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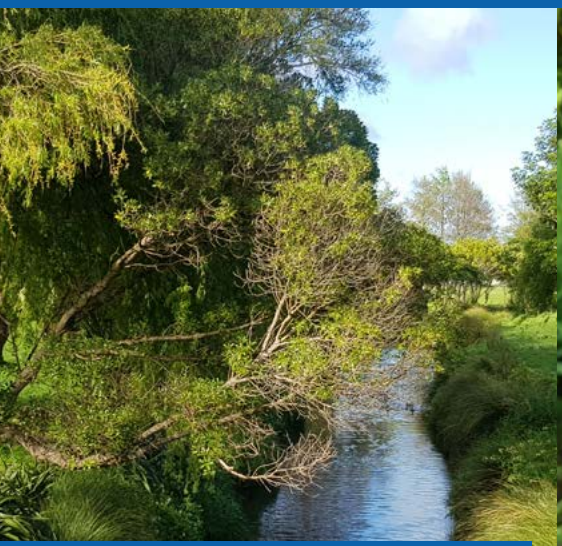
MAKE YOUR STREAM MONITORING DATA COUNT!

A national quality assurance framework for community-based monitoring in Aotearoa New Zealand



Part 2: Background report

Prepared for Envirolink

Prepared by:
Juliet Milne (Traverse Environmental, formerly NIWA)
Amanda Valois (Greater Wellington Regional Council)
Jane Robbins

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

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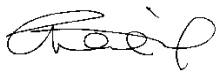	Reviewed by:	Cathy Kilroy
	Formatting checked by:	Juliet Milne
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Main cover photo: Attendees at a Mountains to Sea Conservation Trust freshwater training day assessing stream macrophyte abundance. [Juliet Milne, NIWA]

Contents

Tables

Figures

Executive summary

Rural and urban community-based monitoring (CBM) of fresh waters has grown significantly in Aotearoa New Zealand (NZ), reflecting heightened attention on the state of our streams, rivers and lakes, the wish to understand the effectiveness of restoration projects, and a general need for more data to support catchment-based freshwater management under the National Policy Statement for Freshwater Management 2020 (NPS-FM). Recent advances in technology and testing, including low-cost water quality sensors, mobile apps and environmental DNA, have also opened up exciting new opportunities for communities to monitor fresh waters.

This report sets out the development of a national quality assurance (QA) framework for community-based stream monitoring. This framework has been developed under an MBIE Envirolink Tool grant at the request of NZ's regional and unitary councils to support CBM groups to collect stream data that are of a known quality and fit for purpose. A multi-organisational working group comprising regional council staff working in freshwater science, monitoring and community-oriented initiatives, together with a representative from each of the Department of Conservation, Ministry for the Environment, DairyNZ, Mountains to Sea Conservation Trust and the NZ Landcare Trust was established to support development of the framework.

The starting point for the framework was provided by an initial review of freshwater CBM in NZ, key QA concepts in environmental monitoring, and overseas frameworks and approaches to freshwater CBM QA. This phase, documented in an earlier report, also considered the basis for a prospective NZ-oriented framework, including relevant freshwater management legislation and national freshwater monitoring standards and guidance. Two important elements established from the review were that a NZ framework needed to:

- be sufficiently *flexible* to accommodate the wide range of potential applications of freshwater CBM in NZ (from engagement and education through to informing regulatory decision making), and
- promote *transparency in data quality*, through establishing requirements for documentation of data collection methods and associated critical metadata (e.g., quality checks).

Approach to QA

The national CBM QA framework has been built around a "plan, do and review" process with most of the emphasis on planning, recognising that QA is essentially about planning and procedures put in place *before* monitoring starts. The primary tool developed for this *planning* phase is an electronic **Monitoring and Quality Plan template** to help CBM groups to establish a clear monitoring purpose, what will be monitored, where, how, when and by whom. Unlike some overseas jurisdictions, which requires CBM groups to complete a separate QA plan, the NZ CBM QA framework combines a monitoring plan and a QA plan into one. A single plan is more efficient and ensures that quality – including training and internal and external quality control activities – are always front of mind when a CBM group is developing, carrying out or revising stream monitoring activities.

As well as assisting with the planning phase, the national CBM QA framework supports transition to the *doing* phase. This includes **electronic field form templates** for efficient, standardised capture of field measurements and observations, with built-in, automated quality checks and calculations. These templates are also intended to support the *reviewing* phase by capturing standardised measurements and metadata, including quality check details, to assist with data quality assessment and management.

The electronic field form templates were created using Esri's ArcGIS Survey123 software and can be used on mobile devices such as smart phones via the Survey 123 app, or on any mobile or desktop device via a web browser. A growing number of NZ organisations, including many regional councils, are now routinely collecting freshwater and other environmental data using ArcGIS Survey123. The software is therefore expected to be well supported into the future. Many organisations with suitable ArcGIS account licences may be willing to provide CBM groups with free access to the electronic field forms. ArcGIS Survey123 is already used for citizen science initiatives in NZ and overseas and can be connected with other ArcGIS products and apps, including Dashboards, StoryMaps and ArcGIS Hub so that CBM data can be communicated visually (e.g., in the form of graphs, maps and dashboards) and shared.

Data use categories, stream health indicators and measurement methods

Three broad categories of data use were established to accommodate the potentially wide range of purposes CBM groups can have for monitoring stream health: *engagement and education*, *investigations and surveillance* and *informing regulatory processes*. In reality, these data use categories span a continuum, where time, cost and QA requirements increase as a group moves from education and engagement activities at one end to informing regulatory processes on the other. A group's monitoring questions and intended data use applications will therefore guide the investment level required.

A total of 28 indicators are included in the national CBM QA framework. These indicators span four of the five components of stream (ecosystem) health recognised in the NPS-FM 2020: water quality, aquatic life, physical habitat and water quantity. Selection of each indicator was based on the relevance of the indicator to freshwater management, community interest in measuring it, and the availability of a practical method for CBM with suitable quality checks to facilitate the collection of data of a known quality.

The measurement methods included in the framework were selected or adapted from existing established or nationally recognised standards and guidance. Methods include those used by regional councils (e.g., National Environmental Monitoring Standards, NEMS) and those designed specifically for use by CBM groups (e.g., NIWA's Stream Health Monitoring and Assessment Kit (SHMAK) and Auckland Council's Wai Care programme). In most cases, more than one measurement method is provided for each stream health indicator because different monitoring purposes call for different methods (and quality standards). Additionally, CBM groups may have different amounts of resources to spend on their monitoring.

Training, metadata documentation and quality checks

Quality assurance considerations for each stream health indicator are outlined and address training, metadata requirements and suitable internal and external quality checks. This information was sourced from existing standards and guidance, supported by review from subject matter specialists. In particular, considerable guidance was drawn from overseas approaches to CBM QA (e.g., US EPA) and NEMS.

Because the potential re-use of a CBM group's data by others, such as for catchment, regional or national modelling and national reporting, may not be known, data collection methods and quality check measures need to be documented and made available along with the monitoring data. The Monitoring and Quality Plan and electronic field form templates have been designed with this is mind.

Guidance

A companion guidance document has been prepared for community and catchment group coordinators and support organisations. This guidance outlines the framework and provides information to support CBM groups to prepare a Monitoring and Quality Plan. Information includes, for each of the 28 stream health indicators, the measurement methods (including the broad data use category applicable to each method), equipment and material requirements, an indication of the time, cost and complexity associated with measurement, as well as training resources, metadata documentation requirements, and relevant internal and external quality control measures.

Future direction

Additional stream health indicators and/or measurement methods may be added to the national CBM QA framework in future if and when resources allow. Future updates and implementation of the framework are expected to be overseen by the regional councils of NZ and will likely involve a multi-organisational effort.

1 Introduction

Rural and urban community-based monitoring (CBM) of fresh waters has grown significantly in Aotearoa New Zealand (NZ) over the last 10 or so years (Valois and Milne 2021), reflecting heightened attention on the state of our streams, rivers and lakes, the wish to understand the effectiveness of community-led restoration projects, and a general need for more data to support catchment-based freshwater management under the National Policy Statement for Freshwater Management 2020 (NPS-FM, NZ Govt 2020a). Recent advances in technology and testing, including low-cost water quality sensors, mobile apps and environmental DNA (eDNA), have also opened up exciting new opportunities for communities to monitor fresh waters (Valois and Milne 2021).

This report sets out the technical basis for a national quality assurance (QA) framework for community-based freshwater monitoring initiatives, with a focus on monitoring stream health.[1] The framework has been developed under an MBIE Envirolink Tool grant at the request of NZ's regional and unitary councils (hereafter 'regional councils') to support CBM groups to collect stream data that are of a known quality and fit for purpose. It follows an initial report, prepared by Valois and Milne (2021), that explored CBM in NZ and how a national CBM QA framework might be developed. Suggestions for developing a framework drew on QA frameworks and approaches used overseas where freshwater CBM programmes have been long-established (e.g., United States of America and Canada). Two important elements established from the report were that a NZ framework needed to:

- be sufficiently *flexible* to accommodate the wide range of potential applications of freshwater CBM in NZ (from engagement and education through to informing regulatory decision making), and
- promote *transparency in data quality*, through establishing requirements for documentation of data collection methods and associated critical metadata (e.g., quality checks).

What is community-based monitoring?
Community-based monitoring (CBM) is a form of citizen science where members of the public, as individuals or organised groups, collect scientific data. Alternative terms to CBM include 'volunteer monitoring', 'locally based monitoring' or 'participatory monitoring' (Valois and Milne 2021). In rural areas, many CBM groups operate at catchment or subcatchment scales.

1.1 Why a national QA framework is needed

Not only has CBM grown in NZ, but so too have the reasons and objectives for CBM. While some community groups monitor to explore or learn, others want to track stream health improvement over time when they invest money and time on restoration projects. Many community groups are also interested in having their data used by regional councils and other decision makers (Peters et al. 2015, Kin et al. 2016). However, concerns about data quality are often cited as a key reason why 'professional' scientists will not use the data that CBM groups have collected (e.g., Albus et al. 2019). Good QA is therefore critical for ensuring CBM data are credible. This starts with identifying a clear monitoring purpose and then selecting sites, indicators and methods that are suitable or for that purpose.

While training and support are available for CBM groups in NZ, multiple organisations are involved in different parts of the country, and there is no overarching national framework in place to ensure that stream data collected are of 'known' quality. This means that stream monitoring data are being

[1] Here stream is used to refer to flowing waterways of all sizes, including larger waterways typically referred to as rivers.

collected by many different community and catchment groups across NZ to different standards and stored in various formats and locations. Where CBM data are publicly available, the collection methods and standards are often unknown or not readily available with the data. This makes it difficult to consider using CBM data alongside the data collected by regional councils and other organisations with statutory responsibilities for environmental monitoring, management and reporting. Consequently, a considerable amount of data, often collected at a finer spatial scale than that of regional councils, are not likely to be accessible to inform freshwater management (Valois and Milne 2021).

Over the last decade National Environmental Monitoring Standards (NEMS) have been developed to support regional councils and other organisations to collect data using consistent methods and to known quality standards. A similar national QA framework for CBM groups will help increase the visibility and application of CBM data in freshwater management.

The national QA framework for community-based stream monitoring therefore aims to provide CBM groups with confidence that the data they collect will:

- meet their needs,
- be recognised by regional councils and other organisations as being credible and fit for purpose, and
- support potential re-use by third parties.

The starting point for the framework is that all CBM data can be useful for one or more purposes provided that key metadata about monitoring site locations, data collection (date, time and methods), and quality checks are available with the data.

1.2 Scope of the national CBM QA framework

The national CBM QA framework focuses on monitoring of stream health and incorporates 28 variables. These variables, referred to as *stream health indicators*, span physical, chemical and microbiological water quality, aquatic life, physical habitat quality and water quantity. Some of these indicators are also relevant to monitoring of lakes and coastal waters.

The framework includes:

- An electronic **Monitoring and Quality Plan template** to help establish a clear monitoring purpose, what will be monitored, where, how, when and by whom.
- A **CBM guidance document** outlining the framework and providing
  - information to support completion of a Monitoring & Quality Plan, and
  - for each indicator, the measurement methods (including which type of data use each method is suitable for), equipment and material requirements, an indication of the time, cost and complexity associated with measurement, as well as training and supporting metadata requirements, and quality control measures (called *quality checks)*.
- **Electronic field form templates** for use on a mobile phone, tablet or computer to capture field measurements and observations in an efficient and standardised way, supported by built-in, automated quality checks and calculations.
- This **background report** which sets out the starting point for, and establishment of, the framework, including the stream health indicators, measurement methods, recommended training and quality checks, and CBM data collection and management.

The CBM guidance document (Milne et al. 2023a) and this background report have been prepared for different audiences. The guidance is intended for use by community and catchment coordinators and others in organisations supporting CBM groups. In contrast, this report is intended for use by regional council (and other) scientists and data managers who wish to understand the technical basis for the QA framework and, therefore, the resources that will be required to support CBM groups with electronic data collection.

The Monitoring and Quality Plan template, as well as the guidance document and this report, together with information on the electronic field form templates can be accessed on-line at: https://www.waiconnection.nz/pages/programme.

1.3 Use of the national CBM QA framework

While any CBM group will benefit from following the QA framework, it is primarily intended to assist with:

- repeated data collection over time, as opposed to one-off data collection, and
- the collection of data that are suitable for informing potential use or re-use by third parties, such as for catchment, regional or national freshwater modelling or reporting.

1.4 Document outline

This report has five additional sections:

- Section 2 provides the starting point for the framework, briefly summarising selected findings from a 2021 review of freshwater CBM monitoring in NZ and overseas framework and approaches to freshwater CBM QA.
- Section 3 outlines the development of the national CBM QA framework, including categorisation of monitoring purposes or data uses, the selection of stream health indicators and measurement methods, and identification of training, metadata documentation and quality checks.
- Section 4 sets out, in tabular format, the measurement methods, training resources, metadata documentation requirements and a list of internal and external quality check options for each of the 28 stream health indicators included in the framework.
- Section 5 addresses electronic collection of CBM data under the framework and data management and quality assessment.
- Section 6 provides a brief comment on how the CBM QA framework might be managed and updated into the future.

1.5 Terminology

Some specific terminology is used in the companion CBM guidance document (Milne et al. 2023a). For consistency, the same terminology applied in that guidance is used in this report. The key terms and what they mean are:

- *Stream health:* a broad term that refers to the suitability of a stream to support a healthy aquatic ecosystem and other freshwater values such as human contact for recreation.
- *Indicator:* a variable that is measured to indicate some aspect of stream health (e.g., measurements of the concentration or saturation of dissolved oxygen are an indicator of the ability of the stream to support aquatic life).

- *Quality checks:* internal and external quality control (QC) measures that fit within a wider QA framework.
- *Specialist:* a relevant, suitably qualified and experienced subject matter expert. This may be a freshwater ecologist, water quality scientist or hydrologist but, depending on context or advice sought, it may also be a land or catchment management officer, a laboratory analyst or data manager.

2 The starting point for the framework

Valois and Milne (2021) prepared an initial report to inform the development of the national CBM QA framework. This report provided an overview of CBM, including benefits, challenges and its evolution in NZ. It also defined key QA concepts in environmental monitoring programmes and outlined international CBM QA frameworks in existing use or development, providing a summary of six case studies of potential relevance to NZ. These case studies were drawn from countries with long-established freshwater CBM programmes in place, in particular the United States of America (USA), but also Canada, Australia and the United Kingdom (UK).

This section briefly summarises some of the key findings from Valois and Milne (2021) that collectively helped to provide the basis, or starting point, for the framework described in this report:

- current drivers and opportunities for CBM in NZ,
- CBM data quality and accessibility,
- insights from overseas approaches to CBM QA, and
- key QA elements and considerations identified for a NZ CBM QA framework.

The reader should consult Valois and Milne (2021) for the full details.

2.1 Current drivers and opportunities for community-based stream monitoring in NZ

Early support for freshwater CBM in NZ began around the late 1990s and has continued to grow since, likely driven by increased public awareness and concern around the state of freshwater ecosystems, including risks to 'swimmability' and threatened species (Valois and Milne 2021). Water quality has been consistently rated by the public as the most pressing environmental issue in NZ since surveys on public perceptions of NZ's environment began in 2000 (Hughey et al. 2016, 2019). Policy initiatives introduced in response to this concern, notably the National Policy Statement for Freshwater Management (NPS-FM), first introduced in 2011, promote increased involvement of the community in freshwater management. Monitoring is a natural component of this involvement, offering opportunities for communities to engage as 'catchment citizens and agents of change' (Valois et al. 2019). Developments in technology, including smartphones with built-in global positioning systems (GPS) and internet applications, as well as increased availability of low-cost sensors and other monitoring devices, have also reduced barriers to participation and enable rapid capture and sharing of data (Njue et al. 2019).

Vast gaps in our freshwater data highlighted in a review of NZ's environmental reporting (PCE 2019) present another opportunity for CBM. A major strength of CBM is in augmenting the reach, effort and finite resources of regional councils and other organisations responsible for environmental monitoring. CBM has potential to increase the pool of freshwater data available to inform a range of applications at different scales in time and space. In addition to contributing to regional or national State of the environment (SOE) reporting, CBM may include: supporting the development or validation of models, assessments of biodiversity, biosecurity surveillance, early warning of emerging problems (e.g., algal blooms) and pollution hotspot assessments.

With stream riparian planting a focus for many catchment groups in NZ (Sinner et al. 2022), there is likely a concurrent interest in evaluating the effectiveness of these plantings and other restoration initiatives in improving biodiversity, stream habitat and water quality. Similarly, the near-universal requirement for Freshwater Farm Plans introduced in the National Environmental Standards for Freshwater (NES-F, NZ Government 2020b) has presented another opportunity for CBM. For example,

on-farm water monitoring to characterise existing state, identify hotspots of contamination, and track the effectiveness of land management actions, can provide well-defined objectives for CBM.

An increasing number of councils, central government organisations and industry have now established requirements or strategic priorities that promote the collection and/or use of CBM data. Valois and Milne (2021) identified, for example:

- Several regional councils, including GWRC and Environment Southland, have draft citizen science strategies in development or have included citizen science in internal science plans (e.g., Bay of Plenty Regional Council); some councils, including GWRC, Auckland Council and Nelson City Council, have dedicated budgets for citizen science.
- The Conservation and Science Roadmap (MfE and DOC 2017) identified *"Citizen science, co-development and co-design of research, and effective communication of science"* as a research topic, with the outcome: *"Findings facilitate informed citizen participation in environmental decision-making, and uptake of robust scientific knowledge and data for informing policy."*
- Strategic Direction 1 of the Biosecurity 2025 Direction Statement for New Zealand's Biosecurity System (MPI 2016) describes *"A biosecurity team of 4.7 million"*, noting that (for example) *"everyone can become citizen scientists by contributing their observations… to an online portal"*.
- Our Freshwater 2020 (MfE and Stats NZ 2020) identified citizen science amongst future opportunities for improved environmental reporting.
- Fonterra and DOC's Living Water programme of partnerships with farmers, rural catchment groups and councils seeks to restore wetlands and *"measure their impact on water and wildlife quality"*.

2.2 CBM data quality and accessibility

There are multiple, well documented benefits and challenges associated with CBM (e.g., Goudeseune et al. 2020, Walker et al. 2020, Kanu et al. 2016) (Table 2-1). Key amongst the challenges that a NZ CBM QA framework should seek to address are *data quality* and *data accessibility.*

Questions about data quality are typically the first to arise when CBM is proposed. Concerns about data quality are often cited as one of the key reasons CBM data are underutilised (Kosmala et al. 2016, Albus et al. 2019). Many aspects of CBM can reduce confidence in data quality, including the use of more simplified monitoring equipment or methods, challenges with equipment storage, maintenance and calibration, the perceived limited skills and/or experience of group members, and a lack of appropriate QA (e.g., documented procedures).

As outlined in Valois and Milne (2021), there is now a well-established – and expanding – body of evidence that CBM can produce reliable, quality datasets on par with those produced by specialists. This has largely been established from comparison studies (e.g., Fore et al. 2001, Gollan et al. 2012, Moffet and Neale 2015, Safford and Peters 2017, Dyer et al. 2014, Storey et al. 2016), such as:

1. side-by-side or parallel monitoring between CBM groups and specialists (on the same day, usually with the same method and for a short period of time), where the professional measurement is typically considered the correct or 'true' value,
2. paired comparisons of data collected by CBM groups and specialists at the same sites through time (but not on the same day), and
3. method comparison (i.e., low-cost/simplified versus high-cost/standard methods).

Table 2-1: Summary of benefits and challenges of CBM. Reproduced from a review by Conrad and Hilchey (2010). 'Volunteer' can be replaced with 'CBM group'.

Benefits	Challenges
Increasing environmental democracy (sharing of information	Lack of volunteer interest/lack of networking opportunities
Scientific literacy (broader community/public education)	Data fragmentation, inaccuracy, lack of objectivity
Social capital (volunteer engagement, agency connection, problem solving)	Inability to access appropriate information/expertise
Citizen inclusion in local issues	Lack of funding
Data provided at no cost to government	Poor experimental design
Ecosystems being monitoring that otherwise would not be	Insufficient monitoring expertise
Government desire to be more inclusive is met	Monitoring for the sake of monitoring
Support proactive changes to policy and legislation	Utility of data for decision-making, environmental management, conservation, etc.
Can provide an early warning/detection system	

Information from the comparison studies referenced above indicates that monitoring programme design and structure impact data quality. Standardised (and documented) protocols, training/certification and professional oversight/support are common elements of programmes in which data have been deemed to be of comparable accuracy to those collected by professionals (Kosmala et al. 2016, Albus et al. 2019). However, one limitation of many comparison studies is that they are small in scale or short in duration. The scale of comparisons can be important because CBM datasets accumulate variability over time, because of frequent changes in locations and personnel (Albus et al. 2019). However, variability due to personnel and site changes also applies to regional council SOE datasets and highlights the importance of building in ongoing paired comparison checks in long-term monitoring programmes (Davies-Colley et al. 2019).

The advent and rapidly increasing availability of new monitoring technology, including smaller, portable and less expensive sensors represents another challenge. The performance of such new monitoring technology is often unknown, raising questions about the quality of the resulting data (NACEPT 2016).

Access to CBM data and associated metadata can also present a challenge. Much of the CBM data that are collected continue to be inaccessible or stored in formats that make the data difficult to use (Newman et al. 2011, Kanu et al. 2016). The use of CBM data in informing local actions or decisions at a catchment – and especially at a regional or national scale – requires multiple sources of information to be aggregated and translated. Fortunately, increasing technological advancements and a growing trend towards open data are creating new opportunities to address improved management, sharing and interpolation of CBM data (Newman et al. 2011, Kanu et al. 2016).

2.3 Insights from CBM QA approaches in place overseas

Various approaches already exist overseas to guide QA and the appropriate use of CBM data. Six freshwater CBM case studies are summarised in Valois and Milne (2021); the Chesapeake Monitoring Cooperative and Florida Lakewatch in the USA, the Canadian Aquatic Biomonitoring Network (CABIN) and the Mikisew Cree First Nation CBM Program in Canada, the West Gippsland Waterwatch programme in Australia, and the Anglers' Riverfly Monitoring Initiative in the UK.

Of the four international frameworks considered, the USA has the most well-developed approach to QA, supported by a long history of citizen science initiatives (within which CBM fits) overseen by the Environmental Protection Agency (EPA) and strengthened by the Crowdsourcing and Citizen Science Act 2016. This Act gives US government organisations authority to use crowdsourcing and citizen science methods to advance scientific research. Some of the key elements of the EPA's approach include:

- the existence of tiers of citizen science data use that span from engagement through to supporting regulatory decisions and enforcement (Figure 2-1),
- a requirement for monitoring groups funded by the EPA to have an EPA-approved Quality Assurance Project Plan (QAPP) that outlines the monitoring project procedures to ensure that measurements, samples, data and subsequent reports are of sufficient quality to meet project objectives,
- a suite of resources, including a handbook, templates, procedures and an online tool to help CBM groups prepare a QAPP, and
- quality checks that include field and laboratory sample replicates and periodic independent external checks of sampling and testing practices by trained coordinators.

Most states follow EPA guidelines for developing a QAPP, both for agency data collection and citizen science projects (Harvard Law School 2019). Some states (e.g., Massachusetts) require a QAPP for all citizen science data that will be used by the state agency. Other states (e.g., Illinois and North Carolina) require a QAPP only when data are being collected for the purpose of state decision-making (e.g., listing or de-listing of waters under the Clean Water Act), but not when data are collected for educational purposes. In almost all states, the state environmental agency has a general QAPP in place for its own, state-sponsored community-based water quality monitoring programme (Valois and Milne 2021).

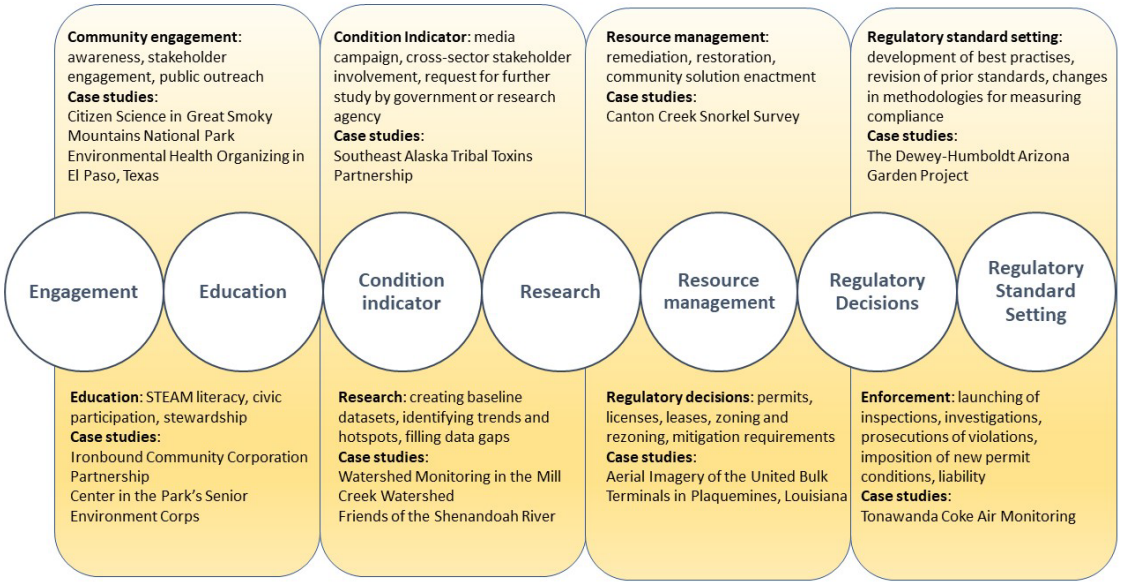

Figure 2-1: The spectrum of citizen science data use by the US EPA with case study examples. Details on these case studies can be found in NACEPT (2016).

Many elements of the USA's approach, including the use of "data tiers" and associated "data confidence standards", were also present in Australia's Waterwatch programme. In contrast, the Canadian and UK governments did not have a specific data quality framework for CBM, although, at the time of completing the review, Valois and Milne (2021) noted that the UK was in the early stages of developing such a framework (modelled on that used by the Chesapeake Monitoring Cooperative).

Training was one universal requirement across all of the case study CBM programmes examined, with different levels of training – from basic to more advanced – a common feature, ensuring that a range of options is available to participating groups. However, somewhat surprisingly, refresher training or re-certification was not required across all programmes.

In terms of data checks, while all six of the programmes considered as case studies restricted entry of data into databases to approved group members, there was considerable variation in the extent of further data checks; in the CABIN programme in Canada, no checks were made on data once entered whereas data collected under the West Gippsland Waterwatch programme in Australia were subject to both built-in automated checks and verification by a Waterwatch coordinator or officer.

2.4 Key considerations for a NZ CBM QA framework

Valois and Milne (2021) recommended that a QA framework for CBM in NZ should align with our legislative context for freshwater management, and existing freshwater monitoring and reporting standards, guidance and resources. The framework should also be flexible and transparent.

2.4.1 Freshwater management

The NPS-FM (NZ Govt 2020a) provides an overarching structure for managing freshwater resources in NZ. The NPS-FM 2020 establishes *Te Mana o te Wai* as a fundamental concept which recognises that protecting the health and mauri of freshwater protects the health and well-being of the wider environment.[2] Te Mana o te Wai establishes a "hierarchy of obligations", in terms of managing fresh water in a way that prioritises (in this order):

- the health and well-being of water,
- the health needs of people, and
- the ability of people and communities to provide for their social, economic and cultural well-being.

Under the NPS-FM all regional councils are required to establish objectives and water quantity and quality limits to manage freshwater for compulsory national values of *ecosystem health*, *human health for recreation*, *threatened species* and *mahinga kai*. A series of attributes (e.g., nitrate toxicity, periphyton), most with associated minimum acceptable states (termed "national bottom lines"), exist for two of these values (ecosystem health and human contact) and must be monitored at the scale of a catchment or freshwater management unit. There are an additional nine national values or uses identified in the NPS-FM that must also be considered in managing freshwater: natural form and character; drinking water supply; wahi tapu (sacred sites); transport and tauranga waka; fishing; hydro-electric power generation; animal drinking water; irrigation, cultivation, and production of food and beverages; and commercial and industrial use (NZ Govt 2020a).

The NPS-FM 2020 and other recent national policy direction recognise that the Treaty of Waitangi forms the underlying foundation of the Crown–Māori relationship regarding freshwater resources in NZ. In particular, Treaty settlements have played a critical role in providing the legislative foundation

[2] At the time of finalising this report, the incoming coalition government has signalled that Te Mana o te Wai is to be removed as the underpinning basis of the NPS-FM. However, Te Mana o te Wai is expected to remain in some form.

for a range of new co-governance and co-management institutional arrangements for the governance and management of fresh water and the active implementation of rehabilitation strategies and actions to meet Māori and community aspirations (Fenwick et al. 2018). A national CBM QA framework should therefore be designed in a way that Māori can access and use elements of it as they consider appropriate, without imposing 'constraints' on their exercise of mātauranga. This is important because mātauranga is a science and knowledge base in its own right; it is not the same as CBM.

2.4.2 Freshwater monitoring and reporting

There is already a range of standardised sampling protocols, monitoring tool kits, websites, and other resources available to support CBM initiatives (see Valois and Milne 2021). Some of these resources, including the National Environmental Monitoring Standards (NEMS) and several national guidelines or protocols (e.g., Clapcott et al. 2011) already feature in some regional plans, catchment plans and resource consent conditions, and could inform method selection and QA requirements for CBM activities that seek to inform regulatory processes.

Many of the Statistics NZ (2007) principles and protocols for producers of Tier 1 statistics, including statistical indicators used in national freshwater reporting, are useful to keep in mind in developing a national CBM QA framework. For example:

- Principle 1: Relevance – e.g., of monitoring indicators to CBM groups and data users,
- Principle 2: Integrity – use of objective and transparent methods,
- Principle 3: Quality – use of sound methods that are appropriate for the monitoring purpose, and
- Principle 6: Efficiency – e.g., of surveys and processing systems.

Underpinning these principles is a need for transparency in data quality. Transparency can be achieved through establishing requirements for documentation of data collection methods and other metadata. Establishment of plans for monitoring and QA will be critical to ensuring data are of a 'known' quality and evaluating whether they are fit for the intended purpose. This documentation is also needed to support assessment of data for suitability for other potential (secondary) uses (e.g., for inclusion in regional or national scale modelling applications). Standard templates should be developed to facilitate consistent and complete documentation of monitoring and QA plans.

2.4.3 Flexibility

A national framework needs to be sufficiently flexible to accommodate the potentially wide range of data collection purposes in NZ. Consistent with the approaches used in the USA and Australia, flexibility could be achieved through multiple tiers of data purpose/use, each with QA requirements commensurate with that data type or purpose.

A flexible framework would also provide for a range of monitoring methods from simple and inexpensive through to more complex and rigorous to facilitate (a) participation across a broad range of CBM groups and (b) selection of the right method for the right type of data use.

3 Framework development

This section outlines the development of the QA framework for CBM in NZ. This includes:

- the two main tools identified to underpin QA – electronic monitoring plans and field forms, categorisation of monitoring purposes/data uses,
- the selection of monitoring indicators and methods, and
- identification of training resources and recommended quality checks.

The national CBM QA framework was developed in two phases (Figure 3-1). The first phase established a starting point for a framework in NZ (refer Section 2), outlining freshwater CBM in NZ, key QA concepts in environmental monitoring, and overseas frameworks and approaches to freshwater CBM QA. Documented in Valois and Milne (2021), the first phase also considered the basis for a prospective NZ-oriented framework, including relevant freshwater management legislation and national freshwater monitoring standards and guidance. An online workshop with regional council staff was held as part of this and the discussions shaped the MBIE Envirolink Tool proposal to fund the second phase.

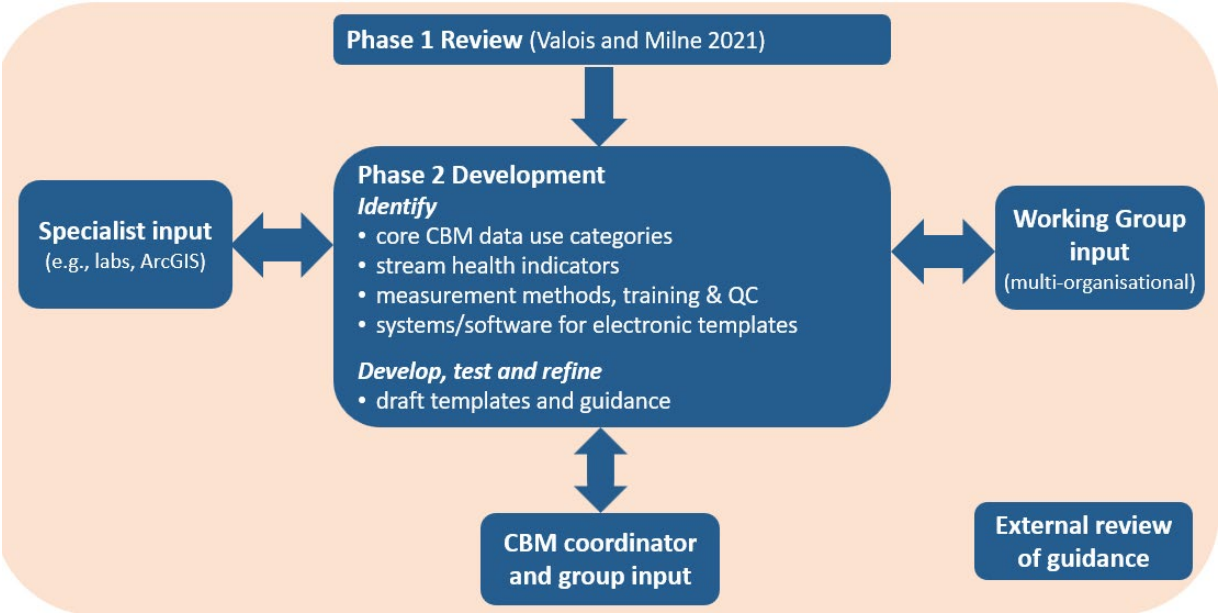

Figure 3-1: Summary of the development of the national CBM QA framework.

The second phase focused on building the framework, starting with identifying the scope and components of the QA framework, including data use categories, stream health indicators, measurement methods, and monitoring plan and data collection templates. These elements were established in consultation with a multi-organisational Working Group. The group included a range of regional council staff, together with a representative from each of the Department of Conservation, Ministry for the Environment, DairyNZ, Mountains to Sea Conservation Trust and the NZ Landcare Trust. Specialist input was also sought to assist with specific aspects of the framework, such as electronic data collection and details of quality checks for laboratory water quality and eDNA testing. A critical part of the framework development was input from community group coordinators and members to test the draft templates and guidance. The National Advisory Group for Freshwater Citizen Science[3] provided a forum to discuss ideas and identify opportunities to connect with community and catchment groups to trial the draft monitoring templates.

[3] The NAG-FCS is an informal advisory group established by NIWA in 2017 to support a revision of the Stream Health Monitoring and Assessment Kit (SHMAK). It brings together people and organisations interested in supporting and further developing freshwater citizen science in NZ. The current advisory group membership includes representatives from central government, local government, research organisations, monitoring NGOs, industry and private consultancies.

3.1 Approach to quality assurance (QA)

The national CBM QA framework has been built around the "plan, do and review" process commonly used in managing environmental monitoring and other projects, with most of the emphasis on planning, recognising that QA is essentially about planning and procedures put in place *before* monitoring starts. The aim of QA is to manage quality throughout all stages of the monitoring process.

Important components of QA include training, standard operating procedures (SOPs), and quality control (QC) measures that can confirm whether the data collected are fit-for-purpose (Figure 3-2). These components are typically customised and documented separately for each individual monitoring programme based on the programme's purpose, scope and available resources.

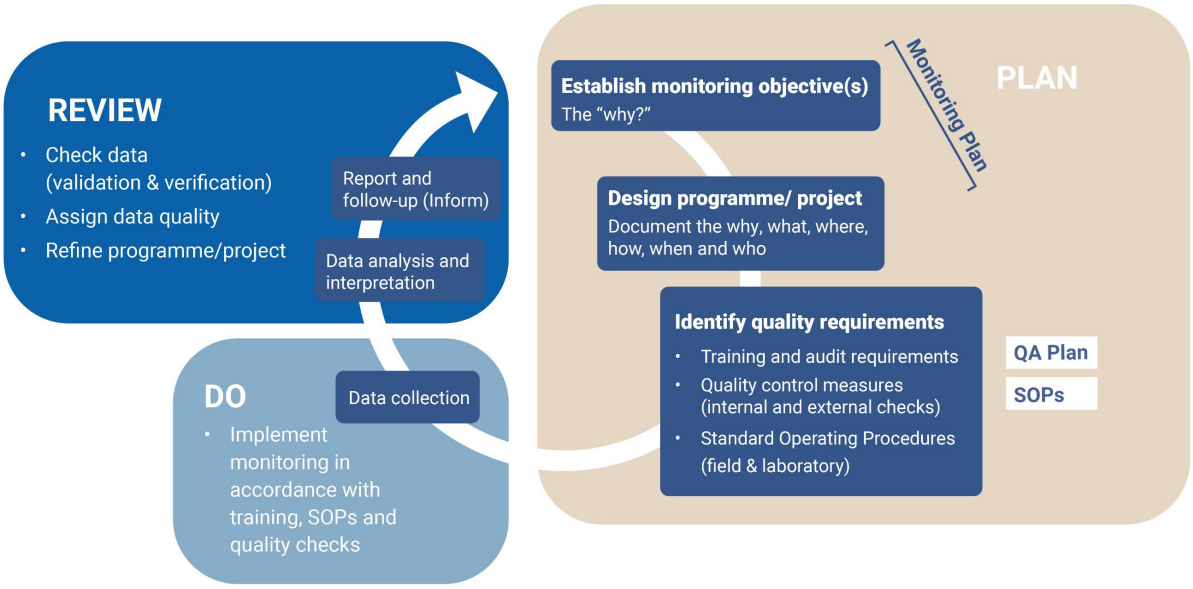

Figure 3-2: How QA fits within the general monitoring process. CBM groups should be encouraged to think of monitoring as a continuous loop of plan, do (implement) and review. Adapted from Valois and Milne (2021).

To avoid overwhelming CBM groups with multiple documentation processes, it was decided that the best approach to support them in collecting credible, fit for purpose stream health data was to develop a **Monitoring and Quality Plan template**. Therefore, unlike the US EPA, which requires CBM groups to complete separate monitoring plans and Quality Assurance Project Plans (see Section 2.3), the NZ CBM framework combines a monitoring plan and a QA plan into one. This is more efficient and ensures that quality is always front of mind when a CBM group is developing, carrying out or revising stream monitoring activities.

As well as assisting in the *planning* phase, in the form of a Monitoring and Quality Plan, the national CBM QA framework supports transition to the *doing* phase. **Electronic field form templates** have been developed for efficient, standardised capture of field measurements and observations, with built-in, automated quality checks and calculations. These templates are also intended to support the *reviewing* phase by capturing standardised measurements and metadata, including details of quality checks that will assist with data quality assessment and management.

3.1.1 Monitoring and Quality Plan

The Monitoring and Quality Plan template was built starting with the recognised scientific practice of establishing the reason or purpose for monitoring, including the intended end use of the data. It then follows the common approach recommended in existing CBM guidance resources (e.g., NIWA 2019, USEPA 2019) to focus on identifying what will be measured, where, how, when, and by whom. All of

this information is captured in a Microsoft Excel template, which has seven forms (A to G) to be completed. Each form deals with a different component of the plan (Figure 3-3). An eighth form (H) automatically tabulates the responses to the mandatory fields in forms A to G. These mandatory fields (Table 3-1), highlighted with a blue asterisk in each form, are referred to as minimum essential information requirements. The mandatory fields must be completed for a CBM group's data to be considered for re-use by third parties. Examples of mandatory fields are monitoring site locations and measurement methods.

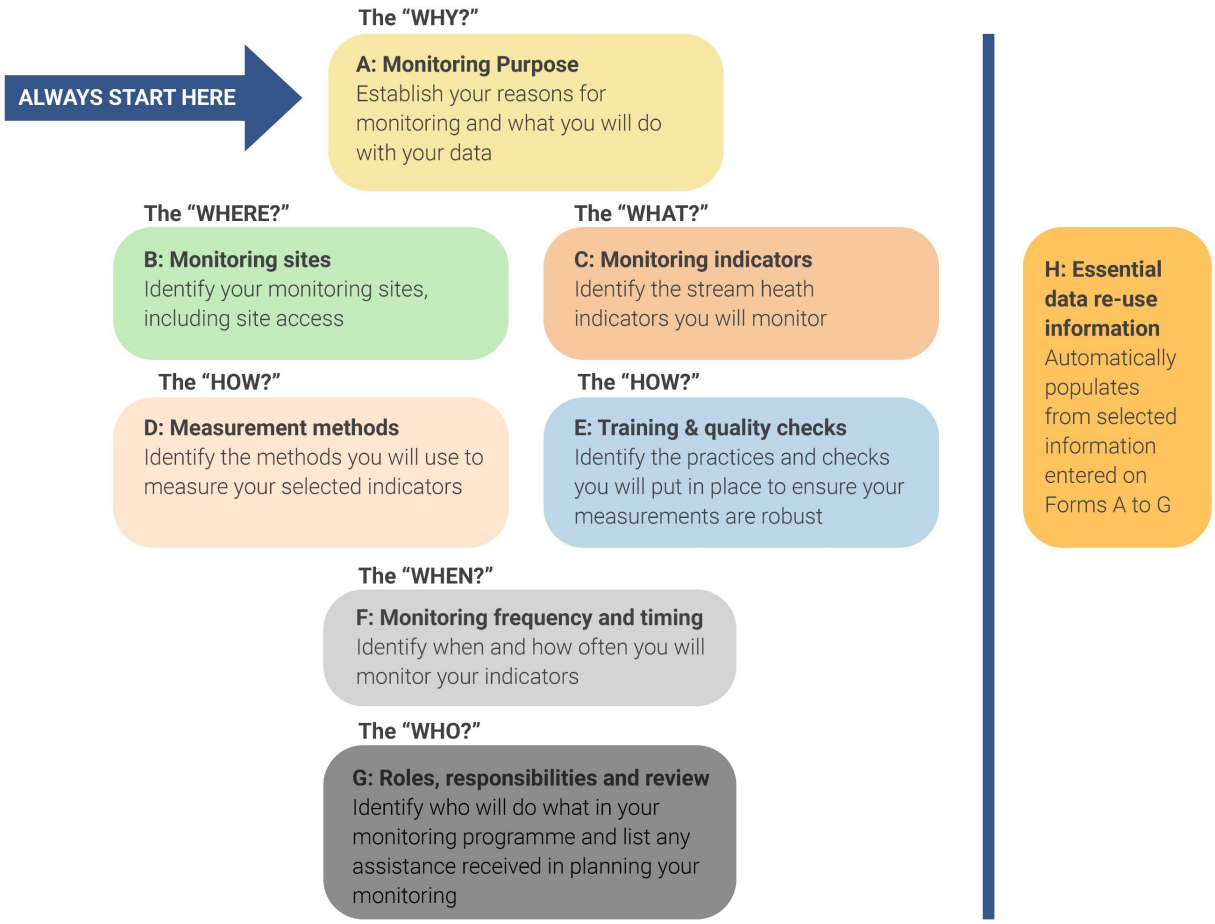

Figure 3-3: The seven forms that make up the Monitoring and Quality Plan template. Minimum information requirements identified on each form must be completed to ensure monitoring data can be considered for use or re-use.

Although only a subset of the fields in each form of the Monitoring and Quality Plan template need to be completed, CBM groups should be encouraged to complete the template in full to produce a robust plan. Groups should always start with Form A, their monitoring purpose, given this establishes the foundation of the plan and determines what they will monitor, where, how and when. It will also determine the amount of QA effort they will need to invest. Further, it is at this early stage that the CBM group will need to consider whether they wish to share the data they collect (see Section 5.1.1 for commentary on data access, privacy and sovereignty).

There is no specific order to follow after Form A but it is likely that the monitoring purpose will lead on to selection of monitoring sites (Form B) or indicators (Form C) next, followed by measurement methods (Form D) and monitoring frequency (Form F). The template also includes forms to record information on proposed training and quality checks (Form E), as well as the roles and responsibilities of different group members (Form G), and what specific specialist assistance was received in preparing and/or reviewing the plan.

Table 3-1: Summary of the first seven forms of the Microsoft Excel Monitoring and Quality Plan for completion by CBM groups. Mandatory field information auto-populates on a summary worksheet (Form H) which should be submitted to a regional council or other organisation hosting the electronic ArcGIS Survey123 field forms. These details also need to be made available to third parties if a CBM group wants their data to be considered for potential use or re-use.

Mandatory fields	Recommended additional fields
Form A: Monitoring purpose	
▪ CBM group name ▪ Who will use the data you collect? ▪ Do you support your data being considered for use in national environmental reporting and other applications? If no, why not?	▪ Why are you interest in monitoring your particular stream(s)? ▪ List any specific questions you want your monitoring to address? ▪ What do you want to achieve from your monitoring?
Form B: Monitoring sites	
▪ Site code ▪ Site name ▪ Site type (e.g., stream, drain) ▪ Easting and northing ▪ Stream bank access (TLB or TRB)	▪ Reason for site selection ▪ Site location access notes ▪ Health and safety notes ▪ Dominant streambed material ▪ Approx. stream width at monitoring site ▪ Main adjacent land use (both banks) ▪ Presence of artificial structures (both banks) ▪ River Environment Classification (REC) class
Form C: Monitoring indicators	
▪ Stream health indicators to be monitored	▪ Relevance of indicator for monitoring purpose ▪ Any additional indicators being monitored
Form D: Measurement methods	

▪ For each indicator
  ○ Measurement type (e.g., field, lab)
  ○ Measurement method
  ○ Meter/instrument/test kit made and model
	▪ Additional notes on measurement methods

Form E: Training and quality checks	

▪ What type(s), if any, training the CBM group has already received (dropdown selection list)
▪ Proposed training – who, what, when, etc.
▪ Refresher training – who, what, when, etc.
	▪ Name of person/organisation that provided the training
	▪ Internal quality checks for:
	  ○ Field measurements
	  ○ Water sample collection and testing
	  ○ Macroinvertebrate sample collection
	▪ External quality checks

Form F: Monitoring frequency and timing	
	▪ For each indicator, frequency and timing, and any special stream/weather conditions for monitoring ▪ When monitoring will start and might finish
Form G: Roles and responsibilities – and plan review	
▪ CBM group contact name and email ▪ Details of any help received in completing the plan ▪ Details of any external specialist check/review of the plan ▪ Date of plan finalisation	▪ Group member names, roles and tasks ▪ Future review dates

Section 3 of the companion CBM guidance document steps CBM group coordinators (or equivalent with a CBM support organisation) through each of Forms A to G, explaining important factors to consider when selecting monitoring indicators, sites, methods and frequency. Section 4 of the guidance also explains common data quality terms and checks. For stream health indicators and measurement methods (Forms C and D, respectively) and training and quality checks (Form E), the reader is referred to indicator-specific tables in Sections 4 and 5 of the guidance, respectively.

The mandatory and (recommended) additional fields included in the Monitoring and Quality Plan template are summarised in Table 3-1. The template (and a completed example plan) is available in both Microsoft Excel and Google Sheets format from the resources section of www.waiconnection.co.nz.

3.1.2 Electronic field forms

Following a high-level review of electronic data collection options for freshwater CBM (Butcher and Gay 2022) and discussion with the Working Group, electronic field form templates were created using Esri's ArcGIS Survey123 software. Survey123 is a web and mobile/field application (app) which enables the creation of electronic survey (i.e., field) forms. It is form-centric and allows a variety of pre-configured question types, including selection or text-based questions. Built-in 'logic' allows different question flows depending on the answers given.

Survey123 can be used on mobile devices such as smart phones and tablets via the Survey 123 app, or on any mobile or desktop device via a web browser. The app can be downloaded through the Apps Store or Google Play. While internet access is required to download the Survey123 app and the field forms, the forms can be used offline in the field.

Although other software options exist, such as QGIS and Global Mapper, ArcGIS is the industry standard for geospatial software and has both desktop and enhanced cloud-based products, enabling digital field work and communication of data (Butcher and Gay 2022). ArcGIS Survey123 can be connected with other ArcGIS products and apps, including Dashboards, StoryMaps and ArcGIS Hub so that CBM data can be communicated visually (e.g., in the form of graphs, maps and dashboards) and shared (Figure 3-4).

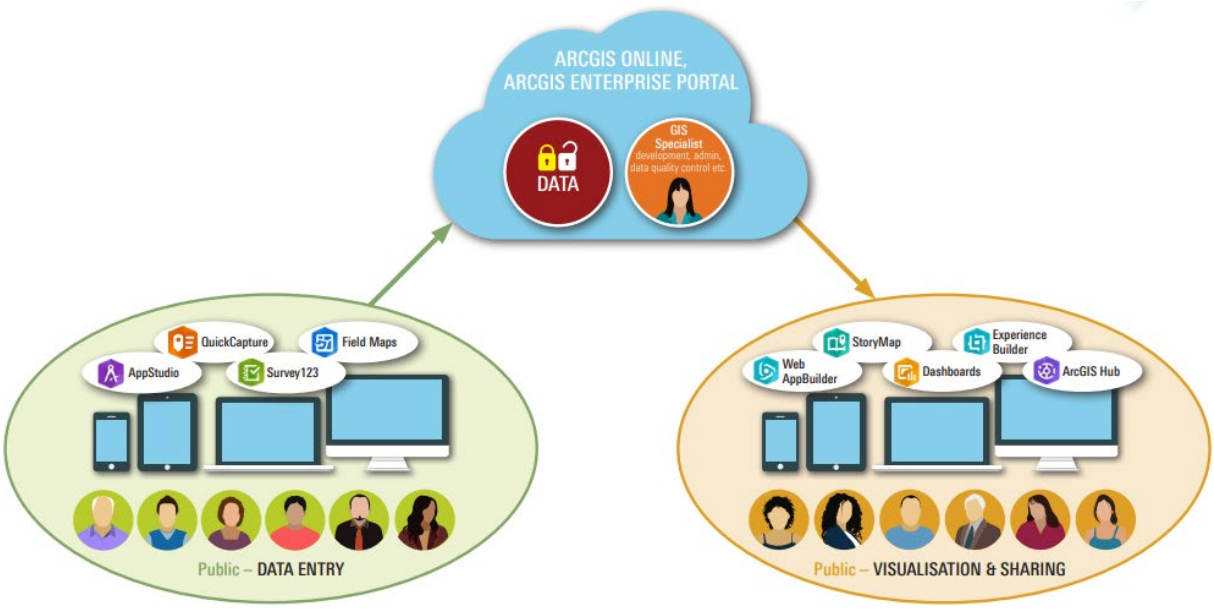

Figure 3-4: A schematic outlining the process CBM groups would follow to enter, visualise and share data through an ArcGIS licence hosted by a regional council or other organisation. Data access, privacy and sovereignty are discussed in Section 5. Reproduced from Butcher and Gay (2022) © EOS Ecology.

A growing number of NZ organisations, including many regional councils, are now routinely collecting freshwater and other environmental data using ArcGIS Survey123. The software is therefore expected to be well supported into the future. Many organisations with suitable ArcGIS account licences may be willing to provide CBM groups with free access to the electronic field forms. Additionally, as outlined in Butcher and Gay (2022):

- Survey123 is also already successfully being used in CBM initiatives nationally (e.g., EOS Ecology's visual clarity monitoring programme, Streamed – www.streamed.org.nz) and internationally (e.g., Arizona Water Watch, QWildlife), and
- Esri offers software licences at a reduced price for not-for-profit CBM groups.

The ArcGIS Survey123 forms are briefly overviewed in Section 5.

3.2 Data use categories

Valois and Milne (2021) identified, with the input of regional council staff, that a national CBM QA framework needed to be sufficiently flexible to accommodate the potentially wide range of purposes CBM groups can have for monitoring stream health. Consistent with the approaches adopted in the USA and Australia, it was agreed that this flexibility – and therefore capacity to be inclusive of all CBM activities – could be achieved through broadly grouping CBM activities into multiple tiers of data purpose/use, each with QA requirements commensurate with that data type or purpose. However, it was decided with the Working Group that these tiers should be called *data use categories* to avoid confusion with Statistics NZ terminology for Tier 1 and Tier 2 reporting statistics, and to recognise that tiers suggest a hierarchical order that isn't necessarily appropriate.

Figure 3-5 presents the three broad categories of data use identified in consultation with the Working Group's input: *engagement and education*, *investigations and surveillance* and *informing regulatory processes*. In reality, the data use categories span a continuum, where time, cost and QA requirements increase as a group moves from education and engagement activities on the left to informing regulatory processes on the right. A group's monitoring questions and intended data use applications will therefore guide the investment level required.

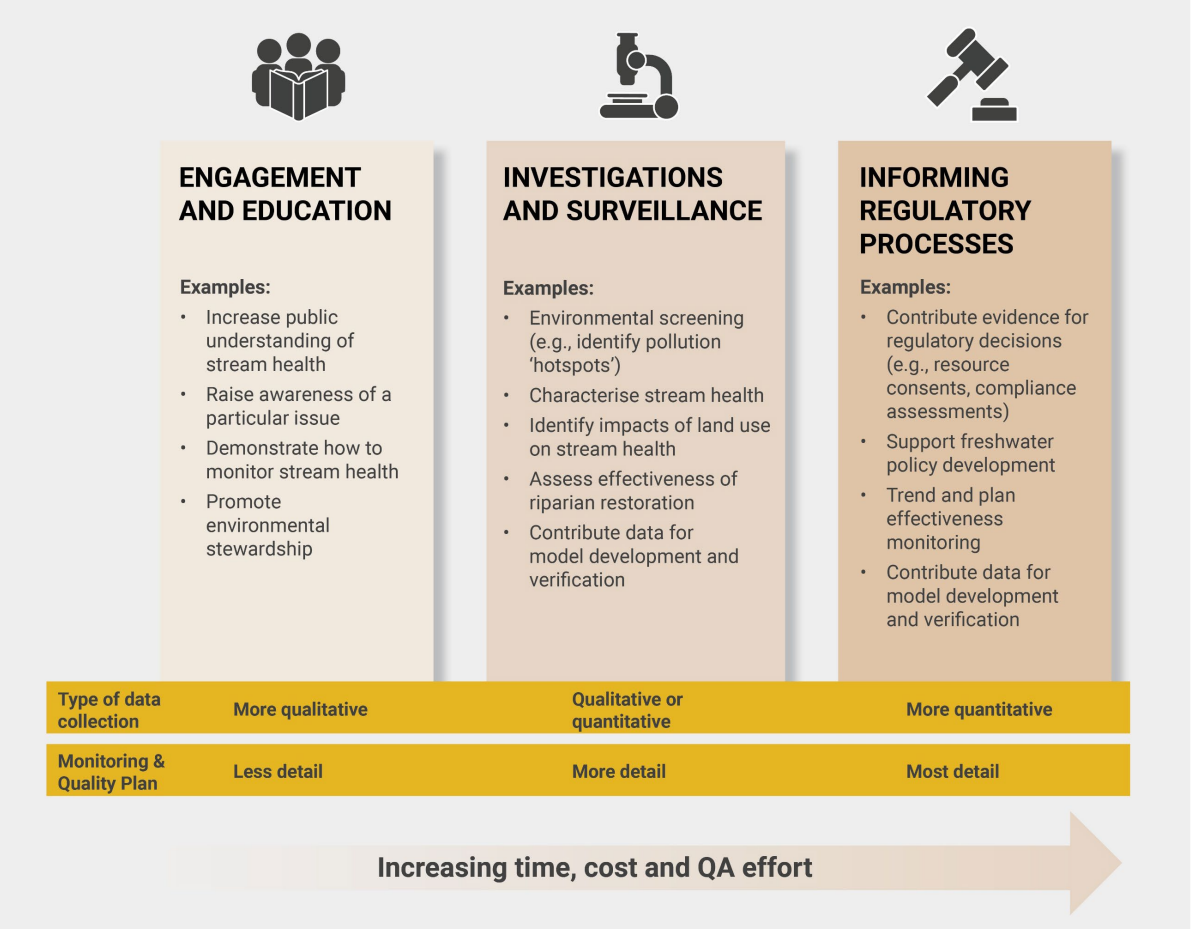

Figure 3-5: Primary data use categories in the national CBM QA framework with examples of possible data collection purposes that sit in each. In reality, the data use categories span a continuum, where planning, time, cost and QA requirements increase from left to right. Note: Inclusion of *contribute data to model development and verification* as an example in two data use categories is intentional as data requirements for models can vary widely.

3.3 Selection of stream health indicators

The selection of stream health indicators was guided by four primary factors:

- their relevance to freshwater management, including alignment with mandatory freshwater values in the NPS-FM 2020,
- current and emerging interests of community-based monitoring groups, identified by Working Group members and partner organisations experienced in working 'on the ground' with CBM groups,
- the availability of one or more existing and (preferably) nationally recognised measurement methods suitable for use (as is or with minor modification) by CBM groups, and
- the scope of the MBIE Envirolink tool project, which anticipated sufficient resourcing to incorporate an initial set of 25 indicators into a national framework.

Overall, the indicators selected align primarily with two of the four mandatory freshwater values of the NPS-FM 2020: *ecosystem health* and *human contact.* Some indicators are also relevant to the mandatory freshwater values of *threatened species* (e.g., dissolved oxygen, physical habitat quality) and *mahinga kai* (e.g., visual water clarity, *E. coli*). However:

- the most appropriate indicators to monitor (and methods to use) for a threatened

species will likely be species and potentially geographically specific, and need identifying with the input of a relevant freshwater ecologist or conservation specialist, and

- mahinga kai practices are rohe-specific, reflecting different traditions and practices, and consistent MfE (2020) guidance for NPS-FM implementation, should be developed and monitored by local Māori (i.e., tangata whenua).[4]

While monitoring the state or condition of mahinga kai should be based on local indigenous knowledge, or mātauranga, the close relationship between mahinga kai and ecosystem health suggests that some of the 'western-science' orientated NPS-FM attributes and CBM framework indicators (e.g., *E. coli,* visual water clarity and dissolved oxygen) are likely to be relevant to informing mahinga kai assessments. Therefore, the option exists for iwi, hapū and other Māori groups to use elements of the national CBM QA framework alongside mātauranga where they find it appropriate and useful to do so. The Maniapoto freshwater cultural assessment framework adopts this approach, with NIWA SHMAK-based indicators and methods such as visual clarity measured using a clarity tube and *E. coli* using 3M™ Petrifilm™ plates incorporated alongside, for example, a cultural health index and visual assessments of the presence of taonga species (e.g., tuna) and kai (Kaitiaki Contributors et al. 2020). For more information on iwi and hapū-based tools and methods for assessing freshwater environments, see Rainforth and Harmsworth (2019).

A total of 28 indicators are included in the national CBM QA framework (Figure 3-6). These indicators span four of the five components of stream (ecosystem) health recognised in the NPS-FM 2020: water quality (Table 3-2), aquatic life (Table 3-3), physical habitat (Table 3-4), and water quantity (Table 3-5). Table 3-6 lists additional indicators (ecosystem metabolism, kākahi and habitat pressures) that were considered for possible inclusion in the framework but could not be accommodated at the present time. It is anticipated that these and/or other further indicators may be added in the future.

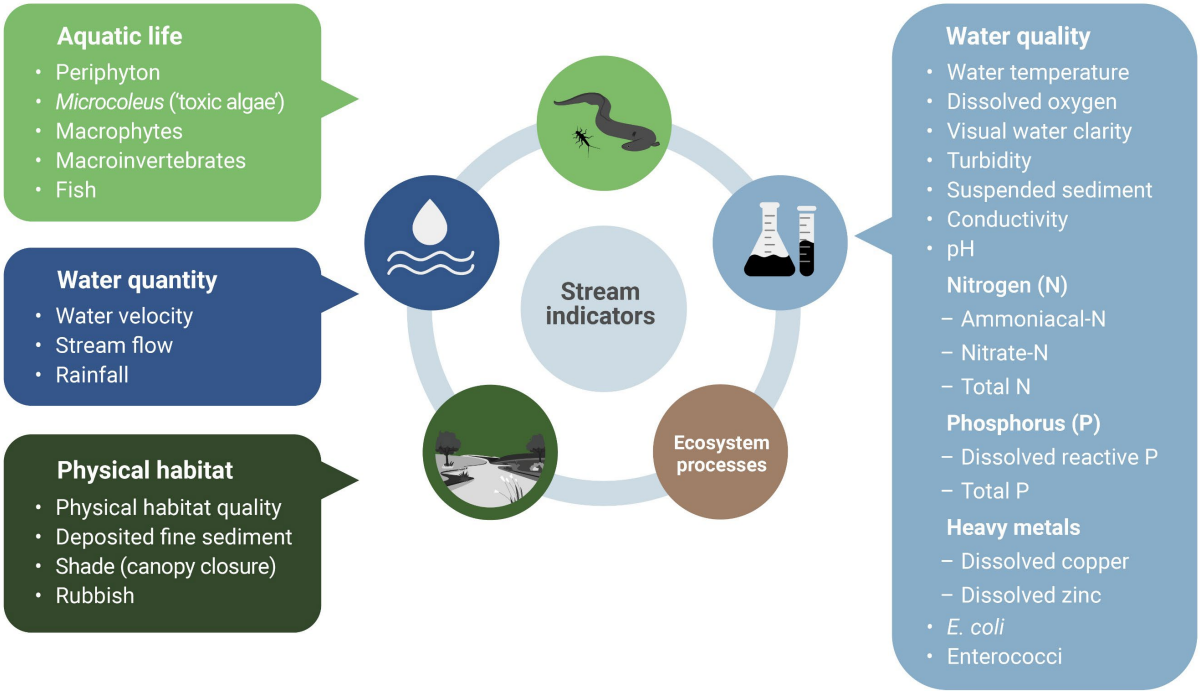

Figure 3-6: Indicators of stream health included in the national CBM QA framework. These indicators are grouped according to the five components of ecosystem health in the NPS-FM. Although *E. coli* and enterococci are living bacteria, as they are tested on water samples they are included under water quality in this framework (i.e., water quality includes physical, chemical and microbiological indicators). No indicators of ecosystem processes have been included at this stage as suitable CBM methods are still to be developed.

[4] The MfE (2020) guidance acknowledges that *"tangata whenua are the experts for the values and knowledge they hold for their local waterbodies and provide an avenue for the te ao Māori to be recognised in the freshwater management system".*

Table 3-2: Stream health water quality indicators in the national CBM QA framework. An asterisk indicates that the indicator is also an NPS-FM attribute for rivers.

Indicator	Relevance to stream health
Water temperature	One of the most important variables for aquatic ecosystems. Influences the rates of chemical and biological processes (e.g., algal growth rates) and recreational use, and affects other indicators of stream health such as dissolved oxygen, conductivity and the toxicity of ammonia to aquatic life.
Dissolved oxygen (DO)*	The amount of oxygen dissolved in water and therefore a direct indicator of a stream's ability to support aquatic life. Low levels may indicate organic pollution (e.g., from wastewater or animal effluent entering the stream) and result in release of nutrients stored in sediments on the streambed. Very low DO levels can result in fish kills.
Visual clarity* and turbidity	*Visual clarity:* A measure of underwater visibility in streams that reflects the amounts of fine sediment, algae, and other particles suspended in the water. *Turbidity:* The murkiness or cloudiness of water, indicating the presence of suspended sediment, dissolved solids, chemicals, algae, etc. Best used only as a proxy for visual clarity or suspended sediment. Reduced visual clarity (high turbidity) can harm aquatic animals and river birds who rely on sight to find prey and avoid predators, and swimmers who may not see underwater hazards. Reduced clarity also reduces the amount of light passing through the water to the streambed for use by plants for photosynthesis. Low visual clarity may indicate that fine sediment is getting into the stream and this is often accompanied by faecal and nutrient contamination.
Suspended sediment	Sediment suspended in the water column, often consisting of a mixture of inorganic clays and silts and organic particles such as algae and tiny fragments of dead leaves. As well as reducing visual clarity and light penetration, suspended sediment may carry other contaminants (e.g., phosphorus, metals) and can clog the gills of fish and benthic macroinvertebrates. It can also settle out on the streambed, reducing the quality of this habitat and smothering organisms that live there.
Conductivity	A measure of the ability of a water to pass an electrical current and therefore a useful general measure of water quality as it indicates the concentration of dissolved substances and minerals present. Conductivity is influenced mainly by catchment geology and groundwater inflows and streams tend to have a relatively constant range of conductivity. A significant change in conductivity could suggest that some source of pollution has entered the stream.
pH	The hydrogen ion concentration of the stream water measured on a logarithmic scale, essentially representing its acidity (low pH) or alkalinity (high pH). Aquatic life can't tolerate extremely low or high pH. pH also influences the toxicity of ammonia and some metals (e.g., copper and zinc).
Nutrients (N and P)	Essential elements for plants and animals and natural components of healthy streams. As outlined below, in certain forms and amounts, N and P can impact aquatic life, recreational values and human health.
• Ammoniacal N*	A soluble form of N in water. Rarely found in any significant amounts in natural waters so its presence most commonly indicates wastewater or animal effluent is also present. Can be toxic to aquatic life at high concentrations, especially fish. The toxic component is free ammonia. The proportion of ammoniacal N that is free ammonia increases as water temperature and pH increase.
• Nitrate N*	Very soluble in water and forms the main component of N that is biologically available. Concentrations above natural levels (which are typically very low) can increase nuisance growths of algae and aquatic plants, provided requirements for

	other essential nutrients (like P) are met. Toxic to aquatic life at very high concentrations. Can also be harmful to livestock and human health.
• Dissolved inorganic N (DIN)	Represents the total dissolved or soluble inorganic component of the total N in the water column (i.e., includes both ammoniacal N and nitrate N). Often similar to a stream's nitrate N concentration except where streams are impacted by high levels of pollutants and low DO levels (both of which are associated with increasing ammoniacal N).
• Total N	The sum of all forms of N present in a stream, including organic and inorganic forms organic (e.g., in suspended algae cells) , TN indicates how much nitrogen could potentially become biologically available instream or in downstream environments such as lakes and estuaries if the right conditions exist.
• Dissolved Reactive P* (DRP)	A soluble form of P in water, making it readily available for uptake by aquatic plants. Concentrations above natural levels (which are typically very low) can increase nuisance growths of algae and aquatic plants and degrade stream habitat.
• Total P	Indicates how much P could potentially become biologically available instream or in downstream environments such as lakes and estuaries if the right conditions exist. Often closely correlated with suspended sediment and turbidity as some forms of phosphorus 'stick' to fine sediment, entering streams through surface runoff and bank erosion.
Copper (dissolved) Zinc (dissolved)	Copper and zinc are natural elements that are essential for metabolism but can be toxic to aquatic life at high concentrations and can accumulate in sediments and living organisms. Both metals are common urban contaminants transported to streams via stormwater from roads (zinc from vehicle tyre wear, copper from brake pad wear), buildings (e.g., zinc from galvanised roofs and copper from spouting and other fixtures) and industrial yards. Copper is also found in some antifouling paints as well as some fungicides used in residential gardens and horticultural areas. Dissolved concentrations represent the forms that are most readily available to impact aquatic life.
*E. coli**	Microbiological indicator bacteria for faecal contamination and the preferred indicator for determining the suitability of fresh waters for drinking and contact recreation, including food harvest. *E. coli* can also be used as an indicator in some estuarine waters. The presence of *E. coli* may indicate the presence of harmful pathogens[1] that can cause eye, ear, nose and throat infections, skin diseases, and gastrointestinal disorders – a number of pathogens can also be transmitted by contaminated water to livestock and affect their health. Nearly always found in high numbers in the gut of humans (i.e., present in wastewater discharges) and warm-blooded animals (e.g., sheep, cattle, birds).
Enterococci	Microbiological indicator bacteria for faecal contamination[1] and the preferred microbiological indicator bacteria for assessing human health effects from recreational activities in saline waters. See also *E. coli*.

[1] Faecal indicator bacteria such as *E. coli* and enterococci are measured in water rather than the actual pathogens (e.g., salmonella, campylobacter, cryptosporidium, giardia) because the latter are only episodically present (when a sick person or animal is shedding the pathogen) and pathogen assays are often difficult and expensive.

Table 3-3: Stream health aquatic life indicators in the national CBM QA framework. The specific measurement for each indicator is provided in the tables that follow in Section 4.2. An asterisk indicates that the NPS-FM includes one or more attributes for this indicator type (for rivers).

Indicator	Relevance to stream health
Periphyton*	Periphyton provides a food source for macroinvertebrates but thick growths can lead to reduced food quality and may also change macroinvertebrate habitat. Thick periphyton growths also look unsightly and can be a nuisance, spoiling recreational activities such as swimming and fishing, and clogging water intakes and filters. Periphyton blooms are usually a symptom of a stream system stressed by factors such as nutrient enrichment, and high light and water temperatures. Thick and extensive periphyton cover can deplete night-time dissolved oxygen levels.
Microcoleus cyanobacteria	Originally known as *Phormidium, Microcoleus* can taint drinking water and fish with a musty odour and produce toxins that are harmful to animals and humans. In NZ, there have been well over 100 dog deaths associated with *Microcoleus.*
Macrophytes	Macrophytes produce oxygen while photosynthesising during the day, provide refuge for fish and habitat for benthic macroinvertebrates, and contribute to nutrient cycling. However, in high volumes, macrophytes can impact swimming or fishing, impede river flow (increasing flooding risk), clog water intakes, contribute to depleted dissolved oxygen levels at night, and cause fine sediment to settle on the stream bed. Some macrophytes, such as hornwort, *Egeria* and *Lagarosiphon,* are invasive or noxious weeds that can quickly form large dense beds that choke waterways and outcompete other plant and animal species.
Macroinvertebrates*	Macroinvertebrates are a key part of stream food webs, feeding on periphyton, macrophytes, leaf litter from nearby trees, dead wood or each other. The aquatic larvae are an important food source for fish and the winged adults are often eaten by birds and bats. The tolerance of different macroinvertebrate types to habitat and water quality conditions is well known so the variety of bugs present in a stream can tell you about ecosystem health. Unlike water quality indicators, which only reflect one point in time, invertebrates reflect a range of habitat and water quality conditions over a longer period of time.
Fish*	Fish are top predators in stream ecosystems, where the type and number of each species present affects macroinvertebrate abundance and some ecosystem processes. Native fish species are an important part of NZ's freshwater biodiversity. Most native species are declining in number and some are threatened with extinction. The range of fish present can tell us about stream habitat and water quality, both at a specific monitoring site and between the site and the sea. Also, about a third of native species spend some part of their lives at sea so they need to be able to travel between the sea and their freshwater habitats to complete their life cycle. This means that certain species may not be present at a stream site if there is a physical barrier to migration, such as a dam or culvert, downstream of the site. Other relevant factors that affect the presence and abundance of native fish species include loss of riparian vegetation, low dissolved oxygen levels, depleted food sources, and the presence of introduced fish species.

Table 3-4: Physical habitat indicators in the national CBM QA framework. An asterisk indicates that the NPS-FM includes an attribute for this indicator.

Indicator	Relevance to stream health
Physical habitat quality	The various physical features of a stream reach (e.g., substrate size and composition, water depth and velocity, bank stability, riparian vegetation and shade) influence the quality of the living space for aquatic life. Degraded physical habitat reduces the range, abundance and condition of aquatic life. It can also affect the amenity and aesthetic values of streams, or their suitability for recreation and cultural uses.
Deposited fine sediment*	Deposited fine sediment can clog the spaces between streambed gravels and cobbles used by invertebrates and fish and degrade food sources and sites used as habitat for egg laying. Excessive fine sediment can affect the types of invertebrates that live in the stream, and lead to changes in behaviour, feeding and growth. It can also affect the suitability of rivers and streams for recreation.
Shade (canopy closure)	Shading by riparian trees and vegetation keeps stream water cool and helps reduce the growth of nuisance algae and plants.
Rubbish	Rubbish often impacts amenity and recreational values, can pose a human health hazard (e.g., broken glass, soiled nappies) and may harm aquatic life and birds (e.g., through leaking of toxic contaminants or entrapment in plastic). A lot of rubbish is eventually transported downstream to estuaries or out to sea where it can continue to impact the environment.

Table 3-5: Stream health water quantity indicators in the national CBM QA framework.

Indicator	Relevance to stream health
Water velocity	Water or current velocity is an important aspect of aquatic habitat and affects the mixing and dilution of contaminants. Fast currents bring more food to aquatic animals and can help aerate the water.
Stream flow (discharge)	Many other indicators of stream health, including most water quality indicators, change with stream flow. Multiplying stream flow by the measured concentration of a particular water quality variable (e.g., total nitrogen or suspended sediment) gives the total load of the contaminant in the stream. Understanding contaminant loads is important because this can influence the health of lakes and estuaries downstream. For aquatic life indicators like periphyton and macroinvertebrates, it is the flow conditions in the days or weeks before monitoring that can influence when best to sample and what you may find. A stream with a highly varying flow may be a more difficult habitat for aquatic plants and animals to live in than a more stable stream.
Rainfall	Rainfall is an important source of water for recharging stream flows but, depending on how heavy it is (intensity) and long it lasts (duration), rainfall also flushes sediment, nutrients, microbes, metals and other contaminants from the land into streams. Sharp increases in stream flow can occur after heavy rainfall and this can increase bank erosion, resuspend contaminants in the streambed sediments, and wash periphyton and invertebrates away.

Table 3-6: Additional stream health indicators considered for inclusion in the national CBM QA framework.

Indicator	Comment
Ecosystem metabolism (EM)	A NPS-FM attribute that fits under the ecosystem processes component of stream health. Determined from calculations of high frequency *in situ* sensor-based measurements of water temperature and dissolved oxygen made over periods of up to six months. A lot of sensor maintenance (and data management) is required over this period of time and, compared with other indicators, much is still to be understood about EM data across different stream types.
Kākahi	A native freshwater mussel and taonga species that would fit under the aquatic life component of stream health. Kākahi presence/abundance is commonly used as indicator of (good) water quality. Auckland Council has recently adapted an existing regional council monitoring protocol for use by CBM groups but as this protocol was still to be reviewed when this framework was being finalised, it was not possible to include it at this time. There are already kākahi CBM initiatives in NZ (e.g., Lake Wairarapa – see Fenwick 2023) and it is likely to be a popular indicator for some CBM groups.
Rapid habitat pressures assessment (RHPA)	A recently established indicator (Holmes 2022) that is intended to complement the existing national rapid habitat assessment (RHA). While the RHA largely measures *current state* of physical stream habitat, the RHPA focuses on biophysical *pressures* affecting stream habitat. The Holmes (2022) protocol provides a standardised visual assessment to score the condition of 12 habitat variables on a scale of 1 (high) to 10 (low). The assessment can be carried out bankside in less than 20 minutes and is intended, amongst other things, to support catchment management through identifying sites at risk of degradation. The RHPA protocol was only finalised in July 2022 and, although developed with regional council input, might benefit from a period of use by councils before it is included in this framework.

Recognising that some CBM groups may monitor additional stream health indicators outside of the national CBM QA framework, the Monitoring and Quality Plan template has a space to capture any additional stream health indicators a CBM group may be monitoring, as well as the measurement methods for these indicators. This ensures that a group can capture all of their monitoring details in one place. Selection of additional indicators (and/or measurement methods) is likely to be particularly important for:

- CBM groups involved in stream restoration initiatives wanting to measure improvements in stream health over time (given it can be decades before improvements in some indicators may be detected – e.g., Parkyn et al. 2010, MacNeil and Holmes 2021, Clapcott et al. 2021),
- iwi or hapū-based groups, and
- groups with very specific questions (e.g., investigating the impact of landfill leachate or spawning habitat for a particular fish species).

3.4 Selection of measurement methods

The measurement methods included in the national CBM QA framework were selected or adapted from existing established or nationally recognised standards and guidance. These include a mix of methods used by regional councils (e.g., National Environmental Monitoring Standards, NEMS) and those designed specifically for use by CBM groups (e.g., NIWA's Stream Health Monitoring and Assessment Kit (SHMAK) and Auckland Council's Wai Care programme).

In most cases, more than one method is included in the CBM framework to monitor a specific indicator. This is because monitoring purposes often differ across CBM groups and different monitoring purposes call for different methods (and quality standards). Additionally, CBM groups may have different amounts of resources to spend on their monitoring. A CBM group's monitoring

questions and intended data use applications will therefore guide the investment level required. Because the potential re-use of a CBM group's data by others, such as for catchment, regional or national modelling and national reporting, may not be known, data collection methods and quality check measures need to be documented and made available along with the monitoring data.

In a few cases, small modifications were made to existing standard methods or an additional simplified option was introduced. An example is streambed periphyton cover where the standard NEMS (2022a) method requires cover to be estimated at a minimum of 20 points within the stream to the nearest 5%. While this method is included in the national CBM QA framework for those groups wanting to collect data in line with regional council SOE monitoring, so too was a simplified version that only requires periphyton cover to be estimated at 10 points and to the nearest 10%. A basic three cover-category bankside assessment was also included, following feedback from CBM group trainers that some groups wanted a quicker method that that available in the NIWA SHMAK.

Simplifying methods makes it easier to participate in CBM and for CBM groups to collect high quality data (e.g., Buytaert et al. 2014). However, a careful balance is needed between ensuring that what is "do-able" is also "meaningful" or "useful". It is also important to note that while data derived from modified or simplified protocols may be informative and useful, for example tracking periphyton cover over time, it may not be comparable to that collected following NEMS specifications.

Just as additional stream health indicators may be added to the framework over time, it is also envisaged that additional measurement methods may be included in the future. Examples of situations where this may occur are if there is sufficient community group interest in a particular method (e.g., during the electronic field form testing phase, the Friends of Maitai noted that they use Method 5 (Shuffle index) of the national Sediment Assessment Methods (Clapcott et al. 2011) to estimate deposited fine sediment cover) or if a new method suitable for CBM use emerges (e.g., a photo-point based assessment).

Measurements of stream health indicators in the national CBM QA framework fall into three types: *field*, *self-test kit*, and *laboratory (lab)* measurements. While only one type of measurement is available for some indicators (e.g., water temperature and velocity must be measured in the field, while total nitrogen must be measured by sending a water sample to a lab), for other indicators, such as *E. coli* and dissolved inorganic forms of nutrients, there is a choice between two methods – in this case self-test kits or lab testing. Pros and cons associated with each of the three measurement types, relating to time, cost and information gained (Table 3-7), should be weighed up when working with or supporting a CBM group.

Overall, the national CBM QA framework seeks to strike a balance between consistency and flexibility in measurement methods. Therefore, rather than dictate a single method, the framework generally provides several standard method options, with sections 4 and 5 of the CBM guidance document outlining:

- which types of monitoring purposes/data uses each method is most suitable for,
- equipment requirements,
- an indication of the associated time, cost and complexity involved,
- metadata documentation requirements to support interpretation of the measurement data and/or allow data quality to be assessed, and
- recommended training and quality checks.

Table 3-7: Summary of advantages and disadvantages of the different types of measurement methods in the national CBM QA framework.

	Field measurements	Self-test kit measurements	Lab measurements
Advantages	▪ Immediacy of result ▪ Limited ongoing cost beyond initial purchase of equipment or test materials	▪ Engaging and educational ▪ Immediacy of result ▪ Cheaper than lab tests	▪ Expert advice from analysts ▪ High accuracy and precision ▪ QA/QC in place
Disadvantages	▪ Initial expense of field meter or equipment ▪ Sensor calibration and validation required	▪ Takes time to perform nutrient and especially *E. coli* tests ▪ Sample dilutions may be required to get a result within the measurement range ▪ Lower accuracy and measurement resolution ▪ Components of test kits have an expiry date and will need replacing ▪ Some reagents contain hazardous chemicals	▪ Working in with courier times if a local lab isn't available ▪ Samples need to be preserved (e.g., chilled/frozen) until they reach the lab ▪ It can take from days to weeks to get the results ▪ Some tests are expensive

3.4.1 Discrete vs high frequency (continuous) measurements

Significant developments in sensor technologies over the last 10-20 years mean that a growing number of water quality indicators (e.g., water temperature, dissolved oxygen, conductivity, pH, turbidity and nitrate-nitrogen) can now be measured *in-situ* at high frequency (e.g., every 5 or 15 minutes). Moreover, a number of "low cost" high-frequency sensors are increasingly becoming available, making them an accessible (and exciting) option for CBM groups.

The Working Group acknowledged the growing interest of CBM groups in collecting high frequency data, particularly given that multi-sensor packages and associated apps and software are also now available for viewing data in real or near-real time. However, NIWA and regional council staff experienced in high frequency water quality monitoring activities report that the sensors generally require significant amounts of capital and human resources, particularly in terms of sensor maintenance, to get good quality data (Milne et al. 2023b). Biofouling of sensors is a common issue. Despite the fitting of some instruments with mechanical wipers to clean the sensor face, the wipers are not maintenance-free and only slow rather than eliminate biofouling – and then only on the wiped surface (e.g., optical faces) rather than the whole sensor body (and its housing). Other challenges identified by a survey of regional council science and monitoring staff include sensor reliability/performance (e.g., water chemistry can influence some sensor measurements), deployment (e.g., to reduce the risk of vandalism or sensor removal in flood events), and QA and management of the extensive amounts of data generated (Milne et al. 2023b).

On the advice of the Working Group, based on the time, expense and complexity that is generally involved with high frequency sensor-based measurements of water quality, the CBM framework only includes high frequency measurement of water temperature and dissolved oxygen (DO). High frequency measurements of both of these indicators are of high relevance to stream health, particularly stream restoration projects. The NPS-FM 2020 attribute for DO is a mandatory attribute for ecosystem health and requires high frequency measurements of DO.

To avoid challenges associated with sensor cleaning/maintenance, 'cleaning' and processing raw measurements and managing large datasets, the CBM framework focusses on short-term deployments of water temperature and DO sensors (e.g., from a few days to a few weeks – usually in summer low flow conditions to capture water temperature maxima and DO minima). This timeframe should provide sufficient data for most CBM monitoring purposes. If a group wishes to monitor water temperature or DO for a longer period, or to monitor other indicators at high frequency, then they will require advice and support from a specialist. This is particularly important for indicators such as turbidity and nitrate-nitrogen, where sensor performance will need to be verified using another sensor or lab testing of water samples collected from close to the sensor (Hudson and Baddock 2019). Also, given that turbidity is used as a surrogate measure for other water quality indicators, usually suspended sediment and visual clarity, CBM groups should be advised that they will need to measure these other water quality indicators for a period of time and over a range of stream flows (or rain events) to establish a relationship between turbidity and the water quality indicator(s) of interest (Hudson and Baddock 2019). Only then can their high frequency turbidity measurements be used to estimate suspended sediment concentrations or visual clarity – and on the understanding that periodic sampling will be required to check sensor stationarity and the ongoing validity of the local calibration. Stream flow data will also be needed for data interpretation and if sediment load calculations are of interest.

Overall, when working with CBM groups, it is important that the group considers:

- if they need high frequency measurements to answer their monitoring questions,
- if they have the time and other resources to commit to this type of monitoring, and
- how they will quality check, manage (and interpret) the large volume of data the sensor instrumentation will generate.

3.4.2 Nutrient test kits vs lab measurements

Colorimetric-based nutrient test kits are commonplace in some overseas CBM initiatives (e.g., Waterwatch Australia, Clean Water for Wildlife in England and Wales) and also feature in NIWA's SHMAK kit and Auckland Council's Wai Care programme. Despite test kits having advantages over lab testing in terms of lower cost and immediacy of results (Table 3-7), questions are often raised around the accuracy of the results. A study in the UK evaluated Kyoritus PackTest nitrate-nitrogen (nitrate-N) and dissolved reactive phosphorus (DRP) test results against lab testing and identified that the kits performed well*, "broadly matching the results of laboratory analysed samples"* and were able to separate "clean" and "highly polluted" sites with sufficient reliability (Biggs et al. 2016).[5] However, the study also found that test kit nutrient concentrations at more than one third of sites bordering the "clean" boundary (according to the test kit result) may actually fall within the middle category of "mildly polluted" (according to the laboratory test result).

To confirm suitable uses of nutrient test kits in the NZ CBM QA framework, in January 2022 a small number of stream water samples were tested for nitrate-N and DRP using selected test kits and NEMS specified lab test methods. Bulk water samples from streams of varying nutrient and optical[6] status in the Wellington region were collected and split, with one set couriered overnight to Hill Labs in Hamilton for testing in triplicate. The other samples were processed for nutrients in accordance with the manufacturer's instructions for each test kit. The results, summarised in Appendix A, reinforce

[5] The Clean Water for Wildlife citizen science project sought to differentiate between three broad nutrient categories: "clean water" (nitrate-N <0.5 mg/L and DRP <0.05 mg/L, with the latter broadly aligning with the European Union Water Framework Directive 'high' status), "some evidence of nutrient pollution" (nitrate-N 0.5-1 mg/L and DRP 0.05-0.1 mg/L), and "high or very high levels of nutrient pollution" (nitrate-N >1 mg/L and DRP >0.1 mg/L).

[6] For example, streams with variations in visual clarity and water colour (e.g., presence of tannins).

those of the Biggs et al. (2016) study; the kits have good potential to pick up evidence of gross nutrient pollution but are unlikely to detect smaller changes in nutrient concentrations. A key reason for this is that measurement resolution is coarse relative to lab testing. Lab testing is therefore essential for the precise measurement of nutrient concentrations that is needed to track changes in concentrations over time. This is reflected in the CBM QA framework measurement methods where test kits are only recommended for engagement, education, general environmental screening, and nutrient hotspot detection purposes.

It is important that test kit users follow the instructions closely. For example, some Lamotte® phosphate kits warn that, unless the sample is filtered, the presence of fine sediment or colour may interfere with testing. Most kits also require samples to be tested at ambient or room temperature. A lower temperature would likely necessitate a longer reaction time for the test kit reagents. For example, Biggs et al. (2016) noted that Kyoritus, manufacturers of the PackTest phosphate kits, recommend a sample test temperature of 20-40˚C and indicated a sample at 10˚C would need a response time of 20 minutes rather than the normal 5 minutes noted in the test kit instructions. For the PackTest nitrate-N kit, the manufacturer recommends a sample test temperature range of 15-40˚C.

Finally, because the colour charts with nutrient test kits show a change in colour *intensity*, rather than a colour *change*, this may look different in different light, so test results should be viewed in reasonably bright daylight. Further, it is important to correctly follow the stated reaction time as the colour will often continue to darken after this time (Biggs et al. 2016).

3.5 Training, metadata documentation and quality checks

Quality assurance considerations for each stream health indicator included training, metadata requirements and suitable internal and external quality checks. This information was identified from a mix of existing standards and guidance and review by subject matter specialists. In particular, considerable guidance was drawn from overseas approaches to CBM QA, as summarised in Valois and Milne (2021). Within NZ, various NEMS documents were also key sources of guidance, particularly NEMS (2019) for discrete water quality measurements such as visual water clarity.

3.5.1 Training resources

There are currently no formally recognised national training courses or certification available in NZ that specifically target community-based stream monitoring. However, many regional councils and not-for-profit organisations such as the Mountains to Sea Conservation Trust and New Zealand Landcare Trust (and associated partner organisations) have staff who train community groups to use freshwater citizen science tools and resources, such as NIWA's SHMAK and Auckland Council's Wai Care kits. Some scientists in research organisations, universities and consultancies also support community and iwi-based groups interested in monitoring stream health.

As well as user manuals, such as those which come with water quality field meters, self-test kits and NIWA's SHMAK and Auckland Council's Wai Care monitoring kits, many short videos are now available on-line which demonstrate how to monitor different stream health indicators. These videos make excellent training and refresher training resources. Relevant videos are provided in the companion CBM guidance document (outlined in the relevant indicator tables in Sections 4 and 5, with the relevant web links listed in Section 7).

Experience overseas indicates that CBM training is most effective when a range of approaches is provided, including self-based learning (e.g., through videos), in-field demonstrations and periodic check-ins with trained support organisations or a subject matter specialist. A combination of these different approaches is reflected in the training and quality check details included for each stream health indicator in Section 4 of this background report.

As illustrated in Figure 3-7, the extent and frequency of training and quality checks adopted should align with a CBM group's intended monitoring purpose and data use. If a CBM group is embarking on a long-term monitoring programme and has an interest in using their data to inform regulatory-type processes, it is a good idea to encourage and support them to develop some SOPs alongside their Monitoring and Quality Plan. This will help groups maintain consistency in their monitoring should group members carrying out the monitoring change over time.

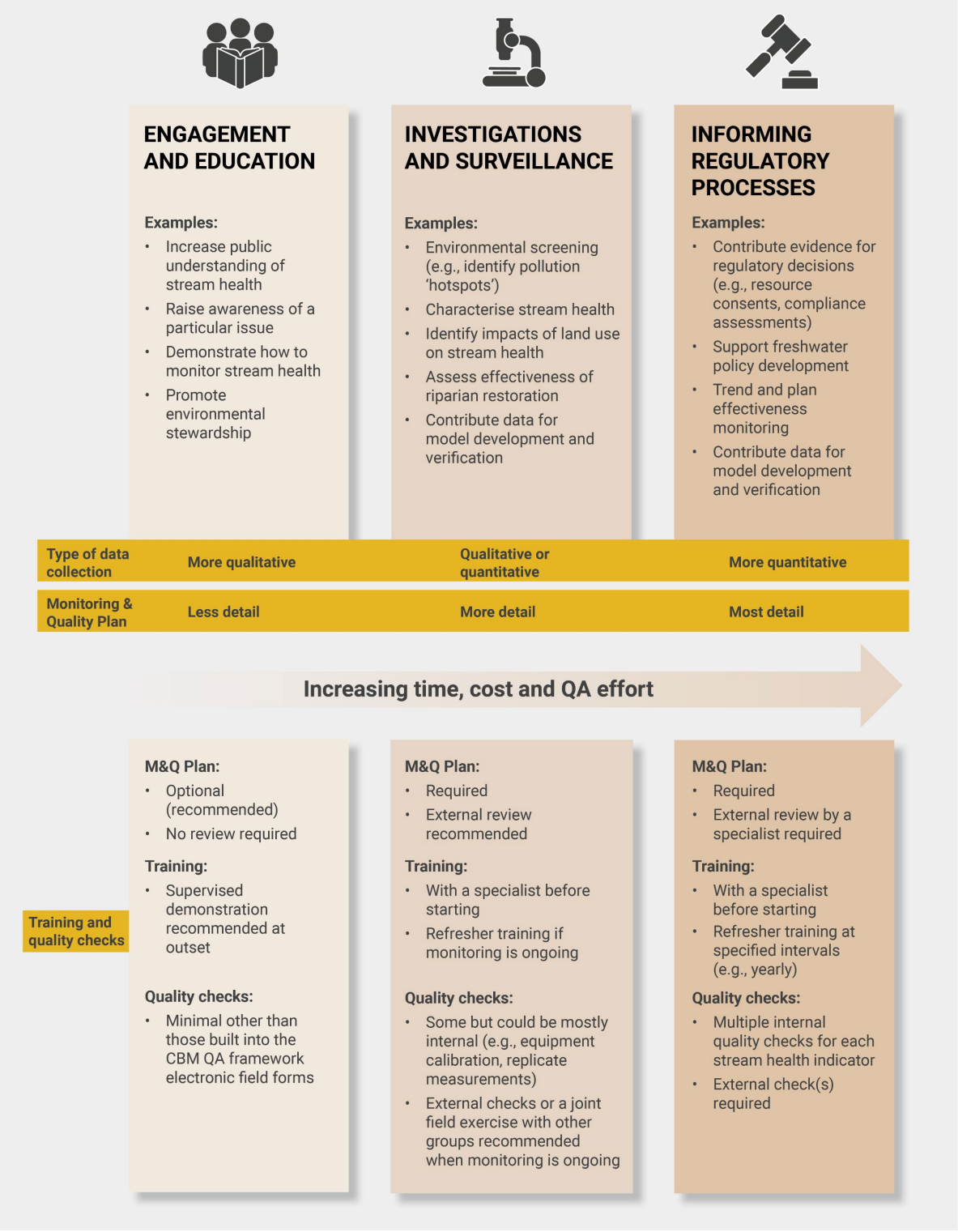

Figure 3-7: Primary data use categories with recommended QA activities that sit in each. In reality, this is a continuum, and time, cost and QA requirements will likely vary within these categories depending on the specific monitoring purpose and data use.

3.5.2 Metadata

Metadata form a critical component of all environmental monitoring and are also central to the national CBM QA framework. As well as indicator-specific metadata (outlined in Section 4), the framework includes site visit metadata relating to weather and stream observations (Table 3-8). The ArcGIS Survey123 electronic field forms included in the framework capture these observations before any stream measurements or sample collection takes place. The forms also allow photos of a site or any unusual or concerning feature (e.g., streambank collapse, algal bloom) to be uploaded together with any additional comments a CBM group may wish to capture.

Table 3-8: Site visit metadata that must be captured on the Survey123 field form on every visit to a monitoring site, in addition to site location, date, time and observer name(s). Unless indicated otherwise, only one option can be selected.

General conditions	Field form selection options
▪ Weather	▪ Partly cloudy, Overcast, Drizzle, Rain Calm, Light, Moderate, Strong
▪ Wind	▪ Calm, Light, Moderate, Strong
▪ Rain in last 24 hr?	▪ Yes, No, Unsure
General conditions	**Options**
▪ Stream water level	▪ High, Normal (or base flow), Low
▪ Stream observations *(select all that apply)*	▪ Stock on banks/in water, Wildfowl in water, Local bank erosion, Surface scums/oils, Rubbish on banks/in water, Periphyton, Macrophytes, Fish
▪ Stream odour	▪ Nothing unusual, Sewage, Petrol/chemical, Dead animals, Rotting vegetation, Musty
▪ Stream water appearance	▪ Clear and colourless, Slightly murky, Turbid, Humic-stained, Other

3.5.3 Types of quality checks

Both internal and external quality control measures, referred to as *quality checks* in the companion CBM QA guidance document, are provided for each indicator in Section 4.

Internal quality checks

Internal quality checks incorporated in the national CBM QA framework include:

- **Equipment checks** to ensure that all the necessary pieces of equipment are available for use and maintained in good working order (e.g., checking the condition of the black disc viewer and macroinvertebrate sampling net, and checking the expiry dates of reagents used in self-test kits and standard solutions used to calibrate field meters).
- **Calibration standards** to validate and (when appropriate) calibrate the accuracy of field meter sensors or lab instruments.
- **Field replicates** to assess how closely two or more sets of results agree (i.e., a check of precision or repeatability).
- **Field blanks** comprising distilled water to check for contamination of water samples during sample collection, transport and testing (primarily recommended for monitoring streams with very low nutrient or faecal bacteria concentrations).
- **Lab replicates,** primarily for CBM groups using nutrient or *E. coli* self-test kits.
- **Lab blanks**, primarily for CBM groups using *E. coli* self-test kits.
- **Voucher specimens** to verify the accuracy of taxonomic identification (also useful as a 'mystery box' in training sessions to check the skill levels of CBM group members).

- **Photographs** to help confirm species identification (e.g., macroinvertebrates) or check point-based observations of stream health indicators such as the percentage of the streambed covered in fine sediment or periphyton.

If a CBM group's samples are sent to a lab for analysis (e.g., nutrients, suspended sediment) or identification (e.g., macroinvertebrates), it is expected that the lab will carry out its own internal quality checks (see Section 4.1.3).

External quality checks

External quality control in the national CBM QA framework involves verification by an independent organisation that a CBM group is correctly carrying out measurement, sampling, testing and/or identification activities. Regional councils and other organisations supporting CBM groups should encourage and assist with external verification exercises to provide groups with reassurance that they are collecting good quality data. External verification exercises can also help identify when training refreshers might be needed, and keep groups up to date with new or emerging monitoring methods.

Under the framework, external verification is expected where a CBM group intends to have their data considered for use in informing regulatory processes (Figure 3-7). Some form of external verification or a joint field exercise (sometimes referred to amongst regional council monitoring staff as a "regatta") with other CBM groups is also encouraged for these and long-term investigation and surveillance-type data applications.

External verification can address:

- checks of field measurements (e.g., through observation of measurement technique and also, ideally, by taking an independent set of measurements and comparing how close they agree with those of the CBM group, Figure 3-8),
- taxonomic identification (e.g., taxa in one or more macroinvertebrate samples are independently identified and counted by a specialist to confirm the accuracy of the CBM group's identification (and counting)), and
- lab verification of water quality indicators measured using field meters or self-test kits (e.g., a water sample is periodically sent to a lab to check how well the results agree with those obtained by the CBM group).

Figure 3-8: Monitoring officers from NIWA and Otago Regional Council carrying out side-by-side field measurements (left) and water sample collection (right). The two water samples were sent to the lab for nutrient analysis to check whether there was close agreement in the results (as would be expected). Photos: Juliet Milne.

While a CBM group could also consider a check on the performance of their lab (through collecting a single bulk water sample and splitting this into two subsamples, one for their regular lab and the other to another lab as an independent check), this is not a priority given that labs have extensive quality check programmes in place. However, this might be important if a CBM group is using a lab that isn't IANZ accredited to perform a particular test and wish to use their data for regulatory purposes.

4 Indicators, measurement methods and quality checks

This section provides details of the measurement methods, training resources, metadata requirements and quality checks for each of the 28 stream health indicators (refer Figure 3-6) included in the national CBM QA framework. Information in this section forms the basis of Sections 4 and 5 of the companion CBM guidance document (Milne et al. 2023a). That document also includes an indication of the time, cost and complexity associated with measurement method, based on input from scientists familiar with the indicators and methods involved. *Data use* in the stream health indicator tables in this section refers to the three broad categories of data use outlined in Figure 3-5: *Engagement and education*, *Investigations and surveillance* and *Informing regulatory processes*.

4.1 Water quality indicators

Most of the water quality indicators in the national CBM QA framework need to be measured either *in-situ* with a field meter or by performing a test on a water sample collected from the stream. Therefore, key requirements for field meter measurements, water sample collection and lab testing are outlined first. Measurement methods, training, metadata requirements and quality checks specific to each water quality indicators then follow in table format for each indicator.

4.1.1 Field meter measurements

Water temperature, DO, conductivity, pH and turbidity are the five water quality indicators in the national CBM QA framework that can be measured using a field meter (visual clarity is also measured in the field but typically involves using a clarity tube or black disc – see Section 4.1.6). Of these, only water temperature and DO *must* be measured using a field meter. Conductivity, pH and turbidity can also be measured by collecting a water sample and sending it to a lab for testing.

Whether or not a CBM group purchases a field meter will depend on what water quality indicators they want to measure and their available budget and time. A wide range of inexpensive thermometers are available for measuring water temperature if this is the only water quality indicator they wish to measure in the field. Conductivity meters can be purchased for as little as $100 and are a worthwhile one-off investment for measuring conductivity and water temperature in the field. At the very least a group will need to access a field meter if they wish to monitor DO and this will include a temperature sensor.

It is important for CBM groups to understand that field meters require regular maintenance and checks of sensor performance. This is particularly important for DO, pH and turbidity measurements because these sensors typically drift over time. Conductivity sensors are generally more stable – but a validation check will still need to be made with standard solutions to confirm the sensor is reading within an acceptable range.

An optical sensor is the most reliable for DO measurement (NEMS 2016) and requires less maintenance than membrane-based galvanic or polarographic sensors. However, the price of DO meters with an optical sensor starts from around $1,500 NZD. If it isn't possible for a CBM group to loan a field meter from a regional council or other organisation, they may be able to pool resources with another monitoring group to purchase one.

Similar to DO, pH and turbidity meters are generally upwards of $1,500 NZD each. This expense, as well as the time (and cost) involved with sensor quality checks, mean that it is generally easier to collect a water sample for a lab to measure pH and turbidity. A test-strip can also be used to estimate pH if a CBM group does not require a precise measurement.

Although turbidity is correlated with multiple water quality indicators, measurements are sensor-specific so turbidity is typically used as a surrogate for another indicator, most commonly visual clarity

or suspended sediment (Davies-Colley et al. 2021). As such, any field or lab turbidity measurements need to be accompanied by field measurements of visual clarity and/or lab measurements of suspended sediment to establish the relationship between these indicators. Some commentary on this is included in the companion CBM guidance document in relation to high frequency sensor-based measurements.

The table on the following page addresses training, records and quality checks for discrete measurements of water temperature, dissolved oxygen (DO) and conductivity. Measurement resolution and metadata records for field measurements of pH and turbidity are also included in the table. However, as the national CBM QA framework recommends that pH and turbidity are measured in the lab (with built-in QA/QC protocols), training and quality checks for these indicators are not included here. CBM groups wanting to measure pH or turbidity with field sensors should seek specialist advice and instruction on sensor selection, calibration and validation. This advice should be referenced against the requirements of NEMS Discrete Water Quality (NEMS 2019).

<table>
<tr><td>Training</td><td>In-field demonstration and practice based around the quality checks below</td></tr>
<tr><td>Resources</td><td>• NIWA e-Learning training videos (you tube):
o WQ Rivers – field measurements
o WQ Rivers – field measurements from a bridge</td></tr>
<tr><td>Refresher frequency</td><td>Annually</td></tr>
<tr><td>Records</td><td></td></tr>
<tr><td>Measurement resolution</td><td>• Water temperature: nearest 0.1˚C (or 0.5˚C for an analogue thermometer)
• DO: 0.01 mg/L and 0.1%
• Conductivity: nearest 1 µS/cm (or 0.1 mS/m)
• pH: nearest 0.1
• Turbidity: 0.1 FNU or NTU between 0 and 10, otherwise nearest 1 FNU or NTU</td></tr>
<tr><td>Supporting metadata</td><td>• Measurement device used, including field meter make and model*
• Sensor validation and calibration details*
• Barometric pressure (for DO if the meter does not automatically compensate for this)</td></tr>
<tr><td>Quality checks</td><td>Equipment checks</td></tr>
<tr><td>Internal checks</td><td>• Sensor accuracy:
o Water temperature: 0.5˚C
o DO: 0.3 mg/L and 3%
o Conductivity: 1 µS/cm at 25˚C (or 0.5% full scale)
• Membrane is intact (no bubbles) – applies to galvanic and electrochemical DO sensors only
• Sensor validation and calibration as follows**:
<table>
<tr><td>Water temperature</td><td>Check (validate) the sensor against 2 traceable reference thermometers (a council or lab may be able to assist with this) at least once every 12-months. Replace sensor if it fails.</td></tr>
<tr><td>DO</td><td>On each day the sensor is used, before monitoring, check the sensor is within the valid range of ± 0.5% saturation using 100% saturated air or water. If the measurement is outside of this range, calibrate the sensor following the manufacturer’s instructions.</td></tr>
<tr><td>Conductivity</td><td>On each day the sensor is used, before monitoring, check the sensor’s accuracy against at least 2 lab standard solutions:
• standards ≤ 10 µS/cm: measurement should be within ± 25%
• standards 10-200 µS/cm: ± 15%
• standards >200 µS/cm: ± 5%
If the measurement is outside the accepted range, calibrate the sensor following the manufacturer’s instructions.
(NEMS (2019) also requires the sensor to be re-checked at the end of the day in a 148 µS/cm standard solution (should agree within ± 15%) and a note recorded with any measurements if the end of day sensor check is outside of the accepted range.)</td></tr>
</table>
Field measurement checks
• Sensors deployed in running water and allowed to stabilise before measurements are read
• DO: Corrected for barometric pressure (if correction not built-in)
• Conductivity measurements are recorded at 25˚C
• A repeat measurement (using the same sensor) is periodically made by a second, independent observer – the original and repeat measurements should agree within ± 5%</td></tr>
<tr><td>External checks</td><td>• The same checks listed above made by an independent (trained) observer or specialist
• Side-by-side measurement with a specialist using pre-calibrated sensors – measurements should agree within ± 5%</td></tr>
</table>

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

** The checks listed align with NEMS (2019) requirements for data of the highest quality. However, in the case of conductivity, most sensors are reasonably stable over time and for most CBM group data uses, it may be sufficient just to check the sensor at the start of the day at three-monthly intervals against one standard solution.

4.1.2 Water sample collection

The national CBM QA framework is built around discrete water sampling for most water quality indicators. Collection of water samples for eDNA testing is outlined in Section 4.2.1.

The sample collection methods follow those specified in NEMS (2019), with stream water samples to be collected just below the water's surface, usually by hand, or with the aid of a sampling pole. A bucket and rope may be needed when it isn't safe to access a stream directly.

Collection methods	By hand or with aid of a sampling pole or bucket and rope
Method instructions available from	Instructions and videos available from various sources, such as: • Section 4 of the NEMS Discrete Water Quality (Part 2: Rivers) (NEMS 2019) • NIWA SHMAK manual
Equipment	Disposable gloves (recommended), chilly bin and ice or cooler pads to store and transport water samples after collection
Caveats	Sampling by hand will not always be possible (e.g., when the stream is too deep, swiftly flowing or turbid for safe entry) and a sampling pole is highly recommended addition to your stream monitoring kit. A bucket and rope are usually reserved for sampling from bridges or towers when the water may be some distance down and can be difficult.
Training	In-field demonstration and practice based around the quality checks below

Useful resources	• NIWA e-Learning training videos (you tube):
	  ○ WQ Rivers – bottle sampling methods
	  ○ WQ Rivers – sample handling and dispatch
	• NEMS Discrete Water Quality: Part 2 Rivers
	• NIWA SHMAK video: How to collect a water sample

Refresher frequency	Annually
Records	
Supporting metadata	• Collection method* (e.g., grab sample by hand, sampling pole) • Stream water appearance* (e.g., clear and colourless, slightly murky) • Sample collection time* • If the sample might be compromised in any way (e.g., if sediment on the streambed was disturbed and entered the sample bottle, a non-sterile sample bottle was used to collect a sample for *E. coli* testing)
Quality checks	
Internal checks	• Water sample(s) are representative of the site, collected in flowing water facing upstream and ~0.2 m below the water's surface • Correct lab sample bottle(s) used for the indicator(s) to be measured and correctly rinsed and/or filled (see box opposite page) • Sample bottles clearly and permanently labelled with a site identification code • Samples promptly removed from light and placed in chilled containers • Completed Chain of Custody form accompanies water samples sent to a lab, including site name (or code), date and time of sample collection and dispatch, and anything unusual about samples (e.g., if they are brackish) • Field replicates[1] • Field blanks[1]
External checks	• The same checks listed above made by an independent (trained) observer or specialist • Side-by-side water sample collection with a specialist with samples sent to the same lab (measurements should agree within the range specified for different indicators in this section (e.g., ±5% for conductivity)

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

[1] Annually if samples are going to a lab but at least quarterly if self-testing for *E. coli* or nutrients.

4.1.3 Lab testing

Regional councils and other organisations supporting CBM groups are encouraged to assist groups to connect with a lab. Although the measurement methods are included in the national CBM QA framework, there are often queries about aspects of sample preservation (e.g., filtering) and testing (e.g., method detection limits) and it is in the best interests of both CBM groups and support organisations with an interest in using the monitoring results to ensure that samples are correctly preserved for lab testing and the most appropriate measurement methods are used.

Additionally, CBM groups could be supported to negotiate the best deal from a lab. For example:

- For many stream indicators, labs perform tests in large batches and may offer a lower price per test if an agreed minimum number of samples will be provided.
- Depending on the lab, a group may be able to get a package of tests at a cheaper price than the standard price of each test.
- Some labs may be willing to offer a discount to support CBM initiatives and may assist with chilly bins, labelled sampling bottles and courier tickets.

Labs have their own QA procedures that address training and both internal and external quality control measures. Many labs have their methods IANZ accredited which is a useful quality check – and essential for CBM groups that wish to use their data to inform regulatory processes.

One way for a CBM group to check on their lab's performance is to adopt a common regional council SOE monitoring programme practice of periodically collecting and splitting a sample into two bottles. The duplicate water sample is then sent to the lab under a dummy site name: the results from the two samples should generally agree closely (within 10-15% for most indicators).

In line with NEMS (2019), all water samples submitted to a lab by CBM groups should be accompanied by a Chain of Custody (CoC) form that specifically requests information on sample arrival time and condition. This information can then be used to help confirm the quality of the lab's measurements. The lab report should also be checked for any special notes about the measurements made (e.g., if there was an interference that prevented the standard method detection limit from being met).

Under the national CBM QA framework, a CoC form is essential if CBM groups wish to use or have their data considered for use in regulatory processes. The quality checks included in the CoC form and other quality checks are listed in the table below.

Quality checks	**Comment**
The lab confirms receipt of samples within appropriate timeframes for testing	Information provided by return of the CoC form
The lab confirms samples were in acceptable condition for testing	Information provided by return of the CoC form
The lab is IANZ accredited to perform the selected test method	This is required if CBM groups wish to use their data in regulatory processes and is consistent with NEMS (2019) requirements
The lab records on its report if any issues may have affected the quality of test results (e.g., labs will report water samples that arrive for *E. coli* testing outside of the recommended 24-hour processing time)	This information should be provided as a note on the bottom of the lab report

4.1.4 Water temperature

Water temperature is separated into discrete and high frequency sensor-based measurements in the national CBM QA framework. Section 3 of the companion CBM guidance (Milne et al. 2023a) provides commentary on the benefits and uses of high frequency water temperature measurements.

Discrete measurements

Measurement units	˚C	
Measurement type	Field measurement	
Measurement methods	Thermometer	Field meter
Data use	Suitable for education and some scientific uses (e.g., general environmental screening). Not recommended for regulatory uses.	Suitable for all three types of data use application
Method instructions available from	• NIWA SHMAK manual • Wai Care manual	NEMS Discrete Water Quality (Part 2: Rivers)
Equipment	Analogue or digital thermometer	Field meter with a temperature sensor (e.g., a dissolved oxygen or conductivity meter)
Caveats		NEMS requires a sensor accuracy of ±0.3˚C and ±0.5˚C is the minimum acceptable
Training	See Section 4.1.1	
Records		
Quality checks		

Continuous measurements

Continuous measurements of water temperature require a temperature sensor with a waterproof logging function, such as Onset's Hobo® Pendant MX Water Temperature data logger (included in the NIWA SHMAK kit). This and other similar loggers are enabled with Bluetooth wireless access so deliver temperature measurements straight to a mobile phone or a Windows computer. The data are delivered using an app (e.g., HOBOconnect app).

As noted in Section 3.4.1, the national CBM QA framework only addresses short-term deployments (e.g., from a few days up to a month – usually in summer low flow conditions to capture water temperature maxima). This should prevent the need for sensor cleaning/maintenance which can be required on a regular basis when deployments occur over an extended period.

Data use	Suitable for all three types of data use application
Method instructions available from	• NIWA SHMAK manual (Hobo pendant logger) • NEMS Continuous Water Temperature (NEMS 2017)
Equipment	Temperature sensor with a waterproof logging function, and something to mount or attach this device to (e.g., waratah and cable ties or bracket)
Caveats	The NEMS (2017) recommends measurement intervals of no less than 5 minutes (but 15-60 minute intervals should be sufficient for many data uses and will reduce the volume of measurements to manage). Parkyn et al. (2010) recommend every 15 or 30 minutes over at least one month in mid-to-late summer to best characterise a site's thermal regime.
Training	Portable sensors such as Onset's Hobo® Pendant MX Water Temperature data logger are supported by online instructional videos
Records	See Section 4.4.1
Quality checks	
Internal checks	Check the manufacturer's instructions but could include: • Data logger batteries and set-up are OK • Sensor is deployed in a representative location and is likely to remain secure and under water for the period of deployment • A water temperature measurement is taken adjacent to the sensor using a calibrated field meter or reference thermometer to verify sensor performance
External checks	• An independent specialist checks the deployment set-up and takes a water temperature measurement adjacent to the sensor using a calibrated field meter or reference thermometer to verify sensor performance

4.1.5 Dissolved oxygen

Dissolved oxygen (DO) is separated into discrete and high frequency sensor-based measurements in the national CBM QA framework. Section 3 of the companion CBM guidance (Milne et al. 2023) provides commentary on the benefits and uses of high frequency DO measurements.

Discrete measurements

Only *in-situ* sensor-based measurements of DO are included in the framework. Although DO can also be measured using a Winkler titration, as is currently the case in Auckland Council's Wai Care programme, this method was not included in the framework because is time consuming and difficult to perform reliably in the field (NEMS 2016).

Measurement units	% saturation and mg/L (equivalent to gm/^{3})
Measurement type	Field measurement
Measurement methods	Field meter* • Optical (luminescent) sensor – recommended (see Section 4.1.1) and NEMS compliant • Electrochemical, membrane-based (polarographic or galvanic) sensor
Data use	Suitable for all three types of data use application
Method instructions available from	NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)
Equipment	DO meter (or a field meter with a DO sensor). Optical sensors are more stable and, require less maintenance and calibration than membrane-based sensors.
Caveats	NEMS (2019) requires a sensor accuracy of ± 3% and ±0.3 m/L. Barometric pressure must be recorded if the DO sensor does not automatically measure this. Electrical conductivity must also be measured if the stream is tidally influenced.
Training	See Section 4.1.1
Records	
Quality checks	

Continuous measurements

Continuous measurements of DO require the use of a DO sensor with a waterproof logging function, such as a PME miniDOT® Clear Logger or a Hobo U266 DO Logger. Measurements are typically recorded to an internal SD card and can be downloaded onto a laptop or desktop via an optical USB interface following sensor retrieval.

Similar to water temperature, the national CBM QA framework only addresses short-term DO sensor deployments (e.g., from a few days to a few weeks – usually in summer low flow conditions to capture DO minima). This should prevent the need for sensor cleaning/maintenance during the deployment period.

Data use	Suitable for all three types of data use application
Method instructions available from	NEMS Continuous Dissolved Oxygen – NEMS (2016)
Equipment	DO sensor with a waterproof logging function, and something to mount or attach this device to (e.g., waratah and cable ties or bracket)
Caveats	NEMS (2016a) requires a sensor accuracy of ± 3% and ±0.3 m/L. Barometric pressure must also be recorded if the DO sensor does not automatically measure this. Electrical conductivity also needs to be measured if the stream is influenced by coastal tides. NEMS (2016a) recommends measurement intervals of 5 min or less but 60 min intervals could be sufficient for many data uses and will reduce the volume of data to manage).
Measurement range and resolution	Sensor dependent (e.g., the PME miniDOT® Clear Logger data logger ranges from 0 to 150% saturation and a measurement resolution of 0.01 mg/L)
Training	Portable sensors such as the PME miniDOT® Clear Logger data logger and Hobo U266 DO Logger are supported by online instructional manuals, software and/or videos
Records	See Section 4.1.1
Quality checks	
Internal checks	Check the manufacturer's instructions but could include: • Data logger batteries and set-up are OK • Sensor is deployed in a representative location and is likely to remain secure and under water for the period of deployment • A DO measurement is taken adjacent to the sensor using a calibrated field meter to verify sensor performance
External checks	• An independent specialist checks the deployment set-up and takes a DO measurement adjacent to the sensor using a calibrated field meter to verify sensor performance

4.1.6 Visual water clarity

The national CBM QA framework incorporates two measurement methods for visual water clarity – the horizontal clarity tube measurement (Kilroy and Biggs 1998) developed for the NIWA SHMAK kit and the horizontal black disc method (Davies-Colley 1998, NEMS 2019) used by NIWA and most NZ regional councils. The clarity tube and black disc methods are equivalent up to horizontal visual clarities of at least 0.5 m, above which they deviate (Kilroy and Biggs 1998). If visual clarity at a site is routinely greater than 0.5 m and a CBM group wants to quantify and track changes in visual clarity over time, then the black disc method should be used (i.e., reserve use of the clarity tube to occasions when visual clarity measurements are less than around 0.5 m). This is consistent with the direction of NEMS (2019).

Measurement units	m	
Measurement type	Field measurement	
Measurement methods	**Clarity tube**	**Horizontal black disc**
Data use	Suitable for all three types of data use application except where visual clarity needs to be quantified above 0.5–1 m	Suitable for all three types of data use application and essential where visual clarity needs to be quantified above 1 m
Method instructions available from	• NIWA SHMAK manual • NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)	
Equipment	Clarity tube and magnet set	Set of 3 x black discs, underwater viewer and measuring tape
Caveats	Limited to a measurement of between 0 and 1 m and the relationship with black disc is only equivalent between 0 and 0.5 m	Unsuitable in very shallow streams and unsafe in high or very turbid flows (use a clarity tube in these conditions)
Training	In-field demonstration and practice based around the quality checks below	
Resources	• NIWA SHMAK videos: Water quality – visual clarity • Environment Canterbury video: Visual clarity tube measurements • NIWA e-Learning training videos for NEMS Discrete Water Quality (You tube): WQ Rivers – black disk or visual clarity measurements	
Refresher frequency	Annually if not regularly making visual clarity measurements or if regular measurements are made without a check by a second observer	
Records		
Measurement resolution	Nearest 0.01 m (1 cm) or nearest 0.1 m if visibility using a black disc is >10 m	
Supporting metadata	• Measurement device used (i.e., clarity tube or black disc)* • General lighting conditions (sun, shade, mixed)* • Appearance and reappearance distances* • Disc size used (black disc only)*	
Quality checks	*Clarity tube and black disc*	
Internal checks	• Path of sight uniformly lit (avoid shadows) • Measurements made without being affected by a sediment/disturbance plume • Observer's eyes are snug to the tube end/viewer and time is allowed for eyes to adjust to stream lighting • Appearance and reappearance distances measured and recorded • A repeat set of measurements is made by a second, independent observer (the two average values of the appearance and reappearance distances should agree within ± 10%)*	
	Black disc only (additional to above)	
	Equipment checks • Discs painted in black matte with no chipped or worn areas • Viewer window and mirror are clean and scratch-free	
	Measurement checks • Measurement made in flowing water, preferably in a run • Appropriate diameter disc size is used:* o 200 mm: where visibility is >1.5 m o 60 mm: where visibility is 0.5-1.5 m o 20 mm: where visibility is ≤0.5 m (or a clarity tube is used) • Measurement tape is kept taut/firm and straight	
External checks	• The same checks listed above made by an independent (trained) observer or specialist • Side-by-side measurement with a specialist – measurements should agree within 10%	

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.1.7 Turbidity

As noted in Section 4.1.1, the reason for including turbidity in the national CBM QA framework is its potential use as a surrogate or proxy variable for other water quality variables of interest (e.g., visual water clarity, suspended sediment, total phosphorus, *E. coli*). It is also commonly offered as part of lab water quality test suites offered to CBM groups.

It is important for CBM groups to understand that turbidity measurements from one sensor are unlikely to be directly comparable with those from another sensor owing to different sensor configurations (e.g., Davies-Colley et al. 2021). In NZ, the NEMS (2019) recommends the use of IS0 7027 compliant sensors for river and stream water quality monitoring. Most labs also still offer the long established (for drinking water quality assessments) "white light" sensor-based method. Whatever sensor is used, it is critical that that the sensor make, model and units are recorded with the measurement values. It is also critical that the same sensor make and model are retained over time.

As reliable turbidity sensors are likely cost-prohibitive for most CBM groups, lab measurements should be encouraged over field measurements. However, the field forms do allow field-based sensor measurements to be captured (along with mandatory information on sensor type and calibration) should a CBM group have access to reliable sensor.

<table>
<tr><td>Measurement units</td><td colspan="2">Various – generally Nephelometric Turbidity Unit (NTU) and the Formazin Nephelometric Unit (FNU)</td></tr>
<tr><td>Measurement type</td><td colspan="2">Field measurement or lab measurement made on a water sample</td></tr>
<tr><td rowspan="2">Measurement methods</td><td>Turbidity meter (field)</td><td>Turbidity meter (lab)</td></tr>
<tr><td colspan="2">▪ IS0 7027 (near infra-red light, FNU) – NEMS compliant
▪ APHA 2130 B (white light, NTU)</td></tr>
<tr><td>Data use</td><td colspan="2">Suitable for all three types of data use application</td></tr>
<tr><td>Method instructions available from</td><td colspan="2">NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)</td></tr>
<tr><td>Equipment</td><td>Turbidimeter (or a field meter with a turbidity sensor)</td><td>Sample bottle, chilly bin and ice packs</td></tr>
<tr><td>Caveats</td><td>Turbidity measurements vary with sensor make and model so consistency in sensor type through time is critical. The upper range of the measurement on some sensors is only 1,000 so will not return a measurement for sediment-laden/ flood water samples. Regular sensor calibration and validation is also required (formazin is typically used and must be handled carefully as it is a known carcinogen).</td><td>If measurements are to be made on very sediment-laden (flood water) samples, the lab should be asked to take measurements on diluted samples to prevent the sensor over-ranging.</td></tr>
<tr><td>Measurement range and resolution</td><td colspan="2">Sensor dependent but generally a minimum of 0 to 1,000, with some field and lab sensors able to record up to 4,000 without needing to dilute the sample. Report to one decimal place between 0 and 10, and to no more than the nearest whole number above 10.</td></tr>
<tr><td>Training</td><td rowspan="3">Specialist advice and instruction is required. Refer Section 4.1.1.</td><td rowspan="3">See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)</td></tr>
<tr><td>Records</td></tr>
<tr><td>Quality checks</td></tr>
</table>

4.1.8 Suspended sediment

In the national CBM QA framework, suspended sediment refers to total suspended solids (TSS), sometimes shortened to suspended solids. Measurement of suspended sediment concentration (SSC) has not been included in the framework because this requires a more expensive and time-consuming test (and is not offered by some NZ labs). A TSS test will answer most sediment-related questions CBM groups may have but if sediment load monitoring is a priority for a CBM group, then they should be encouraged to engage the services of a suitable lab for SSC testing. NEMS (2020) provides guidance on sediment load estimation.

The companion CBM guidance document (Milne et al. 2023a) includes an explanation of the different between TSS and SSC.

Measurement units	milligrams per litre, mg/L (equivalent to g/m^3)
Measurement type	Lab measurement on a water sample
Measurement methods	APHA 2540 D
Data use	Suitable for all three types of data use but some specific investigations or regulatory applications, or some regional councils, may require measurement of suspended sediment concentration (SSC) rather than TSS (e.g., in sediment load estimation)
Method instructions available from	Contact your lab. Also see NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)
Equipment	Sample bottle, chilly bin and ice packs. May require a sample pole or similar device for sampling in high flow conditions.
Caveats	Can require a large volume of sample to be collected for clear waters. The test may be biased low (i.e., underestimate the actual amount of sediment present) when a sample is very dirty or contains large amounts of (fast-settling) sand.
Training	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)
Records	
Quality checks	

4.1.9 Electrical conductivity

Measurement units	µS/cm @ 25˚C – although other measurement units may be used (e.g., mS/cm or mS/m)	
Measurement type	Field measurement or lab measurement made on a water sample	
Measurement methods	**Conductivity meter (field)**	**Conductivity meter (lab)** • APHA 2510 B (NEMS compliant)
Data use	Suitable for all three types of data use application but to meet the highest quality that may be required for some regulatory purposes, NEMS (2019) requires a sensor accuracy of ± 1 µS/cm – some low-cost sensors may not meet this requirement	Suitable for all three types of data use application
Method instructions available from	▪ NIWA SHMAK manual and video ▪ NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)	
Equipment	Conductivity meter (or a field meter with a conductivity sensor)	Sample bottle, chilly bin and ice packs
Caveats	Conductivity increases with increasing water temperature and should be measured using a meter that can output the measurements at a standard reference temperature of 25˚C, in line with NEMS (2019) requirements and reporting of conductivity by NZ labs	
Training	See field meter measurements (Section 4.1.1)	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)
Records		
Quality checks		

4.1.10 pH

The national CBM QA framework incorporates two measurement methods for pH – test strips (self-measurement) and lab measurement on a water sample. Although pH can, and often is, measured *in-situ* with a field meter, it is widely recognised that it can be very difficult to calibrate and get accurate measurement values from pH sensors (NEMS 2019). For this reason, and also noting that reliable sensors are likely cost-prohibitive for most CBM groups, pH measurements using a field meter are not specifically included in the national framework. However, the field forms do allow field-based sensor measurements to be captured (along with mandatory information on sensor type and calibration) should a CBM group have access to (and support to use) a reliable sensor.

Measurement units	pH units	
Measurement type	Field measurement (self-test kit) or lab measurement made on a water sample	
Measurement methods	**Field measurement (self-test kit)** • pH test strips (e.g., MColorpHast™)	**pH meter (lab)** • APHA 4500-H+ B (NEMS compliant)
Data use	Primarily suitable for education. May also be suitable for some science purposes (e.g., as a supporting measurement to assess potential ammonia toxicity) but will depend on the measurement resolution and specific intended data use	Suitable for all three types of data use application
Method instructions available from	Test kit	NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)
Equipment	Test strips	Sample bottle, chilly bin and ice packs
Caveats	Test strips have low measurement precision especially if the strips span the full pH 1–14 range, and so less precise than lab measurements. For most stream monitoring, selecting strips with a limited pH range closer to that typically measured in streams (e.g., 5–9) will increase measurement precision and provide more useful data.	Water sample needs to be airtight (no air bubbles) and dispatched promptly to the lab
Training	Demonstration and practice based around the quality checks below, including practice with sample filtering and dilutions if these are likely to be used	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)
Records	• Water sample collection method* • Test strip make and measurement range*	
Quality checks		
Internal checks	• Expiry date of test strips • The test strip reading is made within recommended timeframe and verified by a second observer • A repeat test is performed by a second, independent observer* (the two results should agree within the same measurement increment) • Measurement performed on a standard solution of known pH and agrees within the same measurement increment • The test strip reading is made within recommended timeframe and verified by a second observer	
External checks	• Side-by-side sample testing with an independent specialist – measurements should agree within the same measurement increment • A sample is sent to the lab for measurement (should fall within the same increment range of the test kit)	

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.1.11 Ammoniacal nitrogen

The national CBM QA framework provides for two measurement methods for ammoniacal nitrogen – self-test kits and lab measurement on a water sample. As concentrations of ammoniacal nitrogen are typically very low in all but very degraded streams, self-test kits will likely only be useful for detecting ammonia in grossly polluted streams. Lab measurement is therefore recommended in almost all circumstances.

Measurement units	mg/L (equivalent to g/m^3)	
Measurement type	Self-test (in the field) or lab measurement made on a water sample	
Measurement methods	**Visual test kit** (example) ▪ CHEMets® Ammonia Test Kit K-1510 low range (0-1 mg/L), Direct Nesslerization method	**Lab test method** (recommended) ▪ APHA 4500-NH_3 H (flow injection analyser) – NEMS (2019) compliant, performed on a 0.45 micron filtered sample
Data use	Primarily suitable for engagement and education purposes. May also be suitable for streams and drains with degraded water quality to confirm a suspected impact from animal effluent or human or industrial wastewater inputs.	Suitable for all three types of data use application
Method instructions available from	Provided with the test kit – also see water sample collection requirements	Not needed – see water sample collection requirements
Equipment /materials	Test kit and sample bottle	Sample bottle, chilly bin and ice packs
Caveats	Turbid samples should be filtered prior to testing. Chlorine (e.g., if associated with wastewater treatment) may interfere with the results. Sample reagent contains mercury (i.e., hazardous).	Concentrations in most streams are very low, often below lab method detection limits – take extreme care not to contaminate the sample. NEMS (2019) requires a method detection limit of 0.005 mg/L.
Detection limit	Depends on test kit but 0.05 mg/L at best	0.005–0.01 mg/L
Measurement range and resolution	CHEMets® Ammonia Test Kit K-1510 low range: 0.05–1 mg/L at 0.1 mg/L increments (estimate the measurement to the nearest half increment)	From 0.005 mg/L upwards*, typically reported to 2 or 3 significant figures
Training	See nitrate-N test kit measurements (Section 4.1.12)*	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)
Records		
Quality checks		

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt capture of the records and quality checks denoted with an asterisk in Section 4.4.12.

** A water sample with a very high concentration is diluted until it can be quantified.

4.1.12 Nitrate-nitrogen

The national CBM QA framework includes two measurement methods for nitrate nitrogen – colorimetric-based self-test kits and lab measurement on a water sample. Although self-test kits state a measurement range starting at 0 mg/L, they are not sufficiently sensitive to reliably detect this value. Therefore a reading that appears to the observer as being closest to zero on the colour chart should be replaced with a censored value of less than the first positive measurement increment (e.g., < 0.05 mg/L). Right censored measurements will be required when the colour intensity is greater than the upper most measurement value on the colour chart (e.g., >0.8 mg/L) or a sample dilution should be performed using distilled water (e.g., a 1:5 sample dilution for a 0-0.8 mg/L test kit will extend the measurement range to 2 mg/L). Lab measurements should follow NEMS (2019).

Measurement units	mg/L (equivalent to g/m^3)	
Measurement type	Self-test (in the field or at home) or lab measurement made on a water sample	
Measurement methods	**Test kit** – most common options used in NZ ▪ AquaSpex Microtest® Nitrate-N NED (SHMAK), colorimetric test ▪ Hach® Nitrate-N test strips (Auckland Council Wai Care) – also separately measure Nitrite-N	**Lab test method** ▪ APHA 4500 B-NO_3 I (NEMS 2019 compliant), performed on a 0.45 micron filtered sample
Data use	Suitable for education and some science applications (e.g., general environmental screening and identification of pollution 'hotspots').	Suitable for all three types of data use application. Essential for regulatory data uses.
Method instructions available from	Provided with the test kit and also see relevant NIWA SHMAK or Wai Care manual	NEMS Discrete Water Quality (Part 2: Rivers) and the testing lab
Equipment / materials	Test kit (may include a syringe) and sample bottle	Sample bottle, chilly bin, ice packs
Caveats	If test kit does not go below 0.5 mg/L, a lab test is recommended. Turbid samples should be filtered prior to testing. A sample dilution is required if test result is above the upper end of the measurement range.	Prompt chilling and dispatch to lab required so that the sample can be filtered (preserved). NEMS (2019) requires a method detection limit of at least 0.002 mg/L.
Detection limit	Depends on test kit but 0.05 mg/L at best	0.002–0.005 mg/L
Measurement range and resolution	• AquaSpex Microtest® Nitrate-N NED (HS): 0.05–0.8 mg/L • AquaSpex Microtest® Nitrate-N NED: 0.23–4.5 mg/L • Hach® Nitrate-N test strips (low range): 0.15–3 mg/L	From 0.002 mg/L upwards**, typically reported to 2 or 3 significant figures
Training	Demonstration and practice based around the quality checks below, including practice with sample filtering and dilutions if these are likely to be required	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)
Resources	NIWA SHMAK video: Water quality – nitrate	
Refresher frequency	Annually	
Records		
Measurement resolution	Estimate the measurement to the nearest half increment	
Supporting metadata	• Water sample collection method* • Test kit make, model and measurement range* • If a sample was filtered prior to testing* • Details of any sample dilution performed prior to testing*	
Quality checks		
• Internal checks	• Expiry date of test strips or reagents • Turbid water samples are filtered* • Sample test made at ambient air or water temperature • Reading of the test measurement is made within recommended timeframe (e.g., 60 seconds for Hach nitrate-N strips) and verified by a second observer • Results presented as nitrate are converted to nitrate-N* • A repeat test is performed by the same or a second (different) observer* (the two results should agree within the same measurement increment or 10%) • A standard solution of known concentration is tested using the kit and the measurement falls within the correct measurement increment (or 10%)	
• External checks	• Side-by-side sample testing with an independent specialist – measurements should agree within the same measurement increment or 10% • A sample is sent to the lab for testing (note the lab will filter the sample and the test method may differ but if the sample was relatively clear and colourless, the lab measurement should fall within the same increment range of the test kit)	

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

** A water sample with a very high concentration is diluted until it can be quantified.

4.1.13 Dissolved inorganic nitrogen

Dissolved inorganic nitrogen is the sum of ammoniacal nitrogen, nitrite-nitrogen and nitrate-nitrogen. It can be measured on a water sample submitted to the lab (see nitrate-nitrogen) and will cost around double a nitrate-N test because it involves two different measurements and a calculation.

4.1.14 Dissolved reactive phosphorus

As with nitrate-nitrogen, the national CBM QA framework includes two measurement methods for DRP – colorimetric-based self-test kits and lab measurement on a water sample. As DRP concentrations are typically low in most NZ streams, lab testing is recommended for most monitoring applications.

Measurement units	mg/L (equivalent to g/m^3)	
Measurement type	Self-test (in the field or at home) or lab measurement made on a water sample	
Measurement methods	**Test kit** – most common options used in NZ • Hanna® HI-713 Phosphate Pocket Checker (NIWA SHMAK) – recommended • AquaSpex Microtest® Phosphate-P MB+ (HS) (Auckland Council Wai Care) Note: Other test kits exist	**Lab test method** • APHA 4500-P G, flow injection analyser (NEMS 2019 compliant) performed on a 0.45 micron filtered sample
Data use	Suitable for education and some science applications (e.g., general environmental screening and identification of pollution 'hotspots') – see caveats below	Suitable for all three types of data use application. Essential for regulatory data uses.
Method instructions available from	Provided with the test kit – also see water sample collection requirements (Section 4.1.2)	Not needed – see water sample collection requirements (Section 4.1.2)
Equipment /materials	Test kit and sample bottle	Sample bottle, chilly bin and ice packs
Caveats	• Except in highly degraded streams, DRP concentrations are often lower than most test kits can reliably measure and lab measurement is recommended • Turbid samples should be filtered prior to testing (tests on unfiltered samples may not be comparable with lab tests which are always performed on filtered samples) • A sample dilution is required if test result is above the upper end of the measurement range (unlikely in NZ streams)	Prompt chilling and dispatch to lab required so that the sample can be filtered (preserved). NEMS (2019) requires a method detection limit of 0.001 mg/L.
Detection limit	• Hanna® HI-713: 0.03 mg/L (as DRP) • AquaSpex: 0.05 mg/L	0.001–0.004 mg/L
Measurement range and resolution	• Hanna® HI-713: 0.01–2.5 mg/L, reported to nearest 0.01 mg/L as phosphate (~0.03 mg/L as DRP) • AquaSpex: 0.05–0.4 mg/L as DRP, reported to nearest half increment of the test strip	From 0.001 mg/L upwards**, typically reported to 2 or 3 significant figures
Training **Records** **Quality checks**	See nitrate-N test kit measurements (Section 4.1.12). Results presented as phosphate should be multiplied by 0.326 to convert them to phosphate-P (i.e., DRP)*	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will automatically calculate this conversion for Hanna HI-713 test kits and will prompt capture of the records and quality checks denoted with an asterisk in Section 4.1.13.

** A water sample with a very high concentration is diluted until it can be quantified.

4.1.15 Total nitrogen and total phosphorus

Total nitrogen and total phosphorus must be measured on water samples sent to a lab (as part of the testing involves a strong acid digestion).

	Total nitrogen	Total phosphorus
Measurement units	mg/L (equivalent to g/m^3)	
Measurement type	Lab test made on a water sample	
Measurement methods	• Direct measurement – APHA 4500-NO3 I (NEMS 2019 compliant) following a potassium persulphate digestion (APHA 4500-N C or APHA 4500-P J digestion) • Indirect measurement – calculated from the sum of Total Kjeldahl Nitrogen (TKN, measured via APHA 4500-Norg D) plus nitrite-N and nitrate-N	• APHA 4500-P G (NEMS 2019 compliant) following a APHA 4500-P B 5 or J acid persulphate digestion
Data use	Suitable for all three types of data use application	
Method details	See NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)	
Equipment /materials	Sample bottle, chilly bin and ice packs	
Caveats	The two methods often produce different results, particularly when water samples contain suspended particles. Check which method your regional council uses/requires. NEMS (2019) requires a method detection limit of at least 0.01 mg/L.	NEMS (2019) requires a method detection limit of at least 0.002 mg/L
Detection limit	0.01 mg/L (0.05-0.11 mg/L for indirect measurement)	Varies from 0.001–0.005 mg/L
Measurement resolution	From 0.01 mg/L upwards*, typically reported to 2 or 3 significant figures	From 0.001 mg/L upwards*, typically reported to 2 or 3 significant figures
Training	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)	
Records		
Quality checks		

* A water sample with a very high concentration is diluted until it can be quantified.

4.1.16 *Escherichia coli (E. coli)*

The national CBM QA framework incorporates both self-measurement and lab measurement methods. Self-test options include plating methods (e.g., NIWA SHMAK kit) that have been demonstrated as suitable for use by community groups (e.g., Vail et al. 2003, Stepenuck et al. 2011) and the Aquagenx® compartment-bag test (Gronewold et al. 2017). Although the latter is quick and easier to use (McNeil and Holmes 2021), it is more expensive and best reserved for quick on-site drinking water quality assessments where low *E. coli* counts are expected. For on-site recreation-based water quality assessments, the plating methods offer greater resolution of *E. coli* counts although the Aquagenx® test can be used if a 10-fold sample dilution is performed.

Measurement units	The number of *E. coli* colonies per 100 mL, presented as either the most probable number (MPN) or colony forming units (CFU) per 100 mL	
Measurement type	Self-test (at home) or lab test made on a water sample	
Measurement methods	**Test kit** – most common options used in NZ: • 3M™ Petrifilm™ *E. coli* plates (NIWA SHMAK) • MC-Media Pad® *E. coli* plates • Aquagenx® CBT EC-TC MPN kit	**Lab test method** ▪ APHA 9223 B, Colilert (NEMS compliant) ▪ APHA 9222 G, membrane filtration
Data use	Suitable for engagement and education as well as some investigation and surveillance uses. Regulatory uses will likely require testing by an accredited lab.	Suitable for all three types of data use application but some regulatory uses may specify a minimum detection limit (e.g., drinking water assessments require a MDL of < 1 *E. coli* per 100 mL) or number of samples
Method instructions available from	• Plate methods: See NIWA SHMAK manual • Aquagenx®: See instructions provided with the kit	Contact your laboratory. Also see NEMS Discrete Water Quality (Part 2: Rivers)
Equipment /materials	Test kit and sterile sample bottle plus a chilly bin, ice and an incubator for plate methods	Sterile sample bottle, chilly bin and ice packs
Caveats	• Sample must be removed from the light and tested within 24 hours • Plate methods: Sample dilution with distilled water is required to quantify heavily contaminated waters (e.g., >8,000-10,000 *E. coli* per 100 mL) • Aquagenx®: Designed for drinking waters and can not quantify higher *E. coli* counts found in many streams as well as the plate test methods. Sample dilution is limited to a single 10-fold sample dilution option.	• Sample must be removed from the light, chilled to below 10˚C and dispatched to the lab for testing within 24 hours • The Colilert test method can't produce an *E. coli* count above 2,419 MPN/100 mL unless a sample dilution is performed • Membrane filtration methods may not work well on very turbid samples and a sample dilution may be needed
Detection limit	1 MPN/100 mL or 1 CFU/100 mL**	
Measurement resolution and range	Depends on test method and volume of sample tested but plate methods offer high precision. Colilert and Aquagenx® MPN results vary based on statistical "look up" tables.	
Training	See water sample collection (Section 4.1.2) and self-test measurements (table next page)	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)

* *E. coli* bacteria range from very low to very high numbers in some streams, so getting a reliable measurement using plate methods often requires multiple tests using different volumes of subsample from the sample.

** Only applies when 100 mL of sample is tested. If only a 10 mL subsample is tested, both the detection limit and measurement resolution reduce to 10 *E. coli* per 100 mL.

Self-testing

It is important to communicate to CBM groups that microbial testing is associated with much lower precision than measurements of nutrients. *E. coli* and other indicator bacteria multiply exponentially and therefore a logarithmic 'rules' need to be applied to assess repeatability as part of quality checks (B. Müller[7], pers. comm. 2023). This is reflected in the table below.

Training	Demonstration and practice based around the quality checks below, including practice with sample filtering and dilutions if these are likely to be used.
Useful resources	NIWA's SHMAK kit is supported by 3 short videos demonstrating: • How to analyse a water sample for *E. coli* with 3M™ Petrifilm™, using the direct plating method for high concentrations. • How to analyse a water sample for *E. coli* with 3M™ Petrifilm™, using the filtering method for low concentrations. • How to count and report the *E. coli* colonies on a 3M™ Petrifilm™ gel. The Aquagenx® website has a video demonstrating *E. coli* testing using the Compartment Bag Test (CBT) EC-TC MPN kit
Refresher frequency	Annually
Records	
Measurement resolution	To nearest whole number (CFU tests) or as per the statistical tables for the test (MPN test)
Supporting metadata	• Water sample collection method* • Water sample condition* • Water sample testing date* • Sample incubation temperature and timeframe (CBT) EC-TC MPN test kit only)* • Plate/bag *E. coli* count, including if the *E. coli* colonies were *"too numerous to count"** and which plate(s) were used in calculating the final measurement*
Quality checks	
Internal checks	• Sterile sample bottle used* and filled directly, with a small air gap • Water sample removed from light and chilled promptly following collection • Plates/CBT kits have not expired • Sterile pipette and tweezers used (plate methods only) • Sample blank tested and no *E. coli* colonies found after incubation • More than one plate dilution is made and, where *E. coli* is abundant, one plate has *E. coli* present in the optimum range for counting by eye (20 to 80 colonies, see box opposite page) • The plate count or CBT reading for *E. coli* is verified by a second observer • A repeat test is performed by a second, independent observer* – the two measurements, after translation to a Log value, should agree within around ± 0.5 Log value
External checks	• Side-by-side sample collection with an expert followed by paired testing – measurements, after translation to a Log value, should agree within around ± 0.5 Log value • A duplicate water sample is collected, with one of the samples sent to an IANZ accredited lab for testing using a similar test method (the self-test and lab measurements, after translation to a Log value, should agree within around ± 0.5 Log value)

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.1.17 Enterococci

Measurement of enterococci requires collection of a water sample for lab testing. Details are the same as for a lab-based *E. coli* test, except that the method options in the CBM framework are:

- APHA 9230 D b (Enterolert) with MDLs of 10 MPN/100mL and 1 MPN/100 mL for saline and freshwater samples, respectively, and
- APHA 9230 C (membrane filtration) with a MDL starting from 1 CFU/100 mL.

[7] Barbara Müller, Client Services Manager, Hill Labs.

4.1.18 Dissolved copper and dissolved zinc

As the toxicity of copper and zinc to aquatic life varies with the physical and chemical conditions of stream water, CBM groups should be aware that there are some additional indicators to measure if they wish to compare their metal results against NZ freshwater toxicity guidelines. More information on toxicity modifying factors is provided in Gadd et al. (2023).

	Dissolved copper	Dissolved zinc
Measurement units	mg/L (equivalent to g/m^3)	
Measurement type	Lab measurement made on a water sample	
Measurement methods	APHA 3125 B (ICP-MS) performed on a 0.45 micron filtered sample preserved with nitric acid (NEMS 2019 compliant)	
Data use	Suitable for all three types of data use application. For regulatory purposes, samples will likely need to be tested at trace level together with the supporting indicators listed in the caveats below	
Method details	Contact the test lab. Also see NEMS Discrete Water Quality (Part 2: Rivers) – NEMS (2019)	
Equipment /materials	Sample bottle, chilly bin and ice packs	
Caveats	• Samples must be dispatched promptly to the lab – otherwise they will need to be filtered after collection into a lab bottle containing nitric acid preservative • For comparison of copper results against environmental toxicity guidelines, dissolved organic carbon (DOC) also needs to be measured. For zinc, DOC, hardness and pH also need to be measured. A sample for DOC measurement needs to be collected in a dark brown glass bottle (the lab will supply this). • NEMS (2019) requires the detection limits listed below	
Detection limit	Varies depending if screen or trace level is selected*	
	(NEMS 2019 requires at least 0.0005 mg/L)	(NEMS 2019 requires at least 0.001 mg/L)
Training and quality checks	See water sample collection (Section 4.1.2) and lab testing (Section 4.1.3)	

* Although ultra-trace tests are available, these are unlikely to be required for most CBM purposes and a very high attention to detail is required to avoid contamination during sampling (e.g., sunblock and powdered disposable gloves generally contain zinc).

4.2 Aquatic life indicators

Most of the aquatic life indicators in the national CBM QA framework are observation-based measurements but macroinvertebrates may also be monitored by collecting and preserving a sample for identification later by a CBM group or a specialist lab. The framework also provides for monitoring of macroinvertebrates and fish through collection of stream water samples for environmental DNA (eDNA) testing. Because eDNA testing will also detect the presence of other species (e.g., plant, birds and mammals), eDNA test requirements are presented first in their own table.

4.2.1 Environmental DNA (eDNA)

Environmental DNA, or eDNA, refers to various traces of genetic material shed by living organisms as they move in, through and around the environment. In NZ, testing of stream waters for eDNA has attracted large interest by CBM groups, boosted by *Wai Tuwhera o te Taiao – Open Waters Aotearoa* programme, a national initiative introduced by the Environmental Protection Authority in partnership with Wilderlab. Under the programme, CBM groups have been provided with specialist kits at reduced cost to take water samples from streams and other surface water environments to learn more about their local ecosystems.

The primary reasons for including eDNA testing in the national CBM QA framework were:

- there is very strong CBM interest in eDNA and good technical support is available,
- regional councils and other organisations involved in freshwater monitoring and management (e.g., DOC) are increasingly adopting eDNA testing as a complementary tool for ecological monitoring (in particular fish monitoring which is time-intensive), and are contributing to further research to standardise eDNA monitoring methods (Banks et al. 2020),
- it is a very quick and useful screening and surveillance tool for detecting a large range of animal and plant species, including the potential presence of threatened (endangered) native species or invasive species,
- it reduces the need for specialist taxonomic knowledge, and
- collecting water samples creates less disturbance in a stream than traditional collection and handling of biological samples.

It is important that CBM groups are aware that eDNA testing, like all methods, has some limitations. For example, the taxa list generated from a sample(s) will rarely include all of the species present as not all species are currently available in eDNA reference databases. Also, a particular species of interest that isn't listed may be actually present in the stream but insufficient genetic material was captured in the sample to detect it. Currently, an eDNA test also won't provide anything definitive about:

- how many individuals are present of each species,
- if the species were dead or alive at the time of sample collection, or
- whether the species is located at the sampling site or further upstream.

Testing of eDNA in NZ is rapidly evolving and improving. The number and types of species that can be identified will continue to increase, along with confidence in the accuracy of species identification and possibly the ability to estimate the likely number of species present and their condition.

Two forms of eDNA water sample collection are included in the CBM framework:

- Active sampling method: water samples are filtered in the field with a syringe and filter.

- Passive sampling method[8]: a small filter pod is deployed for 24 hours in an area of stream with moderate to high flow to collect eDNA before retrieval and dispatch to the lab for analysis.

The patchy distribution of eDNA in water (over space and time) means that, for all purposes other than engagement, education and perhaps general environmental screening, replicate samples should be collected at each site. For active sampling, Banks et al. (2020) recommend at least three replicate samples. However, high replicate, nationwide eDNA sampling by regional councils of 51 rivers during the summer 2020/21 has since identified that six 1 L samples is the optimum number to maximise the probability of species detection in SOE-type monitoring programmes (Melcher and Baker 2023).

Measurement units	Taxonomic (e.g., species, genus or family)
Measurement type	Lab test made on a filtered water sample
Measurement methods	eDNA sequencing using polymerase chain reaction (PCR) technology
Data use	Suitable for education and some scientific uses. Will not be suitable for some specific science and regulatory uses.
Method instructions available from	Instructions and video available from the Environmental Protection Authority and Wilderlab websites
Equipment	Disposable gloves, special sample syringes and packaging for transport (provided by the lab)
Caveats	Test results represent a snapshot in time of what species are present or were (recently) present. They won't tell you how many individuals are present of each species, if the species are alive or dead, or where in the stream the species is located. Also, a test that is negative for a particular species of interest doesn't necessarily mean that species is not present. Replicate samples are required along with extreme care to avoid sample contamination.
Detection	Dependent on the eDNA library and sample volume. Although a single sample can be tested, six 1 L replicate samples (six) are recommended for the most robust eDNA assessments.
Training	In-field or video demonstration
Video resources	Video available from the Environmental Protection Authority and Wilderlab websites
Refresher	Annually
Records Supporting metadata	• Sample collection method* • Number of samples* and sample identification number* • Volume of water filtered *(for active (syringe) sampling only)** • Deployment time *(for passive samplers only)** • If the sample might be compromised in any way*
Quality checks	
Internal checks	• Samples are not collected immediately after heavy rain* • Sterile gloves are used during sample collection and handling • Replicate samples, where collected, are collected from downstream to upstream • Water sample(s) are representative of the site, collected below the surface in flowing water and facing upstream • Samples have a unique code* • 1 L of stream water is filtered or, if the water is turbid, filtering continues until the filter is clogged • Completed Chain of Custody form accompanies water samples sent to the lab, including site name (or code), date of sample collection and dispatch, and anything unusual about samples (e.g., if they are brackish) • Field blank collected[1]
External checks	Side-by-side water sample collection with an experienced independent specialist, with both samples sent to the same lab for testing

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

[1] An option if replicate samples are not collected but this will come at additional cost and the lab will have internal quality checks in place on every test run.

[8] Wilderlab note that the passive method is still considered a development in progress. It is recommended for flowing sites with very high sediment load, post-rainfall sampling, and pest mammal monitoring.

4.2.2 Periphyton

Streambed cover, as opposed to biomass, was selected as the periphyton indicator in the national CBM QA framework because a range of low-cost monitoring options is available to CBM groups. Four methods are included, including a very basic bankside visual assessment with filamentous and mat cover categories that allow assessment against the Biggs (2000) guidelines, and the existing SHMAK stone method. More comprehensive *in situ* assessments of streambed cover involve either the 20-point estimate required in the NEMS Periphyton (NEMS 2022a) or a simplified option that allows periphyton cover to be estimated to the nearest 10% at 10 locations. Including a simplified option of NEMS (2022a) recognises that 20-point estimates to the nearest 5% cover may be too time-consuming and/or difficult for many CBM groups. Nonetheless, it is important for CBM groups to understand that if robust periphyton cover estimates are required to satisfy their monitoring questions, the more observations made, and at standardised transect locations, the more accurate the final cover estimates will be.

Specific indicator	Percentage of the visible or wadeable streambed covered by periphyton			
Measurement type	Field measurement			
Measurement units	%			
Measurement methods	**Bankside visual assessment** Basic estimate of percentage cover of three categories of periphyton: bare rock/thin films, mat-forming algae and filament-forming algae	**Instream stone method (NIWA SHMAK)** Estimate of percentage cover across 10 stones of six periphyton categories: as for the bankside assessment but with *Microcoleus* (toxic algae) and Didymo in separate categories + moss/other category	**Instream visual assessment – simplified** Estimate of percentage cover at 10 points on the streambed, generally from 2 cross sections, of four periphyton categories: bare rock, thin films, mat-forming algae and filament-forming algae	**Instream visual assessment – detailed (NEMS 2022a)** As per instream visual simplified assessment but made at 20 points on the streambed, generally along 2 or 4 cross sections and to a higher resolution
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., general environmental screening). Not suitable for regulatory purposes.		Suitable for engagement and education as well investigative and surveillance applications. Likely to be suitable for some regulatory applications but this will depend on the specific data use.	Suitable for all three types of data use application but additional periphyton categories may be required for some purposes (e.g., didymo, sludge) – see NEMS Periphyton (NEMS 2022a)
Method instructions available from	CBM field form. The NIWA SHMAK periphyton identification guide may also be useful	NIWA SHMAK guidance manual, video and periphyton identification guide	• NEMS (2022a) • NIWA SHMAK guidance manual, video and periphyton identification guide	NEMS (2022a)
Equipment	None	None	Underwater viewer recommended	Underwater viewer
Caveats	Limited by what can be viewed from the bank	Biased method because it targets stones of a certain size. Therefore, comparisons between sites can be qualitative only	Simplified from NEMS (2022a)	
Measurement resolution	Low (varies by category)	Nearest 10%	Nearest 10%	Nearest 5%

Training	Field demonstration with an experienced specialist identifying different types of periphyton and estimating their streambed coverage with an underwater viewer, followed by practice
Resources	• NIWA National River Water Quality Network periphyton ID guide • NEMS Periphyton (NEMS 2022a)– includes photos of the different periphyton categories and details on how to use a viewer • NIWA SHMAK video: Stream life – periphyton
Refresher frequency	Annually for instream cross section methods
Records	
Supporting metadata	• Viewer method (for instream visual assessments)* • The side of the bank observations are made or started from (true left or true right)* • The number of cross sections surveyed* • Estimate of shade cover at survey area* • Estimate of stream width surveyed* • Presence of *Microcoleus* (toxic cyanobacteria) mats exposed at or near the stream edge*
Quality checks	
Internal checks	• Correct use of a viewer (for instream visual assessments), viewer window positioned horizontally under water to up to 20 cm depth • Survey commences from downstream and moves upstream • Some observation(s) are repeated by a second, independent observer to verify the periphyton types identified and cover estimates (cover estimates for the most dominant types should agree within 10-20%). Comparisons should be made over the same area(s) of streambed as far as possible. • Supporting metadata are recorded
External checks	• Photographs are taken for an independent specialist to verify the dominant periphyton types present • The same checks listed above are made by an experienced independent specialist

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.2.3 *Microcoleus* cyanobacteria

All periphyton assessment options included on the CBM field form have been designed to capture if *Microcoleus* cyanobacteria are present at the site but only the in-stone periphyton assessment method will capture information on the amount of cover present. For quantitative data on streambed coverage of *Microcoleus*, CBM groups should select one of the two methods in the table below.

Specific indicator	Percentage of the visible or wadeable streambed covered by *Microcoleus* cyanobacteria mats ("toxic algae")	
Measurement type	Field measurement	
Measurement units	%	
Measurement methods	**Bankside visual assessment** Simple four cover-category estimate	**Instream visual assessment** Estimate of cover at 10 points on the streambed, generally from two cross sections
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., general environmental screening)	Suitable for all three types of data use application but an underwater viewer is essential for robust assessments
Method instructions available from	CBM field form and Cawthron Institute video on river toxic algae to support identification	See periphyton monitoring instructions for cross section establishment and Cawthron Institute toxic algae video
Equipment /materials	None	Underwater viewer (recommended)
Caveats	Limited by what can be viewed from the bank	
Measurement resolution	Four cover categories (0%, <20%, 20-50% and >50%)	Nearest 10%
Training **Records** **Quality checks**	The training, metadata records and quality checks should be the same as for periphyton cover (Section 4.2.2) except that the focus is on identifying and estimating coverage of *Microcoleus* to the nearest 10%	

4.2.4 Macrophytes

The national CBM QA framework incorporates a macrophyte indicator based on the abundance of macrophytes present. This indicator is the same as that included in version 3 of the NIWA SHMAK manual (NIWA 2019) and is drawn from earlier national guidance (Matheson et al. 2012). It includes two measures:

- the amount of water surface area occupied by macrophytes, and
- the amount of water surface area and water volume occupied by macrophytes.

For alignment with regional council monitoring and a more robust assessment of nuisance macrophyte growth and its potential impacts on stream health, both components of abundance should be estimated. However, recognising that some CBM groups may find estimation of the second (water column volume) measure challenging, it was decided to include an option for groups to estimate the amount of stream surface cover only. This option will be useful for some applications, such as tracking over time whether stream shade provided by riparian plantings is reducing the amount of surface cover of macrophytes.

Specific indicator	Macrophyte abundance – 2 options: • Amount of water surface area occupied by macrophytes • Amount of water surface area and water volume occupied by macrophytes (recommended)	
Measurement type	Field measurement	
Measurement units	%	
Measurement methods	**Bankside visual assessment**	**Instream visual assessment**
	Estimate of abundance from 3-5 points across 5 sections of stream (minimum of 20 points)	
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., general environmental screening)	Suitable for all three types of data use application but some regulatory uses may require other information. Using a quadrat is essential for robust assessments.
Method instructions	NIWA SHMAK guidance manual	
Equipment /materials	Measuring tape	Measuring tape, 0.5 m x 0.5 m quadrat (square frame)
Caveats	Limited by what can be viewed from the bank. Requires very clear water for the water volume component.	An underwater viewer may be needed for robust assessments of the volume component if the water is not clear
Measurement resolution	Nearest 10%	
Training	Field demonstration with an experienced specialist estimating macrophyte abundance and volume, followed by practice	
Resources	NIWA SHMAK video: Stream life – macrophytes	
Refresher frequency	Annually	
Records		
Supporting metadata	• Assessment method (e.g., bankside vs instream)* • Length of stream reach assessed* • The side of the bank observations are made or started from (true left or true right)* • The number of cross sections surveyed and point observations made* • Comments (e.g., if only part of stream width assessed, presence of exotic or pest species, if known)*	
Quality checks		
Internal checks	• For bankside estimates, the water is clear enough to see the stream bottom • Survey starts from downstream and moves upstream • Some abundance estimate(s) are repeated by a second, independent observer and these agree within 20% • Supporting metadata are recorded	
External checks	• Photographs are taken from the bank across the width of the stream for an experienced independent specialist to verify the water surface cover estimates • The internal checks listed above are made by an experienced independent specialist	

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.2.5 Macroinvertebrates

Consistent with most CBM monitoring in other countries and regional council monitoring, the macroinvertebrate indicator included in the national CBM QA framework is based on taxa type and abundance. As well as eDNA testing on stream water samples (Section 4.2.1), options are included for both field (self-) and lab-based processing of samples. Field-based assessments are best suited to engagement and educational monitoring purposes and/or groups experienced in macroinvertebrate identification. Use of macroinvertebrate data for regulatory purposes will require samples to be preserved and sent to a lab for processing using standard methods.

The macroinvertebrate indicator method has two parts (presented across two tables)

- sample collection, and
- sampling processing (macroinvertebrate counting and identification).

Although a variety of macroinvertebrate collection methods exists, only the SHMAK instream stone method and the kicknet method are recommended in the national CBM QA framework. The stone method offers a low-cost and less invasive option for CBM groups. Inclusion of the kicknet method reflects that kicknets are the most common sample collection equipment used by regional councils in NZ and are suitable for use across a wider range of stream types and habitats than Surber samplers (NEMS 2022b). However, the CBM field forms do provide for the capture of data from Surber (or other) samplers should a CBM group wish to, for example, collect quantitative macroinvertebrate data or compare their data with an earlier survey that used a different method.

Part A: Sample collection

Specific indicator	Macroinvertebrate types and abundance	
Measurement type	Field assessment or lab assessment made on a macroinvertebrate sample	
Measurement units	Taxonomic (e.g., species, genus or family)	
Measurement methods	**Instream stone method** – riffle habitat, stony bottom stream (NIWA SHMAK) Collection of 10 randomly selected stones	**Kicknet method** – 2 options: • riffle habitat (stony bottom stream), or • mixed habitat (NEMS compliant) Mixed habitat targets the range of streambed (e.g., stone, mud, gravel) and habitat (e.g., riffles, runs, pools, macrophytes) types present across the sampling reach
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., general environmental screening)	Suitable for all three types of data use application but some investigative, surveillance and regulatory uses will require replicate samples and the same stream habitat types to be sampled between sites
Method instructions available from	NIWA SHMAK guidance manual	NIWA SHMAK guidance manual For samples that will be processed by a lab, see NEMS Macroinvertebrates (NEMS 2022b) for sample sorting and preservation requirements
Equipment /materials	White ice cream container or tray to place rocks and some stream water into	Measuring tape, dish brush, white tray, bucket, sieve(s) + sample containers and preservative for samples that will be processed by a lab
Caveats	Will only find invertebrates that are clinging to the stones	NEMS (2022b) requires a rapid habitat assessment to be carried out (see Section 4.3.1)

Part A: Sample collection *cont.*

Training	Field demonstration with an experienced specialist to collect and either: • sort and identify the invertebrates in the sample, or • sort and preserve a sample for lab identification followed by practice

Resources	• NIWA SHMAK guidance manual
	• NIWA SHMAK videos
	  ○ Stream life – collecting benthic macroinvertebrates using the stone method
	  ○ Stream life – collecting benthic macroinvertebrates using the kicknet method
	  ○ Stream life – collecting benthic macroinvertebrates in muddy bottomed streams
	• For samples that will be processed by an external lab, see NEMS (2022b) for sample sorting and preservation requirements

Refresher frequency	Annually prior to sampling
Records	
Supporting metadata	• Name of group member collecting the sample • Sample collection method* • Number of kicks made *(kick net method only)** • Streambed habitat types sampled* • Whether samples are being processed live or preserved for identification later* • Rapid habitat assessment (see Section 4.3.1)
Quality checks	

Internal checks	• Kick net is clean and any holes have been repaired before use
	• 0.5 mm mesh is used
	• There have been about 2 weeks of stable stream flows prior to sample collection
	• Sample collection starts downstream and moves upstream
	• A good seal is made between net and streambed
	• The streambed is disturbed sufficiently to dislodge invertebrates into the net, including use of hands if need be
	• Habitats sampled match the method selected
	• Samples are sorted for either processing live or preservation, with large sticks, stones and leaves discarded once attached macroinvertebrates have been removed
	• Where samples are preserved:
	  ○ a legible sample label is included inside and outside the container, and
	  ○ sufficient preservative is added to the sample container to achieve a concentration of at least 70% (allowing for stream water already present)
	• Supporting metadata are recorded

External checks	• The internal checks listed above are made by an independent specialist

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

Part B: Sample processing (macroinvertebrate identification and counting)

The information presented here is for CBM groups that intend to identify and estimate macroinvertebrate abundance on unpreserved samples. If samples are being sent to an external lab for identification and enumeration, the lab's internal QA and QC requirements will ensure the samples are processed correctly. The NEMS Macroinvertebrates (NEMS 2022b) includes quality control requirements for labs processing samples for state and trend assessments.

Specific indicator	Macroinvertebrate types and abundance		
Measurement type	Field assessment or laboratory assessment made on a macroinvertebrate sample		
Measurement units	Taxonomic (e.g., species, genus or family) and abundance (actual counts or category-based – rare, common, etc.)		
Measurement methods	**Instream stone method** – riffle habitat, stony bottom stream (NIWA SHMAK) Field-based identification and counting of different invertebrates	**Kick-net method**. Two options: • field processing • lab processing (NEMS compliant) Field and lab identification options, and different options within these	
Data use	Suitable for education and some science applications (e.g., general environmental screening)	Suitable for all three types of data use application but some science and all regulatory uses will require accurate identification and counting in a specialist lab	
Method instructions available from	NIWA SHMAK guidance manual, macroinvertebrate ID videos and macroinvertebrate field ID guide	**Field ID** NIWA SHMAK guidance manual, macroinvertebrate ID videos and macroinvertebrate field ID guide	**Lab ID** NEMS Macroinvertebrates requirements
Equipment /materials	White tray, magnifying glass, tweezers, invertebrate field guide	White tray, magnifying glass, tweezers, invertebrate field guide	-
Caveats	Accuracy and precision dependent on a CBM group's experience		-
Taxonomic resolution	Low to moderate – limited to SHMAK macroinvertebrate classes and abundance scores	Low to high, depending on level of identification and counting applied	Very high
Training	Demonstration with an experienced specialist to identify and count (or estimate) the number of the invertebrates in a sample, followed by practice		

Resources	Various macroinvertebrate identification guides are available – for example:
	• NIWA SHMAK guidance manual
	• NIWA SHMAK videos
	  ○ Stream life – how to get your benthic macroinvertebrate sample ready for sorting
	  ○ Stream life – how to sort and identify your benthic macroinvertebrate sample
	• NIWA SHMAK invertebrate guide		

Refresher	Annually prior to sampling		
Records			
Supporting metadata	• Name of group member(s) processing the sample* • Macroinvertebrate types identified* • Estimate or count of macroinvertebrates present* • Comments on any problems with macroinvertebrate identification*		
Quality checks			
Internal checks	• Macroinvertebrate identification guides are used to confirm identifications • Another group member independently checks the identifications made		
External checks	• The identification of selected macroinvertebrates is confirmed by sending photographs of them to an experienced independent specialist • The internal checks listed above are made by an experienced independent specialist • Voucher specimens (or entire sample) preserved and sent to an experienced independent specialist or lab for identification		

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.2.6 Fish

Presence/absence is the primary fish indicator included in the national CBM QA framework, with the option to also make a count or categorical estimate of abundance.

Specific indicator	Fish presence/absence and abundance	
Measurement type	Field assessment	
Measurement units	Taxonomic (e.g., species, genus or family) and abundance (actual or category-based)	
Measurement methods	**Spotlighting** Carried out after sunset to identify and count nocturnally active fish. Can include estimating and/or measuring fish size classes	**Trapping** – 2 net types: • Gee minnow traps • Fyke nets Traps and nets are set over a stream reach and left overnight before returning to identify and count captured fish. Can include estimating and/or measuring fish size classes
Data use	Suitable for all three types of data use application but most investigation, surveillance and regulatory data uses will require: 1) net and trap dimensions (e.g., mesh size) to be consistent through time to minimise variability in sampling (catch) effort, and 2) identification of the fish by a specialist.	
Method instructions available from	NIWA SHMAK guidance manual and Sections 3.5 and 3.6 of the NZ freshwater fish sampling protocols (Joy et al. 2013)	
Equipment /materials	Measuring tape, torch/lamp, field form	Measuring tape, fish buckets/bins, field form, gee minnow nets, fyke nets
Caveats	Designed for wadeable streams (<1 m deep) and requires calm water conditions at low or base stream flow. Good for detecting galaxiids but less likely to detect juvenile eels and lamprey	Designed for wadeable streams (<1 m deep) and requires stable stream flows prior to and during the trapping period
Taxonomic resolution	Depends on the expertise and experience of group members	
Training	Demonstration with an experienced specialist to identify and count (or estimate) the species and number of fish seen (spotlighting) or caught (trapping), followed by practice	
Resources	• NIWA online freshwater fish ID guides • NZ freshwater fish sampling protocols (Joy et al. 2013)	
Refresher training	Annually prior to sampling	
Records		
Supporting metadata	• Method(s) of fishing* • Stream and weather conditions* • Name of group member(s) that carried out the fishing* • Whether a freshwater fish ecologist/monitoring officer assisted with the survey and fish ID* • Supporting water quality measurements (optional to collect)* • Water depth range* • Length of stream reach surveyed* • Stream reach habitat types surveyed* • GPS coordinates for downstream end of reach and net(s)* • Details of traps used (type, number, mesh size)* • Fish identified* • Estimate or count of fish sizes and abundance (optional to collect)* • Comments on any pest fish or problems with fish identification*	
Quality checks		
Internal checks	• Fish ID guides are used to confirm identifications • Unexpected fish are compared against existing records for the catchment/area (e.g., the NZ Freshwater Fish Database)	
External checks	• ID of selected fish is confirmed by sending photographs to an experienced independent specialist	

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

The framework includes two of the three standard fish monitoring methods used by regional councils in NZ (Joy et al. 2013): spotlighting and trapping. The third method, electric fishing, is not included in the framework because it requires an electric fishing machine that must be used by a certified operator. A CBM group interested in electric fishing should enlist the help of a regional council or other organisation with experience and capacity to carry out the fishing.

Fish presence/absence can also be assessed using eDNA testing (Section 4.2.1).

4.3 Physical habitat indicators

All four physical habitat indicators included in the national CBM QA framework are observation-based.

4.3.1 Physical habitat quality

The physical habitat quality indicator in the national CBM QA framework is a composite score of the overall quality of stream habitat based on protocol 1 of the national Stream Habitat Assessment Protocols (Harding et al. 2009). This protocol is a visual assessment of 10 stream habitat variables, including substrate size and composition, water depth and velocity, bank stability, riparian vegetation and shade.

The specific physical habitat assessment methods included in the framework are the NIWA SHMAK visual assessment method and the Clapcott (2015) variation of protocol 1, referred to as the national rapid habitat assessment (RHA) method. Both methods allow each habitat variable to be scored between 1 (poor) and 8–10 (excellent). Except where a CBM group has already used the SHMAK method for some time, we recommend that the RHA method is adopted as it is nationally recognised and widely used by regional councils.

Harding et al. (2009) and specialist input should be consulted if a CBM group has a monitoring purpose or question that requires the use of more quantitative habitat methods.

Measurement type	Field measurement	
Measurement units	None (point-based score)	
Measurement methods	**SHMAK visual habitat assessment** Scoring of 8 habitat variables	**National Rapid Habitat Assessment (RHA)** (recommended) Scoring of 10 habitat variables
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., general environmental screening). A survey that collects quantitative data will be essential for robust assessments of habitat quality.	
Method instructions available from	NIWA SHMAK guidance manual	National RHA protocol (Clapcott 2015)
Equipment /materials	Measuring tape (recommended)	
Caveats	Not completely comparable with the national RHA method which is widely used by regional councils	
Measurement scale	Produces a total score between 0 and 64	Produces a total score between 10 and 100
Measurement resolution	Each variable is scored between 0 and 8	Each variable is scored between 1 and 10
Training	Field demonstration with an experienced specialist running through each of the different habitat variables and how to score them, followed by practice	
Resources	• NIWA SHMAK habitat video – visual habitat assessment (8 variables) • Cawthron National RHA method video	
Refresher frequency	Annually	
Records		
Supporting metadata	• Habitat assessment collection method* • Names of group members completing the assessment* • Width of wetted stream channel* • Length of stream reach assessed* • Photograph(s) taken	
Quality checks		
Internal checks	• There has been at least a week of stable stream flow prior to the survey • For bankside estimates, the water is clear enough to see the stream bottom • At least a 50 m stream reach is assessed • Some or all variables are scored independently by another group member and estimates agree within the same categorical assessment or 20%** • Supporting metadata are recorded	
External checks	• The survey is completed side-by-side by an independently experienced specialist and estimates agree within the same categorical assessment or 20%**	

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

** 20% is considered indicative only, based on overseas data quality objectives for stream habitat variables (e.g., Schoen 2008).

4.3.2 Deposited fine sediment

Although a categorical assessment of deposited fine sediment (DFS) is included as a component of the physical habitat quality indicator (Section 4.3.1), with sediment one of the major diffuse source contaminants affecting fresh waters (e.g., Gluckman 2017) and an attribute in the NPS-FM 2020, some CBM groups will likely want to collect semi-quantitative data on DFS. The two methods included in the table that follows are drawn from the national Sediment Assessment Methods (Clapcott et al. 2011) and are the most common methods in use amongst regional councils (Clapcott et al. 2020). The instream visual assessment method also aligns with that specified for monitoring the DFS cover attribute in the NPS-FM. However, similar to the visual estimates of streambed periphyton cover (Section 4.2.2), estimates of DFS cover are only required to the nearest 10% (rather than 5%).

Fine sediment is defined as particles <2 mm in diameter – typically sand, silt and mud.

Indicator	Percentage of the visible streambed covered by fine sediment < 2 mm in diameter	
Measurement type	Field measurement	
Measurement units	%	
Measurement methods	**Bankside visual assessment** Simple 4 category estimate of cover in run habitat	**Instream visual assessment** Semi-quantitative assessment of cover at 20 points on the streambed in run habitat, generally from 5 cross sections
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., general environmental screening)	Suitable for all three types of data use application but some investigation, surveillance and regulatory purposes may require quantitative measurements of deposited sediment
Method instructions available from	CBM form: Simplified from Protocol 1 of the national Sediment Assessment Methods (SAM1)	Based on Protocol 2 of the national Sediment Assessment Methods (SAM2)[1]
Equipment /materials	None	Underwater viewer (recommended)
Caveats	Limited by what is visible from the bank. Requires very clear water	Use of a viewer essential to support data use in regulatory applications
Measurement range and resolution	0 to 100%, in 25% increments	0 to 100%, in 10% increments
Training	Field demonstration with an experienced specialist estimating the percentage of the streambed covered in deposited fine sediment with an underwater viewer, followed by practice	
Resources	Cawthron Institute video of national RHA method video includes commentary on sediment cover assessments	
Refresher frequency	Annually for instream cross section methods	
Records		
Measurement resolution*	• Bankside estimate: Not applicable – selected from the survey cover category options • Instream cross section method: nearest 10%	
Supporting metadata	• Viewer method (for instream visual assessments)* • The side of the bank observations are made or started from (true left or true right)* • The number of cross sections surveyed* • Estimate of stream width surveyed*	
Quality checks		
Internal checks	• Correct use of a viewer (for instream visual assessments), viewer window positioned horizontally under water to up to 20 cm depth • Survey commences from downstream and moves upstream • Some observation(s) are repeated by a second, independent observer to verify the cover estimates (cover estimates should agree within the same categorical cover or 10-20% • Supporting metadata are recorded	
External checks	• Photographs are taken for an experienced independent specialist to verify some of the percentage cover estimates made • The survey is completed side-by-side by an independently experienced specialist and estimates agree within the same categorical assessment or 20%	

[1] SAM Protocol 2 requires cover to be estimated to the nearest 5% (as opposed to 10% here).

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.3.3 Shade (canopy closure)

The stream physical habitat quality indicator (Section 4.3.1) in the national CBM QA framework incorporates a categorical assessment of riparian shading that may be sufficient for many groups monitoring needs. However, with stream riparian planting a focus for many catchment and community groups in NZ (Sinner et al. 2022), some CBM groups may want to collect quantitative data to track changes in shade over time as riparian plantings grow. The national framework has therefore included a specific indicator for shade, based on canopy closure estimated using a densiometer.

It is important to recognise that canopy cover is not the same as shade. Canopy cover estimates of shade are biased because they do not take into account the position of the sun. Shade is the amount of solar energy that is obscured or reflected by vegetation or topography above a stream. It is expressed in units of energy per unit area per unit time, or as a percent of total possible energy. In contrast, canopy cover is the percentage of the sky covered by vegetation or topography (OWEB 2000).

If a CBM group needs a direct measurement of riparian shade that can produce accurate and precise data, twin photosynthetically active radiation (PAR) sensors, are considered the best option (Davies-Colley and Rutherford 2005).[9] PAR sensors measure light intensity at frequencies associated with photosynthesis and so provide information on light levels that are most relevant for instream plant growth. However, as the sensors are upwards of $1,500 NZD each and need to be calibrated before deployment, PAR-based measurements are unlikely to be feasible for most CBM groups without specialist assistance from a council or other support organisation. If PAR sensors cannot be sourced an alternative approach would be to convert reach-scale canopy cover estimates made with a densiometer to shade measured by a canopy analyser using the relationship established by Matheson et al. (2018) (see Appendix B). A canopy analyser also provides accurate and unbiased measurements of shade.

If sufficient interest exists, inclusion of PAR sensor measurements in the national CBM QA framework could be revisited in the future. Until then, readers wanting further information on the use of PAR sensors to measure riparian shade are referred to Davies-Colley and Rutherford (2005) and Davies-Colley and Payne (2023).

A densiometer is an instrument which contains concave or convex mirrored metal with 24 squares engraved on its surface that reflect the incident light at an angle of 180°. The mirror is fixed into wooden housing with an in-built bubble to level the equipment at the time of its reading. The canopy image is reflected in the densiometer and a count is made at four points (quarters) within each square if vegetation (as opposed to sky) is showing.

The use of densiometers originates in assessments of canopy closure in forestry blocks and a protocol developed by Lemmon (1956). The traditional method has the observer make four counts within each grid (Figure 4-1) giving a maximum count of 96. The count is then multiplied by 1.04 to present canopy closure as a percentage. In the national CBM QA framework, we have adopted the Strickler (1959) modification, documented by OWEB (2000) and used by the US Wildlife Service for monitoring stream canopy closure. This method converts 24-grid squares to 17 points by covering the lower portion of the densiometer with tape. As well as being easier to use, the surface exposed after the modification emphasises overhead vegetation over foreground vegetation, to correct for overestimate of canopy density that occurs when reading unmodified densiometers (Odes 2007). Although some precision in canopy closure measurements is sacrificed with the modification, fewer readings at fixed intersection points on the densiometer should be easier for CBM groups than making readings at four quarter points within each grid. The count is divided by the maximum possible (17) and multiplied by 100 to convert to canopy closure as a percentage (see Appendix B).

[9] PAR sensors also have the benefit of relating stream shade to stream cooling (see Davies-Colley and Payne 2023). PAR measurements must be collected on an overcast day.

Specific indicator	Shade (canopy closure)
Measurement units	%
Measurement type	Field measurement
Measurement method	Spherical densiometer, modified for stream assessments (see Appendix B)
Data use	Suitable for engagement and education as well as some investigative and surveillance applications. Data use for some specific purposes, particularly informing regulatory processes may require direct measurements of shade using light sensors
Method instructions available from	See Appendix B. See also Protocol 3d (riparian) of Harding et al. (2009).
Equipment	Spherical densiometer, tape and measuring tape. A tripod is also recommended to ensure the densiometer is kept level and read at a consistent height (0.3 m) above the water's surface.
Caveats	Requires safe access across the entire stream reach and width. The same stream reach should be assessed over time and at the same time of year (ideally by the same observer(s)). Precision is less than that achieved using a traditional 24-square densiometer
Measurement range and resolution	0 to 100%, in increments of approx. 6%
Training	Field demonstration followed by practice with a specialist experienced in assessing stream shade or habitat
Video resources	U.S. Fish and Wildlife Service video: Measuring stream canopy closure using a spherical densiometer
Refresher frequency	As required
Records	
Supporting metadata	• Type of densiometer used* • If a tripod was used to take measurements* • The length of stream reach surveyed* • The number of cross sections surveyed* • Name of group member making the observations* • Number of vegetation 'hits'* • Photos of canopy cover looking upstream and downstream*
Quality checks	

Internal checks	• Correct densiometer set-up – Strickler modification as per Appendix A
	• Tripod used or otherwise kept level at a consistent height ~0.3 m above the water's surface
	• Measurements correctly taken in all four directions from the centre of the stream (A) and (especially for wide streams or where data on overhanging vegetation is wanted) facing each stream bank (B)
	• A second set of measurements is made by a second group member to verify the cover estimates. Cover estimates should agree within around:
	  o 10-15% when canopy cover is very sparse (<20%) or dense (>80%)**
	  o 15-25% when canopy cover is between 20% and 80%**
	• Supporting metadata are recorded

External checks	• Photographs looking up at the canopy from the centre of the stream are taken for an experienced independent specialist to review • The survey is completed side-by-side by an independently experienced specialist and cover estimates agree within the same ranges specified for the internal checks above

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

** Data summarised in OWEB (2000) indicate that that measurement variability tends to be greater what intermediate levels of canopy cover.

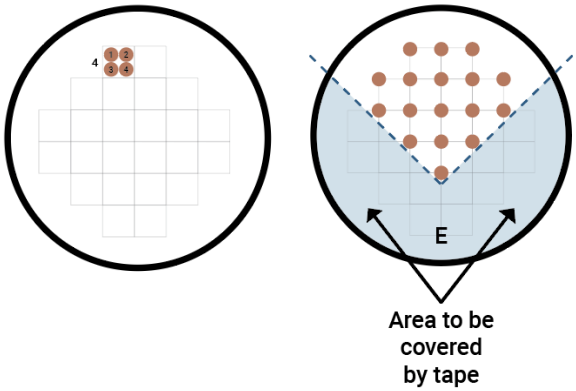

Figure 4-1: Traditional measurement (left) and modified (right) assessment of canopy closure using a densiometer.

4.3.4 Rubbish

Assessments of rubbish (litter) in the national CBM QA framework adopt existing methods available in the NIWA SHMAK kit and adopted by the national Little Intelligence initiative.

Measurement units	Point-based score or counts and weight	
Measurement type	Field measurement	
Measurement methods	**Visual reach assessment** (NIWA SHMAK Level 1 method) Screening of five aspects of rubbish, including the amount, likely sources and impacts on aquatic life and human health	**Rubbish tally method** (NIWA SHMAK Level 2 method – equivalent to the Litter Intelligence protocol for Fresh Water) Collection, identification and counting of different types (e.g., plastic, rubber, cloth, paper, metal) of rubbish in the stream and on the stream banks using the Litter Intelligence categories
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., general environmental screening)	Suitable for engagement and education as well as some investigative, surveillance and regulatory applications. Data use for some specific investigative, surveillance and regulatory purposes may require other types of measurement or detail
Method details	• Level 1: SHMAK guidance manual and video • Level 2: SHMAK guidance manual and video and Litter Intelligence website	
Equipment /materials	Tape measure (30 m)	Tape measure (30 m) rubbish bags, gloves and pick-up claw or kitchen tongs
Caveats		Requires at least 2 people
Measurement scale	Assigns a score from 1 (poor) to 8 (excellent) to 5 variables	Lists over 100 rubbish items for collected rubbish to be recorded against (as a count and/or estimated weight)
Training	Field demonstration with a specialist experienced in assessing rubbish followed by practice. Litter Intelligence offers training workshops (funding dependent)	
Refresher frequency	As required	
Records Supporting metadata	• The length of stream reach surveyed • Name of group member(s) making the observations • Site photos (upstream, left bank, right bank) • GPS coordinates	
Quality checks		
Internal checks	• An additional group member independently verifies the rubbish types identified	

External checks	• Photographs are taken to verify the rubbish types present
	• 10% of surveys are audited whereby:
	  ○ the survey area is re-searched and the number of missing items is recorded (the number of missing items should be <10% of the total count), and
	  ○ the rubbish items collected are re-counted and re-weighed (the count and weight error should be <10%)	

4.4 Water quantity indicators

Three water quantity indicators are included in the national CBM QA framework: water velocity, stream flow and rainfall.

4.4.1 Water velocity

Measurement type	Field measurement	
Measurement units	Metres per second (m/s)	
Measurement methods	**Float method** Time taken for a floating object to travel a known distance	**Current meter** Measurements at one or more points across the width of a stream
Data use	Suitable for engagement and education as well as some investigative and surveillance applications (e.g., coarse environmental screening)	Suitable for engagement and education as well as some investigative and surveillance applications. Suitability for some applications, including informing regulatory processes will depend on the specific intended data use and the number of point measurements made. Specific meter models or specifications may also be required.
Method instructions available from	NIWA SHMAK guidance manual	NIWA SHMAK guidance manual and current meter instructions
Equipment /materials	Measuring tape, stopwatch/timer and an orange (or other neutral density float)	Current meter, measuring rod/ruler, stopwatch/timer
Caveats	Measures surface velocity and a standard correction factor (alpha = 0.85, Hauet et al. 2018) is used to convert this to average stream velocity. Requires a relatively straight reach of stream.	Must know the meter's coefficient number to convert meter readings to velocity. Requires a relatively straight reach of stream.
Measurement resolution	Low to moderate	Moderate to high, depending on the number of point measurements made
Training	See stream flow (Section 4.4.2)	
Records		
Quality checks		

4.4.2 Stream flow

Stream flow (discharge or Q) in the national CBM QA framework is calculated from measurements of water velocity (V) and measurements (or an estimate) of the cross-sectional area (A) of the stream. The accuracy and precision of the estimated average stream flow is strongly influenced by the number of water velocity and (especially) depth measurements made across the stream channel. Fewer measurements are needed if the stream reach is relatively straight and has a consistent width and depth.

Average stream flow (m^3/s) = average stream velocity (m/s) x average stream cross-sectional area (m^2)

Measurement units	Cubic metres per second (m^3/s)	
Measurement methods	**Float method** As per water velocity above but includes an estimate (or measure) of average water depth at several points across the stream in order to estimate cross-sectional area	**Current meter** As per water velocity above but includes measurements of water depth at several points across the stream in order to estimate average velocity and cross-sectional area
Training	Field demonstration followed by practice (use of a current meter should include a demonstration with an experienced specialist). Although the necessary calculations to arrive at velocity and flow are performed automatically in the ArcGIS Survey123 field forms, monitoring groups should be familiar with what these calculations involve.	
Video resources	Various, including protocol P2b of Harding et al. (2009) and NIWA e-Learning training YouTube videos: • Float gauging method • Reading an external staff gauge • Current meter gauging practice	
Refresher frequency	As required, potentially annually for current meter measurements	
Records		
Supporting metadata	• Description of measurement reach characteristics* • Depth measurement method*	
	Float method (additional to above) • Float device* • Length of measurement reach* • Timing device used* • Stream wetted width*	*Current meter (additional to above)* • Current meter make and model* • Meter's coefficient number
Quality checks		
Internal checks	• One person manages the float and another measures the travel time • Velocity measurement repeated three times • Multiple depth measurements made across the width of the stream (aim for 10 unless the stream is very narrow or has a uniform channel)	• The observer is positioned downstream of the current meter and in a way that does not impact the flow • The current meter is positioned directly into the flow at the correct depth (0.6 of the depth from the water's surface) • The current meter is operated for 60 seconds at each point location to obtain the average velocity • Multiple current and depth measurements are made across the width of the stream (aim for 10 measurements unless the stream is very narrow or has a uniform channel)
	• The measurement reach is relative straight, free of obstacles and has a uniform width and depth • Supporting metadata are recorded • If a council (or other) water level monitoring site is operated at or near the site, a photo is taken to verify the water depth and/or the estimate is compared with that of council	
External checks	• The same checks listed above and, where a current meter is used, a second set of measurements are made by an experienced independent specialist (velocity and flow estimates should agree within approximately 10% and 20%, respectively)	

* The electronic ArcGIS Survey123 field forms in the national CBM QA framework will prompt collection of this information.

4.4.3 Rainfall

Regional councils, MetService and NIWA operate networks that measure rainfall across much of NZ. CBM groups should therefore check their regional council website as a starting point to see what rainfall data might be available in the vicinity of their group's stream catchment.

If a CBM group is monitoring in a remote rural or bush location, or specifically wants to measure rainfall, the table on the following page sets out details for measuring daily rainfall with a standard or manual rainfall gauge (i.e., a graduated cylinder rain gauge). While other types of rainfall gauges are available (e.g., tipping bucket rain gauges), the simple design, affordability and ease of installation and operation of manual rain gauges makes them well suited for CBM (Buytaert et al. 2014).

The details provided in the table have been adapted from NIWA's instructions for volunteer rainfall observers (Harper 1994). The NEMS Rainfall Recording (NEMS 2017b) is another source of information on rainfall monitoring but is focussed on more sophisticated and automated methods of rainfall measurement.

As a wide range of manual rain gauges is available on the general market that will likely meet many CBM group needs, the national CBM QA framework does not dictate the type of gauge that must be used. However, for CBM groups interested in aligning with volunteer rainfall observers that contribute to part of a larger national network administered by NIWA, the instructions provided in Harper (1994) are based on the use of:

- a 5-inch (127 mm) rain gauge that is buried in the ground so that its rim is level and 0.3 m above the surface (Figure 4-2), or
- a 4-inch (100 mm) plastic rain gauge attached to a short wooden stake that sits 0.35 m above the ground surface.

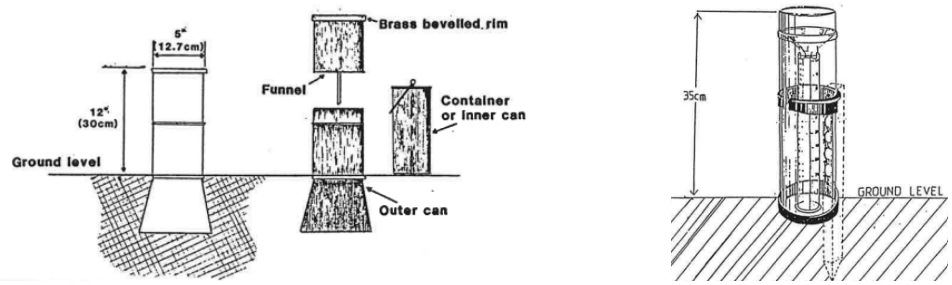

Figure 4-2: Standard 5-inch rain gauge (left) and 4-inch plastic rain gauge (right). Source: Harper (1994).

Specific indicator	Rainfall
Measurement units	mm/day
Measurement type	Field measurement
Measurement method	Manual rain gauge
Data use	Suitable for engagement and education as well as some investigative, surveillance and regulatory data applications
Method instructions available from	NIWA's instructions for rainfall observers (Harper 1994)
Equipment	A graduated cylinder rain gauge and a bracket and stake (or equivalent) to secure it in place
Caveats	Suitability for some specific applications, especially regulatory processes, may require the use of a specific rain gauge and/or the rain gauge to be calibrated or verified by an independent specialist
Measurement range and resolution	Typically 0 to ~180 mm at 1 mm intervals but better if following NIWA's instruction to pour the precipitation captured into a 0.1 mm graduated glass measure
Training	
Refresher frequency	As/if required
Video resources	UK Met Office you-tube video: Measuring rainfall
Records	
Measurement resolution	• To the nearest 0.5 mm (4 inch plastic gauge) or 0.1 mm (5 inch gauge)
Supporting metadata	• Type of rainfall gauge • Rain gauge set up details, including height above ground • Whether the rain gauge location and set-up has been externally checked • Date and time of rainfall measurement period recorded
Quality checks	
Internal checks	• The rainfall gauge is positioned in open space, away from buildings, trees and other objects that may interfere with rainfall collection, as well as excessive wind • The opening of the rainfall gauge is 0.3 m off the ground and is confirmed level (e.g., using a spirit level) • Measurements are made at regular intervals, ideally at 9 am local time each day • The rainfall measurement is read at eye level and at the bottom of the meniscus • A second person periodically verifies the primary observer's rainfall measurement
External checks	• The rainfall gauge set-up and water level reading procedure are checked by an experienced independent specialist, either in person or through supply of photographs

5 Data collection and management

This section provides an overview of the ArcGIS Survey123 field forms for data collection and commentary on data quality assessment.

5.1 ArcGIS Survey123 field form templates

As outlined in Section 3.1.2, electronic field form templates have been created using Esri's ArcGIS Survey123 software. Survey123 works on smart phones, tablets, laptops and desktop computers. Provided the software and field form template are downloaded onto a device in advance, data can be captured in the field regardless of whether a CBM group has an internet connection at their stream location.

Data relating to measurements of most of the stream health indicators in the national CBM QA framework can be entered into one of four different forms:

- **CBM (streams) – A:** the main survey that contains all the water quality and other indicators (stream velocity and flow, and periphyton, cyanobacteria and deposited fine sediment cover), likely to be measured the most frequently
- **CBM (streams) – B:** a survey that contains four indicators likely to measured only once a year: macroinvertebrates, physical habitat quality, shade (canopy closure) and macrophytes
- **CBM (streams) – eDNA:** a short survey for collection of filtered stream water samples for eDNA testing
- **CBM (streams) – fish:** a survey for fish monitoring data.

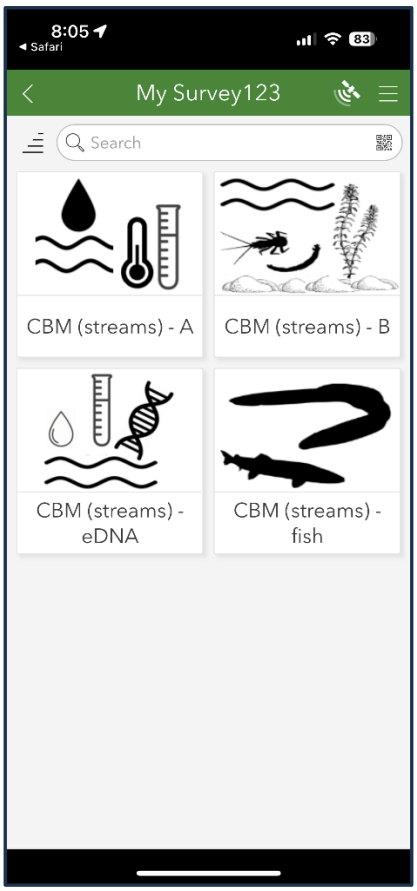

Figure 5-1: The ArcGIS Survey123 landing page on a smart phone when all four CBM survey forms have been downloaded.

The survey forms do not include the rubbish or rainfall indicators because there are well-established existing national citizen science initiatives for CBM groups monitoring these indicators:

- Rubbish: Litter Intelligence app
- Rainfall: NIWA citizen science rainfall

In addition, the main Survey123 field form template (CBM Streams) – A, does not capture continuous water temperature and dissolved oxygen measurements. If a CBM monitoring group has installed a logging device at one or more monitoring sites to measure these indicators at high frequency, the device will come with a software package and instructions that allow the data to be download and viewed. For example, the Onset HOBO® TidbiT water temperature data loggers available as part of NIWA's SHMAK are supported by a free HOBOconnect app and step-by-step instructions that will allow measurements to be downloaded onto a smart phone or a Microsoft Windows-compatible laptop or computer. From there the data can be viewed, exported and shared with others.

Lastly, although there is a template for recording fish data, CBM groups should also be encouraged to enter what data they can into the NZ Freshwater Fish Database (NZFFD).[10] This national database is maintained by NIWA and can be accessed at: https://nzffdms.niwa.co.nz/

5.1.1 Access to the survey forms

The survey forms have been designed to serve as national templates that will facilitate electronic collection, exchange and (the potential future) storage of CBM data in a consistent format across NZ. The templates need to be hosted by a regional council or other organisation that has a valid ArcGIS licence and the capacity to support CBM groups (Figure 5-2).

To use the CBM forms, a CBM group is expected to first:

- complete the seven forms of the Monitoring and Quality Plan (see Figure 3-3), Section 3.1.1), likely with some assistance from a community or catchment group coordinator and a specialist,
- provide a copy of at least Form H ("Essential data re-use information", see Table 3-1) of the Plan to a host organisation, and
- agree with the host organisation on the arrangements for access to, and management and any sharing of, the data they collect (see *Data access, privacy and sovereignty* information box, next page).

The host organisation will use the CBM group name and monitoring site names captured on Form H of the Monitoring and Quality Plan to customise the relevant survey templates for the CBM group. As well as saving the group time by not having to re-enter the same details each time they visit their monitoring sites, setting up templates in advance will ensure the same site names are used and spelt consistently and the host organisation has the correct monitoring site details.

Once the CBM group's name and monitoring sites have been added to the survey templates, the host organisation will provide a link to the forms that the CBM group can download (Figure 5-2). The exact details of survey access will depend on the hosting arrangements. The option with the least administration would likely be for the host organisation to operate a single master copy of each field form template that they add new groups and monitoring sites to. All CBM groups would therefore access the surveys from the same link and, after loading the relevant survey, simply select their monitoring group to bring up their monitoring site list in a dropdown menu.

[10] The NZFFD has a specific format and fields.

Data access, privacy and sovereignty

The national CBM QA framework is intended to promote sharing and re-use of monitoring data on stream health but only with the prior permission of the participating CBM group and an understanding that personal details of monitoring group members will remain private and confidential. This is consistent with the NZ Privacy Act. Where iwi or hapū-based groups use some indicators and methods in the framework alongside mātauranga-based indicators of stream health, the host organisation will need to establish with the group how it will ensure protection of its mātauranga. Guidance is available in *Te Kāhui Raraunga – Māori Data Governance Model* (Kukutai et al. 2023).

It is expected that most community groups will access the Survey123 field forms through an organisation holding a valid ArcGIS licence (i.e., a host organisation). Therefore, all data submitted via the app will be stored, at least initially, in the host organisation's internet cloud service provider. For some CBM groups, this may raise concerns around data sovereignty, in terms of protecting them as original owners of the data and the privacy of their data. Data sovereignty is closely linked with data security and ensuring that data collected or created in one country remain subject to that country's laws, regardless of where the data may be stored. In NZ, data sovereignty also seeks to protect knowledge and information from uniquely Māori sources. This aspect of data sovereignty recognises Māori as the indigenous people of NZ and relates to the rights and interests that Māori have to their digital information and its ethical distribution.

Currently, cloud server capacity in NZ is limited and the cloud server will likely be in Australia in most instances (T. Steinmetz[1] pers. comm. 2022). However, if the host organisation is a council or other government organisation, data storage in the cloud will likely be short-lived with frequent downloads of the data onto a secure local data server or other platform. Some regional councils and other organisations are also combining data submitted via Survey123 with other compatible software in the ArcGIS suite to create data portals and hubs that allow community groups to view and share their monitoring data (Figure 5-2).

A range of options are available within ArcGIS to ensure CBM data are accessible and secure. The host organisation should explore these options, including data ownership and any expectation or requirement for the CBM group to share their data, *before* a group commences their monitoring to ensure that they are comfortable with the data sovereignty and protection agreements in place. The agreed position on data privacy and sharing should be documented in the Monitoring and Quality Plan. A specific data access and sharing agreement/Memorandum of Understanding may be needed.

[1] Tilmann Steinmetz, Principal Technician – GIS Data Administration, NIWA.

Other more customised alternatives to complete "open access" within the survey forms are possible. For example, a password entry specific to a CBM group could also be added within the first page of each survey template. This would limit the user to viewing and selecting their CBM group and monitoring sites.

Operating off a single master template means that the host organisation would be periodically publishing updates after adding a new CBM group or monitoring sites. CBM groups would need to be advised to look out for notifications of these updates from time to time and download them to ensure that they are using the latest survey versions. These notifications are clearly prompted within the app (Figure 5-3A).[11]

[11] At times, there will also be updates driven by ArcGIS, such as through periodic release of an update to the Survey123 app (e.g., to reduce bugs or improve functionality).

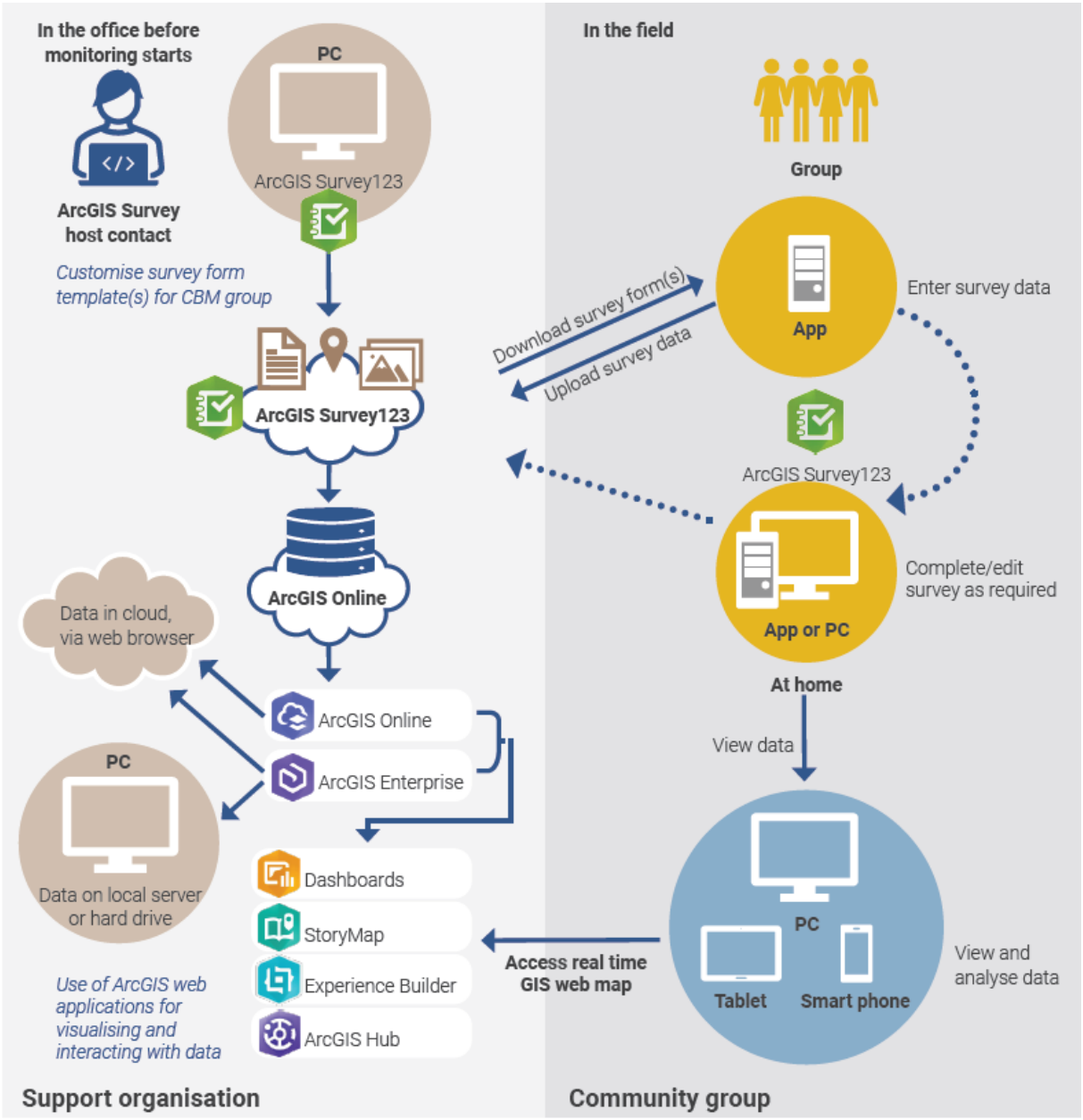

Figure 5-2: An overview of data collection under the national CBM QA framework and how the data could be accessed and shared. A support organisation (left) will create and host the ArcGIS Survey123 field forms for a CBM group (right) to collect their data. The framework only addresses data collection but the lower half of the diagram illustrates what may be possible for a CBM group to subsequently view and interact with their data.

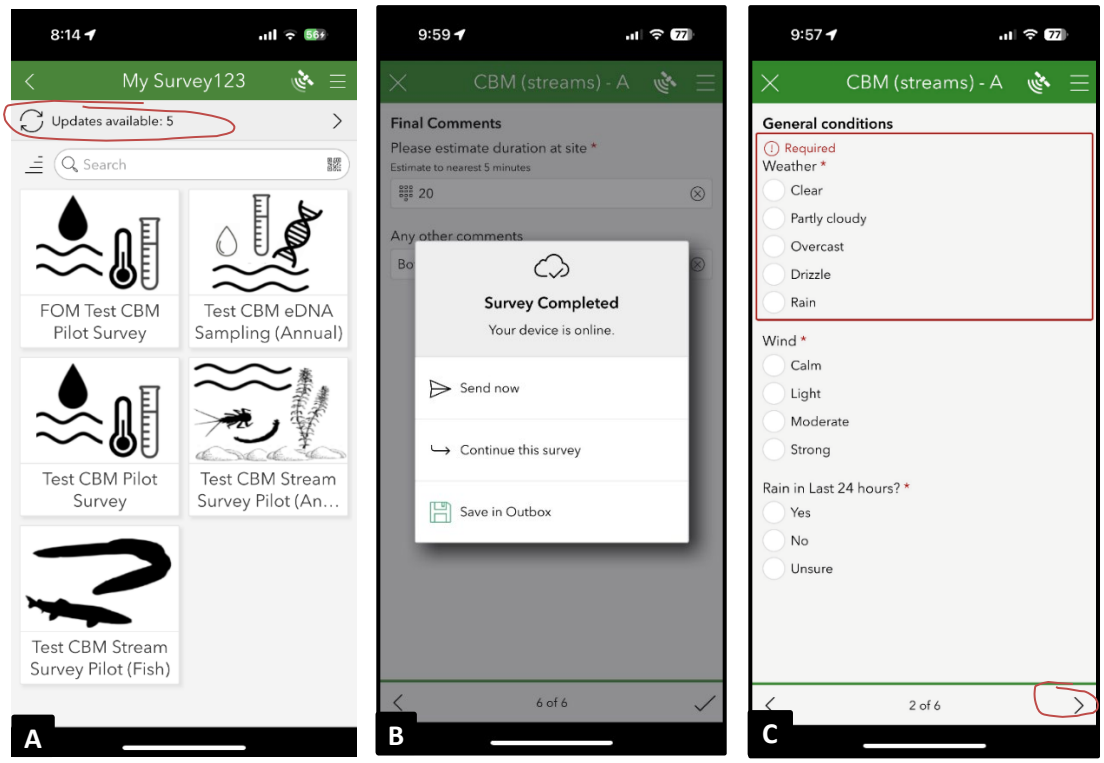

Figure 5-3: Various screens within the ArcGIS Survey123 CBM forms. A) The landing page on a smart phone showing updates are available (circled in red). **B)** The final pop-up box that appears when the user selects the tick (circled) after successfully completing the circle. **C)** An example of an automated prompt to complete a missing mandatory field. This prompt will appear if a user attempts to submit an incomplete survey.

5.1.2 Submitting data via Survey123

When a CBM group has completed the survey questions for their selected stream health indicators, the group member using the Survey123 app will be able to select the tick at the bottom right corner of the final page of the survey to submit their survey data. If some of the mandatory fields in the survey have not been completed, Survey123 will automatically take the user back to the fields that need to be completed (Figure 5-3B).

When the survey is successfully completed, a box will appear telling the user if they are online or offline (Figure 5-3C). The device needs to be online for the CBM group's survey data to be sent to the host organisation. Otherwise, the survey can be saved in the user's outbox and sent later once internet access is available.

Exactly what happens with the submitted survey data will depend on what has been agreed between the CBM group and host organisation in terms of data access and management[12]. As a starting point, unless otherwise agreed, the host organisation should promptly download CBM data submitted via ArcGIS Survey123 and return this to the CBM group. The default ArcGIS data output is a Microsoft Excel csv file but customised data reports can be made. See Figure 5-2 that illustrates how ArcGIS Survey123 can be linked to interactive ArcGIS dashboards and story maps for CBM groups to interrogate.

[12] This agreement will have necessarily factored in what is possible for the host organisation in terms of their ArcGIS licence type and internal data management systems.

5.2 Assessing data quality

The national CBM QA framework facilitates assessments of CBM data quality through two main mechanisms:

- establishing a Monitoring and Quality Plan template with minimum essential information that includes sampling and measurement method metadata, as well as details of training and quality checks, and
- the ArcGIS Survey123 field forms which capture critical metadata, including quality checks (see the asterisked fields for each indicator measurement presented in Section 4).

Where stream water or biological samples are sent to a lab for testing, two additional pieces of information will be needed to assess data quality:

- the Chain of Custody form confirming the date, time and condition of samples received for testing, and
- the laboratory report which will note if there were any difficulties with sample processing that affected the accuracy or precision of the test results.

5.2.1 Data standards

Using standardised electronic CBM field forms across host organisations will ensure that the Survey123 template *name* and *label* fields[13] used to capture data for the various site visit metadata (i.e., general weather and stream conditions) and stream health indicators will remain nationally consistent.

Organisations may wish to transfer submitted data into an off-line database for storage, or import it into an existing online application that already has data for these stream health indicators. In that case, an initial one-off exercise will be to create a look up table to 'map' the CBM form *name* fields to the organisation's appropriate corresponding existing fields. For example, while both the national CBM QA framework templates and NIWA's Hydro Web Portal both use the name *visual water clarity* (and it represents the same measurement), the *stream flow* and *ammoniacal nitrogen* indicator name fields in the CBM framework template would need to be mapped to the *Discharge* and *Ammonia* name fields in the Hydro Web Portal. In many cases new fields will be required (e.g., if the host organisation's existing database field name for *Wind* represents a different estimate of wind (e.g., the 12-point Beaufort scale) to the four-category wind estimate used in the CBM weather observations).

While it may be tempting for a host organisation to customise the templates for a particular CBM group to be consistent with their own data coding practices, doing so will make it more difficult to facilitate CBM data sharing between organisations and nationally.

5.2.2 NEMS and quality coding

Quality codes are not included in the national CBM QA framework. This is because the framework provides for a range of CBM purposes and, consequently, data uses and the accuracy and precision of data required will vary. However, as noted above, in facilitating the assessment of data quality, the framework also provides a starting point for quality codes to be assigned.

[13] In Survey123 the *name* field will correspond with the *name* field in the host organisation's database. The *label* field in Survey123 acts as a question in the survey that prompts the user to enter the relevant data.

The only nationally recognised and established quality coding system for freshwater monitoring data in NZ at present is that provided by the NEMS initiative (NEMS 2016b). There are NEMS standards for various water quality and water quantity indicators. Standards addressing stream ecological indicators are currently limited to periphyton and macroinvertebrates.

Because the NEMS primarily addresses long-term state and trend monitoring, the quality coding framework is designed for assessing the quality of data for this specific purpose. Therefore, while the CBM framework was designed to capture the necessary metadata to enable CBM data quality to be coded against the NEMS quality coding schema, this code should be seen only in the context of the suitability of the data for use in formal state and trend assessments.

The only CBM data that will be eligible for the highest NEMS quality code (QC 600) are water quality, periphyton and macroinvertebrate indicator measurements made using the NEMS methods identified in Sections 4.1, 4.2.2 and 4.2.5. In the case of periphyton, one of the method options for assessing streambed cover includes two modifications of NEMS specifications (i.e., relaxing the number of observations from 20 to 10 and the resolution of cover estimates at each observation point from 5% to 10%). Following NEMS 2022(a), a quality code of QC 400 would be the maximum quality code that could be assigned to data collected using this method.

Regional councils and other organisations wishing to assign a quality code to water quantity CBM data under the existing NEMS framework could consider using a supplementary (i.e., child) code under QC 200 (No quality). This would provide a way to recognise that the data are known to have been submitted via the national CBM QA framework which includes data quality checks. See NEMS (2016b) for details on supplementary quality codes.

6 Managing and updating the CBM QA framework into the future

It is expected that additional indicators and/or measurement methods may be added to the national CBM QA framework in future if and when resources allow. Adopting new indicators and methods should be guided by the same factors that supported the selection of the initial indicators and measurement methods (Sections 3-3 and 3-4). These include the both the relevance of the indicator to freshwater management and community interest in measuring it, as well as the availability of a practical method for CBM with suitable quality checks that will facilitate the collection of data of a known quality.

The regional councils of NZ collectively own the national CBM QA framework and therefore will oversee its implementation and future updates of it. However, given the wide range of organisations involved or interested in community-based monitoring in NZ, just like its development, future updates will likely involve a multi-organisational effort, such as through the National Advisory Group for Freshwater Citizen Science.

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- Sally Shand completed the cover and diagram design work, and
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Appendix A: Comparison between nutrient test kit and lab testing

As outlined in Section 3.4.2, to confirm suitable uses of nutrient test kits in the NZ CBM framework, in January 2022 a small trial was carried out involving paired testing of stream water samples for nitrate-N and dissolved reactive phosphorus (DRP) using test kits commonly used in NZ and Hill Labs, a commercial laboratory with IANZ accreditation for nutrient testing.

On 21 January 2022, water samples were collected from eight stream sites in the Wellington Region (Table A-1). These sites were selected after scanning results of previous monitoring by Greater Wellington Regional Council to identify sites with:

- some differences in visual clarity and/or dissolved organic carbon content (as potential interferences in colourimetric self-test kit measurements), and
- a range of nutrient concentrations.

At each site, water temperature and conductivity were measured *in situ* and recorded alongside general observations of stream and weather conditions. Where the water was noticeably turbid, visual clarity was also measured using a SHMAK clarity tube.

Each water sample was split, with one set of subsamples (denoted 'lab samples') dispatched in a chilly bin by overnight courier to Hill Labs in Hamilton. The remaining set of subsamples were refrigerated overnight ahead of self-test kit measurements (denoted 'test kit samples') the next morning. Aliquots of all test kit samples were processed in accordance with the instructions provided with the test kit. Aliquots from a selection of the samples were also filtered through a 0.45 micron filter before testing to provide a direct comparison with the filtered lab samples. Details of the self-test kit and lab test methods are listed under the test results in Tables A-1 and A-2. Hill Labs tested each subsample in triplicate.

Dissolved reactive phosphorus

The primary test kits of interest were the Hanna® HI-713 Phosphate Low Range test used in NIWA's SHMAK kit and the Microtest® Phosphate-P MB+ (HS) test used in Auckland Council's Wai Care kit. Insta-TEST® Pro LR Phosphate Test Strips were also included for comparison.

Unsurprisingly, none of the test kits could measure the very low concentrations of DRP present in some samples. Overall, the Hanna® Phosphate Low Range test kit, an adaption of APHA Standard Method 4500 P E, performed the best across the eight sites when compared against the Hill Labs test results (Table A-1). In general, the concentrations were consistently a little higher that the lab (at one site, Taueru River at Te Kopi Rd, the concentration was an order of magnitude higher), although agreement improved for one site when testing was repeated on a filtered subsample.

The Microtest® kit results did not compare well against Hill Labs, with particularly poor results for the tannin-stained samples (with and without sample filtration).

The Insta-TEST® Pro LR Phosphate Test Strips, while quick to use, proved difficult to read. Some results were within proximity of the Hill Labs test results (e.g., Beef Creek at Matarawa Rd) but many were not.

Overall, the inclusion of a handheld colorimeter with the Hanna® Phosphate Low Range test kit provides for improved detection of DRP at lower concentrations and reasonable measurement resolution (increments of ~0.003 mg/L). The colorimeter also eliminates the need to estimate the DRP concentration (based on colour intensity) by eye and any associated issues with ambient lighting when estimates are made.

Nitrate-nitrogen

Two kits were tested: the Microtest® Nitrate-N NED (HS) Low Range test used in NIWA's SHMAK kit and the Hach® Nitrate-N Test Strips used in Auckland Council's Wai Care kit. These two test kits vary significantly in their measurement range (0.05-0.8 mg/L and 0-50 mg/L, respectively).

Microtest nitrate-N results agreed well with Hill Lab results for samples that were within the measurement range of the test (Table A-2). However, at half of the sites, nitrate-N concentrations were greater than Microtest measurement range and dilutions on a subsample were necessary. These produced mixed results when compared against those of Hill Labs – from good agreement (e.g., Taueru River at Te Kopi Rd) to poor agreement (e.g., Mazengarb Drain).

All Hach test strip nitrate-N results showed reasonable agreement with the Hill Lab test results considering the low measurement resolution (large increments) of the test strips which prevents a precise measurement (e.g., concentrations for three sites could only be reported as <0.5 mg/L). As the Wai Care programme is often focussed on pollution identification, precise measurement of concentrations at the lower range is not a priority (Hazel Meadows, pers. comm, Auckland Council).

Table A-1: Summary of DRP results (mg/L) for river and stream sites sampled in the Wellington Region in January 2022. Sites with an asterisk are characterised by tannin-stained water.

Stream and location	Conductivity (µS/cm at 25°C)	Water temp (°C)	SHMAK tube clarity (m)	Hill Labs (median)	Unfiltered samples					Filtered samples			
					Insta-TEST® Pro LR Phosphate Test Strips	Microtest® Phosphate-P MB+ (HS)	Hanna® HI-713 Phosphate LR			Insta-TEST® Pro LR Phosphate Test Strips	Microtest® Phosphate-P MB+ (HS)	Hanna® HI-713 Phosphate LR	
Hutt R at Boulcott	115	17.7		<0.004	<100 (<0.033 mg/L)	<0.025	0.020	<0.003					
Beef Ck at Matarawa Rd	165	19.7	0.48	0.119	Closest to 300 (0.098 mg/L)	>0.4	0.192	0.186					
Taueru R at Te Kopi Rd Br	432	22.2		<0.004	Closest to 100 (0.033 mg/L)	0.05-0.1	0.010						
Otukura S at Wards Line	151	20.9		0.131	Closest to 200 (0.065 mg/L)	0.2-0.4	0.157	0.170	0.163				
Mangaroa R u/s Hutt R confluence*	113	20.9	>0.75	<0.004	Closest to 100 (0.033 mg/L)	0.1-0.2	<0.003	0.023	<0.003				
Whareroa S at QE Park*	273	21.9		0.040	Mid-way 0-100 (0.016 mg/L)	0.2		0.052		0-100 (<0.033)	>0.4 by some margin	0.039	0.049
Mazengarb Dn at Mazengarb Rd	438	25.8		0.625	At least 1,000 (>0.326) (same result on repeat test)	1.25 (10-fold dilution)	0.753	0.727	0.620	1,000-2,500 (0.33-0.82)	1.25 (10-fold dilution)	0.73	
Kaiwharawhara S at Trelissick Pk	298	19.1		0.041	Nearest to 200 (0.065 mg/L)	0.05-0.1	0.059	0.055	0.055				

* Tannin-stained

Hill Labs	APHA 4500-P G (0.45 micron filtered sample), flow injection analyser - method detection limit 0.004 mg/L
Insta-TEST® Pro Low Range Phosphate Test Strips	0, 100, 200, 300, 500, 1000, and 2500 ppb or 0, 0.1, 0.2, 0.3, 0.5, 1 and 2.5 mg/L as phosphate (equivalent to 0, 0.033, 0.065, 0.098, 0.16, 0.33 and 0.82 mg/L as DRP)
Microtest® Phosphate-P MB+ (HS)	0, 0.05, 0.1, 0.2 and 0.4 mg/L as DRP
Hanna® HI-713 Phosphate Low Range Checker	0 to 2.5 mg/L in 0.01 mg/L increments as phosphate (equivalent to 0 to 0.815 mg/L as DRP)

Table A-2: Summary of nitrate-N results (mg/L) for river and stream sites sampled in the Wellington Region in January 2022. Sites with an asterisk were characterised by tannin-stained water.

Stream and location	Conductivity (µS/cm at 25°C)	Water temp (°C)	SHMAK tube clarity (m)	Hill Labs (median)	Unfiltered samples				Filtered samples	
					Hach® Nitrate-N Test Strips		Microtest® Nitrate-N NED (HS)		Hach® Nitrate-N Test Strips	Microtest® Nitrate-N MB+ (HS)
Hutt R at Boulcott	115	17.7		0.24	<0.5		0.3	0.2-0.4		
Beef Ck at Matarawa Rd	165	19.7	0.48	1.08	1.5	1.5-2	1.5-1.75#	1.25#		
Taueru R at Te Kopi Rd Br	432	22.2		1.51	2	2	>0.8	3#		
Otukura S at Wards Line	151	20.9		0.064	<0.5	<0.5	0.05-0.1			
Mangaroa R u/s Hutt R confluence*	113	20.9	>0.75	0.38	0.5	0.5	0.6			
Whareroa S at QE Park*	273	21.9		0.042	<0.5	<0.5	0.075		<0.5	<0.05
Mazengarb Dn at Mazengarb Rd	438	25.8		4.8	5	5	>1.54#	6.25-8.75#	5	
Kaiwharawhara S at Trelissick Pk	298	19.1		1.23	1.5		>0.8	2#		

Dilution performed to obtain a measurement within range

Hill Labs APHA 4500-NO_3.I (0.45 micron filtered sample) - method detection limit 0.001 mg/L
(Calculated by subtracting Nitrite N (automated dye colorimetry, flow injection analyser) from NNN (automated cadmium reduction, FIA))

Hach© Nitrate-N Test Strips 0, 1, 2, 5, 10, 20 and 50 mg/L as Nitrate N

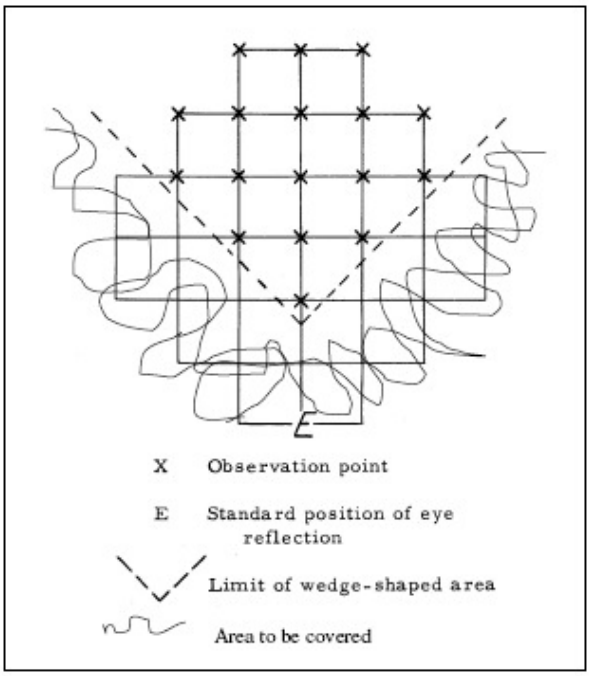
Microtest© Nitrate-N NED (HS) 0.05, 0.1, 0.2, 0.4 and 0.8 mg/L as Nitrate N

Appendix B: Modifying and using a densiometer to estimate stream canopy closure

The following instructions are based on a combination of Standard Operating Procedure (SOP) 4.9.1.2 prepared by Burres (2010), a SOP for canopy closure prepared by Odes (2007) and video instructions provided by the United States Wildlife Services (USWS) for assessments of stream shade carried out as a part of their biophysical habitat monitoring. They are for the use of a 17-point convex spherical densiometer in accordance with Strickler (1959). The Strickler modification is to correct for over-estimation of canopy density that occurs with unmodified densiometer readings.

Modifying a densiometer

Using black electrical tape to cover the lower left and right portions of the densiometer mirror so that a total of 17 (upper AND centred) points can be read, as shown below.

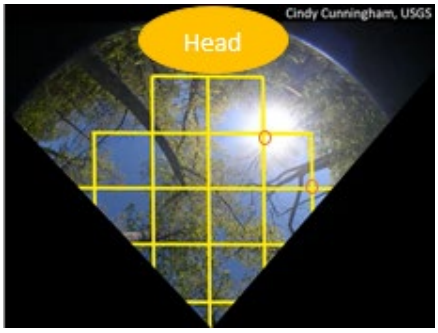


Using the modified densiometer

The assessment included in the CBM framework aims for 20 observations with, as a minimum, four observations taken in all four directions from the centre of the stream (A). An additional observation facing each stream bank is recommended, especially for wide streams or where data on overhanging vegetation is wanted) facing each stream bank (B).

Densiometer set up for observations at mid-stream (A) and a single observation bankside (B). Photos: USWS.

1. Lay out a series of 3-5 transects along the length of a representative reach of stream.
2. For each transect, make one observation of canopy closure at the stream edge facing the left bank, four observations from the centre of the stream (facing upstream, downstream, the left bank and the right bank) and one observation at the opposite stream edge facing the right bank.
    a. For each observation, ensure that the densiometer is held level (using the built-in bubble level) and at a consistent height of 0.3 m above the water's surface (best ensured through the use of a camera tripod) – your head should be positioned so that is just showing close to the top edge of the grid.
    b. Count the number of intersection points covered by overhanging canopy/vegetation, called vegetation 'hits' (in the example image below, only 2 of 17 points are not covered).



<u>Recommended optional extras</u>
The electronic field forms in the national CBM QA framework providing for the following options:

- have a second observer repeat the measurements, and/or
- upload of photos of the stream canopy closure looking upstream from the bottom of the reach and downstream from the top of the reach.

Supporting metadata to record
The electronic field forms in the national CBM QA framework require the following information to be captured:

- type of densiometer used (i.e., convex or concave),
- if a tripod was used to take measurements,
- the length of stream reach surveyed,
- the number of cross sections surveyed,
- name of group member making the observations,
- number of vegetation 'hits', and
- photos of canopy cover looking upstream and downstream.

Calculating canopy closure
The electronic field forms in the national CBM QA framework will automatically calculate canopy closure (%) as data are entered, using the formula below. As well as an overall average measurement for the stream each, the form will calculate an average for each of mid-stream and the bankside and on a per transect basis. The 88% closure below is for the observation example in the photo above.

$$\% \text{ canopy closure} = \left(\frac{\text{\# hits}}{\text{total observations}}\right) \times 100$$

$$\% \text{ canopy closure} = \left(\frac{15}{17}\right) \times 100 = 88\%$$

B.1 Converting canopy closure to estimates of stream shade

It is possible to convert reach-scale canopy closure estimates made with a densiometer to shade measured by a canopy analyser using the relationship established by Matheson et al. (2018) (Figure B-1). Like PAR sensors,) a canopy analyser also provides accurate and unbiased measurements of shade.

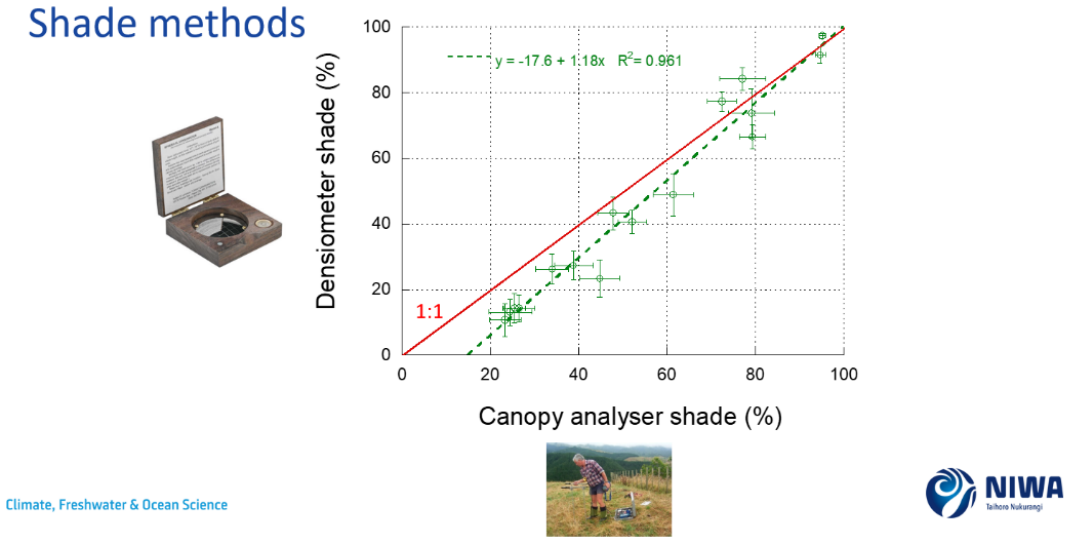


Figure B-1: Relationship between "biased" reach-averaged shade measured with a densiometer and "unbiased" reach-averaged shade measured with a canopy analyser. From Matheson et al. (2018). Measurements made in streams and rivers in the Piako River catchment, Waikato, NZ.