an ongoing negotiated restoration project, now into its 26th year, called ‘Project River Recovery’ (http://www.doc.govt.nz/our-work/project-river-recovery/).

Box 3: What is water harvesting and what effects does it have?

Water harvesting or “flood harvesting” involves collecting river water during high flows and storing it in off-channel reservoirs, or by retention behind on-channel dams, for later use during dry periods. This has the benefit of maximizing water availability for irrigation whilst maintaining minimum flows at critical times of the year. Where the water is extracted from rivers and streams only during flood flows, the effect on normal and low flows should be minimal. However, retained floodwater is likely to be sediment-laden and not suitable for some uses. Flood harvesting also reduces natural geomorphic processing by rivers, including the removal of encroaching terrestrial vegetation and accumulations benthic algae and fine sediment on river beds, and transport of sand and gravel to the coast. These effects can be partly mitigated by releasing artificial floods from reservoirs on a schedule that maximizes the environmental benefits from a given volume of impounded water.

Alterations to natural lakes

Controlling the lake level in large natural lakes to optimise storage for downstream hydro-electricity results in altered lakeshore ecologies (e.g., Lakes Taupo, Waikaremoana, Coleridge, Hawea and Manapouri). The Manapouri lake levels were the subject of major environmental debates and decisions in the 1970s and subsequent consents for hydropower have often focussed on the effects of altered lake levels (Freestone, 1992). Hydropower development temporarily increased the natural 3-m fluctuations in Lake Hawea to over 20 m (Mark, 1987), which eliminated shallow beds of native macrophytes and altered the function of the lake littoral zone. This effect was considered unacceptable and the operating range is now restricted to 8 m (Young et al., 2004; Thompson, 2008), still more than twice the natural range but with ecological consequences considered acceptable.

4.3 EFFECTS OF CONTAMINANTS (SEDIMENT, NUTRIENTS, BACTERIA AND TOXICANTS) FROM AGRICULTURAL AND URBAN LAND

Pollutants enter lakes, rivers and groundwater through ‘point sources’ such as discharge pipes and ‘diffuse sources’ such as surface runoff, land erosion and leaching. Toxic chemicals, pathogenic microbes and nutrients from both point and diffuse sources have adverse effects on aquatic ecosystems and potentially on human health.

The most significant water quality issue facing New Zealand is diffuse pollution from rural and urban sources. Diffuse-source pollution is widespread, and national and international experience shows that it can be difficult to manage. The diffuse-source contaminants of greatest concern are excess nutrients (nitrogen and phosphorus), sediments, pathogens and heavy metals.

Pollutants from point sources

Prior to the 1990s, point source discharges of pollutants from industry (including meat and food processing plants, wool scours, tanneries, and pulp and paper mills) and municipal wastewaters degraded many rivers in New Zealand, including some of our largest - in the 1970s, the Waikato River was often referred to as 'the main drain'. The passage of the RMA in 1991 and its requirement for all discharges to consider the effects on receiving environments before being consented has greatly reduced point source pollution, although this control began after the passage of the Water and Soil Conservation Act 1967. Currently, even small discharges (e.g., individual dairy sheds) need consents and these usually come with mitigation requirements.

In most large and developed catchments, point sources now contribute smaller annual loads of nutrients and pathogens to fresh water than diffuse sources. For example, discharges from the 13 largest point sources to the Waikato River account for 9% and 18% of the total N and P loads, respectively, whereas the diffuse N and P loads from developed land account for 48-68% of the N load and 36-69% of the P load, with the remainder from background natural sources (Vant, 2010). However, at the local or reach-scale, point source discharges can still lead to harmful contaminant effects in receiving waters even though they might be minor contributors at the catchment-wide scale.

The most common point sources are dairy shed effluent treatment systems, despite a reduction in their numbers over the last decade as dairy operations have shifted to effluent irrigation on land. Municipal wastewater treatment plants (WWTPs) are the next most common point sources (Cass, 2016), with approximately 330 WWTPs in New Zealand, most of which discharge to fresh water, although several large coastal cities discharge to estuaries or the open coast. About 11% of the national WWTP flow is discharged to land, with Rotorua being the largest - serving a population of 68,000 (Cass, 2016). Two issues with land application of municipal wastewater are the availability of suitable land and the need to dispose of wastewater in the winter when soil moisture levels are high, which leads to greater risks of diffuse pollution entering fresh waters. Consequently, large winter storage capacity may be required if 100% land application is planned. Many municipalities have adopted combined systems whereby some wastewater is discharged to waterways at high flows, mostly in winter.

Pollutants from diffuse sources

National scale modelling (Elliott et al., 2005) indicates that diffuse sources account for 97% of the total nitrogen and 98% of the total phosphorus lost from land and transported to the sea – with most of these losses being human-induced rather than from natural processes. Strong positive correlations have been reported linking nitrogen and phosphorus concentrations in rivers to the proportion of upstream catchment used for intensive agriculture (Larned et al., 2016).

Given the large area of pastoral farming, it is not surprising that New Zealand's fresh waters are impacted by diffuse pollution. The link between pastoral intensification and declining water quality is clear and has been acknowledged by recent Government reforms of water legislation that seek to limit contaminant discharges to fresh water (Ministry for the Environment, 2014). While urban and mining-impacted streams are typically of lowest 'ecological health' in New Zealand, as they are in other countries, they comprise a very small proportion of total stream length (< 1%). Streams in pastoral agriculture comprise far greater proportion of total stream length and many are moderately-to-severely impacted by three groups of diffuse pollutants: fine sediments, microbial pathogens and nutrients (Larned et al., 2016).

A large body of literature tells us that, within the pastoral land use category, dairy farming is associated with the highest diffuse pollution footprint for nitrogen – meaning on a per hectare basis, dairy land use makes a disproportionally large contribution to the total load of nitrogen entering waterways. National-scale modelling in 2005 showed that overall, total nitrogen losses from dairying and wintering of stock were slightly lower than those from sheep, beef and deer farming combined, but only because dairying occupies a much smaller overall proportion of land. In that analysis, 37% of the total nitrogen load entering the sea originated from the 6.8% of the land area occupied by dairy farming, while the 'other pasture' category (sheep, beef, deer, etc.) accounted for 39% of the total nitrogen load from 32% of the land area (Elliott et al., 2005).

The amount of land used for dairy farming increased from 2002 to 2012 by 28%, to 4 million hectares, and sheep and beef farming decreased by the same amount, covering 10.8 million hectares of land (Statistics New Zealand, 2013). It is likely that the proportion of the nitrogen load entering the sea from dairying has now exceeded that of the other pastoral farming activities, even though sheep and beef farming still remain the most extensive commercial agricultural land-use activity in New Zealand. A 2013 modelling study in Southland showed that small reductions in losses from individual sheep, beef and/or deer systems could make significant differences to net regional losses, because of the large land area involved (Legard, 2013).

Pollutants change in concentration and form as they move through catchments. Attenuation of overland flow occurs through natural interception mechanisms and good management practices on farms and on stream and lakes margins. Particulate and dissolved inorganic nutrients and microbes are removed when overland flow paths intersect riparian vegetation before reaching the stream channel or lake surface. Once in streams and lakes, processes such as plant and microbial uptake, denitrification, sedimentation and physical sorption on sediment surfaces remove nutrients, microbes and sediment from flow-paths. These attenuation processes are highly variable in space and time and are strongly influenced by local environmental conditions such as flow, water temperature, light, and mitigation measures (see Section 5). There is increasing evidence of high variability in attenuation processes in groundwater, particularly for nitrate. For example, there is minimal nitrate attenuation in the well-oxygenated groundwater near Lake Rotorua, but high attenuation in the hypoxic and anoxic groundwater near Lake Taupo where it is surmised that these conditions have led to higher denitrification (Stenger et al., 2013).

An important consideration for the movement of pollutants through water bodies is the 'residence time' – the average amount of time that water stays within a system. For example, residence times determine how long it will take for a pollutant to reach and contaminate a groundwater drinking water source or a surface water body, and at what concentration it will arrive. Depending on the depth, structure and location of the aquifer, this can vary from 5-10 years (e.g. Canterbury shallow aquifers) to 100 years or more (e.g. Lake Rotorua catchment), and there are implications for restoration from these variable residence times. Residence times also influence how long it takes for pollutants and nutrients to be cleared from the system – reflecting the legacy of previous activities. Nitrates in groundwater provide a cogent example (see Box 4).

Sediment

Fine sediment is a very widespread pollutant in New Zealand, affecting lakes and rivers by reducing water clarity and impacting on primary producers and consumers in aquatic food webs. This is a particular problem when fine sediment is transported at low flows or in systems like spring-fed creeks, where there is limited capacity for flushing. Pastoral erosion produces more sediment than an equivalent area of forest, but during the period when trees are harvested and replanted erosion rates can increase drastically. Sediment affects downstream coastal and estuarine areas by reducing water clarity, shoaling by sedimentation and smothering shellfish beds. Low visual clarity derived from fine sediments also commonly limits the suitability of New Zealand's rivers for swimming, their appeal for other recreational activities, and their scenic value (Davies-Colley & Ballantine, 2010).

Box 4: The curious case of nitrate – time lags

Of special note in relation to the management of nitrate pollution are the legacy issues that relate to extended residence times of polluted groundwater. For example, in the Central North Island nitrate emerging with groundwater-fed springs and seeps can be a significant contributor to the total nitrogen load of rivers and lakes but this nitrate reflects the land use of several decades ago rather than that of today. In the Lake Taupo catchment the groundwater ages vary from 2.5 to 80 years (Morgenstern, 2012), with a mean age of 37 years for streams arising from aquifers and entering the lake. Thus, the lake currently receives nitrate from farming activities several decades in the past. It also means that farming practises today will affect water quality several decades into the future - this future delivery of pollutants to water bodies from current land-use is often referred to as 'the load to come'. By the same reasoning, on-land measures to reduce nitrate leaching will take the same length of time to manifest themselves in improvements in receiving water quality. When establishing water quality targets (including timelines), communities and regulators need to be aware of the potential for this slow response.

Knowledge of such time lags should emphasise the need to set environmental limits before the likely effects become apparent. However, in the case of Lake Taupo, this knowledge became apparent in the late 1970s, but limits were not put in place until the 2000s, and greater cost in both economic and environmental terms.

Nutrient enrichment leading to eutrophication impacts

The major groups of freshwater plants (periphyton, phytoplankton and macrophytes) play vital ecological roles, assimilating sunlight and nutrients to provide the energy at the base of freshwater food webs. However, excessive plant biomass, typically driven by increased levels of nitrogen and phosphorus, can cause eutrophication conditions that in turn degrade freshwater values.

Trends in nitrogen losses into fresh waters vary by region, depending on land-use change. In the North Island, with the exception of the Waikato, sheep numbers are reducing at a much faster rate than dairy cattle numbers are increasing, and nitrogen losses are trending downward, meaning less nitrogen is being transported into waterways from the land (Dymond et al., 2013). However the nitrogen trend is upwards (increasing transport of nitrogen into waterways) for some areas of the South Island, where rapidly increasing dairy cattle numbers exceed the reduction in sheep numbers (in terms of equivalent livestock units). Canterbury has seen a 10-fold increase in dairy cattle numbers of the past 20 years, and a corresponding increase in nitrate leaching. Southland has experienced even greater increases (Dymond et al., 2013).

Phosphorus rather than nitrogen is the most significant nutrient loss problem for many hill country sheep and beef farms, with much of this phosphorus being lost through attachment to eroded soil (Wilcock et al., 2007). Phosphorus-based fertilisers are used on pastoral land to maximise grass yield, and phosphorus is present in imported feed used when grass supply is poor, or to allow increased stock numbers above pasture-based carrying capacity. Excess use results in retention of phosphorus in soils, and runoff to waterways. Given its attachment to soil, the effects of loss of phosphorus are more episodic than the more continuous process of nitrogen loss, and thus requires a different approach to control.

Excess nitrogen and phosphorus entering streams and lakes promotes plant growth that leads to eutrophication. Examples of eutrophication effects include:

- Reduced visual appeal and desirability for recreational use (e.g., swimming, boating) due to high phytoplankton biomass, low clarity and altered colour, and potentially toxic cyanobacterial blooms and mats.
- Reduced drinking water quality due to taste and odour problems and toxins, increasing treatment costs to make the water potable (Hamilton et al., 2014).
- Reduced safety of mahinga kai for consumption.
- Reduced fishability due to attached and floating periphyton clogging lines.
- Fish kills due to plant-driven anoxia (depletion of dissolved oxygen as a result of high rates of decomposition), pH fluctuations and resultant high levels of toxic ammonia and sulphide
- Reduced light penetration due to phytoplankton blooms, resulting in loss of rooted plants and shallow lake “flipping” (i.e., rapid transition from clear water conditions and abundant rooted plants to turbid, devegetated conditions (Schallenberg & Sorrell, 2009)).
- Loss of habitat for taonga species (e.g., kōura extirpated from Lake Okaro (Kusabs et al., 2015))

Faecal contamination and health risks

Pathogens from faecal matter affect contact recreation, water supplies and coastal shellfish harvesting at commercial, recreational and traditional harvest sites. *E.coli* concentrations indicate the presence of pathogens such as *Campylobacter* and *Salmonella*. (see Box 1)

Modern wastewater treatment plants are generally effective at removing zoonotic pathogens (infectious agents, generally bacteria and protozoa, that transmit disease from vertebrate animals to humans). Treatment plant upgrades across New Zealand have also greatly reduced point-source discharges of untreated wastewater, but these can be overloaded under extreme weather conditions. Poorly maintained septic tanks are another source and this particularly impacts on some recreational sites.

The major sources of faecal contamination are now diffuse. Although urban diffuse sources are important at the local scale, by far the most important source of faecal contamination nationally is input from pastoral farmland. Strong positive correlations have been reported linking *E.coli* concentrations in rivers to the proportion of upstream catchment used for intensive agriculture (Larned et al., 2016). Heavy rain leads to greater runoff of potential pathogens to water bodies.

Direct human contact with water in streams and lakes during activities such as swimming, wading and boating can result in some exposure to pathogens. In rural settings, where large animal populations shed faeces directly onto land (and sometimes directly into water), these pathogens are predominantly zoonotic (bacteria and protozoa). Exposure to human-sourced viruses is more common in urban settings. Zoonotic pathogens or ‘zoonoses’ (derived from infected animals) can predominate in surface drinking-water sources, given that source waters are usually located in rural areas, but these should be effectively removed by water treatment processes, as mandated by legislation.[43] Subsurface sources have been historically considered safer than surface sources, and not requiring treatment, although the 2016 Havelock North groundwater contamination event indicates the limits of that assumption (http://www.hastingsdc.govt.nz/hnwc).

Zoonoses are the most common notifiable diseases in New Zealand, and many are potentially waterborne. Furthermore, some foodborne cases may result from contamination of processing water. Currently, campylobacteriosis dominates those statistics, with a reported rate of slightly less than 150 per 100,000 people per annum (ESR, 2016), but the 2016 outbreak in Havelock North will lead to a spike in that reported rate for that year. Cattle, sheep and poultry are all substantially implicated as zoonosis sources (McBride, 2011). In a nation-wide study of faecal pathogens and faecal indicators at 25 recreational freshwater sites in 1998–2000, *Campylobacter* was the most widely occurring pathogen, being present in two-thirds of all samples and sometimes at high concentrations (Till et al., 2008).

Toxic and emerging contaminants

The toxicants of primary concern for freshwater ecosystems in New Zealand are ammonia and nitrate, metals, organic compounds and micro-pollutants. As well as functioning as inorganic nutrients at low concentrations, ammonia and nitrate can be directly toxic. Their toxicity at high concentrations has resulted in their inclusion as attributes that need to be managed for ecosystem health in the National Objectives Framework (NOF) of the NPS-FM. The numeric values for the A, B, C and D quality bands in the NOF that characterise the different levels of toxicity of nitrate and ammonia are primarily derived from overseas studies and mostly relate to toxicity for trout and salmon. It is unclear how these relate to our native species' tolerance. Given the high level of endemism in New Zealand's freshwater biota, testing of toxicity towards native species is now underway to determine whether the current toxicity bands are adequate (Thompson et al., 2015).

Copper and zinc are ubiquitous contaminants in urban stormwater and in diffuse agricultural inputs; both are widely used as animal supplements and copper is used in agricultural fungicides (Hickey, 2000). Typically the "first flush" of urban stormwater includes high concentrations of metals and organics (particularly polycyclic aromatic hydrocarbons), but it is not known how much these short-duration exposures contributes to toxic effects compared to chronic low-concentration exposures.

Micro-pollutants (also known as emerging organic contaminants or EOCs) comprise thousands of organic contaminants that are biologically active at very low concentrations (i.e., parts per billion) (Stewart et al., 2016). Some micro-pollutants degrade rapidly, but many are "pseudo-persistent" because of continuous inputs from anthropogenic sources such as wastewater discharges, landfill leachate and some industrial activities. Urban micro-pollutants include pharmaceuticals and personal care products, flame retardants, steroids, antimicrobials, plasticizers and the degradation products of these substances. Micro-pollutants have been linked to toxic effects as estrogenicity, mutagenicity and genotoxicity.

EOC sources, concentrations in receiving environments, rates of accumulation in sediment, and uptake and bioaccumulation rates in biota in New Zealand are similar to those observed in comparable studies overseas (Stewart et al., 2016). New Zealand's generally low human population density means that agricultural discharges are probably the most widespread sources of aquatic micro-pollutants that include estrogens from cows (Gadd et al., 2010), antibiotics, and

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[43] New Zealand Legislation. Health (Drinking Water) Amendment Act 2007. http://www.legislation.govt.nz/act/public/2007/0092/latest/DLM969845.html

other veterinary pharmaceuticals. However, sites that have a large urban land use component, and where most New Zealanders live, have highest concentrations, particularly where such micro-pollutants can settle out and accumulate (e.g., weakly flushed estuaries). Scientific understanding of the environmental fate and effects of these micro-pollutants in New Zealand is lacking.

There is a high level of concern about toxins in aquatic species that are harvested for human consumption, most notably eels, trout and watercress. Contaminants including a range of organic, metal, and metalloid (arsenic) substances have been detected in some locally important wild food (mahinga kai) species at concentrations that should cause consumers to limit their intake at some locations (Stewart, 2011). There is a long-standing concern in New Zealand about mercury intake due to consumption of fish exposed to geothermal water (Kim, 1995). Toxic cyanobacterial blooms can also contaminate mahinga kai species (Clearwater et al., 2014) or cause direct toxicity.

4.4 INVASIVE PEST SPECIES

Invasive non-native ('pest') species, both plant and animal, pose a significant threat to New Zealand freshwater ecosystems, having a wide range of impacts including consumption of native species, alteration of food webs, and ecosystem 'engineering' (i.e., modification of physical habitat) (Champion et al., 2002; Ricciardi et al., 2013; Collier & Grainger, 2015; Hamilton, Collier, et al., 2016). In addition to these negative ecological impacts, invasive species are an economic burden and impact upon amenity (e.g. visual attractiveness) values. Examples include obstruction of hydropower generation and irrigation intakes and overbank flooding due to proliferations of pest plants, and negative effects of these proliferations on waterfront property values.

Pest species are considered second only to habitat loss as the drivers of biodiversity decline in freshwaters globally (Millennium Ecosystem Assessment, 2005b; Simberloff et al., 2013) and freshwater environments are regarded as amongst the most invaded systems internationally and in New Zealand (Champion et al., 2002; Ricciardi et al., 2013). Globalisation in trade, travel and recreational use all increase the risk of introduction and spread of pest species. To combat the increased risk, there is an increasing need for preventative strategies based on enhanced border control, public education, formalised surveillance strategies and investment in pest control. Although there is a need for research into new cost-effective control methods, there are also opportunities to manage invasive freshwater pests and mitigate their impacts with current tools (see Section 5).

Introduced algae, fish and weeds that have invaded and altered freshwater habitats in New Zealand include the alga didymo (*Didymosphenia geminata*) (see Box 5), the bloom-forming cyanobacteria *Cylindrospermopsis* (Wood, S.A. et al., 2014), the zooplankton *Daphnia pulex* (Duggan et al., 2012), pest fish such as koi carp, catfish, rudd, and gambusia (mosquito fish), and a number of aquatic weeds including hornwort (*Ceratophyllum demersum*), oxygen weed (*Lagarosiphon major; Hydrilla verticillata; Egeria densa*), eelgrass (*Vallisneria australis*), common reed (*Phragmites australis*), floating fern (*Salvinia molesta*), Mexican water lily (*Nymphaea mexicana*), fringed water lily (*Nymphoides peltata*), water hyacinth (*Eichhornia crassipes*) and Manchurian wild rice (*Zizania latifolia*). Some of these species have limited distribution or have been eradicated, but active biosecurity is required to minimise the likelihood of further incursions (Champion et al., 2012).

Box 5: What is didymo and can we control it?

The invasive alga *Didymosphenia geminata* (didymo or 'rock snot') is an introduced pest species inhabiting many rivers in the South Island, producing thick mats that cover large proportions of the river bed and smother native species. Didymo blooms are unusual in that they occur in rivers with low nutrient concentrations. As a consequence, blooms have occurred in some pristine, low-nutrient rivers and many other pristine rivers are at risk. In the 12 years since didymo was first observed in the South Island, it has not been detected in the North Island, suggesting that either rivers of the North Island are not suitable for its growth, or that minimising transport on human vectors can help to limit its spread. The "Check, Clean, Dry" public awareness campaign run by MPI (http://mpi.govt.nz/funding-and-programmes/other-programmes/campaigns/check-clean-dry/) emphasises the importance of cleaning and drying fishing, boating and tramping gear before moving between waterways, and may have helped to slow the spread of didymo, but eradication is considered impossible.

4.5 ARTIFICIAL BARRIER EFFECTS ON MIGRATION AND CONNECTEDNESS

Built infrastructure associated with the development of waterways and adjacent land has restricted access of biota to many thousands of kilometres of streams and rivers in New Zealand. Single barriers (e.g., dams, tide gates and perched culverts [Fig. 9]) can impede or obstruct access to large areas of suitable habitat for fish, with barriers in the lower reaches of river networks having the largest effects on diadromous fishes[44] (Cote, 2009). Barriers may impede upstream movements, downstream movements, or both, and their effects may be intermittent or permanent.

Connectivity between habitats used by different life stages of New Zealand's freshwater biota is critical to ensuring the survival of populations and entire species. Many of the most widespread and highly valued native fish species, (e.g., whitebait and eels) are diadromous (Leathwick et al., 2008). And many of the migrating native fish species are small-bodied and weak swimmers, so small obstructions in waterways act as barriers (Franklin & Baker, 2016; Link & Habit, 2014; Mallen-Cooper & Brand, 2007). For example, fall heights (vertical drops) at culverts of greater than 10 cm are a complete barrier to the migration of juvenile inanga (*Galaxias maculatus*) and common bullies (*Gobiomorphus cotidianus*) (Baker, 2003). Larger dams also affect freshwater fish populations and communities, reducing species richness and percentage of diadromous species and increasing the percentage of non-diadromous fish species present upstream of dams (Jellyman, 2012).

Dispersal of aquatic insects can also be interrupted by instream barriers (e.g., culverts and dams), terrestrial barriers (e.g., degraded riparian vegetation) and loss of continuous flow (Parkyn & Smith, 2011). The ability of aquatic insects to disperse by flight during the adult life-stage makes then less susceptible than fish to the effects of instream structures on migration. However, a Christchurch study showed that the number of caddisflies captured immediately below culverts was about 2.5 times the number caught above them, indicating that road culverts are potential barriers to upstream flight dispersal (Blakely, 2006).

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[44] Diadromous fish are fish that spend part of their life cycles in fresh water and part in salt water – migrating between rivers and estuarine or marine habitats.

While increased connectivity is generally beneficial, that is not always the case. For example:

- Many threatened populations of the endemic non-migratory galaxiid fish populations in New Zealand only exist upstream of natural barriers that exclude predatory trout (Townsend, 1991).
- Irrigation and hydropower schemes that involve inter-basin transfers can open new dispersal pathways for exotic/pest species (Leuven, 2009; Jackson, 2010).
- Restoring desirable native species by removing barriers to migration can also increase the risk of dispersal of competing exotic species (McLaughlin et al., 2013; Rahel, 2013).

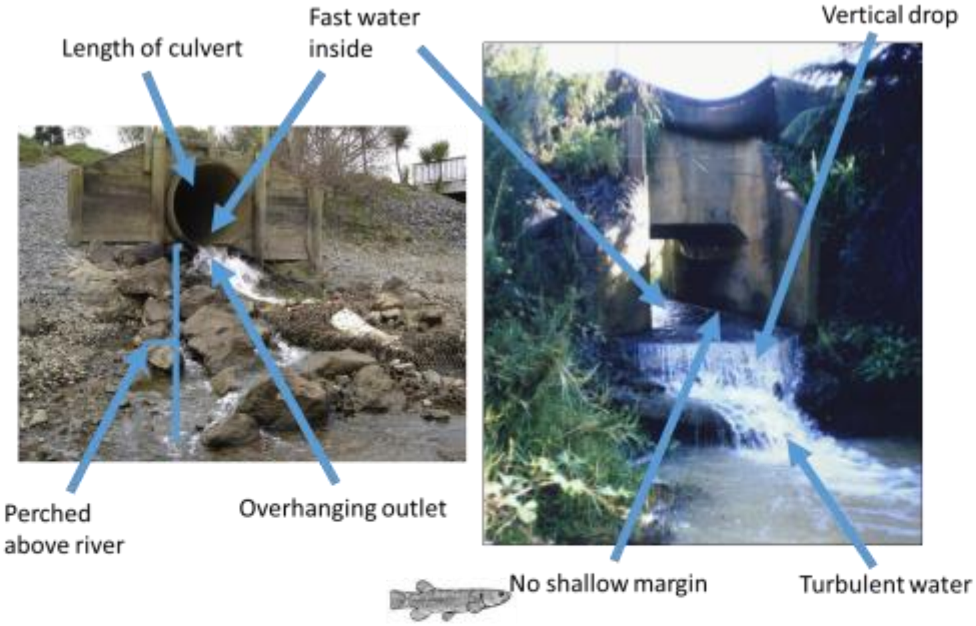

Figure 9: Some of the components of migration barriers to upstream movement of fish.©NIWA

4.6 EXPECTED IMPACTS OF CLIMATE CHANGE ON FRESH WATERS

Further warming in New Zealand this century is virtually certain (Gluckman, 2013; Royal Society of New Zealand, 2016). Impacts of climate change on fresh water include alteration to river flows, floods and droughts, effects on hydropower generation, water demand, infrastructure and biodiversity. Lakes, rivers and wetlands will respond to changes in snow, rainfall, and air and water temperature through changes to physical ecosystem structure and the direct effects of increased temperatures on freshwater organisms (Robertson et al., 2013; Jiménez Cisneros et al., 2014).

Rainfall

Changes in rainfall will result in changes in river flows and in lake and wetland and wetland water levels. In New Zealand, annual average rainfall is projected to increase in the west and south and decline in the east and north (Mullan, 2008). Projections of extreme rainfalls also show significant variability that, in turn, varies across the country. Increases in extreme rainfall of up to 8% per 1°C increase in temperature are projected across New Zealand (Mullan, 2008; Ministry for the Environment, 2010; Carey-Smith, 2010) and severe weather systems are projected to increase by 3–6% over most of the country by 2020-2100 relative to 1970-2000 (Mullan, 2011).

At the opposite end of the precipitation scale, drought occurrence with associated reductions in river flows and groundwater levels is also projected to increase in many areas (Clark, 2011). Drought periods are projected to double or triple by 2030–2049 compared with 1980–1999 in eastern and northern New Zealand (to more than two months per year for parts of Northland, Gisborne, Canterbury and Otago).

Snow and ice

Changes in air temperature and precipitation are projected to have opposing effects on snowfall volume and distribution and on glacier dynamics. While warmer temperatures would lead to reductions in the area and duration of snow and ice cover, greater precipitation in alpine areas would tend to increase coverage. Studies of New Zealand's glaciers in the last three decades have shown significantly reduced ice volumes (Collins & Tait, 2016) and those reductions are projected to continue. River flows from glacial areas may increase in some catchments in response to glacial retreat (Chinn, 2001), but the flow increases will be small compared with mean annual flows for most of the rivers, and compared to changes in flows caused by changes in precipitation (Bliss et al., 2014). The timing of river flow peaks may change in alpine-fed rivers, in response to shifts in the timing of snow and ice melt (Zammit, 2011).

River flows and floods

Change in river flows will track changes in precipitation, and the most likely future scenario for river flow is decreased runoff in the east of both islands (except rivers with alpine headwaters) and for increases elsewhere, particularly the central North Island (Fig. 10). East coast rivers with alpine headwaters such as the Canterbury braided rivers are predicted to have increased flows, as indicated in Figure 4.8. However, the uncertainties in these studies are substantial (Woods & Zammit, 2012). They arise from differences in alternative scenarios and from the global climate models used to generate the alternative climates. A review of studies considering climate change implications on river flood discharges and inundation concluded that the projected increase in high intensity storms would invariably cause more intense floods (Collins, 2012). However, modelling with a range of emissions scenarios showed that these projections are also accompanied by large uncertainties.

Groundwater

Several climatic influences are likely to affect groundwater levels and flows. For example, declining precipitation and increasing evaporation are predicted to result in a 10% decrease in land-based recharge to the aquifer under the Canterbury Plains portion in the Rangitata River catchment (Aqualinc Research Ltd, 2011). In the fully allocated Rangitata groundwater zone, this means a 10% decrease in irrigation from groundwater over a period when demand for water is expected to increase. In contrast, a projected increase in precipitation in portions of the Wellington region may result in a doubling in annual potential groundwater recharge (Mollema & Antonellini, 2013). Groundwater tables in aquifers near the coast may reasonably be expected to rise due to projected sea-level rises.

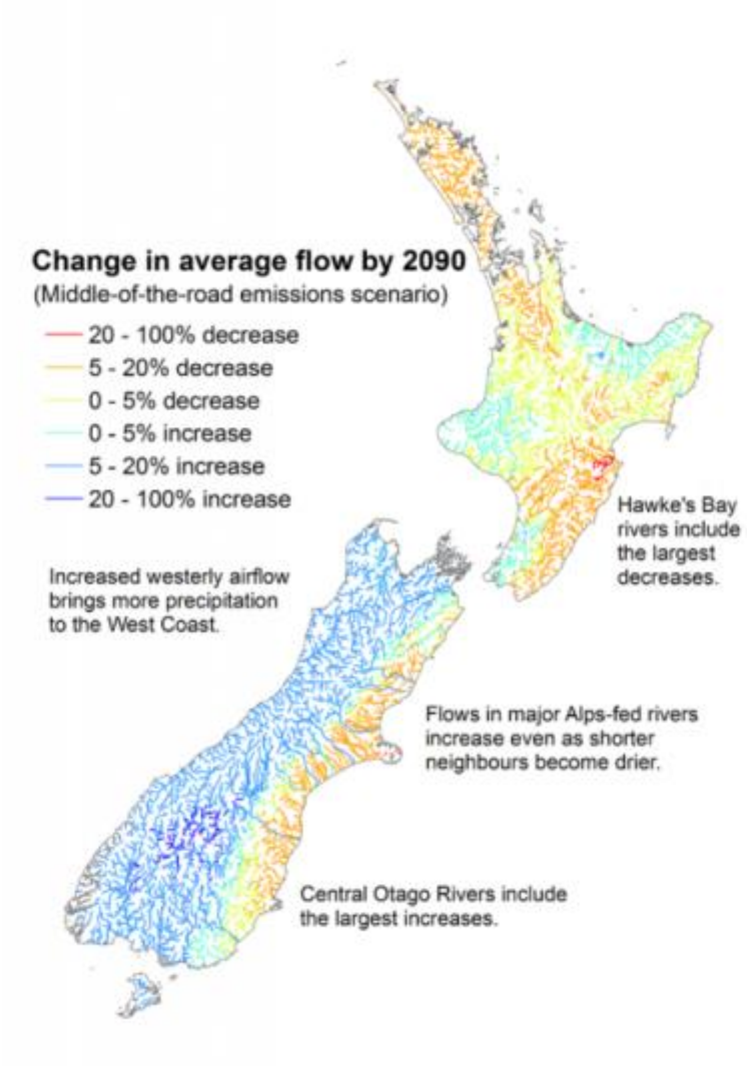

Figure 10: Projected change in mean annual discharge between 1990 and 2090, based on the middle-of-the-road A1B emission scenario and multiple General Circulation Models. Figure modified from Collins and Tait (2016); ©New Zealand Hydrological Society and New Zealand Freshwater Sciences Society

Freshwater ecosystems

Increases in water temperature and changes in flow regimes are likely to be the major climate-change related drivers of ecological effects, although related factors such as glacial retreat and increased abstraction of water may also be important (Winterbourn et al., 2008). Increasing water temperatures are likely to result in shifts in the latitudinal and altitudinal ranges of temperature-sensitive aquatic organisms such as trout and salmon. However, there is uncertainty about responses in most native fish species (Ling, 2010), particularly non-diadromous species (species that do not migrate to the coast). Of particular concern are the observed and future potential declines in glass eels, which may be related to climate (August & Hicks, 2007; Jellyman, 2009). Increased temperatures may increase periphyton growth directly, which can then be compounded by changes in flows and in river nutrient levels (Piggott et al., 2015). Responses to changes in the magnitudes and frequencies of floods and low flows are likely to vary between species and groups of species. For example, some fish communities in gravel-bed rivers appear to be resilient to floods when refuge habitats are available (Jowett, 2005; Davey et al., 2006).

Long-term warming trends have been recorded in several lakes (Hamilton et al., 2013; O'Reilly et al., 2015; Woolway, 2016). The effects of future climate change on lakes will be highly dependent on the lake morphometry, on the geological settings, on the hydrology of the catchment and the dynamics of lake mixing. It will be further affected by alterations to catchment processes and land-use that result from climate change. Warmer lake surface temperatures are likely to increase the severity of cyanobacterial blooms, as long as sufficient nutrients are available to sustain their growth. Cyanobacteria thrive under of conditions of a warm and stably stratified water column with high nutrient concentrations. In contrast, in deep, nutrient-poor lakes, enhanced stratification by warming can reduce the return of nutrients from deep water to the surface layer where they support algal growth (Trolle et al., 2011). Thus the impact of atmospheric warming and possible increased windiness will have complex effects on lake ecosystems that depend on depth, morphometry, altitude and level of nutrient enrichment.

The responses of invasive species to climate change are of particular concern for freshwater ecosystems. Climate change impacts on invasive freshwater species may include shifts in ranges based on temperature tolerance and range expansions due to increased connectivity of water bodies through irrigation infrastructure (de Winton, 2011).

With regard to invasive pest fish, increased water temperature is likely to favour the expansion of warm water species such as koi carp, goldfish, tench, rudd and catfish. These fish can cause water quality degradation and reduced native biodiversity (Kernan, 2015). Increased water temperatures may also facilitate the establishment of tropical fish that are sold in the New Zealand aquarium trade and intentionally or accidentally released.

Increasing temperatures will favour warm-climate invasive aquatic plant species such as water hyacinth (*Eichhornis crassipes*) and *Salvinia* (Burnett, 2008) (Leathwick, 2016). Other invasive, warm-climate species that are present in New Zealand, such as Brazilian pepper (*Schinus terebinthifolius*), cannot be sold and are eradicated where found outside of cultivation.

In the case of invasive invertebrates, increased water temperatures and increased precipitation in some regions will favour species introduced from tropical and subtropical areas. Several disease transmitting mosquitoes in the genera *Culex*, *Aedes* and *Ochlerotatus* have been intercepted at New Zealand ports, primarily in second-hand tyres imported from tropical and subtropical countries (de Wet, 2005; Kean, 2015).

Societal implications

Climate change effects on fresh waters in New Zealand will have profound effects on the social values outlined earlier in this paper and particularly public health, rain- and irrigation-dependent agriculture and hydropower generation (Gluckman, 2013). With regard to public health, the incidence rates of water-borne diseases including salmonellosis, campylobacteriosis, cryptosporidiosis, and giardiasis are likely to increase as a result of increases in river temperatures (Britton, 2010; McBride, 2011; Lal et al., 2013).

Irrigated agriculture is a significant component of New Zealand’s economy and is vulnerable to climate change through shifts in water supply and demand. On the supply side, increasing evaporation and more severe droughts may be expected to reduce supply. Shifts in water supplies are projected to decrease reliability for surface and groundwater abstraction and for larger irrigation schemes (Aqualinc Research Ltd, 2011). On the demand side, greater agricultural water use is highly likely as the primary sector seeks to grow its contribution to the economy, and as rising temperatures lead to increased evaporation from land used for agriculture.

Solutions to the impending gap between water supply and demand are essential areas of agricultural and hydrological research and development. The possible approaches include shifting the mix of agriculture to less water intensive systems, drought resistant forage and crop species, potentially using new biotechnological approaches, precision irrigation (including soil moisture sensing), and artificial intelligence-based water supply and demand forecasting.

Changes in precipitation and glacial retreat are likely to increase winter inflows to both North and South Island hydropower lakes. Electricity production may therefore become more reliable during these times, but in summer months this may reverse (Renwick et al., 2010), as the prediction is for less snow melt to counteract reduced rainfall. Warmer climates and shifts in the magnitude and timing of electricity demand (probably more energy demand for cooling in summer, and less for heating in winter) will also influence hydropower generation.

4.6 CUMULATIVE EFFECTS OF STRESSORS ACTING TOGETHER

The degradation of freshwater environments, communities and populations often results from the cumulative effects of multiple stressors. These factors may be anthropogenic in origin (e.g., synthetic contaminants, biological invasions) or occur at levels that have been exacerbated by human activities (e.g. hypoxia, acidification, eutrophication). Their interactive effects are often synergistic (i.e., effects greater than the sum of individual stressor effects). Furthermore, the responses to stressors are often non-linear and may involve thresholds or “tipping points” beyond which rapid degradation occurs and responses to restoration show hysteresis[45]. Examples include lakes that ‘flip’ from a clear, vegetated state to a turbid, de-vegetated state, usually in response to the combined effects of nutrient enrichment and pest fish (Schallenberg & Sorrell, 2009), and algae proliferations and degradation of invertebrate communities, in response to sedimentation, excessive nutrient enrichment, and increased temperatures in agricultural streams (Quinn, 2000; Matthaei et al., 2010). Managing multiple stressor situations requires systems thinking to link knowledge of multiple pressures to ecosystem responses and community values, and to identify effective mitigations. It also means that limit setting for individual stressors is context dependent.

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[45] Hysteresis is a situation where the state of an ecosystem is dependent on its history and not just on current environmental variables. It means that to reverse a change, the environmental factor responsible for the change has to be set back to a level that is lower than that which led to the recent change.

SECTION 5. WHAT ARE WE DOING, AND WHAT MORE CAN BE DONE?

Key messages:

Solutions to freshwater issues created by stressors are often complex but typically require three components – the availability of appropriate technologies and procedures (e.g., upgraded wastewater treatment, changes to urban or farm management, and mitigation systems); some form of policy intervention (e.g., rules and incentives); and societal pressure and commitment for change.

There are proven methods and technologies for minimising or reducing stresses imposed on fresh waters, including:

- Protecting and restoring riparian zones and wetlands, and prioritising their protection in regional planning rules. This includes riparian planting and fencing to keep livestock out of waterways.
- Ensuring water allocation does not exceed requirements for sustainable flow regimes in rivers.
- Longitudinal monitoring regimes with the monitoring sites appropriate to the nature of the catchment and its likely issues.
- Improving treatment of point source and diffuse source discharges and applying on-site and off-site mitigation tools to ensure that contaminant inputs do not exceed critical thresholds.
- Using pest control technologies to reduce the abundance and spread of pest populations.
- Retrofitting migration barriers to allow fish passage and developing alternative transfer methods.
- Developing and expanding fisheries management for both native and exotic species.
- Ensuring management and restoration efforts consider all stressors so that bottlenecks to improved ecosystem health are removed.

5.1 MITIGATION STRATEGIES FOR DIFFUSE SOURCE POLLUTION

Diffuse pollutants move from land to water through several mechanisms, and understanding these is critical to designing effective mitigation strategies. On-land and in-water solutions to diffuse source contamination have been a major area of research and practical application studies over many years.[46] On land, mitigation measures include: altering fertilizer use and timing as part of a nutrient budgeting approach, soil conservation plantings and hillslope retirement, bridging stock crossings over streams, proper fencing wherever there are livestock, ensuring planted riparian zones and vegetated filter strips, creation of wetlands and denitrification walls, protection of seepage wetlands, restricted grazing in critical source areas for runoff, better management of soil water balance in irrigated land, and enhanced treatment of dairy shed wastewater through advanced pond systems, greater storage and low rate effluent application (McDowell, 2013).

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[46] National Science Challenges. Our Land and Water: http://www.ourlandandwater.nz

Managing surface runoff

Overland flow is probably the largest source of diffuse pollution in New Zealand and comprises mostly particulate pollutants (fine sediment, microbes and particulate nitrogen and phosphorus). Surface runoff is highly dependent on rainfall events, and most of the pollutant load in surface runoff originates in 'critical source areas' (CSAs) such as gullies and dips, where runoff accumulates in high concentrations. CSAs may represent small proportions of catchments, i.e., a large proportion of runoff and associated contaminant transport is generated from a small proportion of the land surface. These are the sites where priority mitigation actions need to be concentrated for cost-effective management of surface runoff pollution (McDowell & Srinivasan, 2009). Good management practices such as contour tilling and planting, and maintaining grassy strips, wetlands and stream-bank vegetation can establish 'filters' to intercept diffuse pollutants in the surface runoff before it enters waterways.

Other good management practices include the use of slow release fertiliser such as rock phosphate that minimises soluble fertiliser loss during rainfall (Hart et al., 2004), and livestock stand-off pads that prevent soil damage from treading compaction during wet weather.

Riparian management

Managed riparian buffers reduce inputs of sediment, nutrients and pathogens to water by intercepting surface runoff, by preventing livestock access to water and banks and associated contaminant input, pugging and erosion, and by removing contaminants in surface and shallow groundwater flows from upslope. Riparian management has been a key part of New Zealand efforts to control diffuse source pollution and maintain habitat values in land used for urban, production forestry and for some agricultural uses for many years, and has been a major focus of stream restoration activity (McKergow et al., 2016).

Forested riparian buffers (average 18 m wide) along pine plantations on the Coromandel Peninsula were shown to be effective in mitigating stream habitat damage during logging, whereas without buffers clear-fell logging impacts on macroinvertebrate communities persisted (Reid et al., 2010). Riparian buffers along pastoral headwater streams have been shown to increase shade and reduce stream temperatures and instream vegetation within six years of planting (Quinn et al., 2009). These changes were associated with changes in stream macroinvertebrate communities towards those more typical of native forest streams, particularly in the smaller streams. However, some constraints need to be overcome, such as physical separation from populations of invertebrates that are needed to recolonise the riparian restoration sites (Parkyn & Smith, 2011). Spatial arrangement of riparian restoration projects should be considered when prioritizing effort, so as not to limit the rate of aquatic invertebrate community recovery.

Despite its successes, riparian management is not a universal panacea. For example, it will not stop sediment mobilised from heavy rainfall after land disturbance in steep country, so both land use controls and riparian management together are needed.

Wetland restoration and construction

Wetlands are referred to as the 'kidneys of catchments' because of their role in filtering and purifying water. Removing nutrients, bacteria and sediment from land is a major ecosystem service provided by natural, restored and constructed wetlands. For this reason, protective management of remaining small wetlands on farms and constructing new wetlands at critical points in catchments are important actions that farmers can take to protect and restore the water quality of receiving waterbodies (Fig. 11; (Tanner & Sukias, 2011; Tanner et al., 2015).

Preventing direct access of livestock to water

Stock access to lake, wetland and stream margins adversely affects water quality by damaging stream margins, increasing their susceptibility to erosion and runoff, and by direct dung and urine deposits in surface waters. Prevention of livestock access by fencing is well-recognised as an important good management practice, with bridged stream crossings also important on dairy farms where cows often cross streams as they move to and from milking sheds. As a result of the Sustainable Dairying Water Accord, DairyNZ reports that 96% of dairy cows have now been excluded by fencing from waterways >1m wide and >30cm deep on farms where they graze (DairyNZ, 2013). However, beef cattle, deer and sheep also contribute to pollution. Stock exclusion regulations have been recommended by the Land and Water Forum (Land and Water Forum, 2015), and will soon be promulgated.

Figure 11: Examples of created wetlands on farmland to treat surface runoff (left) and drainage (right) (photos Chris Tanner, ©NIWA).

Limiting leaching to groundwater and subsequent discharge in surface water

Leaching is a major pollutant pathway in New Zealand due to the large areas of porous alluvial and volcanic soils underlain by aquifers. Leaching is particularly problematic where nitrate accumulates in aquifers that have sufficient dissolved oxygen to prevent denitrification to nitrogen gas. Nitrogen leaching from pastoral land is primarily sourced from urine patches of grazing stock, and this is exacerbated through nitrogenous fertilisers and humus from nitrogen-fixing pasture plants. On irrigated land, leaching can be minimised by careful application of fertiliser and water, i.e., by ‘precision irrigation’. Leaching can also be intercepted at the stream boundary by riparian buffers or constructed interception wetlands and denitrification beds or walls[47] (Tanner et al., 2003; Tanner & Sukias, 2011; Christianson & Schipper, 2016).

Managing eutrophication

Eutrophication encompasses a wide range of effects when nutrient-enhanced plant growth exceeds ecologically beneficial levels. Effective management of eutrophication generally begins with broad consideration of the local and downstream context of the eutrophication issues and drivers to identify appropriate solutions. For lakes this may involve a combination of:

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[47] Denitrification beds and walls are structures (containers or trenches) that contain woodchips or sawdust, with carbon that provides an energy source for bacteria that convert nitrogen into nitrogen gas and release it into the atmosphere. Effluent and surface water discharges from agricultural land can be filtered through these structures to remove nitrate.

- External nutrient controls: management of diffuse and point source pollution and riparian management (Hamilton, Salmaso, et al., 2016).
- In-lake nutrient management: diversions of polluted inflows, dredging, bottom-water oxygenation, flocculation, destratification, increased flushing, and lake bed nutrient capping[48] (Beutel & Horne, 1999; Hickey & Gibbs, 2009; Özkundakci et al., 2010)
- Pest fish control: fish such as koi carp or rudd can act as nutrient pumps by consuming nutrient-rich sediments and excreting bioavailable nutrients into the water column, and their feeding actions also resuspend sediments (Collier & Grainger, 2015).

Nutrient enrichment is typically the main focus of eutrophication control. Plant and bacterial growth in an aquatic system becomes limited by the availability of an essential element, generally nitrogen or phosphorus. This, in theory, constitutes the limiting nutrient for that system at that time (Correll, 1998), suggesting that inputs of that nutrient can be managed to limit eutrophication. However, given that trophic status can vary spatially and temporally due to a number of dynamic factors including climate, flow, geology, soil composition, and biological processes, this is now considered to be overly simplistic.

The relationships between nitrogen and phosphorus concentrations and eutrophication symptoms (e.g., algal biomass measured as chlorophyll *a* and visual clarity) are more straight-forward and generalized for lake phytoplankton than for periphyton in rivers. In lakes, well-established relationships exist between average and annual maximum concentrations of phytoplankton chlorophyll-*a* (a measure of phytoplankton concentration) and TP and/or TN concentrations. Internationally, phosphorus has been the focus of eutrophication management in lakes because some lake cyanobacteria fix atmospheric nitrogen to compensate for shortages in bioavailable nitrogen, which would then shift the limiting nutrient to phosphorus (e.g., (Correll, 1998; Schindler et al., 2016; Wang & Wang, 2009). Comparisons of lake nutrient limitation using both historical and recent data suggest that nitrogen limitation is more prevalent in New Zealand systems than overseas, although phosphorus limitation, and co-limitation of both nitrogen and phosphorus, is widespread and can be spatially variable within lakes (Abell et al., 2010).

An assessment of nitrogen- versus phosphorus-limitation in New Zealand rivers, based on DIN:DRP ratios, suggests that nitrogen availability limits periphyton growth in at least 15% of the sites assessed (McDowell et al., 2009). Furthermore, the cyanobacterium *Phormidium*, which commonly forms thick, potentially toxic, mats in rivers, is able to scavenge phosphorus from fine sediment entrapped in its mat (Wood et al., 2015) and does not fix nitrogen from the atmosphere, and thus appears to be controlled at many sites by DIN availability (Wood, S.A. et al., 2014; Heath et al., 2016).

These generalized predictions about nitrogen- versus phosphorus-limitation do not address the fact that limiting nutrients may shift in time and space, and that simultaneous co-limitation by nitrogen and phosphorus may be as common as either nitrogen- or phosphorus-limitation (McDowell et al., 2009). Moreover, algae in coastal fresh waters tend to be nitrogen-limited more frequently than phosphorus-limited (Paerl, 2009). These considerations support the need for both nitrogen and phosphorus management to control eutrophication in New Zealand (Wilcock et al., 2007; Abell et al., 2010), and is acknowledged worldwide as a necessary management approach (Paerl et al., 2011; Lewis et al., 2011; US EPA, 2015).

In rivers, dynamic interactions, including uptake and release, between dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) in the water column and periphyton on

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[48] Nutrient capping or sediment capping is the application of a thin layer of (non-porous) material on the lake bed sediment to stop the release of nutrients (mainly phosphorus).

the riverbed greatly complicates nutrient-periphyton relationships in space and time. Periphyton can deplete water nutrients as it grows, which reduces nutrient levels downstream. The consequence can be that as periphyton may show rapid growth in the period between flow disturbance events, so that high periphyton biomass can be associated with low nutrient levels at the time of sampling. Furthermore, recent studies indicate that phosphorus associated with sediment deposited on streambeds and scavenged by periphyton mats can support periphyton growth during low-flow conditions (McDowell, 2015; Wood et al., 2015). These dynamics, and between-river variations in other influences including flow regimes, shade (and water temperature), bed stability, and grazing by benthic herbivores, lead to high variation in nutrient/periphyton relationships (Larned, 2010) and high uncertainty in statistical models used to predict periphyton biomass from these combined influences (Snelder et al., 2014). As a consequence, location-specific studies and location-specific nutrient targets are needed to effectively manage periphyton. This is very complex and difficult from a management perspective.

Riparian shading in small-medium streams (Davies-Colley & Quinn, 1998) and flow regime management (Biggs et al., 2008; Nilsson & Renöfält, 2008) can also support eutrophication control.

5.2 MODIFYING PRIMARY SECTOR PRACTICES

The primary sector has set out several commitments and codes of practice to address diffuse source pollution, but in the absence of more stringent regulations, success will depend on the decisions of thousands of individual farmers. In 2013, the dairy industry signed the Sustainable Dairying: Water Accord,[49] a set of national 'good management practice' benchmarks aimed at lifting environmental performance on dairy farms. The Accord includes commitments to "targeted riparian planting plans, effluent management, comprehensive standards for new dairy farms and measures to improve the efficiency of water and nutrient use on farms." Irrigation New Zealand has a recommended set of principles for sustainable irrigation known as SMART (Sustainably Managed, Accountable, Responsible and Trusted)[50] to minimize the environmental impacts of irrigated farming. Efforts such as the Taranaki Riparian Management Programme, begun in the early 1990s with ratepayer support, is a voluntary scheme that entails a significant investment for farm property owners, but offers a choice to take the lead in environmental stewardship rather than waiting for regulatory enforcement (Taranaki Regional Council, 2011). Other sectors within the primary industries have similar voluntary 'environmental codes of practice'. Such codes are important, but they are unlikely to achieve the nationwide improvements in fresh water sought through the NPS-FM and expected by many New Zealanders. As explained elsewhere in this report, in some places the gap is just too big, and there are significant legacy issues to be addressed.

The fertiliser industry is supporting commitments to improve sustainable use of freshwater resources in the primary sector. These commitments include that "by 2013 80% of nutrients applied to land nationally are managed through quality assured nutrient budgets and nutrient management plans…" (Land and Water Forum, 2010). The use of models for improving farm practices to reduce nutrient losses has increased considerably in the last decade.[51] The Overseer nutrient budget model (OVERSEER®) is a farm-scale nutrient management tool and is one of a growing number of on-line tools supporting New Zealand farmers to farm better. Being able to

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[49] DairyNZ. Sustainable Dairying: Water Accord https://www.dairynz.co.nz/environment/in-your-region/sustainable-dairying-water-accord/

[50] Irrigation New Zealand, SMART irrigation. http://smartirrigation.co.nz/smart-irrigation/what-is-smart-irrigation/

[51] AgResearch. Online tools to help farmers, land and waterways. www.agresearch.co.nz/news/online-tool-helps-farmers-land-and-waterways/

estimate nitrogen and phosphorus losses to the environment has not only benefited farmers in cost-effective nutrient management, it has also seen OVERSEER become an important tool for regional councils as part of their role in managing water quality, but more behavior change is still needed.

McDowell et al. (2013) summarised knowledge of the cost effectiveness of strategies to minimize diffuse nutrient pollution from farms. Technologies such as wetland construction or denitrification beds can be very effective but, in general, effectiveness is related to cost of implementation.

Effective control of diffuse pollution involves management actions (Table 4) at several levels across a catchment landscape: 1) reductions of pollutant inputs at sources (e.g., reducing fertiliser applications or animal stocking rates); 2) widespread use of on-land mitigation methods to reduce pollutant loss; 3) retiring, or not permitting certain activities on sensitive land; and 4) employment of downstream mitigations, interventions and restoration activities. Solutions need to be focussed on the processes by which pollutants move from land to water and the processes by which pollutants are transported and transformed in the interconnected waterways of catchments. But the cost effectiveness of these various strategies varies widely.

Table 4: Mechanisms that mitigate nutrient loss from farm soils to waters and measures that enhance attenuation in and near streams (Adapted from (Howard-Williams, 2010)©OECD).

Reducing nutrient loss from farms	Enhancing attenuation in and near waters
Improved weather and climate forecasting	Riparian strips
Precision irrigation to minimise leaching	Wetland and seep protection
Feed pads, herd homes, wintering off-site	Maximising aerobic-anaerobic interface for denitrification
Fencing off waterways	Constructed wetlands
Riparian and farm drain management	Managing natural wetland
Reducing fertilizer use and increasing use of slow release fertilizers	Promoting in-channel vegetation
Nitrification inhibitors	
Constructed wetlands and denitrification walls	
Nutrient budgets, nutrient mapping and on-farm nutrient models	
Nutrient trading/capping	

In combination, diffuse sources of sediment, pathogens, nitrogen and phosphorus are an ongoing problem. This creates a core policy dilemma – can land use intensification continue to meet the Government’s economic goals[52] while being matched by improved land management, improved implementation of mitigations, and stronger measures in regional policies and plans driven by the NPS-FM (2014) and the primary sector – or will the drive to agricultural intensification need to be reviewed? Can major shifts in land-use and production patterns and/or new technologies help resolve this challenge? Lags in policy implementation are also highly important in the context of systems with tipping points (Mueller et al., 2015). This is a major and complex set of decisions for New Zealand which merits deep discussion beyond traditional political rhetoric.

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[52] Ministry of Business, Innovation and Employment: Business Growth Agenda http://www.mbie.govt.nz/info-services/business/business-growth-agenda

5.3 INVASIVE SPECIES MANAGEMENT

Invasive freshwater plants and animals have adverse effects on economic, ecological, amenity and cultural values and can be a significant bottleneck to freshwater restoration initiatives. Control methodologies exist for some pests but not all, and the success of these methodologies is situation-dependent. Eradication of some freshwater pests has been possible and there has been some success in limiting the geographic spread of others.

Preventing new incursions at the border

Many of our current pest fish species were legally introduced into New Zealand for ornamental or recreational fishing purposes, or to control mosquitoes (Collier & Grainger, 2015), with some (e.g., rudd) illegally entering the country. More than 90% of the freshwater plant pests arrived via the aquarium or nursery trade (Duggan, 2010). Other pathways of introduction to New Zealand include shipments of aquarium and pond plants contaminated with pests, contaminated fishing and boating gear, mosquitoes in imported used tyres, and importation of culinary species (Champion et al., 2007; Derraik, 2004).

All legally imported organisms and identified risk pathways are subject to Import Health Standards under the Biosecurity Act 1993. The border is now effectively closed to legitimate importation of freshwater organisms, with no new freshwater organisms imported since the passing of the Hazardous Substances and New Organisms Act 1996 - however, accidental or illegal introductions still regularly occur (Champion et al., 2007).

The threats posed by numerous plant and fish species that have not yet reached New Zealand have been assessed, and their likely pathways of entry identified (Champion et al., 2002; Rowe & Wilding, 2012). This information has been used to determine a list of species that are prohibited from entry into the country. Potential pest species that are already in New Zealand, but are not yet naturalised or sparingly naturalised with limited published evidence of impact, have been evaluated for the risk they pose through competition experiments (Champion et al., 2007; Hofstra, 2010).

Despite the application of tools to predict likely new invasive species, a number of pest species have been observed in New Zealand that had no or minor pest histories elsewhere (e.g., marshwort (*Nymphoides montana*) and water net (*Hydrodictyon reticulatum*) (Wells, 1999; Kilroy & Unwin, 2011). New Zealand must maintain a capacity for adaptive incursion response in order to deal with the potentially unpredictable consequences of future incursions if and when they eventuate.

Pest establishment in natural environments

Once introduced into New Zealand, the next stage of pest invasion is establishment in one or more freshwater systems. Unlike many terrestrial and marine systems, freshwater systems do not form spatially interconnected habitats and can be viewed as 'islands in a terrestrial sea', with barriers to dispersal for the majority of freshwater pests that are circumvented only by human activities. Therefore, opportunities exist to protect valued systems or to curtail the geographic spread of some pests. However, detection and delimitation poses challenges as many freshwater pest species are cryptic, and become visible only when well established. Further, increased connectivity of water bodies through irrigation and inter-basin transfers reduce barriers to dispersal (de Winton, 2011).

Transfer of pest species between water bodies is predominantly human-mediated. The main mechanism of pest fish spread has been by deliberate stocking, with additional, accidental transfers in eel nets, trailers and boat bilge water and bait tanks. Asexually reproducing pest plant species are also spread between water bodies by human activities, including aquarium liberation or ornamental plantings, contaminated water-craft and trailers, fishing nets, or drainage equipment.

In addition to their use in preventing new incursions, pest risk assessments have been used to prioritise management for aquatic pest species that are already in New Zealand (Reaser, 2008). For example, 30 aquatic plants that ranked highly as pests are now banned from sale and distribution nationally (Champion, 2000, 2014). Early detection of new freshwater pest incursions can allow pre-emptive management of those species before they fully establish in a region (or nationally), with the possibility of removal of pest populations.

Surveillance programmes have been designed for both pest plants (Champion, 2008) and pest fish (Grainger, 2015). Molecular detection tools offer the promise of early detection of some pest species (Banks, 2015). Surveillance has been guided by modelling approaches used to identify sites where there is a high probability of pest introduction and establishment (Compton, 2012) (Leathwick, 2016). Further research investigating the dynamics of human-mediated spread of aquatic pests is planned under the Biological Heritage National Science Challenge.

There is currently no nationally coordinated surveillance strategy for fresh waters and, despite most regions having regional pest management plans that include freshwater pests (Byers, 2015), surveillance typically has a high reliance upon public reporting. Methodologies to design robust and efficient surveillance programmes exist for invasive plants (Champion, 2008, 2014) and fish (Collier & Grainger, 2015) but the scale of the issue means that public reporting will always have a key role in incursion detection.

Six of the highest ranked aquatic weeds[53] are in the early stages of invasion in New Zealand and are targeted by national eradication programmes initiated by MPI in 2008. One of those weeds, *Ceratophyllum demersum* (hornwort), has now been eradicated from all known South Island sites. A further six aquatic weed species have been eradicated nationally (Champion, 2014). Control techniques available to manage plant invasions include manual and mechanical removal, habitat manipulation, and herbicides (Champion et al., 2002; Hofstra, 2012; Collier & Grainger, 2015).

Successful eradication of established populations of the pest fish koi carp have been achieved in the northern South Island (Collier & Grainger, 2015). Even if eradication is not feasible, there are considerable environmental and cost benefits to containing outbreaks and actively slowing pest spread before widespread management is required. Management techniques for fish invasions include barriers, screens, trapping, electrofishing, and piscicides. Current research areas include developing a natural bio-control agent for submerged weeds and an attractant bait for pest fish.

The improvement or restoration of freshwater systems is a high priority for the New Zealand public, but invasive species and their impacts are major obstacles to restoration. A combination of selective control tools to suppress invader populations below impact thresholds and techniques to aid the establishment of indigenous biota is needed.

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[53] Includes the aquatic pest species *Phragmites australis* (common reed or cane grass), *Hydrilla verticillata* (water thyme), *Zizania latifolia* (Manchurian wild rice), *Ceratophyllum demersum* (hornwort), and *Eichhornia crassipes* (water hyacynth)

Figure 12: Examples of techniques to retrofit fish migration barriers. Left: oyster spat ropes for climbing galaxiids (photo Bruno David, Waikato Regional Council). Middle: culvert flow baffles. Right: rock ramps (photos Paul Franklin, ©NIWA).

5.4 RESTORING CONNECTIVITY

Since regulations were first promulgated in 1947, dams and diversion structures in New Zealand are required to have provisions to maintain fish passage, but in many cases these are either lacking or ineffective. Re-establishing within-stream connectivity has become a goal for river restoration projects worldwide (Lake, 2007; King, 2016) and it can be a cost-effective and rapid means of recovering freshwater biodiversity and ecosystem processes (Roni, 2008; O'Connor, 2015). However, research in New Zealand indicates that fish passage designs and other methods used to re-establish connectivity in the Northern Hemisphere are ineffective for some native New Zealand species due to differences in their biological characteristics and ecology (Franklin, 2016). This presents challenges for enhancing connectivity for fish in New Zealand, which are being addressed by new research and the recently established New Zealand Fish Passage Advisory Group.[54]

The first priority should be preventing the installation of barriers to fish passage. But to mitigate the impacts of existing instream barriers such as weirs and culverts, a number of retrofit solutions have been developed, including fish ramps, baffles and mussel spat ropes, and inlet and outlet pools (Fig. 12). Understanding of the effectiveness of these solutions in practice remains limited (Baker, 2003; Katopodis, 2005; Roni, 2008; Franklin, 2012, 2016). To date there has been little uptake of technical fish pass designs in New Zealand, although work in Australia has shown that vertical slot fishways are effective for facilitating the upstream passage of inanga at low-head obstructions (Morgan, 2006). New research should improve fish passage enhancements by providing better understanding of the physical capabilities of fish (e.g., swimming speeds, jump heights) and the factors that influence their behaviour as they approach and pass instream structures (e.g., water velocity gradients, turbulence).

Hydropower dams impede the upstream and downstream migrations of several native and sport fish species (Jellyman, 2012). In New Zealand, mitigation for the effects on hydropower dams on fish migrations have largely consisted of trapping juvenile fish at dam faces and manually transferring them upstream. Approximately 10 million juvenile eels are transferred around New Zealand hydropower dams annually. Large eels migrating downstream are killed by turbines or by suffocation on intake screens (Boubée, 2001; Young et al., 2004). Methods for providing safe downstream passage for migrant eels at hydropower dams remains a significant technical gap in New Zealand, although progress is being made internationally (e.g. (Piper, 2015; Silva, 2016)).

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[54] Department of Conservation. New Zealand Fish Passage Advisory Group. http://www.doc.govt.nz/nature/habitats/freshwater/fish-passage-management/advisory-group/

5.5 MANAGING FISHERIES

Fishing is a key activity through which New Zealanders and tourists experience our fresh waters. However, fishing also creates risks of over-exploitation, which can reduce populations below sustainable levels or encourage the spread of non-native sports fish such as brown trout (Crowl et al., 1992; Rowe & Wilding, 2012). Because freshwater kai (food) is fundamental to Māori culture, iwi have a long tradition of sustainable harvest, and iwi authorities have a growing role in the management of customary fisheries of eels/tuna, lamprey/kanekane/piharau, freshwater crayfish/kōura and mussels/kākahi/kāeo (McDowell, 2011). Species such as eels and salmon are expected to be particularly sensitive to high fishing pressure because they only breed once at the end of their lives.

Commercial and customary eel fishing are managed by MPI under the Quota Management System. Despite this management, there is evidence of reduced abundance of large eels and an associated decline in customary fishing. The combined effect of fishing, wetland loss and migration barriers has been estimated to have reduced the biomass of large longfin eels to less than 20% of historical values (Ministry for Primary Industries, 2014). A review of the status of longfin eels included a recommendation that the commercial catch be suspended until stocks have recovered (Parliamentary Commissioner for the Environment, 2013).

Whitebait runs are believed to have declined from historic levels due to habitat loss, particularly wetland drainage and damage to riparian spawning areas (Hickford & Schiel, 2011), although catch rates vary greatly from year to year. The whitebait fishery is managed under national regulations that regulate the season, time of day and methods for fishing, but do not limit the total catch and permit catch sales. The impact of fishing on whitebait abundance is not known, but recent measurements of whitebait movement rates suggest that current fishing methods could have negative impact on adult recruitment (Baker, 2015). Recent advances in identification of whitebait spawning habitat have led to widespread restoration efforts based on stock exclusion and artificial spawning substrates (Hickford, 2013).

Salmonids (trout and salmon) and coarse fish (e.g., perch and tench) are managed mainly by the Fish and Game Councils. Sports fishing pressure has remained relatively constant over the last twenty years at around 1.27M angler-days per year (Deans et al., 2016). Significant declines in angler use of some areas, such as lowland Canterbury streams as a result of declining fish populations as measured by spawning surveys and drift diving, have been matched by increases in effort elsewhere, such as inland Otago and Canterbury lakes. The management tools for sports fish, involving hatchery replenishment of stocks, spawning season closures and bag limits, together with increasing voluntary adoptions of ‘catch and release’, appear to be effective in managing stocks.

SECTION 6. CATCHMENT MANAGEMENT CHALLENGES ARE EMERGING

Key messages:

- New Zealand has a long history of catchment management to address land and water issues
- The NPS-FM requires regional councils to manage all their fresh waters on a catchment basis, including the setting of environmental limits to protect both instream and out-of-stream interests in water.
- The larger the catchment the more complex and difficult catchment management becomes
- Catchment management is dependent on robust science, including appropriate monitoring regimes, to account for spatial variation in the geography and geomorphology of the catchment, the sources of water and contaminants and natural attenuating processes
- Catchment management needs science to quantify time frames for transport of water and contaminants and the environmental response to these.
- Adaptive management will be a long-term process that may involve infrastructure change.
- Holistic catchment management requires that communities work together to address land and water issues and that these are seen as measurable improvements in ecological bottom lines.
- In large catchments, we have yet to measure success of catchment planning and management primarily because of the long time-scales needed for improvements to take effect.
- Social and societal expectations need to be taken into account in catchment-level management.

New Zealand has a long history of involvement in catchment management. In the 1940s to 1960s soil and water conservation activities, largely regulated through Catchment Boards, resulted in several successful catchment management initiatives primarily aimed at reducing erosion (e.g. Lake Taupo Catchment Control Scheme 1966; Kaituna Catchment Control Scheme). The Resource Management Act (1991) gave Regional Councils, whose jurisdictions are essentially catchment-based, responsibility for managing catchments. The National Policy Statement for Freshwater Management (Ministry for the Environment, 2014) has provided clear direction to Regional Councils "*To improve integrated management of fresh water and the use and development of land in whole catchments including the interactions between freshwater, land, associated ecosystems and the coastal environment.*"

The holistic nature of this direction sits well with much of what has been covered in this report – the multiple stressors on fresh waters, that fresh waters are a product of their catchments, and that restoration requires that key 'bottlenecks' need to be overcome. Freshwater science advice is increasingly sought in the area of catchment management and catchment-scale planning for development of regional policies and plan rules. Evidence-informed policy development is important, recognizing that there is a need to consider how scientific advice on improving water quality and ecological health is placed alongside advice on the economic, social and cultural impacts of implementing that advice.

It is inherently logical, and apparent from our experience in New Zealand, that the success of catchment management in delivering clear biophysical benefits to water quality and quantity is easier when catchments are small. The New Zealand Landcare Trust (www.landcare.org.nz) has been particularly successful in promoting catchment management in several parts of the country, and has shown that with clear plans and dedicated stakeholder groups, small catchments can be managed in an integrated way to achieve environmental and economic goals.

A well-studied example of implementing catchment mitigations to achieve water quality and ecological health improvement is the Mangaotama catchment, a sub-catchment within the Waipa River catchment (Hughes & Quinn, 2014). The Mangaotama Stream faced several issues including high rates of erosion and nutrient and bacterial contamination, reduced water quality, and loss of aquatic biodiversity. Catchment management actions included poplar tree planting for erosion control, native vegetation planting in riparian zones and hillslopes, and stock exclusion from waterways. In addition to these actions, land use changes included pine afforestation on steep land and changes in sheep and beef grazing practices and breeds. Post-management trends in water quality included increasing water clarity, increasing macroinvertebrate community index scores at two of five sites, and reduced phosphorus and nitrogen losses at the catchment outlet. The relatively small size of this stream catchment undoubtedly contributed to these successes.

Environmental bottom lines can be met in small catchments with community collaboration, where the aim is to reduce a single target attribute (e.g. the Aorere River) and when environmental externalities are constrained within a catchment headwater area (e.g. the Mangatoama). However, management gets more difficult as catchment size increases. Management at large catchment scale is not just a question of upscaling from small catchments because as catchment size increases so does the:

- range of geographical and geomorphological influences on the catchment;
- range of water and contaminant source characteristics;
- range of interlinked receiving environments;
- complexity of hydrological network, usually involving interactions between surface water and groundwater;
- fresh water and salt water interactions at the coastal interface;
- number and range of stakeholders and diversity of their interests; and
- number and complexity of multiple stressors and their interactions.

The complexity of managing large catchments can be seen through examples in the Selwyn River (Canterbury) and the Waikato River.

The Selwyn River catchment

The Selwyn River catchment (256,000 ha) is subject to Variation 1 of Canterbury Land and Water Plan. Multiple and complex issues are faced in the Selwyn catchment following a long legacy of impacts from land use that include: reductions in river flows, wetland drainage, river gravel extraction, irrigation takes, land use intensification and increasing nitrogen loads, and the river flows and water quality no longer being swimmable or supporting once high trout stocks. Furthermore, at the bottom of the catchment the receiving water body is Te Waihora/Lake Ellesmere, a treasure for Te Runanga o Ngai Tahu and most diverse wildlife habitat in the country. This lake is well known for its environmental issues (Hughey & Taylor, 2009). It is classed as a hyper-trophic lake with high suspended sediment concentrations and algal and cyanobacterial blooms (sometimes toxic). Lake levels are managed in a way that has not always been to the benefit of the ecological health of the lake. The lake has high biodiversity values and significant fishery values (cultural and commercial). The catchment has large, complex groundwater aquifers that interact with the inflowing Selwyn River and considerable water abstraction in the catchment (Larned, 2008). High levels of nutrients enter the lower reaches of the river from the aquifers. It is not possible to identify the sources of those nutrients other than from general farming practices across the Canterbury Plains. To protect the river and Lake Ellesmere/Te Waihora, all farms have been issued with a nitrogen discharge allowance and there is a zone in the catchment demarcated for phosphorus controls (Variation 1 of Canterbury Land and Water Plan). A "Cultural Landscapes Management Area" in the Selwyn-Waihora Plan has special provisions covering the high cultural value of the lake and calls for precautionary approach to dealing with this. In aiming for lake restoration to meet the expectations of Maori, Ngai Tahu have recognized an 'intergenerational' time-frame for restoration of the lake.

The Waikato River catchment

The Waikato River catchment is very large (1.1 million ha) and currently subject to a change to the Waikato Regional Plan that will set policies and rules to reduce sediment, bacteria and nutrients (N and P) entering water bodies. The goal of the 'Healthy Rivers Plan for Change' is to "*restore and protect water quality in the Waikato River, while maintaining a vibrant economy*". The proposed plan change for the next 10 years is the first step towards meeting the Vision and Strategy for the Waikato River/Te Ture Whaimana o Te Awa o Waikato over the next 80 years (also an inter-generational time frame). Two of the (many) issues that make management difficult in this catchment relate to spatial complexity and time lags in water turnover rates. Large catchments such as the Waikato have wide differences in geology, soil types and land uses. This complexity means that some interventions will need to differ in different sub-catchments if the desired improvements in water quality are to be achieved most efficiently. This makes policy and plans (and associated rules) difficult to draft, challenges large scale limit-setting, and leads to 'winners and losers' and varied perceptions of fairness between different types of land use.

Successful management of a small catchment – the Aorere Catchment Project

One good example successful small catchment management is the Aorere River catchment in Golden Bay, where the aim was to target faecal microbial pathogens that affected downstream water users. The Aorere catchment flows into Golden Bay. Over 80% of the catchment is made up of native forest, with the remainder being 16% dairy pasture (13,000 cows), 3% scrub and 1% exotic forest. Despite the small proportion under pastoral agriculture, water quality was declining. The estuary and nearby coastal receiving waters are home to a significant shellfish aquaculture industry ($15M pa), and declining water quality and particularly microbial pathogens from farming were adversely affecting harvesting of aquaculture in the Bay.

A catchment management project was initiated under the NZ Landcare Trust in 2006 and involved a dairy community-led project that supported modelling of contaminant (particularly pathogen) loss from land; tailored individual farm planning and implementation to address water quality issues and community problem solving (with experts/scientists assisting). Within two years, notable increases in shellfish harvesting had been recorded. The Aorere River Project[55] continues to improve the ecological health of the river and coastal environment and has assisted dairy and marine farmers to coexist and maintain their livelihoods sustainably. Improvements in the catchment environment resulted in the Aorere River Project winning the inaugural Morgan Foundation NZ Riverprize at the International River Symposium awards in Brisbane in September 2015.

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[55] The Aorere Catchment Project in the Golden Bay area of the Tasman District is an award-winning community approach to improving catchment wellbeing. http://www.landcare.org.nz/Regional-Focus/Nelson-Office/Aorere-Catchment

SECTION 7. CONCLUDING REMARKS – FRESH WATER AND THE FUTURE

What kind of waterscape will the next generation of New Zealanders inherit? As this report illustrates, the issues are complex, the stakeholders multiple, and potentially contentious and very challenging decisions will be needed. We will require innovative science and technology to progress towards effective and in some cases ground-breaking solutions that are broadly accepted. We will need national conversations that are nuanced and go beyond traditional political rhetoric.

There is a need for research that extends from the basic natural sciences to the applied sciences, including the social sciences. The recently released Conservation and Environmental Science Roadmap[56] and the soon to be released Primary Sector Science Roadmap[57] are important guides to the research gaps that will need to be filled. Several of the National Science Challenges also directly contribute to the research effort. While the quality of environmental reporting has been improved by the commitment to a regular series of State of the Environment reports, there remains the need for expanded and systematic data collection and monitoring regimes.

However, the science can only go so far; its role is to provide the evidence-base to inform policy and actions and to suggest the options and opportunities that exist. Central and local government, the private sector and non-governmental organisations (NGOs) all have a major role to play. Participation of Māori has and will continue to have a strong influence on freshwater management and investment.

The state of fresh water in New Zealand is the consequence of human endeavours over many decades. Changes in land use through farming and deforestation, urbanisation, industrialisation, and intensifying pastoral agriculture have simultaneously led to the development of New Zealand as an advanced economy and to range of adverse impacts on the freshwater estate. To a significant extent, these changes could be irreversible if humans continue to live and thrive on this land in the way we have in the past. However as we have become more conscious of our impact on our environment, New Zealanders have become more aware of and concerned about addressing these adverse effects.

To do this we need to take into account the many human-induced stressors we have placed on our freshwater resource, and the fact that stressors may act independently or in concert. Limit setting for individual stressors will need to be context dependent and not myopic, because focussing only on those stressors for which limits have been developed may cause us to miss taking action on other important matters.

The challenge remains: we rely on agriculture for economic prosperity, we exploit our rivers and lakes for power generation and we live in sprawling urban areas in close association with our freshwater estate. Yet we also value high quality lakes and rivers for our tourism industry, ecosystem services, and for their cultural and recreational values. Shifting this relationship is not simply a matter of shifting emphasis, it will require deeper consideration of longer-term strategies including how new technologies and approaches can assist both the economy and the environment.

Considerable work is now being directed by research agencies, academics, industry organizations and regional and central government to address the freshwater issues facing New Zealand. In addition, there is increased stakeholder and community participation in freshwater planning,

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[56] Ministry for the Environment and Department of Conservation: The Conservation and Environment Science Roadmap http://www.mfe.govt.nz/about-us/our-policy-and-evidence-focus/conservation-and-environment-science-roadmap

[57] Ministry for Primary Industries, in progress

limit setting and in restoration activities. There is no universal set of solutions – in many cases the solutions will need to be catchment-specific, and some, because of the nature of the catchment, may take decades to have maximal effect. New ways of utilizing our land for economic gain that also have lower environmental footprints need to be found and adopted if we are to meet the vision New Zealanders have for their fresh waters. In turn this may create a further set of societal discussions that will continue to challenge us as a nation.

GLOSSARY

Abstraction: the process of taking water from a river, groundwater or other source, either temporarily or permanently, for irrigation, industry, recreation, flood control or treatment to produce drinking water.

Aesthetic/amenity value: The natural or physical features of an area or thing that contribute to people's appreciation of it, such as its visual appeal. (e.g. whether it looks clear and clean for swimming).

Algae: Small, often microscopic plants. Freshwater algae grow in the water or on rocks on river beds and lake shores. Large quantities of algae are also called algal blooms.

Algal bloom: A rapid increase in the population of algae in an aquatic system. Blooms can reduce the amount of light and oxygen available to other aquatic life. Some types of algae may be toxic if ingested or can be an irritant to skin and eyes.

Allocation: A process where resources are divided and distributed to individuals or groups for their use. Water take consents for consumptive use include drinking water supply, industry, irrigation and stock water supply.
Allocation can also mean that a river is capable of assimilating contaminants. For example, a discharge consent may allocate the amount of contaminants that can be discharged to a river.

Alluvial soil: A fine-grained fertile soil deposited by water flowing over flood plains or in river beds.

Anatoxin: neurotoxin produced by cyanobacteria

Anoxic: depleted of dissolved oxygen (an extreme form of hypoxia)

ANZECC: Australian and New Zealand Guidelines for Fresh and Marine Water Quality

ANZECC trigger values: values for water monitoring indicators that denote marginal water quality for ecosystem health. If the median value of an indicator for a particular site exceeds the trigger value, then it is intended to "trigger" a response on the part of water managers, which might be to initiate special sampling or carry out an investigation of reasons for the degraded water quality.

Aquifer: A geological layer of sand, gravel, or fractured rock that contains groundwater. Confined aquifers are underneath impermeable layers of silt or clay so they do not receive water and pollutants from land directly overlying them. Unconfined aquifers lack these layers and are thus susceptible to pollutants leaching into them from the overlying land.

Attribute: a measurable characteristic of fresh water, including physical, chemical and biological properties, which supports particular values such as 'human health for recreation'. Attributes defined in the NPS-FM are those that need to be managed by regional councils.

Benthic: anything that is bottom-dwelling. Usually refers to organisms that live on the bottom sediments of a stream, river, lake, or ocean. The majority of New Zealand's native freshwater fish are benthic, compared to trout that like to swim in the water column.

Biodiversity: The variety of life in all living organisms at a given time in a given place. Healthy natural water bodies generally have a high biodiversity, with many different species.

Biomass: the total quantity or weight of organisms in a given area (or volume, such as in a lake)

Carbon sequestration/carbon sink: a natural or artificial process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form. Freshwater wetlands act as 'carbon sinks' because their plants absorb carbon dioxide from the atmosphere through photosynthesis, and standing water reduces respiration of that carbon dioxide back to the atmosphere.

Catchment: the total land area draining into a river, reservoir, or other body of water

Chlorophyll a: a green pigment in plants (phytoplankton) that is used for photosynthesis and is a good indicator of the total quantity of algae present. It can be measured in micrograms per litre (ug/l) or reflective fluroscence units (RFU).

Conductivity: An indirect measure of charged particles (electrolytes) in water. For example, salt water has high, and freshwater low, conductivity.

Coarse fish: freshwater fish including koi carp, tench, rudd, etc that are fished recreationally, but that are not game fish (salmonids - salmon, trout or char)

Critical source areas: Areas contributing most pollution in a watershed. These tend to be small, low-lying parts of farms such as gullies, where runoff accumulates in high concentration.

Cyanobacteria: A group of bacteria that can photosynthesise like true algae. Some species are benthic and grow on the beds of rivers and lakes while others live in the water column. Unlike freshwater algae, some species of cyanobacteria produce toxins and some are able to convert nitrogen gas to plant nutrients.

Denitrification: Part of the nitrogen cycle. A process where bacteria in soil breaks down nitrates into atmospheric nitrogen gas. Nitrate that is left over from plant uptake can be denitrified under soil conditions of low or no oxygen, in the presence of a carbon source. In a farm setting, this occurs when a soil is very wet, e.g. after a high rainfall event or a high irrigation event, and also when soils are compacted. This combination makes soils highly vulnerable to the process of denitrification.

Destratification: Artificially breaking down lake stratification to oxygenate the bottom water

Diadromous: describes species of fish that spend part of their lives in freshwater and part in saltwater

Ecosystem services: the benefits people obtain from ecosystems. Ecosystems are widely considered to provide four categories of services: supporting (e.g. nutrient cycling, soil formation and primary production); provisioning (e.g. food, fresh water, wood, fibre and fuel); regulating (e.g. climate regulation, food and disease regulation, and water purification); and cultural (aesthetic, spiritual, educational and recreational).

Endemic: native or restricted to a certain place (e.g. species found only in NZ)

Endemism: an ecological state in which a species is restricted to a particular geographic region. Organisms that are indigenous are not endemic if they are also found elsewhere.

Eutrophic: a lake that is rich in nutrients and therefore supports a dense plant population, the decomposition of which kills animal life by depriving it of oxygen.

Eutrophication: The enrichment of water with nutrients, such as nitrogen and phosphorus. Eutrophication can lead to growth and blooms of large masses of plant material such as phytoplankton and/or macrophytes.

FRE3: river flow assessment index of the frequency of high flows – based on the average number of flow events (floods) per year that exceed three times the median flow. FRE3 provides an index of flow variability that determines the ability of algae, macroinvertebrates and other aquatic biota to become established. A low FRE3 value indicates a stable flow regime.

Freshwater management unit (FMU): A water body, multiple water bodies or any part of a water body determined by the regional council as the appropriate spatial scale for setting freshwater objectives and limits and for freshwater accounting and management according to the National Policy Statement for Freshwater Management (NPS-FM). Allows water bodies to be grouped together where appropriate, and for a single objective to apply to freshwater bodies that are not connected.

Groundwater: Sub-surface water occupying the saturated zone (in which all voids, large and small, are filled with water), excluding soil moisture.

Hypoxia: a low-oxygen condition, often triggered by consumption of dissolved oxygen in water by decomposing plants or algal blooms.

Indicator: a measurable feature against which environmental or human health conditions and trends can be assessed.

Instream values: values associated with the river’s natural environment, its traditional uses for Māori, and its recreational and aesthetic values (habitat, recreation, biodiversity, landscape/natural character)

Karst: a type of landscape that is formed by the dissolution of soluble rocks, including limestone and dolomite. Karst regions contain aquifers that are capable of providing large supplies of water.

Leaching: loss of soluble nutrients (nitrogen and phosphorus) as they move through soil water (generally excess water below the root zone) into ground or surface water. Coarse-textured soils hold less water and therefore have greater potential to lose nutrients.

Macrofauna, also called macrobenthos, are invertebrates that live on or in sediment, or attached to hard substrates. A majority of recognized animal phyla (18 out of 34) have benthic **macrofaunal** representatives living in marine, estuarine or freshwater environments.

Macroinvertabrate community index (MCI): A community-level biological indicator of general river health based on the presence or lack of macroinvertebrates such as insects, worms and snails in a river or stream. The MCI assigns a score to each species or taxon based on its tolerance or sensitivity to organic pollution, then calculates the average score of all taxa present at a site.

Macrophytes: Large water plants and algae that live in freshwater and are visible to the naked eye, as opposed to the microscopic periphyton and phytoplankton. Macrophytes can be either submerged, floating or emergent.

Mahinga kai: indigenous freshwater species that have been traditionally used as food, tools or other resources.

Minimum acceptable state (NPS-FM): The minimum level at which a freshwater objective may be set in a regional plan in order to provide for the associated national value (NPS-FM definition). This state represents the national 'bottom line' for a particular freshwater attribute.

National bottom line: the minimal acceptable state for compulsory values in the NPS-FM.

National Groundwater Monitoring Programme (NGMP): A long-term research and monitoring programme operated by GNS Science in collaboration with all NZ regional authorities, providing a national perspective on groundwater monitoring used to define "baseline" groundwater quality, and data linking groundwater quality with causative factors such as land use and other human activities.

National Policy Statement (NPS): A planning document under the Resource Management Act 1991 (RMA) that gives central government direction for making resource management decisions about nationally significant issues. Councils must ensure that their policy statements and plans 'give effect' to a national policy statement.

National Policy Statement for Freshwater Management (NPS-FM): Directs councils, through regional plans, to set limits on the amount of water that could be taken from, or contaminants that could be discharged to, freshwater in order to maintain or improve freshwater quality in their region. The NPS provides for ecosystem health and human health for recreation as compulsory national values which must be included in regional plans.

Natural attenuation: A variety of physical, chemical, or biological processes (e.g. biodegradation, dispersion, dilution, radioactive decay, transformation, etc) that, under favourable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater.

Nutrient cycling: The movement and exchange of organic and inorganic matter back into the production of living matter.

Nutrient loss: Mobilisation of nutrients such as nitrogen and phosphorus from soils into the wider environment

Out-of-stream values: Values associated with using river water as a resource (abstraction, diversion, damming, changing land use patterns)

Over-allocation: The situation where the resource (a) has been allocated to users beyond a limit; or (b) is being used to a point where a freshwater objective is no longer being met. This applies to both water quantity and quality (NPS-FM definition).

Periphyton: Algae, fungi, and bacteria that grow on beds of rivers, lakes and streams (usually in shallow water) and turn dissolved nutrients into food for invertebrates.

Pesticides: Manufactured chemical substances intended to prevent, destroy, repel or mitigate any pest. Includes herbicides, fungicides and other substances.

Phytoplankton: Microscopic algae and cyanobacteria that drift or float in the water column and are able to produce oxygen through photosynthesis.

Plankton: Organisms drifting or floating in water, including some algae, some cyanobacteria, waterborne pathogens, and microscopic invertebrates.

Primary production: The production of organic compounds from aquatic or atmospheric carbon dioxide through photosynthesis (using sunlight as energy) and/or chemosynthesis (using oxidation/reduction of chemical compounds as energy). In freshwater aquatic systems, algae are the predominant primary producers.

Primary contact recreation: Water recreation activities that involve a significant risk of water ingestion, such as wading by children, swimming, water skiing, diving, surfing, and whitewater sports (kayaking, canoeing, and rafting).

Reach: A stretch of river with similar characteristics, often defined by upstream and downstream tributaries, or significant geological controls, or bed controls

Residence time: The average amount of time that water stays in a particular system (e.g. a river, lake, acquifer or reservoir), which for rivers is generally a few days, while in large lakes residence time ranges up to several decades. Residence time is relevant for modelling the changing concentration of a contaminant in a system. It is based on the inflow, outflow, volume, initial concentration of contaminant.

Groundwater residence time assessments are useful for determining the amount of time it will take for a pollutant to reach and contaminate a ground water drinking water source and at what concentration it will arrive

Resource Management Act 1991 (RMA): The Resource Management Act (RMA) is New Zealand's main piece of environmental law. The purpose of the RMA is to promote the sustainable management of New Zealand's natural and physical resources. The RMA enables people and communities to provide for their social, economic and cultural wellbeing, their health and safety. Regional, district and city councils all have specific functions under the RMA, including setting policies, rules, and other methods, in plans to sustain the potential of New Zealand's natural and physical resources for future generations.

Riparian: Relating to the banks of a river or wetland; A riparian strip is a strip of land that is directly adjacent to a waterway and which contributes to maintaining and enhancing the natural functioning, quality, and character of the waterbody. These areas are managed (e.g. with planting +/- fencing) to act as buffers zones, reducing impacts of land activities on aquatic values.

Run-off: Water that is not absorbed by soil but drains off the land into lakes, rivers, streams or the ocean. Run-off is also that part of rain that appears as stream flow and often carries fine sediment and dissolved pollutants.

Secondary contact recreation: Recreation where there is direct contact but swallowing wter is unlikely. It includes activities such as boating, wading and fishing. Secondary contact recreation generally carries a lower risk from faecal contamination in the water.

Sediment: Small bits of soil, plant and/or animal matter that are transported by water, either in suspension or by movement in the river bed. Fine sediment, which is smaller than 2mm, can fill up the small spaces between rocks and make the habitat unsuitable for fish and macroinvertebrates to live in.

Stratification (lakes): layering effect where the lake surface warms up and cooler water underneath sinks. When stratification occurs, the colder water that sinks toward the bottom contains reduced oxygen levels.

Suitability for Recreation Grade (SFRG): grade giving the overall health risk from microbiological contamination, for recreational activities like swimming and surfing. This grading system has been used by the Ministry for the Environment since 2011.

Suitability for swimming indicator: relates to microbiological (faecal) contamination. Detection of Escherichia coli (*E. coli*) is used as a cost-effective surrogate indicator of a range of harmful pathogens (e.g. campylobacter, cryptosporidium, giardia, hepatitis A viruses, and salmonella) that may be present as a result of contamination of waterways from animal or human faecal matter.

Swimmability: suitable for primary-contact recreation

Te Mana o te Wai: the innate relationship between te hauora o te wai (the health and mauri of water) and te hauora o te taiao (the health and mauri of the environment), and their ability to support each other, while sustaining te hauora o te tāngata (the health and mauri of the people).

Time-integrating variable: a measured attribute indicative not only conditions at the time of sampling, but also reflecting conditions over the past weeks or months (e.g. MCI)

Trigger value: threshold value for a monitored water-quality variable indicating action must be taken to mitigate the water quality issue; e.g. a level known to have important biological or human health consequence.

Trophic Level Index (TLI): a measure of the overall health of New Zealand lakes, calculated using four separate water quality measurements - total nitrogen, total phosphorous, water clarity, and chlorophyll-a.

Trophic state: a classification that describes the lake's biological productivity – essentially the growth of algae – which affects the lake biology as a whole. The level of production that occurs is determined by several factors, but primarily by the concentration of phosphorus and nitrogen ('nutrients') in the lake and by the volume and residence time of the water in the lake.

Water body: fresh water or geothermal water in a river, lake, stream, pond, wetland, or aquifer, or any part thereof, that is not located within the coastal marine area. (RMA definition)

Water column: a vertical section of water from the surface to the bottom of a water body.

Weighted Usable Area (WUA): the wetted area of a stream weighted by its suitability for use by aquatic organisms or recreational activity. The WUA serves as an index of the capacity of a stream reach to support the species and life stage, or recreational activity being considered, expressed as actual area or percentage of habitat area predicted to be available per unit length of stream at a given flow.

Zoonoses: diseases of animals that can be transmitted to humans. Zoonotic diseases can be caused by germs including viruses, bacteria, parasites and fungi.

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