# Quality assurance for community-based freshwater monitoring in Aotearoa New Zealand

## An overview of international frameworks and approaches


*Prepared for Hawke's Bay Regional Council and MBIE Envirolink*

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*Cover photo:* Volunteers dig for kākahi (freshwater mussels) during annual count at Wairarapa Lake Shore Science Reserve. [Greater Wellington Regional Council]

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# Executive summary

The number of rural and urban community-based groups, including farmers, restoration groups and schools, interested in monitoring the health of our fresh waters in Aotearoa New Zealand has grown rapidly over the last ten years. Often referred to as 'citizen science', volunteer monitoring or community-based monitoring (hereafter CBM) is also now recognised by an increasing number of councils as an effective way to engage local communities in freshwater management and increase the pool of data available to inform various council applications. Potential applications range from engagement, education and farm environmental planning through to catchment model development and validation, environmental reporting and regulatory decision-making. In addition to collecting data for their own interest, understanding and use, volunteers can support collection of data at finer spatial and temporal scales than in professional programmes, as well as from geographically remote locations. Therefore, CBM has the potential to help offset some of the rising cost of increased freshwater monitoring associated with implementation of the National Policy Statement for Freshwater Management (NPS-FM) and other recent legislation. Enabling greater community involvement in monitoring can also help build trust between councils – as resource managers – and the public.

As well as an increase in requests from community groups for monitoring guidance and support, many council staff have also reported growing expectations among CBM groups that their data will be used by councils and other decision makers. While multiple organisations currently provide varying levels of training and support across different parts of the country, there is no overarching framework in place to ensure and verify that freshwater (and other) data collected by volunteers are of 'known' quality and 'fit for purpose'. Quality assurance (QA) is critical for ensuring all environmental data are credible but credibility is particularly relevant for CBM groups because concerns about data quality are often cited as a key reason why 'professional' scientists and decision-makers will not use CBM data. However, an increasing pool of evidence suggests that, under the right circumstances, community volunteers can produce data of comparable quality to professionals.

This report has been prepared for a consortium of eight regional and unitary councils led by Hawke's Bay Regional Council as part of the first phase of developing a national QA framework for community-based freshwater monitoring. Funded through an MBIE Envirolink Medium Advice Grant, this report provides an overview of QA concepts and CBM QA frameworks in existing use or development in the United States of America (USA), Canada, Australia and the United Kingdom (UK). Six CBM case studies are summarised; 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. Prospects for a QA framework for New Zealand are also outlined drawing on insights from the case studies and discussions from informal meetings with interested individuals and organisations, a workshop with regional sector staff in August 2020 and a CBM data stewardship workshop in December 2020 with representatives across central government, local government, primary industry and the private sector.

Quality assurance is essentially the totality of the plans put in place *before* monitoring to manage quality throughout all stages of the monitoring process. This begins with a monitoring plan that establishes, amongst other things, the reason or purpose for monitoring and the type and specifications of the information sought (referred to as data quality objectives in the USA). Data quality objectives or criteria required of a particular CBM group or monitoring project will depend on the intended purpose and use of the data. Groups who expect their data to be used by other organisations need to understand at the outset of a project what the quality requirements expected by those organisations are and the steps they need to take to meet those requirements. In many cases, data collected for one purpose may also be useful for another unintended purpose but this can only be known if the data collection methods and associated QA information and other metadata are documented and readily accessible.

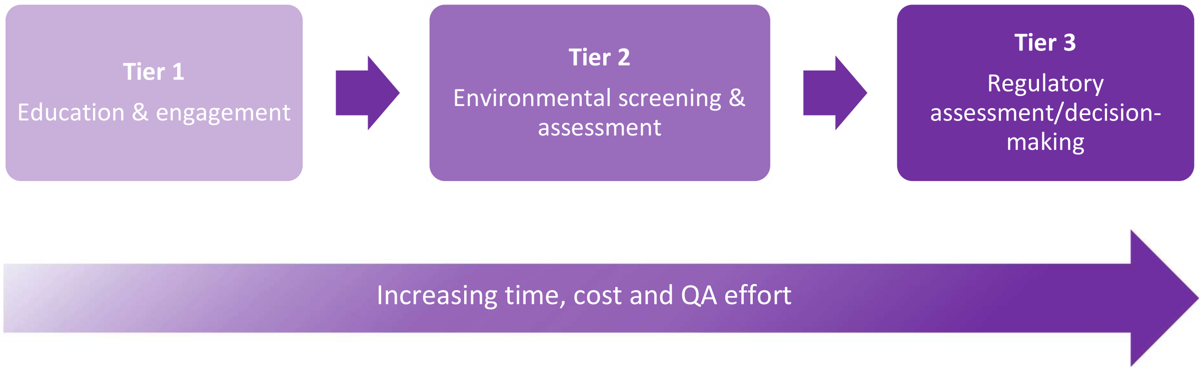
Other core components of QA include developing a specific plan for managing QA, standard operating procedures (i.e., step-by-step instructions for carrying out specific routine components of the monitoring), training, audits and quality control (QC) measures. Examples of QC measures applicable to monitoring of water quality variables include sample blanks (which can assess contamination during any stage of sample collection or analysis), sample replicates (to assess precision in sample collection or analysis), and spiked samples (samples of a known contaminant concentration which assess for errors with sample testing/measurement). For biological monitoring (e.g., benthic macroinvertebrates), QC measures often target sample sorting efficiency and identification but should also be applied to sample collection and preservation.

Of the international CBM frameworks we looked at, the USA has the most well developed approach to QA, supported by a long history of CBM initiatives overseen by the US Environmental Protection Agency (EPA) and strengthened by the Crowdsourcing and Citizen Science Act 2016 that gives the US government the authority to use crowdsourcing and citizen science methods to advance scientific research. Many elements of USA's approach, including the existence of multiple data tiers with varying levels of QA, a requirement for a CBM group to have a Quality Assurance Project Plan (QAPP) and a suite of template plans and procedures to support CBM groups, are also present in Australia's Waterwatch programme (where a Data Confidence Plan is the equivalent of a QAPP). In contrast, the Canadian and UK governments do not have a specific data quality framework for CBM, although the UK is in the early stages of developing such a framework. Field and laboratory sample replicates and independent external checks of sampling and testing practices by trained coordinators are common components of CBM QA in the USA and Australia.

Training was a universal requirement across the six CBM case studies examined, with varying training levels (from basic to more advanced) a common feature, ensuring that a range of options is available to participating groups. Somewhat surprisingly, refresher training or re-certification was not always required.

While all of the programme case studies restrict entry of data into databases to approved group members, there is considerable variation in the extent of further checks made on data after they have been entered. For example, in the CABIN programme (Canada), no checks are made on data once entered whereas data collected under the West Gippsland Waterwatch programme (Australia) are subject to both in-built automated checks and verification by a Waterwatch coordinator or officer.

In New Zealand, increased recognition of CBM and its many potential benefits has resulted in the development of standardised sampling protocols, monitoring tool kits, websites and other resources. These resources, together with various national freshwater guidelines and National Environmental Monitoring Standards (NEMS), provide a solid basis to inform the development of a national QA framework. The NPS-FM 2020, in establishing that all freshwater must be managed for the national values of ecosystem health, human health for recreation, mahinga kai and threatened species, provides a series of mandatory attributes that could be incorporated into the framework. Mahinga kai attributes will be rohe-specific and need to be developed and monitored by tangata whenua. The framework needs to be flexible to accommodate a range of data collection purposes; similar to the USA and Australia, this could be achieved through a multi-tiered system of data collection, with the rigour and frequency of QA requirements increasing with each tier. The framework also needs to promote transparency in data quality, through establishing requirements for documentation of data collection methods and associated QA and other metadata.




**The basis of a possible 3-tier (or category) CBM data collection system for New Zealand.** The listed applications are suggested primary data uses only; secondary data uses (e.g., modelling) would be dependent on end users assessing the suitability of data collection methods and QA measures for their intended use.

While a national QA framework will provide the basis for the collection of CBM data to consistent standards and of ‘known quality’, realising the full potential benefits of CBM will also require ongoing support and feedback for CBM groups, both to sustain the motivation of volunteers and to maintain data quality. The data collected by CBM groups also needs to be visible and easily accessible via a database or portal to ‘house’ the data and associated metadata (with due consideration given to data privacy and sovereignty issues). Overall, greater coordination of existing CBM initiatives and support efforts, including a strategy for data management and sharing, would greatly advance the consistency, value and benefits of CBM in New Zealand.

# 1 Introduction

Heightened attention on the state of our natural environment in Aotearoa New Zealand, particularly fresh waters, has seen rapid growth in the collection of data by rural and urban community-based groups, including farmers, restoration groups and schools. Generally termed ‘citizen science’, volunteer monitoring or community-based monitoring (hereafter CBM) is also being recognised by an increasing number of councils as an effective way to engage local communities in freshwater management as well as to contribute data to inform various regional council (and other agency) applications. Such applications range from engagement, education and farm environmental planning through to catchment model development and validation, environmental reporting and regulatory decision-making. In addition to collecting data for their own interest, understanding and use, volunteers can support collection of data at finer spatial and temporal scales than in more formal monitoring programmes, as well as from geographically remote locations. This has the potential to help offset some of the rising cost of increased freshwater monitoring associated with implementation of the National Policy Statement for Freshwater Management (NPS-FM) and other recent legislation. In addition, enabling greater community involvement in monitoring may help build trust between councils as resource managers and the public.

CBM is not only growing in New Zealand, but so too are the desires or expectations of CBM groups that their data will be used by councils and other decision makers (Peters et al. 2015, Kin et al. 2016). While multiple organisations now provide varying levels of training and support in different parts of the country, there is no overarching framework in place to ensure and verify that freshwater (and other) data collected by volunteers are of ‘known’ quality and ‘fit for purpose’. Quality assurance (QA) is critical for ensuring data are credible. Although applicable to all environmental monitoring, QA is particularly relevant for CBM groups because concerns about data quality are often cited as a key reason why ‘professional’ scientists will not use the data that these groups have collected (e.g., Albus et al. 2019).

## 1.1 Report purpose and scope

This report has been prepared to support the first phase of developing a national QA framework for community-based freshwater monitoring. It provides an overview of QA concepts and international CBM QA frameworks in existing use or development, as well as case study applications of potential relevance to New Zealand. This report, funded through Envirolink Medium Advice Grant HBRC257 (MBIE Contract C01X21302), has been prepared for a consortium of eight regional and unitary councils led by Hawke’s Bay Regional Council. Some funding from this grant also supported a workshop with representatives from these councils in August 2020 to scope an Envirolink Tool concept proposal to develop the QA framework. Development of the framework is being championed by Greater Wellington Regional Council and will involve collaboration with a range of central government, industry and private organisations. The framework, to be developed between July 2021 and June 2023, is focused on freshwater, reflecting an immediate council and national need in this domain. However, it is envisaged that the framework will be applicable to other environmental domains (e.g., terrestrial, marine).

## 1.2 Approach

To identify how a QA framework for CBM data might be developed for New Zealand, we looked overseas at countries we know have long-established freshwater CBM programmes, in particular the United States of America (USA), but also Canada, Australia and the United Kingdom (UK). We accessed relevant information on CBM in these countries, including example CBM case studies, via a combination of existing knowledge/contacts, and website and publication searches. We also used on-line searches to source relevant publications on CBM, particularly those with a focus on water-based monitoring, and reviewed the reference lists of these publications to identify further potentially relevant publications to support an overview of key CBM concepts and QA considerations. The primary factor that determined the selection of the six case studies summarised in this report was access to readily available information to sufficiently describe the CBM initiative and, in particular, how QA aspects are addressed.

As well as insights generated through our review of international literature and case studies, the principles and other considerations underpinning a prospective national QA framework presented in this report were also informed by discussions via informal meetings with interested individuals and organisations, including the on-line workshop with a selection of regional sector staff in August 2020. A further workshop hosted by NIWA (in December 2020, with funding from the Our Land and Water National Science Challenge – Toitū te Whenua, Toiora te Wai) supported an initial conversation with representatives across central government, local government, primary industry and the private sector on needs and opportunities for collaboration around stewardship of CBM data. The proposed national QA framework will provide critical information on data collection methods and data quality but, to be useable, the collected data must also be visible and easily accessible (Milne and Valois 2021).

## 1.3 Report outline

This report comprises five sections:

- Section 2 provides an overview of CBM, including its relationship with the often more widely used term 'citizen science' and some of the recognised benefits and challenges associated with CBM. We also present a brief history of key developments in citizen science/CBM in New Zealand to date and outline current drivers and emerging opportunities for freshwater CBM.
- Section 3 introduces the concept of QA, why it's needed, and its key components, including monitoring plans, standard operating procedures, training and quality control measures.
- Section 4 sets out existing international CBM frameworks or approaches, primarily focusing on the USA, Canada, Australia and the UK. One or more CBM case studies are also presented for each of these countries to provide more detail on what QA is involved.
- Section 5 outlines the prospects of developing a QA framework for freshwater CBM in New Zealand, drawing on material presented in Sections 2 to 4, as well as the August and December 2020 workshops outlined in Section 1.2.

# 2 Overview of community-based monitoring

This section provides an overview of community-based monitoring (CBM), with a freshwater management lens. We begin by defining CBM, including its relationship with the often more widely used term 'citizen science', before outlining some of the recognised benefits and challenges associated with CBM. We then present a brief history of key developments in citizen science and CBM in New Zealand to date. Finally, we outline current drivers and emerging opportunities for freshwater CBM in New Zealand.

## 2.1 What is CBM?

Community-based monitoring is essentially a type of citizen science (Figure 2-1) that focuses on the collection of scientific data by members of the public, as individual or organised groups of 'volunteers'. Alternative terms to CBM used in the literature include 'volunteer monitoring', 'locally-based monitoring' or 'participatory' monitoring'. Other related terms include 'participatory sensing', 'crowd sourcing' and 'citizen laboratories'. Variants of CBM include CBEM (community-based environmental monitoring; e.g., Peters et al. 2016) and CBWM (community-based water monitoring; e.g., Valois et al. 2019).

Many CBM projects are contributory projects; organised and run by 'professional' scientists in which citizens help gather data. However, collaborative and co-created participation models also exist where at least some members of the community are involved in analysing data and sharing results (collaborative projects) or even setting research questions and choosing monitoring methods (co-created projects) (Bonney et al. 2009, Wilderman and Monismith 2016).

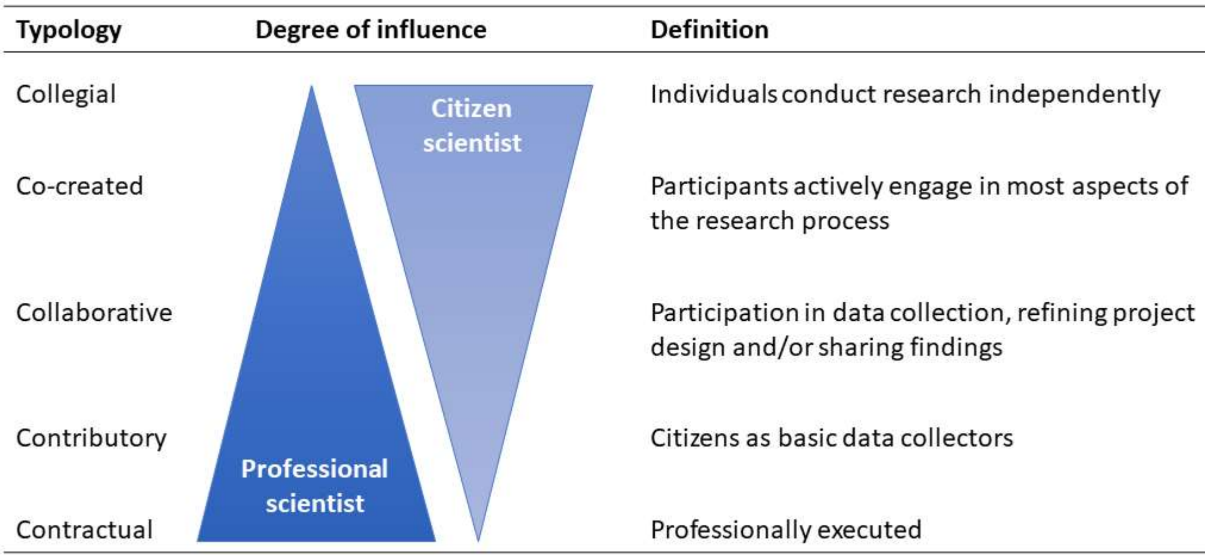



**Figure 2-1: Types of citizen science and the relative degree of influence for 'citizen' and 'professional' scientists.** Note that the categorisation of a project is subjective and examples such as CBM and participatory modelling could move up or down the scale. (Source: After Walker et al. (2020) and Njue et al. (2019).

### 2.1.1 Who is involved in CBM?

Community-based monitoring includes a wide range of participant types[1], covering different ages, skill levels, motivations and capacity to participate. Research has demonstrated that volunteers are

[1] Participants are most often represented by volunteers but can include students and academics and employees of non-government organisations (NGOs) or consultants, many of whom are paid to collect data as part of a programme.

typically older adults and are highly educated. For example, an online survey of participants in Estuarywatch and Waterwatch Victoria (Australia) found that 80% of participants held a teritiary qualification, 40% held a postgraduate degree, and 60% were retirees[2]. Beyond education and age, projects also vary in the socio-economic background of participants, with those in higher income brackets over-represented. This is important within the context of data quality protocols for CBM programmes to ensure that these are not so complex as to exclude some groups from participation (Lukyanenko et al. 2016).

### 2.1.2 When should CBM be used?

Community-based monitoring is often initiated at the 'grassroots' level in response to local environmental interests or concerns. When a council or other organisation is considering supporting or initiating a CBM project, careful consideration is needed of what it wants to achieve. McKinley et al. (2017) suggest a fundamental question to ask of any citizen science project might be: "Can it improve the scientific process and elicit the most useful public input and engagement?"

Monitoring methods and analyses to address specific questions sometimes require specialised knowledge, training equipment and time commitments that make CBM inefficient or impractical. Pocock et al. (2014) outlined six main factors to consider when assessing the suitability of CBM for an environmental monitoring programme (Figure 2-2). They also developed a decision support framework for the Scottish Environment Protection Agency (SEPA) to guide where CBM would be most useful for understanding the environmental pressures relevant to SEPA. This process identified environmental pressures such as nutrient enrichment, fish passage barriers, recreational impacts and invasive species (The Scottish Government 2011).

Increasing suitability for a CBM approach (↑)

| Question | Engagement | Resources | Scale | Complexity | Motivation |
|---|---|---|---|---|---|
| Clear aim or question | Engagement is important | Plenty of resources | Large-scale sampling | Simple protocol | Good reason to participate |
| Vague aim/question | No engagement or only one-way communication | No resources | Small-scale sampling | Complex protocol | Reasons to participate not clear |

**Figure 2-2: Six main factors to consider before adopting a CBM (or citizen science approach) within a programme.** Adapted from Pocock et al. (2014).

### 2.1.3 What types of data can CBM collect?

There are many ways volunteers can get involved in monitoring. Freshwater CBM methods can include:

- ***Sensing***: Volunteers can deploy and/or maintain sensors or use sensors in their mobile phone to collect data (e.g., 'citizen observatory' approach popular in Europe which can include measurements of soil moisture, water level, surface water velocity, water transparency and air quality[3,4]).

[2] http://www.vic.waterwatch.org.au/resources/EstuaryWatch%20&%20Waterwatch%20Vic%20Volunteer%20Survey%202020%20Final%20Summary.pdf
[3] https://monocle-h2020.eu/Citizen_science
[4] https://ec.europa.eu/easme/en/news/have-you-heard-about-concept-citizens-observatories

- ***Collect and send***: Volunteers collect samples (e.g., water samples for water chemistry, microplastics or environmental DNA (eDNA) analysis, phytoplankton and benthic macroinvertebrate samples) and send these to a laboratory for processing/analysis. This approach is common in North America.
- ***Replicating professional methods***: Volunteers use identical methods to professionals (e.g., black disc visual clarity measurements, spotlighting for fish).
- ***Modifying professional methods***: Volunteers use simplified professional methods (e.g., use of a clarity tube to measure visual water clarity, use of portable colourimetric test kits to measure water column nutrient concentrations). This is common for complex methods where simplification reduces error, such as using live-counts for benthic macroinvertebrates (Valois et al. 2009) or higher-level taxonomy (Di Fiore 2017) which reduces the need for expensive equipment or advanced taxonomic skills.

Some of the most well-established and long-running CBM projects are focussed on the collection of water quality and/or benthic macroinvertebrate data from lakes or rivers, particularly in the USA (Firehock and West 1995, Alender 2016) and Canada (e.g., ECCC's Canadian Aquatic Biomonitoring Network), but also in the UK (e.g., the Riverfly Partnership's Anglers' Riverfly Monitoring Initiative, ARMI) and New Zealand (e.g., the Styx Living Laboratory in Christchurch).

In addition to measuring a wide range of water quality variables, freshwater CBM initiatives can include measurements and observations from stream habitat and litter surveys and monitoring of phytoplankton blooms, periphyton cover and fish diversity. Ecosystem function processes can also be monitored. The Stroud™ Water Research Center[5] operates the Leaf Pack Network, an international citizen science monitoring initiative in which participants use tree leaves and aquatic insects to monitor stream health and function. In Canada, EcoSpark[6] developed a citizen-friendly cotton strip decomposition method with citizen deployers called the "rot squad".

CBM is now embracing new environmental monitoring technologies, including sensors in mobile phones (e.g., to measure water colour[7]), low-cost *in-situ* sensors (e.g., the Riffle (Public Lab) and Mayfly (EnviroDIY) data loggers which allow for monitoring of basic water quality variables such as temperature, conductivity and pH). Auckland Council's Wai Care programme is currently trialing low-cost sensors in the Puhini Stream (measuring water temperature, conductivity and water level) and the Matakana River (measuring turbidity and suspended solids).

## 2.2 Benefits and challenges of CBM

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 provides a summary of benefits and challenges drawn from a review by Conrad and Hilchey (2010). Walker et al. (2020) point out that whether stated benefits for participants are actually realised and whether any negative impacts are experienced are not routinely assessed in CBM initiatives.

[5] www.leafpacknetwork.org
[6] https://www.ecospark.ca/blog/running-with-the-rot-squad-in-headwater-streams
[7] https://www.eyeonwater.org/

**Table 2-1: Summary of benefits and challenges of CBM.** Reproduced from Conrad and Hilchey (2010).

| 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 | |

### 2.2.1 Benefits

Benefits of CBM in the context of freshwater management can be grouped into two broad themes: increasing the pool of environmental data and increasing community engagement and literacy.

#### Increasing the pool of environmental data

A major strength of CBM is in its potential to collect fine-grained information over broad areas and long periods of time (Gouraguine et al. 2019), augmenting the reach, effort and resources of professionals. In parts of the USA, the number of lakes sampled and the frequency of sampling by community volunteers far exceed the number and frequency achieved by government staff. For example, in the state of Michigan, volunteers in the Michigan Clean Water Corps (MiCorps) programme conduct biological and habitat assessments at over 225 lakes per year. In contrast, the Michigan Department of Environmental Quality's Lake Water Quality Assessment Programme is limited to similar assessments at approximately 70 lakes per year (Latimore and Steen 2014).

With environmental research and modelling increasingly relying on "big data", CBM can contribute to large-scale databases, providing for determination of trends at scale. Poisson et al. (2020) found that over half of all long-term (>15 years) lake monitoring records for water clarity, nutrients and algal biomass in a large a multi-state, multi-party database were sourced from volunteers (Figure 2-3).

Of particular benefit to councils (and other organisations involved in freshwater and wider environmental management) is the ability of CBM to target locations that are geographically remote or otherwise less easily accessible (e.g., land in private ownership). In addition, the broad areas CBM initiatives often span, along with closely spaced sampling over time, can provide for 'early warning' of potential risks to ecological or human health, such as through detection of algal blooms, or leaking or damaged wastewater pipes. For example, the volunteer-based Angler's Riverfly Monitoring Initiative (ARMI) in the UK has detected pollution events through routine monthly sampling, including a large-scale benthic macroinvertebrate kill in the River Kennet due to a pesticide spill (Thompson et al. 2015).

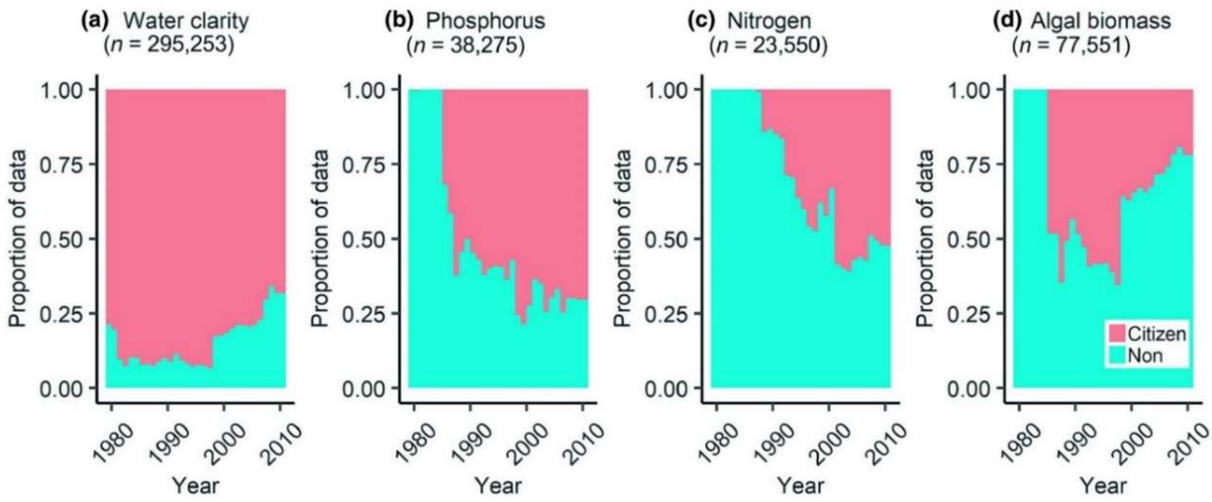



**Figure 2-3: Proportion of lake water samples collected by volunteers (pink) and government or other agencies (green) from 1980-2010 across seven US states.** From Poisson et al. (2020).

The place-based focus of many CBM projects also allows volunteers to respond quickly and secure timely data on environmental 'events', such as sudden floods, pollution incidents or fish kills. For example, in the Wellington Region:

- a community stream care group conducting routine monitoring of the health of a stream in Lower Hutt identified spikes in water temperature that were successfully tracked to an unknown (and unauthorised) industrial cooling water discharge; and
- a community stream care group monitoring in a tributary of the Porirua Stream captured evidence of inputs of sediment-laden runoff associated with earthworks activity on a subdivision site (J. Milne[8], pers. obs).

In providing easier access to geographically remote areas, and surveillance and event-based monitoring, CBM can offer a cost-effective alternative to council monitoring. Further, this monitoring may not be constrained to office hours, a particular benefit for event-based monitoring.

### Increased engagement and science literacy

Community-based monitoring can play a role in increasing scientific literacy among participants, including a better understanding of local issues and how to apply this knowledge in the context of environmental stewardship (Conrad and Hilchey 2011). Interviews with New Zealand freshwater CBM groups have highlighted how participants developed a better understanding of water quality and the links between their actions on-the-land and water quality, as well as improved awareness of council processes and freshwater legislation (Blackett et al. 2011, Coates 2013, Kin et al. 2016). Storey et al. (2016) found that CBM participants had developed a closer relationship with their council and felt better equipped to engage in council-led planning processes (although only a minority said they planned to in the future). Most participants felt they could better share their knowledge of freshwater issues with others in their community.

[8] Juliet Milne was an employee of Greater Wellington Regional Council when the care groups reported these cases.

### 2.2.2 Challenges

Community-based monitoring is not without its challenges and there can be significant barriers to implementing a successful CBM programme or project, or using the data generated. Some key challenges relate to resourcing, volunteer motivation, and data quality and accessibility. Application of the key principles for citizen science (Box 1) might help to overcome some of these challenges.

**Box 1: Key principles of Citizen Science**

The European Citizen Science Association has established ten key principles of Citizen Science (ECSA 2015) that underlie good practice in citizen science. Applying these principles might help to overcome some of the potential challenges to CBM outlined in Section 2.2.2.

1. Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding.
2. Citizen science projects have a genuine science outcome.
3. Both the professional scientists and the citizen scientists benefit from taking part.
4. Citizen scientists may, if they wish, participate in multiple stages of the scientific process.
5. Citizen scientists receive feedback from the project.
6. Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for.
7. Citizen science project data and metadata are made publicly available and where possible, results are published in an open access format.
8. Citizen scientists are acknowledged in project results and publications.
9. Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.
10. The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.

#### Resources

Although working with the community can be cost-effective in terms of data produced, CBM is not free for either the volunteers or the organisations that support them. Both financial and human resources are required to purchase and maintain monitoring equipment, train, support and communicate with volunteers, analyse samples, and manage data and documentation.

Roy et al. (2012) reviewed 30 CBM projects in the UK and found that annual running costs ranged between £70K and £150K. In terms of personnel time, the Alliance for Aquatic Resource Monitoring (ALLARM) based in Pennsylvania (US) estimated that it takes up to six months to help a catchment monitoring group develop a study design, with additional time required to provide feedback after data collection (Wilderman and Monismith 2016).

## Volunteer motivation

Effective CBM programmes depend on the active engagement of motivated participants (Kanu et al. 2016). Inability to access appropriate equipment, information or expertise, the use of complex or cumbersome methods, a lack of feedback on monitoring efforts and an absence of action by a regulatory agency in response to data that identifies a potential environmental concern, have all been cited as factors that can reduce volunteer motivation (e.g., Peters et al. 2015, Kin et al. 2016, Pierson 2021). Managing expectations of volunteers around such things as resourcing, support and end use of data is important for sustaining volunteer interest (Goudeseune et al. 2020).

The motivations behind an individual's or group's participation in CBM can also present a challenge to potential end users of CBM data. An on-line survey conducted of EstuaryWatch and WaterWatch Victoria volunteers in early 2020 revealed that most volunteers were motivated by a desire to improve waterway management and waterway health (Bonney et al. 2020). While similar motivations of environmental concern and sustainability underpin many CBM programmes and projects, conflicts of interest and personal biases can come into play, impacting the objectivity and integrity of data collection (Guerrini et al. 2018).

## Data quality and accessibility

Questions about data quality are typically the first to arise when CBM is proposed and 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. Examples are: the use of more simplified monitoring equipment or methods; challenges with equipment storage, maintenance and calibration; the perceived limited skills and/or experience of the volunteers; and a lack of appropriate quality assurance, including documented procedures.

There is now a well-established – and growing – body of evidence that CBM can produce reliable, quality datasets on par with those produced by 'professionals'. 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 volunteers and professionals (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 volunteers and professionals 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).

Information from the comparison studies referenced above indicates that monitoring programme design and structure impact data quality. Standardised (and documented) protocols, training/certification and professsional 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 volunteer datasets accumulate variability over time, because of more frequent changes in locations and personnel (Albus et al. 2019). Variability due to personnel and site changes also applies to professional datasets and highlights the importance of building in ongoing paired comparison checks in State of the Environment (SOE) and other 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 is collected continues to be inaccessible or stored in formats that make it 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 The evolution of freshwater CBM in New Zealand

Figure 2-4 presents a timeline of some interesting milestones relevant to CBM activities in New Zealand. The origins of CBM in this country are closely connected with community involvement in environmental restoration activities (Atkinson 1988). Recent estimates of volunteer efforts from Conservation Volunteers New Zealand indicate that there were over 100,000 volunteer days between 2006 and 2020, spanning activities such as planting and weeding, litter clean-ups and invasive species control. Freshwaters (rivers, lakes, and wetlands) represent the ecosystems most commonly targeted by community groups for restoration, with nearly half of those groups conducting stream monitoring (Peters et al. 2015).

Early support for freshwater CBM in New Zealand began around the late 1990s through a range of programmes. These programmes were administered by a mixture of regional authorities (e.g., 'Stream Sense' by Waikato Regional Council, 'Wai Care' by city councils and (the then) Regional Council in Auckland, and 'Take Care' by Greater Wellington Regional Council), universities (e.g., 'Waterwatch' by Lincoln University), and – later – by independent government bodies (e.g., National Waterways Project by the Royal Society of New Zealand) or trusts (e.g., 'Styx River Catchment Water Quality Monitoring Programme' by the Styx Living Laboratory Trust).

In the late 1990s, NIWA developed the Stream Health Monitoring and Assessment Kit (SHMAK) in association with Federated Farmers and other organisations, including the New Zealand Landcare Trust (NZLT) (Biggs et al. 1998, 2002). The SHMAK uses biomonitoring indicators (periphyton and benthic macroinvertebrates) to assess stream ecological condition, with supporting measurements of water quality and stream habitat variables. The kit was originally developed for the farming community but was soon adopted more widely by community and school groups. It has also been incorporated into many council-run 'stream care' programmes, NZLT monitoring activities, and more recently it has been adopted by Sustainable Coastlines as part of their riparian planting and monitoring programme.

In 2002 the Mountains to Sea Conservation Trust (MTSCT) was established to deliver community and school-based conservation programmes. This included Whitebait Connection (founded with the Department of Conservation, DOC), a dedicated freshwater community conservation education and monitoring programme that currently spans seven regions across New Zealand. According to MTSCT (2019), over 90,000 people have engaged in river monitoring and 87 inanga spawning sites have been restored. As part of their fish monitoring activities, MTSCT contribute data to the NZ Freshwater Fish Database (Baseley et al. 2014).

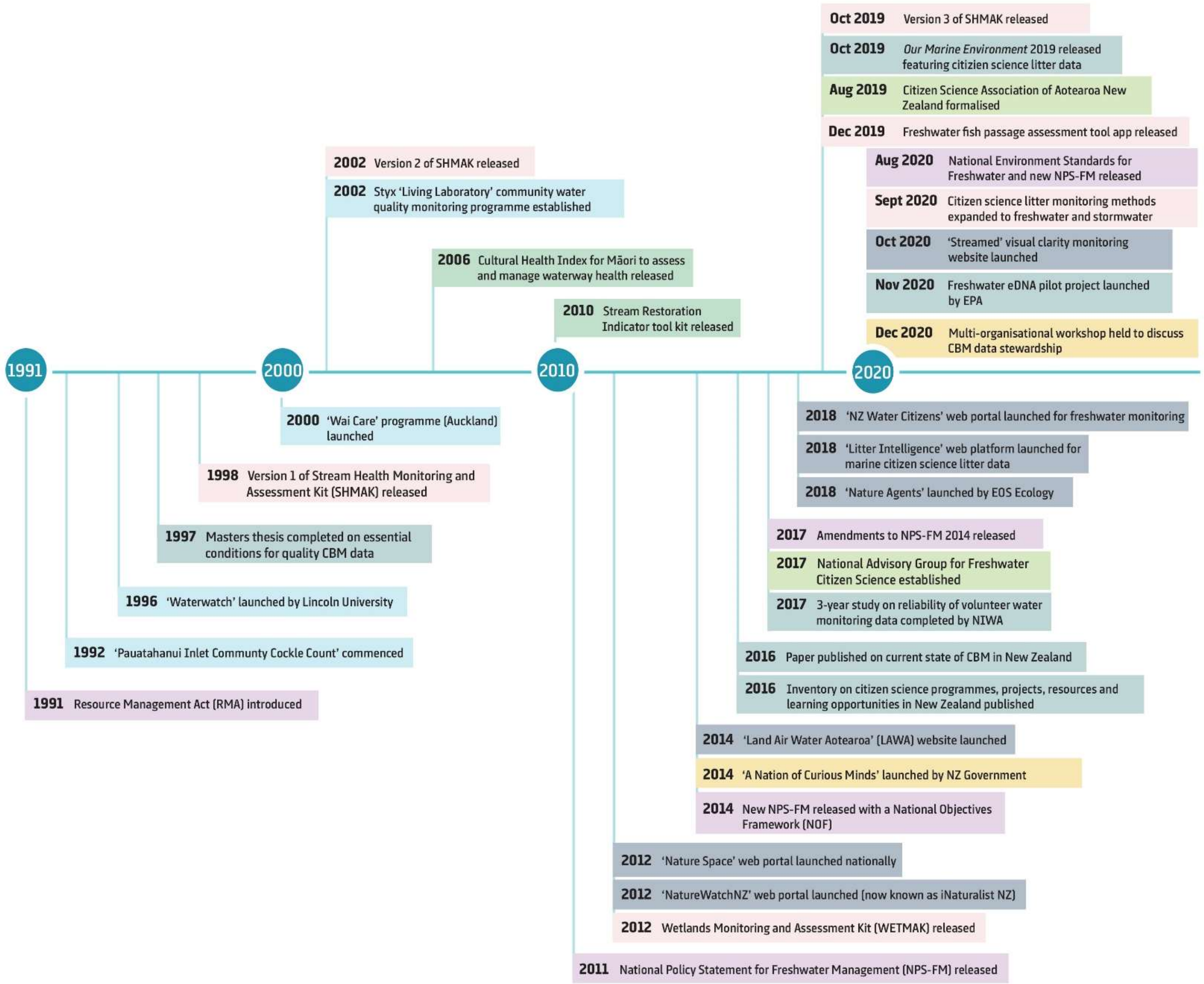



**Figure 2-4: Timeline of interesting milestones relevant to CBM activities in New Zealand.** Selected milestones only.

### 2.3.1 Recent initiatives

Since around 2015, continued use of SHMAK and growing community interest in using the monitoring data to inform freshwater management sparked the start of several stream monitoring research and development initiatives. These initiatives, summarised in Valois et al. (2019) include:

- Comparison-based studies of volunteer results using SHMAK and professional results for a selection of SOE variables (e.g., Storey et al. 2016, Storey and Wright-Stow 2017)[9];
- An upgrade of the SHMAK to incorporate additional variables (including *E. coli* and nutrient testing) and standardised protocols for volunteers to measure many SOE-based variables;
- Release of instructional videos and other training resources;
- The development of a web-based database and mobile phone app (NZ Water Citizens) for CBM groups to enter, visualise and share their SHMAK data; and
- Trialling assessments of swimming quality of waters with community groups (e.g., Valois et al. 2019).

A training programme to introduce CBM groups to freshwater monitoring and provide instruction on how to use the SHMAK was recently developed by Greater Wellington Regional Council (GWRC) and Mountains to Sea Wellington. The programme was initally class and field-based but moved to online delivery in 2020 during the COVID-19 outbreak (using the RiPPLE platform).

Additional CBM programmes and databases have been set up in the last few years. Litter Intelligence, led by Sustainable Coastlines, in close collaboration with the Ministry for the Environment (MfE), DOC and Statistics NZ (Stats NZ), is an example of a recently established CBM programme operating at the national scale. Launched in May 2018, Litter Intelligence supports collection of litter data by community groups and displays this on a web portal; the ultimate aim is to demonstrate the extent of New Zealand's litter problem so as to create behavioural change (Milne and Valois 2020). The initial focus was litter in the marine environment where adoption of standardised survey protocols led to acceptance of the litter data for use as a Tier 1 statistic in the MfE/Stats NZ (2019) marine domain national state of the environment report. More recently, standardised protocols for monitoring litter in freshwater and stormwater have been developed in partnership with NIWA, Auckland Council and Nelson City Council.

Many regional or place-based CBM initiatives have also been established across New Zealand in the past five to ten years. Freshwater examples include:

- NZLT supported catchment groups – including both small subcatchment partnerships and large catchment groups such as the Pomahaka Water Care Group (2014) and the Rangitīkei Rivers Catchment Collective (2017), many of which collect water samples for laboratory testing;
- The Touchstone Project – a direct action initiative involving community members concerned about the Lake Wanaka water catchment, including algal blooms and

[9] These studies found good agreement between volunteer results using SHMAK and professional results for a number of variables (e.g., water temperature, visual water clarity, periphyton, benthic macroinvertebrates and, to a lesser extent, *E. coli* indicator bacteria). Moffet and Neale (2015), in an assessment of stream macroinvertebrate results from volunteers using Wai Care methods and professionals using Auckland Council SOE methods, also found significant correlations between most common indices of ecological health (and concluded that volunteer data could detect long-term trends in ecological health).

water quality in the lake and its tributaries (established by Aspiring Environmental in 2015);

- Tomahawk Lagoon Citizen Science Team – a 'lake health' programme involving regular water quality monitoring carried out by groups of intermediate and high school students in Dunedin (established by the ECOTAGO Charitable Trust in 2017); and
- Nature Agents – a 'Learning Experiences Outside the Classroom' (LEOTC) waterway health programme for schools and community groups in Christchurch (established by EOS Ecology in early 2018).

Several national funding streams have supported CBM initiatives. A number of freshwater CBM groups were able to establish due to funding from MBIE's Participatory Science Platform (e.g., the Touchstone and Tomahawk Lagoon projects mentioned above). This funding platform, established in 2015, is part of MBIE's Curious Minds initiative which also includes the funding scheme 'Unlocking Curious Minds'. Unlocking Curious Minds has been deferred for 2021 but the Participatory Science Platform is still active in the three pilot regions (South Auckland, Taranaki and Otago). The MfE's Community Environment Fund has been funding projects which encourage participation in environmental initiatives, including water monitoring, since 2010. The DOC's Community Conservation fund was established in 2014 to support community-led conservation projects on public and private land and recently awarded MTSCT three years of funding to support SHMAK-based monitoring of stream restoration projects. More recently, the Environmental Protection Authority launched 'Wai Tūwhera o te Taiao – Open Waters Aotearoa', a pilot eDNA science programme in which community groups and hapū across the country were invited to collect and submit to a laboratory water samples from rivers, lakes, estuaries and wetlands for assessment of biodiversity using eDNA.

## 2.4 Current drivers and opportunities for CBM in New Zealand

The recent growth of CBM initiatives in New Zealand is likely driven by increased public awareness and concern around the state of freshwater ecosystems, including risks to 'swimmability' and threatened species. Water quality has been consistently rated by the public as the most pressing environmental issue in New Zealand since surveys 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 water management. Water 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). As noted in Section 2.1.3, 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, also reduce 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 New Zealand's environmental reporting (PCE 2019) present another opportunity for CBM. Councils and other organisations responsible for freshwater management have finite resources for monitoring. As noted in Section 2.2.1, a major strength of CBM is in augmenting the reach, effort and resources of professionals to increase the pool of freshwater data available to inform a range of applications at different scales in time and space. Potential applications, in addition to contributing to regional or national SOE reporting, include development or validation of models, biodiversity surveys, biosecurity surveillance, early warning and hotspot assessments, and evaluation of the effectiveness of restoration initiatives. The pending near-universal requirement for a Farm Environment Plan (FEP) introduced in the National Environmental Standard for Freshwater (NES-FW, NZ Government 2020)[10] presents another opportunity for CBM: on-farm water monitoring will assist with establishing baselines and tracking the effectiveness of land use management actions.

An increasing number of councils, central government organisations and industry have established requirements or strategic priorities that promote the collection and/or use of CBM data. 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), and 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) identifies *"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) is *"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".*

## 2.5 Synthesis

Community-based monitoring is a form of citizen science which offers community members an opportunity to participate in the collection of environmental data. Although both professional scientists and decision-makers have raised concerns over the quality of CBM (and other citizen science) data, an increasing pool of evidence suggests that, under the right circumstances (e.g., adequate training, support and feedback), community volunteers can potentially produce data of comparable quality to professionals. This has led to an increased recognition nationally and internationally of the potential of CBM to increase community engagement and science literacy and inform environmental assessments and decision-making through filling data gaps in time and space.

While other challenges also exist with CBM, including availability of sufficient resources, sustaining the motivation of community volunteers, and ensuring the collected data are accessible, increased recognition of its value has resulted in the development of best practice and shared learning. There

[10] A FEP will likely be required for farms with 20 or more hectares in arable or pastoral land use, or with 5 or more hectares in horticultural land use.

are now many standardised sampling protocols, monitoring tool kits, websites and other resources available to support CBM initiatives.

Over the past two to three decades, CBM – particularly freshwater CBM – has grown and become more organised in New Zealand. Growing acceptance of CBM and recognition of its potential value in freshwater (and wider environmental) management is reflected in an increasing number of local and central government strategies promoting the collection and/or use of CBM data. However, to ensure that CBM data can be used to its full potential, it needs to be credible, visible and accessible. In the next section, we introduce the key components of quality assurance that underpin data credibility.

# 3 Quality assurance

Any environmental monitoring programme or project, whether it be professional or community-based, must aim to produce information that is accurate, reliable and adequate for the intended purpose. Quality assurance (QA) is central to ensuring data credibility and is important throughout the entire environmental monitoring process, from field measurements to sample collection, dispatch, storage and analysis, and subsequent data processing, analysis and management. In this section we outline the key concepts relating to data quality management, including QA, standard operating procedures (SOPs), quality control (QC), accuracy, precision, bias, uncertainty and metadata.

## 3.1 What does data quality management tell us?

Data are either useful, or not useful, for their intended purpose. A quality management system ensures that a user of data has the contextual information (or metadata) necessary to judge whether the data are adequate for the intended (or another potential) purpose. Different uses of data typically have different quality-related requirements. For example, the required precision (and therefore accuracy) of water column nitrogen measurements to inform a compliance assessment with receiving environment limits on a resource consent will be greater than the accuracy and precision requirements required to identify pollution 'hotspots' along the length of a river.

## 3.2 Quality assurance vs quality control

Quality assurance (QA) refers to a broad suite of documented plans and procedures for maintaining quality in all aspects of an environmental monitoring programme or project. Documentation should describe how monitoring will be undertaken, including detailed instructions of all procedures (e.g., calibration and sampling processes), training of personnel, study design, data management and analysis, and record keeping. It also includes specific quality control (QC) measures that confirm the QA methods are functional and that information collected is accurate, precise and properly recorded.

Quality assurance forms a key component of a larger quality management system that provides the framework for planning, implementing and assessing activities performed by an organisation and for carrying out required QA and QC activities (Figure 3-1). In this section we focus on QA and QC because these activities apply at a programme or project scale (i.e., the scale at which CBM activity typically occurs). Consistent QA/QC activities produce data of known quality.


**Figure 3-1: Relationship between a quality system, quality assurance (QA) and quality control (QC).**
QA and QC requirements are defined during the monitoring design process when monitoring objectives are established.

## 3.3 Components of QA

Quality assurance is essentially the totality of the plans put in place *before* monitoring to manage quality throughout all stages of the monitoring process. The number and type of QA components are often variously described, in part depending on whether QA relates to a monitoring programme or a monitoring project (the latter relating to activities designed with a defined start and end point in time). Here we briefly describe some common components of QA, including a QA plan. We start with the overall monitoring plan since this forms the basis for establishing a QA plan. Figure 3-2 summarises how QA fits within the general monitoring process, highlighting its importance in the planning phase.

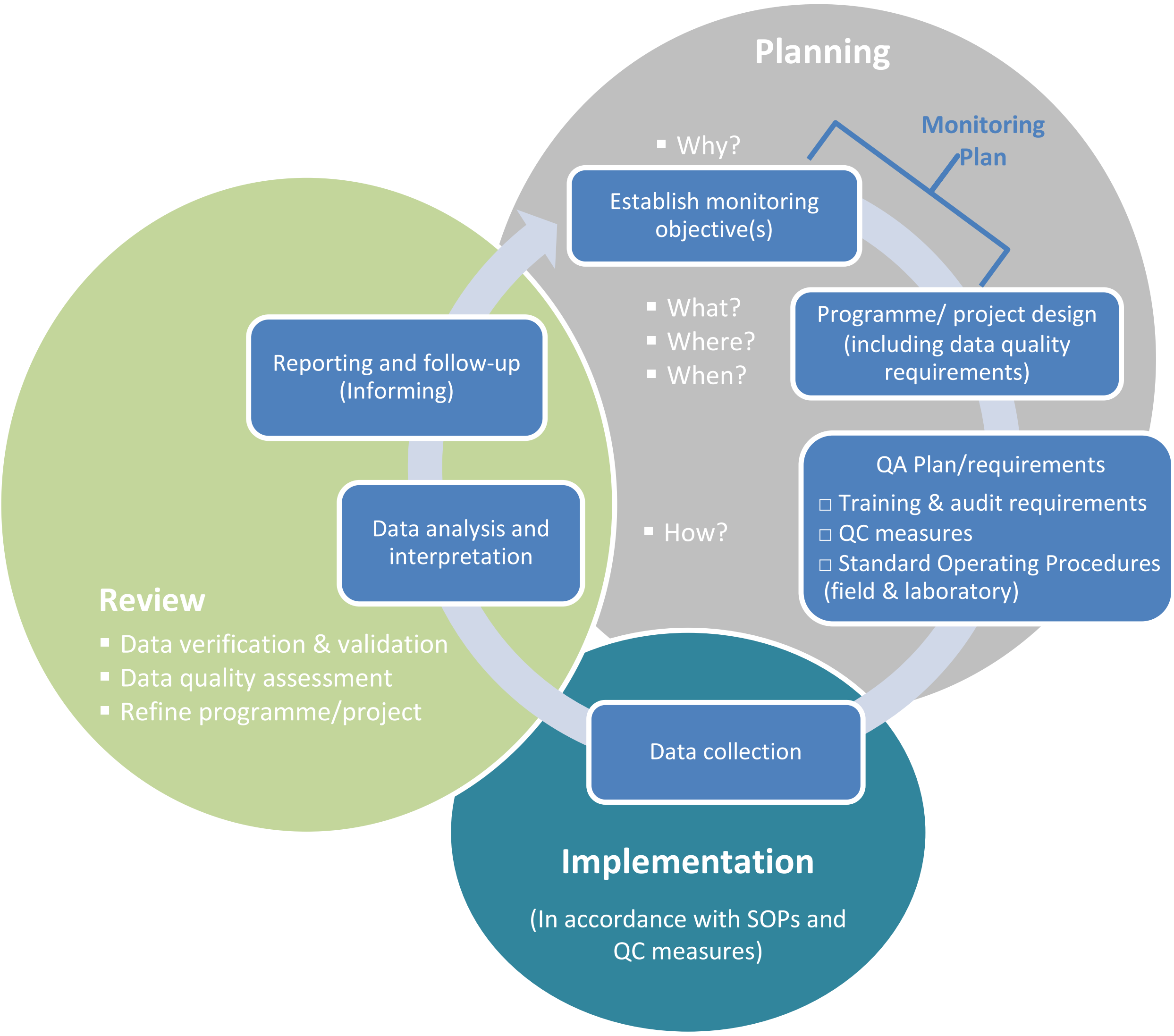



**Figure 3-2: Schematic illustrating how QA fits within the general monitoring process.** Concepts based loosely on EPA (2002) project level quality system components and tools.

### 3.3.1 Monitoring plan

A monitoring plan establishes the reason or purpose for monitoring and outlines what to monitor, where, and when, as well as the roles and responsibilities of the project team members and other existing data that could refine any monitoring questions. A monitoring plan also supports consistency through time and so is particularly important for long-term programmes where sampling personnel (as well as equipment and methods) may change.

A critical requirement of the monitoring plan is to clearly establish the type and specifications of the information sought, referred to by the United States Environmental Protection Authority (EPA) as data quality objectives. These objectives are qualitative and quantitative specifications that are used to define the QA and QC requirements for individual monitoring variables in a closely associated QA Plan or Quality Manual. An important point in the context of CBM is that data quality objectives are often set by end users of the data together with relevant technical experts. The objectives will also be influenced by the method of measurement, particularly in relation to accuracy and precision, highlighting the importance of checking the comparability of methods before adopting a new or alternative method.

In New Zealand, the National Environmental Monitoring Standards (NEMS)[11] establish data quality criteria for many hydrometric, water quality and other environmental variables collected as part of 'professional' SOE (or similar) monitoring programmes. For example, to be eligible for the highest quality code rating of QC 600 in the NEMS Water Quality (the standard expected for long-term state and trend monitoring), laboratory-based measurements of dissolved chloride concentrations in groundwater must be made on water samples filtered in the field through 0.45 micron filters using test method APHA 4100 B and a minimum method detection limit of 0.5 mg/L.

### 3.3.2 QA plan

A QA plan sits alongside (or sometimes within) the monitoring plan and sets out the procedures and QC performance measures used to ensure that the data collected are of the type, quality and quantity specified in the monitoring plan. A QA plan typically includes reference to relevant training and SOPs. It provides confidence to data users, who can view the details of the monitoring programme, and eliminates questions of how the data were collected. This is particularly important for CBM given that concerns are often cited about data quality (refer Section 2.2.2).

### 3.3.3 Standard Operating Procedures

Standard Operating Procedures (SOPs) are step-by-step instructions for carrying out specific routine components of the monitoring such as equipment use and maintenance, sample collection, and data processing. Detailed instructions are generally prepared for long-term monitoring programmes taking into account relevant and recognised monitoring standards and guidance, as well as Health and Safety requirements.

Many SOPs for freshwater monitoring include templates or standard forms to aid consistent documentation of critical activities and information. For example:

- A monitoring site form that sets out key site metadata requirements (observations) to be maintained such as the name, number and location of a monitoring site, site access details, relevant environmental characteristics (e.g., immediate and/or upstream catchment land use, nearest weather station) and specific Health and Safety considerations;
- A calibration form for field meter validation and calibration checks;
- A field record form to record details of field visit measurements and any samples collected, including the names of the field personnel, the protocols used, and observations (visit metadata) of the environmental conditions under which these measurements and samples were collected (e.g., weather); and

[11] www.nems.org.nz

- A Chain of Custody (CoC) form for inclusion with samples couriered to a laboratory or third party to provide an audit trail of sample integrity from sample dispatch to sample arrival.

The information captured on these forms provides an essential record for QA assessments.

### 3.3.4 Training

Training of personnel in environmental monitoring and data management is often overseen at an organisational level but may be specific to a monitoring programme or project. For CBM, training may include online, class-based and field-based activities for group members to learn about different aspects of monitoring (e.g., site selection, sampling methods, data entry and data analysis). Training can include an element of certification (pass/fail) or just be participation-based.

### 3.3.5 Audits and checks

Periodic audits of the different QA components ensure that the criteria in the QA plan are being met. Some of these checks represent an example of QC and can be made internally and/or externally. In New Zealand, many commercial laboratories have their analytical methods independently audited as part of *International Accreditation New Zealand* (*IANZ*), the accreditation body of the Testing Laboratory Registration Council in New Zealand. Having IANZ accreditation is a requirement of the NEMS for groundwater and surface water quality laboratory measurements to be eligible for the highest quality code. It is often also a requirement of resource consents that include conditions for water sample analysis.

Although an IANZ equivalent does not exist for field-based environmental monitoring activities in New Zealand, the NEMS recommends – and in some cases requires – independent checks of practices by third party organisations. Such checks are commonplace for many CBM initiatives (Albus et al. 2019) and may form part of a certification process for volunteers (e.g., the Missouri Stream Team[12]).

### 3.3.6 QC

Quality control refers to an overall system of technical activities or measures that determine whether the collected environmental data meet the quality requirements specified in the QA Plan (EPA 2002). These activities, set out in the QA Plan, are carried out during monitoring and include both internal activities performed by the monitoring organisation/group and external activities carried out by a third party such as an independent sampling agency or laboratory.

Three key and interrelated aspects of QC are measurements of *accuracy*, *precision* and *bias*. Accuracy is the closeness of agreement between a measured value and the true value (McBride 2005) and comprises two main aspects:

- **Precision**, referring to random error, is the closeness of agreement between repeated independent measurements of a variable on the same sample, carried out under unchanged conditions of measurement.[13]
- **Bias**, referring to systematic error (Davies-Colley et al. 2012), is consistent over- or under-reporting in the measurement of a variable because of, for example, a field or

[12] http://mostreamteam.org/water-quality-monitoring.html

[13] Precision is sometimes used interchangeability with repeatability and reproducibility. Strictly speaking, repeatability is the precision determined under conditions where the same methods and equipment are used by the same operator to make measurements on identical samples/specimens. In contrast, reproducibility is the precision determined under conditions where the same methods but different equipment are used by different operators to make measurements on identical samples/specimens (Csavina et al. 2017).

laboratory sensor that consistently over-reports the concentration of a contaminant present in a water sample. Unlike random error, which can't be corrected for, bias or systematic error behaves in a predictable way and can be corrected when the true value is known (e.g., the value assigned to a calibration standard).

High quality (i.e., accurate and, therefore, reliable) data exhibit high precision and low bias (Figure 3-3). Uncertainty can provide an estimate of accuracy and is typically expressed as an interval about the result (e.g., 0.013 ± 0.002 mg/L), at a stated level of confidence (e.g., 95% confidence interval or about ± 2 standard deviations). Many analytical laboratories refer to this as the uncertainty of measurement (UoM), which represents an estimate of the variability inherent in a measurement based on instrument and equipment calibrations, purity of chemicals used for making calibration standards, and human factors (NEMS 2019).

Because the true value of a given environmental attribute is typically unknown, the best we can do to infer accuracy is to measure the level of agreement or 'reproducibility' between different agencies or groups independently sampling/measuring the same environmental variable. While close agreement implies accuracy, it does not guarantee it, because both agencies could be subject to bias of the same type (Davies-Colley et al. 2019).

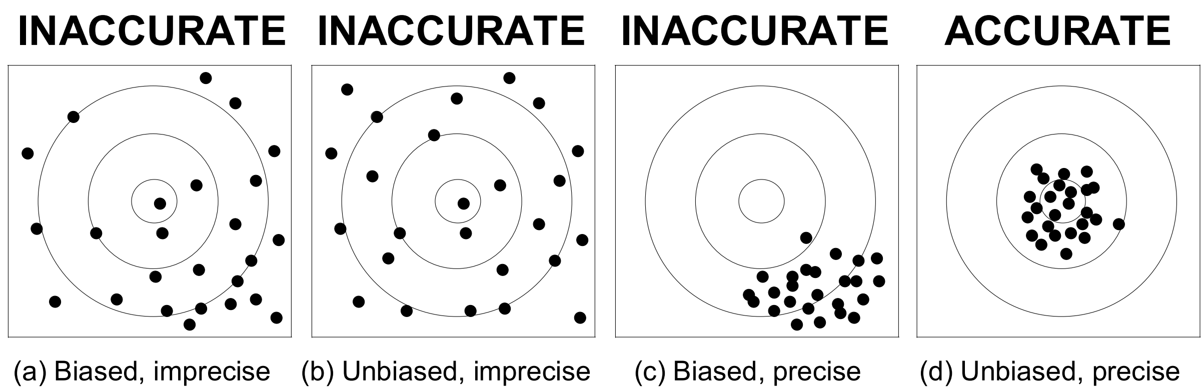



**Figure 3-3: Accuracy, precision and bias in environmental measurements.** These concepts are illustrated by the analogy of a dart board in which the true value of some environmental variable (e.g., total nitrogen) is represented by the bulls eye. After McBride (2005).

Examples of QC measures applicable to monitoring of water quality variables include sample blanks (which can assess contamination during any stage of sample collection or analysis), sample replicates (to assess precision in sample collection or analysis), and spiked samples (samples of a known contaminant concentration which assess for errors with sample testing/measurement (Table 3-1, NEMS 2019). For biological monitoring (e.g., benthic macroinvertebrates), QC measures often target sample sorting and identification but should also be applied to sample collection and preservation (NEMS 2020). This is necssary to ensure that representative samples are collected and sample integrity is maintained throughout the period between collection and processing.

Collection of field replicates and independent external checks of sampling and testing practices by professional monitoring agencies and laboratories are common practice in many CBM initiatives. Periodic checks by professionals are particularly important for variables that are measured *in-situ*, such as visual water clarity and stream habitat variables.

**Table 3-1: Common QC measures applicable to monitoring of water quality and biological variables.** Adapted from NEMS (2019) and EPA (2002).

| QC measure |
|---|
| ***Water quality in-situ (field) measurements, and water sample collection and analysis*** |
| Field blanks: 'Clean' samples collected in the field using distilled water used to check for any background contamination arising from the sample container, collection or handling. Particularly important when measuring natural waters with very low nutrient/contaminant concentrations (e.g., reference sites). |
| Field replicates: Two or more field measurements (e.g., visual clarity, dissolved oxygen) or water samples collected at the same site at the same time but measured independently to characterise variability between field personnel or, where collected by the same personnel, laboratory performance. In CBM, replicate field measurements or samples may be collected by another group member or by an independent third party such as a different CBM group, a trained facilitator or a professional monitoring agency (refer to audits in Section 3.3.5).<br>*Note: Replicate water samples for laboratory measurement should be 'blind samples' assigned a false name so that the laboratory does not know the actual location of collection.* |
| External laboratory verification: A water sample is submitted to a professional laboratory to verify in-situ measurements (commonplace with CBM groups; for example. to validate measurements made from portable test kits) or a field or laboratory replicate is submitted to another laboratory as an independent check on the primary laboratory. |
| Laboratory replicates: A single field sample that is split into 2 or more subsamples in the laboratory to assess analytical precision. |
| Calibration standards: A traceable standard used for checking the accuracy of and adjusting (calibrating) field or laboratory instruments – typically a solution of standard concentration. |
| Spiked samples: A known quantity of an analyte is added to the water sample of interest and then measured. Typically reserved for the laboratory to validate test methods (helps to identify sample matrix effects and determine the recovery of an analyte and method sensitivity). |
| Standard reference materials (SRM): A certified water sample of known chemical composition and/or physical properties typically used by laboratories to confirm the accuracy of a test method. In CBM, these are often referred to as 'mystery box' samples and are presented 'blind' to participants. |
| ***Biological variables – in-situ assessments, and sample collection and analysis*** |
| Field replicates: Similar to water quality field measurements and sample collection, two or more samples collected at the same site at the same time to characterise variability between field personnel or the laboratory. |
| Photographs: Used to assist with or verify species identification (e.g., periphyhton, macrophytes) or point estimates of cover (e.g., fine sediment, filamentous algae) on the bed of a river or other waterbody. |
| Voucher specimens: A preserved, representative sample(s) of a plant or animal species used to verify the accuracy of taxonomic identification. In CBM, voucher specimens can be used as 'mystery box' (preserved or photos) to assure volunteer skill levels or identification resources are suitable. |
| External taxonomic verification: Common with macroinvertebrate monitoring, taxa in one or more samples are independently enumerated and identified by a second person to confirm the accuracy of counts and identifications. |

## 3.4 Synthesis

Quality assurance is critical for ensuring data are credible. Although applicable to all environmental monitoring, good documentation of monitoring procedures and associated QA requirements is particularly relevant for CBM groups or other non-professionals because concerns about data quality are often cited as a key reason why professional scientists will not use the data collected by these groups.

The data quality objectives or criteria required of a particular CBM group or monitoring project will depend on the intended purpose and use of the data. For groups who expect their data to be used by other organisations, they must understand at the outset of a project what the quality requirements expected by those organisations are and the steps they need to take to meet those requirements. In many cases, data collected for one purpose may also be useful for another unintended purpose but this can only be known if the data collection methods and associated QA information and other metadata are documented and readily accessible. A Monitoring Plan and a QA Plan should be critical components of CBM. In the next section we examine the approaches taken overseas to address QA in CBM.

# 4 International QA frameworks and initiatives for CBM

Various approaches already exist overseas to guide QA aspects and the appropriate use of CBM data. In this section, we review some of the QA frameworks and/or guidance that have been developed for citizen science projects (with a focus on community-based water monitoring programmes where possible) in the United States of America, Canada, Australia and the United Kingdom. We selected these nations because they have some long-established CBM water monitoring programmes in place relevant to CBM in New Zealand, we have existing relationships with some of the programme coordinators in these countries and information was generally more readily accessible. Europe lacks a QA framework for CBM but brief commentary is provided on recent developments in Europe relevant to CBM.

Case studies, in the form of one or more specific CBM programmes or projects are also presented for each country to provide specific insights into QA, including data management and use. We note that some country-specific differences in terminology (e.g., watershed vs catchment) and spelling (e.g., program vs programme) exist in this section. There are also differences in the completeness of information on some aspects of QA measures, reflecting differing levels of information available on relevant websites and in the literature.

## 4.1 The United States of America (USA)

In the USA, the Environmental Protection Agency (EPA) is the federal agency responsible for protecting human health, national resources and the environment from pollution, and for setting and enforcing limits on pollution. The EPA has identified a range of purposes for citizen science that span from engagement and education through to regulatory decisions and enforcement (Figure 4-1). Volunteer water quality monitoring efforts were some of the earliest citizen science programmes supported by the EPA in response to meeting the requirements of the 1972 Clean Water Act (Jalbert and Kinchy 2015). According to the National Water Quality Monitoring Council, there were approximately 1,720 volunteer water monitoring groups across the USA in 2014[14].

In 2016, the Crowdsourcing and Citizen Science Act was passed, granting the US government authority to use crowdsourcing and citizen science methods to advance scientific research. Since the passing of the Act, a number of significant documents have been published in relation to the effective use of citizen science data by the EPA. For example:

- *Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA* (NACEPT 2016) – the National Advisory Council for Environmental Policy and Technology (NACEPT) assessed the EPA's existing approach to citizen science and made recommendations to embrace citizen science as a core tenet of environmental protection, invest in citizen science for communities, partners and the EPA, enable the use of citizen science data at the EPA, and integrate citizen science into the full range of the EPA's work.
- *Information to Action: Strengthening EPA Citizen Science Partnerships for Environmental Protection* (NACEPT 2018) – a follow-on to NACEPT's first report, this report outlines how the EPA can foster collaboration and partnerships to use citizen science information and data for action that improves human health and the environment.

[14] https://acwi.gov/monitoring/vm/

- *A Manual for Citizen Scientists Starting or Participating in Data Collection and Environmental Monitoring Projects* (Harvard Law School 2019) – a manual that helps individuals and organisations to identify, design and implement citizen science projects. It is supported by a survey of laws across all 50 US states relevant to the activities of citizen scientists and includes regulatory and evidentiary standards applicable to uses of environmental data.

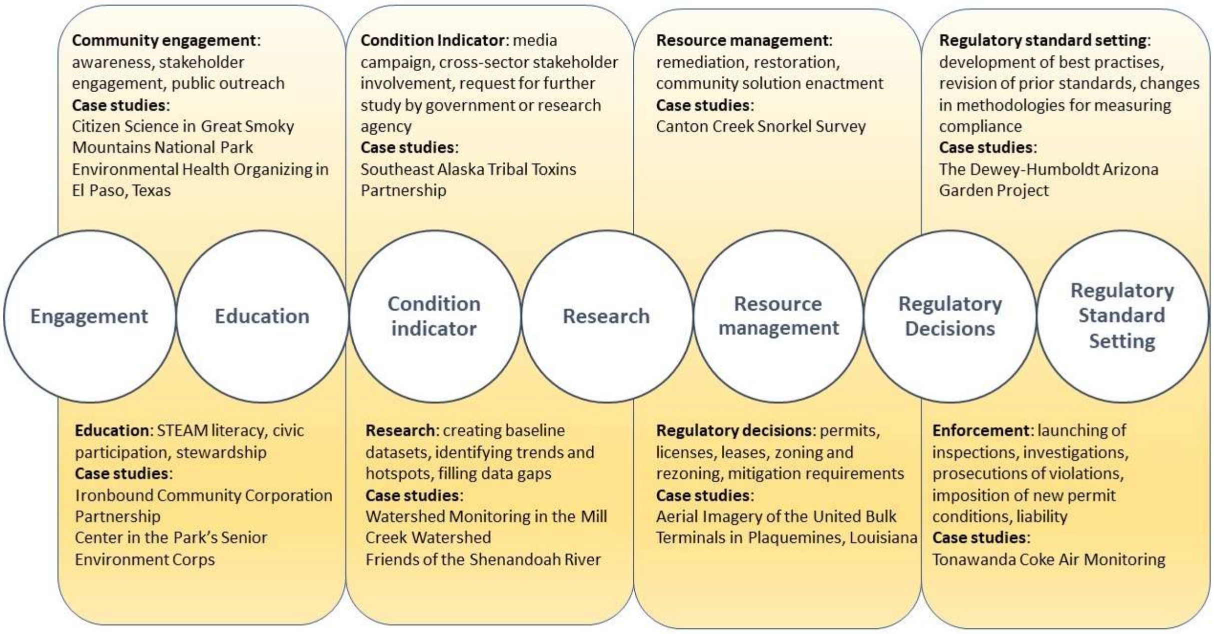



**Figure 4-1: The spectrum of citizen science data use by the EPA with case study examples.** Details on these case studies can be found in NACEPT (2016).

A Quality Assurance Project Plan or (QAPP) is central to ensuring QA for all projects implemented or supported by the EPA. Similar to a QA Plan outlined in Section 3.3, the QAPP is a document that outlines the procedures a monitoring project will follow to ensure that measurements, samples, data and subsequent reports are of sufficient quality to meet project objectives (EPA 1996). In 1996, the EPA released the first guide to a volunteer QAPP focussing on freshwater and estuarine data. In 2019, the volunteer QAPP process was updated to include a graded approach to data quality reflecting three tiers or general categories of citizen science data use:

1. Increasing public understanding;
2. Scientific studies and research; and
3. Supporting legal action and policy.

While the tiered approach suggests potential data uses, data uses can extend beyond those suggested, and it is ultimately the decision of the end users to choose the data which are appropriate for their specific use(s) based on the metadata supplied. The QAPP process outlines what should be documented in the metadata to adequately assess the quality of the data.

The updated QAPP process includes a number of new resources, such as:

- *The Handbook for Citizen Science Quality Assurance and Documentation* (EPA 2019a) – sets out common expectations for quality assurance and documentation; and best management practices for organisations that train and use volunteers in the collection of environmental data.
- *Templates for Citizen Science Quality Assurance and Documentation* (EPA 2019b) – comprises 19 templates that together make up a QAPP, and examples of completed templates to help CBM groups prepare a QAPP.
- *Quality Assurance Project Plan Development Tool*[15] – an online tool that steps CBM participants through the process of planning and documenting a citizen science project.

All citizen science projects funded by the EPA that involve the collection or use of environmental data are required to have an EPA-approved QAPP. Most states follow EPA guidelines for developing a QAPP, both for agency data collection and citizen science projects (Hardvard 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 volunteer water quality monitoring programme.

Data collected by CBM groups can be found in both the EPA's Water Quality Portal as well as state water quality databases (Read et al. 2017). Some states have databases specifically for their state-sponsored volunteer water quality monitoring programme (e.g., Indiana's Hoozier Riverwatch database[16]).

### 4.1.1 Case Study 1: Chesapeake Monitoring Cooperative

The Chesapeake Monitoring Cooperative (CMC) is a multi-state initiative (the first of its kind in the USA) that supports the collection of freshwater and estuarine water quality monitoring data and freshwater benthic macroinvertebrates in the Chesapeake Bay catchment on the United State's east coast. Chesapeake Bay is the largest estuary in the USA, with the CMC spanning seven juristications and designed to integrate data across both state borders and a multitude of partners (Tango 2019). As of January 2021, 541 individuals belonging to 105 monitoring groups and collecting data from over 1,700 sites contribute to the CMC[17].

The CMC supports CBM groups through four service providers; the Alliance for the Chesapeake Bay, the Izaak Walton League of America (IWLA), the Alliance for Aquatic Resource Monitoring (ALLARM), and the University of Maryland Centre for Environmental Science. The CMC was formed in 2015 (although the service providers have been working with community groups for much longer) and is resourced by the EPA through to December 2021.

Community groups participating in the CMC monitor for a wide range of purposes. The 2016 Chesapeake Monitoring Census (Rubin et al. 2017), which canvassed over 600 community groups to

[15] https://www.epa.gov/quality/quality-assurance-project-plan-development-tool#tab-1
[16] https://www.hoosierriverwatch.com/
[17] https://cmc.vims.edu/#/home

understand monitoring activities across the catchment,[18] identified that the most common monitoring purposes were to monitor water quality and habitat change in response to restoration activities (27% of respondents) and collect baseline data (22% of respondents)[19]. The CMC programme itself has identified four specific goals which informed the development of their QAPPs:

- to understand the status and trends of Chesapeake Bay waters based on watershed inputs;
- to identify nutrient and sediment inputs from contributing waters to verify progress of management actions;
- to identify nutrient and sediment hot spots for targeted restoration; and
- to assess the health of the waters at prominent input sites (Alliance for the Chesapeake Bay and Alliance for Aquatic Resource Monitoring 2017).

Monitoring groups use a range of methods. For example, monitoring groups residing in the lower Chesapeake Bay catchment are trained by the IWLA and follow the IWLA Macroinvertebrate Methods Manual while those in the upper catchment are trained by ALLARM and follow the ALLARM Macroinvertebrate Monitoring Methods Manual. Community monitoring groups who have protocols that differ from CMC protocols can apply to have their monitoring and QA protocols validated and included, particularly if they have been collecting data for a long time[20].

The CMC follows the tiered data framework of the EPA, with each step up in tier demanding more rigorous QA standards, requiring more time and expense. Most community monitoring groups involved in the CMC monitor at Tier 1 or Tier 2, supported by pre-approved general QAPPs (developed by the CMC) to follow to collect water quality and benthic macroinvertebrate monitoring data that will meet the requirements of these tiers (e.g., Chudoba et al. 2017). General QA requirements for data collection at each of these tiers are summarised in Table 4-1. It is important to note that in this programme data quality objectives are specific to each variable and method. For example, where dissolved oxygen (DO) is measured using the Winkler titration method, precision of duplicate DO measurements must be ± 0.6 mg/L. Community groups trained to collect Tier I DO data will include duplicates 10% of the time while those trained to collect Tier II data will include a DO duplicate on every sampling occasion. When collecting temperature data, precision requirements are ±1°C if using an armored thermometer but ±0.5°C if using a digital thermometer.

The laboratory QA practices are not outlined in Table 4-1 but water samples that require laboratory analysis are required to be sent to certified laboratories that follow standard QA procedures (Chudoba et al. 2017).

The CMC identifies and invites experienced monitoring groups it considers suitable to apply for Tier 3 status. Those groups must undergo an audit of their methods and demonstrate that they have incorporated the requirements outlined in the audit through submitting a formal QAPP for approval. An EPA QA officer is responsible for Tier 3 QAPP approval. The CMC prioritises groups monitoring at Tier 3 status due to data needs, with monitoring of tidal waters a priority (Rubin et al. 2017). The Nanticoke Watershed Alliance was the first CBM group to achieve Tier 3 status.[21]

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[18] Not all monitoring groups are registered with the CMC.
[19] http://conservationblog.anshome.org/blog/the-alliance-for-the-chesapeake-bays-chesapeake-monitoring-cooperative/
[20] https://www.chesapeakemonitoringcoop.org/wp-content/uploads/2018/11/Tiered-Framework.pdf
[21] https://www.umces.edu/news/nanticoke-watershed-alliance%E2%80%99s-monitoring-program-reaches-highest-distinction

**Table 4-1: Summary of QA requirements for Tier 1 and Tier 2 water quality data as part of the Chesapeake Monitoring Cooperative.** Details sourced from Alliance for the Chesapeake Bay and Alliance for Aquatic Resource Monitoring (2017).

| QA requirement | Tier I | Tier 2 |
|---|---|---|
| Training | Training not required but must collect water samples under supervision of a certified sampler | Must attend a training workshop and pass certification (with biennial recertification) |
| Equipment | Equipment used must be approved for Tier 1 (or higher) use | Equipment used must be approved for Tier 2 use |
| Site selection | A monitoring site must be approved by a coordinator to ensure that it will provide an adequate representation of the water quality of the stream reach being sampled. The GPS coordinates are verified by a coordinator | |
| Calibration | Volunteers calibrate any equipment that requires calibration prior to being used (within 24 hours of use) | |
| Frequency and completeness | Most water quality variables are required to be measured monthly. At least 75% of the monthly sampling events (9 events per year) must occur | |
| Field replicates[1] | Collect replicate measurements for each variable 10% of the time | Collect replicate measurements for each variable every time |
| Field blanks | 10% of water samples submitted to lab include field blanks | |
| Field duplicates[2] | 10% of water samples submitted to the lab as duplicates | |
| Field audits | Not required | Audits of field collection procedures occur during recertification |
| External laboratory verification[2] | A duplicate water sample is sent to lab and tested for same variables using the same equipment and methods | As for Tier 1 but volunteers must also participate in an external laboratory verification at every recertification workshop |
| Data entry | Must used approved field data sheets and submit original data sheets every 6 months. Ten percent of field data sheets checked against database for errors by the service provider | |

[1] Precision requirements depend on variable/method

[2] Typically relative percent difference ≤20% or within the accuracy range of the equipment

The CMC offers certification workshops for study design, water quality measurement methods, benthic macroinvertebrate methods and data interpretation. Biennial recertification workshops are also offered as are “train-the-trainer” workshops for community members interested in becoming a certified trainer. Certified trainers are required to meet with a CMC coordinator on an annual basis. There is no charge for community monitoring groups to join the CMC and participate in trainings and receive technical assistance. Community groups monitoring in priority areas (identified through a gap analysis overseen by the CMC) may receive funding for equipment (Rubin et al. 2017).

Volunteers upload their data to the Chesapeake Data Explorer with routine automatic transfer of the data to the EPA’s national data warehouse. As well as monitoring data, the Data Explorer can store specific QA/QC data, including equipment details, calibration information and monitoring group descriptions. Each CMC service provider can nominate monitoring coordinators who can add new members and groups to the database and approve the data before they are made public. The data cannot be edited without approval once made public. At the end of 2020, over 300,000 water quality and benthic macroinvertebrate data points were available in the Chesapeake Data Explorer[22].

Data collected under the CMC are used by the Chesapeake Bay Program, which is operated under the direction of the EPA. The data can be used to create catchment report cards and scores, target restoration efforts so that each state can meet the obligations outlined in their Watershed Implementation Plans (WIPs), and detect water quality changes in response to land-use changes (including conservation practises).

### 4.1.2 Case Study 2: Florida Lakewatch

Established in 1986, Florida Lakewatch is a community-based lake monitoring programme that facilitates 'hands-on' citizen participation in managing lakes, estuaries, rivers and springs in the state of Florida. Coordinated by the University of Florida, the primary goal of the programme is the collection of scientifically credible total phosphorus, total nitrogen, chlorophyll *a* and Secchi depth water clarity data from a large number of lakes (Hoyer et al. 2012). With more than 7,700 lakes across Florida, only a small proportion can be monitored by the Florida Department of Environmental Protection (FDEP), the regulatory agency responsible for protecting Florida's water (and air) resources. Public interest and involvement in the programme grew so rapidly in its first few years that the Florida Legislature officially established Florida Lakewatch in 1991 (Chapter 1004.49 F.S.). The Legislature also provides funding to operate the programme.

Lakewatch is one of the largest lake monitoring programmes in the USA, with over 1,500 trained volunteers currently monitoring over 500 lakes, 130 near shore coastal sites, 125 river sites and 5 springs (Florida Lakewatch 2020). Water sampling typically occurs at monthly intervals. In return for their participation in Lakewatch, volunteers receive a quarterly educational newsletter, supplies and use of sampling equipment, individualised training in monitoring procedures, an annual report on their lake, access to lake experts, and invitations to regularly scheduled Lakewatch meetings (Hoyer et al. 2014).

Lakewatch has multiple regional coordinators that train volunteers face to face on their lake in the use of a Secchi disk, the measurement of water depth, collection and handling of water samples (including sample filtration for chlorophyll *a*), and completion of a field record form. A coordinator goes out on the lake with the volunteers where they are trained to sample from one to six pre-determined sites. Sites are generally in open-water areas of each water body and each location is recorded with GPS to maintain site stationarity over time (Florida Lakewatch 2020). The techniques volunteers are taught are outlined in the Water Chemistry Field Sampling and Laboratory Protocols, with volunteers receiving a training manual and laminated summary instructions for use in the field. No audits of volunteer sampling practices appear to be undertaken but since 2020, instructional videos have been available on the Lakewatch website for volunteers who want refresher training. In addition, around 20 regional meetings are held across Florida each year, providing volunteers an opportunity to ask questions as well as receive interpretation of their collected data.

The Lakewatch laboratory (housed within the University of Florida) routinely carries out standard QC checks such as sample blanks and duplicates. The reliability of Lakewatch data has also been assessed via independent comparability studies (Canfield 2002; Hoyer et al. 2012), in part because the

[22] https://www.allianceforthebay.org/project/chesapeake-monitoring-cooperative/#:~:text=At%20the%20end%20of%202020,cover%20all%207%20bay%20jurisdictions.

Lakewatch laboratory lacks national accreditation[23]; a requirement of FDEP's QA Rule (Chapter 62-160 Florida Administrative Code) to ensure the scientific validity and legal defensibility of data used for regulatory purposes. Both comparability studies concluded that Lakewatch data were nearly equivalent to that collected by the FDEP. Hoyer et al. (2012) deemed the quality of LakeWatch data fit for assessment of trends in nutrient and chlorophyll concentrations, noting that detection of a deteriorating trend in water quality could serve as an early warning ("Lakewatch Canary"), enabling the FDEP to direct its limited monitoring resources to gathering the additional data needed for regulation.

Florida Lakewatch and the FDEP have been working towards developing QA procedures that recognise the logistical limitations associated with volunteering monitoring but still provide the documentation needed to ensure Lakewatch data are of sufficient quality for regulatory decision-making. The data have been used to address lake management issues and Lakewatch has also served as a platform for research, education and extension/outreach activities, with data having been used in more than 30 peer reviewed journals (Hoyer et al. 2014). Lakewatch data are also included in the Florida Atlas of Lakes website, a purpose-built website to highlight Florida's lake resources and share data collected by Lakewatch volunteers.

## 4.2 Canada

In Canada, volunteer monitoring programmes and protocols exist across multiple sectors and jurisdictions (Carlson and Cohen 2018). Environment and Climate Change Canada (ECCC) is the department of the Government of Canada responsible for coordinating environmental policies and programmes. In 1994, the ECCC co-founded the Ecological Monitoring and Assessment Network (EMAN), a national citizen science programme to conduct long-term monitoring and assess how Canadian ecosystems are affected by multiple stressors (Brydges and Lumb 1998). Although it was discontinued in 2010 due to budget cuts, many of the EMAN protocols are still in use by community groups across Canada.

The ECCC also directly supports a number of local and regional-scale community monitoring programmes. Examples include the Mikisew Cree First Nation – Community Based Monitoring Program, the Atlantic Water Network, Swim Drink Fish, and the Canadian Shellfish Sanitation Program. Unlike the EPA, the ECCC imposes no requirements for ECCC-funded groups or programmes to adhere to a specific data quality framework. The ECCC incorporates CBM into its national bioassessment programme, the Canadian Aquatic Biomonitoring Network (CABIN), discussed in the case study in Section 4.2.1.

Community-based monitoring and research in Canada is largely spearheaded by two charitable organisations, Living Lakes Canada and the Gordon Foundation. In 2018, these organisations commissioned or wrote the following:

- *A Snapshot of Community-Based Water Monitoring in Canada* (Carlson et al. 2017) – summarises a survey of 123 freshwater CBM groups across Canada to understand what is being monitored, how the data are managed, and what the relationship is between CBM data and policy development.
- *Community-Based Water Monitoring Survey* (The Gordon Foundation 2018) – documents the findings of a national survey undertaken prior to the November 2018

[23] The Florida Legislature restricts the use of Lakewatch data to trends evaluation and general background information; national laboratory certification is not required for these data uses.

National Roundtable on Community-Based Water Monitoring to understand issues and priorities for CBM in Canada and identify emerging opportunities. Sustainable funding and data management were the top two priority topics and survey participants identified a strategic framework and best practices and tools as the outcomes most wanted from the Roundtable.

- *Community-Based Water Monitoring and Decision Making* (Environmental Law Centre 2018) – reviews case studies of CBM data use from the USA, Australia and European Union to identify successful approaches that could be applied to increasing the use of CBM data in Canada. Recommendations included adopting the EPA's QAPP approach to provide cohesive CBM guidance across provincial and territorial governments and allowing for the integration of CBM data into government databases (including allowing CBM groups to upload their own data and have civil servants provide checks of the data).
- *Elevating Community-Based Water Monitoring in Canada: Final Recommendations* (The Gordon Foundation 2019) – documents the National Roundtable on Community-Based Water Monitoring held in Ottawa in November 2018 and a series of steps the federal government can take to advance freshwater CBM in Canada.

Similar to the Chesapeake Monitoring Cooperative, Living Lakes Canada has established the Columbia Basin Water Monitoring Collaborative (the Collaborative – Living Lakes Canada 2020). The purpose of the Collaborative is to increase the amount of data on the Columbia River Basin by coordinating water data collection, including incorporating data from industry, academia and community groups. This involved the creation of the Columbia Basin Water Hub; a central place to gather and archive past, present and future water quantity and quality data, including data from community groups. The Water Hub is currently in a user testing phase. As the Collaborative and the Water Hub are new projects, it is not yet clear how they will incorporate QA measures.

### 4.2.1 Case Study 3: The Canadian Aquatic Biomonitoring Network

Environment and Climate Change Canada (EEEC) delivers the Canadian Aquatic Biomonitoring Network (CABIN), a programme to assess and monitor the biological condition of fresh waters in Canada[24]. Although not strictly a CBM programme, CABIN employs the partner-network model (i.e., a model where several groups and institutions contribute to the implementation of the programme) and includes data collected by non-governmental organisations (NGOs), community groups, Indigenous groups, consultants and academics. As of 2017, there were more than 1,000 trained CABIN users with a contribution of 900 benthic macroinvertebrate samples per year (ECCC 2017). The ECCC is also trialling a new CBM project which involves the collection of bulk DNA samples from rivers using the CABIN protocols for the purpose of using DNA metabarcoding for biomonitoring and biodiversity research[25] (Gibson et al. 2015).

Quality assurance requirements for participation in the CABIN programme include completion of the CABIN training modules (delivered by the Canadian Rivers Institute and including online and in-person training) and adherence to CABIN protocols (Environment Canada 2012). Training costs $125-375 for NGOs and community groups. Quality control measures required for field sampling include sampling 10% of sites in triplicate to assess variability associated with the benthic community and habitat measurements. This involves three different people repeating the habitat measurements at

[24] https://www.canada.ca/en/environment-climate-change/services/canadian-aquatic-biomonitoring-network.html
[25] STREAM DNA Project or Sequencing The Rivers for Environmental Assessment and Monitoring.

the same spot to assess operator variability (this cannot be done for the benthic macroinvertebrate samples as the streambed has already been disturbed). Three riffles are sampled to provide an estimate of within-site spatial variability. Benthic macroinvertebrates are processed by professional laboratories which are required to meet the QA protocols outlined by Environment Canada (2014). Specific QC protocols exist for sorting (e.g., samples are checked to ensure ≥ 95% sorting efficiency and that no entire class of organisms is overlooked) and for taxonomic identification (e.g., re-identification of 10% (or a minimum of 3) samples to ensure ≤ 5% error rate). Additional QC audits are performed on samples from 'pristine' sites used for reference model development by the National CABIN Laboratory.

CABIN data are stored in a centralised ECCC database. Individuals that have received approved data entry training are able to upload CABIN data. There are no additional checks on the accuracy of the data once entered into the database.

CABIN is an example of community-collected data used at both provincial and national levels. There is no graded approach to data quality; all data submitted by trained individuals are considered eligible to support water resource decision making, the assessment of cumulative effects, and the development of reference condition models (Jensen 2006, Armanini et al. 2013). However, in a review of volunteer water monitoring in Canada, only 25% of groups interviewed that collected data for the CABIN programme felt that their data informed government policy, which was significantly less than groups who participated in provincial-level programmes (Carlson et al. 2017). This suggests that groups participating in national-level programmes may not receive feedback on how their data are used.

### 4.2.2 Case Study 4: The Mikisew Cree First Nation CBM Program

The Mikisew Cree First Nation (MCFN) CBM Program was initiated in 2008 by the MCFN's Government and Industry Relations department – the department arm which acts as a liaison between resource developers, operators, government agencies and the community[26]. MCFN's CBM Program operates in Alberta, the oil sands region of Canada. Its vision is "healthy traditional lands that support MCFN members for the next 7 generations"; this is supported by a mission "to protect MCFN Treaty and Aboriginal rights through active monitoring of the environment, using Traditional Knowledge and (western) Science in a respectful balance." Funding partners include federal and state governments, universities, and industry partners, including oil companies.

The purpose of the CBM programme is to measure the state of the environment, the health of wild foods, safe navigation in river channels, and changing snow conditions. Assessment of water quantity through measurements of water depth was outlined as a key purpose because low water levels affect the abililty of MCFN members to reach traditional use areas. The purpose of snow condition assessments are to better understand the relationship between releases of water from dams and ice jams and overland flooding.

Indigenous indicators were developed through interviews with active land users and elders to discuss fish, animal and water health. The first years of the programme involved establishing a baseline of what the initial conditions were before selection of specific indigenous indicators to monitor environmental changes over time.

Western attributes of water quality (water temperature, conductivity, DO, pH, salinity and chlorophyll *a*, all measured using field meters) and indigenous indicators are sampled weekly at

[26] http://mikisewgir.com/cbm

seven sites during the open water season. Water samples are collected quarterly and analysed by an approved laboratory for wide variety of variables, including nutrients and metals. Water depth measurements are collected weekly at six sites (10 samples per site). During the winter, snow depth, ice depth, and indigenous indicators of ice quality and water quality are measured weekly at six sites (MCFN-CBM 2016). Biological samples are taken from wild foods and opportunistically during die-off events in collaboration with local laboratories using western methods but informed by indigenous knowledge.

There are no data use tiers or levels within the MCFN programme. However, one outcome of the programme has been the release of the Geokeeper mobile app that allows anyone to report infomation about unsafe boating conditions, including shallow water levels. These data are used to support the wider data collection undertaken by trained MCFN members (MCFN-CBM 2016).

The indigenous indicators have been validated with elders who also transferred the knowledge associated with those indicators to community monitors or 'Guardians'. The western science indicators are measured following standardised protocols, with quarterly laboratory sample analyses used as a check on the monthly water quality measurements obtained from field meters. All data are collected on a custom app-based database system containing internal QC features (MCFN-CBM 2016). The database also links to the MCFN's wider land use planning and regulatory software, known as the Community Knowledge Keeper[27].

Depth measurements have been used to validate the concept of the Aboriginal Extreme Flow threshold[28] (used for understanding the effects of water levels on the ability to access indigenous territories) and to challenge aspects of Alberta's Surface Water Quantity Management Framework, notably the assumptions associated with their Aboriginal Navigation Index (Aqua Environmental Associates 2016).

## 4.3 Australia

Australia has long recognised CBM as an important source of water data. A national audit of water monitoring activities in 2000 revealed that 11% of the water monitoring programmes were undertaken by non-governmental institutions, including community groups, industry and academic institutions (NLWRA 2001).

Most freshwater CBM projects in Australia are delivered under the Waterwatch programme, which promotes water quality monitoring as a tool to involve communities in local water management. Waterwatch participants have also been called upon to participate in short-term projects including soil sampling, pre- and post-restoration monitoring, and bush fire and drought monitoring (Riverness 2015). Companion programmes include EstuaryWatch, Saltwatch and the Waterbug, Platypus and Frog census.

Waterwatch was formed in 1993 as an Australian Government Programme but in 2003 switched to a regional delivery model, with active programmes in New South Wales (NSW), Victoria, South Australia and the Australian Capital Territory (ACT). Each state supports Waterwatch slightly differently. Similar to the EPA's QAPP approach (Section 4.1), Waterwatch requires the development of a Data Confidence Plan that covers all facets of data collection, including QA/QC measures. The first Data Confidence manual was published by Waterwatch Victoria in 2000. Waterwatch Victoria

[27] https://knowledgekeeper.ca/

[28] https://www.ourcommons.ca/Content/Committee/421/TRAN/Brief/BR8708926/br-external/MikisewCreeFirstNation-e.pdf

also uses a tiered approach to data quality, categorising projects into four tiers (referred to as standards) based on the following broad monitoring purposes:

1. Awareness raising/education;
2. Education with data collection spin-offs;
3. Data collection with educational spin-offs; and
4. Data collection.

Each tier is associated with a set of minimum “data confidence standards”, determined from the following attributes: equipment used, calibration frequency, monitoring frequency, data storage, training and audit requirements, and equipment servicing.

In Victoria, regional coordinators have been appointed to assist community groups with training, data collection and interpretation, and feeding of the collected information into local and catchment management planning processes. All the Waterwatch groups within a catchment are linked through the regional coordinator, ensuring that all data collected are interpreted in the context of the whole catchment. A Data Confidence Plan is developed for each catchment for monitoring groups to follow. Each regional coordinator has relative autonomy in the organisation and delivery of the local Waterwatch programme.

The database used by Waterwatch groups varies by state. Waterwatch ACT and Waterwatch NSW data are uploaded to the Atlas of Living Australia, a national, open-infrastructure biodiversity database hosted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The NSW goverment is currently consolidating environmental data into a single portal called SEED (Sharing and Enabling Environmental Data) and will include Waterwatch data as part of its Citizen Science Hub[29]. In Victoria, data are uploaded to the Waterwatch portal, a database specific to Waterwatch data (Victoria’s Department of Environment, Land, Water and Planning does not integrate Waterwatch data into its own public-facing databases). In South Australia, the South Australian Murray-Darling Basin Natural Resources Management Board has a Community Monitoring Database for Waterwatch data.

In a survey of 47 Waterwatch and Estuarywatch coordinators in Victoria, NSW and the ACT, Bonney et al. (2020) outlined documented cases of data use for catchment decision-making, including data use for strategy and planning, monitoring and implementation, and reporting and evaluation. Despite the many examples provided, data use was verified for less than half of the 70% of monitoring groups that had a goal to inform catchment decision-making (Bonney et al. 2020). Similar to the review of volunteer water monitoring as part of the CABIN programme in Canada (Section 4.2.1), this may suggest that many groups do not consider that they receive sufficient feedback on how (or if) their data are used.

### 4.3.1 Case Study 5: West Gippsland Waterwatch

In the state of Victoria, Waterwatch is delivered by Catchment Management Authorities in each region along with Melbourne Water. The West Gippsland Waterwatch programme was established in 1993 and is aligned with the West Gippsland Catchment Management Authority (WGCMA). The objectives of West Gippsland Waterwatch are to:

[29] https://citizen-science.seed.nsw.gov.au/

1. Increase understanding of water issues and catchment health;
2. Generate useful data; and
3. Increase community involvement in decision making and action in partnership with catchment managers (Waterwatch 2010).

The West Gippsland Waterwatch Programme currently supports five CBM groups to collect data across 17 sites (Waterwatch Victoria 2019). Groups collect data on water and air temperature, conductivity, pH, turbidity, dissolved oxygen, dissolved reactive phosphorus (DRP), stream habitat, and litter. In 2010, a Data Confidence Plan was published, outlining the minimum requirements for data collected under Waterwater Victoria's tiered system (Table 4-3). The tier or standard a group is to follow is identified during an initial interview with a Waterwatch coordinator to determine the group's monitoring goals and plan. Data submitted by the group are then 'tagged' by a coordinator as a known standard, provided the data meet the minimum requirements.

The approach taken by West Gippsland Waterwatch (and the Waterwatch programme in general) differs from that taken by, for example, the Chesapeake Monitoring Cooperative (see Case Study 1, Section 4.1.1, and Table 4-1) in that Waterwatch does not have any specific requirements to submit field or laboratory replicates, or for assessment of measurement precision. The QA requirements for each standard are outlined in Table 4-2.

In common with all Waterwatch participants, West Gippsland Waterwatch programme participants are trained in sampling methods by a Waterwatch Coordinator, with an annual refresher required if collecting data at tiers 2, 3 or 4.

**Table 4-2: Summary of QA requirements for CBM undertaken in different tiers (standards) of the West Gippsland Waterwatch Programme.** Details sourced from Waterwatch (2010).

| QA requirement | Tier I | Tier 2 | Tier 3 | Tier 4 |
|---|---|---|---|---|
| Training | Initial training required | Initial training and annual refresher training/or field audit | Initial training and annual refresher training | Initial training and annual refresher training |
| Equipment | Specific equipment outlined for each tier (e.g., turbidity tube for tiers 1-3, turbidity meter for tier 4) | | | |
| Site selection | Sites are selected with the help of a Waterwatch coordinator | | | |
| Calibration | Not required | Annually for most equipment | Before every use for most equipment | Before every use for most equipment |
| Frequency and completeness | No requirements | Minimum yearly monitoring with optional event monitoring | Minimum quarterly monitoring with optional event monitoring | Minimum yearly monitoring with optional event monitoring |
| Field audits | Not required | Annual audit or refresher training | Annual | Annual |
| Data entry | Data checked by a coordinator for anomalies before approval | | | |

Audits of the monitoring methods and personnel are undertaken in the form of blind or 'mystery' samples where volunteers test water samples with a known pH, conductivity, turbidity and DRP concentration. Volunteers participating in the Waterbug census (a Melbourne Water programme for monitoring benthic macroinvertebrates) can identify benthic macroinvertebrates to test their identification skills. Parallel monitoring with another organisation undertaking monitoring or a Waterwatch coordinator from a different region may also occur. Both mystery samples and parallel monitoring serve as a check that the volunteer equipment and monitoring techniques are accurate, and provide an opportunity to inspect the equipment and for volunteers to ask questions (Waterwatch 2010).

Waterwatch Victoria volunteers enter their data into the Waterwatch Data Portal. The portal has a number of automated checks to reduce data entry error. For example, values entered outside the expected range are highlighted in yellow or red, depending on how far outside the expected range they fall. If a yellow result is deemed correct, a comment must be added in the notes field as to what might explain it. If a value highlighted red is deemed correct, an "Unusual Value Reason" must be entered. All data are verified by a Waterwatch coordinator or officer, as indicated by a green "approved" button when viewing the data online. Data in the portal can be filtered by tier (1-4).

Waterwatch data have been used in regional catchment strategies, which are the primary integrated planning framework for the management of land, water and biodiversity resources (established under the Catchment and Land Protection Act 1994)[30]. These strategies seek to integrate community values and regional priorities with state and federal legislation and policies. Waterwatch also publishes annual achievement reports which describe how community monitoring data are used to inform management decisions (Estuary and Waterwatch 2019).

## 4.4 The United Kingdom (UK)

In the UK, the Environment Agency (EA), Natural Resources Wales, the Scottish Environment Protection Agency and the Northern Ireland Environment Agency are the governmental public bodies responsible for managing water resources, including monitoring and reporting on the objectives of the European Union Water Framework Directive (WFD).[31] In 2013, the UK launched the Catchment Based Approach (CaBA) to support the delivery of the WFD Regulations (DEFRA 2013, Natural England 2015) and to provide a framework under which different community and interest groups can come together through catchment partnerships[32].

There is no national QA framework to support the evaluation of monitoring data collected under CaBA. Catchment partnerships have adopted a variety of different monitoring programmes (e.g., the Angler's Riverfly Monitoring Initiative (ARMI), Freshwater Watch) and data platforms (Cartographer, Survey123), including many bespoke local solutions (Walker and Johnson 2020).

As a result of recommendations from the CaBA Catchment Data User Group (CDUG), the Catchment Monitoring Cooperative was established in 2020, modelled off the Chesapeake Bay Monitoring Cooperative (refer Case Study 1, Section 4.1.1). The purpose of the Catchment Monitoring Cooperative is to integrate a coordinated and cost-effective volunteer-based environmental monitoring programme into CaBA. It is considered that a nationally coordinated approach would have several benefits, including provision of local data of consistent and known quality, thereby

[30] https://www.water.vic.gov.au/waterways-and-catchments/our-catchments/catchment-management-framework
[31] The WFD was adopted in late 2000 as a framework for integrated river basin management for the European Union (EU) community. With Britain's pending departure from the EU, it is unclear how its work under the WFD, including catchment/community-based initiatives, might change.
[32] https://catchmentbasedapproach.org/

enabling national statutory agencies to integrate citizen science data into their decision-making frameworks (Walker and Johnson 2020).

The Catchment Monitoring Cooperative is still in the planning stage (having only released its proposal outlining a three-year strategy in June 2020) and is currently building a knowledge exchange partnership with the Chesapeake Bay Monitoring Cooperative. As part of this planning stage (see Walker and Johnson 2020), the CDUG recommends a tiered approach to data quality, with a range of methods from simple and inexpensive through to more complex and rigorous approaches and a focus on the relevance of evidence for the question the monitoring is designed to help answer (rather than thinking complex methods are 'better'). The Cooperative will initially focus on a limited number of variables with assured methods when building its framework (e.g., chemical water quality, benthic macroinvertebrates, riparian assessments). An accredited training scheme is being developed to certify groups in sampling methods, monitoring programme design and data analysis. Future partnerships with research providers are expected to help develop and test innovative or cost-effective methods (e.g., low-cost sensors, eDNA analysis). In terms of data management, the CDUG has recognised that there is an extensive number of citizen science platforms in the UK and therefore has recommended that the Catchment Monitoring Cooperative develop a data sharing strategy among the different platforms rather than investing in one big platform (Walker and Johnson 2020).

The UK Environmental Observation Framework (UKEOF), a coordinating body established in 2007 to support better communication and sharing of information across different organisations responsible for environmental monitoring[33], is also developing QA resources for CBM data. The UKEOF Citizen Science Working Group published a data management guidance document to support the value of datasets from citizen science projects aimed at practitioners or programme leaders (UKEOF 2020). Key recommendations in relation to data quality include:

1. Adopt technology (e.g., mobile apps) that can make data collection easier, automate repetitive tasks and reduce input errors;
2. Use data standards and terminology to ensure that the data can be incorporated with confidence into other systems or processes (e.g., DarwinCore[34]);
3. Consider protection and security early; often citizen science data are linked to specific people as part of data quality checks and it is good practise to ensure that personal data can be separated from scientific data; and
4. Adopt metadata standards (e.g., Ecological Metadata language) to allow others to understand and appropriately re-use the data.

### 4.4.1 Case Study 6: The Anglers' Riverfly Monitoring Initiative (ARMI)

The ARMI is a UK citizen science programme hosted by the Freshwater Biological Association (a charitable organisation). Launched in 2007, the ARMI was developed by the Riverfly Partnership, a network of nearly 100 partner organisations. This initiative supports over 3,000 volunteers with data from over 2,500 sites available for download on the ARMI database (Moolna et al. 2020). For many groups adopting ARMI into their monitoring, the interest is catchment-scale pollution vigilance. For example, the Action for the River Kennet, a community group who monitors the River Kennet, lists their purpose for incorporating ARMI monitoring into their activities as a check on the health of the

[33] http://www.ukeof.org.uk/about
[34] https://dwc.tdwg.org/

river and to pick up otherwise undetected pollution events[35]. The Riverfly Partnership receives funding to coordinate the ARMI in England from fishing licence sales and grants from the EA.

The ARMI protocols require the collection of benthic macroinvertebrate samples in accordance with a simplified version of the routine biomonitoring methods used by regulatory agencies in the UK (Moolna et al. 2020).

ARMI does not have data tiers but three levels of difficulty which correspond to a wider range of data use:

- Level 1, Riverfly – simplest identification (eight taxa);
- Level 2, Extended Riverfly – more detailed identification (33 taxa) which allows for detection of a wider range of water quality stressors; and
- Level 3, SmartRivers – advanced identification (species-level) where volunteers undertake more extensive training or dispatch samples to an approved laboratory.

Volunteers self-select the river they will monitor but the site must be approved; volunteers are encouraged to select sites that are not currently being monitored by a regulatory authority. The ARMI attempts to establish an ecology contact from the appropriate regulatory agency to set a trigger level for each site; a score (similar in concept to the macroinvertebrate community index (MCI) in New Zealand) below which an acute pollution event is deemed likely to happen (Moolna et al. 2020).

Training is the only requirement for participation in the AMRI project. Volunteers are not required to submit sampling or QA plans and no such template exists for them to follow. Some evaluation of ARMI data has been undertaken (e.g., Brooks et al. 2019, Calhill 2019) but there are no routine QC processes in place.

A one-day ARMI workshop provides standardised initial training in the ARMI protocol, including health and safety, biosecurity, site selection, sampling methodology and equipment, identification of invertebrate groups, and pollution detection and reporting. Experienced volunteers can take additional training to expand the number of target invertebrate taxa identified from 8 to 33. A species-level monitoring course for the River Invertebrate Identification and Monitoring (RIIM) index is currently being trialled in collaboration with Aquascience Consultancy Ltd. The more detailed invertebrate identification training offered (levels 2 and 3) links entomology with angling. Groups are responsible for raising their own funds to cover monitoring equipment (~£700) and training (~£1,000 for a one-day workshop) but regional hubs (which host and deliver the ARMI programme) assist with funding applications.

Quality codes do not exist for ARMI data but the two levels of training, Riverfly and Extended Riverfly, determine which database the data are entered into. A national ARMI database exists for Level 1 (Riverfly) data. Volunteers are given a login to the national database after they have attended training. All data are verified by an ARMI coordinator before public release. The existing national database cannot accept Level 2 (Extended Riverfly) data (33 taxa); these data are stored in GoogleSheets. The project team is currently investigating whether to expand the ARMI database or use another database, Cartographer. Level 3 (SmartRivers – species-level identification) data are uploaded to Cartographer and become publicly available after approval by a coordinator[36].

[35] http://www.riverkennet.org/get-involved/riverfly-monitoring
[36] https://salmon-trout.org/smart-rivers/

If the ARMI score falls below the estabished trigger level, the regulatory authority is notified by the monitoring group and agency officers investigate the cause of the low score (Brooks et al. 2019). In July 2013 a major pesticide pollution event in the River Kent was picked up by volunteers and led to the implementation of measures to prevent any repeat pesticide discharges into the river (Thompson et al. 2015). Level 3 (SmartRivers) allows for calculation of more detailed pressure scores and data collected under this level have been used in regulatory investigations.[37]

## 4.5 Europe

Community-based water monitoring and other citizen science activities are prominent throughout much of Europe (e.g., Capdevilla et al. 2020), and the European Citizen Science Association's (2015) key principles (refer Box 1, Section 2.2.2.) that underlie good practice in citizen science are widely cited in the literature. While there is currently no associated QA framework that applies across the European Union (EU), the European Commission recognises the potential of citizen science to contribute to environmental reporting and is working to develop guidelines regarding the use of citizen science data to complement professional data. Relevant reports prepared over the past three years and their key recommendations with respect to data quality include:

- *Actions to Streamline Environmental Reporting* (European Commission 2017) – an action plan developed to ensure that EU environmental law is delivering its intended effects on the ground; to better inform the European public about these effects (achievements) and at the same time simplify the reporting burden for national administrations and businesses. One of the 10 actions identified was to promote the wider use of citizen science to complement environmental reporting.
- *Citizen Science for Environmental Policy: Development of an EU-wide Inventory and Analysis of Selected Practices* (Bio Innovation Service 2018)[38] – assesses the impact and policy applications of citizen science by providing an inventory of 503 environmental citizen science initiatives of relevance to EU policy and in-depth analysis of 45 selected initiatives.
- *Citizen Science and Environmental Monitoring* (Manzoni et al. 2019) – documents the findings of a two-day workshop to discuss the opportunities and challenges brought forward by the increasing need and use of citizen science approaches to support policy making. Data of differing quality could be used (and reused) provided it is 'fit for purpose'. The workshop highlighted that ensuring reuse of data (through the development of a QA framework to document data quality) would decrease the risks of duplication while allowing for more data sharing and collaborative approaches.
- *Best Practices in Citizen Science for Environmental Monitoring* (European Commission 2020) – this report contains a number of recommendations to ensure that public authorities make more use of citizen science data for environmental monitoring and that citizen science initiatives have greater impact on policy. Recommendation 6 is to "Promote the adoption, effective use and transparency of data management and sharing principles, methodologies and quality assurance/control in citizen science initiatives".

[37] https://salmon-trout.org/2020/08/18/persistence-pays-off-in-the-pursuit-of-a-pesticide-problem/
[38] https://op.europa.eu/en/publication-detail/-/publication/842b73e3-fc30-11e8-a96d-01aa75ed71a1/language-en

## 4.6 Synthesis

Of the four international CBM frameworks described in this section, the USA has the most well developed approach to QA, supported by a long history of CBM initiatives overseen by the USEPA and strengthened by the Crowdsourcing and Citizen Science Act 2016 that gives the US government authority to use crowdsourcing and citizen science methods to advance scientific research. Many elements of the USA's approach, including the existence of multiple data tiers with varying levels of QA, a requirement for a CBM group to have a Quality Assurance Project Plan, and a suite of template plans and procedures to support CBM groups, are also present in Australia's Waterwatch programme. In contrast, the Canadian and UK governments do not have a specific data quality framework for CBM, although the UK is in the early stages of developing such a framework (modelled on that used by the Chesapeake Monitoring Cooperative). Field and laboratory sample replicates and independent external checks of sampling and testing practices by trained coordinators are common components of CBM QA in the USA and Australia.

Training is a universal requirement in the CBM programmes examined across the four countries, 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 consistently required. While all six of the programme case studies restricted entry of data into databases to approved group members, there is considerable variation in the extent of further data checks; in the CABIN programme in Canada, no checks are made on data once entered whereas data collected under the West Gippsland Waterwatch programme in Australia are subject to both in-built automated checks and verification by a Waterwatch coordinator or officer.

# 5 Prospects for a national QA framework for New Zealand

In this section we examine the prospects for developing a national QA framework for freshwater CBM, drawing on material presented earlier in this report, as well as a workshop with regional sector representatives held in August 2020 and a multi-agency CBM data stewardship workshop held in December 2020. We begin with an overview of New Zealand's legislative context for freshwater management, noting that a framework needs to be developed with this in mind. We then explore some key components and considerations for a possible framework before outlining some of the existing resources that could inform its development. Lastly, we touch on three additional matters that need to be addressed if the full benefits of CBM are to be realised; support and feedback for CBM participants, data storage and access, and data privacy and sovereignty.

We note that the ideas in Sections 5.2 and 5.3 are preliminary only and will be explored in more detail as part of the proposed MBIE Envirolink Tool to develop a national QA framework.

## 5.1 Legislative context

Compared with the countries for which we outlined CBM QA approaches in Section 4, New Zealand is small in size and population. With our single tier of national government and all 16 regions managing freshwater and other natural resources via regional policy statements and regional plans prepared under the same national legislative framework (i.e., the Resource Management Act 1991)[39], there seems little need to establish multiple frameworks for CBM. Additionally, as outlined in Section 5.3, we already have many relevant national monitoring standards, protocols and other initiatives to build on, with some of these already specified in regional plans and resource consents conditions.

First introduced in 2011 under s52(2) of the RMA, the National Policy Statement for Freshwater Management (NPS-FM) (NZ Govt 2011, 2014, 2017, 2020) provides an overarching structure for managing freshwater resources in New Zealand that recognises the national significance of freshwater. 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. Te Mana o te Wai establishes a "hierarchy of obligations", in terms of managing freshwater 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.

The NPS-FM sets out objectives and policies that direct local government to manage water in an integrated and sustainable way, while providing for economic growth within set water quantity and quality limits. All regional and unitary 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", "mahinga kai" and "threatened species". A series of attributes (Table 5-1), most with associated minimum acceptable states (termed "national bottom lines"), exist for two of these values and must be monitored at the scale of a catchment or freshwater management

[39] Although the Government has recently confirmed plans to reform the RMA, the NPS-FM (and the wider *Essential Freshwater* package that includes new National Environmental Standards for Freshwater (NES-FW), new stock exclusion regulations under s360 of the RMA and other amendments to the RMA) are expected to remain in place under the proposed new Natural and Built Environments Act.

unit (FMU). 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; hydroelectric generation; animal drinking water; irrigation, cultivation, and production of food and beverages; and commercial and industrial purposes (NZ Govt 2020).

**Table 5-1: Freshwater attributes in the NPS-FM 2020 for the mandatory national values of ecosystem health and human health for recreation.** Attributes marked with an * represent those that require an action plan to be developed if the national bottom line is not met. Other attributes require limits to be set on resource use.

| Ecosystem health | Human health for recreation |
|---|---|
| Phytoplankton (trophic state) – lakes | *E. coli* – lakes and rivers |
| Periphyton (trophic state) – rivers and lakes | Cyanobacteria (planktonic) – lakes |
| Total nitrogen (trophic state) – lakes | *E. coli** (primary contact sites) – lakes and rivers |
| Total phosphorus (trophic state) – lakes | |
| Ammonia (toxicity) – rivers and lakes | *Note: Appendix 1A of the NPS-FM 2020 notes a broader range of "matters" to take into account including "pathogens, water clarity, deposited sediment, plant growth (from macrophytes to periphyton to phytoplankton), cyanobacteria, other toxicants, and litter."* |
| Nitrate (toxicity) – rivers and lakes | |
| Dissolved oxygen (water quality) – rivers below point source discharges | |
| Suspended fine sediment (water quality) – rivers | |
| Submerged plants – natives* (aquatic life) – lakes | |
| Submerged plants – invasives* (aquatic life) – lakes | |
| Fish* – (aquatic life) – rivers | |
| Macroinvertebrates – MCI & QMCI* (aquatic life) – rivers | |
| Macroinvertebrates – ASPM* (aquatic life) – rivers | |
| Deposited fine sediment* (physical habitat) – rivers | |
| Dissolved oxygen* (water quality) – rivers | |
| Lake-bottom dissolved oxygen* (water quality) – lakes | |
| Mid-hypolimnetic dissolved oxygen* (water quality) – lakes | |
| Dissolved reactive phosphorus* (water quality) – rivers | |
| Dissolved reactive phosphorus* (water quality) – rivers | |
| Ecosystem metabolism* (ecosystem processes) – rivers | |

The NPS-FM 2020 sets out five biophysical components that contribute to ecosystem health, noting that all of them need to be managed. They are:

- *Water quality* – the physical and chemical measures of the water, such as temperature, dissolved oxygen, pH, suspended sediment, nutrients and toxic contaminants
- *Water quantity* – the extent and variability in the level or flow of water
- *Habitat* – the physical form, structure, and extent of the water body, its bed, banks and margins; its riparian vegetation; and its connections to the floodplain and to groundwater
- *Aquatic life* – the abundance and diversity of biota including microbes, invertebrates, plants, fish and birds
- *Ecological processes* – the interactions among biota and their physical and chemical environment such as primary production, decomposition, nutrient cycling and trophic connectivity.

There was widespread support at an on-line workshop with a selection of regional council staff in August 2020 for a national QA framework for CBM to include a range of the attributes listed in Table 5-1. In many cases, CBM groups are already monitoring a number of these attributes, in addition to variables such as water temperature and stream flow/depth, reflecting their interest in water quality, and broader ecosystem health and 'swimmability'. An additional ecosystem health attribute raised was streamside shade, recognising that many CBM groups are monitoring the success of riparian restoration on stream habitat.

Including attributes relating to the value of mahinga kai was also of interest to some workshop participants. According to the NPS-FM 2020, the mahinga kai value comprises two main components:

- Kai is safe to harvest and eat; and
- Kei te ora te mauri (the mauri of the place is intact).

As mahinga kai practices will be rohe-specific, relevant attributes are best developed and monitored by local Māori (i.e., tangata whenua). This is consistent with MfE (2020) guidance for NPS-FM implementation which 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".* The role of Māori is explored further next.

### 5.1.1 Māori and Mātauranga

There is strong recognition in recent legislation, including within the NPS-FM 2020, that the Treaty of Waitangi (the Treaty) forms the underlying foundation of the Crown–Māori relationship regarding freshwater resources in New Zealand. In particular, Treaty settlements are playing a critical role in providing the legislative foundation 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).

With mahinga kai now enshrined as a national freshwater value, councils must work with tangata whenua to establish relevant attributes and desired environmental outcomes (MfE 2020). A considerable body of relevant knowledge already exists on potential attributes such as numbers of tuna (eels) or tuangi (cockles) and contaminants in watercress. However, attributes are expected to differ across the country, reflecting different traditions and practices. While monitoring the state or condition of these attributes 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 attributes in the NPS-FM are likely to be relevant to informing mahinga kai assessments (e.g., *E. coli,* visual water clarity and dissolved oxygen).

Care will be needed in developing the national QA framework to ensure that it is designed in a way that Māori can access and use it, without imposing 'constraints' on their exercise of mātauranga. This is important because mātauranga is recognised as a science and knowledge base in its own right and is not the same as CBM. As outlined in Section 2.1, most CBM programmes are contributory (run by professionals), with communities acting primarily as data collectors. This type of participatory framework can lead to more entrenched power imbalances (Bohensky and Maru 2011). However, when CBM programmes are designed and led by indigenous people (e.g., the Mikisew Cree First Nation – Section 4.2.2) and include indigenous indicators which are prioritised and are used to verify western science observations, then these programmes can be a way to asserting sovereignty (Thompson et al. 2020).

Working with one or more iwi or hapū-based groups as part of the development of the national QA framework might provide an opportunity to explore options for matāuranga-based indicators relevant to mahinga kai (and other Māori freshwater values). For example, Ngai Tahu has a well-established Cultural Health Index in place to assess and manage waterways, with mahinga kai/cultural uses one of its three components (Tipa and Teirney 2006). In the Waikato, the Maniapoto Māori Trust Board has recently developed a draft cultural assessment framework, Te Mauri o Waiwaia', to assess the state of freshwater that reflects the unique values of Maniapoto whānau. As part of the exercise, attributes and indicators were identified to help visualise discussions around selected freshwater values (e.g., for the freshwater value of tuna, safe access to waterways and tuna size and condition were identified as being important) (Kaitiaki Contributors et al. 2020).

## 5.2 Key QA elements and considerations

Discussions with council staff have identified two critical requirements – or principles – that should underpin a national QA framework for CBM; *flexibility* and *transparency*. Each of these requirements is outlined below.

### 5.2.1 Flexibility

A framework needs to be sufficiently flexible to accommodate the wide range of potential applications of freshwater CBM in New Zealand, from engagement and education through to regulatory decision making (refer Section 2.4). Consistent with approaches in the USA and Australia outlined in Section 4, we recommend establishing QA requirements commensurate with the type or purpose of monitoring application. We consider that three basic tiers or categories of data collection could be established in New Zealand, with the rigour and frequency of QA requirements increasing with each tier (Figure 5-1):

- Tier 1: Data collection to promote education and engagement around the importance of freshwater resources (e.g., field days, school projects); may involve basic environmental health screening.

- Tier 2: Data collection to assess environmental health or the impact of targeted management/restoration efforts (e.g., assessments of baseline condition and identification of pollution ‘hotspots’ as part of Farm Environment Plan preparation or catchment ‘health’ monitoring and reporting); primarily designed to target further monitoring efforts and for use as supporting evidence in environmental reporting (e.g., in report cards).
- Tier 3: Data collection for use in regulatory assessments and/or decision-making (e.g., determination of attribute state and trends under the NPS-FM, consent monitoring).

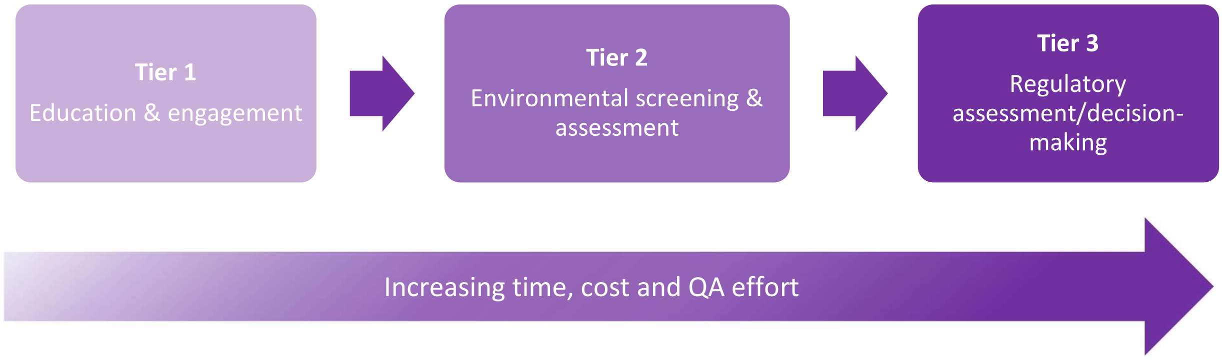


**Figure 5-1: The basis of a possible three-tier (or category) CBM data collection system for New Zealand.** The listed applications are only suggested primary data uses; secondary data uses (e.g., modelling) would be dependent on end users assessing the suitability of data collection methods and QA measures for their intended use.

A tiered approach to data quality will likely involve developing both general data quality requirements for each tier and specific data quality requirements for variables within each tier. Based on successful practices established overseas, general data quality requirements might include developing a monitoring plan, training and/or certification, and participation in audit exercises. Variable-specific data quality requirements might include the type of method chosen, the frequency of sensor calibration/validation, the number of replicate samples taken, and a minimum frequency of data collection.

A flexible framework would provide for a range of methods from simple and inexpensive through to more complex and rigorous to facilitate participation across a broad range of CBM groups and selection of the right method for the right data use. A stocktake and assessment of the key different monitoring methods in use by CBM groups in New Zealand will likely be necessary. Recognising that different methods offer different levels of accuracy, it will be essential that each CBM measurement is linked with its collection method to enable end users to filter out the method(s) they wish to accept. This need for transparency is addressed next.

### 5.2.2 Transparency

A CBM QA framework needs to promote transparency in data quality, through establishing requirements for documentation of data collection methods and associated QA and other metadata. Establishment of a Monitoring Plan and a QA Plan (refer Section 3.3) 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 the data for its suitability for other potential (secondary) uses (e.g., for inclusion in regional or national scale modelling applications).

Standard templates should be developed to aid consistent and complete documentation. This has facilitated CBM uptake and data use in the USA, particularly for Tier 1 and 2-type data uses. In the case of Tier 3 (regulatory assessments), the council (or other end user) would likely need to establish or co-establish with volunteers the requirements of monitoring and QA plans on a case-by-case basis, and review or approve them for implementation. We recognise that this will demand time of councils (or other end users) but it will also give both parties confidence that the data will be fit for purpose.

## 5.3 Existing resources

With the success of the SHMAK and programmes such as Wai Care, Whitebait Connection, and Nature Agents, along with many successful initiatives overseas, we already have a good idea of the types of freshwater variables CBM groups (a) want to monitor, (b) can monitor safely, and (c) can monitor with some level of accuracy. There are now many standardised sampling protocols, monitoring tool kits, websites, and other resources available to support CBM initiatives (Table 5-2). Some of these resources, including the National Environmental Monitoring Standards (NEMS), and national guidelines or protocols (e.g., habitat assessment) already feature in some regional plans, catchment strategies and consent conditions, suggesting that they could inform Tier 3 requirements for regulatory assessments. Some of these resources also offer a range of methods, including simplified ‘rapid assessments’, and could therefore inform QA requirements across multiple tiers.

Lastly, there are a number of ‘volunteer support’ organisations (e.g., New Zealand Landcare Trust and Mountains to Sea Community Trust) with established coordinators in place to facilitate training and provide support for CBM initiatives. As noted next, securing long-term funding to support CBM initiatives can present a challenge for these organisations.

## 5.4 Other considerations

There are additional matters that need to be addressed alongside a national QA framework to realise the full potential benefits of CBM outlined in Section 2.2.1. These include the need for ongoing support and feedback, a database or portal to ‘house’ and access CBM data and associated metadata, and consideration of data privacy and sovereignty issues.

### 5.4.1 Support and feedback

Training and feedback are integral to data quality and maintaining volunteer motivation (Capdevila et al. 2020, Freitag et al. 2016, Kosmala et al. 2016). At a multi-organisational workshop on CBM data stewardship held in December 2020 (Milne and Valois 2021), it was suggested that feedback should include information on how a group’s data are being used and what the data indicate. Scale is an important consideration; data collected at catchment scales may be used at regional or national scales. Feedback and support therefore need to be tailored to the catchment scale where most groups operate. In this way groups can better link actions – such as stream plantings – to outcomes such as increased fish diversity.

An on-line platform hosting CBM data (see Section 5.4.2) could provide mechanisms for ongoing support of, and feedback to, CBM groups. Self-populating graphs with trigger levels or report cards that explain the “so what?” aspects of monitoring results at an appropriate scale, and responses or comments from end-user organisations associated with the monitoring, could be useful (Milne and Valois 2021).

**Table 5-2: Examples of existing resources that could inform the development of a national QA framework for freshwater CBM.**

| Resource | Comment |
|---|---|
| SHMAK | A CBM kit for assessing stream ecological condition – with supporting measurements of water quality and stream habitat variables. Includes standardised protocols and instructional videos as well as a web-based database and mobile phone app (NZ Water Citizens) for CBM groups to enter, visualise and share data. |
| Wai Care | A water quality monitoring, education and action programme for community groups, individuals, businesses and schools in Auckland. Includes educational resources for schools. |
| Whitebait Connection | A national freshwater community conservation education and monitoring programme that includes assessment of stream health using the SHMAK and fish surveys. Supported by regional coordinators and has strong links with councils. |
| Litter Intelligence | A beach litter monitoring programme with training and established QAQC protocols. The Litter Intelligence database allows for collection of QC data and is supported by a data governance group to ensure data integrity over the long term. |
| National Environmental Monitoring Standards (NEMS) – available at www.nems.org.nz | A range of relevant standards already exist spanning hydrology (e.g., water level, open channel flow, rainfall), discrete water quality sampling and testing (groundwater, rivers, lakes and coastal waters), high frequency water quality measurements using in-situ sensors (water temperature, dissolved oxygen and turbidity), and stream ecology (periphyton and macroinvertebrates), as well as a Code of Practice for Safe Acquisition of Field Data In and Around Fresh Water. |
| Stream habitat assessment protocols (Harding et al. 2009) | These protocols include a qualitative Rapid Habitat Assessment (RHA) as well as more comprehensive semi-quantitative and quantitative habitat assessment protocols. A revision of the RHA protocol by Clapcott (2015) has enabled a total 'habitat quality score' to be calculated for a site. |
| Fish passage assessment tool – Available at https://fishpassage.niwa.co.nz/ | A tool (supported by a user guide) for recording instream structures and assessing their likely impact on freshwater fish movements and river connectivity. Data are collected using the Fish Passage Assessment Survey available in the NIWA Citizen Science app and automatically uploaded to a national fish passage database. |
| Deposited fine sediment cover monitoring (Clapcott et al. 2011) | A suite of protocols of varying complexity to assess deposited fine sediment cover in streams. |
| Cyanobacteria guidelines in recreational waters (MfE/MoH 2009) | Interim national guidelines that includes advice on monitoring cyanobacteria in lakes and rivers. |
| Monitoring water quality in urban streams and stormwater (Gadd and Milne 2019) | A guidance manual accompanied by instruction sheets and videos to install Nalgene stormwater sampler bottles and DGTs (diffusive gradients in thin films) in streams and stormwater outfalls. |
| Principles and protocols for Tier 1 statistics (Statistics New Zealand 2007) | A statement setting out key principles and protocols that apply to official (Tier 1) statistics on New Zealand's economy, society and environment (including those used in freshwater reporting). |

Establishing a national QA framework will change how most CBM groups in New Zealand currently operate, in particular the requirement to document all procedures and record QA/QC as part of their metadata. It is likely that CBM groups will need advice on how to record this additional metadata, especially given that the quality and completeness of this information will likely determine whether a potential end user can make use of the data. While developing templates for monitoring and QA plans will assist, CBM groups will likely require support in choosing the appropriate data tier and implementing the data quality requirements, either from NGOs, industry bodies or council staff. We think that training courses should be standardised across supporting institutions for consistency.

### 5.4.2 Data storage and access

A key point made at the CBM data stewardship workshop held in December 2020 was that, to make use of CBM efforts, the data and associated metadata (e.g., methods, data quality codes) must be both visible and accessible for the foreseeable future (Milne and Valois 2021). There are already multiple on-line platforms hosting different types of CBM data or information in New Zealand (e.g., NZ Water Citizens, Litter Intelligence, Know Your Catchment, Streamed, National Īnanga Spawning Database), but all require ongoing resourcing to be maintained.

There may be merit in developing a single on-line platform or portal with an associated QA framework to provide consolidated access to CBM data of known quality in much the same way as Land, Air, Water Aotearoa (LAWA)[40] provides such a platform for the regional sector's environmental data. Whether it is one or multiple platforms, greater coordination in the management of CBM data would be beneficial so that data can be easily entered and extracted (Milne and Valois 2021). Similar to the thinking of the Catchment Monitoring Cooperative in the UK (refer Section 4.4), a data sharing strategy among the different platforms could be a useful approach. Increasing technological advancements and a growing trend towards open data and interoperable systems are creating new opportunities for data exchange, as well as data visualisation.

### 5.4.3 Data privacy and sovereignty

Both data privacy and data sovereignty are further relevant matters to consider with CBM. Some CBM groups may wish to collect data for their own purposes and keep the data private, at least initially (e.g., a rural based CBM group that finds their data point to an environmental impact associated with their land use activities). Data privacy should be considered at the outset of a CBM programme, especially if the programme is funded by a council or other external party with a likely interest in making use of the data. The NZ Water Citizens website offers CBM groups the option of sharing or keeping their data private.

Indigenous cultural and intellectual property and data sovereignty must also be considered. Te Mana Raraunga – Māori Data Sovereignty Network and the Atlas of Living Australia both have a number of resources available. Māori involvement will be needed in governance of any data hosting platforms; in particular, storing data on servers held overseas has implications for Māori data sovereignty. University of Waikato Professor Tahu Kukutai co-led the development of the CARE principles (Collective Benefit, Authority to Control, Responsibility, Ethics) to complement the FAIR principles (Findable, Accessible, Interoperable, Reusable) and these principles could guide database development/upgrades (RDA-IG 2019). The Atlas of Living Australia is currently developing Indigenous Knowledge Protocols for Cultural and Intellectual Property that could also help inform discussions on data management.

[40] https://www.lawa.org.nz/

## 5.5 Synthesis

There is a growing abundance of community-based freshwater monitoring initiatives in New Zealand and associated resources and learnings that could inform the development of a national QA framework. The NPS-FM 2020, in establishing that all freshwater must be managed for the national values of ecosystem health, human health for recreation, mahinga kai and threatened species, provides a series of mandatory attributes that could provide a focus for the framework. Particular care will be needed with inclusion of mahinga kai attributes as these will be rohe-specific and so will need to be developed and monitored by tangata whenua.

A national framework needs to be flexible to accommodate a range of data collection purposes; this could be achieved through a multi-tiered system of data collection, with the rigour and frequency of QA requirements increasing with each tier. The framework also needs to promote transparency in data quality, through establishing requirements for documentation of data collection methods and associated QA and other metadata.

While a national QA framework will provide the basis for the collection of CBM data to consistent standards and of 'known quality', realising the full potential benefits of CBM will also require ongoing support and feedback for CBM groups, a database or portal to 'house' and access CBM data and associated metadata, and consideration of data privacy and sovereignty issues. Greater coordination of existing CBM initiatives and resources, including a strategy for data management and sharing would support more consistent and sustainable CBM in New Zealand.

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# 7 References


Albus K., Thompson R., Mitchell F. (2019) Usability of existing volunteer water monitoring data: What can the literature tell us? *Citizen Science: Theory and Practise,* 4(1): 28.

Alender B. (2016) Understanding volunteer motivations to participate in citizen science projects: A deeper look at water quality monitoring. *Journal of Science Communication,* 15(3).

Aqua Environmental Associates. (2016) Community-based water-depth monitoring in the Peace-Athabasca Delta: Insights and evaluation. Prepared for Athabasca Chipewyan First Nation and Mikisew Cree First Nation. Accessed at: http://mikisewgir.com/cbm.

Armanini D.G., Monk W.A., Carter L., Cote D., Baird D.J. (2013) Towards generalised reference condition models for environmental assessment: A case study on rivers in Atlantic Canada. *Environmental Monitoring and Assessment*, 185: 6247-6259.

Atkinson I.A.E. (1988) Opportunities for ecological restoration. *New Zealand Journal of Ecology*, 11: 1-12.

Baseley A.B., Rutledge M., Jones K., Seitzer S., Kerr V. (2014) *Whitebait Connection (WBC) freshwater discovery and monitoring handbook*. Mountains to Sea Conservation Trust (MTSCT). 108 p.

Biggs B., Kilroy C., Mulcock C. (1998) New Zealand stream health monitoring and assessment kit: Stream monitoring manual Version 1. *NIWA Technical Report* 40 (NIWA and Federated Farmers) ISBN 1174-2631.

Biggs B., Kilroy C., Mulcock C., Scarsbrook M. (2002) New Zealand stream health monitoring and assessment kit: Stream monitoring manual Version 2. *NIWA Technical Report* 111. (NIWA and Federated Farmers and NZ Land Care Trust), ISBN 1174-2631.

Biggs J., Ewald N., Valentini A., et al. (2015) Using eDNA to develop a national citizen science-based monitoring programme for the Great Crested Newt *(Triturus cristatus). Biological Conservation*, 183: 19–28.

Bio Innovation Service. (2018) *Citizen science for environmental policy: development of an EU-wide inventory and analysis of selected practices*. Final report for the European Commission, DG Environment under the contract 070203/2017/768879/ETU/ENV.A.3, in collaboration with Fundacion Ibercivis and The Natural History Museum.

Blackett P., Mackay M., de Monchy C. (2011) *What has changed stream management practices in the Waitao sub-catchment?* Prepared for Robyn Skelton Manager Land Resources Western Bay of Plenty Regional Council. August, 2011. Accessed at: https://cdn.boprc.govt.nz/media/412655/what-has-changed-stream-management-practices-in-the-waitao-sub-catchment_.pdf

Bonney P., Murphy A, Hansen B, Baldwin C. (2020) Citizen science in Australia's waterways: Investigating linkages with catchment decision-making. *Australasian Journal of Environmental Management,* 27(2): 200-223.

Bonney R., Ballard H., Jordan R., McCallie E., Phillips T., Shirk J. (2009) *Public participation in scientific research: Defining the field and assessing its potential for informal science education*. Washington, DC: Center for Advancement of Informal Science Education (CAISE).

Brooks S.J., Fitch B., Davy-Bowker J., Alvarez Codesal S. (2019) Anglers' Riverfly Monitoring Initiative (ARMI): A UK-wide citizen science project for water quality assessment. *Freshwater Science*, 38(2): 270-280.

Brydges T., Lumb A. (1998) Canada's Ecological Monitoring and Assessment Network: Where we are at and where we are going. *Environmental Monitoring and Assessment,* 51: 595–603.

Capdevila ASL., Kokimova A., Ray S.S., Avellan T., Kim J., Kirschke S. (2020) Success factors for citizen science projects in water quality monitoring. *Science of the Total Environment,* 728: 137843.

Carlson T., Cohen A., Hartwig K. (2017) *A snapshot of community based water monitoring in Canada*. Acadia University. Wolfville, Nova Scotia, Canada: 25. Accessed at: https://ees.acadiau.ca/tl_files/sites/ees/pdfs/CBM_Snapshot_Report.pdf

Carlson T., Cohen A. (2018) Linking community-based monitoring to water policy: Perceptions of citizen scientists. *Journal of Environmental Management*, 219: 168-177.

Clapcott J., Young R., Harding J., Matthaei C., Quinn J., Death R. (2011) *Sediment assessment methods: Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values*. Cawthron Institute, Nelson.

Clapcott J. (2015) *National rapid habitat assessment protocol development for streams and rivers*. Report No. 2649 prepared for Northland Regional Council under MBIE Envirolink medium advice grant 1519 by the Cawthron Institute, Nelson.

Csavina J., Roberti J.A., Taylor J.R., Loescher H.W. (2017) Traceable measurements and calibration: A primer on uncertainty analysis. *Ecosphere,* 8(2). https://doi.org/10.1002/ecs2.1683

Davies-Colley R., Milne J., Heath M.W. (2019) Reproducibility of river water quality measurements: inter-agency comparisons for quality assurance. *New Zealand Journal of Marine and Freshwater Research,* 53(3): 437-450.

Davies-Colley R., Hughes A.O., Verburg P. and Storey R. (2012) Freshwater monitoring protocols and quality assurance (QA): National Environmental Monitoring and Reporting (NEMaR) variables step 2. Prepared for the Ministry for the Environment. *NIWA Client Report* HAM2012-092.

Di Fiore D. (2017) *The Anglers' Riverfly Monitoring Initiative: Evaluation of data collected through structured monitoring by amateurs and comparative review of the methodology*. MSc Thesis. University of the West of England, UK.

Dyer F.J., Harrison E.T., Gruber B., Nichols S.J., Tschierschke A., O'Rielly W. (2014) *Waterwatch data quality: an opportunity to augment professionally collected data set*. 7th Australian Stream Management Conference, Townsville, Queensland, Australia.

ECCC. (2017) *National CABIN Science Forum 2017*. Environment and Climate Change Canada. Feb 28-March 1 2017. Canada. Edmonton, Alberta, Canada. 28 p.

EPA. (1996) *The volunteer monitor's guide to quality assurance project plans*. United States Environmental Protection Agency. EPA 841-B-96-003.

EPA. (2019a) *Handbook for citizen science quality assurance and documentation.* United States Environmental Protection Agency. 32p. Accessed at: https://www.epa.gov/citizen-science/quality-assurance-handbook-and-guidance-documents-citizen-science-projects.

EPA. (2019b) *Templates for ctizen science quality assurance and documentation*. United States Environmental Protection Agency. 30p. Accessed at: https://www.epa.gov/citizen-science/quality-assurance-handbook-and-guidance-documents-citizen-science-projects.

EPA. (2002) *Overview of the EPA quality system for environmental data and technology*. United States Environmental Protection Agency, Washington, DC.

European Commission. (2017) *Streamlining environmental reporting – action plan*. Report from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions. COM(2017) 312. 13 p.

European Commission. (2020) *Best Practices in Citizen Science for Environmental Monitoring*. Commission staff working document. SWD(202) 149: 75.

Fenwick G., Greenwood M., Williams E., Milne J., Watene-Rawiri E. (2018) Groundwater ecosystems: functions, values, impacts and management. *NIWA Client Report 2018184CH* prepared for Horizons Regional Council.

Firehock K, West J. (1995) A brief history of volunteer biological water monitoring using macroinvertebrates. *Journal of the North American Benthological Society,* 14(1): 197-202.

Florida Lakewatch. (2020) *Florida Lakewatch training manual and instruction booklet*. University of Florida, Gainsville, Florida. 21p. Accessed at: https://chnep.wateratlas.usf.edu/upload/documents/LW-Training-Manual-2020.pdf

Fore L.S, Paulsen K., O'Laughlin K. (2001) Assessing the performance of volunteers in monitoring streams. *Freshwater Biology,* 46(1): 109-123.

Gadd J., Milne J. (2019) Monitoring water quality in urban streams and stormwater: Guidance for New Zealand practitioners. *NIWA Client Report* 2019168AK prepared for MBIE Envirolink.

Gibson J.F., Shokralla S., Curry C., Baird D.J., Monk W.A., King I., Hajibabaei M. (2015) Large-scale biomonitoring of remote and threatened ecosystems via high-throughput sequencing. *PLoS One,* 10: e0138432.

Gollan J., De Bruyn L.L., Reid N., Wilkie L. (2012) Can volunteers collect data that are comparable to professional scientists? A study of variables used in monitoring the outcomes of ecosystem rehabilitation. *Environmental Management,* 50(5): 969–78. DOI:10.1007/s00267-012-9924-4.

Goudeseune L., Eggermont H., Groom Q., Le Roux X., Paleco C., Roy H.E., van Noordwijk C.G.E. (2020) BiodivERsA citizen science toolkit for biodiversity scientists. *BiodivERsA report,* 44 p.

Gouraguine A., Moranta J., Ruiz-Frau A., Reñones O., Ferse S.C.A., Jompa J., Smith D.J. (2019) Citizen science in data and resource-limited areas: A tool to detect long-term ecosystem changes. *PLoS ONE,* 14(1): e0210007.

Guerrini C.J., Majumder M.A., Lewellyn M.J., McGuire A.L. (2018) Citizen science, public policy. *Science*, 361(6398): 134-136.

Harding J., Clapcott J., Quinn J., Hayes J., Joy M., Storey R., Greig H., Hay J., James T., Beech M., Ozane R., Meredith A., Boothroyd I. (2009) *Stream habitat assessment protocols for wadeable rivers and streams of New Zealand.* School of Biological Sciences, University of Canterbury, Christchurch.

Harvard Law School (2019) *A manual for citizen scientists starting or participating in data collection and environmental monitoring projects*. 2nd edition. Harvard Law School, Emmett Environmental Law and Policy Clinic. 244 p.

Hoyer M., Bigham D., Bachmann R., Canfield D. (2014) Florida LAKEWATCH: Citizen scientists protecting Florida's aquatic systems. *Florida Scientist, 77*(4): 184-197.

Hoyer M.V., Wellendorf N., Frydenborg R., Bartlett D., Canfield D.E. (2012) A comparison between professionally (Florida Department of Environmental Protection) and volunteer (Florida LAKEWATCH) collected trophic state chemistry data in Florida. *Lake Reservoir Management,* 28: 277-281.

Hughey K.F.D., Kerr G.N., Cullen, R. (2016) *Public perceptions of New Zealand's environment: 2016.* EOS Ecology, Christchurch. 82 p.

Hughey K.F.D., Kerr G.N., Cullen, R. (2019) *Public perceptions of New Zealand's environment: 2019.* EOS Ecology, Christchurch. 92 p.

Jalbert K., Kinchy A.J. (2015) Sense and influence: Environmental monitoring tools and the power of citizen science. *Journal of Environmental Policy and Planning*, 18(3): 1-19.

Jensen E.V. (2006) *Cumulative effects monitoring of Okanagan streams using benthic invertebrates, 1999 to 2004*. B.C. Ministry of Environment draft management report. Penticton, B.C. 32 p.

Kaitiaki Contributors, Ratana K., Herangi N, Rickard, D. (2020) Maniopoto freshwater cultural assessment framework. *Science Communication Summary Report* prepared for Maniapoto Māori Trust Board. Published by NIWA, Hamilton (NIWA Information Series 96).

Kanu A., DuBois C., Hendricks E., et al. (2016) *Realizing the potential of community based monitoring in assessing the health of our waters*. Our Living Waters (Pooling Water Knowledge Working Group). 19p. Accessed at: http://awsassets.wwf.ca/downloads/realizing_the_potential_of_community_based_monitoring_in_assessing_the_health_of_our_.pdf

Kin E., Storey R., Wright-Stow A., Davies-Colley R. (2016) *Engaging communities in freshwater monitoring. Benefits and challenges*. *NIWA Client Report* HAM2016-046. 41 p.

Latimore J.A., Steen P.J. (2014) Integrating freshwater science and local management through volunteer monitoring partnerships: The Michigan Clean Water Corps. *Freshwater Science*, 33: 686–92.

Lukyanenko R., Parsons J., Wiersma Y.F. (2016). Emerging problems of data quality in citizen science. *Conservation Biology*, 30(3): 447-449.

Manzoni M., Vohland K., Schade S., Tsinaraki C., Dusart J. (2019) *Citizen science and environmental monitoring: Benefits and challenges*. Publications Office of the European Union, Luxembourg. ISBN 978-92-76-09557-6.

McBride G.B. (2005) *Using statistical methods for water quality management: Issues, problems and solutions.* John Wiley & Sons, New York.

MCFN. (2016) *The Mikisew Cree First Nation community based monitoring: Key program activities and protocol descriptions*. 10 p. Accessed at: http://mikisewgir.com/cbm

MfE and Stats NZ. (2020) *Our freshwater 2020.* Publication No. ME1490, Ministry for the Environment, Wellington.

MfE, DOC. (2017) *Conservation and environment science roadmap.* Publication No. ME1295, Ministry for the Environment, Wellington.

MfE, MoH. (2003) *Microbiological water quality guidelines for marine and freshwater recreational areas.* Ministry for the Environment, Wellington.

MfE, MoH. (2009) *New Zealand guidelines for cyanobacteria in recreational fresh waters – interim guidelines.* Prepared for the Ministry for the Environment and the Ministry of Health by SA Wood, DP Hamilton, WJ Paul, KA Safi and WM Williamson. Wellington: Ministry for the Environment.

MfE (2020) *Mahinga kai and other Māori freshwater values factsheet.* Publication No. INFO 999, Ministry for the Environment, Wellington.

Milne J., Valois A. (2021) Stewardship of community-based environmental monitoring data: A workshop exploring current initiatives and opportunities in Aotearoa/New Zealand. *NIWA Client Report 2021011WN* prepared for the Our Land and Water National Science Challenge. 21 p.

Moolna A., Duddy M., Fitch B., White K. (2020) Citizen science and aquatic macroinvertebrates: Public engagement for catchment-scale pollution vigilance. *EcoScience*, 27(4): 303-317.

MPI. (2016) *Biosecurity 2025: Direction statement for New Zealand's biosecurity system*. Ministry for Primary Industries, Wellington.

NACEPT. (2016) *Environmental protection belongs to the public: A vision for citizen science at EPA*. National Advisory Council for Environmental Policy and Technology (NACEPT) Report: EPA 219-R-16-001.

NACEPT. (2018) *Strengthening EPA citizen science partnerships for environmental protection*. National Advisory Council for Environmental Policy and Technology (NACEPT) Report: EPA 220-R-18-001.

NEMS. (2019) *National Environmental Monitoring Standards for Water Quality, Part 2 of 4: Sampling, measuring, processing and archiving of discrete river water quality data.* Version 1.0.0, March 2019. Ministry for the Environment, New Zealand.

NEMS. (2020) *National Environmental Monitoring Standards for Macroinvertebrates: Collection and processing of macroinvertebrate samples from rivers and streams.* Version 1.0.0, November 2020 (draft prepared for the NEMS Steering Group).

Njue, N., Kroese, J. S., Gräf, J., et al. (2019) Citizen science in hydrological monitoring and ecosystem services management: State of the art and future prospects. *Science of the Total Environment*, 639: 133531.

NZ Govt. (2017) *National Policy Statement for Freshwater Management 2014: Updated August 2017 to incorporate amendments from the National Policy Statement for Freshwater Amendment Order 2017.* New Zealand Government.

NZ Govt. (2020) *National Policy Statement for Freshwater Management 2020.* New Zealand Government, August 2020.

NLWRA. (2000) *Australian Water Resources Assessment 2000.* National Land and Water Resources Audit, on behalf of the Commonwealth of Australia. 130 p.

Peters M.A, Hamilton D., Eames C. (2015) Action on the ground. *New Zealand Ecological Society*, 39(2): 179-189.

Peters M.A., Hamilton D.P., Eames C. (2016) The current state of community-based environmental monitoring in New Zealand. *New Zealand Journal of Ecology*, 40(3): 279-288.

Pierson R. (2021) *An international pilot study of volunteer stream monitoring groups: The role of place attachment in volunteer motivations*. MSc Thesis. University of Vermont, USA.

Pocock M.J.O., Chapman D.S., Sheppard L.J., Roy H.E. (2014) *A strategic framework to support the implementation of citizen science for environmental monitoring*. Final Report to SEPA. Centre for Ecology & Hydrology, Wallingford, Oxfordshire.

Poisson A.C., McCullough I.M., Cheruvelil K.S., Elliot K.C., Latimore J.A., Soranno P.A. (2019) Quantifying the contribution of citizen science to broad-scale ecological databases. *Frontiers in Ecology and the Environment,* 18(1): 19-26.

Research Data Alliance International Indigenous Data Sovereignty Interest Group (2019) *CARE principles for indigenous data governance*. The Global Indigenous Data Alliance. GIDA-global.org.

Ried E.K., Carr L., De Cicco L., et al. (bo2017) Water quality data for national-scale aquatic research: The Water Quality Portal. *Water Resources Research*, 53(2): 1,735-1,745.

Riverness. (2015) *The plan for Waterwatch Victoria.* Prepared for Waterwatch Victoria by Riverness Pty Ltd.

Roy H.E., Pocock M.J.O., Preston C.D., Roy D, Savage J., Tweddle J.C., Robinson L.D. (2012) *Understanding citizen science and environmental monitoring.* Final Report on behalf of UK-EOF. NERC Centre for Ecology & Hydrology and Natural History Museum: 1–179. Available: www.ukeof.org.uk/documents/understanding-citizen-science.pdf.

Rubin L., Donovan C., Fries A., Vastine J., Monismith J.M Spitzer S., Donkersloot D. (2017) *Prioritization report: How volunteer and nontraditional monitoring can help fill data gaps in the Chesapeake Bay Watershed*. Prepared for the Chesapeake Bay Program Partnership. 44 p.

Safford H., Peters C.A. (2017) Citizen science for dissolved oxygen monitoring: Case studies from Georgia and Rhode Island. *Environmental Engineering Science*, 35: 362–372.

Science Communication Unit, University of the West of England, Bristol. (2013) Science for Environment policy in-depth report: Environmental citizen science. Report produced for the European Commission DG Environment. Accessed at: http://ec.europa.eu/science-environment-policy

Statistics New Zealand. (2007) Principles and protocols for producers of Tier 1 statistics. Statistics New Zealand, Wellington. 65 p.

Storey R., Wright-Stow A. (2017) Community-based monitoring of New Zealand stream macroinvertebrates: Agreement between volunteer and professional assessments and performance of volunteer indices. *New Zealand Journal of Marine and Freshwater Research*, 51(1): 60-77.

Storey R.G., Wright-Stow A., Kin E., Davies-Colley R., Stott R. (2016) Volunteer stream monitoring: Do the data quality and monitoring experience support increased community involvement in freshwater decision-making? *Ecology and Society*, 21(4): 32.

Tango P. (2019) Adaptive water quality monitoring and evolving assessments enhance decision-support for watershed and bay recovery in the Chesapeake Bay Program Partnership. National Water Monitoring Conference, Denver, Colorado, USA.

The Gordon Foundation. (2019) Elevating community-based water monitoring in Canada: Final recommendations. Accessed at: https://gordonfoundation.ca/resource/elevating-community-based-water-monitoring-in-canada/.

The Scottish Government. (2011) *Scottish environmental monitoring strategy*. Edinburgh, Scotland.

Thompson M.S.A., Bankier C., Bell T., Dumbrell A.J., Gray C., Ledger M.E., Lehmann K., McKew B.A., Sayer C.D., Shelley F., Trimmer M., Warren S.L., Woodward G. (2015) Gene-to-ecosystem impacts of a catastrophic pesticide spill: Testing a multi-level bioassessment approach in a river ecosystem. *Freshwater Biology*, 61: 2037–2050.

Tipa G., Tierney L. (2006) *A cultural health index for streams and waterways: A tool for nationwide Use*. Ministry for the Environment, Wellington, New Zealand: 54p.

UKEOF. (2020) Data management planning for citizen science. United Kingdom Environmental Observation Framework. Citizen Science Working Group. 8p. Accessed at http://www.ukeof.org.uk/resources/citizen-science-resources/cswg-data-guidance-booklet-web.pdf.

Valois A.E., Davies-Colley R., Storey R., Wright-Stow A. Stott R, Kin E., van Hunen S. (2019) Volunteer monitoring as a focus for community engagement in water management in Aotearoa-New Zealand: Review and prospects. *Water Science and Technology*, 19(3): 671-680.

Valois A.E., Milne J., Heath M.W., Davies-Colley R.J., Martin E., Stott R. (2020) Community volunteer assessment of recreational water quality in the Hutt River, Wellington. *New Zealand Journal of Marine and Freshwater Science*, 54(2): 200-217.

Valois A.E., Somers K., Sarrazin-Delay C., Keller B. (2016) Are bioassessments based on the Reference Condition Approach (RCA) affected by 'rapid' approaches to sample collection and processing? *Journal of Limnology*, 75(2): 393-402.

Waterwatch (2010) *West Gippsland Waterwatch data confidence plan*. 28p. Accessed at: http://www.vic.waterwatch.org.au/resources/WGCMA_Data_Confidence_Plan_V4_Feb_2010.pdf

Wilderman C.C., Monismith J. (2016) Monitoring Marcellus: A case study of a collaborative volunteer monitoring project to document the impact of unconventional shale gas extraction on small streams. *Citizen Science: Theory and Practice*, 1(1): 7.