A Business Case for Investment in Canadian Community-Based Water Monitoring

IISD REPORT

International Institute for Sustainable Development

Geoffrey Gunn
on behalf of the
Community-Based Water
Monitoring Collaborative

November 2021

International Institute for Sustainable Development

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Written by Geoffrey Gunn (IISD) on behalf of the Community-Based Water Monitoring Collaborative, an Our Living Waters Team

Cover photo: Dane nan yḗ dāh Kaska Land Guardian Network

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With support from the RBC Foundation.

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Introduction

The Canadian landscape stretches between three oceans and is dotted with lakes (both great and small) and rivers, as well as spongy bogs, marshes, swamps, and fens. Canoe and kayak defined important places over millennia for Indigenous peoples and settlers alike. Today, nearly half of Canadians perceive water to be this country's most important natural resource—more than fossil fuels, minerals, or hydroelectricity (RBC Blue Water Project, 2017).

However, beneath the surface, these waters are troubled. Less than half of Canada's fresh water is renewable—that is, it can be replenished by precipitation or runoff on a reasonable timeframe (Environment and Climate Change Canada [ECCC], n.d.). The rest is "fossil water" locked in the ground and refilled only over centuries or longer. Canada's lakes are also imperilled by oxygen-depleting algal blooms, invasive species like the sea lamprey and zebra mussel, and the uncertain heat and precipitation that will change with the climate.

Our society and economy depend on the services provided by aquatic ecosystems, and many of Canada's starkest challenges can be framed in terms of water. Ensuring all people have access to clean drinking water, making our communities resilient to climate disasters, and helping economies become clean and sustainable are all commitments made by governments at all levels.

To find solutions and adapt, we need to understand what the human impacts are and how they are affecting water. Unfortunately, this is essentially impossible to do for most Canadian basins: 100 of Canada's 167 sub-watersheds lack sufficient data to report on their health (WWF-Canada, 2020). Even advances in satellite monitoring and Internet-connected sensors have not matched a person watching streams and lakes in their community.

This is a gap best filled by community-based water monitoring (CBWM)—a way that communities and community-level organizations manage their water resources by collecting and using data relevant to their own experience. CBWM can be a cost-effective way for communities to understand complex problems at their own scale, develop evidence to make decisions that influence their own communities, and collect long-term records to monitor industrial impacts and identify subtle impacts of a changing climate. Additional benefits include the capability to understand cumulative impacts of stacked environmental impacts

This report was developed to support a business case for CBWM in Canada—showing that this method of environmental monitoring is a cost-effective way for Canadian and Indigenous communities to assert their interests and make the most informed decisions about their water resources. Part 1 of this report reviews the status of water monitoring in Canada—how monitoring informs management, who is responsible, and how are emerging concepts like citizen science and CBWM are expanding understanding of local waters. This section also reviews what makes CBWM programs successful and how alternative funding models can empower CBWM in Canada. The business case is that CBWM pays dividends to Canadians toward sustainable water management but requires a significant investment and a move away from project-based funds toward core funding that reflects the long-term benefits of monitoring datasets.

Part 2 reviews three examples of CBWM in Canada: the Lake Winnipeg Community-Based Monitoring Network that engages volunteers to help understand where phosphorus pollution comes from across one of Canada's largest drainage basins; the Dane Nan Yḗ Dāh network of Indigenous Guardians which was formed to be the "ears and eyes" of Kaska communities; and the long-running Clean Annapolis River Project, which has developed a long-term dataset on the Annapolis River and its tributaries to protect and preserve one of Canada's most historic rivers.

Finally, a business case is presented in Part 3 as a brief containing the specific recommendations for Canada to encourage and expand the role of CBWM into our environmental observation system of systems and as part of a common monitoring data infrastructure.

Monitoring for Management

Monitoring is an activity distinct from pure science in both design and objectives. Water quality monitoring is, according to the Canadian Council of Ministers of the Environment (CCME), one of the most important components of managing aquatic systems (CCME, 2015) because it allows managers to observe the state and trends of complex ecosystems over a period of time.

In the context of water quality, Bartram and Ballance (1996, p. 8) specify three types of monitoring programs to support management:

- "**Monitoring** is the long-term, standardised measurement and observation of the aquatic environment in order to define status and trends,
- **Surveys** are finite duration, intensive programmes to measure and observe the quality of the aquatic environment for a specific purpose,
- **Surveillance** is continuous, specific measurement and observation for the purpose of water quality management and operational activities."

These are distinguished from science (both public and academic), which seeks to build systematic understanding of the natural world based on experiments and observation (Merriam-Webster, n.d.). While many scientific pursuits benefit from data collected in monitoring programs—and scientists provide invaluable advice in the design and implementation of monitoring—these programs are applications of scientific knowledge and methods in support of public policy.

Monitoring programs carry with them an explicit management objective, whether defining the state or trend of a system, revealing baseline conditions before an expected impact, or developing a framework of function to predict sensitivities.

Monitoring Responsibilities in Canada

The status quo for water management was created by decisions made at the founding of Canada as a modern settler-colonial state—decisions reflected in legislation dating to *The Constitution Act* (1867) and the division of federal and provincial responsibilities that have evolved over that period.

The state of these responsibilities is summarized by a recent report prepared by the Library of Parliament. According to Becklumb (2019), federal responsibilities include:

- Public (federal crown) property
- Freshwater and marine fisheries
- Navigation and shipping
- Criminal law
- Indigenous peoples and reserve lands.

There are also residual powers granted to the federal government by legal decisions, often connected to relationships with foreign nations or disputes between provinces. These include transboundary water apportionment and water quality, migratory birds, and certain components of biodiversity.

Currently, executive power is exercised over water in Canada by over 20 federal departments, each with legislated responsibilities, practical business lines, and roles in regulations and oversight. Departments with major responsibilities for water include ECCC, Department of Fisheries and Oceans Canada, and Natural Resources Canada; Indigenous Services Canada, Health Canada, and Parks Canada all hold minor or limited responsibilities for water resources. The departments of Agriculture and Agrifoods Canada and Infrastructure Canada do not hold specific responsibilities toward water but may collaborate or support water monitoring collaborations with provincial units. Former initiatives and agencies, such as the Prairie Farm Rehabilitation Administration and the Atlantic Coastal Action Program, also conducted and supported water monitoring work but have been closed or modified in the past two decades.

There is a new attempt to rationalize federal responsibilities toward water, most recently a broad consultation regarding a proposed Canada Water Agency. This agency may serve as a conduit between federal departments, Indigenous communities, scientists, and the public or as a water-focused clearinghouse of federal, provincial, and territorial expertise.

According to *The Constitution Act* (1867), provinces hold distinct environmental responsibilities. These include:

- Management of public (provincial crown) property including logging and mining.
- Regulation of private property rights and business practices including emissions.

- Local and private matters, including waste management, provision of drinking water, and removal of wastewater, that are often delegated to municipal governments.
- Management of all local water resources, including groundwater, with the exception of boundary waters (international or interprovincial) and water on federal lands such as national parks.

Canada's three territorial governments have negotiated agreements with the federal government to exercise local water management similar to provinces.

Each province and territory occasionally develops a water strategy that outlines plans and priorities to manage water resources. Water monitoring is sometimes included. For example, in *Living Water Smart: British Columbia's Water Plan* (Ministry of the Environment, British Columbia, 2008) one stated objective was "establishing benchmarks for monitoring progress on water use based on scientific research," while *Water for Life: Nova Scotia's Water Resource Management Strategy* (Province of Nova Scotia, 2010) highlighted water monitoring knowledge as a primary goal. In *Northern Voices, Northern Waters: NWT Water Stewardship Strategy* (Government of the Northwest Territories, 2010) monitoring and particularly community-based or community-partnered monitoring was the keystone of the "Know and Plan" strategy pillar. Ontario's *Great Lakes Strategy* (Ministry of the Environment, Conservation and Parks, 2016) included a section monitoring the economic impact of the water sector as a whole.

Many provincial water strategies also reflect the agencies operating in their jurisdiction that support integrated water management activities, such as conservation authorities (Ontario), watershed districts (Manitoba), or basin councils (Alberta). Prince Edward Island alone has 24 watershed organizations, represented by the Prince Edward Island Watershed Alliance.

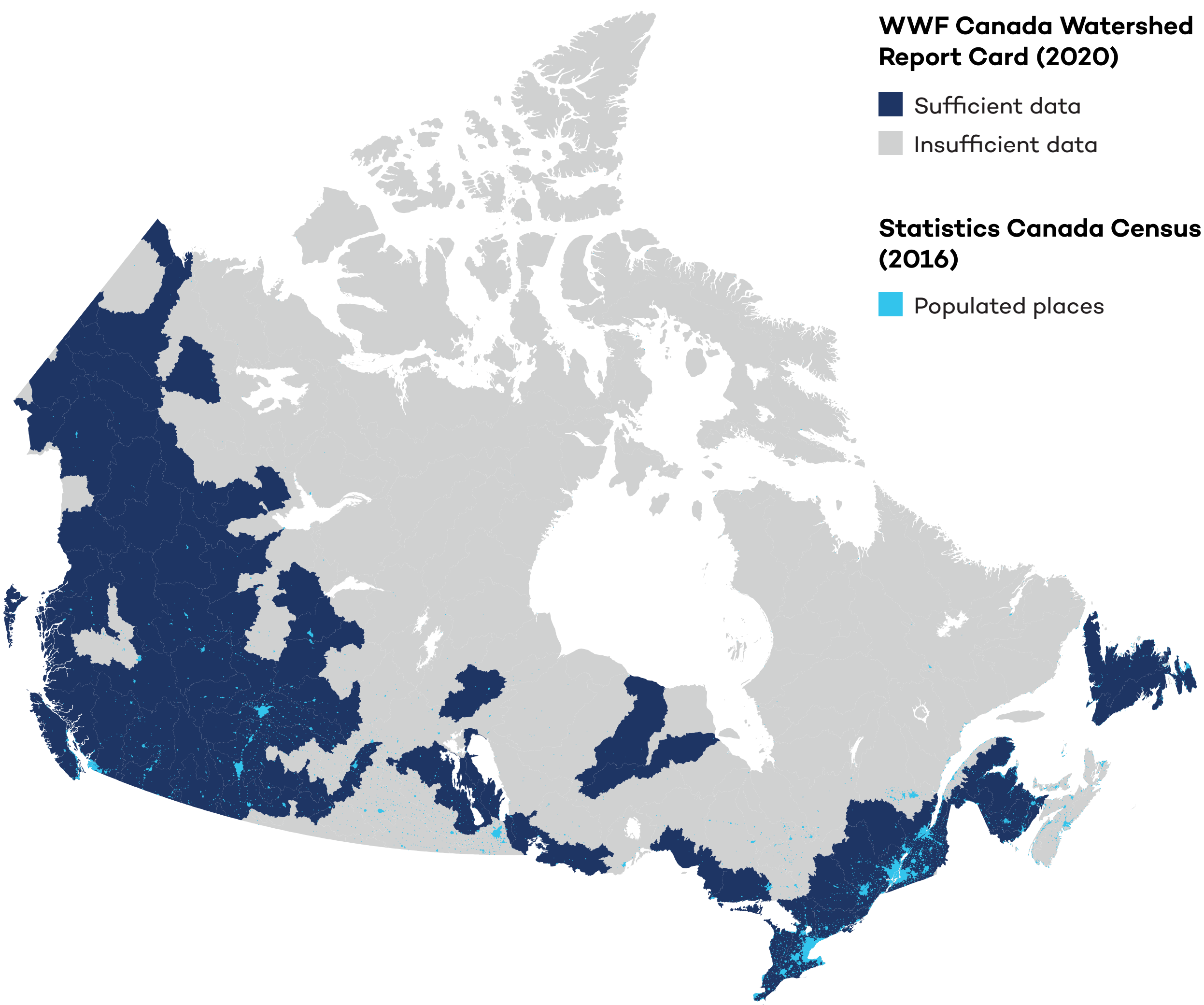
These agencies have fulfilled an important connecting role between provinces, local governments, and individuals. However, according to Shrubsole et al. (2017), they exist in a state of insufficient funding for the tasks they must undertake and hold no legislative authority. In many cases, they must apply for competitive grants like the New Brunswick Environmental Trust Fund to supplement limited or non-existent core funding.

Indigenous governments have continued or are reclaiming stewardship roles on their traditional territories. In the *National Water Declaration,* the Assembly of First Nations (n.d.) asserts that "[w]ater in First Nations territories is often degraded by activities that occur outside or adjacent to our communities and traditional lands. We must continue to exercise our right to protect and care for our waters."

Recent recognition of the importance of Traditional Knowledge and Indigenous Knowledge Systems alongside Western science has been expressed in the framework of "Two-Eyed Seeing." This process, discussed in detail by Bartlett et al. (2012), was developed by Elder Murdina Marshall and Elder Albert Marshall from the Mi'kmaq Nation to integrate different but complementary ways of learning, knowing, and communicating about environmental issues. This strategy has been integrated into subsequent monitoring programs including some Indigenous Guardians programs (Indigenous Circle of Experts, 2018).

Responsibility for a considerable amount of water management in Canada has fallen on community members themselves, often outside of provincial structures. These groups working in water management range from informally organized like-minded individuals concerned about a local issue to national chapters of international non-governmental organizations (NGOs) such as Ducks Unlimited Canada and WWF-Canada. These groups—big and small—conduct surveillance activities to notify authorities of emerging or critical issues, such as citizen sensors who use an app developed by Natural Resources Canada to report spring ice jams and flooding (Burke, 2018), or stakeholders who complete short-term surveys to inform local policy decisions, or volunteers conducting long-term monitoring to fill gaps at the watershed or drainage basin scale.

Figure 1. Watershed data status



Source: Adapted from WWF-Canada (2020).

Differences in jurisdiction, community capacity and above-all geography have created a fragmented landscape of the state of water monitoring in Canada. According to WWF-Canada (2020), watersheds with "sufficient" data to assign a health grade are located in the Western Cordillera, the densely populated Windsor to Quebec City urban corridor, and parts of Atlantic Canada (Figure 1). The Arctic and Prairie regions are particularly sparse.

Filling in the map requires a renewed investment in water monitoring, incorporating all available tools and modes. Alongside novel sensors and satellite platforms, communities who live within these watersheds carry the largest stake in their protection for the future—and can deliver their knowledge and rigorous scientific data to their own local leaders and experts elsewhere. Monitoring based in each community—but connected to regional networks—can generate the data we need to prepare for a changing water future.

What Is CBWM?

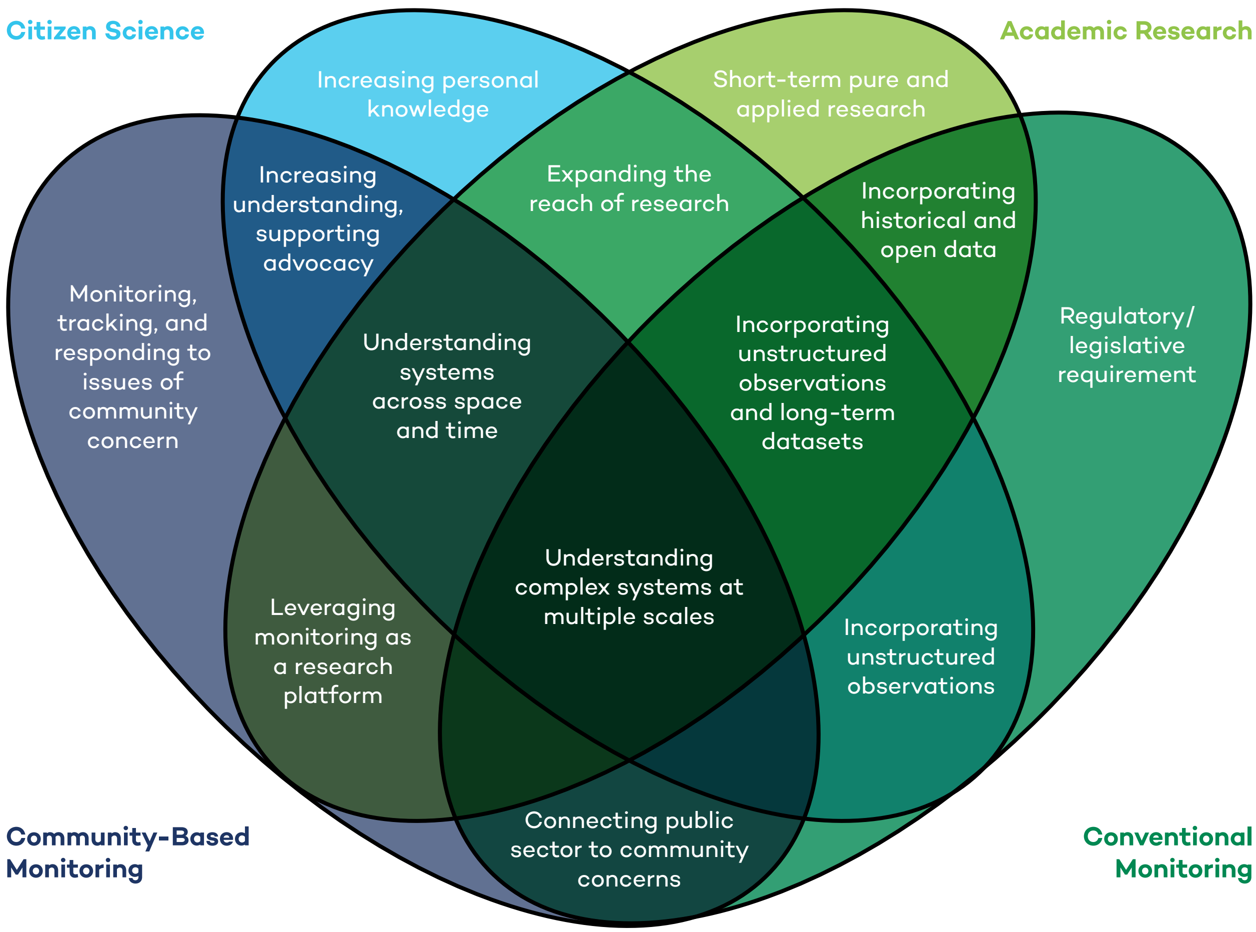
CBWM is represented by a range of organizations, ranging from informal groups of concerned citizens to professionals working with international charities. These institutions vary greatly in organizational capacity, financial resources, and scope. However, they all use principles of community-based monitoring to inform the management of water resources.

Whitelaw et al. (2003) define community-based monitoring as "a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track, and respond to issues of common community concern."

This definition emphasizes the importance of local concerns and the potential for local responses as a way for organizations to address these issues. This community scale of environmental issues appears to be critical in distinguishing community-based monitoring from other ways of understanding environmental or social concerns.

Community-based monitoring exists within multiple modes of building knowledge about environmental systems. Figure 2 shows some of the interactions between four modes of developing environmental understanding: community-based monitoring, conventional monitoring, citizen science, and academic research. This non-comprehensive categorization reflects the continuum of developing understanding for improved management—from surveys (academic research) to surveillance and observation (citizen science) to formal monitoring (community based and conventional).

Figure 2. This four-set Venn diagram highlights the connections between academic research, citizen science, conventional monitoring, and community-based monitoring. Academic research and citizen science are exploratory—often seeking to understand general concepts or systems—while monitoring documents the function of systems at a specific time and place with the goal of informing management.



Source: Author Diagram.

Community-Based Monitoring and Citizen Science

Defining community-based monitoring requires a brief examination of a term that is used somewhat synonymously: citizen scientist. The *Oxford English Dictionary* (2016) added citizen science in 2014, defining it as "Scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions."

In a comprehensive and cautionary examination of the importance of terminology of citizen science, Eitzel et al. (2017) recognize the complexity of the term and a variety of uses, noting that there are two key strands to citizen science in practice: one that dates to the coining of the term by Irwin (1995) which emphasized the democratizing of science to non-specialist participants to advance policies based on both evidence and science; and a second, later, definition that recognized the scientific importance of crowd-sourced data, such as through participatory migratory bird surveys documented by Cooper and Lewenstein (2016). This latter definition has alternatively been called "human sensors," but as Eitzel et al. note, this, along with other terms, may offend or undervalue contributions of participants.

The major distinction between citizen science and community-based monitoring is the nature of the questions to be answered: do they come from academic researchers or from members of the community? Community-based monitoring reflects a focus on local concerns and local action, while citizen science encompasses everything from top-down "crowd-sourced data" (Lämmerhirt et al., 2018) to 'volunteered geography' (Goodchild, 2007) that supports research. In other words, community-based monitoring has a direct pathway to informing management decisions, while citizen science may include this definition as well as including participants in academic research.

Features of Successful Community-Based Monitoring Programs

The common aspect shared by citizen science and community monitoring is capacity volunteered by individuals—often without financial remuneration. Drivers of these participants may be diverse—from curiosity to collaborating with others to solving a specific issue (Tulloch et al., 2013).

Citizen Science: Mapping precipitation across continents

A tangible and illustrative example of citizen science supporting water research is the Community Collaborative Rain, Hail and Snow network (CoCoRaHS). Established following a 1997 flash flood in Fort Collins, Colorado, this volunteer network was established to improve precipitation mapping and forecasting by distributing rain gauges to volunteers in the United States, Canada and other countries. Each day, volunteers contribute their gauge readings (or in the wintertime, snow depths) which meteorologists and atmospheric scientists can compare to models and forecasts. In exchange, participants receive a web platform to store their own observations and view measurements from other contributors. These gauges are placed at the volunteer's discretion, often on private property that is convenient for frequent readings.

What began as a community-based program has now expanded to a continental-scale citizen science program that contributes to the United States National Weather Service, the US Department of Agriculture, and professional scientists around the world. Although initially driven by a scientific and policy failure—a USD 200 million flood event—this program primarily contributes to questions within the domain of applied meteorology (CoCoRaHS, n.d.).

By including a wider variety of contributors early in the process, monitoring program design is more likely to "measure what matters" and, in so doing, demonstrate value to the community, policy-makers, and funders seeking a positive impact or return on investment. By including the community in the implementation—such as including volunteers to conduct monitoring, provide feedback, or sit on steering committees—CBWM reveals a tangible demonstration of interest and support *in kind* by the community—at this scale, interest may not be captured by surveys or in local elections.

San Llorente Capdevila et al. (2018) conducted a broad literature review of citizen science projects that specifically focused on water quality monitoring, particularly in support of the United Nation's Sustainable Development Goal 6.3.2 ("the proportion of bodies of water with good ambient water quality"). They found three sets of factors critical to successful programs:

- The attributes of volunteers (including this awareness of issues, motivation, knowledge and experience, and socio-economic background)
- The attributes of institutions (their motivation, type, and funding available)
- The interactions between the two groups, including supporting structures, systems, and level of communication.

The most successful endeavours are marked by engaged and knowledgeable participants who have enough resources to make meaningful contributions. Examples in the literature note that many early-stage volunteers may be retired scientists or environmental professionals who are already engaged and motivated by both interest and concern (e.g., Schnare, 2011). Participants having only an interest in science or how an ecosystem functions are identified as a "moderate" indicator of success.

The supporting institutions—including government agencies, non-profits, or advocacy organizations—are also essential. Many examples reviewed by San Llorente Capdevila et al. (2018) were initially motivated by the cost effectiveness of volunteer water monitors, given an acknowledged lack of water quality data common to many countries beyond Canada. The cost effectiveness seen in examples is balanced with concerns about data quality and extra steps required to demonstrate rigour.

An example of connecting cost, utility, and rigour is the Chesapeake Monitoring Cooperative, which connects CBWM organizations, conventional state and federal monitoring organizations and local governments surrounding Chesapeake Bay and its watershed (Cohen & Livingstone, 2021). The cooperative uses a tiered framework to assess monitoring rigour and investment and to connect these programs to their best uses—or identify significant gaps. The organization provides important strategic guidance to community-based organizations on the best uses of their data and recommends improvements since they also monitor how community data is used by conventional monitoring organizations and environmental professionals.

San Llorente Capdevila et al. (2018) report that the most important factor for a successful citizen water monitoring program is stable, long-term funding that minimizes or eliminates costs to volunteer participants. Adequate funding also enhances supporting structures between the funding institution and the volunteers. This supporting structure is often a locally based organization that consults the community, designs sampling programs, integrates and implements sampling protocols, and provides quality assessment and dissemination of the data.

Essentially, CBWM is another method of understanding the state and trends of the environment, a concept comparable to other modelling modalities such as remote sensing (see box), *in situ* sampling, or autonomous sensors. Each method generates data that can be incorporated into a nested Global Earth Observation System-Of-Systems (GEOSOS, Craglia et al., 2017). Each monitoring modality has strengths and weaknesses—the global coverage of satellite sensing is balanced against poor resolution and inability to see beneath clouds, land, and water[1] and difficulties connecting detected radiances to actual geophysical parameters; physical sampling by staff or consultants is expensive and time-consuming[2]; while automated stations may be vandalized by people or the harsh environments of a river in flood stage.

CBWM reflects community needs and desires and channels enthusiasm toward supporting better science and better policies—but for this mode of monitoring to thrive, we must understand the full value these organizations provide. As part of a Canadian water observation system of systems (Figure 3), it can deliver better knowledge to meet the environmental, social, and economic challenges of the 21st century.

The Evolution of Satellite Remote Sensing to Support Environmental Monitoring

The growing recognition of community-based monitoring approaches echoes the gradual development and acceptance of remote sensing as a means of understanding human and natural systems.

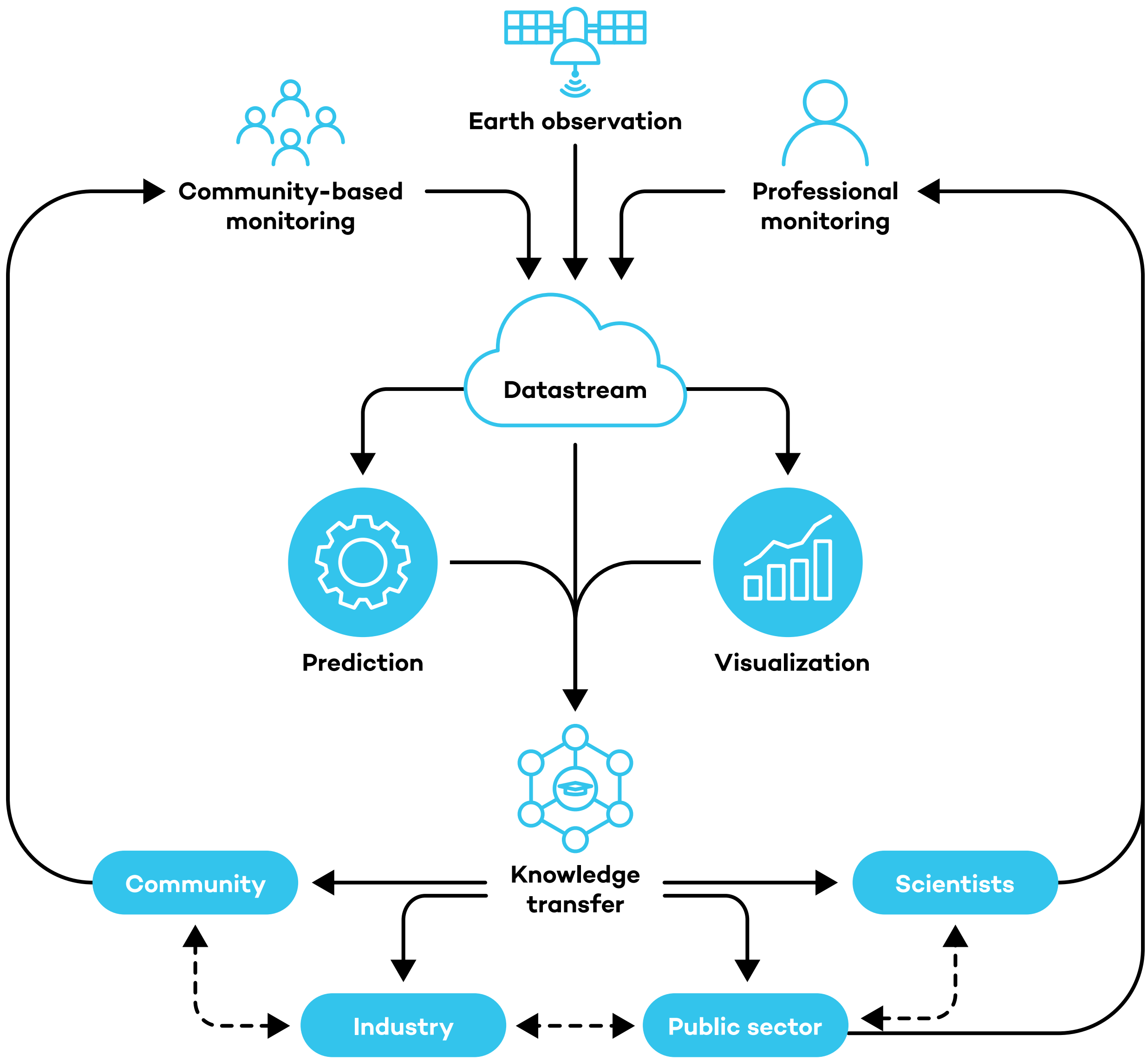
When the first United States Geological Survey Landsat satellite was launched in 1972 there were uncertain expectations regarding the utility of the system, although experience with aerial observation during the wars of the 20th century and lunar exploration raised expectations for mapping vegetation, urban planning, and geology. Considerable value from this dataset is derived from the continuity of monitoring (Wulder et al., 2008).

It remained a specialist tool until the early 2000s, when Google Earth, cloud computing, and improved computing power revealed the power of the Landsat archive to understand topics as diverse as climatology, oceanography, limnology, and disaster prevention. Alongside more recent programs, satellite and airborne remote sensing has established itself in publicly funded programs that return between three and five times the investment to the economy (Dewberry, 2012). Canada pioneered active radar systems and Canadian innovation has created the RADARSAT Constellation.

[1] For systems observing in the visible, ultraviolet, and near-infrared portions of the spectrum. Microwave sensors have separate issues.

[2] See Case Study 1 below for cost-effectiveness comparison.

Figure 3. A conceptual Canadian water observation system of systems



Source: Author diagram.

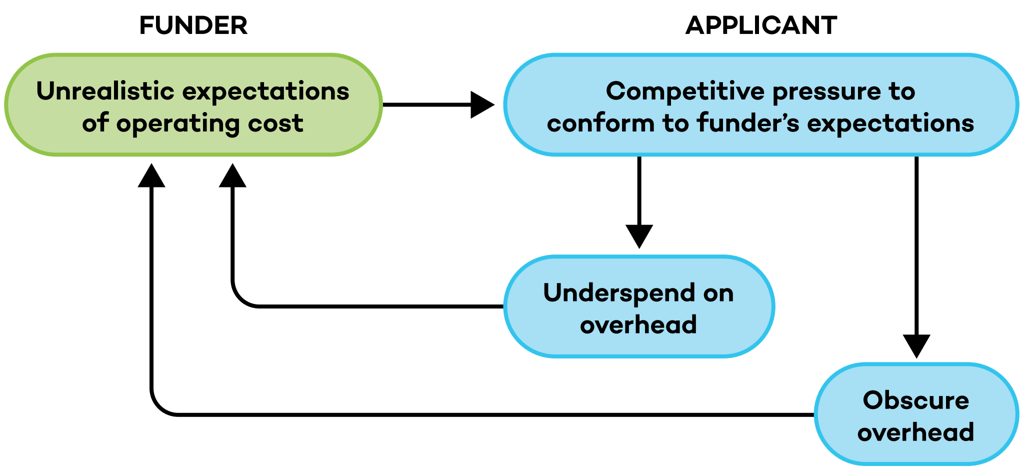
Funding for CBWM in Canada

In a survey of CBWM organizations, Carlson et al. (2017) found many respondents operate on short-term, project-based funding—33% of which reported only annual commitments and 35% reporting multiple-year commitments. Federal support for monitoring may come from currently active programs including the Atlantic Ecosystems Initiative (ECCC), Indigenous Guardians Pilot Program (ECCC), and GeoConnections (Natural Resources Canada)—all of which operate on a pilot or project-delivery basis and no covered core operating expenses. Organizations conducting CBWM programs are forced to apply to multiple competitive requests per year to ensure they have funds to continue into the future and can provide sufficient leveraged funds for future requests for proposals. It also prevents many programs from hiring permanent staff, opting instead for short-term or seasonal staff. This increases staff turnover—particularly for staff with technical or scientific expertise and especially for rural-based organizations.

Within the discipline of business administration, this is known as the "non-profit starvation cycle." Research by Goggins Gregory and Howard (2009) revealed that project-based funding programs delivered over long time scales eventually create a feedback loop between funding agencies and non-profit service providers.

In brief, the competitive grant application process incentivizes organizations to adjust their objectives to the funders' stated goals and probable resource availability. Proposals therefore underestimate expenses and obscure true overhead—administrative support, technology procurement, maintenance, and facilities. The funder then, in evaluating proposals, receives an inaccurate understanding of the "true cost" of project delivery, which influences future funding decisions and resource requirements.

Figure 4. The non-profit starvation cycle



Source: Adapted from Goggins Gregory and Howard, 2009.

When repeated frequently (every year or two), this diminishes a grant-funded organization's investment in longer-term capabilities: whether technological capacity, innovative and opportunistic community initiatives, collaboration, or the more mundane necessities of facilities, training, and staff retention. Altamimi and Liu (2019) analyzed arts and cultural non-profits in the United States and found that unrealistically low expectations of overhead put non-profits at risk of closure, and those that had sufficient overhead from endowments or core funding programs delivered stronger outcomes.

With the vast majority of CBWM organizations in Canada operating as non-profits, we can assume this situation is similar. Additionally, there have been anecdotal indications that funders may have budgets reduced, and many worthy applications sometimes may negotiate reduced funds to support more projects—further squeezing the limited project funds.

Reliance on project-based funding for monitoring programs creates an additional tension. It mirrors the systems used in public sector procurement for private contractors who deliver specific services. If staff use the same or similar procurement models for specific services as well as long-term programming, including CBWM, a "perception as reality" issue may arise. Reflecting this, Cohen and Livingstone (2021) note that "CBWM groups should not be seen as less expensive consultants; instead they are partners in water stewardship, with eyes and ears on the land and water in a way that governments are not able to do."

The definition of monitoring and the scope of a 'project' show that supporting CBWM with ongoing, short-term, competitive grants is unsustainable. Recall monitoring, is defined as "the **long-term**, standardi[z]ed measurement and observation of the aquatic environment in order to define **status and trends**" (emphasis added) (Bartram & Ballance, 1996).

While a project is defined as:

> a set of **time-bound activities** that changes the capability of a program **to deliver outcomes and benefits** … [it] is understood to mean all activities required to deliver the new capability, including change management, organizational change, legislative change, process change, training, communications activities, and so forth. (Treasury Board of Canada Secretariat, 2009)

The incoherence of these definitions should emphasize that, in terms of needs-driven investigations into the state and trends of the environment, project funding is appropriate for surveys and studies, while proven monitoring programs should be supported using a long-term model.

Realizing the Value of CBWM in Canada

Within the past decade, there has been a renewed collaborative effort of organizations that participate in, and rely on, community-based monitoring to answer questions of both local and national importance. A publication by the Pooling Water Knowledge Working Group (Kanu et al., 2016) summarized five challenges to the success of community-based monitoring:

1. Ensuring credible data
2. Connecting Indigenous Traditional Knowledge and Western science
3. Engaging and motivating citizens
4. Informing decision-makers
5. Ensuring data is accessible and reusable.

Subsequently, a renewed roundtable convened in Ottawa in November 2018, drafting recommendations to the Government in Canada for targeted investment in community-based monitoring grouped by five thematic areas of focus (National Roundtable on Community-Based Water Monitoring, 2019):

1. Capacity building
2. Effective monitoring
3. Regional and national collaboration
4. Data management
5. Data to inform decision making
6. Sustainable funding

The value generated by community-based monitoring is documented and highlighted in the case studies within this publication, showing how local-level partnerships are delivering the raw materials for informed decisions. Credible data—which begins before the first sample is collected with standardized protocol selection—is delivered to open-access portals like DataStream in a manner that meets international standards for findable, accessible, interoperable, and reusable (FAIR) data and recognizes ownership, control, access, and possession (OCAP®) principles—both are emerging best practices for environmental data.[3] Data standards developed by the Gordon Foundation and monitoring organizations across the country are an example of standardization that is absent even between federal departments. Rising incorporation of Two-Eyed Seeing and emerging Indigenous Guardians programs are connecting multiple ways of knowing toward a common goal of sustainable development.

Two key challenges remain—ensuring data and knowledge gained by CBWM organizations are being used to their full utility by local, provincial, and federal policy-makers to understand Canada's water and predict its future; and sustaining these programs with a funding model that recognizes the value of these organizations to the business needs of the public service.

Valuing CBWM

The raw materials generated by CBWM programs are the data and information products that would not have existed otherwise. These represent the most tangible outputs and represent one way to demonstrate the value of CBWM. Fortunately, valuing digital assets has recently become a topic of considerable research in the business community.

In 2019, Statistics Canada conducted an evaluation of the value of non-profit data in Canada. Researchers estimated digital assets in the non-profit sector ranging between CAD 2.5 billion and CAD 3.4 billion based on investments made to obtain and store those assets (Statistics Canada, 2019). While some data may be sold on markets by generators or data brokers (Research Group of the Office of the Privacy Commissioner of Canada, 2014), most digital assets are kept and used

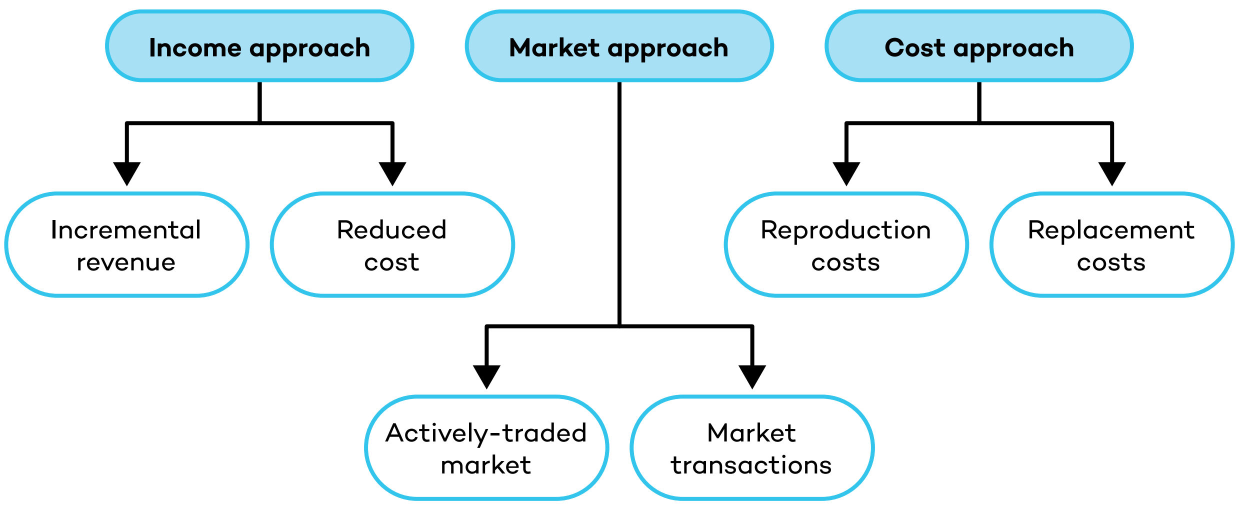
[3] FAIR principles are discussed in Wilkinson et al. (2016); OCAP® principles were developed by the First Nations Information Governance Centre (n.d.).

by the founding institution. To estimate the value of data in Canada, researchers used investment costs—that is the cost of generating data—to understand its value.

This method uses a conservative cost-based approach. Investments are intended to generate returns, and—given the growing importance of data science and growth of digital-focused sectors—these are certainly considerable.

There are alternative ways of measuring the value of data that recognize more than the costs of acquiring it. A brief by global accounting firm PricewaterhouseCoopers (PwC) lists three approaches and six methods for evaluating the value of data assets (Figure 5).

Figure 5. Approaches and methods for estimating the value of data



Source: Adapted from PwC, 2019.

They highlight the three primary sources of data value: how much does it increase an organization's income? What value does the data fetch on the market? Or how much did it cost to acquire or would it cost to replicate?

This structure reveals how CBWM organizations in Canada can understand the value of their data, and examples from case studies within this document may serve as illustrative examples for dataset valuation to make their own business case for CBWM programs.

INCOME APPROACHES

Income approaches to understanding the value of data are common in the private sector. By supporting better decisions, increasing revenue, or understanding the market better, a business can increase profit by driving sales or using dynamic pricing systems to maximize revenue.[4]

[4] For example, many businesses using the Shopify platform use dynamic pricing plugins, such as those discussed here: https://www.shopify.ca/enterprise/102104006-dynamic-pricing-the-art-and-black-magic-of-situational-pricing

For CBWM organizations, this could take many different forms, for example, identifying the value of a monitoring program to existing revenue sources such as individual donors, foundations, or public sector granting agencies. Does the existence and continued data collection influence revenue through positive perceptions of an organization? If so, this difference could be useful to evaluate the value of a program or digital assets.

Alternatively, CBWM programming can help decision-makers within an organization or their communities enhance conservation and stewardship of resources. Identifying when these decisions are made—and estimating the value of ecosystem goods and services—would be a valid addition to the value of a program or dataset. This may be particularly useful when CBWM programs are designed with a surveillance component that connects the community to experts or regulators that can take rapid action in the case of a disaster like a pipeline leak, chemical spill, or dam rupture.

When CBWM reduces operating costs—not just for the organization but for other stakeholders—this can be seen as a component of the data's value. When CBWM organizations fulfill obligations or gaps left by a shrinking public sector, they can create tremendous value by reducing costs or penalties. When CBWM data is used, its value is demonstrated.

For these reasons, organizations should monitor, as closely as possible, who uses their data and for what purposes. Simple estimates of savings to other organizations, improvements in decisions, or protection of systems can quickly accumulate to show large valuations of a CBWM dataset. Occasional surveys of organization members and donors could query the importance of CBWM to them, and this, in turn, can be used to support public sector or philanthropic investments into monitoring programs. Reports like those prepared by Cohen and Livingstone (2021) may also be used to cumulatively identify regional impacts of CBWM data and highlight the strategic importance of community monitoring for environmental conservation, stewardship, and management.

MARKET APPROACHES

The market approach is the classical way of understanding the value of an asset—by determining what a buyer would pay for it. While digital assets are fungible and do not strictly adhere to supply and demand curves, there may be some cases in which CBWM organizations could package and find markets for their datasets.

The fact that many organizations with CBWM programming are committed to open access to their monitoring data using platforms like DataStream or contributing to public programs like the Canadian Aquatic Biomonitoring Network (CABIN) may not preclude them from finding buyers for data.

The most natural market-based solution would be a recognition among public sector organizations that CBWM data can and does help them achieve their objectives, and to establish long-term payment agreements for supplying these data.

Another option may be to work with emerging technology companies, in Canada and elsewhere, to build increasingly large water quality and quantity datasets ("Big Data") that would be suitable for training AI-based models to detect threats or uncover deeper relationships. This could be done without revealing the full datasets or compromising community privacy using systems known as "Data Trusts."[5] This remains an emerging market in the environmental sector, and few examples currently exist.

Income and market approaches can allow an organization to estimate the return on investment—how much additional value is generated compared to the original investment. Unfortunately, many of the benefits generated by CBWM are diffuse and not captured on balance sheets or financial statements. These valuations are desirable since they fit into other accepted data valuation models: they reflect the value of the data in its use.

COST APPROACHES

The most straightforward way to understand the value of a dataset—and to make the business case for increased investment—is to use cost approaches. Methods like cost effectiveness compare the actual costs of acquiring a dataset compared to alternatives and comparisons between CBWM and other modes—like the cost of a private contractor or public sector organization to replicate the dataset. This approach works best when samples are collected and analyzed under strict protocols similar or equivalent to those used by conventional monitoring programs to ensure equivalent levels of scientific rigour are achieved.

Although less desirable than the income and market approaches, this is important for making a case for community-based monitoring as a valid and effective way of collecting credible and useful environmental data. Direct comparisons of cost effectiveness in terms of cost per sample or regional economic impact can show funding organizations that CBWM can enable rigorous science and necessary management outcomes while still showing that they are getting "value for money"—a politically palatable and frequently sought outcome.

Measuring the value delivered by CBWM organizations is an essential component of the business case—it is the return on investment that donors, funders, and water advocates want to see. It is equally important to recognize the costs—what is a realistic, sustainable cost to deliver CBWM benefits to the community, and how can those costs be planned and accounted for? Funding mechanisms for those overhead and infrastructure costs will ensure that CBWM organizations can continue to deliver community-led water stewardship in communities across Canada.

[5] Toronto-based Sightline AI has developed a Data Trust product that allows data generators to securely share sensitive data for analytical uses. For more information see https://sightlineinnovation.com/product.

Conclusion

CBWM organizations have emerged to fill gaps in environmental understanding left by dozens of federal, provincial, and local government entities; they have achieved long-desired objectives and business lines in federal and provincial water strategies; they have built trust with communities over time to clearly communicate issues and evidence; and they are renewing the concept of community stewardship and action. These values—the tangible and intangible—demonstrate the clear business case for renewed and expanded investment in CBWM.

The fact that dozens of organizations across Canada have emerged and thrived does not guarantee their continued existence. If they fail, the value they contribute—whether efficient service delivery, their reputation, and their community networks—will be lost. Although their data is being used by federal agencies and local decision-makers, in courtrooms and in classrooms to advance knowledge and understanding the limited documentation of these uses makes it difficult for each organization to understand and communicate the value they provide.

Canada is facing simultaneous and serious challenges—reconciling historic wrongs to Indigenous peoples while preparing for an uncertain climatic future. A sustainable future will demand that we have data to inform decision making.

The business case for CBWM is supported by a supply of cost-efficient community-based monitoring programs, by grassroots community organizations reclaiming a local role in environmental stewardship, and long-term monitoring programs that can advocate for local interests and identify issues of concern.

2.0 Case Studies of Community-Based Monitoring in Canada

Case Study 1: A cost-effective solution for a "wicked problem"—The Lake Winnipeg Foundation finding phosphorus hotspots across the prairies

Driving Question: How can communities target activities to protect Lake Winnipeg?

In 2013, Lake Winnipeg was named "Threatened Lake of the Year" by the Global Nature Fund—highlighting the cumulative impact of decades of agricultural fertilizers, municipal sewage, and industrial effluent on this large lake (Global Nature Fund, 2013).

This excess phosphorus is changing the once-muddy waters of Lake Winnipeg into a sickly green by encouraging harmful algal blooms. The basin drains much of the land from Alberta to Northern Ontario, and southwards into Minnesota and North Dakota—far away from Lake Winnipeg. The source of these nutrients and the site of their ultimate effects are separated by both distance and political boundaries.

These blooms are why the Lake Winnipeg Foundation developed a CBWM network to understand exactly where the largest phosphorus emissions are coming from. In the basin that spans the Canadian Prairies, the phosphorus can enter the water from many locations hundreds or thousands of kilometres away (Figure 6).

Millions of dollars have been invested in programs to protect Lake Winnipeg, including the Lake Winnipeg Basin Program and the Manitoba Conservation Trust. However, the loading of phosphorus has continued to rise and the specific sources of this phosphorus—beyond a few point sources like wastewater treatment facilities—have remained mysterious. The distance in both space and time between the cause of the problem and its effects creates a challenge for the thousands of people who depend on Lake Winnipeg and other prairie lakes. This also causes tensions, pitting industries against environmentalists, cities against rural municipalities, and cottage owners against farmers. Recognizing that the only way to solve this "wicked problem"[6] (see box) is through a collaborative, evidence-based approach, the Lake Winnipeg Foundation developed a program to gain a more holistic understanding of the basin—and the phosphorus challenge (Venema et al., 2010).

Responding to this challenge required a new approach to monitoring. To answer the question, the Lake Winnipeg Community-Based Monitoring Network (LWCBMN) marshalled a group of

[6] That is, a problem that is difficult to solve due to a challenging set of interconnected, complex causal relationships.

citizen scientists to take samples across the watershed and at the appropriate time to understand where phosphorus comes from—and where action will work best to save Lake Winnipeg.

Figure 6. The Lake Winnipeg Basin

Source: Author diagram.

Barriers to Conventional Monitoring

Understanding where phosphorus comes from is challenging. Scientists need to know:

1. How much water flows from a tributary, and when the peak of discharge happens
2. What the concentration of phosphorus is during periods of high and low discharge
3. What is the area that contributes to flow (the watershed).

The short timeframe of high-flow periods means that monitoring must be responsive to these events. The geographic breadth of the Lake Winnipeg basin (Figure 6), the increasing unpredictability of high runoff events and importance of understanding non-point sources, such as runoff from agriculture, for solving the problem would require a large and available staff complement.

The Governments of Canada and Manitoba both conduct long-term monitoring of water quality, but neither conducts programs that generate the data necessary to target phosphorus hotspots on the landscape. Canada—with over 20 separate departments and agencies that carry some responsibility toward water (e.g., Fisheries and Oceans Canada, Health Canada, Natural Resources Canada) while provinces have constitutionally defined responsibilities such as infrastructure, local government, health, and natural resources.

The public long-term, water quality monitoring systems are unsuitable for understanding the eutrophication challenge faced by Lake Winnipeg because they were not designed as such. Rather, they monitor regulated and emerging contaminants that may threaten natural or human health such as pesticides, heavy metals, and petroleum products, or key ecological indicators like *E. coli,* benthic invertebrates, and algal blooms. Both the spatial distribution of these sites (Figure 7) and temporal resolution (monthly/annually, depending on location and parameter) cannot answer the Lake Winnipeg Foundation's driving question.

High-tech solutions are also not ready, nor are they cost-effective. Since the spring melt carries river ice and shore debris down tributaries that may spill their banks, this makes floating or shore stations impractical. Phosphorus itself is challenging to measure using field-based sensors in prairie streams.

The "Wicked Problem" of Algal Blooms

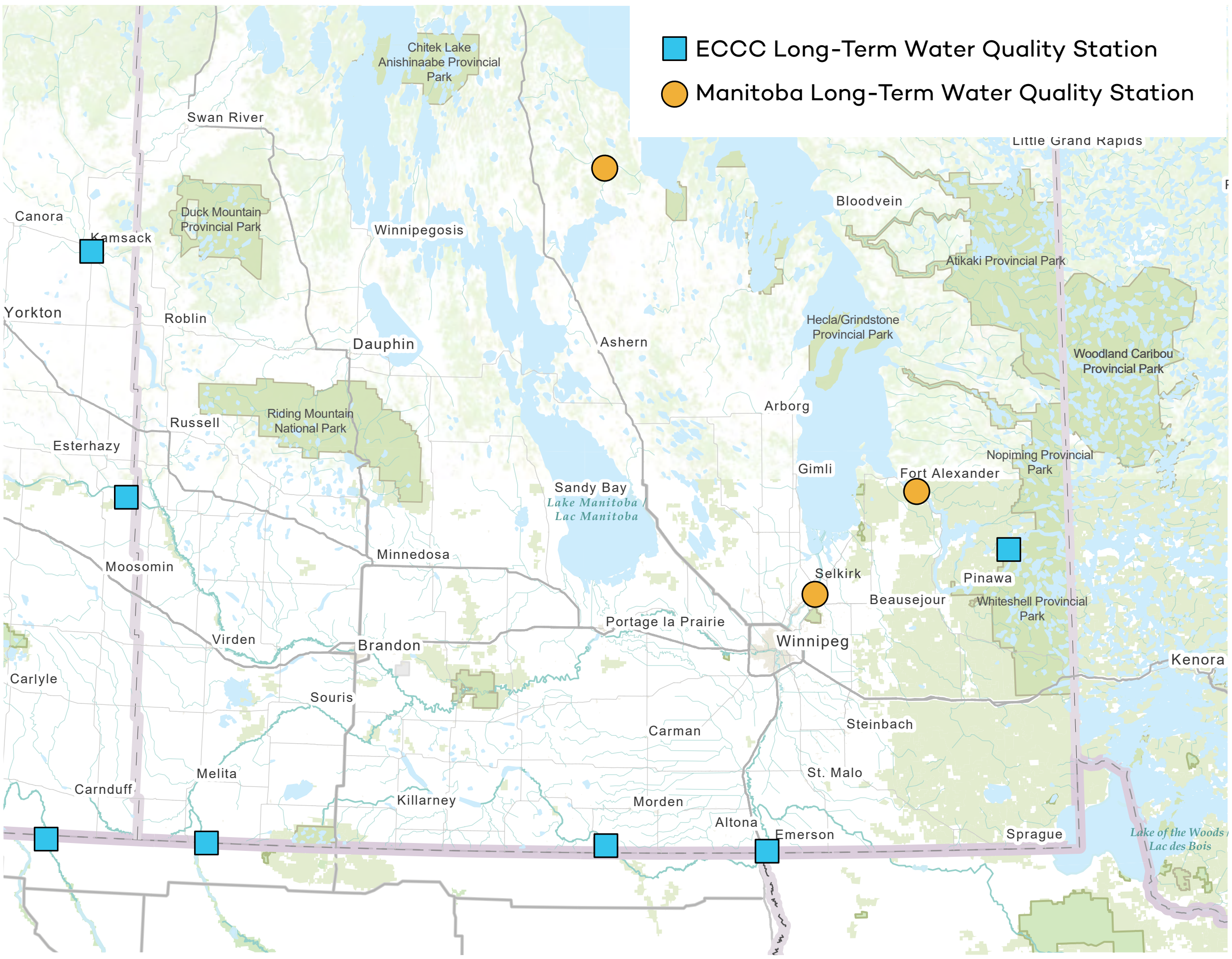
The green in this photo is caused by blooms of algae—often green algae (phytoplankton) but sometimes blue-green algae (cyanobacteria). The blooms disrupt natural cycles of light, temperature, and oxygen to aquatic species—and they clog drinking water systems, contribute to mass fish kills, and poison animals and people.

These algal blooms are caused by an excess load of phosphorus entering inland lakes from sources within the drainage basin. These sources could be from a single point—like phosphorus-containing effluent from a wastewater treatment facility—or from a wider landscape like pasture.

These blooms cause a "wicked problem" wherein there is no single cause or solution, but hundreds or thousands of human actions that contribute a small amount. This allows blame to be shifted and prevents positive action.

Satellite sensing is improving our understanding of the timing and extent of algal blooms in Lake Winnipeg, but the rivers that flow into the lake are notoriously difficult to extract water quality parameters from, and phosphorus itself is not detectable with these platforms.

Figure 7. Water quality monitoring stations in Manitoba



Source. Author diagram.

What Does the Program Deliver?

Local expertise and scientific rigour are derived from a local landmark—the Department of Fisheries and Oceans Freshwater Institute (located in Winnipeg) and scientific research conducted at the Experimental Lakes Area (now operated by the International Institute for Sustainable Development, and is known as IISD-ELA). Since 1969, Canadian and international scientists have used whole-lake manipulations to isolate the cause of toxic algal blooms, which in the mid-20th century began affecting lakes in North America and around the world. Two such experiments—a long-term phosphate addition to Lake 227 and a "curtain" experiment on Lake

226—definitively showed that controlling phosphorus inputs can rehabilitate lake ecosystems (Schindler et al. 2016).

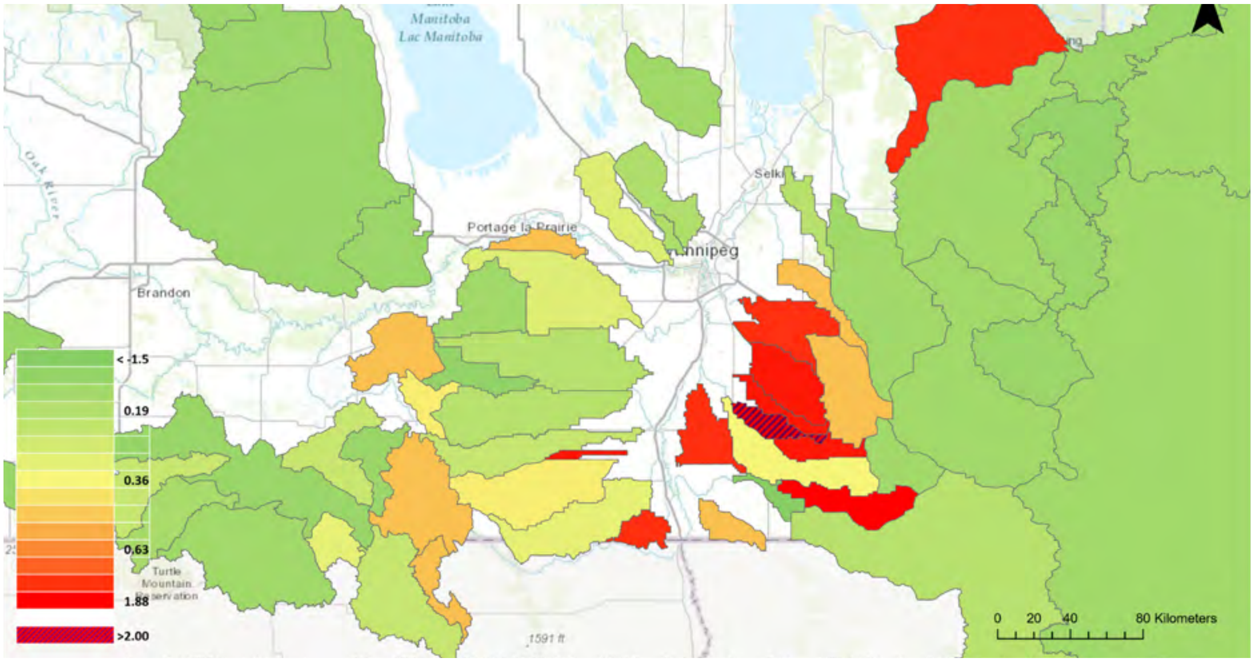
After five decades of operation, the IISD-ELA has not only produced a body of knowledge that can protect Lake Winnipeg—but it has also created an extensive alumni network of water experts, many of whom volunteer their time with the Lake Winnipeg Foundation as board members, scientific advisors, and casual consultants.

Two Department of Fisheries and Oceans and ELA alumni oversaw development of the community-based monitoring program: Michael Stainton, retired environmental chemist with the ELA and the Department of Fisheries and Oceans Canada, and Greg McCullough, research associate at the University of Manitoba. These experienced scientists worked with Lake Winnipeg Foundation (LWF) staff and citizen scientist volunteers to develop sampling and analysis protocols that are both scientifically rigorous and practical for community members.

Using the scientific protocols, citizen scientists collect physical water samples from safe platforms like bridges or docks. Many participants collect samples close to their homes or on their commutes. Others, such as staff of Manitoba's Watershed Districts or industry partners like Manitoba Hydro, collect samples in places they have unique access to or visit as part of their regular work. With minimal travel required by network participants, they can sample locations immediately following snowmelt or summer storm events—when most phosphorus is transported off the land and into the water.

The samples are analyzed by LWF staff and academic research partners for total phosphorus concentration, in micrograms per litre. Along with discharge data from the Canadian Hydrometric Network, staff calculate total load, expressed in kilograms or tonnes per year. Finally, using watershed delineations originally created by Agriculture and Agri-Foods Canada that show contributing basins for each station, they calculate phosphorus loading per unit area (Figure 8).

Figure 8. Phosphorus hotspots map derived from LWCBMN data (net, kilograms per hectare per year, provided by the LWF)



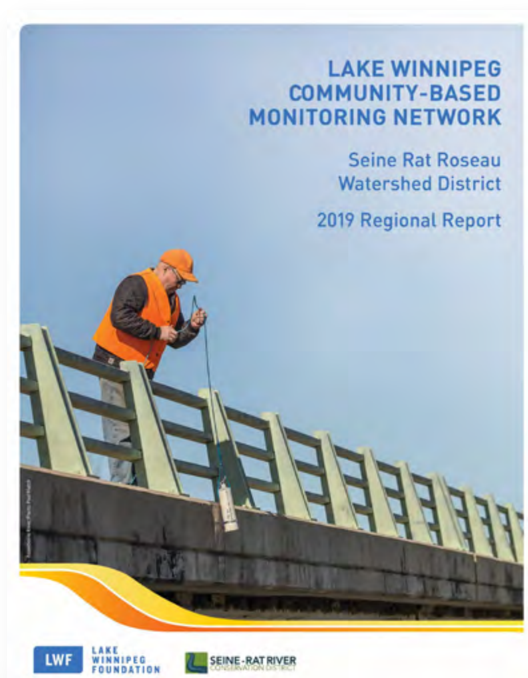
Source: Supplied by the Lake Winnipeg Foundation

Each year, LWF staff produce regional reports for both major and minor tributary watersheds in Lake Winnipeg in collaboration with local Watershed District Staff (Figure 9).

Financial Analysis and Valuation

Using a reproduction cost analysis (PwC, 2019), we evaluated the cost effectiveness of the LWCBMN compared to a sampling program by a public sector entity. We estimate that it would have cost CAD 1,118,732 to have generated the 2016–2019 data collected by the LWF,[7] which cost only CAD 329,000 using the CBWM network. This represents a 3.4:1 difference in expenses—notably because of the significant cost savings on each sample.

Figure 9. Regional report of network findings

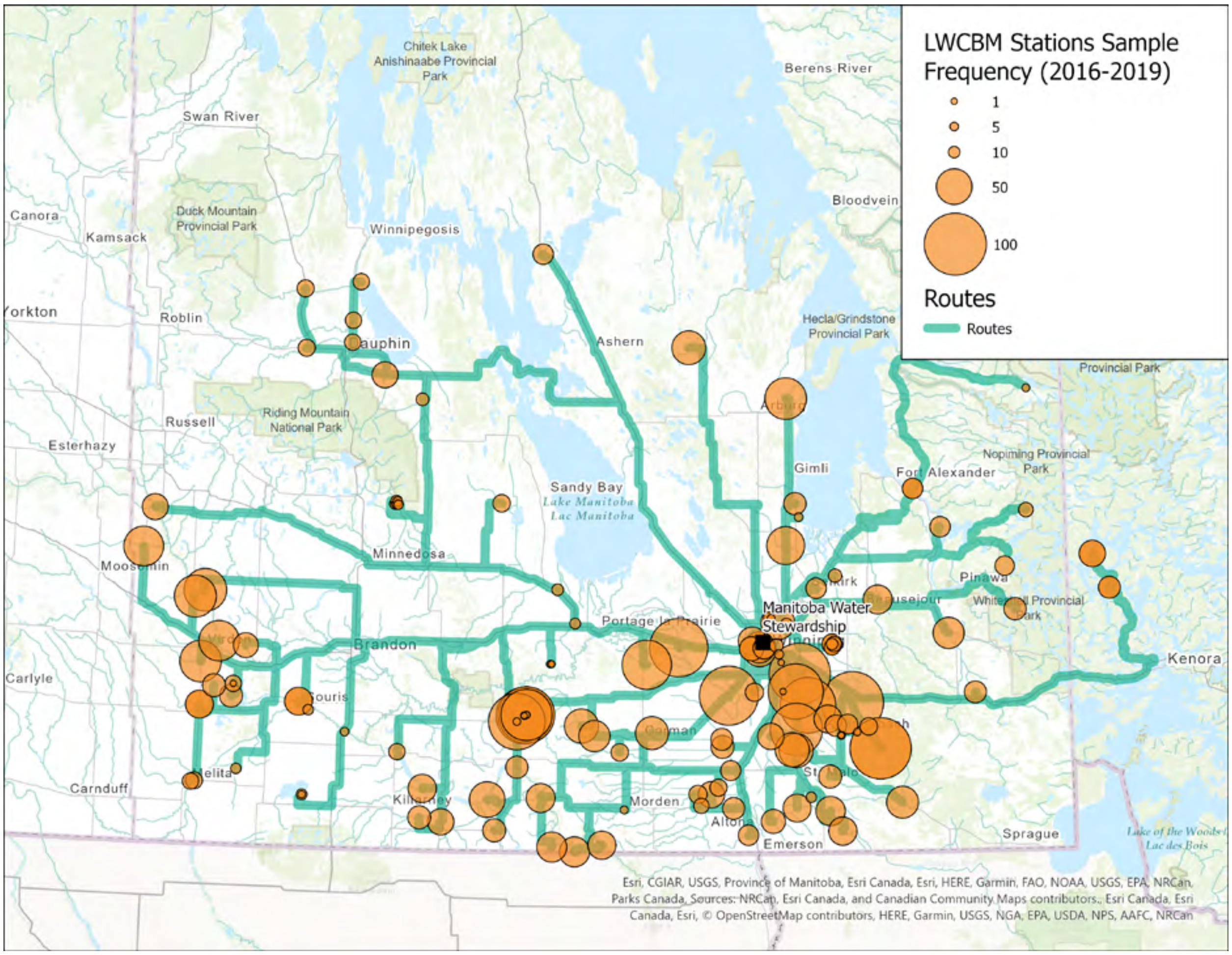


Source: Lake Winnipeg Foundation, 2019.

[7] This is a conservative estimate, assuming no excess costs of maintaining staff outside of peak times when samples are taken.

The scale needed to understand phosphorus loading across the basin can only be reached with a community-based monitoring approach.

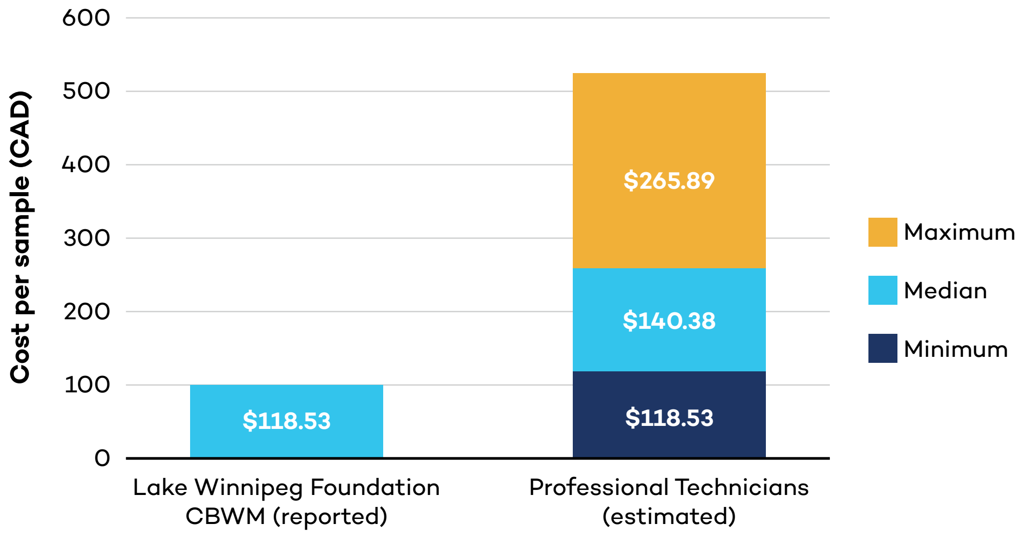
Figure 10. LWCBMN station frequency and travel distance from a hypothetical central location to simulate travel costs of a public sector agency



Source: Author diagram.

The most significant impact on the differing costs per sample is travel time. Using standard mileage and travel rates for Manitoba, costs per sample range from CAD 118 (samples located in Winnipeg) to CAD 525 for the furthest tributaries sampled by the LWF's network, with a median cost of CAD 259 (Figure 11). This compares to an average cost of CAD 100 per sample for the LWF (Figure 11).

Figure 11. Cost per phosphorus sample (2020 CAD), comparison between actual LWCBMN costs and the cost of professional technicians based in Winnipeg



Note: The range in estimated costs reflects the cost differential of travel to remote sites.
Source: Author diagram.

The Case for Community Monitoring to Solve Regional Problems

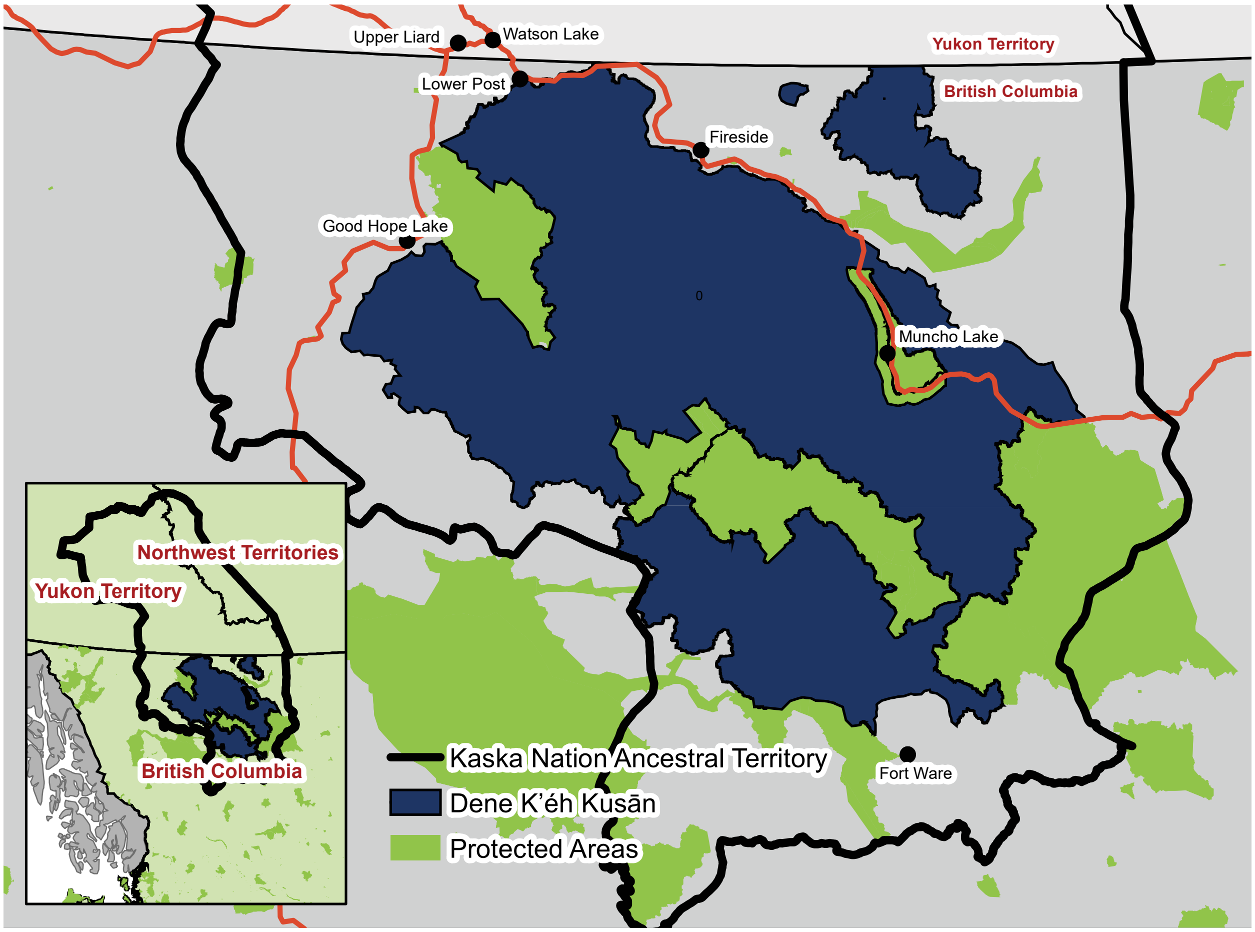
The business case is clear for community-based monitoring to solve regional issues at the scale of large basins. The travel time and effort required of a limited number of professional technicians to cover an area the size of the Lake Winnipeg Basin would preclude an effective sampling strategy—particularly when these observations are most useful immediately after meltwater or storm events.

The LWCBM program delivers a scientifically rigorous evidence basis to target phosphorus hotspots and highlight the most effective policy responses, such as improvements to water infrastructure, agricultural beneficial management practice programming, or remediation of point-source issues. The rigour has been demonstrated using quality-assurance protocols, and data has been disseminated on the newly launched Lake Winnipeg DataStream—allowing professional and community audiences to begin using the data to inform decisions and drive action in the future.

Secondary benefits include a resilient watershed surveillance system, which allowed participants to work during the COVID-19 pandemic since they often sample on or near their own property. The network also allows academic researchers to leverage a distributed group of trained participants to contribute to short-term projects, such as additional sampling for sources of excess salinity or other threats to aquatic ecosystems.

Case Study 2: Always Will Be There—Kaska Guardian Program connecting land and water in the Tāgh'agah Tuēh (Liard River) basin

Figure 12. Dene Kayeh, the traditional lands of the Kaska Dena



Source: Provided by the Dena Kayeh Institute (DKI).

Driving Question: How can Kaska Dena communities protect the land, build relationships with others who use the basin, and integrate both Traditional Knowledge and science to inform community decisions?

The landscape of northern British Columbia and the southern Yukon—the ancestral territory of the Kaska—is both visually stunning and remote. Mountains, forests, and grassed valleys attract tourists: hunters travel from across North America and around the world to track moose, elk, cougars, and both grizzly and black bears. A rise in ecotourism and desire to find "untouched" landscapes has led to more visitors using rivers by canoe and powerboat, as well as trails by foot or all-terrain vehicle. With tourists of all kinds came impacts, from concerns about overhunting to garbage and human waste left in hunting camps and erosion from large river boats. However, with tourists also came economic opportunities—and these communities recognized the need to reclaim their role as stewards and to develop capacity to promote and implement the Kaska land ethic.

In 2004, the DKI was established to "empower, preserve, and protect the Kaska Dena Language, oral traditions, history, culture, and traditional knowledge" (DKI, n.d.). The organization was designated as the representative of the BC Kaska communities to administer, manage, and expand Traditional Knowledge, including Traditional Ecological Knowledge. DKI uses both Traditional Knowledge and Western science to protect the land and develop a sustainable economy that is consistent with the Kaska land ethic.

A decade later, the Dane Nan Yḗ Dāh Network was established to become the "ears and eyes on the ground" in the ancestral territory of the Kaska as a partnership between the DKI, Daylu Dena Council, Dease River First Nation and Kwadacha First Nation. The network approach was necessary: the ancestral territory of the Kaska covers 24 million hectares—2/3 the size of Germany (Figure 12).

One of the program's goals is to build guardian expertise, which includes training youth in the safety and science needed for water monitoring, involving all community members as citizen scientists to record observations, and engaging with Elders and knowledge holders to document Traditional Knowledge and cultural stewardship laws. The latter project was immediately successful, with scientifically trained staff often joined on patrol by Elders who noted changes to the landscape, rivers, and streams.

After the program was established, community-based monitoring of water became a priority stewardship activity. Elders and the community insisted that clean water be a priority, and that baseline data be collected to understand the state of the systems and how they are changing.

The gauges themselves only confirmed what community Elders had reported—that things were changing over the years. In the years since the gauges were installed, the precipitation falling as rain and snow has shifted. The community has now begun measuring water quality parameters in addition to flow.

Barriers to Conventional Monitoring

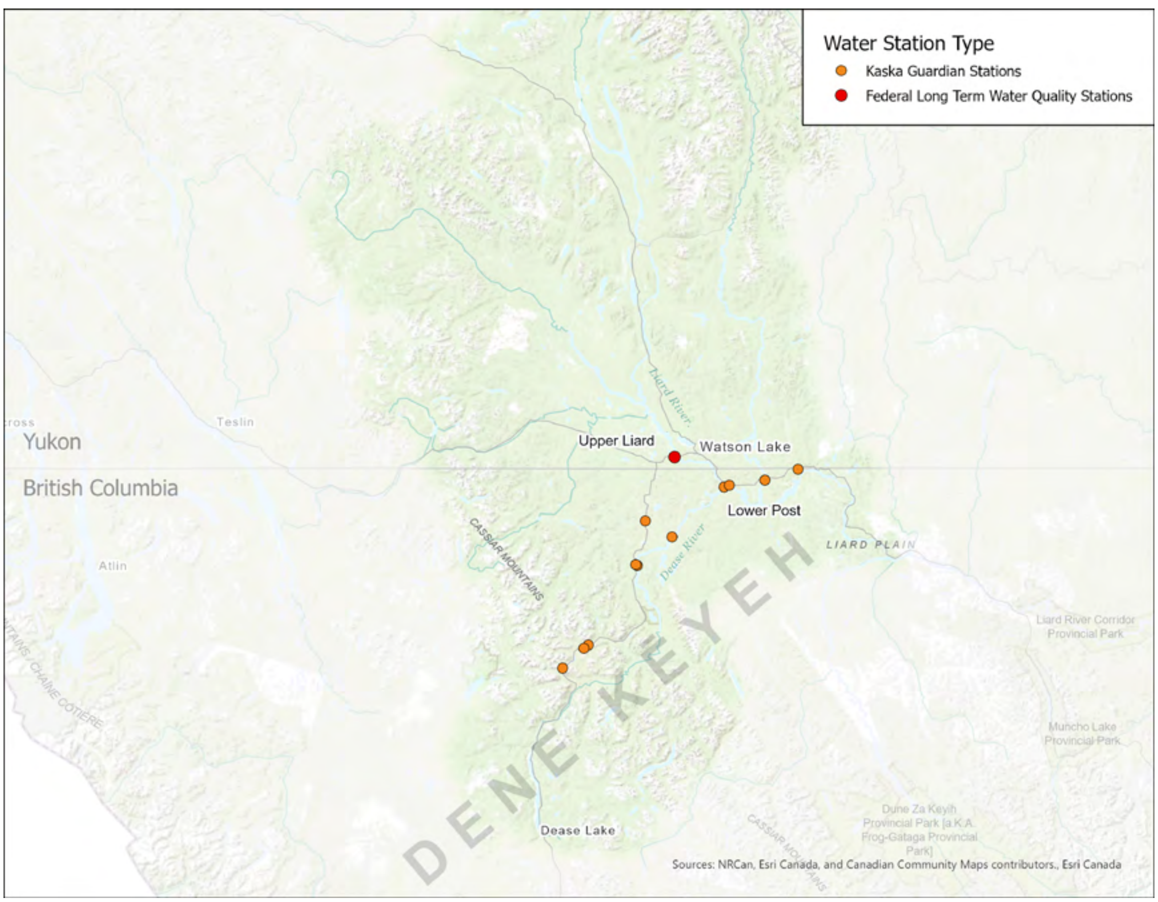
The traditional territory of the Kaska Dena is situated toward the northwest of Canada, across the boundaries of British Columbia, Yukon, and the Northwest Territories. Very little settler-colonial development has occurred in the area, and the nearest city—Whitehorse, Yukon—is over 5 hours from the community of Lower Post, British Columbia.

Accessible provincial and federal water quality monitoring is extremely limited. As part of the ECCC Long-Term Water Quality Monitoring Program, a station was established on the Liard River at the community of Upper Liard in 1991 and continues to the present (ECCC, 2014). This station monitors parameters including carbon, metals, major ions, species of nitrogen and phosphorus, and physical parameters including colour, hardness, pH, turbidity, and temperature at roughly monthly resolutions, although many chemical parameters have multi-year gaps. Much of this data was still listed as "preliminary" when retrieved in early 2021.

Likewise, provincial monitoring in the region by British Columbia is minimal. A limited number of one-off samples are accessible using the provincial Surface Water Quality Monitoring portal within the area, dating back to the 1990s. However, many appear to be part of a broad-scale monitoring program, with few recurrent samples or long-term sentinel sites. Of note, a sample taken in 2001 from a pond adjacent to BC Highway 37 indicated levels of heavy metals including selenium, arsenic, antimony, and lead that exceed Canadian Council of the Ministers of the Environment Guidelines) (Government of British Columbia, 2001).

A key indicator of monitoring success is whether local residents feel like they understand what is happening to the environment. Limited data collection, analysis, and dissemination created the conditions in which the DKI and partners developed the Kaska Guardians Program.

Figure 13. Kaska Guardian monitoring stations



Source: Author diagram.

What Does the Program Deliver?

The CBWM program began in September 2018 by measuring flow using staff gauges (Figure 13) in tributaries of the Liard River including the Dease and Blue river, and as well as Iron, Contact, Hutchinson, Snow, Troutline, McDames, Spring, and French creeks (Figure 13. This also marked the beginning of training sessions for staff on CABIN protocols to begin surveys of aquatic organisms. Cabin sites now include: Contact Creek, Mould Creek, Hutchinson Creek, Quartzrock Creek, Charlie Chief Creek, McDame Tributary, Teeter Creek, Irons Creek, and Geddes Creek.

Establishing staff gauges to monitor the flow of creeks and rivers is a challenge. Not only must they be scientifically relevant and demonstrate impacts on a watershed, they must be secure from vandalism, storm damage, and ice disturbances while also being accessible to technicians. The nature of mountain streams also means rapid changes to sediment through erosion. These readings are important to understand the impacts of precipitation and the health of ecosystems that depend on flowing water.

The organization is building back-end data management systems to help Guardians collect consistent data and share their findings with the community. Using cloud-based tools like Esri Survey123, the Guardians can use a smartphone or tablet in the field and accelerate the flow of data into the community-held database.

Community data ownership is an emerging best practice, especially for Indigenous communities. This ensures that it is available to any potential local user—which has not historically been true of data collected by outside agencies or public sector initiatives. Close connection between users and providers also allows the Kaska Guardians Program remain responsive to community needs and concerns.

Along with innovative technology, the Guardian program connects students and technicians with Elders who join on patrol, sharing their knowledge and wisdom. These experienced Elders, see what is changing and can tell the community what is changing in a way that a scientific dataset cannot (Cox, 2019).

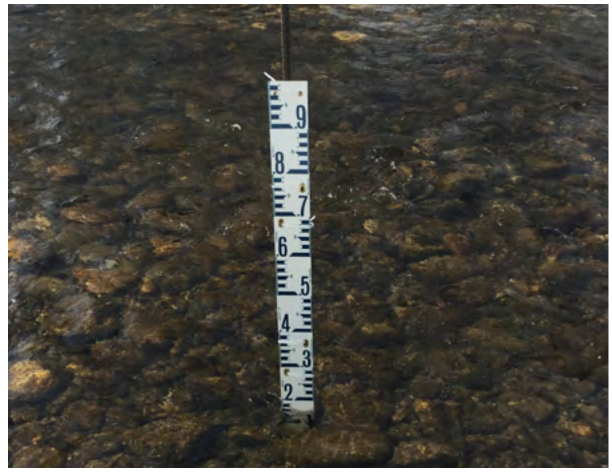
Financial Valuation

A cost-benefit analysis on a monitoring program as new as the Kaska Guardians water monitoring captures neither the complete costs nor the total benefits accrued even despite early successes. Therefore, it is worthwhile to understand how Indigenous Guardians programs are generating real value toward Canada's commitments to the international community and toward reconciliation with people Indigenous to the land.

Canada has committed to conserving 25% of the land and 25% of the ocean within its territory by 2025, commonly known as Canada Target 1 (corresponding to Aichi Target 11) (ECCC, 2021). To achieve this goal in such short time, preliminary work has begun on potentially incorporating Indigenous Protected and Conserved Areas (IPCAs), including a Kaska IPCA—Dene K'éh Kusān—into the federal protected area network.

The Western view of parks and protected areas was established with the founding of Yellowstone National Park in 1872. Since that time, a body of work has developed surrounding the necessity of selecting suitable sites for parks based on physical, biological, and human factors—many of which require developing proper characterization of these features and ultimately understanding opportunity costs of lost economic potential along with the long-term benefits of conservation, protection, and even other sustainable economic uses like low-impact tourism. A full discussion on the economics of park establishment (within an Australian context) can be found in Ulph and Reynolds (1981).

Figure 14. Streamflow measurement using a staff gauge



Source: Provided by DKI.

A task force created by the IUCN—a global body for conservation—evaluated the monitoring needs of protected areas in a report prepared for the Fifth World Parks Conference in 2003. They propose that prior to establishment of new parks, that a monitoring and evaluation plan be created to ensure the protected area meets the needs of the organizing government as well as minimizing impediments to local communities. From experience, they note (Vreugdenhil, 2003, p. 87): "Many threats may stem from misunderstandings between local communities and protected area administrations. To reduce stress between protected areas programmes and neighbouring communities, it is critical to develop cooperative programs with nearby communities."

They also note that monitoring and evaluation programs supporting establishment of parks should be of low cost and highly efficient, incorporate field personnel, and be designed in a way that involves primary users of the data. These characteristics are all present in the emerging Kaska Guardians Program and research conducted by the DKI (e.g., DKI, 2019).

The Western paradigm of parks and conservation is rapidly shifting, particularly in countries with colonial histories. In Canada, the paradigm shift is demonstrated in We Rise Together, a report prepared by the Indigenous Circle of Experts (ICE) (2018) that collected Indigenous and non-Indigenous perspectives on collaboration to meet Canada's Target 1.

The report's authors describe the dark history of protected areas in the past: imposed on local communities and Indigenous people with little feedback, which cleared the land to make way for tourism and economic development—only occasionally under the auspices of conservation. This frequently created clashes between traditional hunters and trappers—the original guardians of the landscape—and government officials, businesses, and tourists.

The ICE report directly connects Indigenous Guardians programs to establishment of IPCAs and meeting many of Canada's international targets, constitutional requirements, and commitments toward reconciliation. Recommendation 22 states: "ICE encourages federal, provincial, territorial and Indigenous governments to work together to support the development of on-the-land programs (e.g., guardian programs or similar community-based initiatives) for the development and management of IPCAs."

The monitoring of water flow, quality, and benthic species is important to understanding and protecting many of the species at risk present within the proposed protected area. Some of these species, like the hotwater physa—a small snail—number fewer than 10,000 individuals and are found only in hot springs that contribute to the Liard River, while others like the grizzly bear, wood bison, and wolverine are emblematic of the northern landscape and depend on the rivers and the landscape. Changes to flow and temperature affect the stability of populations of bull trout *(Salvelinus confluentus)* and cutthroat trout *(Oncorhynchus clarkii)*, both of which are popular game fish with anglers (Dunham et al., 2003; Wenger et al., 2011).

Table 1. Species at Risk Act (SARA) designation

Species at Risk	Level	Year Designated
Bull trout	Special concern	2019
Short-eared owl	Special concern	2012
Wood bison	Threatened	2003
Canada warbler	Threatened	2010
Olive-sided flycatcher	Threatened	2010
Rusty blackbird	Special concern	2009
Peregrine falcon, *anatum* subspecies	Special concern	2012
Wolverine, *luscus* subspecies	Special concern	2018
Porsild's bryum	Threatened	2011
Barn swallow	Threatened	2017
Northern myotis	Endangered	2014
Collared pika	Special concern	2017
Cutthroat trout, *lewisi* subspecies	Special concern	2010
Hotwater physa	Endangered	2003
Woodland caribou (northern mountain population)	Special concern	2005
Grizzly bear	Special concern	2018

Source: Dene K'éh Kusān, 2019.

The Case for Indigenous-Led Community Monitoring

The Kaska Land Guardians is an example of how Indigenous-led monitoring programs can respond to community needs and concerns, support area-based conservation measures, and help communities adapt to dramatic changes seen in the environment. By incorporating local and Traditional Knowledge alongside Western science and supplementing both with digital technologies, these programs can fill watershed monitoring gaps in important basins like the Liard.

Although many programs are relatively new and lack decade-scale time series, the integration of Traditional Knowledge expands a community's understanding of baseline conditions and measures emerging changes. Including the histories contributed by Elders, a deeper understanding of both state and trends of the ecosystems can be developed. This extends from physical characteristics like weather and rainfall to indicator and keystone species.

The case is strengthened by using existing programs like CABIN, which standardize protocols across large regions and allow intercomparison of data between communities that may also have their own interests.

Finally, the case for Indigenous-lead monitoring rests on the commitment of Canada to chart a sustainable pathway of collaboration between settler and Indigenous individuals, organizations, and governments—building a shared understanding of the state and trends of the environment upon which to base a common future.

Case Study 3: Small communities, big changes—Clean Annapolis River Project supporting a clean environment and strong economy in Nova Scotia

Driving Question: How can the community of Annapolis, Nova Scotia protect the Annapolis River estuary and their local economy?

To many Canadians, the Annapolis Valley conjures scenic images of wineries, apple orchards, and other fruits not commonly found in Canadian climates. However, a knowledge gap about the health of the Annapolis River, which cuts through the valley, has threatened to cause discord between the many economic sectors that rely on the river, including tourism and recreation.

The river itself has played a central role to the Mi'kmaq of the region since time immemorial, and to the history of what was to become Canada since the 17th century. Port Royal (now called Annapolis Royal), situated at the mouth of the river, changed hands between the British and French empires and played a central role in the history of Acadia and Nova Scotia. Given its historical pedigree, it seemed like the Canadian Heritage River System would acknowledge the river for its historical significance and natural beauty.

The application to have the Annapolis River designated as a Canadian Heritage River was rejected, reportedly for reasons including environmental degradation. The poor aesthetic state of the river caused by increased agriculture, industry, and a recently developed tidal power station affected fish movement and increased erosion, and the community had no evidence regarding the actual health of the river beyond what it looked like. This revelation may also have threatened tourism, particularly if perceptions of the river's health kept visitors away from the water. How could elected officials, businesses, and concerned citizens make the case that the Annapolis River is valued, important, and worthy of protection?

The community consortium was fortunate, as a federal financial assistance program was emerging. In 1991, Environment Canada established the Atlantic Coastal Action Program (ACAP) to respond to broader concerns about the health of coastal ecosystems and to build local capacity and engagement in these issues.

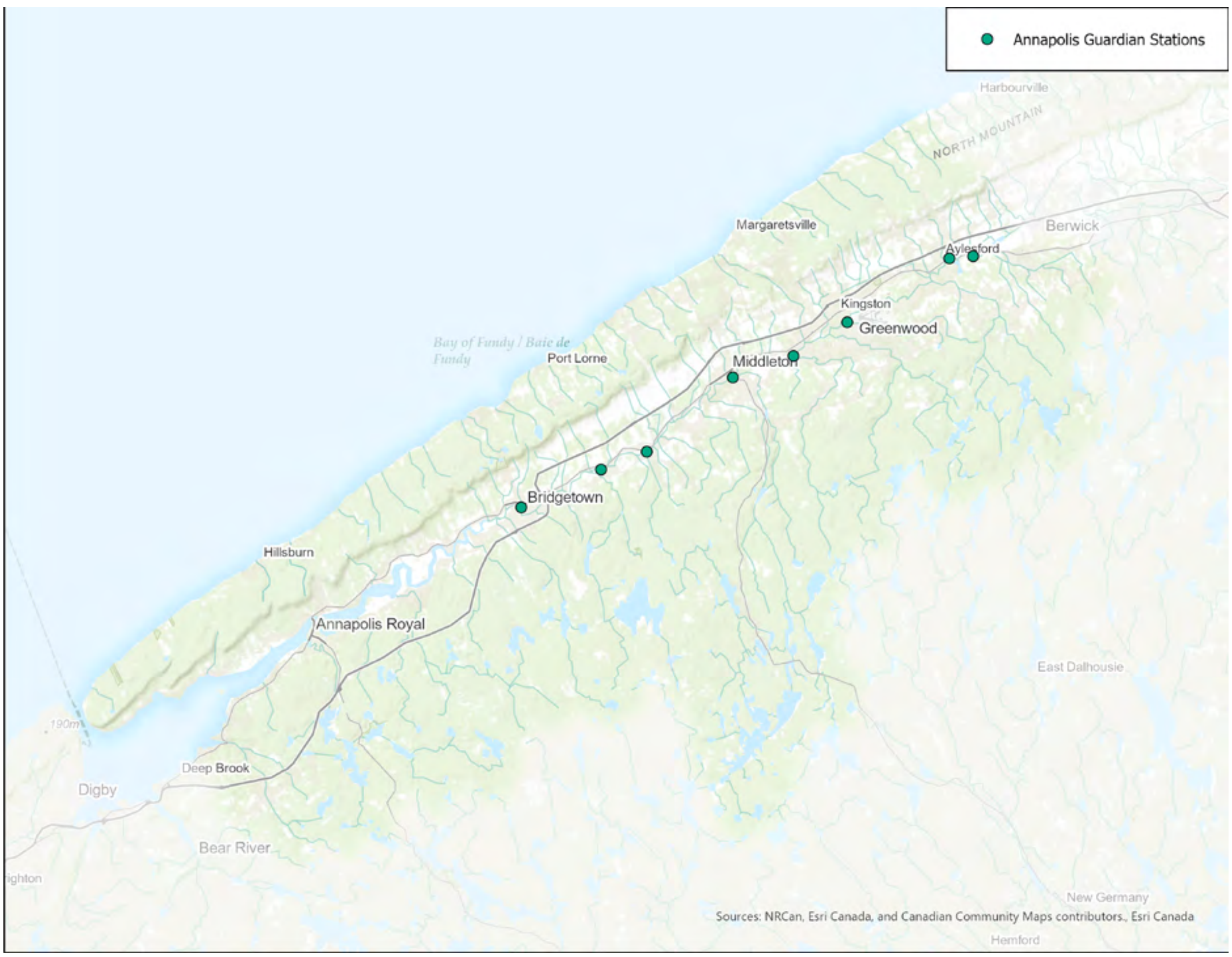
ACAP selected 13 organizations across Atlantic Canada to support, including what became the Clean Annapolis River Project (CARP). An initial annual grant of CAD 50,000 per year was provided to hire staff and begin developing watershed management plans, in consultation with experts from Environment Canada (Cliche and Freeman, 2017). Within a few years, CARP developed its first strategic plan.

This plan, "Our Watershed, Our Responsibility," was based on consultations and focus groups with relevant stakeholders but acknowledged a lack of scientific data regarding the health of the river and the estuary downstream (Garret, 1996). A novel tidal power station had been installed in 1984, and, though water quality was known to be poor in many areas, the precise impacts on water quality were difficult to estimate. This monitoring gap inspired CARP to develop its first—and now longest-running—program: the Annapolis River Guardians.

The Annapolis River Guardians program turned community interest into action by training volunteers as citizen scientists to collect samples and record conditions in the river. Led by professional scientists and supervised by CARP technical staff, the community volunteers monitored the river for temperature, dissolved oxygen, *E.coli,* nutrients, and meteorological parameters. As of 2020, this dataset has grown to over 15,000 records for the eight sentinel sites along the Annapolis River and a number of occasionally sampled tributary stations.

From inception in 1991 until 2019, the Annapolis River Guardians program was composed of a group of volunteer guardians who collected river samples at stations located at a convenient distance to their homes or places of work. CARP staff assisted with sampling equipment, protocols, and data management. A recent lack of funding for the monitoring program along with challenges caused by COVID-19 has seen CARP staff collect limited samples in 2020.

Figure 15. Annapolis River Guardians sampling sites



Source: Author diagram.

Barriers to Conventional Monitoring

The first milestone for all 13 of the initial ACAP-funded organizations in Atlantic Canada was to conduct an environmental quality assessment of fresh water in the region and to understand the issues affecting environmental quality (Ellsworth et al., 1997). This focus suggests that Environment Canada itself lacked a baseline on the health of rivers within the region—many of which are important habitat for the reproduction of marine fish like Atlantic salmon.

The Annapolis River valley is relatively rural, with few population centres. Annapolis County had a population in 2016 of 20,591, mostly situated near the river or along its tributaries such as the communities of Annapolis Royal and Middleton. The river is nearly 2 hours' travel time by car from Halifax.

The lack of data that motivated the creation of CARP and other ACAP-funded organizations has been ameliorated, but there is still important work to be done. The organization reports that they fill a role as an unbiased third party, not speaking on behalf of government, industry, or advocacy organizations and are therefore trusted to collect and disseminate environmental data. Including community members in the process has built trust—the influence of which is expressed by the donation of time (by volunteer monitors) and goods and services (from local businesses) that show the value of the organization to the local community.

What Does the Program Deliver?

The CBWM program, the Annapolis River Guardians, was initiated by Graham Daborn and Mike Brylinsky of the Acadia Centre for Estuarine Research to establish an observation system and provide an early warning of environmental issues; to provide a long-term record of the river's health; to develop community interest and ownership in the river; and to develop local community knowledge in the Guardians who can promote preservation and rehabilitation of the river (Beveridge et al., 2006).

Since the 1990s, CARP has produced annual reports on the scientific data collected and public-facing report cards that demonstrate both the state and trend of the key parameters measured by the Annapolis River Guardians program. This data has been used by a variety of parties, including consultants preparing baseline studies supporting ecosystem impact statements, business and industry to guide investments, local communities to understand threats, and departments of provincial and federal government mandated to monitor aquatic ecosystems.

Given the increased observation of the Annapolis River, citizen scientists have identified environmental issues that led to fast action for remediation. This includes identifying a malfunctioning wastewater treatment facility, identifying nutrient hotspots and working with landowners to build solutions, and educating individuals about the impact of aging septic systems.

The monitoring program itself also serves as a platform for short-term research programming. Recently, CARP has begun collecting environmental DNA samples to understand populations of aquatic invasive species and species at risk. Additional, technical capacity has allowed for short-term studies on wood turtles, striped bass, habitat connectivity, and climate change.

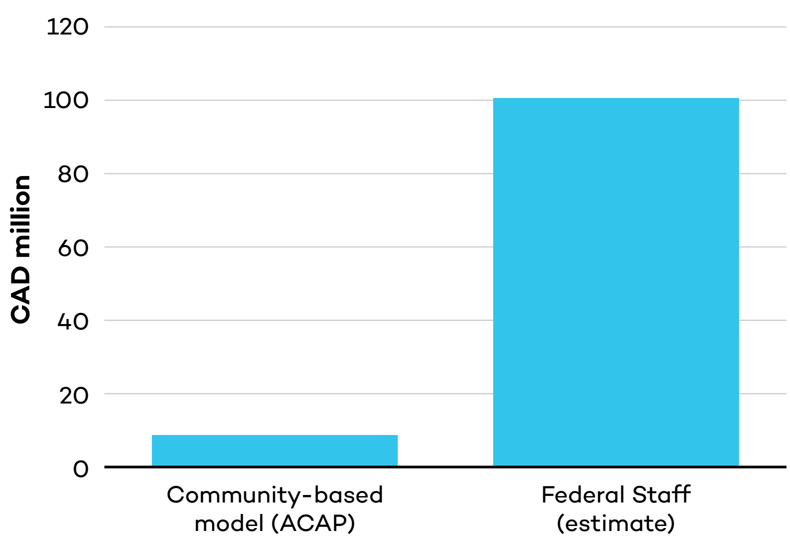
Financial Valuation

The value of the Annapolis Guardians community-based monitoring program is demonstrated by its central role in CARP programming, spinning off into a number of closely related projects while also tracking long-term trends and interfacing with the community.

The cost effectiveness was evaluated by Gardner Pinfold Consulting in 2002 (with an update in 2008) to report on the cumulative impact of ACAP, comparing its cost to a conventional Environment Canada-delivered program. The consultants evaluated all 14 ACAP-funded programs across Atlantic Canada from 1997 to 2002, which included community-based monitoring components and the other portions of ACAP programming.

They reported an annual cost to simulate for the entire ACAP program would be CAD 14,461,000 (2002 dollars) with a 5-year cost of CAD 71,049,000. The actual funding to ACAP over the 5-year period was only CAD 6,100,000, representing a 11.6:1 return on the investment over conventional delivery (Figure 16).

Figure 16. 5-year program cost delivery comparison between ACAP core funding and estimated cost for Environment Canada delivery



Source: Gardner Pinfold Consultants, 2002.

The economic impact of this CAD 6.1 million investment exceeded CAD 22 million including both direct and spinoff impacts, which would accumulate CAD 8.03 million in taxation revenue.

In 2008, after the third 5-year phase of ACAP, Gardner Pinfold arrived at a similar assessment, with an approximately 9:1 differential between conventional models and the community-delivered model.

In 2009, Environment Canada transitioned ACAP into the Atlantic Ecosystems Initiative. This rebranding removed the core funding model in favour of a competitive, project-based granting model. In 2013, ACAP invited other NGOs, Indigenous governments, and research and academic institutions to apply for project funds as well. As of the 2021 program, ecosystem monitoring is not an eligible expense.

In the 2017–2018 CARP Year in Review (2018), Executive Director Levi Cliche wrote:

> The River Guardians program is a prime example of the problem we face with our current funding model. After 27 years the River Guardian program which samples the river water and measures E.coli concentration, has not been able to secure funding for sampling this field season. This is valuable data and the program should continue but CARP does not have discretionary funds to support the program. The current funding model determines what work we can do not necessarily the work that is most important.

The value generated by the Annapolis River Guardians program to the CARP's objectives is clear to the organization's management and the local community. In practice, this program has identified critical issues such as a malfunctioning wastewater treatment facility—leading to an immediate remediation and avoiding considerable costs and penalties for a local community. Less dramatic uses of the data include frequent communication on the state of the river to the community—building a shared understanding of the river's health and threats. Data and sampling capacity are also frequently leveraged in short-term projects, such as an estuary monitoring program and improving agricultural runoff management across Bay of Fundy watersheds. Long-term ecological data, like that collected by the Annapolis Guardians, provides a baseline and response indication for projects across the Annapolis River basin.

The value of long-term ecological studies is outlined in a major publication by Lindenmayer et al. (2012), in which the authors call for ecologists, resource managers, and decision-makers to support ecosystem monitoring as "the raw materials" essential for better decisions. The authors outline five core values of these studies:

- Quantifying ecological responses to environmental change
- Understanding complex ecosystem phenomena that occur over a prolonged period
- Providing core ecological data for use in developing theoretical models and parameterizing and validating simulation models
- Acting as platforms for collaborative studies, thus promoting multidisciplinary research
- Providing data and understanding to support evidence-based policy, decision making, and management of ecosystems.

More recently, Hughes et al. (2017) found a clear relationship between the length of ecological studies and monitoring programs (greater than 4 years in duration) with their impact on science (measured by impact factor) and on policy (measured by citations in reports published by the US National Research Council, or NRC, reports). More concretely, the United States' major scientific granting institution, the National Science Foundation, has recognized the importance of long-term monitoring and studies and created a major investment stream for long-term ecological research (LTER) sites, such as NEON which spans the continental United States. Likewise, European and international programs are investing considerably in long-term data like that collected by the Annapolis River Guardians. Beyond the impact on science and policy, NSF-funded LTER sites attract 2.9x the initial investment from outside funders.

CARP's annual financial reports note, along with the reviews by Gardner Pinfold Consulting, that even during the ACAP core funding period (1991–2008) the core funds allowed the small staff to leverage further project-based funding from provincial, federal, and private sources with the majority of the funding coming from non-ACAP sources, while the funds allowed the program to leverage in kind support from volunteers and the utility of existing data and processes to manage data.

Each of these characteristics of LTER is present in the comparatively small Annapolis River Guardians—in both the value the monitoring program generates to the objectives of CARP and the local community, and in the threats to its future existence since core funding of monitoring has been eliminated.

Non-profits of all types have been squeezed by the "non-profit starvation cycle" (Goggins Gregory & Howard, 2009, described in detail in Part 1). Small non-profits experience reduced capacity over time to maintain administration and technology due to strict limits of project-based funding on overhead. At the same time, expectations of productivity increase as projects experience "scope creep" that eats away at core activities such as long-term monitoring.

A business case for community-based monitoring must highlight the incompatibility of long-term monitoring and project-based funding, particularly when tracking costs and benefits as each funder may have different reporting and accounting requirements.

The Case for Long-Term Community-Based Monitoring

The Annapolis River Guardians is a success story for sustainable core funding and the benefits community-based monitoring delivers for integrated watershed planning. What began as part of a regional funding program—the Atlantic Coastal Action Program—has survived three decades of funding shocks and stresses, generating nearly 5,000 data records as part of its core monitoring and thousands more in short-term projects.

Local expertise and evidence are necessary to prepare for a changing climate and to take advantage of technological innovations that can help communities mitigate climate change or adapt to a new normal. In the innovative models being developed in Canada[8] and around the world[9] to help predict threats and make informed preparations, the quality of local data is often a limiting factor. LiDAR-derived elevation, water flow, and water quality data all improve the potential of high-tech solutions and help local planners ensure these digital solutions are valid in their environments. At the regional scale, the Atlantic DataStream combines Annapolis Guardian data with other datasets from community organizations as well as municipal, provincial, and federal organizations—building a comprehensive regional portal for water quality data.

With long-term data, community-driven monitoring organizations like CARP generate impact multipliers when their data is used. Developing performance indicators on data use will help CBWM organizations make their own business case to the data users and potential funders. With so many potential users spread across government, education, academia, and business, it is important for data generating organizations to understand the scale of their impact—and communicate this impact as part of their own business cases.

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8 Mahone Bay-based 3D Wave Design is an Indigenous-owned company that helps communities visualize and predict water-related threats. For more info see https://3dwavedesign.com/.

9 Upstream.Tech is a public benefit corporation that works with communities and NGOs to understand landscape impacts to water quality using their Lens application. See https://upstream.tech/lens.

3.0 A Cost-Effective Enhancement for Canada's Environmental Monitoring Network: Community-Based Water Monitoring

Summary

- CBWM is a cost-effective (>3:1) and scientifically rigorous method to collect medium- and long-term water quality monitoring data at the watershed scale.
- Public sector organizations with responsibilities for water monitoring should develop long-term (5-year), core funding programs for CBWM activities to complement Canada's environmental observation system of systems.
- Federal and provincial investments in CBWM will ensure the continued operation of effective CBWM organizations as well as two-way knowledge and technology transfer between local and public sector experts and ensure monitoring data conform to established standards for collection, analysis, and dissemination.
- The Canada Water Agency is a candidate to coordinate and oversee a horizontal initiative to connect water monitoring organizations at federal, provincial/territorial, and local levels to minimize redundancy and enhance data interoperability.

Current State

According to WWF-Canada (2020), 100 of Canada's 167 watersheds are so poorly understood that a health score cannot be assigned to them. Even for many with a score, understanding of state and trends is limited. Even measurements of water flow are insufficient: since the 1980s, parts of Canada have not met the World Meteorological Organization's guidelines for hydrometric station density, and the past 30 years have, in fact, seen the number flow-gauging stations decline.

The effects of poor water management are measured in billions of dollars and can last for generations. Canada is still dealing with the costs of the collapse of the East Coast cod fisheries, the legacy of mercury poisoning in Asubpeeschoseewagong First Nation (Grassy Narrows), and increasingly toxic cyanobacteria blooms appearing each summer on lakes. A rapidly changing climate across Canada will exacerbate issues of water quality and quantity—it demands an adaptive management approach.

Community-based monitoring is defined by Whitelaw et al. (2003) as "a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track, and respond to issues of common community concern." It is a bottom-up monitoring strategy driven by local interest and capacity, but has regional impact through networks, shared sampling protocols, and engagement in basin-level management.

In the Federal Sustainable Development Strategy (2019–2022), the Government of Canada has committed to “pristine lakes and rivers” that support economic prosperity and the well-being of Canadians. In addition, it has taken action at a high level to support integrated watershed management planning, support regional water boards, and target action on priority ecosystems. Provincial and territorial governments develop water strategies with common goals, including safe drinking water, understanding threats caused by climatic change and emerging contaminants including microplastics, and preparing for water-related risks like floods, droughts, and fires.

As an actor on the world stage, Canada has also committed to achieving the United Nations’ Sustainable Development Goals, which include Clean Water and Sanitation, Climate Action, and Life Below Water. Bill C-15 (2021) is expected to receive Royal Assent to formally acknowledge Canada’s commitment to the United Nations Declarations on the Rights of Indigenous Peoples, which, through enabling legislation, may strengthen constitutional duties to consult First Nations, Métis, and Inuit communities when resource development may adversely impact them.

Successful programs like the ACAP used a core funding model for over 20 years, developing over a dozen watershed monitoring organizations in Atlantic Canada. Since the core funding model was ended in the early 2010s, almost all CBWM organizations are funded by competitive grants on a 2–3-year cycle to support time-bound projects. This is incompatible with CBWM and has put pressure on many organizations to scale back monitoring, analysis, and dissemination of their data. This reduces the utility of these programs to government experts, industry, and local communities.

Recommended Option: Long-term investment in CBWM

- **Establishing a 5-year pilot project investing in established CBWM organizations** will enhance local capacity, create high-skill jobs in remote regions, and provide cost-effective water monitoring data to local communities.
- Provincial and territorial investments should be able to leverage these funds to support integrated watershed management activities and monitoring relevant to local priorities (e.g., nutrient loads, biodiversity monitoring).
- Long-term (5-year) core funding programs will require accountability mechanisms to ensure public expenditures are returning value; federal investment may standardize environmental monitoring reporting to recognize the multiple value streams generated by CBWM activities.
- Lessons learned from the Indigenous Guardians pilot program (2017–2022) may be integrated, and that program should be extended to advance reconciliation and help Canada meet Aichi Target 11 (Canada’s Target 1) for conserved areas.

Alternative Option: The status quo

- CBWM organizations will continue to operate, but many may reduce long-term monitoring in favour of short-term research projects. This will affect the usability of monitoring data for federal and provincial/territorial business lines.
- High turnover of staff hired on term reduces the efficiency of CBWM organizations.
- Technical capacity of CBWM organizations will suffer, increasing the amounts of "dark data" that cannot be used for governance, policy design, and decision making.
- Many CBWM organizations are only "a few bad years away" from closure when dependent on project-based funding.

Costs of Inaction

- Long-term monitoring is necessary to understand baselines and impacts of climatic change. For the insurance industry, monitoring is incorporated into actuarial models to assess risk. Without water data, areas of Canada may become uninsurable since insurers may avoid the uncertainty of risk (Kovacs, 2020).
- Canadians may not trust the quality of water for drinking or recreation. Governments must demonstrate to the public that water is clean and safe, particularly in light of events at Walkerton or Grassy Narrows, both in Ontario.
- Investment in Canadian companies may be threatened by negative or unknown environment, social, and governance (ESG) scores. Without independent monitoring provided by CBWM, Canadian businesses—particularly those in the resource sector—may find it difficult to attract investment or demonstrate ESG improvement.
- Investments in environmental projects may have less clarity on outcomes, reducing future support.

References

Altamimi, H., & Liu, Q. (2019). The nonprofit starvation cycle: impact of underfed overhead on program outcomes. *Academy of Management Proceedings, (1)*, 19119. https://doi.org/10.5465/AMBPP.2019.217

Assembly of First Nations. (n.d.). *National water declaration.* https://www.afn.ca/uploads/files/water/national_water_declaration.pdf

Bartlett, C., Marshall, M., & Marshall, A. (2012). Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing. *Journal of Environmental Studies and Sciences, 2*(4), 331–340. https://doi.org/10.1007/s13412-012-0086-8

Bartram, J., & Ballance, R. (1996). Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater. *Quality Studies and Monitoring Programmes,* 1–348.

Becklumb, P. (2019). *Federal and provincial jurisdiction to regulate environmental issues.* Parliamentary Information and Research Service. https://lop.parl.ca/staticfiles/PublicWebsite/Home/ResearchPublications/BackgroundPapers/PDF/2013-86-e.pdf

Beveridge, M. A., Sharpe, A., & Sullivan, D. (2006). *Annapolis river 2005 annual water quality monitoring report.* Clean Annapolis River Project.

Binding, C. E., Greenberg, T. A., McCullough, G., Watson, S. B., & Page, E. (2018). An analysis of satellite-derived chlorophyll and algal bloom indices on Lake Winnipeg. *Journal of Great Lakes Research, 44*(3), 1–11. https://doi.org/10.1016/j.jglr.2018.04.001

Burke, A. (2018). *Prototype flood map app captures what satellites can't.* Natural Resources Canada. https://www.nrcan.gc.ca/simply-science/prototype-flood-map-app-captures-what-satellites-cant/21094

Canadian Council of Ministers of the Environment. (2015). *Guidance manual for optimizing water quality monitoring program design.* https://ccme.ca/en/res/guidancemanualforoptimizingwaterqualitymonitoringprogramdesign_1.0_e.pdf

Carlson, T., Cohen, A., & Hartwig, K. (2017). *A snapshot of community based monitoring in Canada, 25.*

Clean Annapolis River Project (CARP). (2018). *2017-2018 CARP year in review.* https://dad07fd8-c559-493b-a933-d88a8ecd1c1a.filesusr.com/ugd/d3fcb1_4aa41e5eacc0464881763a370c1d61fa.pdf

Cliche, L., & Freeman, L. (2017). Applying integrated watershed management in Nova Scotia: a community-based perspective from the Clean Annapolis River Project. *International Journal of Water Resources Development, 33*(3), 441–457. https://doi.org/10.1080/07900627.2016.1238344

Community Collaborative Rain, Hail and Snow Network (CoCoRaHS). (n.d.). *About Us.* https://www.cocorahs.org/Content.aspx?page=aboutus

Cohen, A., & Livingstone, A. (2021). *Using data from community-based water monitoring in Nova Scotia.* https://www.coastalaction.org/uploads/1/2/2/2/122203881/cbwm_data_use_in_ns_clari_final.pdf

Cooper, C.B., & Lewenstein, B.V. (2016). Two meanings of citizen science. *The rightful place of science: Citizen science.* D. Cavalier & E.B. Kennedy (Eds.). Consortium for Science, Policy & Outcomes.

Cox, S. (2019). Meet the Kaska land guardians. *The Narwhal.* https://thenarwhal.ca/meet-the-kaska-land-guardians/

Craglia, M., Hradec, J., Nativi, S., & Santoro, M. (2017). Exploring the depths of the global earth observation system of systems. *Big Earth Data, 1*(1–2), 1–26. https://doi.org/10.1080/20964471.2017.1401284

Dena Kayeh Institute (DKI). (n.d.). *About us.* https://denakayeh.com/about-us/

Dena Kayeh Institute. (2019). *Kaska Dena Conservation Analysis for an Indigenous Protected and Conserved Area in British Columbia* (Issue September). https://denakayeh.com/wp-content/uploads/2020/11/DKI-KDC2019Kaska-Dena-Conservation-Analysis-September2019-Final.pdf

Dewberry. (2012). *National enhanced elevation assessment.* https://www.dewberry.com/docs/default-source/documents/neea_final-report_revised-3-29-12.pdf?sfvrsn=a46dba28_0

Dunham, J., Rieman, B., & Chandler, G. (2003). Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. *North American Journal of Fisheries Management, 23*(3), 894–904. https://doi.org/10.1577/m02-028

Eitzel, M. V, Cappadonna, J. L., Santos-Lang, C., Duerr, R. E., Virapongse, A., West, S. E., … Jiang, Q. (2017). Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and practice, 2*(1), 1. https://doi.org/10.5334/cstp.96

Ellsworth, J. P., Hildebrand, L. P., & Glover, E. A. (1997). Canada's Atlantic Coastal Action Program: A community-based approach to collective governance. *Ocean and Coastal Management, 36*(1–3), 121–142. https://doi.org/10.1016/S0964-5691(97)00044-6

Environment and Climate Change Canada (ECCC). (n.d.). *Water: Frequently asked questions.* https://www.canada.ca/en/environment-climate-change/services/water-overview/frequently-asked-questions.html

Environment and Climate Change Canada. (2014). *Site variable data – List: Liard River at Upper Crossing (YT10AA0001).* https://aquatic.pyr.ec.gc.ca/webdataonlinenational/en/Measurements/ChooseVariables/Sites/YT10AA0001/Projects/PYLTM/Regions/0

Environment and Climate Change Canada. (2021). *Achieving a sustainable future - Winter 2021 update. A Federal Sustainable Development Strategy for Canada 2019 to 2022.* https://www.fsds-sfdd.ca/downloads/Federal Sustainability Development Strategy (FSDS) Winter 2021_Update_EN_FINAL.pdf

First Nations Information Governance Centre. (n.d.). *The First Nations Principles of OCAP®.* https://fnigc.ca/ocap-training/

Gardner Pinfold Consulting. (2002). *An evaluation of the Atlantic Coastal Action Program (ACAP): Economic impact and return on investment.*

Gardner Pinfold Consulting. (2008). *An update of the economic impact of the Atlantic Coastal Action Program (ACAP).*

Garret, J. A. (1996). *Our watershed, our responsibility: Annapolis environmental management handbook.* Clean Annapolis River Project.

Global Nature Fund. (2013). *Threatened lake of the year 2013: Lake Winnipeg in Canada.* https://www.globalnature.org/35753/Living-Lakes/Threatened-Lake-2021/Threatened-Lake-2013/resindex.aspx.

Goggins Gregory, A. & Howard, D. (2009). The nonprofit starvation cycle. *Stanford Social Innovation Review, Fall.* https://ssir.org/articles/entry/the_nonprofit_starvation_cycle

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal, 69*(4), 211–221. https://doi.org/10.1007/s10708-007-9111-y

Government of British Columbia. (2001). *BC EMS ID E243567 – Unnamed Lake 8.5 km south of BC-Yukon Boundary.* https://a100.gov.bc.ca/pub/ems/graphingExceedenceCriteria.do?userAction=showGraph&multilistRequestor=graphingExceedenceCriteria&officeMultilistRequestor=graphingExceedenceCriteria&bean.p_ems_id=E243567&x=40&y=27#

Government of the Northwest Territories. (2010). *Northern voices, northern waters: NWT water stewardship strategy.* https://www.nwtwaterstewardship.ca/fr/node/110

Harker, K. J., Arnold, L., Sutherland, I. J., & Gergel, S. E. (2021). Perspectives from landscape ecology can improve environmental impact assessment. *Facets, 6,* 358–378. https://www.facetsjournal.com/doi/pdf/10.1139/facets-2020-0049

Heidorn, P. B. (2008). Shedding light on the dark data in the long tail of science. *Library Trends, 57*(2), 280–299. https://doi.org/10.1353/lib.0.0036

Hughes, B. B., Beas-Luna, R., Barner, A. K., Brewitt, K., Brumbaugh, D. R., Cerny-Chipman, E. B., … Carr, M. H. (2017). Long-term studies contribute disproportionately to ecology and policy. *BioScience, 67*(3), 271–278. https://doi.org/10.1093/biosci/biw185

Indigenous Circle of Experts. (2018). *We rise together: achieving pathway to Canada target 1 through the creation of Indigenous protected and conserved areas in the spirit and practice of reconciliation.* https://www.changingtheconversation.ca/sites/all/images/Biodiversity Library/WeRiseTogetherReport.pdf

Irwin, A. (1995). *Citizen science: A study of people, expertise, and sustainable development.* Routledge.

Kanu, A., DuBois, C., Hendriks, E., Cave, K., Hartwig, K., Fresque-Baxter, J., Trembath, K., & Kelly, E. (2016). *Realizing the potential of community based monitoring in assessing the health of our waters.* Centre for Indigenous Environmental Resources, Living Lakes Canada, The Gordon Foundation, WWF Canada, Our Living Waters, The Lake Winnipeg Foundation, The Canadian Environmental Grantmakers Foundation, RBC Blue Waters Program, and the Government of the Northwest Territories. http://awsassets.wwf.ca/downloads/realizing_the_potential_of_community_based_monitoring_in_assessing_the_health_of_our_.pdf

Kovacs, A. (2020). *Climate risks: Implications for the insurance industry in Canada.* Insurance Institute. https://www.insuranceinstitute.ca/en/resources/insights-research/Climate-risks-report

Lake Winnipeg Foundation. (2019). *Lake Winnipeg Community-Based Monitoring Network: Seine Rat Rouseau Watershed District 2019 Regional Report.* https://www.lakewinnipegfoundation.org/sites/default/files/2019_Seine-Rat-Roseau.pdf

Lämmerhirt, D., Gray, J., Venturini, T., & Meunier, A. (2018). *Advancing sustainability together? Citizen-generated data and the Sustainable Development Goals.* https://www.data4sdgs.org/resources/advancing-sustainability-together-citizen-generated-data-and-sustainable-development

Lindenmayer, D. B., Likens, G. E., Andersen, A., Bowman, D., Bull, C. M., Burns, E., … Wardle, G. M. (2012). Value of long-term ecological studies. *Austral Ecology, 37*(7), 745–757. https://doi.org/10.1111/j.1442-9993.2011.02351.x

Merriam-Webster. (n.d.). Science. In *Merriam-Webster.com* dictionary. https://www.merriam-webster.com/dictionary/science

Ministry of the Environment, Conservation and Parks. (2016). *Ontario's Great Lakes Strategy.* https://www.ontario.ca/page/ontarios-great-lakes-strategy

Ministry of the Environment, Government of British Columbia. (2008). *Living water smart: British Columbia's water plan.* https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-planning-strategies/living-water-smart

Mishra, A. K., & Coulibaly, P. (2009). Developments in hydrometric network design: A review. *Reviews of Geophysics, 47* (RG2001). https://doi.org/10.1029/2007RG000243

National Roundtable on Community-Based Water Monitoring. (2019). *Context for a national discussion.* https://gordonfoundation.ca/wp-content/uploads/2019/06/CBWM_Roundtable_Discussion-Paper-Final.pdf

Oxford English Dictionary. (2014). *Citizen science*. https://public.oed.com/updates/new-words-list-june-2014/

Pooling Water Knowledge Working Group. (2016). *Realizing the potential of community based monitoring in assessing the health of our waters.* http://awsassets.wwf.ca/downloads/realizing_the_potential_of_community_based_monitoring_in_assessing_the_health_of_our_.pdf

Province of Nova Scotia. (2010). *Water for life: Nova Scotia's water resource management strategy.* https://novascotia.ca/nse/water.strategy/

PwC. (2019). Putting a value on data. *PwC,* 8. https://www.pwc.co.uk/data-analytics/documents/putting-value-on-data.pdf

RBC Blue Water Project. (2017). *2017 RBC Canadian water attitudes survey.* http://www.rbc.com/community-sustainability/_assets-custom/pdf/CWAS-2017-report.pdf

Research Group of the Office of the Privacy Commissioner of Canada. (2014). *Data brokers: A look at the Canadian and American landscape*. https://www.priv.gc.ca/information/research-recherche/2014/db_201409_e.pdf

San Llorente Capdevila, A., Kokimova, A., Sinha Ray, S., Avellán, T., Kim, J., & Kirschke, S. (2020). Success factors for citizen science projects in water quality monitoring. *Science of the Total Environment, 728.* https://doi.org/10.1016/j.scitotenv.2020.137843

Schindler, D. W., Carpenter, S. R., Chapra, S. C., Hecky, R. E., & Orihel, D. M. (2016). Reducing phosphorus to curb lake eutrophication is a success. *Environmental Science and Technology, 50*(17), 8923–8929. https://doi.org/10.1021/acs.est.6b02204

Schnare, K. B. (2011). *Motivations of environmental volunteers: A cross cultural comparison. A Canadian perspective from Taiwan.* National Tainan University.

Shrubsole, D., Walters, D., Veale, B., & Mitchell, B. (2017). Integrated water resources management in Canada: The experience of watershed agencies. *International Journal of Water Resources Development, 33*(3), 349–359. https://doi.org/10.1080/07900627.2016.1244048

Statistics Canada. (2019). *The value of data in Canada: Experimental estimates (No. 13-605– X). Latest developments in the Canadian economic accounts.* https://www150.statcan.gc.ca/n1/en/pub/13-605-x/2019001/article/00009-eng.pdf?st=ORj_NrdI

The Constitution Act. (1867). (UK), 30 & 31 Vict, c 3, https://canlii.ca/t/ldsw

Treasury Board of Canada Secretariat. (2009). *Business case guide*. https://www.canada.ca/en/treasury-board-secretariat/services/information-technology-project-management/project-management/business-case-guide.html

Tulloch, A. I. T., Possingham, H. P., Joseph, L. N., Szabo, J., & Martin, T. G. (2013). Realising the full potential of citizen science monitoring programs. *Biological Conservation, 165,* 128–138. https://doi.org/10.1016/j.biocon.2013.05.025

Ulph, A. M., & Reynolds, I. K. (1981). *An economic evaluation of national parks.* Centre for Resource and Environmental Studies. https://openresearch-repository.anu.edu.au/bitstream/1885/114945/2/b13158181.pdf

Venema, H. D., Oborne, B., & Neudoerffer, C. (2010). *The Manitoba challenge: Linking water and land management for climate adaptation.* International Institute for Sustainable Development. https://www.iisd.org/publications/manitoba-challenge-linking-water-and-land-management-climate-adaptation

Vreugdenhil, D., Terborgh, J., Cleef, A. M., Sinitsyn, M., Boere, G. C., Archaga, V. L., & Prins, H. H. T. (2003). Comprehensive protected areas system: Composition and monitoring. Vth World Parks Congress. Comprehensive Protected Areas System Composition and Monitoring Task Force. In *Vth World Parks Congress* (p. 110). International Union for Conservation of Nature. https://www.cbd.int/doc/pa/tools/Comprehensive protected areas system composition and monitoring.pdf

Whitelaw, G., Vaughan, H., Craig, B., & Atkinson, D. (2003). Establishing the Canadian Community Monitoring Network. *Environmental Monitoring and Assessment, 88,* 409–418.

Wilkinson, M. Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., … Mons, B. (2016). Comment: The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data, 3,* 1–9. https://doi.org/10.1038/sdata.2016.18

Wenger, S. J., Isaak, D. J., Luce, C. H., Neville, H. M., Fausch, K. D., Dunham, J. B., Dauwalter, D. C., Young, M. K., Elsner, M. M., Rieman, B. E., Hamlet, A. F., & Williams, J. E. (2011). Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. *Proceedings of the National Academy of Sciences of the United States of America, 108*(34), 14175–14180. https://doi.org/10.1073/pnas.1103097108

Wulder, M. A., White, J. C., Goward, S. N., Masek, J. G., Irons, J. R., Herold, M., … Woodcock, C. E. (2008). Landsat continuity: Issues and opportunities for land cover monitoring. *Remote Sensing of Environment, 112*(3), 955–969. https://doi.org/10.1016/j.rse.2007.07.004

WWF-Canada. (2020). *WWF-Canada's 2020 Watershed Reports: A national reassessment of Canada's freshwater.* https://wwf.ca/wp-content/uploads/2020/10/WWF-Watershed-Report-2020-FINAL-WEB.pdf

Published by the International Institute for Sustainable Development

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