GROWING THE FLOW

Building water-quality testing capacity in data-deficient subwatersheds through citizen science

PHOTO: Water First, Northern Quebec

Stream testing. PHOTO: Celine Duarte, BC

Kat Kavanagh

MSc in Integrated Water Resource Management,
McGill University
Executive Director of Water Rangers

Emelia Duguay

MSc in Integrated Water Resource Management,
McGill University
Sustainable Development Intern at Water Rangers

Laura Gilbert

PhD Candidate in Renewable Resources,
McGill University
Community Research Coordinator at Water Rangers

Introduction

In a survey conducted by the Royal Bank of Canada in 2017, more than half of Canadians said that water is a part of their identity (Royal Bank of Canada (RBC), 2017). This is unsurprising, considering "probably no country in the world has as much of its surface area covered by freshwater as does Canada" (Natural Resources Canada, 2017). At the same time, roughly 30% of Canadians "strongly agree" that regions in Canada are at risk of freshwater quality problems, and 25% "strongly agree" that Canadians are at risk of water supply shortages (RBC, 2017). Canadians say that they care about the safety and security of their water, yet our leaders do not echo this same sentiment; Canada's water policies lack coordination and clarity on roles at the federal, provincial and municipal levels (Linton, 2015). Ultimately, this leads to inaction in collecting baseline water quality data, and prevents remediation from effectively occurring (Conrad and Daoust, 2008).

In 2017, World Wildlife Fund (WWF) Canada published their Watershed Reports. This comprehensive assessment of Canada's freshwater resources illustrates just how stressed the country's watersheds are, and more alarmingly, how much we do not know about them: 110 out of 167 sub-watersheds are considered data-deficient, and gaps exist for all health indicators, including flow, water quality, benthic invertebrates, and fish. Similarly, gaps exist for all stress indicators, including pollution, climate change, flow alteration, water use, habitat loss, invasive species, and loss of connectivity (WWF, 2017).

Given the extent of knowledge gaps that exist in relation to Canadian watersheds, this paper explores the role of citizen science as an emerging tool to build capacity in data deficient regions. In order to do so, a case study is presented in which Water Rangers, a Canadian-based citizen science organization, worked with communities and WWF to begin building local capacity for water quality testing.

Citizen science

Citizen science can be defined as the participation of non-scientists in creating new scientific knowledge (Buytaert, 2014). Wiggins and Crowston (2011) suggest that citizen science projects fall into five types: action, conservation, investigation, virtual, and education, all of which have different goals and limitations. For the most part, success criteria for citizen science projects are based on the program or researcher's criteria, but most include scientific and educational goals (Bonney et al., 2009).

Irwin (2002) argues that the development of local community-based expertise through the use of citizen science is essential for the sustainable development of a society, for two main reasons: (1) it challenges scientific institutional segregation, and (2) it offers a way for us to understand society in the context of people's relationships with the environment, in ways that traditional scientific inquiry does not.

Collaboration between stakeholders is a fundamental component of Integrated Water Resource Management (IWRM), the accepted water management paradigm in Canada, but many times public interest and ability to participate is limited (Rahaman and Varis, 2005). The inclusion of stakeholders is based on the principle of subsidiarity, meaning that management should be done by the most relevant and most competent authority. Community-based monitoring programs are important as they can help bridge gaps between diverse stakeholders and build educational and monitoring capacity so that stakeholders can collaborate more meaningfully to affect policy (Couvet et al., 2008). Models like IWRM and Adaptive Management (AM) as processes for managing water have often failed to achieve their goals; inadequate system monitoring and low stakeholder buy-in are often cited as reasons for this (Aceves-Bueno, 2015). Citizen science's strengths emerge as a potential solution for these two problems since its aims are to increase public engagement and to collect more data (Rahaman and Varis, 2005). However, in order for citizen science to inform decision-making processes, large quantities of temporal and spatial data are often needed.

Lack of water quality data

According to WWF-Canada (2017), many watersheds in Canada were determined to be data deficient due to a lack of temporal or geo-spatial sample diversity. Of those with data, 42 out of 67 were rated as 'poor' or 'fair'. Factors that contribute to these data deficiencies include the physical geography and population distribution of Canada, government budget cuts, and the limited technical capacity of data collectors.

Canada's population is sparse: the country is home to only 3.9 people per square kilometre on average, most of which are concentrated in the southern provinces (Statistics Canada, 2016). Canada's unique population distribution results in significant challenges for water monitoring; with 2 million lakes across the country (Canadian Wildlife Federation (CWF), n.d), many are located in sparsely populated regions where testing seasons are very short. This often results in transportation and lab testing costs being much more expensive in Canada than in smaller and more densely populated countries.

Technology and 'more data' are sometimes touted as the solution for data deficiencies. However, even though more technological tools are being implemented and continuous monitoring programs are emerging, data deficiencies remain. For example, the continuous collection of data by automated buoys and other inexpensive instruments has been increasing in popularity. These instruments aim to help provide an understanding of water quality over time, especially based on time of day, weather, and more. While there is a benefit to this type of data collection, two problems with it have been noted: first, these monitoring systems often remove human interaction and thus lead to less stakeholder involvement (Jalbert and Kinchy, 2016).

College students testing after a storm.
PHOTO: Bianca Amaral-Stewart, Ontario

How a secchi disk works. PHOTO: Dan, Ontario

Second, they create massive quantities of data, which leads to administrative and financial burdens associated with the storing and analysis of this data (Jalbert and Kinchy, 2016). For those that are responsible for the management and administration of programs, this can lead to a reduced likelihood of overall project success, as they do not have the time or resources to sort through massive amounts of data.

Cutbacks in government programs over the past several decades have also meant that many sample sites are no longer being monitored, and the provision of historical data in an open and accessible manner is not being prioritized. With growing concern over governmental budget cuts, such as the defunding of 'non-essential' Ontario Conservation Authority services (including long-term monitoring), data deficiencies could increase (Canadian Broadcasting Corporation (CBC) News, 2019). Thus, while continuous data collection is increasing, overall water testing is decreasing, and very little of the data that is gathered via these methods is able to be mobilized.

Additionally, the data that is being collected is often hard to access and dispersed. Some data collection organizations have expressed a desire to reduce barriers associated with sharing data, and some non-profit organizations like WWF Canada, the Gordon Foundation, and others have worked to convene data holders (Community-Based Water Monitoring (CBWM) Roundtable, 2019). They are amongst the few successful, scalable projects that have emerged that share data in an open, accessible way and that allow for meaningful public participation. However, political will for investing in and unifying a vision for Canada's freshwater remains a barrier to filling water data gaps (CBWM Roundtable, 2019).

Community-based water monitoring: growing and unstable

Lack of funding and difficulty in collecting data over large geographic areas mean citizen science is becoming a fundamental part of many research projects (Rotman et al., 2014). This type of research is reliant on technology to achieve scale and can include the use of sensors, probes, and physical tests (Rotman et al., 2014). Citizen scientists can help collect large temporal and geographic datasets that would be impossible to collect by 'traditional' researchers alone. For example, The Christmas Bird Count, which asks citizens in the Northern Hemisphere to track birds, has been collecting data for over one hundred years (Catlin-Groves, 2012). This helps form one of the largest wildlife data sets in the world, which is frequently used by researchers to assess bird demographics ("Christmas Bird Count", n.d.).

While the number of monitoring programs in Canada tripled in the last two decades, most efforts are highly localized and protocols are based on local priorities (Carson et al., 2017). Public consciousness and emerging technologies are factors that have helped grow the community-based monitoring movement, while funding and sharing remain barriers to providing long-term, meaningful testing.

Funding

Funding for continuous community-based water quality

Teaching youth. PHOTO: Lee, BC

monitoring is rare; many funding sources are for a single year or are project-based, with more and more environmental funds not supporting ongoing operations or existing projects (Conrad and Daoust, 2007). While intentions are often noble in the initial years of a project, insufficient funding often leads to a loss of momentum and a loss of data continuity (Danielsen et al., 2005). Community-based monitoring programs are also rarely self-sustaining, as they rely on grants and fundraising for survival (Wiggins and Crowston, 2011). Many successful projects are abandoned when the funding disappears, meaning the establishment of long-term trends is difficult to achieve, while set-up costs are often lost (Carson et al., 2017). However, there is a growing demand for long-term monitoring to be prioritized, especially long-term government support for water quality monitoring in Indigenous communities (CBWM Roundtable, 2019).

Public participation

Keeping participants engaged in long term volunteer projects continues to be a challenge for citizen science projects, as user motivations tend to change over time. These motivations may include activism, validation, or personal gain, education, and more (Rotman et al., 2014). The motivations that encourage volunteers to sign up for research projects are often different from those that encourage them to continue (Bussell and Forbes, 2003). Developing a further understanding of users' values and motivations for using citizen science platforms and tools is of paramount importance so that they can be developed in a way that will allow them to maintain sustained public engagement. That being said, locality has long been identified as a factor which motivates continuous involvement; local stakeholders often have more knowledge of local conditions and will be more invested in the success of a project that directly affects them (Sheppard and Terveen, 2011; Rotman et al., 2012). Additionally, techniques like acknowledging participants' efforts may help with long term engagement, and communication remains key to 'bring people back' (Rotman et al., 2012).

Technology

Creating easy to use platforms and tools helps increase and maintain public engagement. For example, web interfaces that use design principles to improve user experiences are more inviting for public engagement in environmental monitoring than traditional data gathering methods

Checking depth. PHOTO: Jacy, Ontario

Water sampling in progress. PHOTO: Water First, Quebec

(Eveleigh et al., 2014). Also, advances in mobile phone technology and improvements to real-time water quality tests (including emerging technologies such as those that use artificial intelligence for interpretation or analysis) all contribute to more effective tools for citizen science (Crowston, 2012). Data gathered by citizen scientists are most commonly submitted using a web form, which the use of smartphones has proven to be useful for. They lower the amount of required technical skills, time, and tools needed to gather data, for example, by automatically tracking a person's location (Kim et al., 2011).

These advances in technology also make it easy to include engagement strategies to maintain public participation. One such strategy is gamification, which consists of creating elements that go beyond the purpose of gathering data to entertain users. Gamification elements, which can be as simple as a points system for each entry or more complex like geocaching, have been shown to increase participation by Millenials, an important demographic (Bowser et al, 2013). For example, the citizen-science platform eBird was originally designed for scientific data collection, but with the addition of gaming elements such as personal profiles and competition, contribution increased exponentially (Hochachka et al., 2012).

Legitimacy

Citizen science continues to be distrusted by some scientists and policy-makers who have concerns about data quality and reliability (Catlin-Groves, 2012). This is despite the fact that studies have found that data collected by citizen scientists more often than not matches the quality of data collected by scientific staff (Kosmala, 2016). Tools that help catch errors early on in the monitoring process, lower user error, and the removal of poor data could help improve the relationship between citizen monitoring and the scientific community.

PHOTO: Wemindji Youth, Northern Quebec

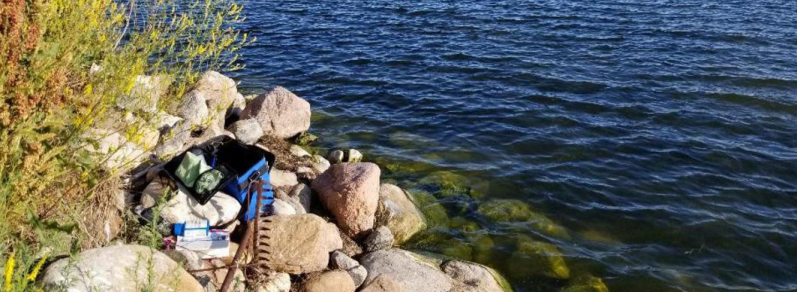
Data sharing

Open data has become an important facet of government and publicly supported data, and there is a general societal push towards open data policies (Baack, 2015). However, open data is often found through computer web services like Application Programming Interfaces (APIs), and viewing and interpreting the data requires technical knowledge and skills most members of the public do not have (Begoli and Horey, 2012). While the trend toward openness is continuing, interoperability (the ability of systems to make use of information) and exchangeability (how easily data can be compared between different protocols) remain challenges, and so data is often not easy to compare between different sources. There are however some social impediments to open data. For some, it means relinquishing control of how the data is used once it is shared. It also means that tracing responsibility for poor quality data is harder than with other types of data (Janssen et al., 2012). In countries such as Germany, open data and regional data hubs are well established (Baack, 2015) and have progressed much more quickly than in Canada. In Canada, platforms like DataStream, a platform for sharing open data on water quality in the Mackenzie, Winnipeg, and Atlantic watersheds, have been integral in building capacity to share water data ("DataStream", 2020). Regional hubs like these help bring data out of silos and into areas where they can be used.

Determining project success

Several factors determine whether a citizen science project is successful. Cox et al. (2015) created a citizen science success matrix, which includes contributions to science (data value and project design and resource allocation) and public engagement (dissemination and feedback, participation and opportunities for learning). In the past, many citizen science projects have been seen as marginally useful to local research or management, and others have produced no scientific results even after years of effort (Kim et al., 2011). Project design plays a large role in determining the outcome of projects. It usually requires a cross-disciplinary team to develop different aspects of the project for diverse stakeholders, including scientists, user experience designers, and more (Bonney et al., 2009), and project design is integral to successful projects. For example, citizen science projects that are designed in partnership with local organizations, government, and scientists are more likely to contribute to local decision making (Kim et al., 2011). Collaborative project design and engagement strategies (previously discussed) ensure that citizen science produces useful and actionable knowledge.

Testkit out in the field. PHOTO: Lee, BC



Case study:

Water Rangers equipping data deficient subwatersheds

This section outlines a cross-Canada citizen science project led by Water Rangers that aimed to build water testing capacity in data deficient watersheds.

Selection criteria	Points	Analysis
Located in a data deficient subwatershed?	0 or 10	92% scoring points
Indigenous connection	0 - 10	38% scoring points
Quality of application	0 - 10	Average: 8.7
Enthusiasm	0 - 10	Average: 8.2
Total	**0 - 40**	**Average 28.8**

Table 1: Selection criteria for the winning 26 applicants. Two candidates scored 40.

About Water Rangers

Water Rangers (waterrangers.ca), founded in 2015, is a design-led non-profit organization connecting people to their local waterways through citizen science. Their online open-data platform includes customizable community tools, time-series observations, issue reporting, offline data collection in the field, and integrations for partner websites. Their water quality testkits include tests for general health parameters that give accurate results instantly, and online training in plain language helps lower knowledge barriers.

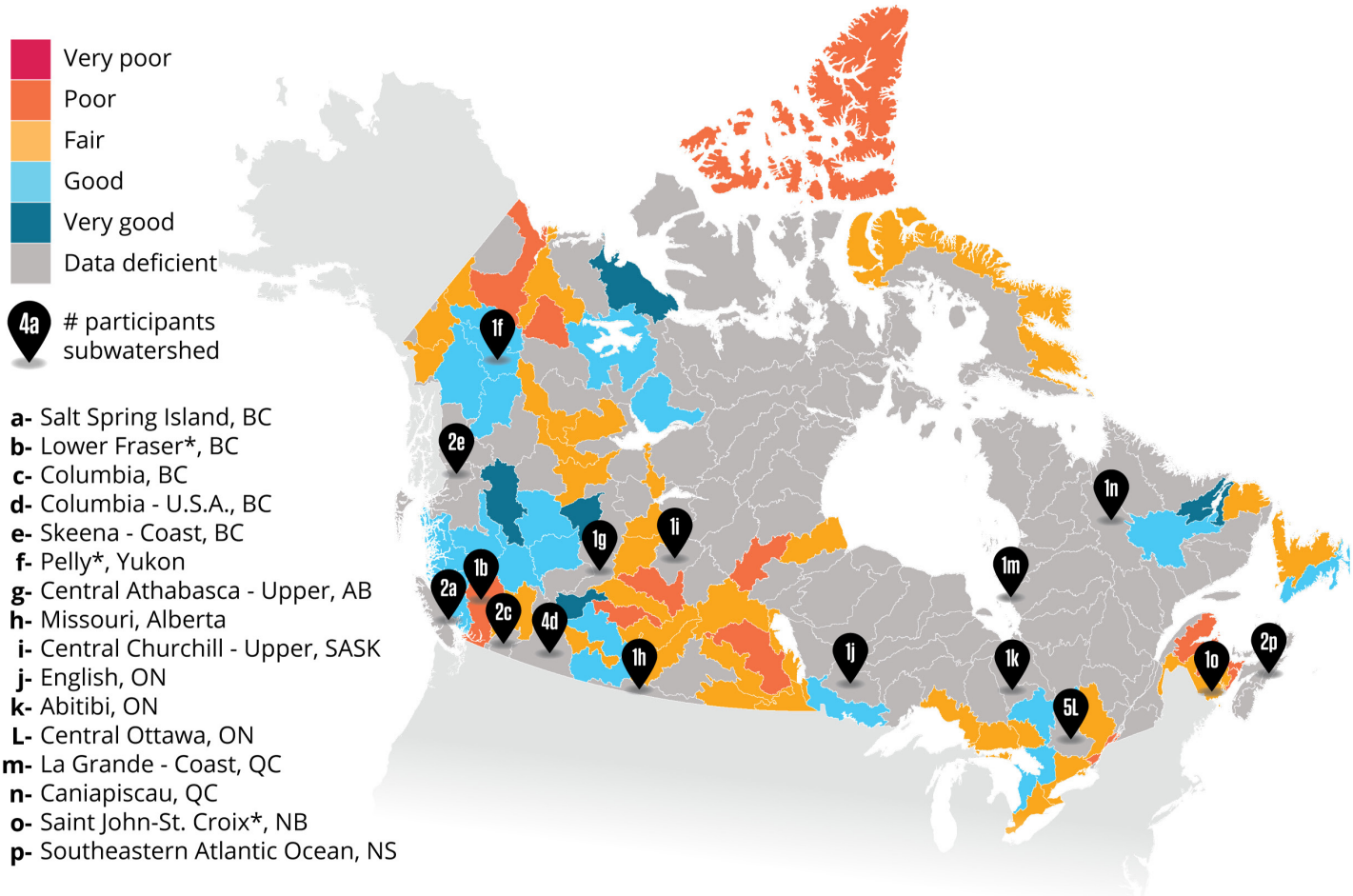


Figure 1: The base map shows WWF's Watershed Assessment for water quality. Map markers show where participants were based.

**These participants were chosen from watersheds that were not data deficient. While watershed data deficiency was the most important factor in scoring applicants, some gained enough points to rank based on the quality of their application and whether there was a gap in our map. See Table 1 for selection criteria.*

About the funding

While the 2017 report by WWF was a wake-up call for a unified and collaborative vision for freshwater assessment and protection, taking action on collecting more data and improving water conditions was identified as the next step.

Made possible as a result of Loblaw's plastic bag charge and in partnership with WWF, the Loblaw Water Fund sponsors projects that take specific steps toward ecosystem restoration and/or the collection of data for long-term monitoring initiatives. The fund has sponsored 73 projects from 2014 to 2020, which have contributed to the restoration of 3,340 hectares of freshwater ecosystems, the planting of 80,000 native plants, the collection of almost 15,000 samples, and the engagement of over 16,000 Canadians ("Loblaw Water Fund", n.d.).

The following project was supported by the Loblaw Water Fund in 2019.

Project

The project, titled "Equipping Data Deficient Watersheds with Water Testing Capacity" and conducted by Water Rangers, had the following goals, based on the priorities of the WWF Loblaw Water Fund to help fill data gaps in Canadian sub-watersheds:

GOAL 1: Empower communities (where it is difficult to get resources) with the tools they need to collect water samples for the first time.

HOW: Distribute water quality testkits to selected applicants in under-served communities. Teach them how to test using simple water quality parameters and how to train others using online tools.

GOAL 2: Support continuous, long-term community-based water quality testing that builds capacity.

HOW: Applicants agree to follow Water Ranger's testing schedule, and conduct 16 tests in 4 locations in 2019. In order to keep the testing equipment, they must commit to long-term monitoring. Participants were encouraged through reminders, community-building publicity, and gamification. Water Rangers aimed to connect applicants to data holders and decision-makers and built their capacity for long-term monitoring through online resources. Participants were told to talk to 20 people about water testing and train four to use the testkit.

GOAL 3: Expand open-source data and citizen-monitoring to inspire Canadians to protect waterways and fill data gaps.

HOW: Running a community-based program can be time-consuming and expensive. The aim is to automate data sharing, reminders, and give data tools to organizers. Connect community groups to share resources, celebrate successes, make testing fun, and give ideas to grow the movement!

Participant selection

In April 2019, Water Rangers recruited participants from across Canada with the help of existing partners, as well as through paid advertising on social media (Facebook and Instagram). There were 42 serious applications, of which 27 were chosen based on selection criteria (See Table 1). See Figure 1 for their spatial distribution across Canada.

Results

All participants received their water quality testkits (see Figure 2) by June 15, 2019. From June until the end of October 2019, participants were trained through online webinars (waterrangers.ca/training), coached on selecting sample locations, provided bi-weekly newsletters, and engaged through social media.

Conductivity meter in water sample.
PHOTO: Sarah, New Brunswick

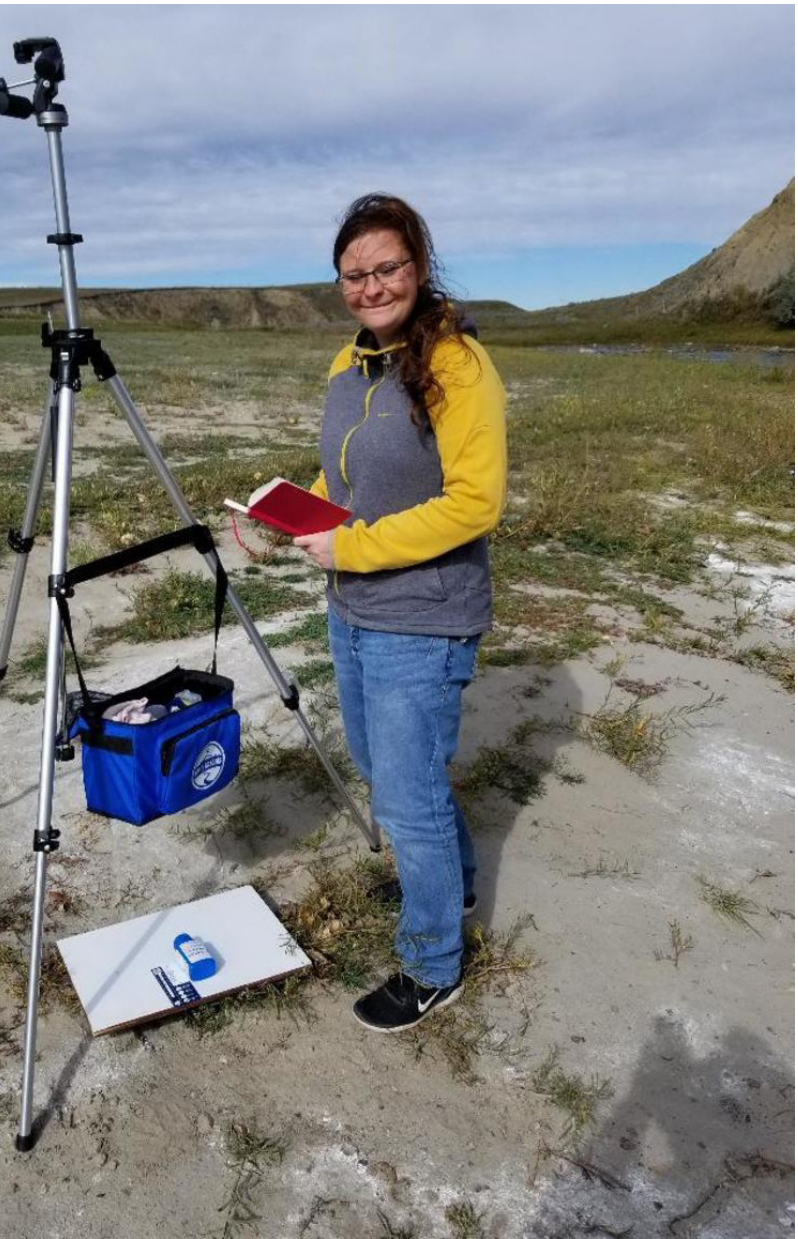
Data collection

The target was for each participant to collect 16 observations in 4 locations, where testing occurred monthly. The 25 participants completed a total of 634 observations in 226 locations, for an average of 25.4 observations (58% higher than goal) at 9 locations (125% higher than goal). The median was 15 observations in 5.5 locations, representing the uneven distribution of observations (with some 'star' testers completing many more observations and one or two completing none).

Social education

The project aimed to encourage participants to become advocates and teachers for waterways, by talking to 20 people and training four in water testing protocols. Participants were asked how many people they spoke to about the project, as well as how many people they had trained to use the kit. Participants spoke with more than 1,390 people about the program (average: 58, 190% higher than goal) and taught 224 people how to test (average: 9.3; 132.5% higher than goal). Most of the participants had fun stories about their engagement, including a participant from British Columbia who wrote: "Taught others: 20+ most folks are excited (and a little nervous), though soon realize that it is not that difficult. Emphasis is on repeatability and consistency for the science to be useful. Folks are excited when you tell them as it is all new science and has never been done before (which is true!)."

PHOTO: Chris, Alberta



Connecting data to purpose

All participants were encouraged to connect to organizations, decision-makers, and regional data hubs. A few participants then connected Water Rangers to those organizations, with leads on how to better integrate systems. Additionally, 62.5% reported that they made new connections with regional organizations. For example, a participant from New Brunswick responded: "YES!!! I've connected with several watershed restoration committees, which are helping me take things to the next level (riparian restoration, culvert replacement, creel surveys etc). Also connected with several First Nations communities, who have a spiritual connection to water and are leading the way in caring for watersheds (Mi'kmaq Water Walkers & Wabanaki Water Walkers)."

Through publicity and word-of-mouth, Water Rangers connected with national or regional data hubs, mostly in Western Canada, where very few Water Rangers users are currently located. For example, a participant from British Columbia noted that "There is Columbia River water monitoring Network that is starting, and they had questions about which quality parameters we are testing", and this led to a joint call between WWF, the Columbia Monitoring Network and Water Rangers to see how their work could be better integrated.

Furthermore, after publicity with CBC and others (Kavanagh, 2019), various groups contacted Water Rangers; for example, a member of Northern Affairs Canada contacted Water Rangers to look at opportunities to leverage their tools, presentations were made for Parks Canada, a potential collaboration with the Toronto Region Conservation Authority was organized, and further collaboration was planned with DataStream.

PHOTO: Dan, Ontario

Appreciating nature and taking action

A large portion of this project focused on building community capacity and enthusiasm. The following are responses from some of the post-study surveys. Participants were asked to answer questions using a five-point Likert scale, where 1 was "Strongly Disagree" and 5 was "Strongly Agree". Statistics presented below include participants who scored either a 4 (Agree) or 5 (Strongly Agree). Included below each one is testimonials or comments made by participants, which give a more 'human' quality to the program.

I spent time in nature: 92%

"It gives the youth a chance to connect with nature, and provides baseline data for current stream conditions in my area. My area is relatively undeveloped, however there are growing concerns about how climate change might impact water temperatures and aquatic wildlife and water quality. Being able to show kids how important cold, clean water is and providing them with skills to measure it is an important educational tool." - *Dominique, B.C.*

I visited local water bodies: 96%

"It is an important project and it gets people interested and involved in their local watercourses or waterbodies. You can learn some new techniques and put them to use to gain a better understanding of your surrounding environment, and meet new people who are interested as well!"
- *Mike, Ottawa*

I visited new places I had never been before: 79%

"I went to a local beach called Malay Falls to test the water and have a swim." - *JoAnne, Nova Scotia*

I spoke to others about water chemistry or water stewardship: 88%

"I spoke to many people along the way about water testing. Common questions consisted of, why? What type of tests do you conduct? What does it mean (parameters, data, etc)" - *Cristina, Northern Ontario*

I spoke to others about protecting the environment: 96%

"Just normal people, those who have never earned a biology degree, can be curious about the world around them. Exploring the water where you live not only gets you outside and engages you in your community, but also inspires you to learn more. Citizen Science works for every age and stage! Interested in what is in your water? Is it optimum for life? Like playing with little test kits. Have a few waters you could test and compare? Maybe Water Rangers is for you. Get outside and learn!" - *Lee, B.C.*

"It was amazing to me how many really care, but don't know what to do--or, where to begin."
- *Chris, Alberta*

I tested the water of a local waterbody: 83%

"I really enjoyed being a Water Ranger this summer. I have learnt so much about the local watershed, and surprised at the constancy of the results, which is deeply pleasing and shows that the ecosystem is well balanced. I have seen many other sites which I would like to test but time escapes me. Perhaps next year I can select different sites and see how they change over time." - *JoAnne, Nova Scotia*

I went out of my way to do something to protect the environment (besides water-testing): 80%

"In a cooperative event, our local watershed group and Greata Creek Camp held a family forest day where we instructed 45 people about [water testing] and they really enjoyed it. The children all had [the] opportunity to test and [use] the booklet in the kit [to] tell others what [each tool] was about. ie. conductivity." - *Lee, Nova Scotia*

I would like to join and actively participate in an environmentalist group: 83%

"Encouraging people to explore and become more knowledgeable about their local water bodies. Helping to fill in gaps of information pertaining to local water bodies."
- Jacy, Ontario

Presently I feel that I know a great deal about my local waterbodies: 88%

This program has allowed us to collect baseline water samples at strategic points along our river, as our community faces a proposed mine which will sump into the river. We've also documented & tested the mine's proposed discharge brook. We then tested several other tributaries of the river where other quarries exist, and subsequently found areas that need further testing & mitigation measures. This program gave the community a sense that we are proactively protecting the river we love, in case the mine is approved. It has given us confidence that if it is approved, we have baseline data, and can hold industry to a higher standard." *- Sarah, New Brunswick*

It is important for me to do what I can to preserve the natural environment: 100%

"I think Water Rangers is a fantastic program that helps connect people to their environment and allow them to collect meaningful data on aquatic environments while also providing opportunity to engage with and educate others on the benefits as well."
- Chris, Saskatchewan

I believe my actions can make a difference in helping conserve the natural environment: 83%

"The Water Rangers program has renewed interest in water quality testing within our watershed. The program is easy to follow, very relevant to monitoring climate change and the support provided is fantastic! Every watershed could benefit from this program!" *-Joanna, Northern B.C.*

Further research

Funding limitations meant that 27 testkits were distributed; a larger sample size is suggested for future years, with multiple water testkits per region. Additionally, participants were asked to fill out a pre- and post-program survey prepared by the Happiness Lab at Carleton University, which combined

Algae bloom. PHOTO: Chris Anderson, Alberta

questions on nature connectedness. However, only the post-program engagement results are presented here, and further exploration of themes of nature connectedness and values would demonstrate the effectiveness of this model.

Conclusion

Water quality data deficiency in Canada is not a problem that will be solved in a single year or by one group's efforts to collect data. Community capacity building, public engagement, tools, and strategies for continuity and quality assurance, along with data sharing arrangements that automate updates all play a part in building resilient systems to monitor waterways. Public support for water quality monitoring investment could prompt politicians and government officials to look into new ways of empowering community-based water monitoring programs. However, remote learning/coordination remains a challenge and will need to be addressed through the careful design of technology through collaboration.

Furthermore, embedded educational programs, where youth have the opportunity to connect with nature, will help increase overall public support. In the Water Rangers program, many participants mentioned those moments of understanding, especially for youth. For example, Bianca from Ottawa said, "We even got to observe a "discharge event" after a rainfall. The students were able to see the creek fill with stormwater discharging from upstream and measure the spike in conductivity, which was a really neat teaching/learning opportunity!"

With further investment, citizen science and community-based water monitoring have the potential to move beyond small case studies to a wide-scale solution for Canada's water quality data deficiencies.

Acknowledgments: First and foremost thank-you to the participants in this program for their enthusiasm. All photos presented in the presentation and paper were taken by them. Thank-you to the WWF Freshwater team for their support in this project and on publicizing its vision to Canadians. Thank-you to Najeeba Ahmed for her work in managing these volunteers during the testing season.

References

Aceves-Bueno, E., Adeleye, A. S., Bradley, D., Brandt, W. T., Callery, P., Feraud, M., . . . McCullough, I. (2015). Citizen science as an approach for overcoming insufficient monitoring and inadequate stakeholder buy-in in adaptive management: criteria and evidence. Ecosystems, 18(3), 493-506.

Baack, S. (2015). Datafication and empowerment: How the open data movement re-articulates notions of democracy, participation, and journalism. Big Data & Society, 2(2), 2053951715594634.

Begoli, E., & Horey, J. (2012). Design principles for effective knowledge discovery from big data. Paper presented at the 2012 Joint Working IEEE/IFIP Conference on Software Architecture and European Conference on Software Architecture.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: a developing tool for expanding science knowledge and scientific literacy. BioScience, 59(11), 977-984.

Bowser, A., Hansen, D., He, Y., Boston, C., Reid, M., Gunnell, L., & Preece, J. (2013). Using gamification to inspire new citizen science volunteers. Paper presented at the Proceedings of the First International Conference on Gameful Design, Research, and Applications, Toronto, Ontario, Canada. https://doi.org/10.1145/2583008.2583011

Bussell, H., & Forbes, D. (2003). The volunteer life cycle: a marketing model for volunteering. Voluntary Action.

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., . . . Dewulf, A. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. Frontiers in Earth Science, 2, 26.

Canadian Broadcasting Corporation (CBC) News. (2019, August 20). Province directs conservation authorities to 'wind down' programming. Retrieved from https://www.cbc.ca/news/canada/london/london-ontario-conservation-authority-1.5252717

Canadian Wildlife Federation. (n.d.). Lakes & Rivers. Retrieved from https://cwf-fcf.org/en/explore/lakes-rivers/

Carlson, T., Cohen, A., & Hartwig, K. (2017). Snapshot of Community Based Water Monitoring in Canada: Adaptation to Climate Change Team, Simon Fraser University.

Catlin-Groves, C. L. (2012). The citizen science landscape: from volunteers to citizen sensors and beyond. International Journal of Zoology, 2012.

Christmas Bird Count. (n.d.). Birds Canada. Retrieved from https://www.birdscanada.org/bird-science/christmas-bird-count/

Community-Based Water Monitoring Roundtable. (2019, April). Final Recommendations: Elevating Community Based Water Monitoring in Canada [PDF file]. Retrieved from https://gordonfoundation.ca/wp-content/uploads/2019/04/CBWM_Roundtable_Recommendations-Final.pdf

Conrad, C. T., & Daoust, T. (2008). Community-based monitoring frameworks: Increasing the effectiveness of environmental stewardship. Environmental management, 41(3), 358-366.

Couvet, D., Jiguet, F., Julliard, R., Levrel, H., & Teyssedre, A. (2008). Enhancing citizen contributions to biodiversity science and public policy. Interdisciplinary science reviews, 33(1), 95-103.

Cox, J., Oh, E. Y., Simmons, B., Lintott, C., Masters, K., Greenhill, A., . . . Holmes, K. (2015). Defining and measuring success in online citizen science: A case study of Zooniverse projects. Computing in Science & Engineering, 17(4), 28-41.

Crowston, K. (2012). The future of citizen science: emerging technologies and shifting paradigms. Frontiers in Ecology and the Environment, 10(6), 298-304.

Danielsen, F., Burgess, N. D., & Balmford, A. (2005). Monitoring matters: examining the potential of locally-based approaches. Biodiversity & Conservation, 14(11), 2507-2542.

DataStream. (2020, May 27). Retrieved from https://gordonfoundation.ca/initiatives/datastream/

Eveleigh, A., Jennett, C., Blandford, A., Brohan, P., & Cox, A. L. (2014). Designing for dabblers and deterring drop-outs in citizen science. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.

Get equipped and trained. (n.d.). Retrieved from https://waterrangers.ca/act/how-to-test/water-rangers-test-kit-training/

Hochachka, W. M., Fink, D., Hutchinson, R. A., Sheldon, D., Wong, W.-K., & Kelling, S. (2012). Data-intensive science applied to broad-scale citizen science. Trends in ecology & evolution, 27(2), 130-137.

Irwin, A. (2002). Citizen science: A study of people, expertise and sustainable development: Routledge.

Jalbert, K., & Kinchy, A. J. (2016). Sense and influence: environmental monitoring tools and the power of citizen science. Journal of environmental policy & planning, 18(3), 379-397.

Janssen, M., Charalabidis, Y., & Zuiderwijk, A. (2012). Benefits, Adoption Barriers and Myths of Open Data and Open Government. Information Systems Management, 29(4), 258-268. doi:10.1080/10580530.2012.716740

Kavanagh, K. (2019, August 4). Retrieved from https://waterrangers.ca/2019/08/04/water-rangers-on-breakfast-tv-cbc-and-radio-canada/

Kim, S., Robson, C., Zimmerman, T., Pierce, J., & Haber, E. M. (2011). Creek watch: pairing usefulness and usability for successful citizen science. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.

Kosmala, M., Wiggins, A., Swanson, A., & Simmons, B. (2016). Assessing data quality in citizen science. Frontiers in Ecology and the Environment, 14(10), 551-560.

Linton, J. (2015). Water as a Social Opportunity: McGill-Queen's Press-MQUP.

Natural Resources Canada. (2017, October 30). Water. Retrieved from https://www.nrcan.gc.ca/maps-tools-publications/tools/geodetic-reference-systems/water/16888

Paul, J. D., & Buytaert, W. (2018). Citizen science and Low-cost sensors for integrated Water resources management. Advances in chemical pollution, environmental management and protection, 3, 1-34.

Preece, J. (2016). Citizen science: New research challenges for human–computer interaction. International Journal of Human-Computer Interaction, 32(8), 585-612.

Rahaman, M. M., & Varis, O. (2005). Integrated water resources management: evolution, prospects and future challenges. Sustainability: science, practice and policy, 1(1), 15-21.

Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., . . . Jacobs, D. (2012). Dynamic changes in motivation in collaborative citizen-science projects. Paper presented at the Proceedings of the ACM 2012 conference on computer supported cooperative work.

Rotman, D., Hammock, J., Preece, J., Hansen, D., Boston, C., Bowser, A., & He, Y. (2014). Motivations affecting initial and long-term participation in citizen science projects in three countries. iConference 2014 Proceedings.

Royal Bank of Canada (2017). RBC Canadian Water Attitudes Survey. In: Royal Bank of Canada Toronto, Canada.

Sheppard, S. A., & Terveen, L. (2011). Quality is a verb. Proceedings of the 7th International Symposium on Wikis and Open Collaboration - WikiSym 11. doi: 10.1145/2038558.2038565

Statistics Canada. (2019, February 20). Population and Dwelling Count Highlight Tables, 2016 Census. Retrieved from https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/hlt-fst/pd-pl/Table.cfm?Lang=Eng&T=101&S=50&O=A

Water Rangers. (n.d.). Retrieved from https://waterrangers.ca/

Wiggins, A., & Crowston, K. (2011). From conservation to crowdsourcing: A typology of citizen science. Paper presented at the 2011 44th Hawaii international conference on system sciences.

The Loblaw Water Fund. (n.d.) Retrieved from http://www.wwf.ca/conservation/freshwater/loblaw_water_fund/

World Wildlife Federation Canada. (2017). Watershed Reports: A national assessment of Canada's freshwater [PDF file]. Retrieved from http://assets.wwf.ca/downloads/WWF_Watershed_Reports_Summit_FINAL_web.pdf