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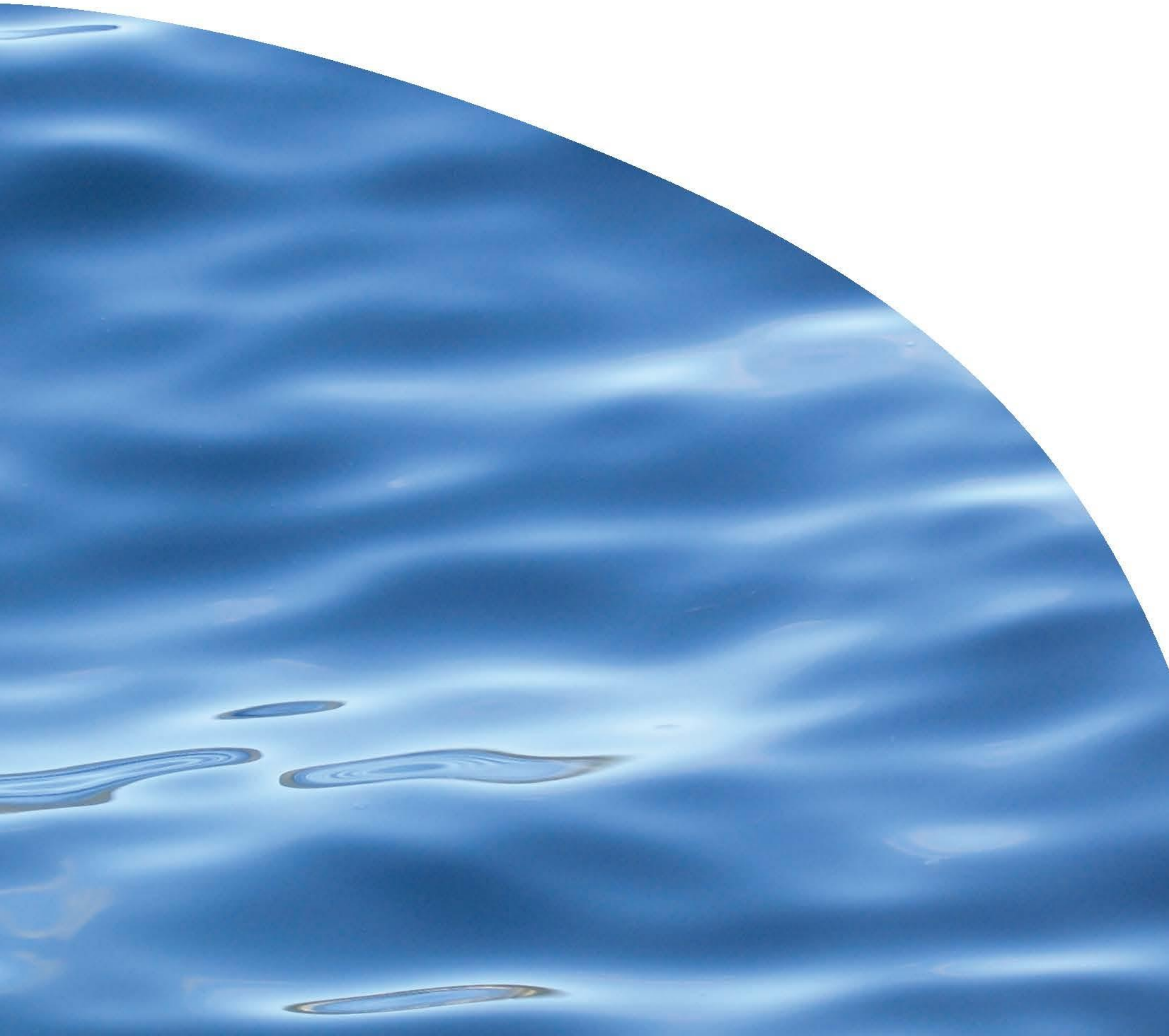
FRESHWATER BIOPHYSICAL ECOSYSTEM HEALTH FRAMEWORK



FRESHWATER BIOPHYSICAL ECOSYSTEM HEALTH FRAMEWORK

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EXECUTIVE SUMMARY

This report describes a proposed framework for the integrated assessment of the biophysical ecosystem health of fresh waters in Aotearoa New Zealand. The Ministry for the Environment commissioned the framework to help freshwater managers meet their monitoring and reporting requirements, in particular, under the National Policy Statement for Freshwater Management 2017 and the Environmental Reporting Act 2015.

We undertook a series of workshops and a critique of existing frameworks and relevant literature to identify the key requirements for developing and implementing a framework for Aotearoa New Zealand. The purpose of the framework was defined as: To provide a consistent approach for assessing biophysical ecosystem health of fresh waters, enabling central and local government, communities and individuals to gauge the maintenance and improvement of ecosystem health.

A healthy freshwater ecosystem has ecological integrity when it can maintain its evolving structure and function over time in the face of external stress. A consistent assessment of ecological integrity requires reference benchmarks.

The proposed framework has five core components that together provide an integrated assessment of ecological integrity. These include: aquatic life, physical habitat, water quality, water quantity and ecological processes.

Performance attributes of the framework include: consistent (has broad application across fresh waters), representative (integrates multiple components), robust (is informed by science), informative (is easily understood), flexible (suits varied application) and scalable (can be modified for reach- to national-scale assessments).

Application of the framework requires knowledge of the suitability of its component indicators and their appropriate benchmarks, as well as of methods for data aggregation, harmonisation and integration, and reporting. This report provides an example of how component indicators can be identified for river health assessments, but further effort is recommended to develop a ‘toolbox’ for resource managers. Further recommendations for framework application include: development of conceptual models to illustrate the core components and indicator links to management options, development of best practice guidelines for data analysis and reporting (including pilot analysis of existing data at multiple spatial scales), as well as communicating with resource managers throughout any subsequent policy process.

Finally, although the proposed ecological integrity framework is biophysical and based on ‘western’ science, it could be a helpful complement to a kaupapa Māori approach, along with other tools and approaches such as the Cultural Health Index, to support iwi to identify their values, aspirations and subsequent indicators for fresh water. We recommend further consideration of how this biophysical approach can be used to contribute to a holistic picture of fresh water that also reflects other cultural, social, economic and environmental values.

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GLOSSARY

CABIN	Canadian Aquatic Biomonitoring Network
CCME	Canadian Council of Ministers of the Environment
CHI	Cultural Health Index
CWA	Clean Water Act
DO	Dissolved oxygen
DOC	Department of Conservation
ER	Ecosystem respiration
FARWH	Framework for the Assessment of River and Wetland Health
GPP	Gross primary productivity
IBI	Index of Biotic Integrity
IECA	Integrated Ecosystem Condition Assessment
LAWA	Land Air Water Aotearoa
MCI	Macroinvertebrate Community Index
MfE	Ministry for the Environment
NARS	National Aquatic Resource Surveys
NEMaR	National Environmental Monitoring and Reporting
NEMS	National Environmental Monitoring Standards
NHMS	Natural Heritage Management System
NIWA	National Institute of Water & Atmospheric Research
NPS-FM	National Policy Statement for Freshwater Management 2014
REC	River Environment Classification
RMA	Resource Management Act 1991
SDG	United Nations Sustainable Development Goals
SHAP	Stream Habitat Assessment Protocols
SHMAK	Stream Health Monitoring and Assessment Kit
SEPA	Scottish Environment Protection Agency
SEQ EHMP	South East Queensland Ecosystem Health Monitoring Program
SEV	Stream Ecological Valuation
SOE	State of the Environment
SRA	Sustainable Rivers Audit, Australia
USEPA	United States Environmental Protection Agency
WFD	European Union Water Framework Directive 2000
WRISS	Waikato River Independent Scoping Study
WRRC	Waikato River Report Card

1. INTRODUCTION

1.1. Why we need an ecosystem health framework

There has been a longstanding recognition of the need for a more comprehensive and consistent approach to measuring the state of freshwater ecosystems in Aotearoa New Zealand. Recent reports on the state of fresh water have highlighted that while we have information on some aspects related to freshwater ecosystem condition, we don't have a complete picture, and importantly, there is no approach to assessing ecosystem condition overall (Gluckman 2017; Ministry for the Environment & Statistics New Zealand 2017). We monitor and report on a range of freshwater variables that measure ecosystem health, but focus primarily on biochemical water quality, often overlooking physical and ecological aspects such as habitat quality, biological diversity and ecosystem functionality.

New Zealand is not alone in its historical focus on monitoring water chemistry to assess freshwater health. In many parts of the world, river health monitoring has traditionally focused on chemical contaminants owing to a need to manage pollutants from industrialised landscapes and to the relative ease of chemical analyses. However, freshwater ecosystems worldwide are increasingly threatened by more than just chemical contamination, including: impacts from over-extraction of water to support rapidly increasing human populations; loss of habitats due to wetland drainage; changes to physical form and connectivity of waterways through channelisation, barriers and altered flow regimes; direct impacts on biota by species introductions; and eutrophication from land-use intensification (Carpenter et al*.* 1992; Allan 2004). There is now broad recognition that measuring water quality alone is not enough to assess ecosystem health. This recognition has led to a greater focus on ecological values in ecosystem health assessments in other countries (e.g. the European Union Water Framework Directive). To develop an ecosystem health framework for fresh waters in Aotearoa New Zealand, we need indicators to represent the condition of all the biological, physical and chemical components, and then guidance on how to account for the interactions and processes between these, to understand the ecosystem as a whole.

A high-level framework for assessing overall ecosystem health of fresh water will contribute to:

- Helping resource managers, communities and decision-makers assess the overall biophysical condition of freshwater ecosystems. This will in turn contribute to discussions over the desired condition of fresh water, and the range of decisions needed to achieve it.
- Reporting on ecosystem condition, including national-level reporting under the Environmental Reporting Act 2015.
- Providing context for interpreting and evaluating existing or future metrics and approaches, so that the extent that they contribute to understanding the

biophysical aspects of ecosystem health is understood, and any gaps are transparent.

1.2. Policy setting

The National Policy Statement for Freshwater Management 2014 (NPS-FM, amended 2017) is an instrument of the Resource Management Act 1991 that enables central government to prescribe objectives and policies. Regional policy statements, regional plans and district plans are then all required to give effect to (i.e. implement) these. Objectives A1 and B1 of the NPS-FM are to safeguard the life-supporting capacity, ecosystem processes and indigenous species, including their associated ecosystems, of fresh water.

Ecosystem health is a compulsory national value for fresh water in New Zealand. In a healthy freshwater ecosystem 'ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change' (MfE 2017). Resource managers are required to identify freshwater objectives and set resource limits that maintain and improve ecosystem health (Figure 1).

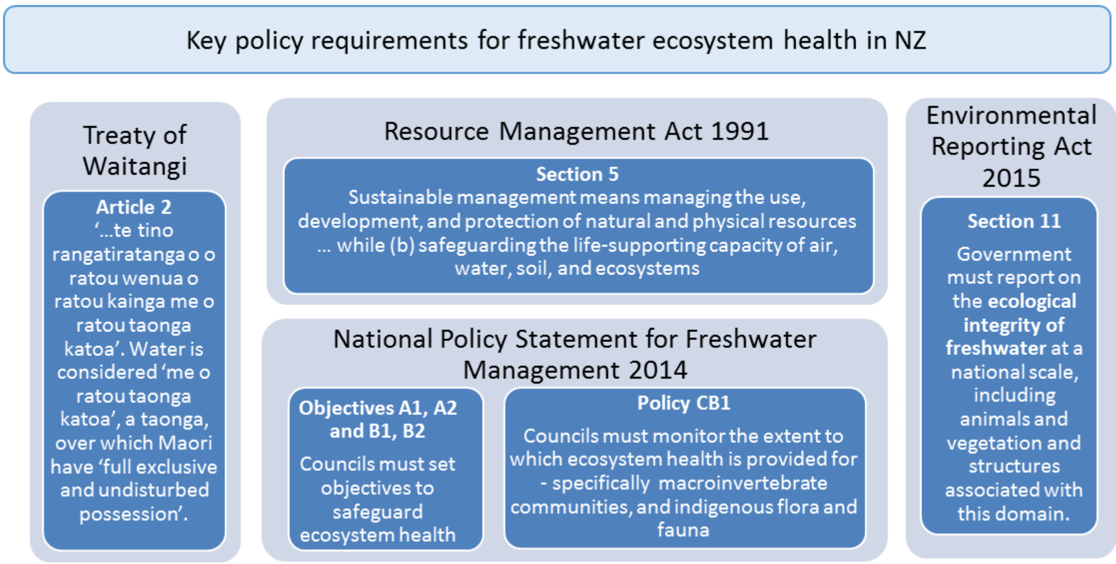


Figure 1. Key policy context for the development of a freshwater ecosystem health framework in Aotearoa New Zealand.

The NPS-FM preamble identifies The Treaty of Waitangi/Te Tiriti o Waitangi as the underlying foundation of the Crown–iwi/hapū relationship with regard to freshwater resources. Addressing tangata whenua values and interests, and the involvement of iwi and hapū in the overall management of fresh water, are key to giving effect to the Treaty of Waitangi (Figure 1). Consequently, the NPS-FM further recognises Te Mana o te Wai as an integral part of freshwater management: 'Te Mana o te Wai is the integrated and holistic well-being of a freshwater body' (NPS-FM 2014). Upholding Te Mana o te Wai acknowledges and protects the mauri of the water. Doing so ensures that the health of the environment (Te Hauora o te Taiao), the health of the waterbody (Te Hauora o te Wai) and the health of the people (Te Hauora o te Tangata) are all provided for.

The Environmental Reporting Act 2015 further requires government to report on the ecological integrity of fresh water at a national scale (Figure 1). Ecological integrity is akin to ecosystem health in that biological organisms are at the heart of assessment. To report on ecological integrity at a national scale requires a national-level assessment of biophysical ecosystem health.

1.3. Freshwater indicators

We use a lot of freshwater indicators in New Zealand. Within the NPS-FM framework, some indicators are referred to as 'attributes' and used to set national compulsory objectives to maintain and improve ecosystem health. Such attributes include, for example in lakes, phytoplankton (trophic state), total nitrogen (trophic state) and total phosphorus (trophic state). In rivers, they include periphyton (trophic state), nitrate (toxicity), ammonia (toxicity) and dissolved oxygen. Some indicators are used in monitoring programmes to assess the progress towards, and the achievement of, freshwater objectives for ecosystem health, for example, the Macroinvertebrate Community Index. Within national and regional state of the environment (SOE) reporting frameworks, there are indicators of water quality such as nutrients, water quantity such as water allocation, habitat such as fine sediment cover, and species such as periphyton abundance, macroinvertebrate community composition, or the presence and conservation status of native fish.

All of these indicators represent components of freshwater ecosystem health. What we lack in New Zealand is a framework, and associated indices, that allows us to integrate these indicators to provide an overall assessment of ecosystem health. An understanding of overall ecosystem health would help people detect and understand problems, express the level of ecosystem health they want, develop solutions to achieve that, monitor effectiveness and adapt where necessary.

1.4. Framework development process

In July 2017, the Ministry for the Environment held a workshop with freshwater science experts to scope a project to develop a consistent approach to assessing the biophysical aspects of ecosystem health in New Zealand rivers. The 2017 workshop included discussion on the project's purpose, its proposed scope and approaches to measuring ecosystem health. The ideas suggested in the workshop helped inform the Ministry's development of the current project, where the primary objective is to develop a high-level national framework (and sub-indices) for assessing the biophysical condition of river and stream ecosystems. Social and cultural indicators are not part of this biophysical framework.

In February 2018, another workshop was held to inform the technical work and the design and content of the framework and potential (sub) indices (Appendix 1: Ecosystem health project workshop notes). The workshop agenda were designed to encourage sharing and review of relevant existing national and international frameworks, and to collect consensus and further information on core framework components (e.g. biota, water quality, habitat) and framework qualities (e.g. representative, scalable, consistent, flexible, robust and informative). Attendees at the workshop included project team members as well as representatives from regional councils, Ministry for the Environment and Statistics New Zealand.

Key discussion points at the workshop included:

- Why we need an ecosystem health framework
- The scope of a biophysical assessment of ecosystem health as part of a wider framework
- Examples of existing national and international approaches to assessing ecosystem health
- Framework components and qualities.

Following the workshop, a more in-depth review of existing national and international approaches to assessing ecosystem health was conducted. Common elements and key lessons from existing frameworks were used to develop the current framework. This report is the final output of the current project, recommending a framework for the holistic assessment of the biophysical ecosystem health of fresh waters in Aotearoa New Zealand.

1.5. Project scope and report structure

As a part of the broader Te Mana o te Wai framework, this project focuses on the development of a framework to integrate measures of the biophysical component of Te Hauora o te Wai, from a western science perspective. A kaupapa Māori framework for assessing the overall ecosystem health of fresh waters is not within the scope of the current project. Instead, the framework developed in the current project may complement, or help inform the development of, a kaupapa Māori framework(s) in the future.

This report addresses the key question in this project – how can the framework be applied to rivers and streams, considering further opportunities to adapt the approach for other water bodies (e.g. lakes and wetlands), and interact with other elements of ecosystem health (i.e. human values).

The Ministry for the Environment (MfE) and regional councils have previously procured and undertaken work on national indicators for freshwater monitoring and reporting. This project identifies and builds on relevant previous work, avoiding unnecessary duplication or repetition.

The report has three key sections. After this introduction, Section 2 reviews existing frameworks in terms of their relevance to developing a national New Zealand framework. Section 3 describes the proposed framework including its purpose, relevant ecological concepts and core components, and discusses how the proposed framework is consistent and representative, robust and informative, and flexible and scalable. Section 4 provides guidance on how to apply the proposed framework as well as recommendations for further research to support framework implementation. A brief summary and further recommendations are provided at the end of the report.

2. RELEVANCE OF EXISTING FRAMEWORKS FOR ASSESSING FRESHWATER HEALTH IN NEW ZEALAND

2.1. International frameworks

Water management is driven globally by a broad array of policy and social practices. A focus on the ecological health of waterways has surfaced in recent years and resulted in international programmes with shared objectives. Here we review a non-exhaustive list of overseas frameworks to assess their relevance to informing a freshwater ecosystem health framework for New Zealand.

2.1.1. UN Sustainable Development Goals and SDG 6

The United Nations' (UN) Sustainable Development Goals (SDG) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. There are 17 Goals, which are all interconnected, in that successfully achieving one may depend on successfully achieving another. 'Clean water and sanitation' is SDG 6 and has the goal of ensuring universal access to safe and affordable drinking water for all by 2030 by investing in adequate infrastructure and protecting and restoring water-related ecosystems. An Integrated Monitoring Initiative for SDG 6 supports countries in monitoring water- and sanitation-related issues. Global indicators for SDG 6 include drinking water, sanitation and hygiene, wastewater treatment, water quality, water-use efficiency, water stress, water resource management, transboundary cooperation, and water-related ecosystems (UN Water 2017).

For the SDG 6 'water quality' indicator, 'good' indicates an ambient water quality that does not damage ecosystem function and human health according to core ambient water quality parameters. For surface water, these parameters are dissolved oxygen (DO), electrical conductivity, nitrogen, phosphorus and pH, and for groundwater, they are electrical conductivity, nitrate and pH. Measured values are compared to national target levels for the different parameters, and if values do not exceed the target level, the water body is classified as good (http://www.sdg6monitoring.org/indicators/target-63/indicators632/). Data on 'water quality' feed directly into the monitoring of 'water-related ecosystems' and relates to the target to protect and restore water-related ecosystems including mountains, forests, wetlands, rivers, aquifers and lakes.

A key point of SDG 6 is that it recognises that water has multiple values and that they are all related—success in one may depend on another. For example, achieving good ecosystem health will require good water quality and low water stress, and will require improved water resource management. Likewise, achieving good ecosystem health in New Zealand will be connected to meeting objectives for other freshwater values.

Also, if a New Zealand framework is consistent in terminology and targets with UN goals, then New Zealand could report on achievement of UN goals. New Zealand already collects the data required to report on 'water quality'. A clear freshwater framework will allow New Zealand to also report on 'water-related ecosystems'.

2.1.2. European Water Framework Directive 2000

Another cross-border framework with shared objectives is the European Union (EU) Water Framework Directive 2000 (WFD). The Directive outlines water policy and objectives for member states of the European Union. It was established to streamline legislation across Europe to assist with water pricing and is recognised as one of the most ambitious and substantial pieces of European environmental legislation (Voulvoulis et al. 2017). The main purpose of the WFD is to protect and enhance the health of aquatic ecosystems while maintaining socioeconomic systems. It is applicable to all waterbodies—surface water, groundwater and coastal water. All member states were tasked to achieve at least 'good ecological status' for all 'natural' waterbodies by 2015 and at the latest by 2027. Good ecological status comprises three components known as 'Quality elements'. These are:

- Biological quality, such as the composition and structure of fish, benthic invertebrates, aquatic flora
- Hydro-morphological quality, such as river-bank structure, river continuity or substrate of the riverbed
- Physical-chemical quality, such as temperature, oxygenation and nutrient conditions.

Good ecological status is also required for those waterbodies that are deemed heavily modified. Actions required to reduce anthropogenic pressure and restore aquatic ecosystems have to be implemented through river-basin management plans, irrespective of administrative borders. Like the 'maintain and improve' elements within New Zealand's NPS-FM, deterioration of ecological status is generally prohibited in the Directive (Hering et al. 2010).

The WFD provides guidance to member states on what component indicators are necessary to assess the ecological status of surface waters. These include biological quality, hydro-morphology and physicochemical attributes. Prior to implementation of the WFD, pollution monitoring was the primary focus for many member states. Chemical status (e.g. contaminants or toxicants) is still assessed separately. Status is graded as 'high', 'good', 'moderate', 'poor' or 'bad' based on the degree of change from a reference condition. Implementation of the WFD varies widely from country to country (see Scottish example below). However, this variance means attention has been paid to inter-calibration between states for comparative reporting purposes, with much focus on standardising reference conditions (Moss 2008). For example, biological assessment results need to be expressed using an ‘Ecological quality ratio’ on a scale of 0 to 1 to provide a common scale of ecological quality (Figure 2).

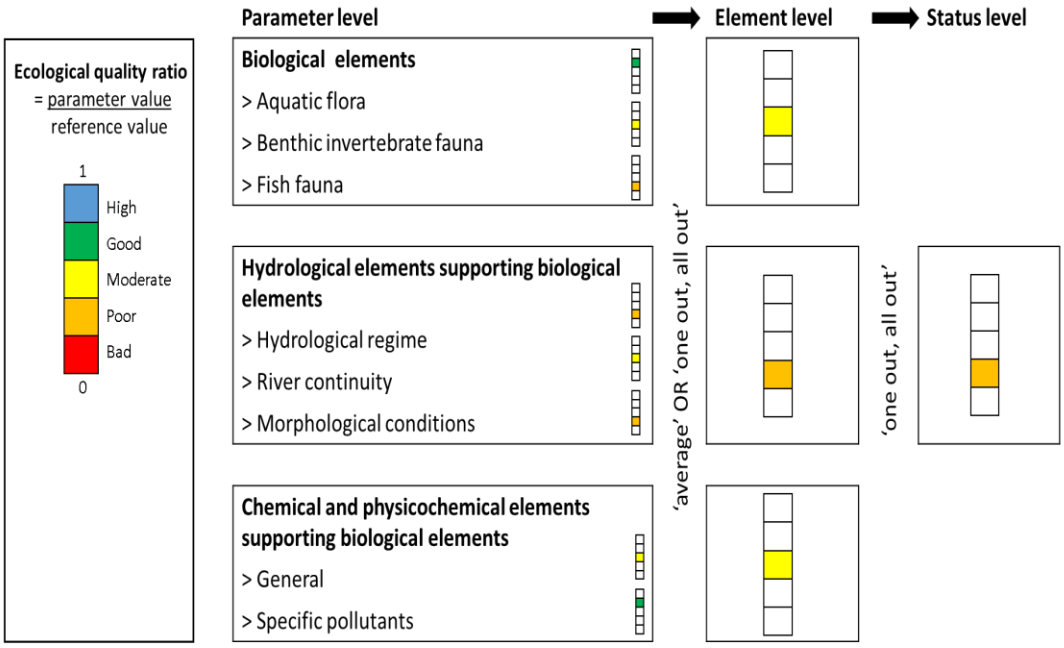


Figure 2. Example of how indicator ‘ecological quality ratios’ are calculated and combined to estimate quality elements in the Water Directive Framework (adapted from van de Bund & Solimini 2007).

After almost two decades since the WFD’s implementation, criticisms of the Directive include: the unrealistic timeframes to reach good ecological status (Hering et al. 2010); the lack of functional indicators, especially given that the Directive defines ecological status as ‘an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters’ (Moss 2008); and, that the methods used to integrate component indicators with the EU’s ‘one out, all out’ approach viewed as too restrictive (Hering et al. 2010). The ‘one out, all out’ approach is where the lowest score is used to determine the status of quality elements or overall ecological status (Figure 2). Main achievements have included transboundary cooperation in the development of river-basin management plans and the development of standardised protocols for biomonitoring methods and data analysis, resulting in a comprehensive basin-wide picture of ecological status, not just pollution.

Lessons to be learned from the WFD include the recognition of the need for long-term goals in framework implementation. It takes time to collect representative data for existing indicators and further time to develop and validate new indicators to provide an integrated assessment of ecosystem health, e.g. functional indicators. A future framework for New Zealand needs to be adaptive and hold space for new indicators but also for changes in approaches to integrating data, such as moving from a ‘one out, all out’ approach to a more balanced-reporting approach. Finally, the strength of standardised approaches cannot be overlooked. Standardised protocols for data collection and analysis remove the need for complicated calibration among regions and countries.

2.2. National frameworks

There is a reasonable level of international consistency in how the concept of freshwater ecosystem health is perceived. However, there are differences in how countries apply the concept, mainly due to differences in legislation. For countries in the EU, the WFD provides strong guidance but still allows for flexibility in regional approaches.

2.2.1. Scotland's ecosystem health framework

The Scottish Environment Protection Agency (SEPA) monitors the ecological and chemical condition of Scotland's fresh waters to support the River Basin Management Plan process and to ensure that regulation of activities and pressures is improving the condition of fresh waters and securing the sustainable use of the water environment. SEPA works with a host of other government and non-government organisations and reports on the ecosystem health of Scotland's surface waters and groundwater via the *Scotland's environment* webpage (https://www.environment.gov.scot). The condition of waterways is reported in relation to the EU standard of being at 'good' or 'high' status as defined in the Directive.

In Scotland, ecosystem health is a measure of the status of ecosystems, through a combination of three inter-related elements:

1. Condition—how far from a 'good' state. Indicators of the ecological condition of fresh waters include physicochemical measures (e.g. temperature, soluble reactive phosphorus (SRP), DO, pH) biological elements (e.g. invertebrates, aquatic plants, fish and fish barriers), specific pollutants (e.g. copper (Cu), ammonia (NH_3)), morphology and hydrology.
2. Function—the extent to which ecosystems retain their natural function and so have the capacity to deliver a range of benefits. Indicators of ecosystem function in river basins include habitat connectivity (how well species can move from one habitat patch to another), and 'critical loads', which are thresholds for the deposition of pollutants causing acidification and/or eutrophication (i.e. acid and nitrogen).
3. Sustainability or resilience—the extent to which the health of ecosystems (and their capacity to deliver benefits) can be sustained under human and environmental pressures, including climate change. Indicators of freshwater resilience include habitat restoration (e.g. peatland) and invasive non-native species (e.g. North American signal crayfish), and resilience indicators in other environments include climate change adaptions (e.g. plant disease occurrence and extent) and soil sealing (i.e. extent of impervious areas).

Furthermore, ecosystem health monitoring occurs across a risk-based network of sites; the majority of sites are concentrated in areas of high population density or agricultural activity. Measures and reporting occur at site and river-basin scales. Ecosystem health has links to ecosystem services, natural capital and biodiversity, but each are reported separately. Scotland's ecosystem health framework meets the requirements of the Directive (hence it uses the WFD's terminology), yet is flexible enough to incorporate measures of ecosystem function and resilience (which is more in line with NPS-FM definition of ecosystem health). An interactive website is used to host report cards and link to technical information, which supports transparency and fosters engagement with stakeholders.

The Scottish approach is built off existing data from pre-established monitoring networks, so suffers from spatial bias towards impacted sites. Despite this, the SEPA meets its EU reporting obligations and are able to publicly convey the status of monitored sites via a webpage. These are key lessons for the development of a New Zealand framework.

2.2.2. United States National Aquatic Resource Survey

In the USA, the objective of the Clean Water Act (CWA) is '… to restore and maintain the chemical, physical and biological integrity of the Nation's waters'. Under the CWA, the United States Environmental Protection Agency (USEPA) must periodically report on the condition of the nation's water resources by summarising water quality information provided by the states. However, approaches to collecting and evaluating data vary from state to state, making it difficult to compare the information across states, on a nationwide basis, or over time. Subsequently, in the early 2000s, the USEPA, states, tribes, academics and other federal agencies began collaborating on a series of statistics-based surveys called the National Aquatic Resource Surveys (NARS) to provide the public and decision-makers with improved, statistically-valid environmental information. The NARS framework includes rivers, lakes, estuaries, coasts and wetlands.

In particular, the goals of the River and Stream Assessment are to determine the extent to which rivers and streams support a healthy 'biological condition' and the extent of major stressors that affect them. Biological condition is seen as the most comprehensive indicator of water body health: 'When the biology of a stream is healthy, the chemical and physical components of the stream are typically in good condition' (USEPA 2016). The only current standardised methods used nationally for assessing biological condition are for macroinvertebrates. Chemical measures (total phosphorus, total nitrogen, salinity and acidification) and physical measures (streambed excess fine sediments, riparian vegetative cover, riparian disturbance and instream fish habitat) are also measured nationally using standardised methods. Results for assessments of biological condition, chemical and physical measures are presented nationally as well as by regions (grouped into three climatic and nine ecological regions).

A key lesson from the NARS framework is that the collection of statistically-valid environmental information to assess freshwater health can be achieved by the random selection of sites in a network that is spatially representative at the ecoregion scale. Also, the NARS framework focuses on biological integrity to infer ecological integrity. Physical and chemical measures are used to link biological integrity to anthropogenic drivers.

2.2.3. Canadian Aquatic Biomonitoring Network and Water Quality Index

In Canada, the monitoring of river ecosystem health is governed at a provincial level and there is no national legislative requirement for monitoring and reporting. However, similar to the USA, a co-ordinated approach to measuring freshwater ecosystem health with standardised methods was initiated across Canada in 2006. The Canadian Aquatic Biomonitoring Network (CABIN) is primarily a national database consisting of biomonitoring (mainly macroinvertebrates, but also fish and algae) and associated habitat information from thousands of wadeable stream and wetland sites across Canada. The data are collected using standardised methods by certified individuals, including scientists, government, First Nations, non-government organisations, industry and consultants, academia and community groups. The data are analysed using a reference condition approach and used to report on state and trends in aquatic health, for informed decision-making on issues such as implementing regulation or rehabilitation measures, and for other purposes such as biodiversity research. However, there has not been a coordinated large-scale effort to report on overall river health.

To date, there have been limited connections at the national level between CABIN and the Water Quality Index (WQI) data of the Canadian Council of Ministers of the Environment (CCME). The CCME WQI summarises complex water quality data consisting of multiple parameters into a single number. It has been used extensively in Canada since 2001 and has been trialled for adoption elsewhere, including in New Zealand regionally (e.g. Marlborough District Council, Henkel 2016) and nationally (e.g. as part of the development of New Zealand's National Environmental Monitoring and Reporting programme, Unwin & Larned 2013). The WQI assesses water quality relative to its desirable state as defined by water quality guidelines. It incorporates three elements: 1) scope—the number of parameters not meeting water quality guidelines, 2) frequency—the number of times these guidelines are not met, and 3) amplitude—the extent to which the guidelines are not met. Once the index value has been calculated, water quality is classified as 'excellent', 'good', 'fair', 'marginal' or 'poor'. The specific parameters, guidelines and time period used in the index can vary from region to region depending on local conditions and index's purpose. A national level assessment of nutrients based on WQI data (1990–2006) was conducted for the first time in 2011 (Environment Canada 2011).

A key strength of the CABIN and neighbouring NARS frameworks is that they are based on standardised methods, which facilitates national-scale reporting. The CABIN framework is also flexible in that it supports citizen-science monitoring through a certification system. In contrast, the flexibility of the CCME WQI can be a weakness. Consistent and transparent use of model settings are necessary to achieve comparable assessments over time and to communicate the results to the public.

2.2.4. Australian Integrated Ecosystem Condition Assessment Framework

The Australian Department of the Environment and Energy (Commonwealth Environmental Water Office) developed the Integrated Ecosystem Condition Assessment (IECA) Framework to provide a flexible method for undertaking an integrated assessment of ecosystem condition for aquatic ecosystems (Department of the Environment and Energy 2017). In many respects, the IECA Framework is very similar to the Framework for the Assessment of River and Wetland Health (FARWH; Storer et al. 2011), which was developed as part of the now-defunct National Water Initiative (Norris et al. 2007). Both the IECA Framework and FARWH were designed to be applied at various spatial scales and include different methods for assessing the condition of aquatic ecosystems. The IECA Framework, however, includes all inland and estuarine waters (not just flowing rivers and wetlands) and provides a means of harmonising scores across indices. It recommends that component scores be aggregated across spatial scales (using averaging, modelling or summing, depending on the sample unit) before components are integrated into overall scores; additional guidance is provided on how to do so (Robinson & Butcher 2017). Another difference is that FARWH assesses the data against a reference condition (usually pre-European) whereas the IECA Framework reference condition is based on ecological values at a set point in time, not necessarily pre-European. The IECA Framework is seen as an integral part of adaptive management process and not just for environment reporting.

The IECA Framework suggests eight steps in the process to develop an ecosystem health framework: 1) Identify and prioritise ecological values; 2) Identify and prioritise threats; 3) Develop key evaluation questions; 4) Identify and prioritise indicators; 5) Design assessment and implementation; 6) Analyse and aggregate; 7) Harmonise and integrate; 8) Develop report card. At every stage, assumptions and knowledge gaps are to be documented to ensure transparency.

In developing a framework for New Zealand, guidance can be taken from the IECA Framework on how to aggregate, harmonise and integrate component scores for reporting at multiple scales. The six component themes in the IECA Framework (hydrology, water quality, structural integrity, aquatic ecosystem connectivity, biodiversity and ecosystem services) are also compatible with the definition of ecosystem health in New Zealand's NPS-FM. However, it could be argued that biodiversity and ecosystem services are freshwater values separate from ecosystem health. Another lesson from the IECA Framework process includes the usefulness of conceptual models in communicating the link between indicators and stressors and hence the link between ecosystem health state and adaptive management options.

2.3. Regional frameworks overseas

Numerous regional frameworks have been developed internationally and often before national frameworks. For example, two Australian examples (reviewed here) highlight regional differences in the application of ecosystem health frameworks. The IECA Framework, discussed above, was developed to allow data from these regional frameworks to be integrated at a national level.

2.3.1. South East Queensland Ecosystem Health Monitoring Program

The South East Queensland (SEQ) Ecosystem Health Monitoring Program (EHMP) was instigated by the SEQ Healthy Waterways Partnership (a joint federal, state and local government initiative) to help realise the statement 'By 2026, our waterways and catchments will be healthy ecosystems supporting the livelihoods and lifestyles of people in South East Queensland, and will be managed through collaboration between community, government and industry' (SEQHWP 2007). The EHMP was seen as integral to the adaptive management process and focused initially on the lower catchments and estuaries of the Moreton Bay region before expanding to all freshwater catchments in the region. A robust desk-top and pilot-study approach was used to select indicators for the freshwater EHMP. Indicators were chosen based on their response to the dominant land-use pressures (agricultural, urban and riparian). For rivers and streams, indicators included measures of physicochemical structure, ecosystem processes, macroinvertebrates, nutrient assimilation and fish (Bunn et al. 2010).

The EMHP has been in place since 2001, with initially annual and then biannual monitoring of indicators at sites chosen to represent major river sub-catchments. Indicators have been analysed in relation to spatial patterns with pressures (Fellows et al. 2006; Sheldon et al. 2012). Annual reporting via an online report card has been used to share Ecosystem Health results with stakeholders and also to provide a wealth of information, from simple through to technical details.

In 2015, the EHMP and the report card evolved (now called the 'Healthy Waterways Monitoring Program') and now include measures of condition, benefits and actions. Ecosystem Health is part of the Environmental Condition Assessment and new measures are pollutants (including sediment and nutrient loads) and habitats (including the extent of key habitats such as riparian vegetation). The Environmental

Condition of each sub-catchment is graded, from A to E. A new Waterway Benefits Rating measures the level of social and economic benefits that waterways provide to local communities and is reported with up to 5 stars. Indicators of 'actions' measure the willingness and ability of landholders and community groups to help protect and improve the waterways and are reported by the number of dollars spent and an outline of case studies.

There are several lessons that can be taken from the SEQ EHMP. Firstly, selecting the correct range of indicators is paramount—they need to be sensitive and, when combined, representative of ecosystem health. However, indicators can change over time and a framework needs to be flexible enough to accommodate this and still assess temporal patterns. Secondly, the partnership across levels of government as well as with industry and community stakeholders has fostered the longevity of the EMHP. Lastly, online visualisation for reporting and sharing of information has aided with communication and trust (i.e. transparency of information).

2.3.2. The Murray-Darling Basin Sustainable Rivers Audit

The Sustainable Rivers Audit (SRA) provides an assessment of the ecological health of rivers in the Murray-Darling Basin in Australia. It is a collaborative study between the state jurisdictions, the Australian Government and the Murray-Darling Basin Authority. The SRA was designed to not only provide an integrated assessment of river health but to also give river managers and users unbiased information.

Environmental metrics derived from field samples and/or modelling are combined as indicators of condition in five themes (hydrology, fish, macroinvertebrates, vegetation and physical form). The Basin has been divided into 23 valleys and four altitude-based zones. Sampling sites are selected randomly within each valley to ensure representativeness. Data are, and have been, collected annually since 2004 and 3-yearly and 6-yearly reports integrate data across themes, compare valleys and provide a formal health assessment. 'Expert rules' are used to combine the indicators into sub-indices, which are aggregated into theme indices. The resulting index values are seen as a guide to the condition of that theme rather than the actual assessment. A descriptive integrated assessment that assimilates the results across themes provides an overall assessment of the river health of each valley and zone.

Key aspects of the SRA relevant to a New Zealand framework include: representative sampling; including themes covering a range of ecological components and systematic sample collection and analysis (i.e. standardised protocols); use of a reference condition as a benchmark for standardising assessments; conceptual models that describe links between ecological components and key drivers (i.e. to support adaptive management and communication of results); and interjurisdictional cooperation and agreements including central funding (Davies et al. 2010). Questions remain about the best means to account for climate change, especially how to differentiate shifts in river health from long-term adaption to changed catchment run-off (i.e. quantifying resilience).

2.4. Previous framework and index development in New Zealand

Regional and national frameworks have previously been developed in New Zealand but for a broader purpose than to assess biophysical ecosystem health alone. For example, the Stream Ecological Valuation (SEV) method compensates for the loss of stream ecosystem services due to the impact of urban development. The Waikato River Report Card (WRCC) assesses ecological integrity as one of eight different values. Similarly, other assessment frameworks based on kaupapa Māori approaches include biophysical ecosystem health as part of a holistic assessment. At a national scale, the Department of Conservation (DOC) has developed a framework focused on biodiversity and MfE has previously explored the development of national indices as one way to integrate freshwater indicators and provide an overall assessment. This section reviews these key projects to identify aspects that can be applied in the development of a national freshwater health framework.

2.4.1. Stream Ecological Valuation (SEV)

The Stream Ecological Valuation (SEV) framework was developed to provide a method for compensating for the effects of urban development on streams using stream functions as a common denominator across different stream types (Storey et al. 2011). As such, the key components of the SEV are stream functions, including: hydraulic (natural flow regime, floodplain effectiveness, connectivity for migrations, connectivity to groundwater), biogeochemical (water temperature control, dissolved oxygen maintained, organic matter input, instream particle retention, decontamination of pollutants), habitat provision (fish spawning habitat, habitat for aquatic fauna), and biodiversity (fish fauna intact, invertebrate fauna intact, riparian vegetation intact). Stream functions are not measured directly. Instead, functions are calculated from one or more easily measured (or database) variables. For example, assessing biogeochemical function of organic matter input requires field measurements of riparian extent as well as the type of woody vegetation present. A weighted algorithm is then used to calculate each function on a scale between 0 and 1 and values at reference sites are used for comparisons and also to set maximum possible scores.

The SEV is used widely in the Auckland region for SOE monitoring and resource consenting. It has also been trialled in several other regions. The interesting lesson from the SEV framework is its potential to assess ecological processes through the measurement of structural variables. This may be worthy of consideration when functional indicators are not available or measured. Also, different algorithms have been explored for calculating scores relevant to a reference condition and for integrating scores into indices during SEV development. These algorithms could provide a test approach for developing a national framework.

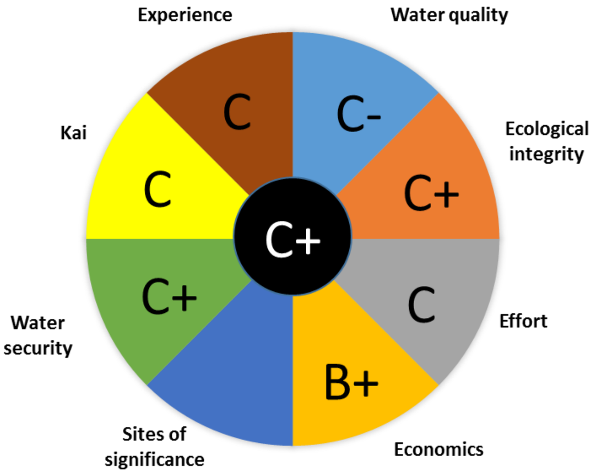
2.4.2. Waikato River Report Card (WRCC)

A regional-scale framework has been developed for reporting on the health of the Waikato River by the Waikato River Authority. This Crown-iwi organisation was established in 2010 to oversee a 'Vision and Strategy' for the improved health and well-being of the Waikato River and Waipa River. 'Health and well-being' has a broader definition than just the biophysical health of waterways. Instead, it is more synonymous with mauri, which is often translated as life principle or life force. As long as the river has the ability to sustain life, the mauri is said to be active (WRISS 2010).

The Report Card builds on the analysis in the Waikato River Independent Scoping Study (WRISS 2010) and includes eight components or taura (strands of a rope). It was recognised that the status of each component may depend on another and they all need to be addressed to meet the aspirations of the Vision and Strategy. The eight taura are: kai, water quality, sites of significance, ecological integrity, experience, water security, economics, and effort (
Figure 3). For each taura, weighted averages of indicator scores were used to assign grades from A to D at the sub-catchment scale. When indicator data were missing, no score was applied. For the ecological integrity taura, a wide range of biophysical indicator values were collated from available datasets including dissolved oxygen, temperature, NH_4 (ammonium), arsenic in sediment, arsenic in water, zinc in sediment, periphyton, macrophytes, macroinvertebrates, riparian extent and composition, native fish, exotic fish, connectivity (hydrology and fish passage), waterbirds, emergent plant extent, and invasive pest plant presence (Williamson et al. 2016). Indicator values were compared to numerical objectives (from existing policy or expert opinion) to assign their A–D grades.

A key point is that the WRRC provides a framework for looking at more than the biophysical aspect of ecosystem health. It uses the term 'ecological integrity' to refer to the biophysical component, but assesses water quality and kai separately. It makes the most of existing data but has the framework in place to adopt new data as it becomes available. There is some justification provided for the inclusion of specific indicators, but no guidance on what the core components of ecological integrity could or should be (Williamson et al. 2016).

Key lessons from the WRCC relevant to developing a national framework include the need to consider how cultural frameworks interact with 'western science-' based frameworks for local and national assessment. Also, transparency around how data are collected and analysed is needed, including acknowledgement of representativeness of data or missing data. Finally, simple visual reporting is highly effective at communicating complex assessments.



Taura (Values)	Indicator group
Kai	Tuna, Whitebait, Kaaeo / Kākahi, Kōura, Piharau, Trout, Waterfowl
Water quality	Nutrients, Clarity, Chlorophyll, Microbiological quality
Ecological integrity	Physico-chemical stressors, Riparian Condition, Aquatic plants, Macroinvertebrates, Fish, Water birds, Connectivity

Figure 3. Visualisation of the Waikato River Report Card framework, illustrating the eight taura (values) as well as groups of indicators used to calculate kai, water quality and ecological integrity taura.

2.4.3. *Kaupapa Māori frameworks and indicators*

Across Aotearoa New Zealand, several kaupapa Māori frameworks and indicators have been developed and applied. Most kaupapa Māori frameworks and related indicators have local or regional application, with the exception of the Cultural Health Index (CHI) framework, which has been applied by a larger number of iwi-Maori groups on waterways throughout the country.

Examples of kaupapa Māori frameworks include the above-mentioned Cultural Health Index (2006) developed for MfE by Ngāi Tahu to assess river values of cultural importance; it requires ongoing site visits by multi-generational tangata whenua (Tipa & Teirney 2006). The Mauri-o-meter (2006) is a decision-making framework that combines a stakeholder assessment of worldviews with an indicator-based impact assessment to determine sustainability and trends over time (Morgan 2006). The Mauri Compass (2009) is a framework to report the current state of waterways, focusing on tuna (eel) as mahinga kai in Turanganui a Kiwa (Gisborne) rohe (https://www.mauricompass.com/).

Some of these frameworks include biophysical assessments, but they all include a visual assessment by local kaitiaki. Consideration should be given to how the multiple frameworks currently in place across the country could contribute to a new framework for assessing the biophysical aspects of ecosystem health, and broader concepts such as Mauri and Te Mana o te Wai. Likewise, consideration of a how a national framework can contribute to cultural assessments is required.

The Wai Ora Wai Māori Framework was specifically developed for Waikato-Tainui to monitor mahinga kai using a kaupapa Māori approach (independent of the WRCC described above). In the Waikato-Tainui framework, the process involves identifying the metaphysical, physical and economic elements of mahinga kai and subsequent attributes/indicators to measure the state of each element (Figure 4). Attribute scores were graded A to D and used to set mahinga kai objectives and to assess management performance against those objectives. The Wai Ora Wai Māori assessment tool is not limited to the assessment of mahinga kai and could be universally applied as a robust and holistic framework for assessing and managing multiple freshwater values (Awatere et al. 2017). Like the WRCC approach, it assesses more than just the biophysical aspect of ecosystem health, and demonstrates the holistic nature of Te Ao Maori and mātauranga Māori. Although the Wai Ora Wai Māori framework is not specifically about biophysical components of ecosystem health, it does highlight the need to consider how cultural indicators and biophysical indicators can complement each other to provide a wider picture.

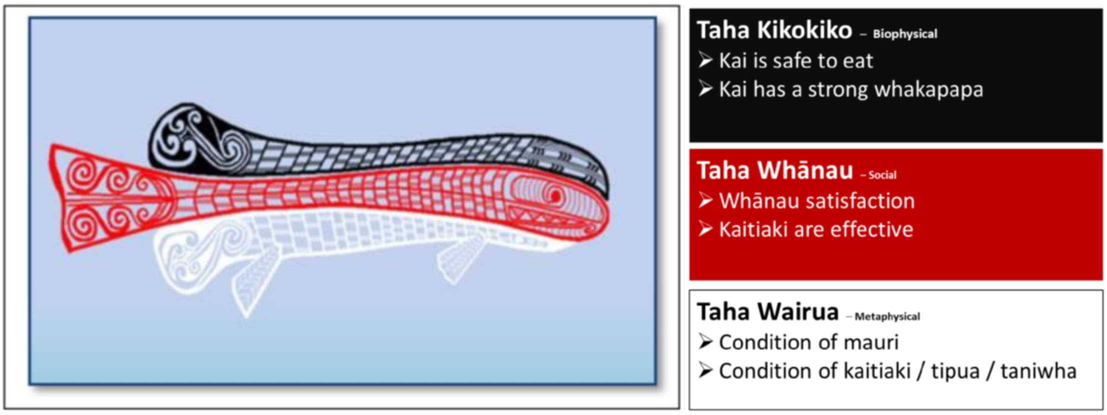


Figure 4. The three domains of the Wai Ora Wai Māori Framework and their associated attributes: Taha Kikokiko, Taha Whānau and Taha Wairua. Collectively termed 'Ngā taha tuatoru' (represented by the artist's impression of īnanga) (Awatere et al. 2017).

2.4.4. Department of Conservation (DOC) Biodiversity Framework

A framework to assess the ecological integrity of river and wetland ecosystems in New Zealand has been previously developed by the Department of Conservation (DOC). Ecological integrity was defined as 'the degree to which the physical, chemical and biological components (including composition, structure and process) of an ecosystem and their relationships are present, functioning and maintained close to a reference condition reflecting negligible minimal anthropogenic impacts' (Schallenberg et al. 2011).

Instead of directly measuring ecological integrity, the DOC framework uses measures of human pressure on freshwater ecosystems as surrogates, assuming ecosystems with least pressure have the most ecological integrity and so retain the most biodiversity. Spatially-explicit measures of human pressure (e.g. land-use intensity, percentage catchment clearance) were derived from several national datasets. Subsequent studies quantified the relationship between land-use pressures and the ecological integrity of rivers and streams (Clapcott et al. 2012) and shallow coastal lakes (Drake et al. 2011). During the validation studies, measures quantifying the ecological integrity of rivers included water quality (nutrients, clarity), biological (macroinvertebrates, fish) and functional (ecosystem metabolism, nutrient and organic matter processing) components. For lakes, measures included physicochemical (depth, flow, water chemistry, light attenuation) and biological (chl-*a*, invertebrates, macrophytes, fish) components. For rivers, a multi-metric index of ecological integrity was calculated by the weighted averaging of observed scores divided by expected scores for component indicators at the site level. The multi-metric index showed predictable unidirectional relationships with land-use pressures and was used to predict the ecological integrity of all stream reaches at the national scale (Clapcott et al. 2014).

In parallel, DOC developed a biodiversity monitoring and reporting system as part of its Natural Heritage Management System (NHMS). It consists of a hierarchical, integrated monitoring system with three levels or tiers to assess biodiversity in the Conservation estate:

- Tier 1: broad-scale monitoring to inform the status and trends of key indicators on public conservation land
- Tier 2: monitoring associated with select high-priority managed areas through DOC's ecosystem and species optimisation projects
- Tier 3: monitoring at a small number of sites designated for development of management practices (e.g. ecosystem or species restoration).

The Tier 1 monitoring programme is based on Lee & Allen (2011) and components include environmental quality, indigenous dominance, species representation, ecosystem representation and resilience to climate change. To date, the Tier 1 programme has been trialled in the Northland region; it has not been applied nationally.

One of the key points of the DOC biodiversity framework that is relevant to a national framework for measuring the biophysical component of freshwater ecosystem health is its definition of ecological integrity, which is effectively the same as the ecosystem health definition in the NPS-FM, and which focuses on the biophysical assessment of ecosystems. The DOC biodiversity framework also uses a reference benchmark approach that, if adopted, could provide a robust method of reporting ecosystem health in a New Zealand framework. Further, the validation studies quantifying the relationship between ecological integrity and land-use pressures provide valuable information on what existing indicators are sensitive enough to be useful in a national ecosystem health framework.

2.4.5. National Environmental Monitoring and Reporting (NEMaR)

The development of national-scale indices for assessing and reporting freshwater quality in New Zealand has been advanced through the National Environmental Monitoring and Reporting (NEMaR) programme. Relevant reports include:

- Investigation of single indicators for national water quality assessment and reporting (Hudson et al. 2011)
- Dependable monitoring of freshwaters for national-scale environmental reporting (Davies-Colley et al. 2011)
- Indicators for national freshwater reporting (Hudson et al. 2012)
- Developing a composite index to describe river condition in New Zealand (Ballantine 2012)
- Statistical models, indicators and trend analyses for reporting national-scale river water quality (Unwin & Larned 2013).

Fresh 'water quality' in the NEMaR programme refers to an assessment of ecological integrity as defined by Schallenberg et al. (2011), in that it is not limited to physicochemical state but rather extends to include condition and ecological health. An expert-panel approach was used to identify and recommend core freshwater indicators of biota, habitat, water quality and hydrology for four key ecological integrity components (nativeness, pristineness, diversity and resilience) and one optional component for both river and lake condition (Table 1, Table 2). The NEMaR process provided recommendations on how indicators could be combined into discrete sub-indices for water quality, macroinvertebrates and fish, and discussed ways data could be combined into a single index of condition including simple averaging, median and a minimum operator approach.

Key lessons from the NEMaR work include examples of how to harmonise and integrate data, including:

- The usefulness of predictive models for estimating reference conditions for various ecological integrity metrics
- The identification of limitations in data representativeness, for component measures and spatial representation
- The acknowledgment that a lot of decisions are required when choosing how to combine data into composite measures and these can strongly influence the sensitivity and robustness of resulting indices
- Most of the challenges associated with calculating composite indices stem from data limitations
- There is a need to develop standardised approaches to data collection and analysis, to support data combination.

Table 1. Primary and secondary indicators for assessing and reporting river condition identified during the NEMaR programme. Adapted from Hudson et al. (2012). O/E = observed vs expected, QMCI = Quantitative Macroinvertebrate Community Index, EPT = Ephemeroptera, Plecoptera and Trichoptera, GPP = gross primary production.

Relative importance	Ecological integrity component	Variable or metric according to general class			
		Biota	Habitat	Water quality	Hydrology
Primary variable/sub-index	Nativeness	Percent alien species O/E native species			
	Pristineness	QMCI EPT richness Taxon richness	Percent sediment cover Stream Ecological Valuation (reconstructed)	*E. coli* Visual clarity Nutrients[A] Electrical conductivity Dissolved copper, zinc, cadmium	Abstraction index Flow Connectivity
	Diversity	Taxon richness			
	Resilience	Taxon richness			
Secondary variable/sub-index	Optional	GPP Respiration Percent periphyton cover		Temperature, dissolved oxygen concentration (continuous measurement)[B]	Climate change impacts

A Total and dissolved reactive phosphorus; ammoniacal-, dissolved inorganic- and total nitrogen.

B Retained as secondary variables to enable calculation of GPP and respiration.

Table 2. Primary and secondary indicators for assessing and reporting lake condition identified during the NEMaR programme. Adapted from Hudson et al. (2012). SPI = Submerged Plant Index, DO = dissolved oxygen, CDOM = coloured dissolved organic matter, TLI = Trophic Level Index, GPP = gross primary productivity.

Relative importance	Ecological integrity component	Variable or metric according to general class			
		Biota	**Habitat**	**Water quality**	**Hydrology**
Primary variable/ sub-index	**Nativeness**	Lake SPI Pest fish Native fish	Lake SPI/ Macrophytes		Lake level variation Residence time
	Pristineness	Lake SPI Pest fish Cyanobacteria	Lake SPI/ Macrophytes	Chlorophyll-a TP, TN Secchi depth DO profile Temperature profile DIN CDOM	Lake level variation Residence time
	Diversity	Lake SPI Pest fish	Lake SPI/ Macrophytes		
	Resilience	Pest fish Macrophyte variability Cyanobacteria	Lake SPI/ Macrophytes	Chlorophyll-*a* variability	
Secondary variable/ sub-index	**Optional**[A]	Rotifer TLI MCI for lakes Invasive zooplankton	Sedimentation/ sediment loading	pH TSS/VSS Diel DO GPP Developments to TLI	Connectedness

A All optional indicators require further development.

2.5. Lessons from existing frameworks

Our review of approaches to the monitoring and management of river ecosystem health in Europe, North America, Australia and New Zealand has identified several elements that are critical to the development of an integrated framework for assessing the ecosystem health of fresh waters in Aotearoa New Zealand. Similarly, a recent report by the Cawthron Institute titled '*What is a healthy river? A discussion of the concepts and practice relating to river monitoring, reporting and management'* (Young et al. 2018) identified considerations for future efforts to improve programmes to assess and manage river health in New Zealand. Our review and the Young et al. review (2018) both identify the following critical elements.

2.5.1. Strong policy driver

Overseas frameworks have resulted from the need to address new policy and regulations. For example, the WFD has provided impetus for many countries to initiate biomonitoring of waterways and has provided direction for all EU member states on how to analyse and report data in a way that is directly comparable with other countries. Policy also provides the purpose for, and clear direction on, setting narrative objectives for the monitoring, reporting and management of river ecosystem health. For example, in the USA, the objective of the CWA is '… to restore and maintain the chemical, physical and biological integrity of the Nation's waters', and hence the purpose of the National Aquatic Resource Survey (NARS) is to provide robust data to assess chemical, physical and biological integrity. In New Zealand, the NPS-FM provides a strong national policy driver (see Section 1.2) and provides the basis for developing an ecosystem health framework. Furthermore, the NPS-FM provides a definition of ecosystem health that can help shape a framework.

2.5.2. Involvement of a range of stakeholders in the planning and implementation process

International- and national-scale frameworks that have endured over time have involved a wide range of stakeholders at all stages of framework planning and implementation. Associated with this is transparency of resources committed to frameworks. For example, the Australian SEQ EHMP involves an investment across levels of government as well as partnership with industry and community stakeholders. In Canada, CABIN allows anyone trained in standard methods to collect and contribute data to the national network. In New Zealand, regional councils have a statutory requirement to implement the NPS-FM and so will need to assign resources to implement an ecosystem health framework. Unique to New Zealand, the NPS-FM states the need to provide for the involvement of iwi and hapū, and to ensure that tangata whenua values and interests are identified and reflected in the management of fresh water (Objective D1).

2.5.3. A range of metrics

Biological indicators are at the core of all ecosystem health frameworks, and they reflect the need to measure the combined response to multiple pressures in a catchment. Biological indicators are assessed in addition to water quality and habitat indicators. Sometimes water quantity and ecosystem processes are also assessed. Frameworks vary in how flexible they are, in terms of allowing for different metrics to measure each suite of indicators, but in all, biological indicators are measured. In New Zealand, all regional councils measure compulsory NPS-FM attributes (e.g. nutrients and periphyton) and monitor benthic macroinvertebrates in streams. Many also measure habitat components and therefore should have the base data to be used in the implementation of an ecosystem health framework.

2.5.4. Standardisation of protocols

Some overseas frameworks (e.g. NARS, CABIN, SRA) are based on standardised methods including those for designing a network, collecting and processing data, as well as reporting state and trends. Others rely on calibration to compare data from different methods (e.g. WFD, SDG 6). In New Zealand, work is underway on the standardisation of measurement protocols (e.g. National Environmental Monitoring Standards, NEMS) and the identification of a complete range of measurable numeric objectives, but more effort is required on determining how to incorporate the full range of ecological components of river health into assessment programmes in terms of network design and reporting. A national ecosystem health framework should address these gaps.

2.5.5. Effective communication of results

Assessment is at the core of reviewed ecosystem health frameworks and the subsequent reporting of results is imperative. Ecosystem health state is reported at sub-catchment and catchment scales (e.g. WRRC, SEQ EHMP), for eco- and bioregions (e.g. Murray-Darling SRA, NARS), nationally (e.g. Scotland), and continentally and internationally (e.g. WFD, SDG). Reporting is a way to communicate results, and effective communication makes stakeholder engagement in the process of resource decision-making more likely. Most frameworks use web-based reporting tools to allow stakeholders to view results at multiple spatial scales, much in the same way that in New Zealand, the LAWA (Land Air Water Aotearoa) website allows the public to view environmental data at a site, catchment and regional scale.

2.5.6. Adoption of adaptive management principles

Adaptive management is a structured, iterative process that supports robust decision-making in the face of uncertainty. Many ecosystem health frameworks have evolved over time as part of an adaptive management approach, when the need for short-term outcomes based on current knowledge is balanced with the need to gain more knowledge to inform future decisions. For example, the SEQ EHMP was developed with core indicators to describe ecosystem health and has expanded over time to incorporate more diagnostic indicators to inform future decision-making. Understanding where a framework fits in the bigger picture of sustainable resource management is important for achieving long-term outcomes.

2.5.7. Disparities among existing frameworks

When thinking about what is required for the development of an ecosystem health framework in New Zealand, the similarities among frameworks discussed above are important to consider. However, the differences among them are equally important as they can highlight potential challenges in framework design and implementation.

Lacking from current frameworks is a consistent approach on how to integrate information from multiple indicators into a single measure. How ecosystem components *interact* and relate to each other is rarely discussed. Frameworks based on biological monitoring (e.g. NARS) assume that biological indicators depict an integrated response to water and habitat quality and quantity, and hence the biological metrics are weighted more highly to inform an ecosystem assessment. In comparison, other frameworks (e.g. IECA) treat all ecosystem components (i.e. biology, habitat, water quality, water quantity, processes) equally. Furthermore, how metric data are aggregated over space and time strongly depends on network design and can introduce bias into assessments, making it difficult to identify robust changes spatially or temporally. The strengths and weaknesses of various approaches continue to be debated in the scientific literature and, as such, it is perhaps most important to ensure any chosen approach is transparent to allow for critical discussion.

It is not clear how frameworks approach the issue of shifting benchmarks in ecosystem assessment. Some frameworks use the natural state as a benchmark to which the measured ecosystem health state is compared, whereas others use management guidelines. Both reference sites and management guidelines are subject to change; the former in response to global change, whether it be climate change or other global anthropogenic impacts (e.g. acidification), natural events (e.g. earthquakes) or system evolution (e.g. geomorphology). Management guidelines can change as more information becomes available (i.e. as part of adaptive management), they can also change over time in response to public and political expectations (i.e. because of generational amnesia). Future-proofing a framework requires consideration of shifting benchmarks (i.e. 'what is 'expected' and 'what we measure against' may change).

Finally, the need for good data management is rarely discussed as part of framework design (exceptions include CABIN and NARS). Good data management systems facilitate the re-calculation of historical indices should changes occur in benchmarks, but also if changes occur in how and what indicators are calculated from base data.

3. RECOMMENDED FRAMEWORK FOR NEW ZEALAND

3.1. Overview

The biophysical framework presented in this report is only one part of a broader assessment of overall freshwater health that includes social, cultural and economic components. The definition of healthy freshwater ecosystems in the NPS-FM[1] is the basis of the Freshwater Ecosystem Health Framework (hereafter 'The Framework') proposed in this report, and so reflects the importance of physical and chemical as well as biological elements of ecosystems. An assessment of biophysical ecosystem health provides a measure of 'ecological integrity'. Further, ecological integrity is only one part of an assessment of the ability of a freshwater ecosystem to support multiple freshwaters values (Figure 5).

Figure 5. Ecosystem health is one of the many national values of freshwater ecosystems in Aotearoa New Zealand (refer to Appendix 1 of the NPS-FM).

The Framework has five core components: aquatic life, water quality, water quantity, physical habitat and ecological processes (Figure 6). Evaluation of all five core components is required to obtain an integrated assessment of the ecological integrity (biophysical ecosystem health) of fresh waters. Greater diagnostic ability is obtained by measuring all five ecosystem components rather than ecosystem attributes such as biodiversity and resilience (i.e. 'emergent properties'; Davies et al. 2010). These

[1] 'ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change'.

five components are consistent across all freshwater ecosystems (i.e. rivers, lakes, groundwater, wetlands and estuaries) and as such The Framework can be applied to all freshwater ecosystems.

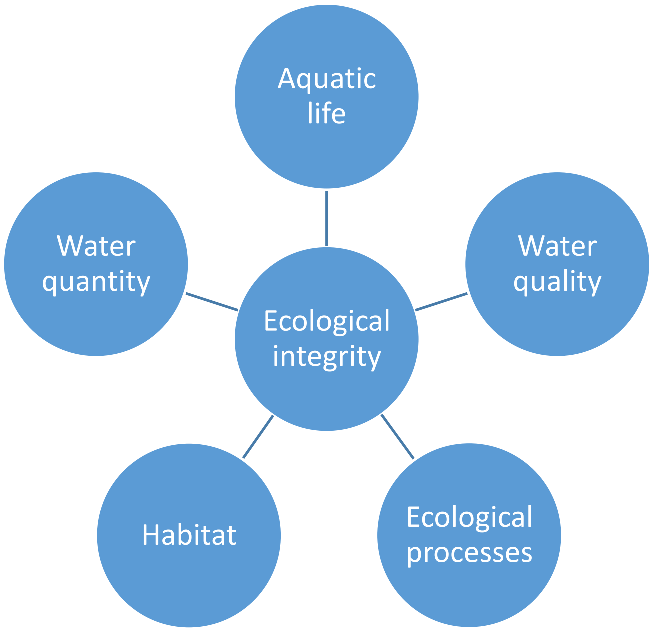


Figure 6. The ecological integrity (biophysical ecosystem health) framework has five core components that provide an integrated assessment of ecological integrity.

The five framework components are assessed using a range of freshwater indicators (Figure 7), chosen for their suitability to describe the character and behaviour of biophysical components, and at the same time, their sensitivity to anthropogenic impacts on water bodies. Indicators are measured with metrics that may vary in where, when and how they are measured and so The Framework is flexible and can accommodate ecological integrity assessment at various spatial and temporal scales.

The use of standardised methods facilitates the aggregation of indicator data at several spatial scales (e.g. (sub-)catchment, regional and national). The harmonisation of indicator data relative to a benchmark (i.e. scaling 0–1) allows for the comparison of indicator scores and the integration of indicator data into component scores as well as an overall ecological integrity (biophysical ecosystem health) score. Indicator, component and overall ecological integrity scores can be reported at multiple scales using a tiered stacking of information, which ensures that The Framework supports an informative assessment of ecosystem health for multiple purposes and users (Figure 7).

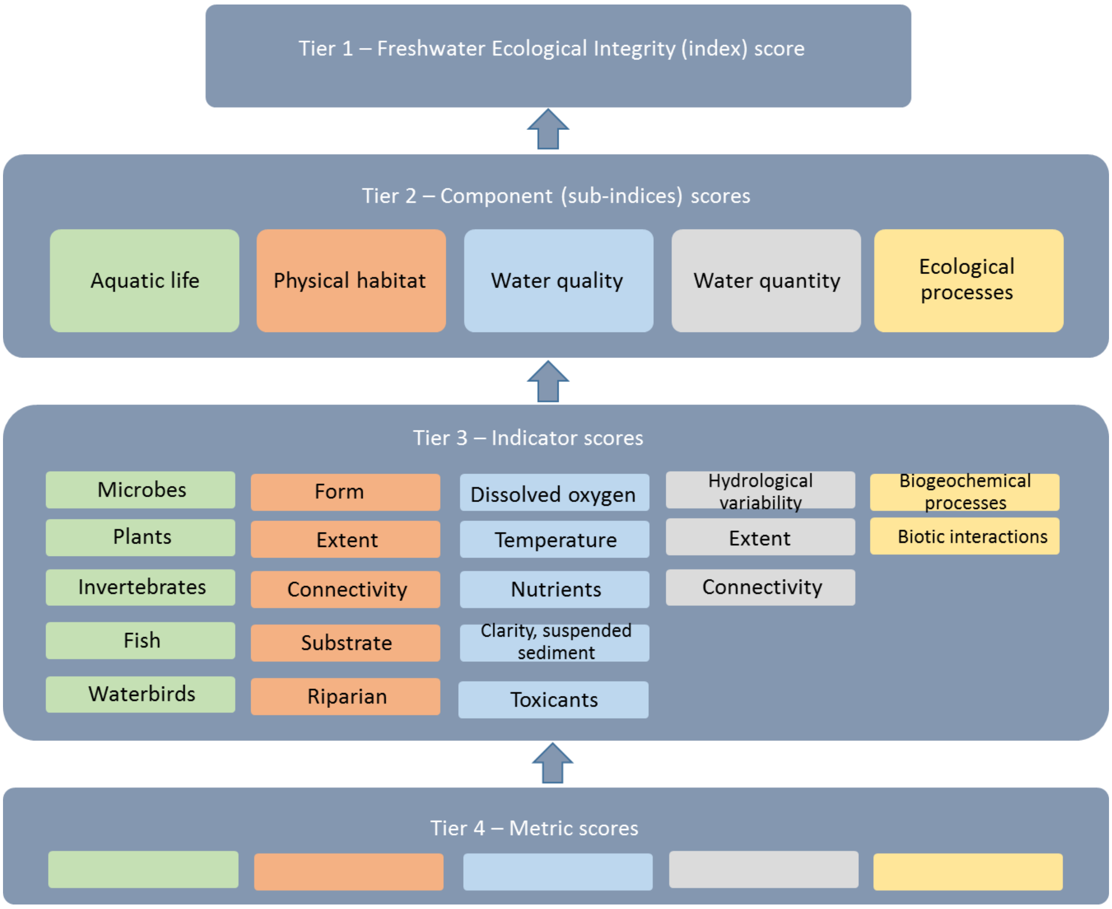


Figure 7. A tiered framework to assess freshwater ecological integrity (biophysical ecosystem health).

3.2. Purpose of The Framework

It is important to set a clear purpose for The Framework. A clear purpose can provide a common vision of ecosystem health for freshwater monitoring and management programmes, decision-makers, communities and central government to work towards; 'without a common objective or direction, it is often difficult to justify public investment in monitoring, and even harder to argue for a management response' (Bunn et al. 2010). Globally, ecosystem health frameworks have been developed to address a strategic need to monitor and report on the condition of fresh waters. They were developed to provide a way to summarise how well visions, strategies, policies and objectives were being met. For example, specific strategies and objectives include:

- 'achieving at least good ecological status for all natural waterbodies' (WFD)
- 'healthy ecosystems supporting the livelihoods and lifestyles of people' (WEQ EHMP)
- 'a future where a healthy Waikato River sustains life and prosperous communities' (WRRC).

The primary basis for developing an ecosystem health framework for fresh water in Aotearoa New Zealand is the Resource Management Act 1991 (RMA), which gives regional councils the functions, powers and duties to give effect to sustainable management, by, for example:

- 'the establishment, implementation, and review of objectives, policies, and methods to achieve integrated management of the natural and physical resources of the region' Section30(1)(a)

Further, as an instrument of the RMA, regional policy statements, regional plans and district plans are all required to give effect to (i.e. implement) the NPS-FM. Objectives A1 and B1 of the NPS-FM are to safeguard the life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems, of fresh water. Resource managers are required to identify freshwater objectives and set resource targets/limits that are consistent with achieving the objectives. A compulsory objective includes the maintenance and improvement of ecosystem health.

A secondary basis for a framework is the Environmental Reporting Act 2015. The Act binds the Crown to report regularly on New Zealand's environment. Each domain report (air, atmosphere and climate, fresh water, land, marine) must:

- Describe the state of the domain (including biodiversity and ecosystems), pressures (that can affect its state) and impacts (on ecological integrity, public health, the economy, te ao Māori, and culture and recreation).

Each domain report must also describe changes to the state of the domain over time and how the state of the domain measures against national or international standards. Therefore, a New Zealand framework needs to support the measurement of ecosystem health in a robust way that allows resource practitioners to implement the NPS-FM and track progress towards objectives over time. Robust measurement would also facilitate environmental reporting of state and trends in the ecosystem health of fresh waters. Consistency, or at least similarity, with international frameworks would allow the state of fresh waters in New Zealand to also be reported and compared internationally (e.g. UN SDG 6: Ensure availability and sustainable management of water and sanitation for all).

*Key feature 1: The **purpose** of the proposed Freshwater Ecosystem Health Framework is to provide a consistent approach for assessing the biophysical ecosystem health of fresh waters, enabling central and local government, communities and individuals to gauge the maintenance and improvement of ecosystem health.*

3.3. Relevant ecological concepts

Concepts of ecosystem health typically reflect both ecological values and human values, as illustrated in Figure 8, for river health (Boulton 1999). This model of ecosystem health incorporates the ecological integrity of the ecosystem (what lives there and the ecological functions they perform) and its resilience to stress (ability to recover from disturbance), along with society's expectations that it will provide goods and services to support human life. This view is also reflected in New Zealand's NPS-FM, where the concept of freshwater management involves considering biophysical condition, people's health, and the values and the services people gain from freshwater environments. Similarly, kaupapa Māori-based frameworks in Aotearoa New Zealand always incorporate both human and ecological aspects. Focusing specifically on the biophysical aspect of ecosystem health does not ignore the importance of other aspects, it simply defines the purpose of the framework at hand.

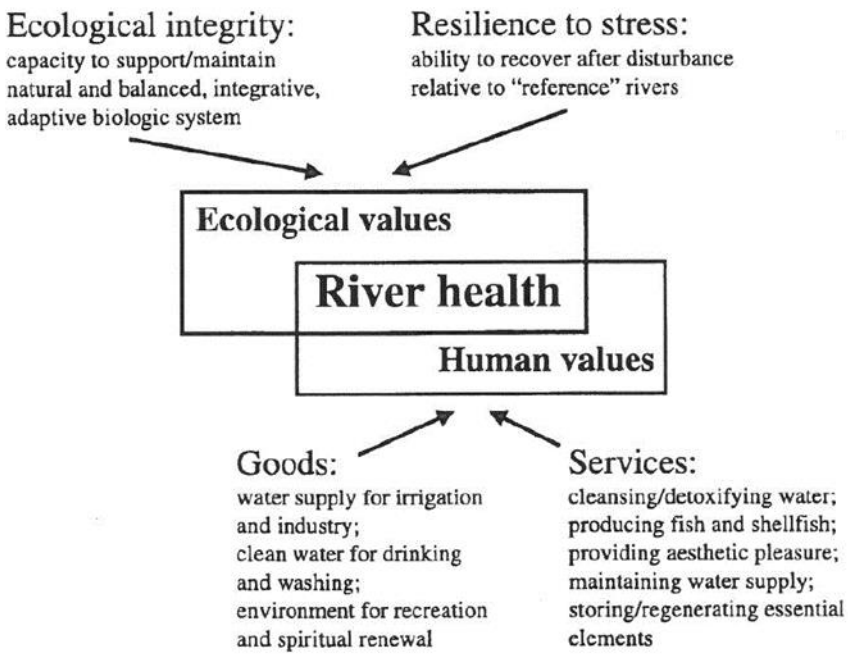


Figure 8. The concept of river health, shown as the intersection between ecological condition values and human values (Boulton 1999).

Existing frameworks that focus specifically on the biophysical aspects of ecosystem health often adopt the term 'ecological integrity'. Whereas ecosystem health focuses on social, economic and ecological outcomes (Costanza 1992; Rapport et al. 1998), ecological integrity focuses on ecological outcomes (Karr 1991). Ecological integrity is 'the sum of physical, chemical, and biological integrity' (Karr & Dudley 1981). Karr (1991) made this term operational in arguing that ecosystems with integrity have a range of biota and processes that can be expected in the absence of human influences. In New Zealand, a review of approaches for assessing ecological integrity defined it as ‘the degree to which the physical, chemical and biological components (including composition, structure and process) of an ecosystem and their relationships are present, functioning and maintained close to a reference condition reflecting negligible or minimal anthropogenic impacts’ (Schallenberg et al. 2011).

With a biophysical focus, Costanza and Mageau (1999) state that a ‘healthy ecosystem is one that is sustainable—that is, it has the ability to maintain its structure (organization) and function (vigour) over time in the face of external stress (resilience)’. Structure or organisation measures the assembly of physical, chemical and biological components. Function (or vigour), on the other hand, is a measure of an ecosystem’s activity and includes key physical, chemical and biological processes as well as the interactions between components. Resilience is a measure of persistence; ecological resilience measures the magnitude of disturbance that a system can absorb before it undergoes changes in structure and function (Holling 1996).

In the NPS-FM, a healthy freshwater ecosystem is defined as one in which ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change. While this is similar to the definition of Costanza and Mageau (1999), it does not explicitly acknowledge the physical and chemical components of fresh waters, nor does it recognise qualities of organisation other than range and diversity (e.g. composition and structure). Nor does it specify ecological resilience in the face of external stress/anthropogenic impacts. We recommend a framework focused on the biophysical elements of ecosystem health that takes these ecological concepts into account.

For assessments to be meaningful, they require benchmarking to some reference condition, whether it be ‘historical’, ‘minimally disturbed’, ‘least disturbed’ or ‘best attainable’ (Stoddard et al*.* 2006). Dufour and Piegay (2009) argue that targets for river restoration should be based on the degree of human benefit obtained rather than ‘natural’ endpoints. A focus on ‘native (*sic*, indigenous) flora and fauna’ in the NPS-FM implies the use of natural state benchmarks, rather than ‘normative benchmarks’, such as the best state attainable under a particular land-use and catchment setting. In practice, a reference condition based on the natural state can be a normative benchmark because it is the standard chosen by humans to reflect the desired state of the ecosystem. This normative state is chosen in recognition of the fact that natural ecosystems support many other values and services provided by fresh water.

Furthermore, a reference condition describes a distribution rather than a single endpoint in recognition of the fact that systems vary spatially. Also, a reference state may evolve naturally over time. If assessments are to be conducted consistently, then a common understanding of the definitions and complications of the reference condition is necessary, including the nuanced meaning of 'shifting baselines'; the effect of natural vs human disturbance on reference (or benchmark) site distributions; circularity in the use of biological data to assist in reference site identification; and the differences in using site-scale measurements vs landscape-level human activity to identify reference conditions (Stoddard et al. 2017).

*Key feature 2: The Framework requires an assessment of the biophysical components of freshwater ecosystems (See NPS-FM Appendix 1) to provide a measure of '**ecological integrity**'. Ecological integrity refers to the ability of an ecosystem to support and maintain structure and function over time in the face of external stress.*

*Key feature 3: The Framework requires **reference state benchmarks** to ensure consistency in the assessment of the biophysical components of freshwater ecosystems. It accounts for the fact that a reference state may change over time.*

3.4. Core components of The Framework

An ecosystem comprises a biological community of interacting organisms and their habitat. This is reflected in definitions of ecosystem health and ecological integrity, which identify consistent elements, including:

- A range of biota and processes (Karr 1991)
- Structure and function (Rapport et al. 1998)
- Physical, chemical, and biological integrity (Barbour et al. 2000).

In freshwater environments, the biological community is characterised by an assemblage of interacting organisms, including microbes, plants and animals. Freshwater habitat is characterised by the quality and quantity of its water and the physical environment that frames the water. The interaction between these habitat characteristics results in a broad range of conditions in any given freshwater ecosystem over space and time, and the biological community has evolved in response to this variability. When assessing freshwater ecosystem health, rarely is a single metric used. A summary of component measures from existing freshwater ecosystem health frameworks (Section 2) shows consistent use of multiple indicators (Table 3).

Component measures include 'biota' or biodiversity as well as 'water quality' or physicochemical measures. In the Stream Ecological Valuation (SEV) example, biogeochemical measures include both water quality and functional variables. Component measures that describe 'hydrology' and 'physical form' are also common. Less common are measures of 'pollutants' and 'riparian' factors. In the SEQ EHMP, the status of these components is reported separate from reporting on ecosystem health, as are contaminants/toxicants in the European Union's WFD, and chemical and physical measures in the United States' NARS.

Despite theoretical recognition of the importance of measuring ecological processes, few frameworks have direct measures of the ecosystem function component of ecological integrity. This may be due to the lack of baseline knowledge of ecosystem functions for many ecosystems, as well as the lack of standardised and affordable methods to obtain that information. However, a lack of existing methods should not preclude the inclusion of key components in a framework. For example, in the SEV example, structural elements are used to estimate stream functions.

Table 3. Component measures of ecological integrity from ecosystem health frameworks. Note the FARWH assessment also includes catchment disturbance and spatial extent measures; the UN SDG 6 also includes spatial extent measures. The status of italicised measures is reported separately to ecological status.

Framework*	Components of ecological integrity considered by different frameworks						
	Aquatic life	Water quality	Water quantity	Physical habitat	Pollutants	Riparian	Processes or interactions
FARWH	Aquatic biota	Water quality	Hydrological change	Physical form		Riparian zone	
IECA	Biodiversity	Water quality	Hydrology; Connectivity	Structural integrity			Ecosystem services
SEQ EHMP	Biota	Physico-chemical			*Pollutants*	*Habitats*	Ecosystem processes
SRA	Biota		Hydrology	Physical form			
WFD	Biological	Physico-chemical	Hydro-morphology		*Contaminants / toxicants*		
Scotland EH	Biological	Physico-chemical	Hydrology	Morphology	Specific pollutants		
SDG	Biological	Water quality	Water quantity				
NARS	Biological	*Chemical stressors*		*Physical stressors*			
DOC	Biological	Water quality					Functional
SEV	Biological	Biogeo-chemical	Hydraulic	Habitat provision			Biogeo-chemical
WRRC	Biodiversity	Water quality	Connectivity		Contaminants	Riparian	

* refer to Glossary.

An integrated assessment of ecosystem health cannot be achieved by a single biophysical measure because an ecosystem is a complex network of interacting biological communities and their physical environment. Existing programmes monitoring ecosystem health consistently involve some core indicators that measure the physicochemical properties of water, structural habitat, biological communities, and sometimes key ecosystem processes or interactions.

To achieve an integrated assessment of ecosystem health or ecological integrity that is consistent with ecological theory and informed by existing frameworks, the core components of a biophysical ecosystem health framework for fresh waters in Aotearoa New Zealand should include: biota/aquatic life, water quality, water quantity/hydrology, physical form/habitat and ecological processes. Many regional councils already measure indicators of these components. Including these core components will provide an integrated assessment of ecological integrity. It will also ensure transparency in reporting when there are missing values and may help justify funding for future investment in monitoring. Additional monitoring of stressors (e.g. contaminants) could be instigated when ecosystem health scores fail to meet desired targets.

Key feature 4: The Framework has ***five core components****: aquatic life, physical habitat, water quality, water quantity and ecological processes.*

3.5. Key Framework features that support performance outcomes

Ideally an ecosystem health framework and its associated indicators will be simple to apply, easily understood, contextually relevant, scientifically justifiable, quantitative and acceptable in terms of costs, from a practical environmental management point of view (Jørgensen 2011). A framework to assess the ecosystem health of fresh water in New Zealand will potentially be used by a range of resource managers at various scales (spatially, temporally) and different levels of resource investment. Likewise, ecosystem health reporting will have a range of audiences who will all require a clear description of the state and trends in ecosystem health, how it was measured and what the measurements mean, especially in terms of meeting freshwater objectives. As such, an ecosystem health framework for fresh waters in Aotearoa New Zealand needs to be consistent and representative, robust and informative, while also being flexible and scalable. These performance outcomes were identified during project workshops. The following sections discuss how existing frameworks and the proposed Framework meet these outcomes.

3.5.1. Consistent and representative

According to the 'Our fresh water' 2017 report, New Zealand has over 425,000 kilometres of rivers and streams, 249,776 hectares of wetlands, and more than 50,000 lakes, about 4,000 of which are larger than one hectare in area. New Zealand's fresh water is also stored in reservoirs (artificial lakes, or natural lakes with raised water levels) ranging from small-farm dams (*sic*) to the 7,500-hectare Lake Benmore. A considerable amount of our fresh water is groundwater in aquifers. (Ministry for the Environment & Statistics New Zealand 2017). There are also approximately 300 estuaries and about 3000 glaciers larger than one hectare. While estuaries and glaciers might be outside the scope of freshwater domain reporting, there is no reason why an ecosystem health framework could not be applied to these ecosystems.

A **consistent** framework provides a shared understanding of what ecosystem health is and how to measure it. For example, the strength of the WFD is that it outlines water policy and objectives for member states of the European Union to work towards. Within the WFD policy, key terminology is defined and common aims are identified. The WFD aims to 'protect and enhance the health of aquatic ecosystems while successfully maintaining socio-economic systems'. All member states are tasked to achieve at least 'good ecological status' for all 'natural' waterbodies. Consistent frameworks, such as the WFD and NARS, also facilitate cross-jurisdictional co-operation in ecosystem health assessment. In New Zealand, the RMA, the NPS-FM (amended 2017) and the Environmental Reporting Act 2015 provide strong policy guidance, as the basis of an ecosystem health framework for all resource managers. Common terminology and methodology should be used where possible.

In addition to consistent aims and objectives, ecosystem health frameworks provide guidance on how to consistently collect, analyse and/or report data. At the highest level, frameworks describe components that should be measured (Table 3). For example, FARWH identifies six component measures that are required for an integrated assessment, but within each component indicators could be measured using a variety of approaches. As mentioned above, the Framework has five components: aquatic life, water quality, water quantity/hydrology, physical habitat and ecological processes.

Many frameworks provide guidance on how indicator data should be analysed to ensure consistency and comparability. For example, data harmonisation (scaling from 0 to 1 relative to a reference condition) is used in the WFD, and in the IECA, the SRA and the SEV frameworks. A criticism of this approach is the reliance on a consistent definition and use of reference benchmarks (Senior et al*.* 2011), which currently may vary for different components within frameworks (e.g. FARWH) or may need to be adaptive in response to climate change (Davies et al*.* 2010). Nonetheless, there is no reason a New Zealand framework should not use a data harmonisation approach for comparing and/or combining indicator data. Key to its application will be ensuring there is sufficient knowledge of a range of reference conditions; to approach this, reference states can be measured or modelled.

At the most prescriptive level, frameworks recommend the consistent use of the same indicators, including standardised methods for data collection. For example, NARS requires the standardised collection and analysis of physicochemical and biological indicator data. This has allowed data aggregation for regional- and national-level reporting (Paulsen et al*.* 2008). While consistent methods for measuring indicators are beneficial, cross-calibration between differing methods allows flexibility (see below) and the adoption of new technologies as they come online, while ensuring consistency in reporting of the state and trends in ecosystem health. Cross-calibration (among methods) and inter-calibration (among ecological status boundaries) has improved comparability across some, but not all, national assessment systems in the

WFD (Poikane et al. 2014). In New Zealand, considerable progress on standardising scientific methods has been made in the last two decades, thanks to increased coordination among the agencies responsible for monitoring and reporting on fresh water. For example, standardised national monitoring protocols for wadeable rivers and streams exist and have been widely adopted for fish (Joy et al. 2013), macroinvertebrates (Stark & Maxted 2007), periphyton (Biggs 2000), deposited sediment (Clapcott et al. 2011) and habitat (Harding et al. 2009; Clapcott 2015). Related initiatives like the NEMS programme and LAWA website have provided a catalyst for improving quality assurance processes.

A **representative** framework includes indicators of the full range of the core components of ecosystem health and how they interact. This ensures that the assessment is complete and highlights the important fact that more than one indicator is required to provide an integrated assessment of freshwater health. Existing frameworks consistently include indicators of the physical, chemical and biological components of ecosystem health (Table 3). Likewise, in a recent review of 119 published studies, 80% of studies used a combination of two or more physical (form and flow), chemical and biological indicators to assess ecosystem health (O'Brien et al. 2016). Furthermore, 30% of studies included indicators of ecosystem processes. A representative framework ensures these core components are acknowledged and measured with sensitive indicators that are system-specific.

The interaction or relationship between components and their respective indicators in a representative framework is considered at two important stages of framework application: 1) sampling network design, and 2) data aggregation and integration. Sampling network design ensures balanced spatial representation in ecosystem health assessment. Within the reviewed frameworks (Section 2), two main approaches to network design are adopted at the regional or stream-classification level, either random site selection (e.g. NARS), or a risk-based monitoring approach (e.g. Scotland's ecosystem health framework as part of the WFD). Either way, component indicators reflect the complexity of ecosystems, such that they respond to drivers operating at different scales, spatially, temporally, and through complex chains of causality. As such, indicators may be sampled at different spatial scales and some indicators may be measured less or more often, or even modelled. Hence, a representative framework allows for variation in sampling network design to accommodate differing component indicators and addresses this variation during data aggregation and integration. The IECA Framework recommends that component scores be aggregated across spatial scales (using averaging, modelling or summing, depending on the sample unit) before integrating the components (using mathematical or non-mathematical rules) into composite indicators, and additional guidance is provided on how to do so (Robinson & Butcher 2017; see also Section 4.6).

Including metrics for all components necessitates a significant investment by resource managers. There is no redundancy among components—all five must be measured to obtain a representative and integrated assessment of ecological integrity. However, there may be benefits to considering other freshwater values when designing monitoring networks. For example, measuring water quality metrics, such as suspended sediment, can inform an assessment of ecological integrity as well as an assessment of primary and secondary recreation and fishing values.

*Key feature 5: The Framework is **consistent and representative**. To achieve this, The Framework has a clear purpose and agreed terminology, and supports standardised method development to facilitate data aggregation and integration.*

3.5.2. Robust and informative

A **robust** framework is informed by rigorous science and justifies the selection of component measures and indicators, thus further supporting investment in resources for integrated monitoring and reporting. Many frameworks have been developed in partnerships between scientists, resource practitioners and government (e.g. SEQ EHMP, WFD, NARS) and this provides transparency on how ecological concepts and scientific knowledge are used to inform framework design. A consistent lesson from successful frameworks is that commitment by all parties from an early framework development stage creates shared knowledge and supports the longevity of freshwater monitoring and adaptive management programmes (Bunn et al. 2010). Robust frameworks are adequately resourced during framework development, testing and implementation by local, national and international government agreements.

Reporting the 'confidence' of an ecosystem health assessment further supports the robustness of a framework. For example, in the SEQ EHMP, the nature of the data used to inform an assessment (e.g. collected over 5 years of bi-annual site visits) was reported alongside the assessment of ecosystem health component indicators (e.g. poor macroinvertebrate health). In FARWH, missing data were acknowledged and river and wetland health were reported only if data were available for at least 3 components and samples represented a minimum 50% of environment types present at the surface water management area scale. Likewise, in the WRRC, a lack of data to inform an assessment of any given component is reported.

An **informative** framework is easily understood, provides the necessary context to interpret information, contextualises existing indicators and approaches, highlights data gaps, and facilitates overall state and trends to be reported. The use of conceptual models provides the necessary context to interpret information. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality identify conceptual models as a critical part of water quality management, allowing managers to clarify goals, develop objectives, identify indicators, identify management actions and communicate outcomes (http://www.waterquality.gov.au/anz-guidelines/resources/key-concepts/conceptual-models). Conceptual diagrams, which illustrate ecosystem components and the mechanistic link between drivers and indicators, have been widely used to help summarise and communicate the scientific context as well as identify management options and data gaps for indicators. For example, the SEQ EHMP used conceptual diagrams to identify potential indicators during framework development (Smith & Storey 2001). Following implementation, SEQ EHMP used conceptual diagrams to communicate to the public the link between land-use drivers and indicator response. Likewise, the SRA, WRRC and IECA Frameworks use conceptual models to link indicators to drivers and potential management options.

Existing approaches, knowledge gaps and potential future metrics are made transparent in an informative framework. This transparency is manifested mainly during reporting. For example, the absence of component data is reported in the WRRC. The adoption of a report card based on a tiered or hierarchical stacking of information supports an informative framework and facilitates reporting at various levels, with underlying data at the base and a data summary at the top (Figure 9; Williamson et al. 2016). The use of reference and normative standards helps communicate what is achievable and what are aspirational goals for ecosystem health.

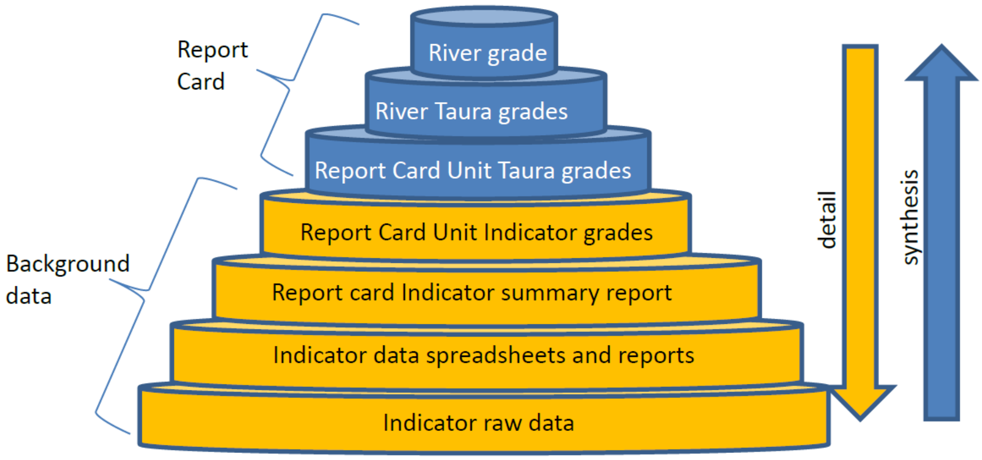


Figure 9. Levels of data detail and synthesis for reporting in the Waikato River Report Card (WRCC; from Williamson et al. 2016).

*Key feature 6: The Framework is **robust and informative**. To achieve this, the Framework builds on existing frameworks and relevant ecological concepts and scientific literature; it supports the development of conceptual diagrams that illustrate ecosystem components and the link between indicators and drivers; it uses tiered reporting, with transparency regarding missing data/data quality; and it commits resourcing to long-term implementation and adaption.*

3.5.3. Flexible and scalable

A freshwater framework should be **flexible** enough to accommodate future assessments for a range of waterbodies, as all freshwater ecosystems effectively consist of the same key biophysical components. Specific indicators will differ across environment types (as will reference conditions), reflecting varied freshwater environments, management contexts and information availability, but The Framework still allows for comparability among waterways. For example, Scotland reports ecological condition for rivers and lakes (lochs) as do many countries committed to the WFD. Likewise, the ecological integrity of both rivers and lakes is assessed in the WRRC; rivers and wetlands, in the FARWH; and even an estuary, in the IECA Framework. Component indicators will naturally differ among ecosystems. For example, to assess 'hydrology' might require measurement of minimum flows in rivers or hydraulic residence time in lakes. As previously noted, consistency can be achieved by cross-calibration or inter-calibration when differing indicators and methods are used. This would facilitate the use of new indicators, such as those focusing on taxonomic groups such as algae, bacteria and other microbiota, which may become easier to measure with advances in molecular technologies (O'Brien et al*.* 2016).

A toolbox approach, with a mix of compulsory and voluntary indicators, that recognises variability in data availability and agency capacity, may support a flexible framework (see Section 3.2 for examples of ecological indicators for rivers). For example, the Restoration Indicator Toolbox describes a range of water quality, habitat and biota indicators suitable for assessing stream restoration (Parkyn et al*.* 2010). Within such a toolbox, it would be useful to illustrate how different approaches are calibrated, for example standardised regional council methods and citizen-science approaches (Storey et al*.* 2016), or cultural indicators of biophysical health (Harmsworth et al*.* 2011).

A **scalable** framework guides appropriate monitoring and reporting at a site and/or river reach, (sub-)catchment, regional and national scale. A scalable framework remains consistent across spatial scales, yet the indicators used to measure framework components may vary at different scales. This may reflect the relationship between indicators and drivers. Similarly, the level and complexity of reporting may vary at different scales. Hierarchical design may facilitate reporting. Data harmonisation (e.g. grading indicators scores from 0 to 1) may further facilitate reporting across spatial scales.

Rolls et al. (2018) demonstrated how relationships between hydrology and freshwater biodiversity depend on what spatial scale 'biodiversity' is viewed in. Flooding, for example, can increase local-scale biodiversity but decrease landscape-scale biodiversity, while channel drying will briefly decrease local-scale biodiversity and increase landscape-scale biodiversity (Rolls et al*.* 2018). Similarly, responses of stream health to primary drivers will vary with spatial scale, with some key indicators responding more to catchment-scale effects whereas others are strongly linked to local effects. For example, because many fish migrate during their life cycle, they are impacted by catchment-scale impacts of land-use changes, such as lost connectivity due to water allocation or fish-passage barriers, whereas primary productivity is mainly affected by local drivers such as shading (by riparian vegetation) and water temperature (Sheldon et al*.* 2012). These studies demonstrate the importance of scale when selecting indicators and reporting on ecosystem health.

Conceptual models can help illustrate hypothetical response scales. For example, during the development of the SEQ EHMP, conceptual models, backed up by the literature, were used to identify hypothetical response scales as well as stressor pathways. Formal statistical analysis was also used in the SEQ EHMP example to quantify the primary scale of effects (Sheldon et al*.* 2012). Once the relative importance of scale is known, it can be used to inform how measures of ecosystem health are combined for reporting overall ecosystem health.

Flotemersch et al. (2016) contend that the most appropriate scale for ecological assessment is the watershed because that is the scale at which anthropogenic pressures primarily impact on river health and hence can be regulated or mitigated. The watershed or catchment is the scale of focus in the USA's NARS (in response to that country's Clean Water Act) and in the European Union's WFD. Catchment and major sub-catchments are the focus of the SEQ EHMP and WRRC assessments. In addition to being the scale at which key ecological processes occur (e.g. habitat provision, hydrologic, sediment, water chemistry and temperature regulation), the watershed is also seen as the most appropriate scale to integrate ecological assessments with social, economic and cultural assessments (Flotemersch et al*.* 2016). However, it may not always be the most appropriate scale to integrate with Māori cultural assessments, especially when specific sites are important.

Key feature 7: The Framework is ***flexible and scalable****. To achieve this, The Framework recognises that: core components apply to all fresh waters yet indicators will vary; it supports the development of a toolbox of indicators; it supports the use of cross-calibration or inter-calibration, to compare across environment types; and it supports the development of a hierarchical system, to support monitoring and reporting.*

3.6. Link to estuaries

Estuaries are defined as part of the Coastal Marine Area and their management is therefore subject to the New Zealand Coastal Policy Statement (DOC 2010), which is led and administered by DOC. However, they are the receiving waters for freshwater systems that are managed in accordance with the NPS-FM, led and administered by MfE. Policy A1(iii) of the NPS-FM requires that regional councils consider 'the connections between freshwater bodies and coastal water'. In addition, Policy C2(b) requires regional councils 'provide for the integrated management of the effects of the use and development of land and fresh water on coastal water' and manage impacts for the most sensitive downstream environment. A project focused on managing upstream areas to protect estuarine state and values is currently underway in New Zealand, commissioned by MfE. In its first stage, the project has identified core attributes and important indicators of estuarine state (Cornelisen et al*.* 2017) and reviewed available data and monitoring methods suitable for assessing estuarine state (Zaiko et al*.* 2017). Future project tasks focus on developing standard methods, critical thresholds and baselines to develop estuarine attributes that can help inform freshwater targets and/or limits.

Key variables identified as important for the assessment of the ecosystem health of estuaries included water quality (e.g. water clarity, concentrations of dissolved nutrients and chl-*a*), habitat (e.g. sediment quality and quantity; extent of saltmarsh, seagrass, macroalgae, shellfish beds), and biota (e.g. macrofauna including shellfish and fish) (Figure 10). These align to core components of freshwater ecosystem frameworks and this alignment demonstrates the potential for a national freshwater framework in New Zealand to also apply to estuaries. The estuarine project also highlights the value to be gained by considering multiple values (e.g. human health, mahinga kai, ecosystem health) within a pressure-state-impact framework. When choosing indicators of the core components of ecosystem health, it may be useful to consider whether the indicators are suitable for assessing other freshwater values as well.

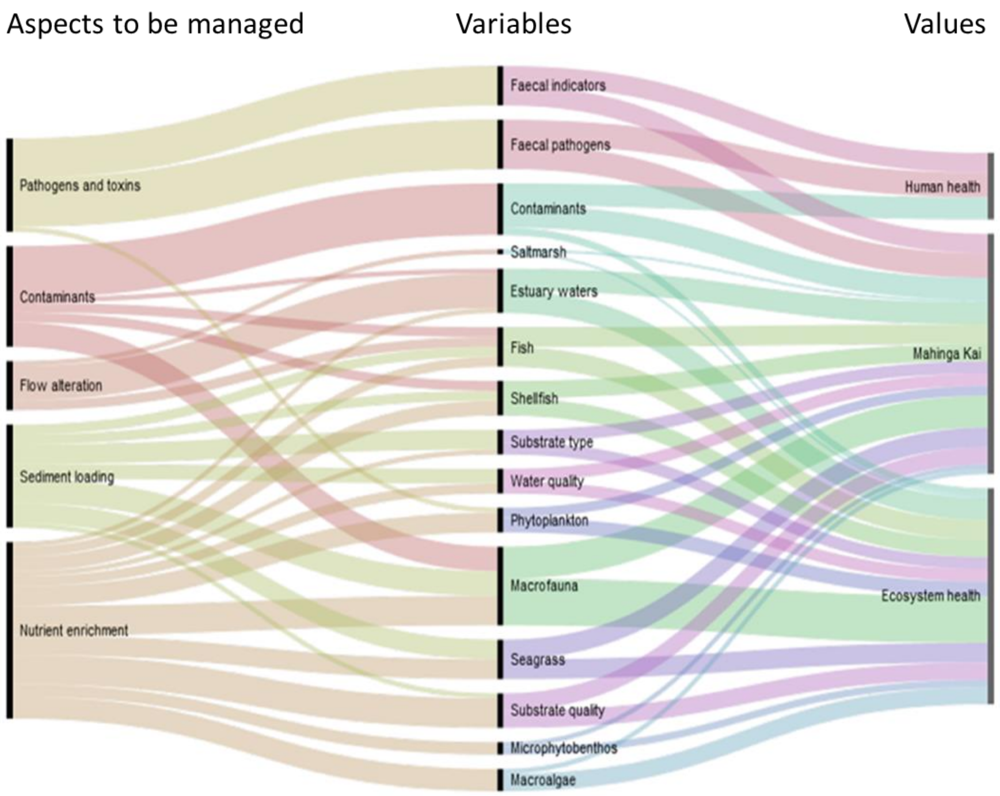


Figure 10. Alluvial diagram showing linkages between aspects to be managed, variables and values identified from an online survey of c. 30 estuarine experts asked to identify characteristics of healthy estuaries (from Cornelisen et al. 2017).

Key feature 8. The Framework is ***applicable to estuaries****.*

3.7. Key features of the proposed Freshwater Ecosystem Health Framework

1. The purpose of the Freshwater Ecosystem Health Framework is to provide a consistent approach for assessing the biophysical ecosystem health of fresh waters, enabling central and local government, communities and individuals to gauge the maintenance and improvement of ecosystem health.
2. The Framework requires an assessment of the biophysical components of freshwater ecosystems (See NPS-FM Appendix 1) to provide a measure of 'ecological integrity'. Ecological integrity refers to the ability of an ecosystem to support and maintain structure and function over time in the face of external stress.

3. The Framework requires reference state benchmarks to ensure consistency in the assessment of the biophysical components of freshwater ecosystems. It accounts for the fact that a reference state may change over time.
4. The Framework has five core components: aquatic life, physical habitat, water quality, water quantity and ecological processes.
5. The Framework is consistent and representative. To achieve this, the Framework has a clear purpose and agreed terminology, and supports standardised method development to facilitate data aggregation and integration.
6. The Framework is robust and informative. To achieve this, the Framework builds on existing frameworks and relevant ecological concepts and scientific literature; it supports the development of conceptual diagrams that illustrate ecosystem components and the link between indicators and drivers; it uses tiered reporting, with transparency regarding missing data/data quality; and it commits resourcing to long-term implementation and adaption.
7. The Framework is flexible and scalable. To achieve this, the Framework recognises that: core components apply to all fresh waters yet indicators will vary; it supports the development of a toolbox of indicators; it supports the use of cross-calibration or inter-calibration, to compare across environment types; and it supports the development of a hierarchical system, to support monitoring and reporting.
8. The Framework is applicable to estuaries.

4. HOW TO APPLY THE FRAMEWORK

4.1. Overview

The Framework provides a consistent approach for assessing the biophysical ecosystem health of fresh waters as part of an adaptive management process that enables central and local government, communities and individuals to gauge and prioritise the maintenance and improvement of ecosystem health. Framework application involves three main steps, as outlined in Figure 11. Step 1 focuses on data collection. First, metrics need to be selected for each indicator of the core components—aquatic life, physical habitat, water quality, water quantity and ecological processes. Ideal metrics are easy to measure, they are able to be measured and repeatedly, they are sensitive to impacts, robust to natural variability, inexpensive to collect data for and provide credible information that can be easily understood. Standardised metrics are useful because they have been developed with the above indicator qualities in mind, along with direction on when and where to apply them. For each chosen metric, the reference condition must be known or estimated. Ideally, reference sites are part of the monitoring network. Next, the scale of application is determined. Broad-scale assessments require consideration of the spatial and temporal representativeness of the selected monitoring network. Monitoring network designs may vary for the five key component indicators but all five indicators need to be measured (or modelled) for the chosen scale of assessment.

Step 2 focuses on data management. First, data are aggregated to the spatial scale of assessment for each metric. Next, data are harmonised, or standardised to a common scale of 0–1, to ensure that the metric data are comparable. This is where reference data can play a key part in establishing baselines for assessment. Finally, data are integrated or combined for reporting at the indicator level, component level, or full ecological-integrity level. Data integration can involve simple averaging or weighted averaging as long as the chosen method is transparent and justified on the basis of environmental science. Missing data should be clearly acknowledged.

Step 3 focuses on environmental reporting. The use of four quality classes such as ‘Excellent’ ‘Good’, ‘Fair’, and ‘Poor’, or A–D, is consistent with the National Objectives Framework of the NPS-FM, and provides a common language for engaging communities in the adaptive management of freshwater resources.

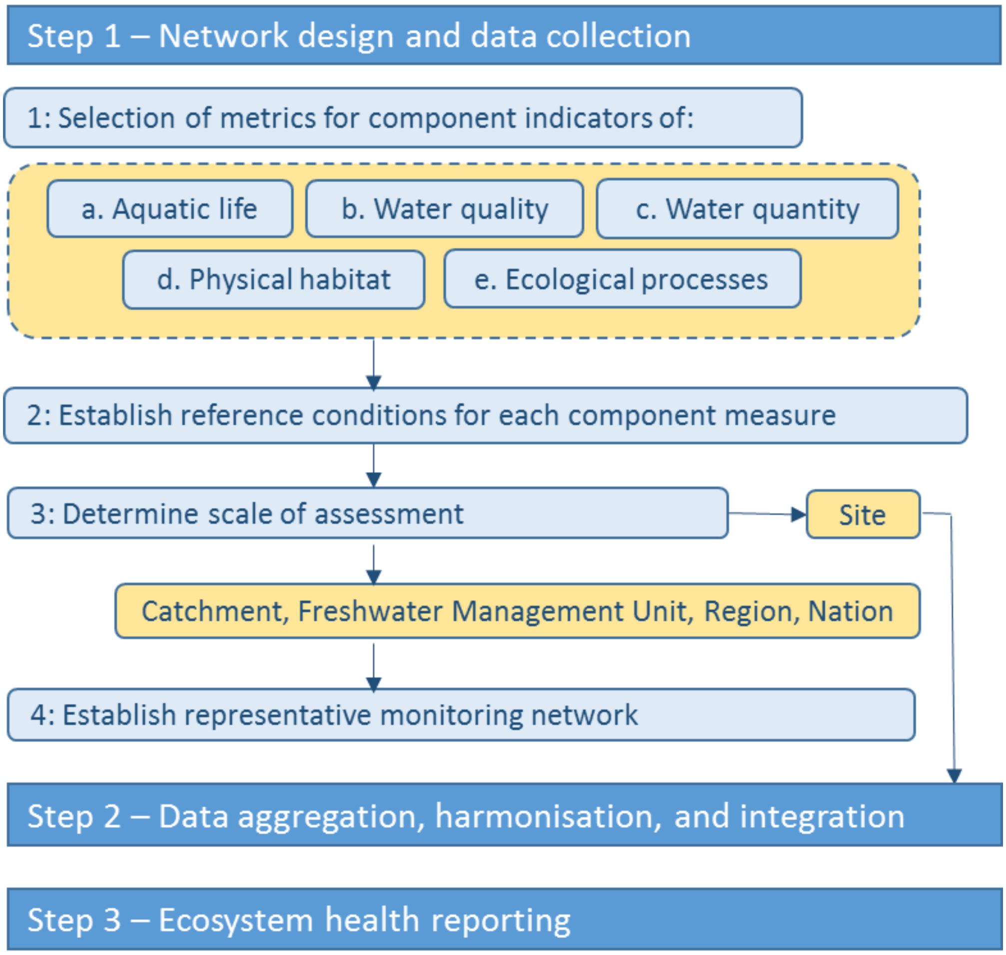


Figure 11. Flow diagram of the steps in the application of The Framework for freshwater ecosystem health.

4.2. As part of an adaptive sustainable management process

The purpose of The Framework is to provide a consistent approach for assessing the biophysical ecosystem health of fresh waters, giving central and local government, communities and individuals clear objectives related to maintaining and improving ecosystem health. The Framework is based on western science and does not adopt a kaupapa Māori approach. It is intended that it might support and align with biophysical values and indicators that iwi identify, through a parallel process. For example, the CHI includes biophysical components as seen through a Māori lens (Tipa & Teirney 2006). Together, The Framework and iwi-led assessments of ecological integrity contribute to a broader assessment of Te Hauora o te Wai and ultimately Te Mana o te Wai.

The Framework can, however, be used to inform measurable, numeric objectives for the biophysical components of freshwater ecosystem health, or 'ecological integrity'. Information on each of the five biophysical components collected at the catchment or regional level can be integrated to report on the catchment, regional or national state of the freshwater environment (Figure 12). This information also provides an evidence base to assess the effectiveness of policy, such as for example, Section 5(b) of the RMA, 'safeguarding the life-supporting capacity of air, water, soil, and ecosystems', and Objectives A1, A2 and B1, B2 of the NPS-FM, 'safeguard ecosystem health'. The Framework can be used to identify when a waterway is not meeting policy objectives and thereby prompt further investigation (Figure 12). It does not provide on-ground 'solutions', but it does provide fundamental scientific guidance to inform approaches to the adaptive management of fresh waters.

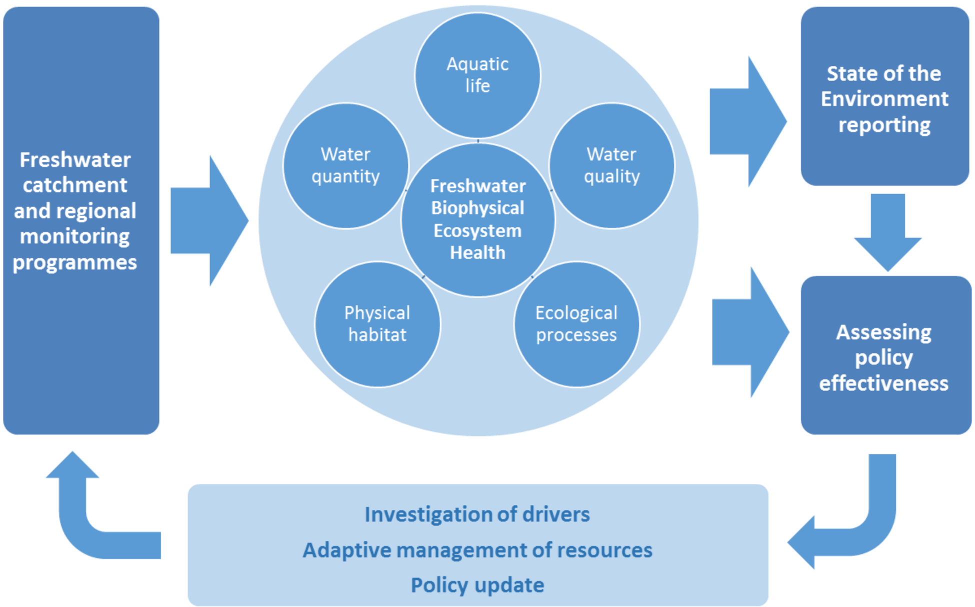


Figure 12. The Framework for freshwater biophysical ecosystem health as part of an adaptive management cycle.

An important part of the adaptive management of fresh water is understanding the links between external drivers and biophysical condition. Human pressures impact on fresh water through numerous mechanisms and produce ecological consequences that can be measured using the Framework (Figure 13). Understanding direct mechanistic links can be challenging, but conceptual models based on best scientific knowledge are useful in identifying the most likely causal pathway. For example, the hypothetical pathways through which various human pressures impact on a macroinvertebrate indicator of ecosystem health are shown in Figure 14. Conceptual diagrams like these can be used to design statistical analyses that provide the empirical evidence to direct management efforts. For instance, recent analysis identified how much the variance in macroinvertebrate metrics could be independently attributed to the influence of nutrient or sediment pathways on macroinvertebrate response (Clapcott et al. 2017a). This evidence can be used to direct further monitoring (which would provide data to empirically link proximate drivers to biophysical condition), and to inform resource allocation (i.e. limit resource use to maintain condition or prioritise restoration actions to improve condition). We recommend that conceptual diagrams be developed for all component indicators and their associated metrics to identify the stressor pathways, so as to inform causal hypotheses, further targeted investigations and, ultimately, adaptive management responses to the state of ecological integrity.

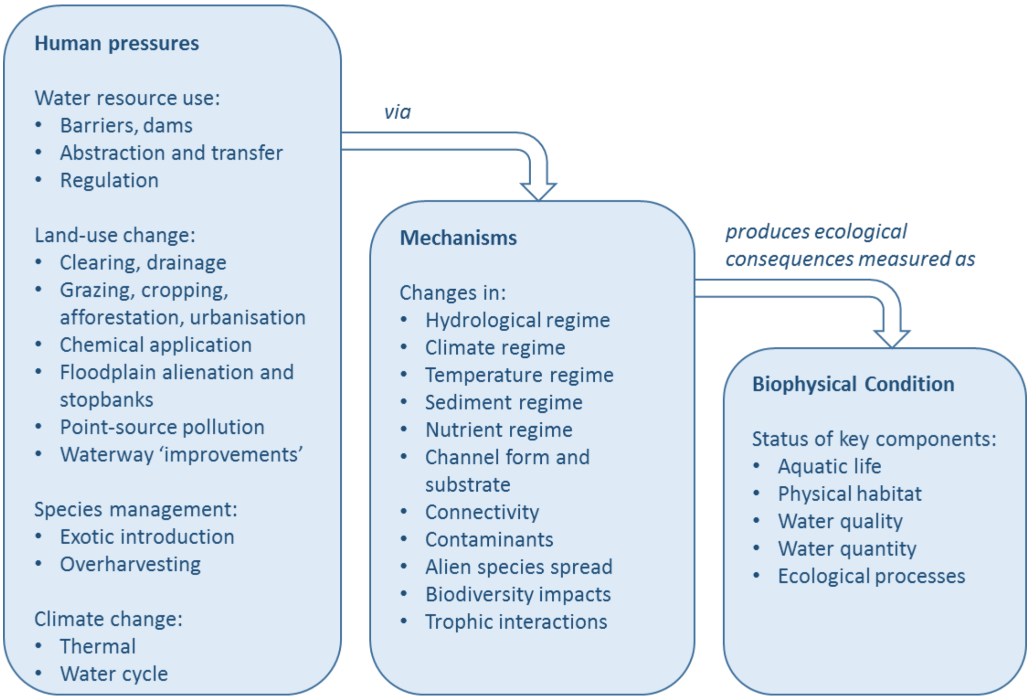


Figure 13. The link between human pressures and the biophysical ecosystem health of freshwaters. Adapted from Davies et al. (2010).

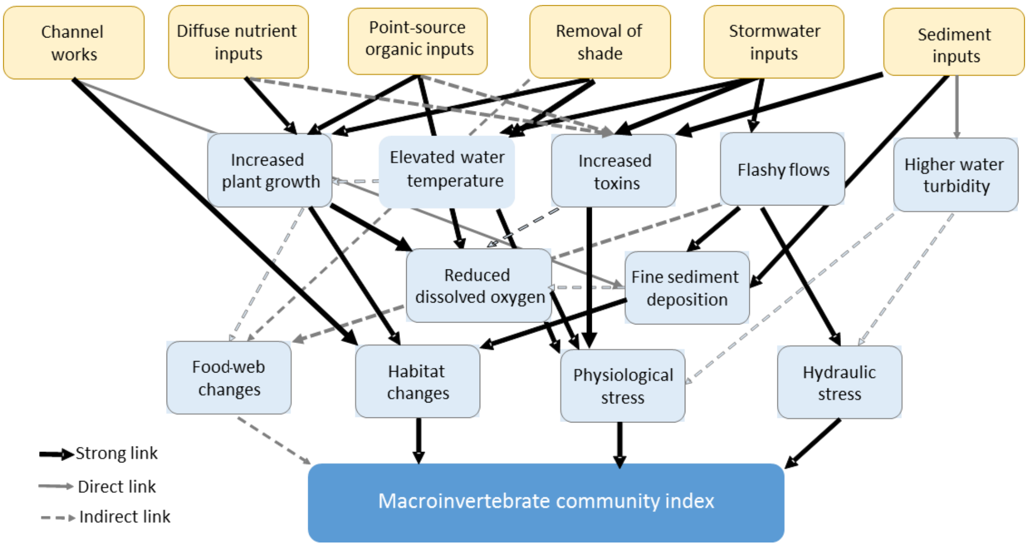


Figure 14. Pathways (hypothesised links) by which various stressors (orange boxes) influence a macroinvertebrate community index. Adapted from Collier et al. (2014).

4.3. Choosing metrics to inform indicators of core components

The Framework has five core components: aquatic life, water quality, water quantity, physical habitat, and ecological processes. Evaluation of all five core components is required to obtain an integrated assessment of the biophysical ecosystem health of fresh waters. Metrics need to be selected for each component, and there is flexibility in the metrics chosen for each indicator, to allow metrics to be selected that suit the aim of the assessment (e.g. restoration, community monitoring, national reporting); we do not recommend a fixed set of metrics in this report.

Here we provide an example of how the five framework component indicators can be used to select a range of freshwater metrics for the assessment of **wadeable river health**. Indicator qualities are rated, similar to the criteria weighting in the DOC ecological integrity framework (Schallenberg et al. 2011), and include:

- sensitivity to anthropogenic impacts (1= no/unknown, 2 = some evidence, 3 = strong)
- standardised methods available (1 = no, 2 = in part, 3 = yes)
- current use (1= rare, 2 = moderate, 3 = common)
- ease of sampling and analysis (1 = difficult, 2 = moderate, 3 = easy)
- calibration to reference state (1 = unknown, 2 = in part, 3 = well known)
- spatial/temporal scale of measurement (1 = site/spot, 2 = reach/seasonal, 3 = (sub-)catchment/continuous)
- primary spatial/temporal scale of impact (1 = site/day, 2 = reach/week–month, 3 = (sub-)catchment/annual)

For example, native fish taxa richness is rated as 'no/unknown' for sensitivity to anthropogenic impacts, 'yes' for standard methods available, 'moderate' for current use, 'difficult' for ease of sampling and analysis, 'unknown' for calibration to reference state, 'reach/seasonal' for scale of measurement and '(sub-)catchment/annual scale' for effect of anthropogenic impacts.

A table identifying indicator qualities can help with the selection of indicators for various applications; the higher the rating, the more suitable the indicator is, based on current knowledge and technology. Conversely, the lower the score, the greater the need for more validation and method development before the indicator is applied to The Framework.

4.3.1. Aquatic life indicators

In a healthy ecosystem, native species of flora and fauna persist and alien species are scarce or absent. In an unhealthy ecosystem, alien species of flora and fauna are dominant and native species are reduced or absent. In more extreme cases, total number of species and community diversity decline (Davies et al. 2010).

‘A range and diversity of indigenous flora and fauna’ (NPS-FM 2014) is measured by indicators of biota, or the aquatic life present in fresh waters. In New Zealand rivers and streams, this includes waterbirds, fish, invertebrates, plants (macrophytes and/or periphyton), and microbes (Table 4). Periphyton biomass is currently the only compulsory aquatic life attribute in the NPS-FM for ecosystem health. However, the NPS-FM requires regional councils to develop a monitoring plan that must at least include the monitoring of macroinvertebrate communities (specifically the Macroinvertebrate Community Index), measures of the health of indigenous flora and fauna and, finally, attributes for any other objectives that have been set. No other biota are specifically mentioned in the NPS-FM.

For each set of aquatic life indicators, metrics ideally describe both the structure and function of the biotic community but, in practice, most developed metrics describe community structure (Table 4). Aquatic life indicators measure the richness and abundance of biota, which further describes the biodiversity of freshwaters (Storey et al. 2018).

Based on the overview provided in Table 4, we suggest that there is sufficient knowledge and development of metrics to provide measures of the indicators for plants, invertebrates and fish for wadeable rivers in New Zealand. We recommend that indicator scores for each of these three core indicators be the goal of an integrated assessment of the aquatic life component. Previous research provides guidance on how to integrate metrics into an invertebrate indicator (Collier 2008; Clapcott et al. 2017a) and could be applied to other biotic groups. Alternatively, a single biotic indicator for each group can be used, when a robust indicator is available.

Table 4. Rating of indicators of aquatic life in New Zealand rivers based on expert opinion. Indicators identified as compulsory attributes for assessing ecosystem health in the NPS-FM are in bold. Indicators commonly measured as part of many regional council monitoring programmes are identified with an asterisk.

Indicator	Sensitivity	Standard methods	Current use	Ease of sampling	Reference calibrated	Scale of measure	Scale of impact	Total
Waterbirds								
Taxa richness	1	1	1	1	1	1	1	7
Abundance	2	1	1	1	2	1	1	9
Native fish								
Taxa richness	1	3	2	1	1	2	3	13
Fish IBI	2	2	2	1	2	2	3	14
O/E fish species	1	2	1	1	2	2	3	12
Pest species	1	2	1	1	3	2	3	13
Invertebrates								
Taxa richness	1	3	3	2	1	1	2	13
MCI*	3	3	3	2	2	1	2	16
%EPT*	3	3	3	2	2	1	2	16
O/E species	2	2	1	2	3	1	3	14
Invertebrate IBI	3	3	1	1	2	1	2	13
SHMAK MCI	2	3	2	3	2	1	2	15
Macrophytes								
% cover	2	3	1	3	1	1	1	12
% native	2	3	1	3	3	1	2	15
MCC	2	3	1	3	1	1	1	12
Periphyton								
% cover*	2	3	3	3	1	1	2	15
Biomass (chl-*a*)*	2	3	3	2	2	1	2	15
% filamentous*	1	3	3	3	2	1	2	15
% cyanobacteria	1	2	1	3	1	1	2	11
SHMAK % cover	1	3	1	3	1	1	2	12
Microbes								
O/E species	1	1	1	3	2	1	1	10
BCI	2	1	1	3	1	1	1	10

IBI = Index of Biotic Integrity, O/E = observed to expected ratio, MCI = Macroinvertebrate Community Index, SHMAK = Stream Health Monitoring and Assessment Kit, MCC = Macrophyte Channel Clogginess, BCI = Bacteria Community Index.

4.3.2. Water quality indicators

In a healthy ecosystem, water quality supports a diverse range of aquatic flora and fauna, and contaminants are scarce or absent. In an unhealthy ecosystem, contaminants are present or exist at levels that inhibit aquatic life and key biogeochemical processes.

The freshwater environment can be assessed by a suite of physicochemical indicators that describe the quality or 'life-supporting capacity' (RMA 1991) of water. Physicochemical indicators include dissolved oxygen (DO), temperature, nutrients suspended sediment and/or clarity, and toxicants (Table 5). In the NPS-FM, a minimum DO attribute is applicable below point sources and there are attributes for ammonia toxicity and nitrate toxicity. The nutrient attributes measure the toxic effects of nitrate, not the trophic state. As such, the current attributes can be considered as measures of contaminants rather than water quality indicators of the state of ecosystem health itself. Other contaminants sometimes measured include various heavy metals, hydrocarbons and pharmaceuticals.

Based on Table 5, we suggest that there is sufficient knowledge of metrics to inform all five key indicator scores for the water quality component, including dissolved oxygen (DO), temperature, nutrients, clarity and/or suspended sediment, and toxicants. Previous research has suggested ways in which metric data can be integrated into indicator scores (e.g. using CCME WQI, by Hudson et al. 2012) and further guidance can be taken from NPS-FM attribute tables for how to apply specific indicators such as DO, and ammonia and nitrate toxicity.

Table 5. Rating of indicators of water quality in New Zealand rivers based on expert opinion. Indicators identified as compulsory attributes for assessing ecosystem health in the NPS-FM are in bold. Indicators commonly measured as part of many regional council monitoring programmes are identified with an asterisk.

Indicator	Sensitivity	Standard methods	Current use	Ease of sampling	Reference calibrated	Scale of measure	Scale of impact	Total
*Dissolved oxygen**								
Minimum DOƚ	2	3	2	2	1	2	2	12
Spot measure	2	2	3	3	1	1	2	13
*Temperature**								
Maximum	2	2	1	2	1	2	1	9
CRI	2	2	1	2	1	2	1	10
Spot measure	1	2	3	3	1	1	1	12
*pH**	1	2	3	3	1	1	2	13
*Susp.sediment**								
Clarity	2	2	3	3	2	1	2	15
Turbidity	2	2	3	3	1	1	2	14
Sediment load^	2	1	1	1	2	3	3	10
*Nutrients**								
Total N and P	3	3	3	3	2	1	3	18
Dissolved P	3	3	3	3	2	1	3	18
Nutrient loads^	2	1	1	2	2	3	3	11
Toxicants								
Ammonia toxicity	3	3	3	3	3	1	1	17
Nitrate toxicity	3	3	3	1	3	1	1	15
Metals	3	3	1	2	3	1	1	14

DO = dissolved oxygen, ƚ = only below discharges, CRI = Cox-Rutherford Index, ^Nutrients and sediment loads can be calculated from flow-weighted measurements or predicted using farm- or catchment-scale models, e.g. OVERSEER™ (Ledgard et al. 1999), CLUES (Woods et al. 2006).

4.3.3. Water quantity indicators

In a healthy ecosystem, the water level and the extent of water are sufficient, as is the flow regime, to support a diverse range of aquatic flora and fauna during their full life cycle. 'Flow regime' includes the floods and droughts that ensure the surface water connectivity between the fresh waters and surrounding terrestrial habitat and other fresh waters (e.g. rivers and their floodplains, and wetlands), the regulation of biotic production and diversity, and that shape the morphology of physical habitat. In an unhealthy ecosystem, water quantity is insufficient to support a diverse range of aquatic life and the flow regime impedes the up- and down-stream dispersal by aquatic plants and animals, as well as the dispersal of terrestrial species laterally and longitudinally within floodplains. Flow regime in an unhealthy ecosystem further limits key biogeochemical processes relying on the inundation and connectivity of floodplain habitats.

The freshwater environment is further assessed by hydrological indicators that describe the quantity of water and flow regime (Table 6) that determines the life history of biota in rivers. The NPS-FM requires regional water management plans to establish freshwater objectives and enforceable limits on water resource use in the form of water quantity limits for all water bodies. Limits on the maximum use of water resources must therefore be set to avoid over allocation. These limits must consist of at least a predefined minimum flow (the flow at which all abstraction must cease) and a total allocation (the maximum rate of abstraction summed across upstream abstractions). There are currently no water quantity indicators prescribed in the NPS-FM. There is, however, a Proposed National Environmental Standard on Ecological Flows and Water Levels (2008) that has been used by some regional councils voluntarily to inform flow setting. The draft NES is yet to be updated and enacted. The Flow Guidelines for Instream Values (MfE 1998) has provided useful guidance on the need for minimum flows and allocation limits to achieve instream management objectives.

The application of water quantity indicators is complicated by the wide variability in natural flow regimes within Aotearoa New Zealand, which requires a reference framework for assessing condition (Jowett & Duncan 1990), and by the temporal variability of flow requirements to maintain ecological processes and provide for the needs of biota (e.g. base flows for fish rearing; high flows for fish spawning; spate frequency for bedload transport, and for controlling channel form, and instream and channel vegetation within healthy bounds). Poff et al. (1997) describe a number of hydrological indices to describe natural flow regimes, which should be linked to the locally relevant ecological values within a framework for setting environmental flows (Horne et al*.* 2017). Booker (2018) has developed a Water Allocation Index as an index of the allocation pressure within a catchment but, given the complexity of flow/biota relationships, the index may also be useful as an integrative water quantity response variable.

Based on Table 6, we suggest that there is sufficient knowledge to describe the water quantity indicators of extent and hydrological variability where they are measured, but less so for connectivity. ‘Extent’ refers to the quantity of water and spatial coverage of a stream that may be impacted by water abstraction or a change in the physical form of a river. ‘Hydrological variability’ refers to the flow regime that may be impacted by water allocation and land-use change. ‘Connectivity’ refers to the temporal coverage of a stream and the occurrence of flows that connect instream water with out-of-channel water and groundwater that, in turn, may also be impacted by water allocation, land-use change and a physical change in the river. National effort is required to determine the appropriate reference conditions for data harmonisation (see Section 4.6) and the subsequent integration of the metrics.

Table 6. Rating of indicators of water quantity in New Zealand rivers based on expert opinion. Indicators commonly measured as part of many regional council monitoring programmes are identified with an asterisk.

Indicator	Sensitivity	Standard methods	Current use	Ease of sampling	Reference calibrated	Scale of measure	Scale of impact	Total
Extent								
Wetted area	1	2	1	3	2	1	1	10
Velocity	1	2	2	3	1	2	1	12
Depth	1	2	2	3	1	1	1	11
Hydrological variability								
Mean*	1	3	2	1	2	2	3	13
MALF*	2	3	2	1	2	2	3	14
Variability	2	3	1	1	2	2	3	13
Flood frequency	2	3	1	1	2	2	3	13
Flood magnitude	2	3	1	1	2	2	3	13
Connectivity								
Floodplain	2	1	1	1	1	2	3	11
Groundwater	1	1	1	1	1	2	3	10

MALF = Mean annual low flow.

4.3.4. Physical habitat indicators

In a healthy ecosystem, the physical form and extent of the waterbody and its surrounding floodplain, including its riparian vegetation, support a diverse range of aquatic flora and fauna throughout their life cycle. Physical structure (e.g. substrate, banks) and processes (e.g. sediment regime) are dynamic and support a mosaic of habitats within the waterbody and surrounding floodplains (Fryirs & Brierley 2009). In an unhealthy ecosystem, the physical form of the waterbody is altered to a degree that it can no longer support a diverse range of aquatic flora and fauna owing to the dominance of unsuitable habitat features, including relatively unstable structure, loss of riparian/floodplain vegetation and physical barriers that impede habitat connectivity within the waterbody (e.g. instream barriers) and with surrounding floodplains (e.g. stop banks).

The freshwater environment is further assessed by habitat indicators that describe the physical form of the wetted area, the river channel and the riparian vegetation (Table 7), which together determine the 'life-supporting capacity' (RMA 1991) of river habitat. There are currently no habitat indicators prescribed in the NPS-FM.

The development of physical habitat metrics for wadeable streams in New Zealand has focused on describing riparian condition, channel form and habitat quality for biota (Harding et al. 2009; Clapcott 2015), as well as measuring deposited sediment (Clapcott et al. 2011). Like for water quantity indicators, the application of habitat indicators is complicated by the wide natural variability in freshwater habitats. Existing landscape-scale classifications, such as the River Environment Classification, are suitable for explaining variation in some ecological indicators (e.g. macroinvertebrates; Snelder et al. 2004), but do not necessarily describe the physical form of rivers and how they are expected to vary over time. Geomorphic principles (i.e. considering natural spatial and temporal variation) may be necessary to provide the relevant reference conditions to assess stream habitats (Brierley et al. 2010).

Based on Table 7, we suggest that there is sufficient knowledge and development of metrics to provide measures of the physical habitat indicators of substrate and riparian state, where it is measured. 'Substrate' describes the relative proportion and stability of bed sediments (in comparison to what is expected). 'Riparian' refers to the vegetated area that is influenced by the river. A Rapid Habitat Assessment method (Clapcott 2015) and other qualitative assessments (Stream Habitat Assessment Protocols (SHAP); Harding et al. 2009) can also be used to inform site-scale measurements of extent and form. 'Extent' refers to the spatial coverage of river habitat. 'Form' refers to the shape and geomorphic processes occurring beyond the wetted river width, i.e. bank and floodplain. However, further effort is required to develop suitable metrics to inform indicators of connectivity, as well as form and extent at the catchment scale, especially in regards to identifying appropriate reference conditions. 'Connectivity' refers to the physical continuity between water-dependent habitats. All five indicator groups (substrate, extent, form, connectivity, riparian) are impacted by proximate and catchment-scale land use, as well as water resource use. All five indicator groups need to be assessed relative to the expected physical habitat mosaic at any given time, while taking into consideration temporal dynamics, i.e. system evolution.

Table 7. Rating of indicators of habitat in New Zealand rivers based on expert opinion. Indicators commonly measured as part of many regional council monitoring programmes are identified with an asterisk.

Indicator	Sensitivity	Standard methods	Current use	Ease of sampling	Reference calibrated	Scale of measure	Scale of impact	Total
Substrate								
% fine sediment*	2	3	2	3	2	2	3	17
Substrate stability	1	2	1	3	1	1	2	11
Interstitial space	2	1	1	3	1	1	2	11
Organic matter	1	1	1	3	1	1	1	9
Extent								
WUA	2	2	2	1	2	2	2	12
Residual pool depth	2	2	1	2	1	2	2	12
RHA*	1	3	2	3	2	1	2	14
Form								
Bank stability	2	1	1	3	1	1	1	10
Sinuosity	2	1	1	1	1	2	3	11
Gradient	1	2	1	3	1	2	2	12
Connectivity								
Floodplain connect	2	1	1	2	2	2	3	13
Riparian								
SHAP Naturalness	2	2	1	2	2	1	1	11
Shade*	2	3	2	3	2	1	1	14

RHA = Rapid Habitat Assessment, WUA = Weighted Usable Area (taxa specific), SHAP = Stream Habitat Assessment Protocols.

4.3.5. Ecological process indicators

'Ecological processes' (NPS-FM 2014) are the interactions among biota and their physical and chemical environment, including biogeochemical processes. In a healthy ecosystem, the retention, transformation and uptake of carbon and other nutrients are optimised by natural diversity, trophic complexity and connectivity of the biophysical components. In an unhealthy ecosystem, lower biodiversity, trophic complexity and connectivity cause the reduced transformation and uptake of carbon and other nutrients. In extreme cases, substantial 'leakage' of bioavailable nutrients can occur (Davies et al. 2010).

Indicators of ecological processes in rivers provide a measure of how well a stream is *functioning* (Table 8), as opposed to how the ecosystem is *structured* (Young et al. 2008). Indicators of stream function can respond to land-use impacts in contrasting ways to indicators of stream structure (Clapcott et al. 2012) and, when used together, structural and functional indicators provide a more informative assessment of river ecosystem health (Clapcott et al. 2014). Functional indicators include measures of biotic interactions, which describe the complexity of the stream food web and how it can be impacted by species management, water resource use and land use. Measures of biogeochemical processes describe carbon and nutrient transformations that are also affected by multiple human impacts, as well as by and, in turn shape, the water quality and aquatic life components of ecosystem health. For example, gross primary productivity (GPP) is determined by the type and abundance of aquatic plants present, and driven by light availability (which is influenced by riparian shade), water temperature (which is influenced by riparian shade, catchment land use and water quantity), and nutrient availability (which is influenced by catchment land use).

Internationally, the development of functional indicators of ecological processes has trailed behind the development of indicators that describe structural ecosystem health components. However, recent research has provided management guidelines for ecosystem metabolism (GPP and ecosystem respiration, ER) as well as organic matter processing (Young et al. 2016). Furthermore, most of the data required to calculate ecosystem metabolism can be collected when assessing the dissolved oxygen indicator for the water quality component. Simple assays that estimate organic matter processing have also been developed (e.g. cotton strip assay; Tiegs et al. 2013) that facilitate the broad functional assessments of rivers across continents (Tiegs et al. in review) and in New Zealand (Clapcott et al. 2017b).

Based on Table 8, we suggest that there is sufficient knowledge and development of metrics to inform an indicator of biogeochemical processes for wadeable rivers in New Zealand.

Table 8. Rating of indicators of ecological processes in New Zealand rivers based on expert opinion. Indicators commonly measured as part of many regional council monitoring programmes are identified with an asterisk.

Indicator	Sensitivity	Standard methods	Current use	Ease of sampling	Reference calibrated	Scale of measure	Scale of impact	Total
Biotic interactions								
Connectance	1	1	1	1	1	1	2	8
Rel. ascendency	1	1	1	1	1	1	2	8
Path length	1	1	1	1	1	1	2	8
Parasitism	1	1	1	1	1	1	1	7
Biogeochemical processes								
GPP	3	2	1	2	2	2	2	14
ER	2	2	1	2	2	2	2	13
Cotton strip assay*	3	3	1	3	1	1	1	13
OM processing	2	1	1	1	1	1	1	8
OM	2	2	1	2	1	1	2	11
Delta15N	2	2	1	1	1	1	1	9
Algal bioassay	2	2	1	2	1	1	1	10
Denitrification	1	1	1	1	1	1	2	8

GPP = gross primary productivity, ER = ecosystem respiration, OM = organic matter retention, Delta15N = the ratio of two stable isotopes of N (15N:14N) in primary producers or consumers.

4.3.6. Suitability of indicators

The Framework is flexible in terms of what indicators can be used to represent each core component and so is suitable for assessing the ecological integrity for multiple purposes (e.g. river restoration at the reach scale, management decisions at the regional scale or reporting at the national level). The above tables could be used to help identify which indicators are most suitable for each purpose, in rivers, and to also identify potential weightings for data analysis. Similar tables or decision trees could be developed to inform the selection of indicators for other fresh waters.

Ideally, a good indicator will be easy to measure, able to be measured accurately and repeatedly, sensitive to impacts, robust to natural variability, inexpensive to collect data for and provide credible information that can be easily understood (Boulton 1999). In reality, most indicators are sensitive to impacts at some scale, but often when selecting indicators a balance must be struck between expense of collecting the relevant data and the resulting data's accuracy. For example, the SHAP (Harding et al*.* 2009) provide four levels of protocols that require varied effort, from a desk-top assessment to spending several hours at a site, to obtain output that could range from a summary to detailed stream habitat data. Few, if any, regional councils have applied the most detailed protocols and, instead, rapid habitat assessments are most often used. However, to obtain more accurate habitat data, rapid protocols are repeated over time. Replication at multiple sites also provides a more accurate estimate of average condition. In this light, less accurate indicators have their place.

Because many indicators are sensitive to impacts, they are also often sensitive to natural variability. For example, macroinvertebrate communities in streams are responsive to natural flood disturbance and vary in relation to natural environmental gradients such as longitude and elevation. Often rules are developed to maximise the indicator signal-to-noise ratio. For example, for macroinvertebrate indicators, samples are not collected within 2 weeks of a high flow event to minimise the noise effect. Likewise, environmental classification systems, such as the Freshwater Ecosystems of New Zealand (Leathwick et al*.* 2008), can be used to identify relevant reference benchmarks and maximise the signal effect. So, knowing when and where indicators can and should be applied is part of indicator development. Standardised methods include this information and help guide indicator selection.

4.4. Benchmarks for assessment and defining reference condition

The Framework requires reference state benchmarks to ensure consistency in the assessment of the biophysical components of freshwater ecosystems. For many metrics of component indicators, knowledge of reference conditions is incomplete and that will be a major limitation to their use in an assessment. Management guidelines can be used in the interim, while reference conditions are determined either from representative sampling and/or predictive modelling.

A range of approaches to determining the status of ecosystem health and/or ecological integrity are used in existing frameworks (Table 9). Most often, a reference condition approach is used, whereby 'reference state' is defined for each component and its subsequent indicator measures. Then deviation from the reference state is usually, but not always, used to assign quality grades or condition scores.

Table 9. Approaches to assigning quality grades and defining reference state in ecosystem health frameworks.

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Framework*	Assessment approach	Reference state
FARWH	Deviation from reference	'As close to natural as possible' (minimally disturbed, historical data, modelling, professional judgement)
IECA	Deviation from reference	'Predetermined baseline' (natural state, least disturbed, best available)
SEQ EHMP	Distribution of all data	Guideline values / modelled
SRA	Deviation from reference	Guideline values / modelled / least disturbed / expert knowledge
WFD	Deviation from reference	Natural state / minimally disturbed
Scotland EH	Deviation from reference	Natural state / minimally disturbed
SDG	Deviation from reference	
NARS	Fixed thresholds / distribution of reference site data	Least disturbed
DOC	Deviation from reference	Natural state / modelled
SEV	Deviation from reference	Natural state (unmodified streams)
WRRC	Fixed thresholds / expert knowledge	Guideline values / least disturbed / expert knowledge

* refer to Glossary

The WFD offers guidance on the determination of reference conditions based on the availability of data (Figure 15). Data from suitable reference sites is the first priority and expert judgement is recommended when no other methods exist to estimate the reference condition.

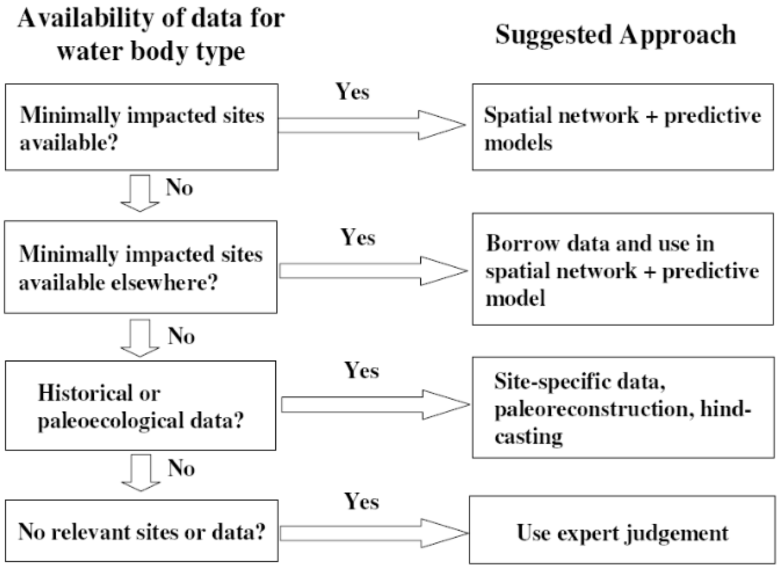


Figure 15. Step-by-step approach for the selection of methods to determine the reference condition (from van de Bund & Solimini 2007).

The IECA Framework highlights the need to consider shifting baselines when setting benchmarks for assessment, recognising that the reference condition can change over time. We recommend that monitoring networks should include contemporary reference sites to account for temporal change in reference conditions. Predictive models should be used to estimate the reference condition in the absence of reference sites. Models predicting reference conditions already exist for many water quality, habitat and biotic variables measured in New Zealand rivers and streams (e.g. Booker 2010, McDowell et al. 2013, Clapcott et al. 2017c, Haddadchi et al. 2018). Importantly, accounting for natural spatial and temporal variation in the environmental template is the foundation of any baseline assessment. There is a need to determine appropriate benchmarks during the selection of indicators. Indicators should not be used in the absence of reference benchmarks.

4.5. Network design

The Framework should be used to design new monitoring networks or to assess how existing networks are meeting the requirements of an integrated ecosystem health assessment. Currently in New Zealand, the SOE network at a national scale is dominated by sites located in the productive landscapes with known anthropogenic issues, and there is an under-representation of sites draining remote high-altitude areas in the DOC estate. The Framework should be used to design, or assess how monitoring strategies take into account, the biophysical attributes of fresh waters (including ecohydraulic variability) and facilitate different networks for different component measures, hence achieving spatial and temporal representation in ecosystem health assessments.

For example, in the Waimea River catchment in Tasman District, data to calculate macroinvertebrate and some water quality metrics are measured at six sites and hydrological variability is measured at one site, according to the LAWA webpage (Figure 16). Additional flow-recorder data and fish survey data are collected in the Waimea catchment, but are not currently displayed on the LAWA webpage. So, missing data for an integrated assessment of ecosystem health in the Waimea River catchment include that for indicators of other aquatic life, of water quality and of water quantity as well as for indicators of physical habitat and ecological processes. Indicators do not necessarily have to be measured at the same sites. However, if the Waimea catchment was to be the scale of assessment, then all five component indicators should be measured (or modelled) within the catchment.

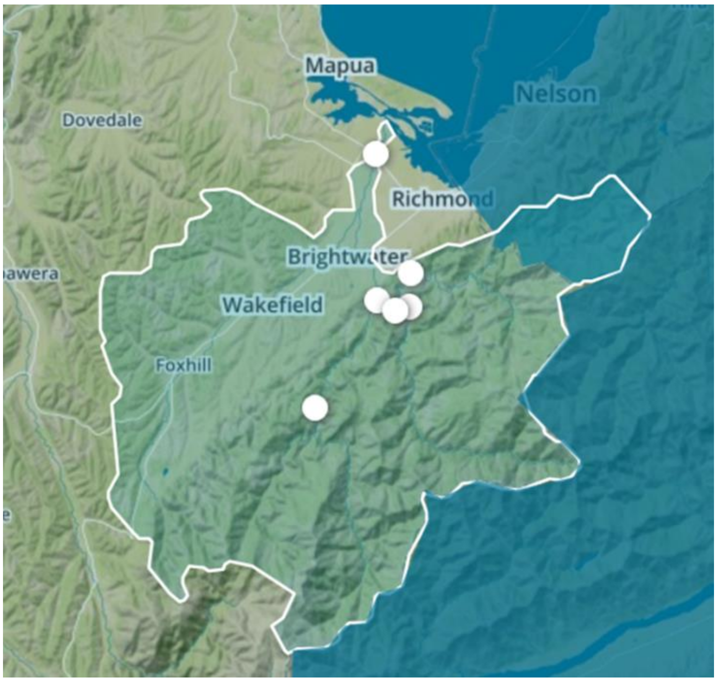


Figure 16. Locations of monitoring sites in the Waimea River catchment where aquatic life (macroinvertebrates) and water quality (nutrients, clarity and suspended sediment) indicators are measured. The site closest to the coast is where hydrology is also measured.

Ideally, site locations within a monitoring network should be geographically representative as well as representative of the ecotypes present at the catchment, Freshwater Management Unit, regional or national scale. Furthermore, sites that can inform a reference state should also be measured. For example, within the Waimea catchment, monitoring sites are located on all three of the major sub-catchments. Monitoring sites are all located on third-order or greater streams, yet 74% of the digital river network consists of first- and second-order streams. Three of the six monitoring sites are located where indigenous forest dominates the catchment and could provide suitable reference conditions.

A randomised network design that takes into account reference sites and stream order is one way to design a monitoring network (e.g. that used by Waikato Regional Council. See Collier 2005; Collier et al. 2007). This may or may not include stratification according to an existing river classification such as the River Environment Classification (REC; Snelder et al. 2004). According to the REC, there are three different climate types in the Waimea catchment (87% of the catchment experiences a cool-wet climate; 12%, a cool-dry; 1%, a warm-dry), three different sources of flow (60% hill, 30% lowland, 9% mountain), three different geologies (57% of the catchment is on hard-sedimentary substrate; 39%, on soft-sedimentary; 4%, on volcanic-basic), and four different dominant land covers (59% of the catchment is covered in indigenous forest; 23%, in exotic forest; 15%, in pasture; 3%, in tussock/scrub). To design a representative monitoring network based on the REC, consideration should be given to how monitoring sites provide a balanced picture of the classes present. Pragmatically, this exercise might be undertaken at the regional and national level rather than (sub-)catchment level. However, if ecosystem health is to be reported on at the (sub-)catchment scale, then the degree of spatial representation should be appropriate.

Previous publications provide guidance on the representative and statistical power of the river monitoring network at the national scale (Larned & Unwin 2012) and recommendation of new sites to improve representativeness (Unwin et al. 2014). Likewise, the representativeness of some regional monitoring networks have been explored to provide recommendations of sites and to identify reference sites in particular (Clapcott & Goodwin 2015). Transitioning from a targeted site design (e.g. Scotland EH network, many regional networks in New Zealand) to a randomised network design (e.g. NARS, Waikato region) is likely to provide a more representative assessment.

4.6. Data aggregation, harmonisation and integration

The Framework recommends that the management of data to assess the biophysical ecosystem health of fresh waters involves three key steps. First, data are aggregated to the appropriate spatial scale of assessment for each metric (Figure 17). Next, data are harmonised, or standardised to a common scale of 0–1, to ensure that metric data are comparable. This is where reference data play a key part in establishing baselines for assessment (Figure 17). Finally, data are integrated or combined for reporting at the indicator level, component level or full ecological-integrity level. Data integration can involve simple averaging or weighted averaging as long as the chosen method is transparent and justified on the basis of environmental science. Missing data should be clearly acknowledged.

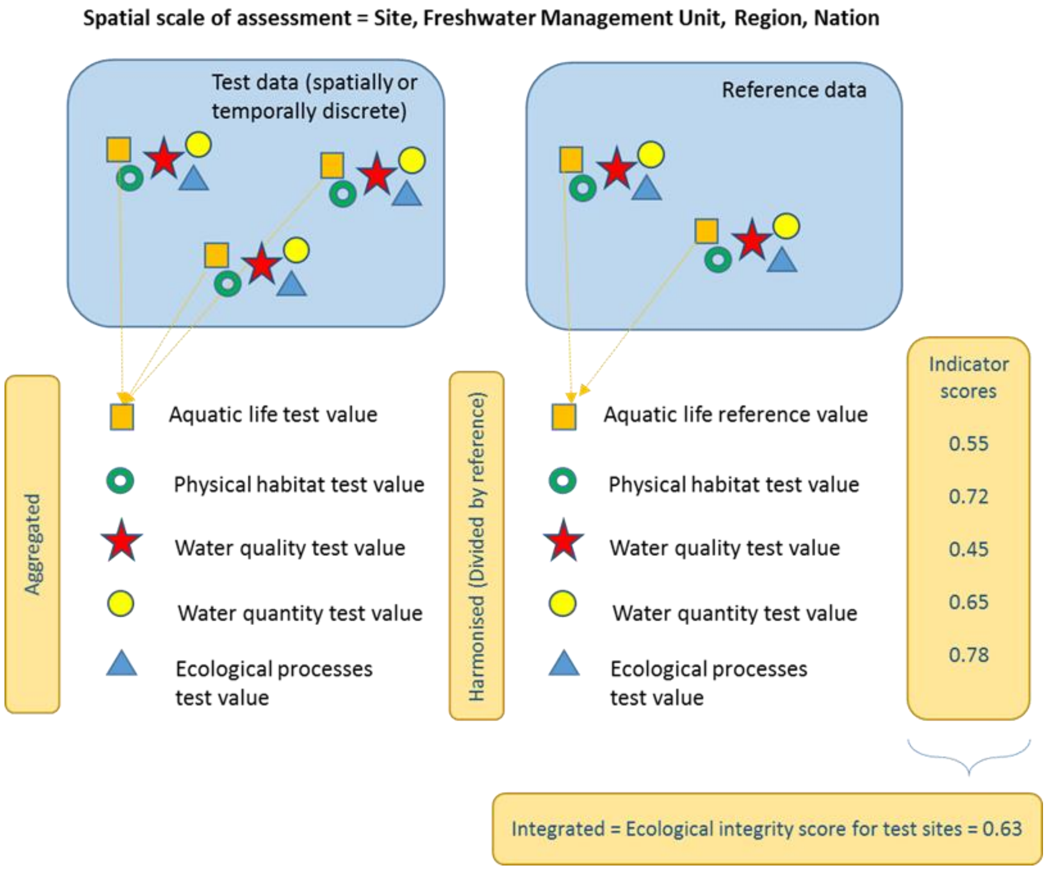


Figure 17. Data aggregation, harmonisation and integration for application of the proposed Framework. Adapted from Robinson and Butcher (2017).

4.6.1. Data aggregation

Data aggregation refers to the compilation of data for a given indicator to be reported at a specific scale, e.g. nitrogen concentrations for multiple sites and/or multiple locations within a given catchment. The Framework suggests that data describing ecological components (e.g. aquatic life, water quality) be first aggregated at the scale appropriate for each indicator.

Aggregation before integration is desirable for multi-site assessments because it is more efficient and simpler, and can create narrower confidence intervals (Robinson & Butcher 2017). It also has the substantial advantage of allowing independent sampling frames for each indicator, such as the disparate water quality and ecology monitoring networks that are currently in place in many regions of New Zealand. Components can be sampled independently of each other and each component can be sampled to a desired level of confidence in assessment. The downside of this approach is that sampling of different components at different scales can require more logistical effort for fieldwork. It also requires individual component scores be aligned to the same spatial scale, such as the catchment or Freshwater Management Unit, before integration.

The Framework recommends the use of standardised methods to facilitate the aggregation of indicator data at several spatial scales (e.g. (sub-)catchment, Freshwater Management Unit, regional and national). Aggregation typically involves averaging, though other statistics might also be used, e.g. the 25th percentile would indicate that 75% of sites are in the specified condition or better. For example, if scale-appropriate indicator data were collected using consistent methods to determine the success of stream restoration (i.e. ecological integrity) at the reach scale, then data aggregation should simply involve taking the mean of temporally discrete measures. If data are measured across multiple sites for a regional assessment, then data should be aggregated by ecotype, if appropriate.

4.6.2. Data harmonisation

Harmonisation (converting to a common scale) and integration (summing) should happen after spatial aggregation (Department of the Environment and Energy 2017). Data harmonisation standardises the range in metric values from 0 to 1 and renders scores unit-less. This necessary step renders assessments using different methods comparable, as well as scores for different indicators and components. A score of 1 corresponds to the best attainable or reference condition, and a score of 0 to a totally degraded condition.

The Framework recommends that each of the metrics be examined to ensure that it is theoretically possible to arrive at indicator values ranging from 0 to 1. Each of the indicator values should also be examined to ensure that they are normally distributed, and values of 0, 0.5 and 1 could be appropriately described as totally degraded, halfway between degraded and pristine, and pristine (Norris et al. 2007). Dividing observed values by expected values (O/E, or 1 – (O/E)) is a preferred approach but can introduce bias when metric scores are not normally distributed or the range in metric reference scores varies widely (Heikki et al. 2018). Alternative approaches include using maximum and minimum observed values as anchor points for scaling values to 0–1 (Department of the Environment and Energy 2017). Either ‘expected’ values or ‘maximum’ values are determined by reference condition.

Indicator harmonisation requires knowledge of the relevant reference condition for that stream (possibly obtained from a Before-After-Control-Impact survey design) or ecotype (measured or modelled) to scale the values to 0–1. The Framework recommends that indicator data be harmonised relative to a benchmark to allow for the comparison of indicator ‘scores’ and the integration of indicator data into component ‘scores’ as well as an overall ecological integrity ‘score’.

4.6.3. Data integration

Integration refers to the summation of different indicators into a combined assessment or score. There are many different ways to select and combine data for environmental assessment, and confusion may result unless the process is transparent. Examples include:

- One out–all out[2] (e.g. WFD)
- Weighted averaging based on expert opinion (e.g. WRRC)
- Weighted averaging based on model confidence and data representation (e.g. DOC ecological integrity multi-metric)
- Simple averaging (e.g. SEQ EHMP, SEV)
- Summing (e.g. as with multi-metric indices (Hering et al*.* 2006))
- Multiplying (e.g. as proposed for a watershed assessment of key ecological processes (Flotemersch et al*.* 2016))

A considered approach on how component scores are integrated will help minimise potential bias. For example, one criticism of the one out–all out approach is that it is too conservative (Hering et al*.* 2010). The IECA Framework provides guidance on how to integrate within a given component (i.e. using multiple indicators for one component, such as water quality), but also recommends against integrating across different components (e.g. water quality and biological diversity) unless it is for broad- and/or national-scale reporting (Department of the Environment and Energy 2017). There is no inherently right or wrong way to aggregate scores from different metrics; any method will have consequences for how results are interpreted.

Following the IECA method, the Framework recommends that metric scores be integrated to provide indicator scores by simple averaging, with the assumption that scores will have been correlated, which is likely (Figure 18). When calculating component scores and an overall ecological integrity score, some type of weighted averaging should be used. Weighted averaging allows the relative importance of aquatic life as the key component of an ecosystem to be emphasised, and can also take into account the relative sensitivity of different metrics (Figure 18). Assigning weights can be done through an expert opinion process (e.g. WRRC, Williamson et al. 2016), analysis of data (e.g. DOC ecological integrity project, Clapcott et al. 2014), or supported by a combination of both expert opinion and data analysis using fuzzy logic software (e.g. SRA, Davies et al. 2010). We recommend pilot data be analysed to determine the most appropriate weightings for metrics contributing to component indicators scores and for component indicators scores contributing to an overall ecological integrity score. The process should be transparent and open to review. A hypothetical weighting approach to investigate further is provided in Figure 18.

[2] To achieve a certain grade, a freshwater system must meet the threshold for all component indicators for that grade.

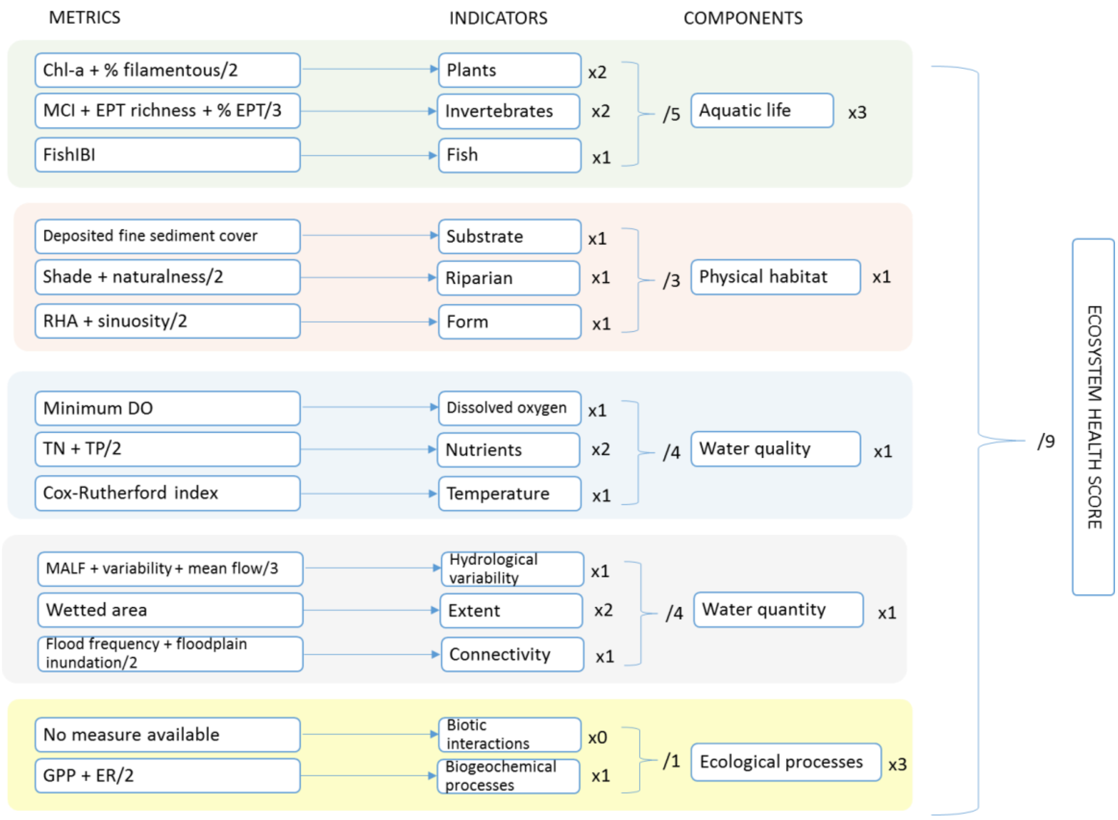


Figure 18. Hypothetical weighting of metric, indicator and component scores for reporting the biophysical ecosystem health of fresh waters.

Many of the decisions that are required for consistent data management are reliant on exploration of the data. Therefore, we recommend that a guidance document be developed to support Framework implementation that, for example, details standardised protocols for data management, analysis and reporting. Existing datasets could be explored to develop the guidelines, such as the Hawkes Bay Ecosystem Health pilot study data funded by MfE, and national SOE data collated for various research project and reporting purposes by MfE.

4.7. Ecosystem health reporting

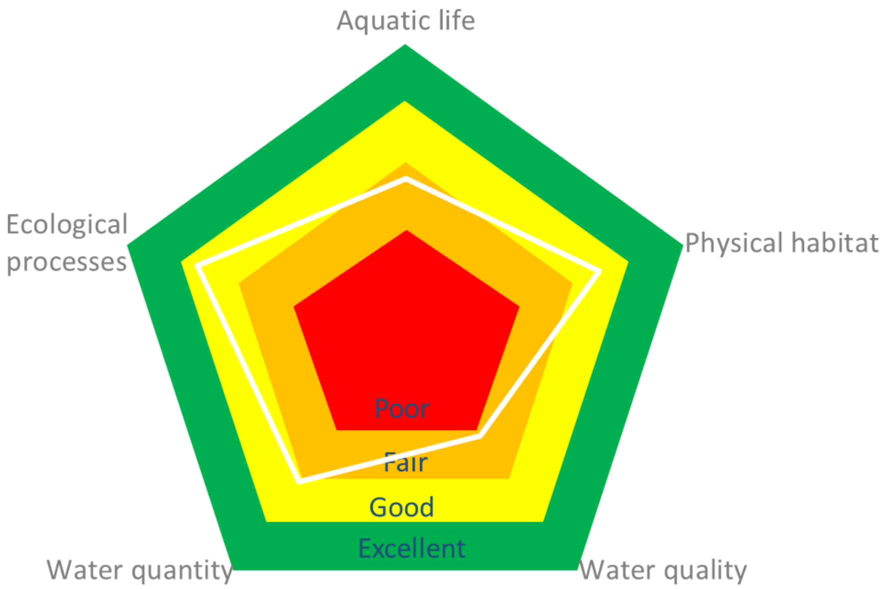
The Framework supports the consistent reporting of biophysical ecosystem health across environment types and spatial scales. When indicator data are not collected using standard methods, then analysis becomes more complicated than the above example. But it is doable. A special journal issue on inter-calibration among EU WFD members outlines how multi-metrics designed specifically for inter-calibration can be used to compare different assessment methods (Furse et al. 2006). For example, a direct comparison of benthic macroinvertebrate indicators of ecological status showed strong correlations between the scores of member state indices despite the data having been collected and analysed differently (Birk & Hering 2006). However, differing methods of assigning score boundaries (i.e. thresholds between A–E scores) led to a significant variation in overall ecological status. That is, all member states used the Ecological Quality Ratio to harmonise data, then assigned ‘high’, ‘good’, ‘moderate’, ‘poor’ and ‘bad’ quality boundaries using different methods. The need for agreement on the reference condition, and hence the assignment of score boundaries based on deviation from that reference, is a major recommendation of The Framework.

For example, if all indicator scores are harmonised to a range from 0 to 1, then from 1 down to some acceptable deviation from 1 would inform an ‘excellent’ state (Table 10). This deviation could vary for individual metrics but should be consistent across all five component indicators and facilitate the direct comparison of component scores. A pilot study is required to determine the appropriate deviation from the reference state for assessment and reporting. The use of narrative quality grades such as excellent, good, fair and poor, that directly translate to A–D scores, provides consistency with attribute grades in the National Objectives Framework (NPS-FM 2017). It further provides a ‘common language’ for stakeholder and public participation in the adaptive resource management of fresh waters.

Table 10. Hypothetical range in component indicator scores used to report on the biophysical health of fresh waters in Aotearoa New Zealand.

Component indicator	Poor (D)	Fair (C)	Good (B)	Excellent (A)
Aquatic life	0–0.4	0.4–0.6	0.6–0.8	0.8–1
Water quality	0–0.4	0.4–0.6	0.6–0.8	0.8–1
Water quantity	0–0.4	0.4–0.6	0.6–0.8	0.8–1
Physical Habitat	0–0.4	0.4–0.6	0.6–0.8	0.8–1
Ecological processes	0–0.4	0.4–0.6	0.6–0.8	0.8–1

Once quality grade thresholds have been designated, then indicator scores should be reported using a diagram that illustrates all five components. For example, this could be in the form of a radar graph or other circular diagram that illustrates relative component scores and potentially contributing metric scores (Figure 19). Importantly, this form of report visually can illustrate the absence of component indicators, if necessary. Such an approach would be suitable for national reporting of both sub-indices and an ecological integrity index score. The ecological integrity score could be used as one component of a broader freshwater values or cultural health report.



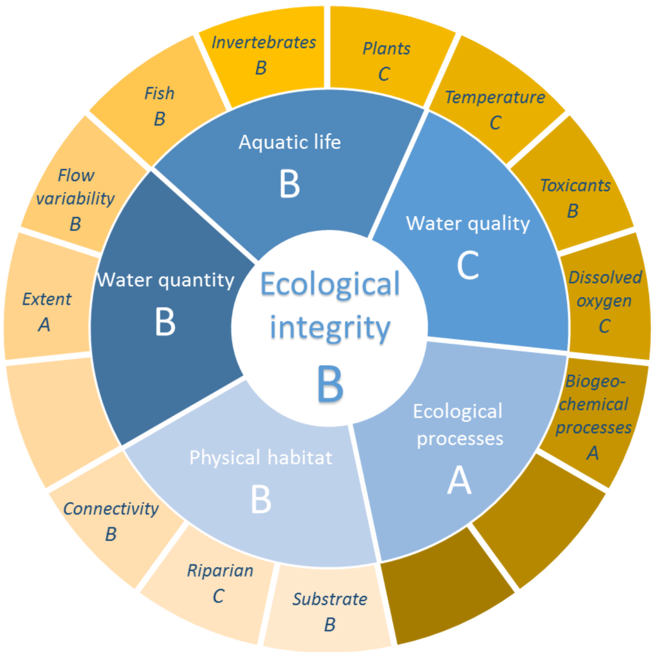


Figure 19. Examples of diagrams that could be used for environmental reporting when applying The Framework. The top example is a radar graph and the bottom example is a circular report card.

4.8. Example Framework applications in non-wadeable rivers

This section provides examples of how The Framework could be applied at three different spatial scales: reach, catchment/regional and national. All scenarios are hypothetical and numbers are fictitious. In reality, further consideration of the costs and benefits of different approaches to network design and data collection, data management and reporting is required. We recommend that national guidance documents be developed to support the three key steps (network design and data collection, data management, and reporting; Figure 11) required to apply The Framework.

4.8.1. Restoration site assessment

Scenario description

A pasture stream has been fenced to exclude stock and stream banks have been planted with native vegetation. Monitoring will be undertaken by local kaitiaki who are interested in measuring ecological integrity using both western science methods and cultural indicators.

Step 1 network design and data collection

Methods for assessing the biophysical components of ecosystem health were selected based on resource availability and reference conditions determined from existing models and management bands (Table 11).

Table 11. Component indicator methods and reference conditions chosen in a hypothetical scenario monitoring the biophysical response of ecosystem health to riparian restoration.

Component indicator	Method	Reference conditions
Aquatic life	SHMAK MCI	SHMAK management bands
	SHMAK periphyton	SHMAK management bands
	Native fish taxa richness	Modelled probability of occurrence validated by local knowledge
Water quality	pH	Native bush reserve stream
	Conductivity	Native bush reserve stream
	Clarity	Regional council guidelines
	Spot dissolved oxygen	Native bush reserve stream
	Spot temperature	Native bush reserve stream
Water quantity	SHMAK stream permanence	SHMAK management bands
Physical habitat	Rapid habitat assessment	Native bush reserve stream
	% substrate composition	Unknown
	% fine sediment cover	Sediment assessment methods
Ecological processes	Not measured	

SHMAK = stream health monitoring and assessment kit; MCI = macroinvertebrate community index.

A reach-scale assessment was undertaken once a year in summer with the monitoring network consisting of three sites: above and within (at the lower end) the restored reach, and at a neighbouring stream of a similar size in a native bush reserve.

Step 2 data aggregation, harmonisation and integration

Each site was evaluated individually. After 1 year of monitoring, there were no replicate data to aggregate. In the future, temporal replications would be used to calculate a 3-yearly mean value for each method. Data yielded from each method was harmonised by converting the score to a 0–1 scale, with the 1 value determined by reference conditions. For example, the harmonised SHMAK MCI value was the restored site value divided by the reference site value, whereas the harmonised temperature value was informed by the percentage deviation from the reference site value, e.g. >10% = 0.8, >20% = 0.6 (Table 12). Aggregated component scores were calculated as the unweighted average of measurements.

Table 12. Harmonisation and aggregation of component indicator scores in a hypothetical scenario monitoring the biophysical response of ecosystem health to riparian restoration.

Component indicator	Method	Measured Score	Reference score	Harmonised score	Integrated component score
Aquatic life	SHMAK MCI	4	7	0.57	0.43
	SHMAK periphyton	4	10	0.40	
	Native fish taxa richness	2	6	0.33	
Water quality	Conductivity	380	360	1	0.77
	Clarity	6.5	12	0.54	
	Spot DO	0.88	0.60	1	
	Spot temperature	16	13	0.55	
Water quantity	SHMAK stream permanence	10	10	1	1
Physical habitat	RHA	58	89	0.76	0.58
	% fine sediment	38	18	0.5	
Ecological processes	Not measured				N/A

Step 3 reporting

Component scores were reported using a simple pie chart that illustrates the relative number of methods that contributed to each score. For example, three methods contributed to the aquatic life component score; three methods, to water quality; one measurement, to water quantity; and two measurements to physical habitat. A space was retained to show that ecosystem processes were not assessed. A traffic light system was used to indicate A to D bands based on variation from the reference state. For example, 0–0.25 = D (red), 0.25–0.5 = C (orange), 0.5–0.75 = B (green), 0.75–1 = A (blue). An ecological integrity score was reported as an unweighted average of measured component scores (Figure 20). Ecosystem processes did not contribute to the score and there was no consideration given to the robustness of chosen methods during the calculation or reporting of scores.

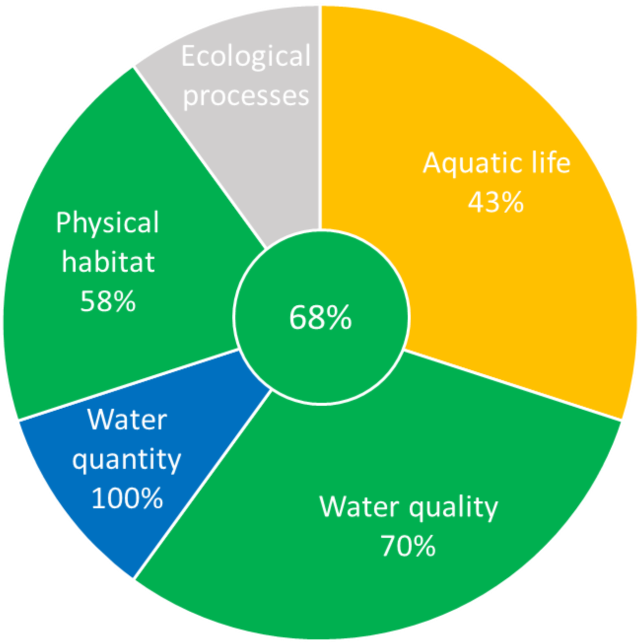


Figure 20. Hypothetical report card for a stream restoration site.

4.8.2. Freshwater Management Unit (FMU) assessment

Scenario description

A regional council Freshwater Management Unit (FMU) was monitored to assess freshwater ecosystem health, deliver local SOE reporting and evaluate the implementation of the NPS-FM.

Step 1 network design and data collection

Standardised methods for assessing the biophysical components of ecosystem health were selected and reference conditions determined from existing models, National Objective Framework (NOF) bands and local measurements of reference conditions (Table 13).

A stratified network design based on stream order (2^{nd}–5^{th}) was used to select 20 sites within the pre-defined FMU. In addition, six reference sites were established to validate and inform local reference conditions. All variables were assessed at all sites. Site assessment was undertaken by trained regional council staff and included monthly to annual measurements, depending on the variable.

Table 13. Component indicator methods or variables and reference conditions chosen in a hypothetical scenario monitoring the biophysical status in a Freshwater Management Unit.

Component indicator	Method/variable	Reference conditions
Aquatic life	MCI	Regional council policy
	Periphyton	NOF bands
	Fish IBI	Local management bands
Water quality	TN	Regional council policy
	TP	Regional council policy
	Clarity	Regional council policy
	Dissolved oxygen	NOF bands applied to all
	Temperature	Regional council policy
	Nitrate toxicity	NOF bands
	Ammonia toxicity	NOF bands
Water quantity	Minimum flows	Draft NES flows
	% allocated flows	Local reference
Physical habitat	Rapid habitat assessment	Local reference
	% fine sediment cover	Modelled sediment cover
	% shade cover	Local reference
	Sinuosity	Local reference
	Bank stability	Local reference
Ecological processes	Gross primary productivity	Management bands
	Ecosystem respiration	Management bands
	Cotton strip assay	Management bands

MCI = macroinvertebrate community index; NOF = National Objective Framework; Fish IBI = fish index of biotic integrity; TN = total nitrogen, TP = total phosphorus, NES = national environmental standards.

Step 2 data aggregation, harmonisation and integration

For each variable, data were aggregated to a 3-year annual summary statistic for each stream order. Summary statistics for each stream order were multiplied by the stream length of each stream order, the sums for all stream orders were added together, and divided by the total length of the stream network to give a representative account of ecological integrity for both reference and non-reference streams. Summary statistics were harmonised to a scale of 0–1 based on relevant reference conditions (Table 14). Harmonised scores were integrated into component scores based on unweighted averaging. Component scores were integrated into an overall ecological integrity score using weighted averaging informed by fuzzy logic.

Table 14. Harmonisation and aggregation of component indicator scores in a hypothetical scenario monitoring the biophysical response of ecosystem health in a Freshwater Management Unit. Hypothetical scores for 3rd-order streams are given.

Component indicator	Variable	Measured Score	Reference score	Harmonised score	Integrated component score
Aquatic life	MCI	108	128	0.75	0.58
	Periphyton	160	50	0.5	
	Fish IBI richness	24	58	0.5	
Water quality	TN	3.2	1.6	0.5	0.79
	TP	1.2	1	0.75	
	Clarity	8	5	1	
	Dissolved oxygen	7	8	0.75	
	Temperature CRI	22	20	0.75	
	Nitrate toxicity	1	1	1	
	Ammonia toxicity	0.2	0.03	0.75	
Water quantity	Minimum flows	20	10	0.75	0.50
	% allocated flows	80	10	0.25	
Physical habitat	RHA	66	93	0.5	0.30
	% fine sediment	38	13	0.5	
	% shade cover	30	75	0.25	
	Sinuosity	1.57	3.3	0	
	Bank stability	30	100	0.25	
Ecological processes	GPP	6.5	3.2	0.25	0.33
	ER	12.3	3.2	0.25	
	Cotton strip assay	1.2	0.6	0.5	

Step 3 reporting

Indicator, component and overall scores were reported using a visual diagram where shading was used to illustrate the relative weighting of component scores in the calculation of the final ecological integrity score. For example, the aquatic life component had an above-average weighting and the ecological processes component a below-average weighting (Figure 21). A to D bands were assigned to the following scores with narratives: ≥1 = A (at or similar to natural state), 0.75–1 = B (low deviation from natural state), 0.5–0.75 = C (high deviation from natural state), 0.25–0.5 = D (substantial deviation from natural state). Theoretically, E bands could also be assigned, and this would indicate no or very limited ecological integrity.

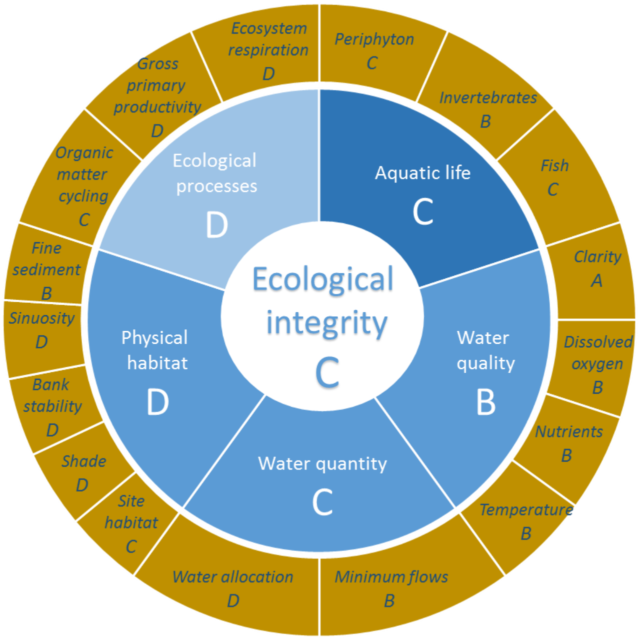


Figure 21. Hypothetical report card for a Freshwater Management Unit.

4.8.3. National State of the Environment (SOE) assessment

Scenario description

The 5-yearly state of the environment (SOE) report for fresh waters was prepared by central government (MfE & StatsNZ) to meet the requirements of the Environmental Reporting Act 2015 to provide a national assessment of the ecological integrity of rivers and streams. In addition to the national 'Our fresh water' report (e.g. Ministry for the Environment and Statistics New Zealand 2017), summary data were used to report on how well New Zealand was meeting the United Nations' SDG 6.

Step 1 network design **and data collection**

Central government collated freshwater data that had been collected throughout New Zealand by communities, regional councils, industry and central government (e.g. DOC). Data were collected by various people using various methods across various networks, including reference and non-reference streams. There were data representing all five biophysical components of rivers and streams.

Step 2 data aggregation, harmonisation and integration

There was a need to normalise data prior to its aggregation owing to the range of methods used to collect the data. The first step involved assigning data to three levels of standardisation to assist with statistical analysis. Level 1 data were collected and analysed (i.e. laboratory processing) using nationally standardised methods subject to quality assurance procedures (e.g. NEMS certified). Level 2 data were collected using published protocols and guidelines but not using national standards or consistent units of measurement. Level 3 data were collected and analysed using out-of-date or regionally-specific protocols.

Next, Level 1 data were prioritised for national analysis. For each method/variable, data were aggregated into stream classes (i.e. a simplified REC classification) and randomly subsampled to provide a balanced representation per class. Data were harmonised to a 0–1 range in scores using class-relevant reference conditions established by measurement or national models, depending on the variable (Table 15). Then for each class, data were integrated into component scores using a range of approaches depending on the component. For example, the water quality data were integrated using the CCME WQI and the aquatic life component data were integrated using the average score.

Table 15. Component indicator variables, reference conditions and integration method chosen in a hypothetical scenario assessing the national state of fresh waters.

Component indicator	Variable	Reference conditions	Integration
Aquatic life	Macroinvertebrate ASPM	National model	Average score
	Periphyton	NOF bands	
	Fish IBI	National model	
Water quality	TN	National model	CCME WQI
	TP	National model	
	Clarity	National model	
	Dissolved oxygen	NOF bands	
	Temperature	CRI proposed bands	
	Nitrate toxicity	NOF bands	
	Ammonia toxicity	NOF bands	
Water quantity	Minimum flows	National model	Average score
	% allocated flows	National model	
Physical habitat	RHA	Local reference	Average score
	% fine sediment cover	Modelled sediment cover	
	% shade cover	Local reference	
	Sinuosity	Local reference	
	Bank stability	Local reference	
Ecological processes	GPP	Management bands	Lowest score
	ER	Management bands	
	Cotton strip assay	Management bands	

ASPM = average score per metric; NOF = National Objective Framework; Fish IBI = fish index of biotic integrity; TN = total nitrogen; TP = total phosphorus; CRI = Cox-Rutherford Index; RHA = rapid habitat assessment; GPP = gross primary productivity; ER = ecosystem respiration.

Step 3 reporting

For national SOE reporting, results were reported by stream class and at the national scale. In report format, simple bar charts and maps were used (Figure 22). Also, interactive webpages (e.g. LAWA, RiverMaps) were used to illustrate the proportion of the stream network represented by the monitoring network and the relative component and overall ecological integrity scores. For reporting on how well New Zealand was meeting the United Nations' SDG 6, the percentage performance against policy goals was used (Figure 23).

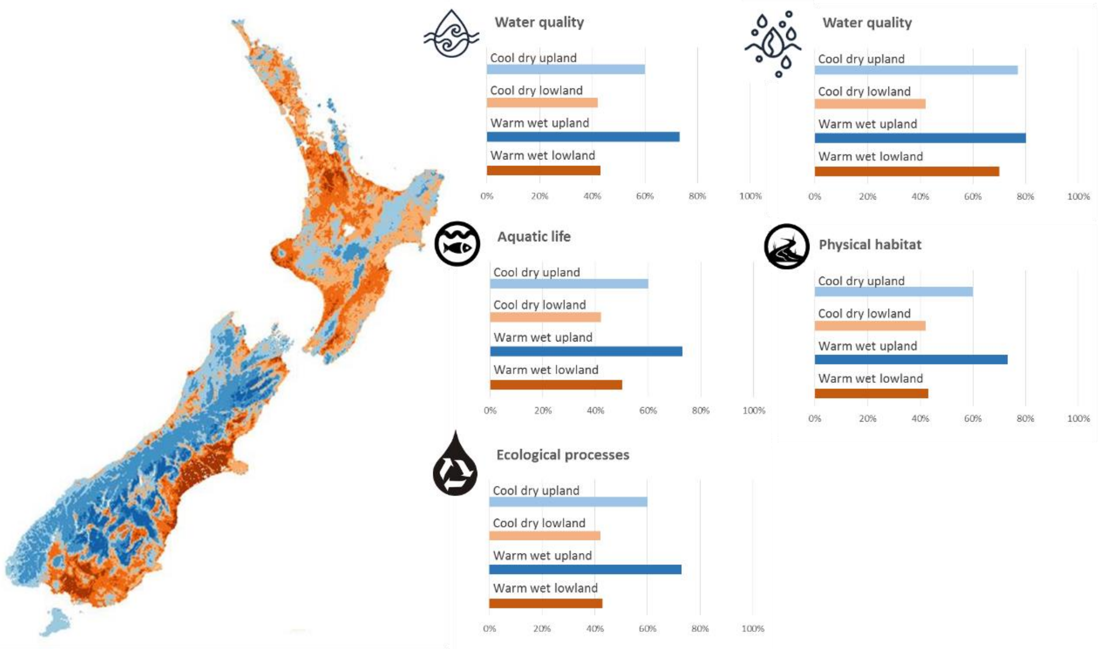


Figure 22. Hypothetical report card for national SOE reporting illustrating freshwater condition for different stream classes. Note that the stream classes and scores shown are fictitious.

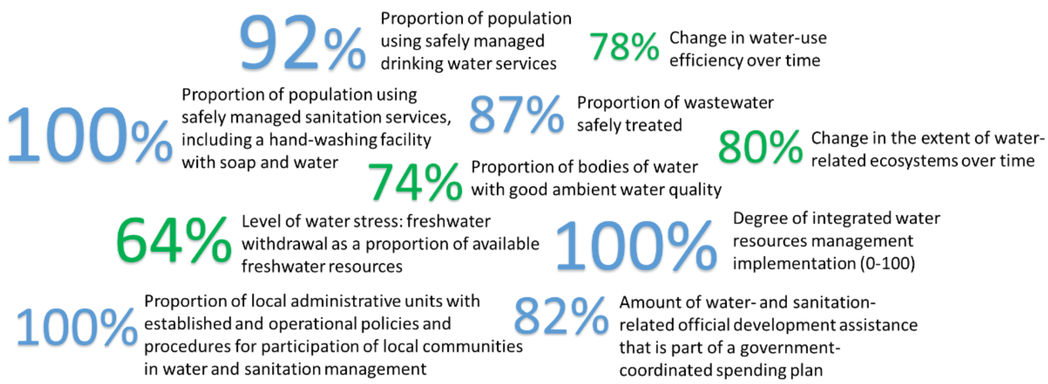


Figure 23. Hypothetical report card for an assessment of New Zealand fresh water in relation to United Nations' SDG 6. Note that indicators informed by a biophysical assessment of freshwater ecosystem health are in green. Scores are fictitious.

5. SUMMARY AND NEXT STEPS

This report has provided a critical overview of existing frameworks and relevant literature to identify the key requirements for developing and implementing a framework to assess the biophysical ecosystem health for fresh waters in Aotearoa New Zealand. As outlined, the recommended Framework will provide a consistent approach for assessing ecological integrity. It is conceptually representative in that it comprises five core components (aquatic life, physical habitat, water quality, water quantity and ecological processes) that together provide an integrated assessment of ecological integrity. An assessment of the emergent properties of an ecosystem, such as life supporting capacity, biodiversity and resilience, can be achieved by measuring these five core components. The Framework is flexible in that differing indicators can be used to assess the core components.

The Framework can be applied to existing networks or help inform new sampling networks. When standard methods are used, indicator data can be easily aggregated, harmonised and integrated into component scores. When non-standard methods are used, or different methods in assigning condition grades are used, inter-calibration or cross-calibration can be used, respectively, to provide comparable assessments. Scores can be reported at multiple scales using a tiered stacking of information, which ensures that The Framework supports an informative assessment of ecological integrity for multiple purposes and users.

This Framework can be used as a tool by iwi, if they wish, in a process to identify iwi values, aspirations and subsequent indicators for healthy freshwater environments.

The next steps in Framework application will depend on the scale of assessment. We recommend that central and regional governments consider the following investments to assist framework implementation.

5.1. Development of conceptual models

Conceptual models are a useful medium to communicate the framework, illustrate the complexity of ecosystems, and identify management options. Simple ‘healthy’ vs ‘unhealthy’ system diagrams, for example, can illustrate the need for five core components to describe the state of ecological integrity (Figure 24). Conceptual diagrams can also be useful to identify the pathways of ecosystem stressors and to inform causal hypotheses, further targeted investigations and, ultimately, adaptive management responses to the state of ecological integrity.

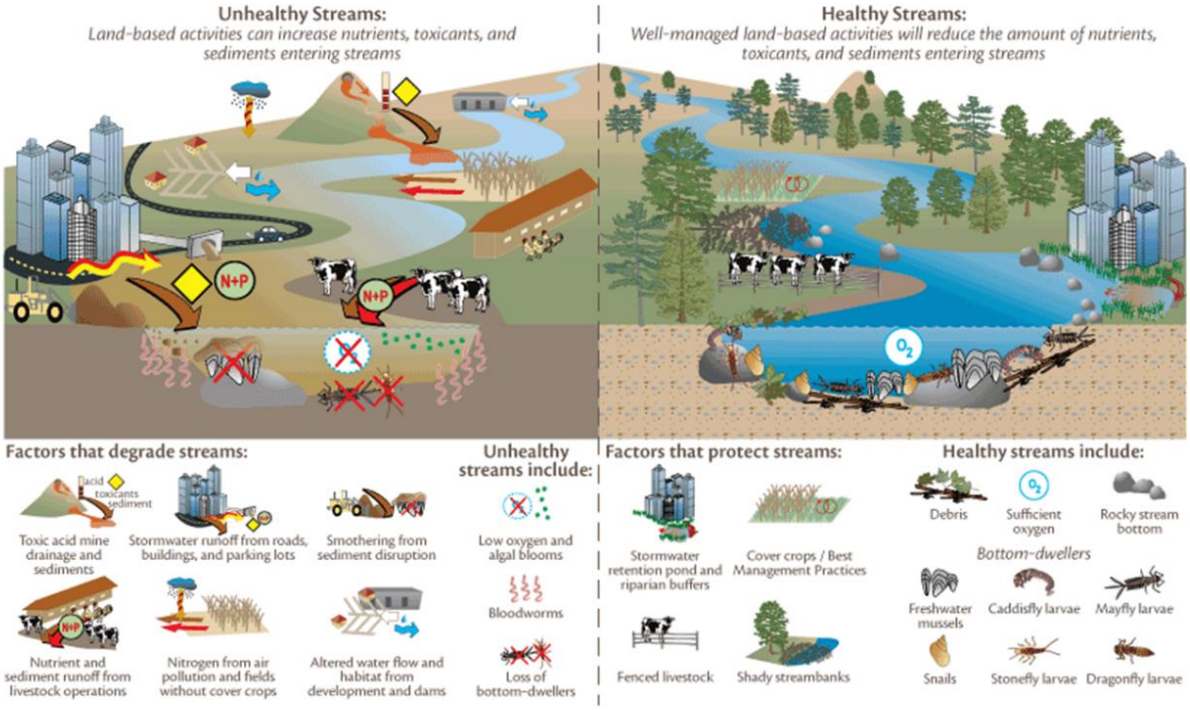


Figure 24. Example of a conceptual diagram used to identify the links between indicators of the biophysical components of river health and land use activities. Source: Queensland Government.

5.2. Selection and development of indicators

Guidance for the selection of indicators for rivers and streams has been provided in Section 4.3, where a paucity of standardised indicators for assessing the extent and connectivity of water quantity, along with extent and form of physical habitat were identified. Likewise, some of the indicators identified require further development in terms of establishing and/or validating reference conditions for varying ecotypes and/or stream classes (e.g. functional indicators). We recommend the development of a toolbox of indicators (e.g. Restoration Indicators Toolbox; Parkyn et al. 2010) that identifies the suitability of different indicators for various applications across different fresh waters. The toolbox would also provide guidance on appropriate benchmarks for assessment.

5.3. Exploration of data management options

Data aggregation, harmonisation, weighting and integration approaches should be tested using case study datasets. It is likely that different approaches to data analysis will be necessary for different applications of the framework. We recommend the development of best practice guidelines for framework application (network design, data analysis) and suggest that the development of these guidelines be supported by the trial application of the framework on three different datasets: data from a restoration, a catchment-scale survey (e.g. the ecosystem health case study undertaken by Hawke's Bay Regional Council in 2018 (data supplied to MfE)), and a national dataset.

5.4. Exploration of reporting options

The best practice guidelines for data management could also contain advice on methods for reporting ecological integrity. A tiered system would provide different levels of information for different applications, i.e. flexibility and scalability in reporting. Best practise reporting would also provide transparency and support robust assessments.

5.5. Communication of the proposed Framework

The users of the Framework should be consulted to ensure it is fit for purpose. Resource managers are important users of The Framework and without commitment to its implementation, The Framework will have limited longevity. We recommend that resource managers be continually engaged throughout the ongoing application of The Framework. This will make sure that investment in Framework development and application is effective.

5.6. Iwi/hapū-led assessment of freshwater health

We recommend that a process be undertaken for iwi/hapū to identify values and indicators for fresh water, at the regional and/or FMU scale. This would help iwi/hapū determine which indicators are appropriate for them. For example, the WaiOra WaiMāori Framework was co-designed with Waikato-Tainui and Ngāi Tahu and Ngāti Whaoa specifically for this purpose (Awatere et al. 2017), and there are multiple other kaupapa Māori-based tools that could be used in this context (see Awatere & Harmsworth 2014 for a full review). With this as a starting point, iwi/hapū partners can collaborate with regional councils to identify which indicators are already included in a biophysically-focused framework and what, if any, additional indicators should be included to support iwi values and aspirations for the FMU or region. For example, such an approach was undertaken in the Ruamāhanga Whaitua process in Greater Wellington (Robb & Harmsworth 2014). Similarly, the ways in which mātauranga Māori can contribute to biophysical assessment of fresh waters could also be assessed during an iwi/hapū-led assessment.

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8. APPENDICES

Appendix 1. Ecosystem health project workshop notes.

Freshwater ecosystem health framework workshop report

Friday 16th February 2018, Environment House, 23 Kate Sheppard Place, Wellington

Attendees (representing)

Joanne Clapcott (Cawthron Institute), Roger Young (Cawthron Institute), Mahuru Wilcox (Manaaki Whenua), Gary Brierley (University of Auckland), John Quinn (NIWA), Richard Storey (NIWA), Adam Canning (Fish and Game), Chris Daughney (GNS), Russell Death (Massey University), Karen Wilson (Environment Southland RC), Megan Oliver (Greater Wellington RC), Tim Davie (Environment Canterbury), Sandy Haidekker (Hawke's Bay RC), Deniz Ozkundakci (Waikato RC), Michael Patterson (Horizons RC), Mark Heath (Greater Wellington RC), Barry Gilliland (Horizons RC), Kate McArthur (DOC), Carl Howarth (MfE), Evan Harrison (MfE), Mereana Wilson (MfE), Kirsten Forsyth (MfE), Sonja Miller (StatsNZ), Lauren Long (MfE), Jo Burton (MfE), Thomas O'Flaherty (StatsNZ)

Apologies

Jim Sinner (Cawthron Institute), Tom Pirie (StatsNZ)

Background to the workshop

In July 2017, MfE held a workshop with freshwater science and management experts to scope a project to develop a consistent approach to assessing the biophysical aspects of Ecosystem Health in New Zealand rivers (MfE scoping workshop final notes). The 2017 workshop included discussion on the projects purpose, proposed scope, and approaches to measuring ecosystem health. The ideas suggested in the workshop helped inform the Ministry's development of the current project, where the primary objective is to develop a high-level national framework (and sub-indices) for assessing the biophysical condition of river and stream ecosystems.

There has been a longstanding recognition of the need for a more comprehensive and consistent approach to measuring the state of freshwater ecosystems. Recent reports on the state of fresh water have highlighted that while we have information on some aspects related to freshwater ecosystem condition, we don't have a complete picture, and importantly there is no approach to assessing ecosystem condition overall. Knowledge gaps include the indicators that represent the condition of all the biological, physical and chemical components necessary, and then guidance on how to account for the interactions and processes between these, in order to understand the ecosystem as a whole. A high-level framework for assessing overall ecosystem health of rivers will contribute to:

1. Helping resource managers, communities and decision makers understand how to assess the overall biophysical condition of freshwater ecosystems. This will in turn help contribute to discussions over the desired condition of rivers, and the range of decisions needed in order to achieve this.

2. Reporting on ecosystem condition, including national level reporting under the Environmental Reporting Act 2015.

3. Providing context for interpreting and evaluating existing or future metrics and approaches, so that the extent that they contribute to understanding the biophysical aspects of ecosystem health is understood, and any gaps are transparent.

While the focus of the current project is rivers and their biophysical condition, attention will be given to how the approach could be adapted for other water bodies (e.g. lakes and wetlands), and interact with social, cultural and economic values. The high-level framework that is developed will be representative, scalable, consistent, flexible, robust and informative.

The Ministry has procured and undertaken work on national indicators for freshwater reporting previously, particularly through the National Environmental Monitoring and Reporting (NEMaR) project. This project will build on relevant previous work, avoiding unnecessary duplication or repetition.

Workshop aims

The purpose of this workshop was to inform the technical work and the design and content of the framework and potential (sub-) indices. The workshop agenda was designed to encourage sharing and review of relevant existing national and international frameworks in the morning sessions, and to collect consensus and further information on core framework components (e.g. biota, WQ, habitat) and qualities (e.g. representative, scalable, consistent, flexible, robust and informative) in the afternoon sessions.

Summary of key points discussed at the workshop

Why we need an ecosystem health framework

Ecosystem health is a compulsory national value for freshwater in New Zealand and in a healthy freshwater ecosystem 'ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change' (NPS-FM 2017). Resource managers are required to identify freshwater objectives and set resource limits that maintain and improve ecosystem health. More broadly, the NPSFM further recognises Te Mana o te Wai as an integral part of freshwater management; 'Te Mana o te Wai is the integrated and holistic well-being of a freshwater body' (NPS-FM 2017).

We use a lot of freshwater indicators in New Zealand. Within the NPSFM framework, some indicators are attributes which are used to set resource limits to maintain and improve ecosystem health, for example, Phytoplankton (Trophic state), Total Nitrogen (Trophic state), Total Phosphorus (Trophic state), Periphyton (Trophic state), Nitrate (Toxicity), Ammonia (Toxicity), Dissolved Oxygen. Some indicators are used in monitoring programmes to assess the progress towards, and the achievement of, freshwater objectives for ecosystem health, for example, the Macroinvertebrate Community Index. Within national and regional state of the environment reporting frameworks, there are indicators of water quality such as nutrients, water quantity such as water allocation, habitat such as sediment, and species such as periphyton abundance, macroinvertebrate community composition, or the presence and conservation status of native fish.

All of these indicators represent components of ecosystem health and what we lack in New Zealand is a framework that allows us to integrate indicators to provide an overall assessment of ecosystem health. An understanding of overall ecosystem health would help people detect and understand problems, express the level of ecosystem health they want, develop solutions to achieve that, monitor effectiveness, and adapt where necessary.

Define the scope: biophysical components of ecosystem health
Upholding Te Mana o te Wai acknowledges and protests the mauri of the water. Doing so ensures that the health of the environment (Te Hauora o te Taiao), the health of the waterbody (Te Hauora o te Wai) and the health of the people (Te Hauora o te Tangata) are all provided for. This project specifically focuses the development of a holistic framework to integrate measures of Te Hauora o te Wai and as such focuses on the bio-physical component of ecosystem health.
Workshop participants discussed the disparate nature of compartmentalising and assessing parts of ecosystem health compared to the kaupapa Māori approach of viewing and assessing the system as a whole. It was agreed that a kaupapa Māori framework for assessing overall ecosystem health and/or other components of ecosystem health (e.g. societal and cultural values) should be discussed further. It was noted that this is important but out of scope of the current project.

Examples of existing national and international approaches to assessing ecosystem health
The following examples were presented and discussed at the workshop. Details of each example and comments will help inform a subsequent review and the development of a national framework. [Excluded as described in greater depth in Appendix 3]

Framework components
A holistic assessment of ecosystem health cannot be achieved by a single biophysical measure because ecosystems are a complex network of interacting biological communities and their physical environment. As seen in the previous section, ecosystem health monitoring consistently involves some core indicators of ecosystem health that measure the physicochemical properties of water, structural habitat, biological communities, and sometimes key ecosystem processes or interactions. Workshop attendees agreed on the following four components as necessary for the assessment of freshwater ecosystem health. These components have structural and functional elements and biogeochemical processes occur as a result of the *interaction* between some or all of the core components.

<table>
<tr><td>Component</td><td>Structural</td><td>Functional</td><td rowspan="5">Carbon, nutrient, and sediment processes</td></tr>
<tr><td>Biota</td><td>Fish, invertebrates, macrophytes, algae, microbes</td><td>Food web interactions</td></tr>
<tr><td>Physical habitat</td><td>Structural template of streambed, bank, riparian zone and floodplain</td><td>Landscape connectivity</td></tr>
<tr><td>Water quality</td><td>Physicochemical properties (e.g. pH, turbidity, nutrients, contaminants)</td><td>(Hydrological cycle?)</td></tr>
<tr><td>Hydrological regime</td><td>Water quantity, flow disturbance template</td><td>Riverscape connectivity</td></tr>
</table>

Framework design
A framework to assess the EH of fresh water in New Zealand will potentially be used by a range of resource managers at various scales. Likewise, EH reporting will have a range of audiences who will require a clear description of the state and trends in EH, how it was measured and what the measurements mean especially in terms of meeting freshwater objectives. As such the EH framework needs to be representative, scalable, consistent, flexible, robust and informative.
Workshop attendees shared thoughts for taking these terms into effect when designing an EH framework.

Representative – account for indicators that represent the full range of core ecosystem health components and how they interact, but be parsimonious (i.e. avoid measure redundancy).
Key considerations for a **representative** framework included:

- Must include all biotic components e.g. fish
- Gets best value out of pre-existing data
- Ensures component indicators are useful for assessing ecosystem health, some type of sensitivity analysis could help inform which indicators are useful/redundant
- Indicators could represent/respond drivers at different scales
- Some indicators could be measured more or less often
- How component measures are weighted, equally or otherwise
- Be context specific—allowing for specific site qualities
- Transferable across classes and archetypes
- Consider statistical representativeness across given management unit/environment type (see Scalable).

Scalable – the approach guides appropriate assessment and reporting at a site/reach, catchment, regional and national scale.
Key considerations for a **scalable** framework included:

- Recognition that this will be challenging! Is it not always appropriate to scale-up. Be clear about why this may not be possible, for example, diversity measures will be scale specific
- Spatially representative recognising that different scales may need different measures
- There may be different scaling issues for different biota or processes, for examples, fish versus microbes, sediment deposition versus transport
- Consider hierarchical framework for reporting such as REC; however, this may be hard to align to a mountains to sea assessment which requires consideration of connectivity
- Advise on new site selection considering that different EH components may require different sites to reflect catchment scale assessments
- May not be able to measure everything so need to know what are site specific versus scalable indicators (see Flexible)
- Adopt a consistent grading system that allows amalgamation across sites/regions that may use different indicators and scales of focus
- Consider use of predictive models; would require assessment across stream orders.

Consistent – help ecosystem health be understood consistently across the country (so that data can be aggregated for reporting at the national level, and comparisons can be made between catchments).
Key considerations for a **consistent** framework included:

- Define relevant terms and use consistently
- Always report in relation to a baseline condition but report shift in baseline, e.g. due to climate change
- Use inter-calibration (by dividing data into percentiles) to ensure quality bands have equivalent meaning across all river types; use common/consistent scales for all EH components, e.g. 0–5, 1–5.
- Cross-calibrate old with technologies as they come online

- Use NEMS where possible
- Consistent components but flexible indicators
- Defines the role of citizen science.

Flexible – able to apply to different types of river, and allow for specific measures or indicators to differ between reaches/catchments/regions to reflect varied freshwater environments, management contexts and information availability; while allowing for comparability between areas.
Key considerations for a **flexible** framework included:

- Framework sits above indicators to inform how to interpret results
- Transferrable across environments (rivers, lakes, wetland, estuaries, groundwater)
- A toolbox approach, with a mix of compulsory and voluntary indicators that realises data availability and agency capacity, which utilises a decision support tool
- Meets multiple needs for both data capture and reporting, e.g. consent, SOE, regional and national reporting
- Advises how to deal with tension between flexibility and consistency? Perhaps grading system to make variable indicators comparable and/or O/E approach
- Advice on how to deal with missing data including the use of predictive models
- Communicate state and trends.

Robust and informative – the framework facilitates overall state and trends to be reported, is easily understood, provides the necessary context to interpret information, contextualises existing indicators and approaches, and highlights data gaps.
Key considerations for a **robust and informative** framework included:

- Use a report card framework based on an information stack to facilitate communication, for example a tiered system with underlying data at the base and data summary at top; helps with communicating at various levels
- Set the context with a drivers framework such as a conceptual model which identifies the mechanistic link between drivers and EH metrics and allows identification of indicator gaps; helps with understanding management options
- Use reference and normative standards – what's achievable versus aspirations
- Provide shared understanding of key terms such as resilience
- Appropriate time scales for state and trends to assist with quantifying conceptual models.

Next steps
The examples of existing national and international approaches to assessing ecosystem health shared during the workshop will be the basis of a review which will help inform framework development. Additional potential resources identified included Scotland's ecosystem health indicators, UN Sustainable Development Goals and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

There was strong agreement that a parallel kaupapa Māori approach to assessing ecosystem health be explored. It was considered outside the scope of the current project.
The current workshop notes along with ongoing input from the science team will be used to recommend a framework to assess the biophysical aspect of ecosystem health for New Zealand's