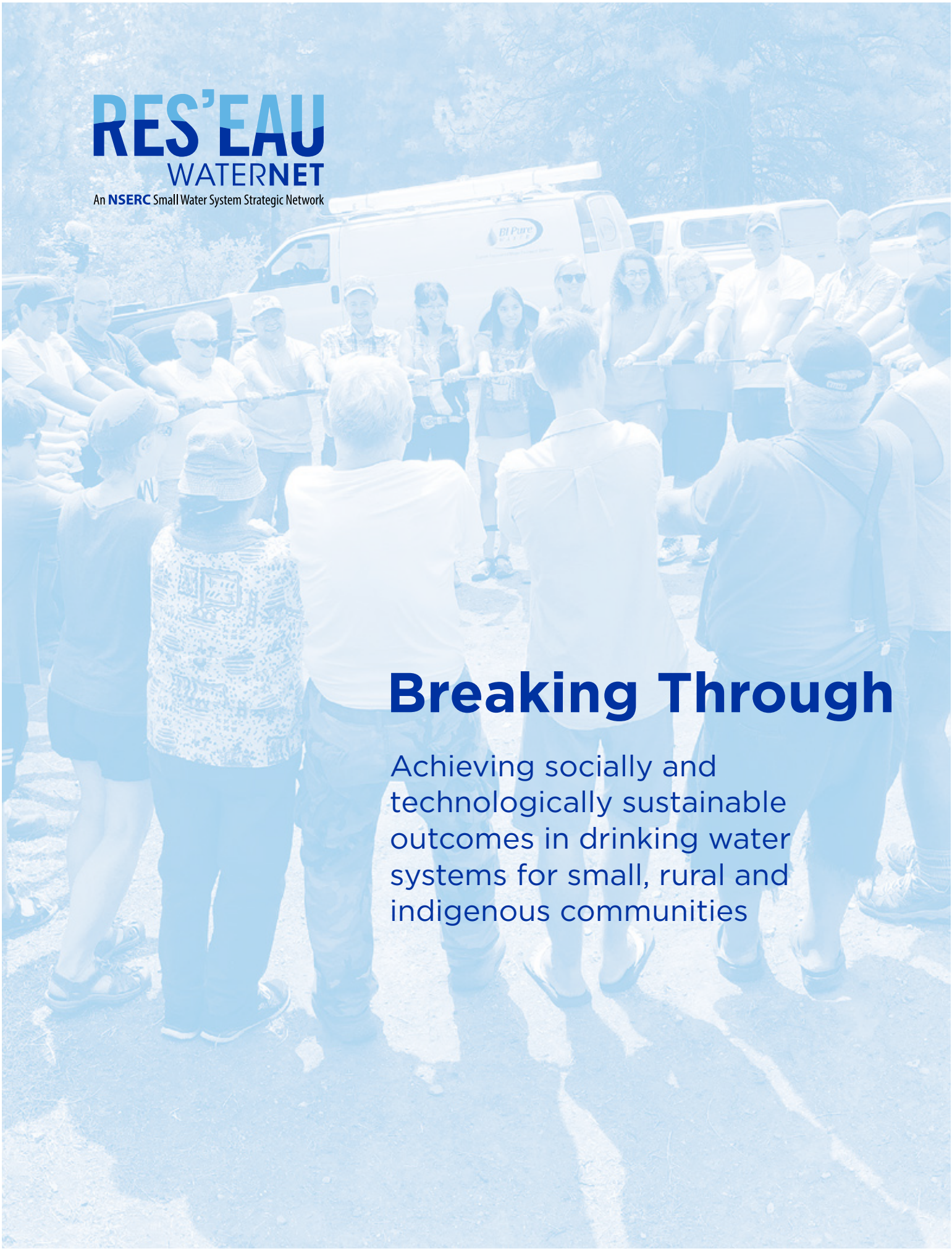
RES'EAU WATERNET

An NSERC Small Water System Strategic Network



Breaking Through

Achieving socially and technologically sustainable outcomes in drinking water systems for small, rural and indigenous communities

RES'EAU-WATERNET

is the Natural Sciences and Engineering Research Council of Canada's (NSERC) strategic response to society's changing expectations about what research and development (R&D) partnerships should deliver. Universities can only survive if they are relevant and meet community aspirations. Inventions can only become innovations when communities buy into them.

This article examines the characteristics of RES'EAU's strategic change from a product-focused R&D network (2008–2013) to a community-focused R&D network (from 2014 to present) and shows why its unique *Community Circles* problem-solving model has been recognized with awards and accolades from around the world.

Bringing together people from industry, academia and communities to solve problems.

RES'EAU is an NSERC Strategic Network working in partnership with many other public and private organizations to deliver local solutions to drinking water issues faced by small, rural and indigenous communities. We are also engaged in the development of policies in support of sustainable drinking water supply to deliver on social, economic and environmental goals. This modern multi-functional role represented a significant change from the traditional economic role of the water industry, which has historically been about technology production and economic growth (the latter arising from attracting and retaining residents and businesses thanks to improved quality of life, as well as increased economic activity among companies providing new infrastructure). The new role is more service-led, with water regarded as the life of a community.

To achieve this evolution, RES'EAU invested a significant amount of time and effort between 2009 and 2013 to transform the small, rural and indigenous community water ecosystem so that all relevant collaborators communicated and worked in a completely different way. RES'EAU increasingly signalled the need for a fundamental shift in the historical and prevailing problem-solving culture. For too long, NGOs, foundations, universities, government and industry worked in silos or near-sighted collaborations that resulted in a non-transparent, hierarchical and centralized approach that ignored and continues to ignore the realities, and therefore the needs, of the communities we serve. This ethos involved system design and economies of scale more concerned with stewardship of funds than with quality of service. The focus was on telling communities what was best for them, which created an adversarial relationship between solution providers and local communities, who felt they were on the receiving end of inappropriate, centralized decisions and unnecessary bureaucracy. The net result was to engender a culture of low trust and a prevailing "us versus them" mentality, as opposed to a more constructive, consultative approach with open communication on all sides — which we quickly learned was the path to success.

It is a fallacy to assume that reasoned argument alone can change deeply embedded assumptions rooted in collective experience built up over long periods of time. There are many instances where the technologies or processes we employ are better explained by the influence of history than by deliberate optimization. A classic example of this concept is the continued use of the QWERTY keyboard configuration for the last 150 years, a design based on avoiding jams in the metal arms of typewriters in the 19th century. To overcome assumptions and past negative experiences, a shift in the prevailing culture of all who play a role in solving complex water issues was necessary. Culture is about behaviour; we cannot have one without the other. We knew that if we didn't achieve meaningful behaviour change among all partners — communities, regulatory, suppliers, consultants, industry — we would not make progress in solving water problems for small communities.

IMPLEMENTING PARADIGM CHANGE

Economic problems faced by small communities are rooted in the complexities of knowledge sharing and utilization — no single individual or organization possesses all relevant quantitative and qualitative data required to holistically assess a complex issue. Similarly, no single individual or organization can solve the problem, and so information flow and collaboration are vitally necessary to success. In this context, the crucial problems are: What is the best method by which the knowledge that is initially dispersed among few people/stakeholders can be made as widely available as possible? And, how can the planning of solutions be coordinated?

Canada has made several well-publicized commitments to tackle these two questions toward achieving universal access to clean drinking water in small communities over the past few years, but a clear roadmap — and even consensus on what success will look like — remains elusive. Conflicting agendas and attitudes, disparate goals and baked-in biases have so far resulted in a failure to embrace the notion that issues in drinking water quality are directly connected to broader health and social challenges.

In short, the narrative has been about water, when what relevant players are really talking about, or ought to be, is community health and wellbeing. Our experience working with small communities has taught us that only the stakeholders who truly embrace this new paradigm will drive innovation.

The term "paradigm change" became trendy soon after it was introduced by Thomas Kuhn in 1962; however, the term remains the most used and least understood aspect of his book. Problem solving is based on prior achievements acknowledged by some scientific communities. These achievements are not just notable — they are what bind its members together as working in the same discipline, and those shared elements that account for the relatively unproblematic character of their professional judgement. Achievements that share these characteristics are referred to as a paradigm (i.e., a taken-for-granted assumption accumulated over time that contributes to how we respond to issues that we face). When a paradigm cannot cope with a cluster of anomalies, crisis results and persists, and the community itself will be in disarray until a new achievement redirects research and serves as the new paradigm. It often takes a long time for an anomaly to be seen for what it is, i.e., something contrary to the established order. The recognition of something as a significant anomaly that must be explained — more than a discrepancy that will sort itself out in time — is itself a complex historical event, not a simple refutation. To reject one paradigm without simultaneously substituting another paradigm would leave us in a quandary as to how we proceed with problem resolution.

FIGURE 1

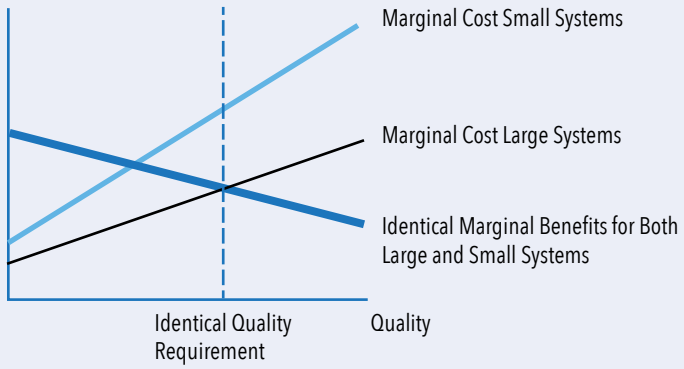
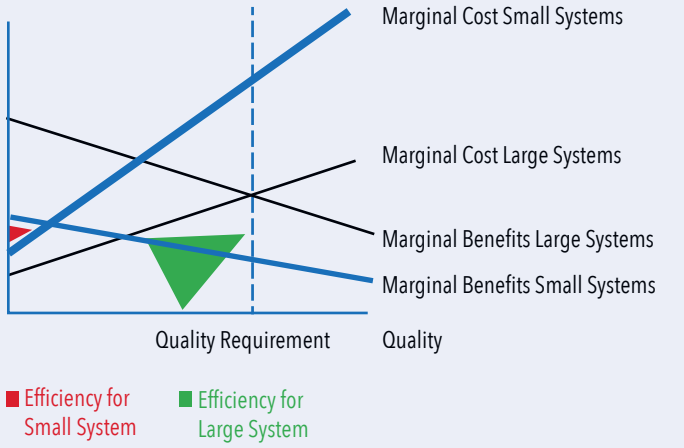


FIGURE 2



It appears that we are about to get stuck in the mud with respect to supply of drinking water to the small communities.

THE TRADITIONAL PARADIGM

For decades access to safe water and sanitation for small communities, and major provisions for dealing with this issue, have been linked to the concept of affordability. Efficiency has been defined where marginal costs (incremental to total cost associated with a unit increase in drinking water quality improvement) are less than or equal to marginal benefits (incremental to total benefits associated with a unit increase in drinking water quality improvement — in other words, willingness to pay). Consequently, broader scientific communities were encouraged to identify affordable "small system compliance technologies." If affordable compliance technologies were not available, they were to identify variance technologies protective of public health by developing clear and formal guidelines about when variances should be granted at the local level. Figures 1 and 2 depict the implication of this paradigm on small water systems compared with larger water systems. Under this paradigm, it is inefficient and inequitable for small systems to meet the same standards as the larger systems, suggesting

that relaxing the requirement for small systems may also improve efficiency and equity. The existing paradigm has its own merits and limitations.

THE NEW PARADIGM

The 2013 United Nations (UN) resolution designating safe drinking water and sanitation as a human right created a new paradigm. Under this approach, the federal government is obligated to provide financial assistance to enable communities to pay for treatment systems that ensure safe drinking water, or to compensate them for having poorer-quality water. When safe drinking water is a right, then water treatment systems are an asset owned by everyone, including people in small communities with lower income.

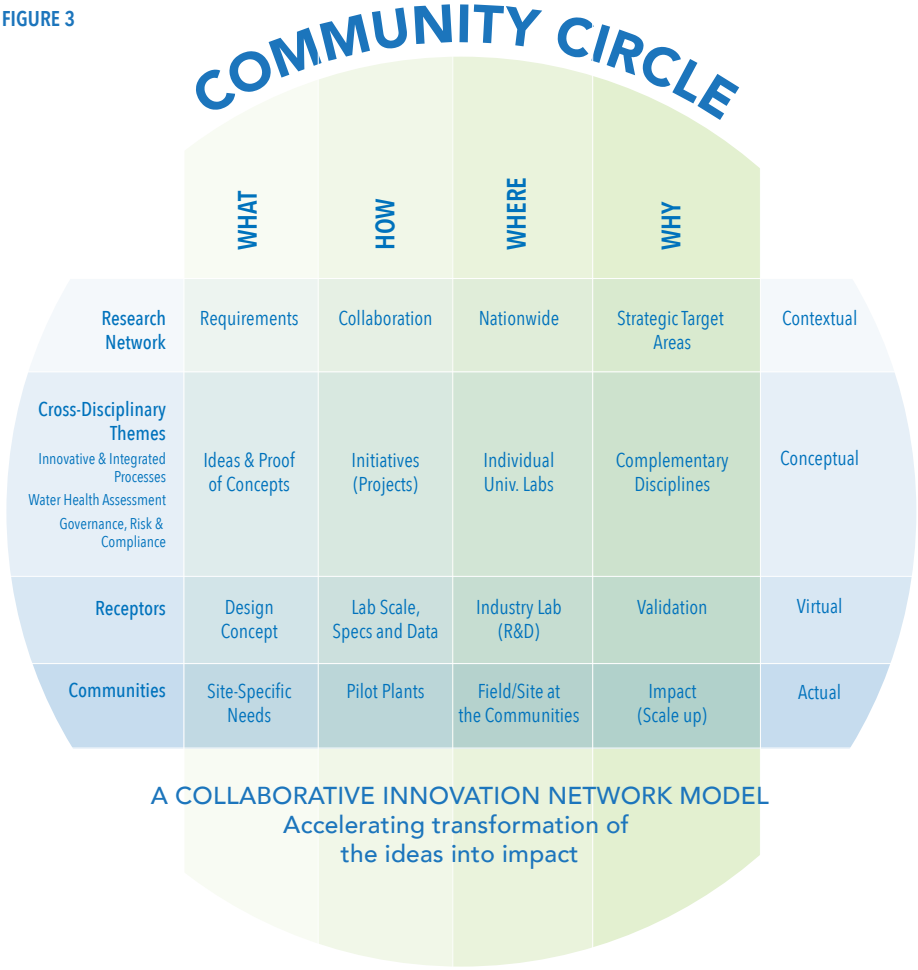
This change in property rights affects the efficiency calculation. Here, it refers to individuals' willingness to accept reduced drinking water quality — that is, the amount required to compensate them for each marginal reduction in quality. The calculations now involve marginal required compensation and marginal cost savings as functions of the reduction in drinking water quality. Efficiency is maximized when marginal cost savings from reduced use of resources for drinking water treatment equals the marginal required compensation for (or willingness to accept) reduced drinking water quality. This suggests that, all things being equal, drinking water quality is higher when efficiency is reached.

SHIFTING INTO A NEW PARADIGM

Sometimes progress toward something requires progress away from what didn't work very well.

As a signatory to the UN's declaration on safe drinking water and sanitation, Canada has created the impetus for a new innovation strategy that emphasizes taking action on community health issues in small communities.

FIGURE 3



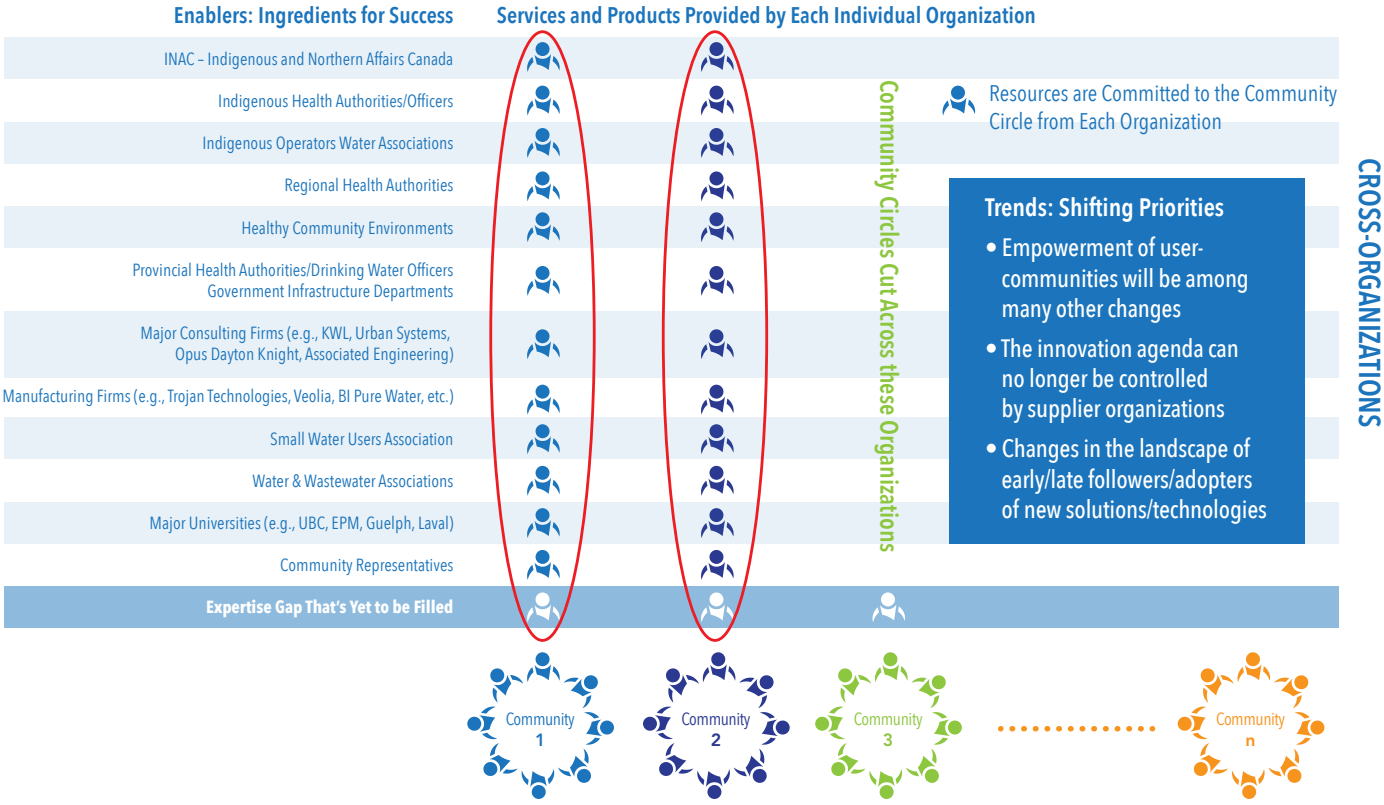
Strategy is a major preoccupation for many of us working in the water space. It links us and the small community ecosystem's concept of supply and demand, and it is meant to identify where we want to be and how we think we can get there. However, the context of national strategy is shaped by the why's — whether these policies and programs are justifiable solely to those directly affected, or whether these investments must be defended in terms of their impact on the economy, technology or another outcome that will benefit the majority of Canadians. The new paradigm calls for an innovative method for reconciling these two views.

Over the past several years, our work with small, rural and remote communities through RES'EAU has shed light on ways water stakeholders can achieve this reconciliation. The network has focused its efforts on producing new knowledge derived from the perspectives of various actors with different levels of cultural awareness (e.g., urban culture, rural culture, production culture, financial culture, indigenous culture and academic culture). This problem-solving collaboration, which we call the *Community Circle*, attempts to systematically capture and weigh all relevant considerations within the ecosystem so that decisions can be made based on a deeper understanding of the issues the *Community Circle* is trying to solve.

Under this community-centric approach, scientific, technological and academic communities play an integral role by re-examining underlying assumptions on which doubts about the viability of small water systems are built, and assesses their plausibility. Concepts such as risk, health (including epidemiological surveillance practices and understanding endemic illnesses), efficiency, affordability, acceptability, market space/profitability, economies of scale and size, demand and

FIGURE 4

EXAMPLE OF CONSTRUCTING CROSS-ORGANIZATIONAL INTERACTIONS IN THE COMMUNITY CIRCLE MODEL



the community's size must be revisited through the lens of this new paradigm. Even the definition of acceptable water quality (and which players decide and enforce it) must be reconsidered.

RES'EAU COMMUNITY CIRCLE MODEL

The RES'EAU *Community Circle* is an award-winning and globally unique precision problem-solving model for drinking water in small, rural and indigenous communities. It proposes the customization of solutions, with decisions, practices, technologies and services being tailored to the individual community.

It also works to support policies that help these communities reach their environmental and public health goals. Figure 3 illustrates how we take the research program out of the lab and into the real world, incorporating communities, operators and all stakeholders' expertise and insight at the earliest stages of the problem-solving process. Students/researchers are working closely with communities to understand the limitations and constraints they face. Together, they identify research priorities and design and execute research to produce knowledge and integrated game-changing solutions. These findings are then validated by industry so that they can be readily diffused and adopted. This approach is paving the way in defining a vibrant market space for innovative solutions specific to rural settings. These solutions will be piloted and remote in collaboration with both public and private sector partners and, according to guidelines set out by regulatory agencies, either at public sector facilities and/or subsequently in actual communities. Successful solutions will then be scaled up through partnerships with national and international strategic programs, or by industry partners.

Figure 4 outlines how participants from every part of the water community bring their individual concerns and experiences together to explore questions such as: What matters to us as users, operators,

engineers, regulators, decision makers and as a community? And why does it matter? How can we begin to create authentic connections and relationships with others, particularly across the different interests and divisions in the water community? How do we change the water community conversation from one of negotiation to one of dialogue? The aim is to develop new conversations free of the cynicism and resignation inherited from the past and to create new possibilities for a future in which everyone has a place and is valued.

It is essential to understand not only the contribution that user communities can make to innovation and how this contribution can best be harnessed, but also the potentials and constraints that exist within the private and public organizations and how realistic participatory approaches may be to implement. Established players develop particular ways of seeing and frame their interactions according to these sets of views. For instance, innovation is often simply a matter of filling a shopping list of needs from the outside. Or, players become preoccupied with the science base and novel inventions that tend to be insufficient, because commercial success is highly dependent on diffusion in the later stages of the innovation process. (Edison's original breakthrough design of electric light bulbs remained almost unchanged in concept, but incremental improvement over a decade and a half led to economies of scale.)

The *Community Circle* model suggests a number of ways to overcome the unintentional dysfunctional implications that stem from partial understanding of the innovation process by improving the dialogue among stakeholders, achieving a more balanced view of the whole innovation process. This includes the mechanisms for the development, diffusions and adoption of the benefits of innovations in the water sector.

In practice, adopting an innovation will depend on the interaction between adopters with different perceptions (or thresholds) of benefits and risk, and

We frequently add the term "remote" when we work with small rural communities.

developers with an emphasis on advantages, availability of data, feedback and reduction of barriers to use.

By placing operators at the heart of the innovation cycle and incorporating research insights at the early stages of problem solving, the *Community Circle* model cuts across the different challenges specified above. However, it is not enough to make operators aware of the need for better technologies and processes. Community members, municipal leadership, provincial/territorial and federal governments must understand the need as well, as their buy-in will ultimately influence whether or not a new technology is adopted. These additional criteria would identify institutional barriers and capture site-specific experiences that highlight successes and failures in introducing new solutions to small communities. The core value of operator/community participation in water innovation processes is now widely appreciated in academia and in some government funding organizations. Yet, industry has been slow to adopt the approach in part because it would necessitate a significant re-prioritization of how firms organize and distribute their resources, particularly with respect to gathering information about communities' needs and preferences and its application to solution development.

However, there are two main barriers in achieving the knowledge exchange necessary among all relevant partners:

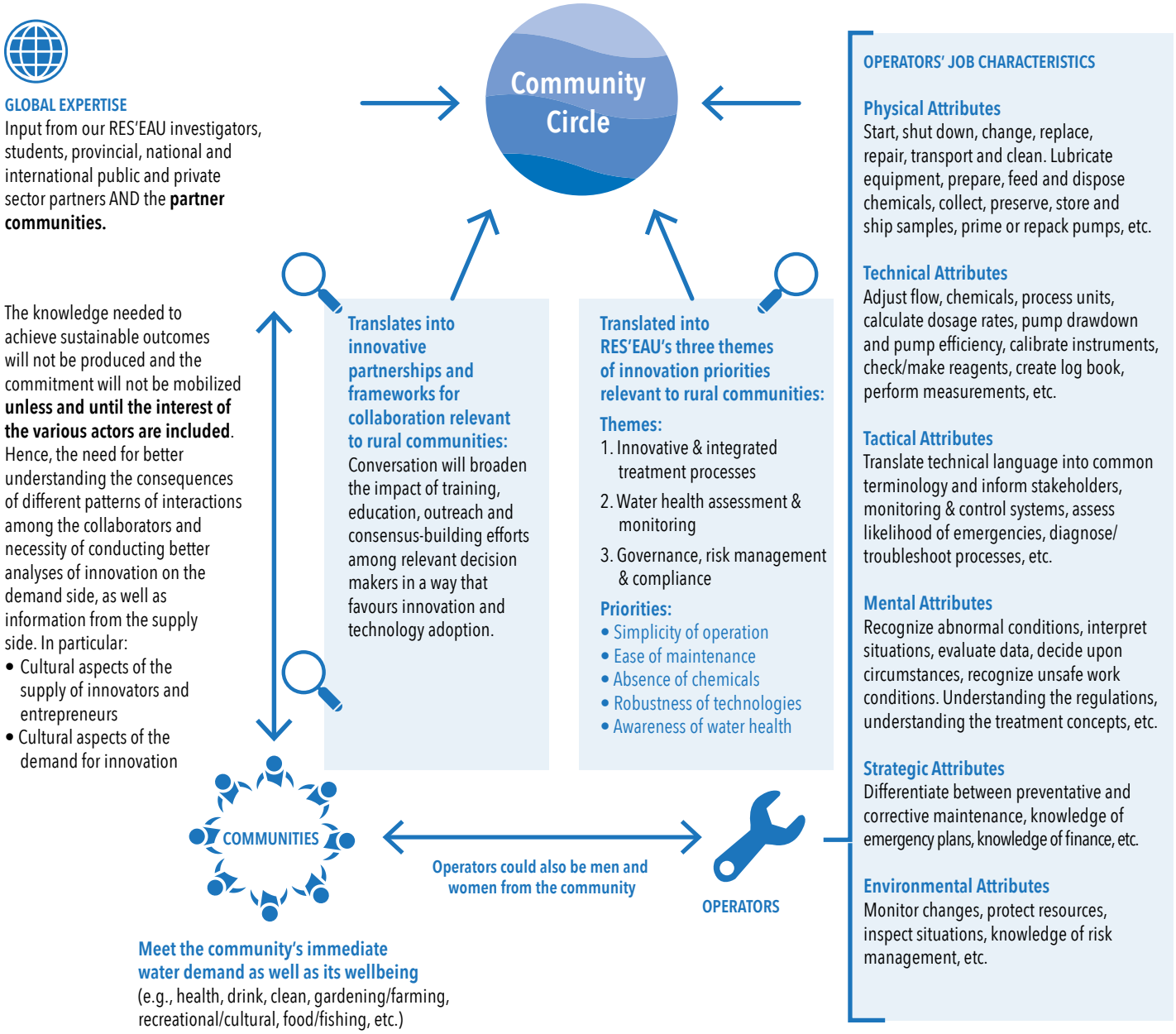
1. Lack of supporting mechanisms to facilitate participation of the operators (and end-users) at scientific and professional events and meetings that investigate water issues related to small systems; i.e., travel expense, conference registration fees and session content not being at an appropriate level have been mentioned when we discuss the matter with operators and end-users. Many operators possess the skills and tools necessary to re-design, adapt or modify the existing technologies to meet their needs. Their contributions should be viewed not simply as critics or evaluators of product but rather as co-designers.

2. Lack of a small-community-relevant sustainability metrics supporting ready buy-in by all partners for a particular solution. Traditionally, technologies are being evaluated based on the degree to which they meet specific regulations or resolve specific technological problems (e.g., removing specific contaminants) and NOT the degree they meet end-users and utility needs, especially for small communities.

FIGURE 5

FLOW OF INFORMATION IN THE COMMUNITY CIRCLE ECOSYSTEM

Achieving Socially and Technologically Sustainable Outcomes for Small Water Systems



CORE COMPETENCIES

- Uncovering and exploring unarticulated needs of the communities;
- Understanding both technological aspects of the solution products as well as behavioural, allowing people to adapt to these solutions and ideas; and
- Create new solutions, removing situational and conceptual barriers to effective knowledge and technology translation by harnessing opportunities in:
  - Economies of Scope,
  - Complementaries and
  - Experience Curves.

The *Community Circle* model — through building new partnerships, providing opportunities for the various parties to meet, creating dynamic participation, ensuring that there are shared topics to relate to — enables designers to question the taken-for-granted assumptions embedded in the conventional problem-solution management frameworks. The model not only acknowledges the implicit importance of questions such as, "Who should be consulted? How to engage with them to maximize their contribution? How to translate their insight into products?" but also recognizes underlying questions concerning, "How do we involve different public and private organizations without limiting their areas of control and expertise? How does the *Community Circle* approach become championed within their organizations?" The deployment of the *Community Circle* model is itself often an exercise in organizational change, bringing diverse stakeholders together who sometimes challenge each other with very different perspectives on the issues. There is not always a short-term commercial gain from its use, particularly if viewed solely in terms of economic metrics. The fieldwork and piloting involved in the *Community Circle* model is not a question of one particular technology; it is best described as a way to draw fresh conceptual boundaries that enable us a brief look at how other people and cultures might view the world. With actors' minds as open as possible to put themselves where they can be as surprised as possible, only then they are able to see beyond their taken-for-granted, unarticulated conceptual distinctions, providing the most comprehensive understanding of the contexts of use in small communities.

Automated systems are most effective during normal operation. When it comes to their trouble shooting, often manufacturers' support staff become the operator/user of these systems, reading, adjusting, installing, connecting, replacing, servicing, cleaning, etc. To prepare for these unexpected situations we have to think about the relationship between the technology and the operators' physical and mental practices. Operators in small communities see, touch, feel, hear, smell, walk in the field and often act on hunches working around the system, and it is crucial for them seeing the process as a whole, not to just rely on technologies or by sitting in the control rooms. Hence the solutions should be structured carefully using the operators' point-of-view.

Marking the completion of a new water treatment plant for a Community Circle partner in BC.

Figure 5 outlines how operators' six general performance components relate to the network's three research themes. It is virtually impossible to isolate each subcomponent from the others when it comes to operating, diagnosing and solving any problems in water systems. However, separating them for the purpose of providing more details as to how each theme empowers operator performance makes the concept more easily understood. For the sake of simplicity, the timeframes and operators' ability/certification level at which each component becomes seriously stressed have been omitted.

SCIENTIFIC RESEARCH AGENDA AND PROTOCOLS

Our research focus is on achieving breakthroughs in engineering, chemistry, genomics and the social sciences that can be applied to water health monitoring and treatment technology development, as well as novel approaches for addressing microbial and chemical contamination, algal toxins and taste and odour compounds.

The network is a five-year, $8 million+ program, with 40% funded from partnerships involving over 20 public and private organizations, and with 60% funding from NSERC. Our R&D team includes world-class scientists from multiple universities across Canada and the United States, supported by more than 100 students and post-doctoral fellows. In addition, the program leverages over $5 million in human and technological capital from dozens of public and private partners to support the implementation of the *Community Circles* model.

RES'EAU capitalizes on its expertise to continue the acceleration of innovation and the provision of treatment solutions to end users in small communities. RES'EAU's multidisciplinary, impact-focused approach to networked R&D focuses on three inter-related themes:

Theme I: Innovative and Integrated Treatment Processes

Research focus: Robust, passive and effective treatment technologies capable of addressing primary contaminants (pathogens and disinfection by-products [DBPs]) along with other emerging contaminants (e.g., algal toxins, taste and odour compounds, pesticides and micropollutants).

Outputs: Innovative UV-based technologies (vacuum UV and LED UV), ion exchange (IX), electrocoagulation (EC) and ferrate oxidation, as well as techno-economic analyses and life-cycle assessments (LCA) of the technologies in a small systems context.

Promise: Treating a broader range of contaminants while adhering to: simplicity of operation, ease of maintenance, absence of chemicals, robustness of technology and awareness of water health.

Impacts: The proposed projects span early-stage research through to pilot- and field-scale demonstration, resulting in new/improved products for the Canadian market. These technologies will be more sustainable than current approaches in terms of energy use, maintenance, operation and disposal of residues.

Theme II: Water Health Assessment and Monitoring

Research focus: Delivering technologies to monitor the presence of microbial and chemical adulterants (as well as their source) to improve source water quality management in SRCs. Microbial and chemical contamination of source waters remains a pervasive risk to human health, and SRCs in particular struggle to manage vulnerable water sources while operating small or independent treatment and distribution systems.

Outputs: Robust, multiplexed platform for accurate detection of microbial adulterants and source tracking, along with in-line technologies that rapidly monitor pre- and post-processed waters that are either routinely or intermittently contaminated from one or more sources.

Promise: Predictive and forecast models, real-time rapid detection of contaminants, automated sensing of total organic content of water and continuous measure of chlorine content in water.

Impacts: These technologies will be transformative in their ability to instill confidence in the quality of water available in SRCs, and will provide critical information relevant to risk and vulnerability assessments of water supplies. These advances could lead to a more rational approach to protecting source water quality across Canada.

Theme III: Governance, Risk Management and Compliance

Research focus: Methodologies and decision algorithms to assess risks and vulnerability of small water systems, understanding how technical and social issues of multiple barriers are incorporated into water safety plans and understanding governance barriers to adoption of innovative solutions in SRCs.

Outputs: Policy notes and guidelines on barriers and opportunities in small system governance and improved water safety plans adapted to the realities and constraints of small water systems, developed through extensive consultation with user communities.

Promise: Optimization residual disinfectant, water safety plans, risk-based quality management and assessment of governance and priorities.

Impacts: These methodologies will include a holistic understanding of the state-of-the-art current practices and constraints that small systems face, while identifying their capacity to incorporate innovative strategies to distribute safe water.

Each research theme is integrated at each partner community, involving several research areas from treatment technologies, sensing and monitoring, risk assessments and water safety plans to social issues and community health. Our approach focuses not only on operators, but also on the role of community leaders in setting out strategies for sustainable operation and maintenance (O&M). Woven through this process is a passionate commitment to students — from undergraduates to post-doctoral fellows, across many disciplines — who participate at every level of a *Community Circle*. Our students are consistently top performers, presenting award-winning posters and talks at nationally and internationally renowned scientific conferences. Their experience with the network takes them out of the lab and into the field, where exposure to real-world challenges and to a wide range of people and organizations working on behalf of small communities brings their training to a new level.

Each theme mixes fundamental and applied research while emphasizing the mobilization of "ideas to impact," while all relevant players/partners in the network work to stimulate adoption and sustainability. The ultimate goal is to develop new solutions for small and rural communities by creating mechanisms for better understanding and model site-specific barriers and interventions. Models are evaluated for their predictive quality for sustainability in realistic settings.

SCIENTIFIC RESEARCH PORTFOLIO SUMMARY

Ultraviolet (UV) and Vacuum UV-Based Projects

1. Laboratory and pilot scale evaluation of VUV advanced oxidation process for the degradation of micropollutants: Objectives: i) Investigate the effects of water temperature and background organic and inorganic solutes on the kinetics of VUV AOP, ii) develop and experimentally validate computational fluid dynamics models for the design and optimization of VUV photoreactors and iii) evaluate the prototype/pilot VUV reactor under various flow rates and water quality conditions for the removal of model micropollutants.

2. Removal of cyanobacterial toxins from surface water using vacuum UV:

Objectives: i) Investigate the degradation of cyanobacterial toxin microcystin-LR (MCLR) using the VUV process; ii) study the effect of water matrices, particularly natural organic matter (NOM), on the degradation kinetics of MCLR in natural bloom water; and iii) examine the impact of Vacuum UV on cyanobacterial cell structure, and the potential to release and treat intracellular toxins in addition to extracellular toxins. Results show that the target microcystin is completely degraded, and that the impact of water matrix constituents, such as organics, alkalinity, chlorides and sulphates with UV doses below 200 mJ/cm^2, is negligible. Tests were conducted in batch and continuous flow reactors using both synthetic and natural waters.

3. Biological stability of surface water during the VUV process:

Objective: Determine the changes in biostability of VUV-treated surface water. The biostability has been assessed quantitatively by measuring assimilable organic carbon (AOC) changes in raw and treated water, biodegradable dissolved organic carbon and disinfection by-product precursor measurements. Tests were conducted at lab scale using both batch and continuous flow reactor approaches, and at pilot scale. As a mitigating step to improve biostability, biological activated carbon treatment is applied downstream of the VUV process, reducing the AOC.

4. Effect of water matrices on the formation of nitrite in nitrate-containing water during the VUV process:

Objective: Study the effect of water matrix (organics and inorganic solutes) on nitrite formation during the VUV process, and to develop a detailed understanding of the mechanism and pathway of nitrite formation from nitrate. Investigating and developing an understanding around the effect of organic carbon, inorganic carbon, sulphate and chloride on facilitation of the application of VUV in water treatment, particularly for surface waters containing nitrate.

Engaging and training tomorrow's water professionals with expertise in small systems.

Collaboration among the public, the private sector and communities in the co-creation of water solutions.

Electrochemical (EC) Processes for Groundwater and Surface Water Treatment and Organic Matter Removals

1. Scale-up of a continuously operating iron EC process, from 1 L/min to 10 L/min, while evaluating the technologies effectiveness for removing NOM from both synthetic and raw surface water:

EC experiments began at a bench-scale (1.35 L/min and 5 L/min) in the laboratory using synthetic surface water and a humic acid surrogate (in place of NOM). Upon completion of bench-scale experiments, flow rate was increased to 10 L/min and integrated into a pilot-plant at Van Anda Improvement District (Texada Island, BC), treating the community's drinking water supply.

2. Determine the current density distribution on electrodes' surfaces in the EC reactor to understand the mass transport limitations and how to improve the EC reactor design:

Experiments were directed toward understanding the electrical current distribution on the electrode surfaces during EC operation using the partial

electrode method. Additionally, computational fluid dynamic modelling of water flow through the EC reactor was used to further understand and complement the experimental results for the EC reactor. This information will allow further improvement of a pilot scale EC reactor.

These project milestones demonstrated that a large variation in current distribution exists, a phenomenon overlooked by prior EC research. This knowledge provides impactful insight into EC reactor design and efficiency and a realistic image of operating current densities, as well as an in-situ process by which future researchers can determine current distribution during an EC process. The understanding developed from this work will allow an improved EC reactor design for small-scale water treatment.

Ion Exchange and Biological Ion Exchange Projects

1. Removal of microcystin from surface water by anionic ion exchange:

Objective: Investigate the efficiency of a strongly basic anion exchange resin for the co-removal of MCLR and NOM. Project-specific objectives include:

- Study the uptake mechanism of microcystins by IX resins.
- Investigate the influence of environmental factors, such as pH, NOM characteristics (concentration, charge density and molecular weight distribution) and other anionic species (sulphate, nitrate and bicarbonate) on kinetics and uptake capacity of IX resins.
- Evaluate the impact of multiple loading cycles, optimization of resin regeneration process and investigation of toxin degradation in brine.

2. Biological ion exchange for the removal or organic contaminants:

Objective: Investigate the removal of NOM using a packed as well as continuously stirred tank ion exchange contactor under biotic and abiotic conditions. Investigate the advantages associated with microbial communities grown on ion exchange resins. Project-specific objectives include:

- Explore the effect of using resin continuously in biological mode (i.e., without regeneration) on the quality of treated water.
- Test the performance of biological IX resin at pilot-scale on turbid (5-10 NTU) and coloured (6-8 mg C/L) surface waters.
- Quantify and compare the performance of biological ion exchange and biological activated carbon.
- Investigate the presence of microorganisms and potential biodegradation of NOM during the anionic ion exchange using packed as well as continuously stirred tank contactor.
- Examine applicability of using spent brine in resin regeneration.

3. Removal of NOM from surface water by combined electrochemical and filtration processes:

Objective: Design combined electrocoagulation and ultrafiltration (UF) process for NOM removal. Evaluate NOM removal, energy intensity and floc/particulate separation. Project-specific objectives include:

- Develop lab-scale setup for hybrid EC/UF process to evaluate its application to NOM removal from surface water.
- Investigate process feasibility and performance in terms of NOM removal, energy consumption and membrane flux capabilities.

Novel micro-scale sensors for free chlorine measurement in water treatment plants and distribution systems

1. Removal of NOM novel micro-scale sensors for free chlorine (Cl) measurement in water treatment plants and distribution systems:

Objectives: To investigate and develop i) Low-cost free Cl and pH sensors — easy-to-use with high sensitivity, fast response and high stability using low-cost manufacturing technologies; ii) reference electrodes for integrated sensors; iii) low-cost integrated sensors for drinking water quality monitoring systems; and iv) filtration modules to minimize sensor biofouling and prolong sensor lifespan.

The principal goal of our work in this area is to develop low-cost, easy-to-use, high-sensitivity, fast-response and long-lifetime sensors for drinking water quality monitoring. These are key features of any sensor system for use in resource-limited areas where small systems are found.

2. Pencil lead-based free Cl sensor:

Our current Cl sensor configuration requires no reference electrode and mixing, so it is an easier-to-use version for small communities. Sensors were tested in very high ppm interfering salts, and have low ppm (0-6) monitoring range for drinking water. Now, we are making the design and usage simpler for practical manufacturing and routine use. We have an industry collaborator pursuing large-scale manufacturing of this sensor.

3. Hand drawing of low-cost free Cl sensor:

We have developed a room-temperature-based Cl sensor that requires no instrumentation or equipment, and can be made by untrained personnel. The fabricated sensor is mechanically stable, reusable, has a wide sensing range (0.5-500ppm) and can accurately measure free Cl concentrations in real water samples. This sensor is of great significance for water quality monitoring in less developed areas where fabrication facilities, analytical equipment and trained personnel are limited, but where the need for analytical devices is critical. It can be used in small systems for periodical monitoring of treated drinking water. It provides a method for individuals to monitor free Cl in their drinking and swimming pool water.

4. Inkjet-printed temperature sensor:

Using the same materials and fabrication processes as a pH sensor we developed, this temperature sensor has high sensitivity and fast response, and is used to compensate pH and free Cl sensing signals to increase accuracy. Temperature sensing range is 0°C to 50 °C, covering most situations in Canada. It is very cost effective and easy to manufacture.

5. Electrochemical sensing of acetaminophen (APAP) using multi-walled carbon nanotube and β-Cyclodextrin:
We are developing voltammetry sensors using a simple sonication technique. Fabricated sensors are stable with wide sensing range (0.05-300 µM of APAP), and can measure APAP in real water samples. We are now developing a low-cost potentiostat for integration with sensors into a hand-held device using disposable, cheap sensor electrodes for monitoring of APAP in drinking water. Sensors provide a method for water authorities in Canada to monitor emerging pharmaceutical contaminants in drinking water at low cost.

Projects on Residual Disinfectant Management in Distribution Networks

Objectives: Research in this area is designed to generate knowledge and tools that support decision makers responsible for small water system management. Outputs will include: i) Elaboration of a guide, projects on residual disinfectant management in distribution networks and fact sheets directed to small systems on the best management strategies for the operation, the conservation and the manipulation of CI solutions; ii) dissemination of results within three reports (reviewed publications) for a) the operational management of hypochlorite solutions in treatment plants of small systems, b) the evaluation of contaminants in chlorine solutions and drinking water associated to the use of hypochlorite in secondary disinfection and c) the review of the presence and modelling of emerging DBPs in drinking water; iii) the development of optimized strategies for the conservation of samples for the analysis of regulated and emerging chlorination by-products; iv) the development of analytical techniques for the analysis of new disinfection by-products (iodinated, aldehydes) to transfer the knowledge for research on small systems; v) the development of a relational database that incorporates the spatiotemporal data on disinfection and disinfection by-products generated in RES'EAU phases 1 and 2 (experimental data and field data from municipal small systems); and v) the development of a framework for the optimized use of residual disinfectant data for decision-making regarding water quality in distribution networks of small systems.


Building an understanding of a community's challenges requires frequent and open communication.


Testing possible solutions on the ground in a small community using actual source waters.

Governance, Risk Management and Compliance – Decreasing Vulnerability through Positive Action

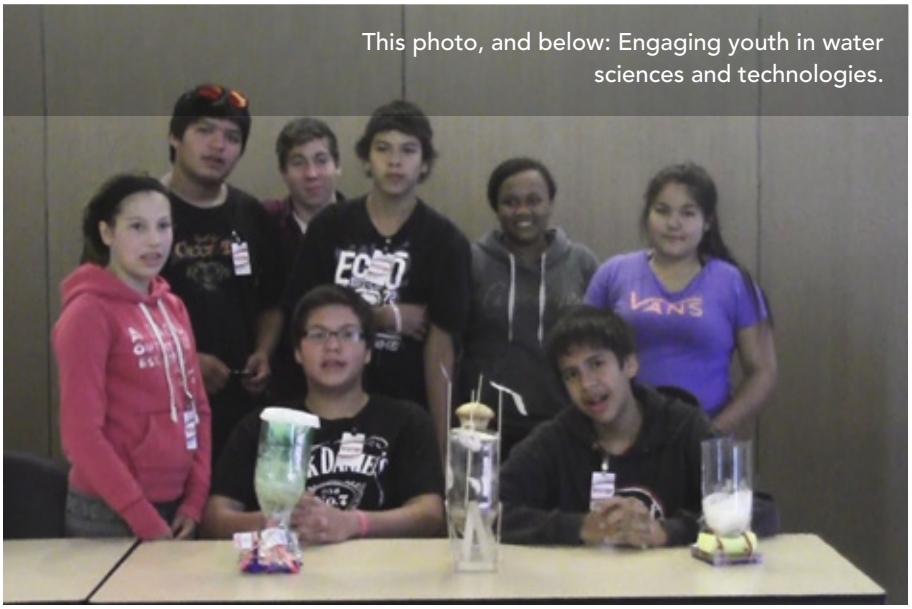
The focus of these ongoing projects has been characterizing the vulnerability of drinking water systems and building capacity (personnel resources) and technical capabilities in positive ways to reduce the vulnerability. This is being approached from many directions, including:

1. Developing improved water safety plans to improve assessment of potential for a water system to fail to deliver safe water:
Many communities lack the technical and financial capacity to develop water safety plans. Strategies are being investigated to assist in the development of water safety plan methods and strategies that are feasible for use for SRCs.

2. Improving capacity building in the First Nations communities by working with members of the communities themselves (e.g., youth):
We have learned that First Nations' youth are very eager to learn, and can be highly motivated by having potential career paths explained. The goal of the RES'EAU's youth engagement strategy is to engender in high-school-aged youths i) an understanding of the challenges that small and remote communities must overcome to provide a safe, sustainable supply of drinking water; ii) an appreciation of the multiple scientific disciplines (the combination of engineering, natural and social sciences) involved in developing treatment processes to address these issues; and iii) an interest in pursuing higher learning and careers related to water care.

3. Identifying strategies that can be used to improve capacity:

As an example, we are working to identify the attributes associated with drinking water advisories (DWAs) to allow focused efforts to decrease vulnerability. Here, our work using data mining has established that communities without adequately trained operators are more prone to having DWAs. Also, when a DWA is issued, a well-trained operator is better able to resolve the issue quickly. Many of the DWAs that have been issued are precautionary, which doesn't necessarily mean that the water being supplied is compromised, just that it might be. The project is working to identify strategies to separate the precautionary DWAs from those that are cause for immediate concern, using real-time monitoring.



This photo, and below: Engaging youth in water sciences and technologies.

CASE STUDIES AND ONGOING *COMMUNITY CIRCLE* PROJECTS

1. *Development of a Strategy on the Cost-Effectiveness of Point-of-Entry Solutions for Small Drinking Water Systems with Full Participation of Homeowners* (partnerships with Lytton First Nations, INAC, FNHA, Trojan Technologies, VIQUA, HomePlus, FN's OWN BC & YT and UBC):

Status: Two First Nations reserves in British Columbia (IR3 Spintlum and IR11 Yawaucht in the Lytton First Nations) celebrated the lifting of long-standing boil water advisories (BWAs) in 2017 using the *Community Circles* approach. The project united the efforts of several partnering organizations including the First Nations Health Authority, Indigenous and Northern Affairs Canada, the First Nations' Operators Water Net for British Columbia & Yukon Territories and private manufacturing, consulting and contracting firms. They worked closely throughout the fourth quarter of 2016 with the Lytton First Nations leadership, dedicated water operators and residents, to assess the feasibility of point-of-entry (POE) systems to meet site-specific needs of individual systems (those serving fewer than five homes).

These systems were not included in the national assessment conducted by INAC between 2009 and 2011.

A community expresses its gratitude with symbolic gifts during a celebration of its *Community Circle* project.

Specifically, the pilot program sought to determine the circumstances under which a POE approach would be cost effective compared with other alternative treatment options. The team will continue to identify site-specific considerations that could impact the system's effectiveness, such as water quality variations, water demand, pilot test protocols, public education, technology selection, installation, operations, monitoring plans, liabilities, capital and O&M costs and logistic and administration strategies.

By the end of 2016, new POE systems were in place, and the BWAs were lifted in January 2017. Follow-up work to assess the community's satisfaction and collaboration with the residents and operators to monitor system performance and O&M costs are ongoing.

Information and data gathered during this period will help to determine if POE systems are a robust, cost-effective solution for small, remote communities where a centralized water system would be cost prohibitive.

2. Lifting of Long-Standing BWAs at in Nickeyeah (IR25) (partnerships with Lytton First Nations, INAC, FNHA, KWL, BI Pure Water, Lillooet Contracting, University of Guelph, Université Laval and UBC):
Status: Completed in 2015. This project is summarized in the following online documents:

https://www.youtube.com/watch?v=F-W6IvO6EE5w&feature=youtu.be

http://www.reseauwaternet.ca/lytton-first-nation

http://journalofcommerce.com/Projects/News/2017/5/Modular-treatment-system-ends-water-advisory-at-Lytton-reserve-1024062W/

http://www.lyttonfirstnations.com/files/1314/1805/7277/December_2014.pdf

3. Evaluating Water Treatment Solution for the City of White Rock (partnerships with the City of White Rock, BC, Fraser Health Authorities, Kerr Wood Leidal, BI Pure Water, Polytechnique Montréal, UBC):
Status: Assessments of efficacy were performed in June 2017 on various treatment methods, where a combination of different processes and their removal efficiency were studied and compared in order to optimize their performances. Read a project summary here: http://www.reseauwaternet.ca/white-rock-bc-11-28-2016


Installing a new system in an indigenous community in BC.


One of the network's Mobile Water Treatment Pilot Plants on location.

4. Evaluation of Various Drinking Water Treatment Solutions for Van Anda Improvement District (VAID) (partnerships with VAID, Vancouver Coastal Health, BI Pure Water, University of Guelph, Université Laval and UBC):
Status: Feasibility and assessment were completed in 2017.

5. Cowichan Valley Reginal District: i) Characterizing and Modelling Impacts Of Climate and Land Use Variability on Water Quality in the Shawnigan Lake Community Water System and Watershed; ii) Regional Surface and Ground Water Management and Governance Study; and iii) Evaluation of Novel Technologies for the Treatment of Shawnigan Lake Water (partnerships with CVRD, VIHA, Veolia, UVic, Université Laval, Polytechnique Montréal, UBC):
Status: Completed in 2015.

6. Dzit'lain'li (Middle River) IR9 Water Treatment Upgrade (partnerships with Tl'azt'en First Nations, Dzit'lain'li, INAC, FNHA, FNOWN BC&YT, Opus International, Université Laval and UBC):
Status: Feasibility study completed in 2017.

7. Investigating Options for Drinking Water Improvement of Towinock (IR2) and McCartney's Flat (IR4) Under the Administration of T'it'q'et (partnerships with T'it'q'et , INAC, FNHA, Urban Systems, and UBC):
Status: Preliminary study in progress.

8. Determining Alternative Drinking Water Source and Treatment Options for Lhoosk'uz Dené Nation (Kluskus First Nations) (partnerships with Lhoosk'uz Dené Nation, INAC, FNHA, FN's OWN BC & YT, Associated Engineering and UBC):
Status: Lake water balance study completed in 2016. Groundwater assessment is in progress.

9. ʔaq'am Community Water System Upgrade – Feasibility of POE Systems at Two Reserves (partnerships with ʔaq'am, INAC, FNHA, Opus International and UBC):
Status: Preliminary study in progress.

10. Streamlined Approach to Implementing Disinfection (SAID) (partnerships with INAC, KWL, FNHA, Opus International, Urban Systems, AE, Trojan Technologies, Small Water Systems Associations, FN's OWN BC & YT, Fraser Health Authorities, BI Pure Water, Health Canada, BC Ministry of Health, Université Laval and UBC):
Status: A technical assessment of questionnaires and checklists was piloted, tested and completed in 2017.

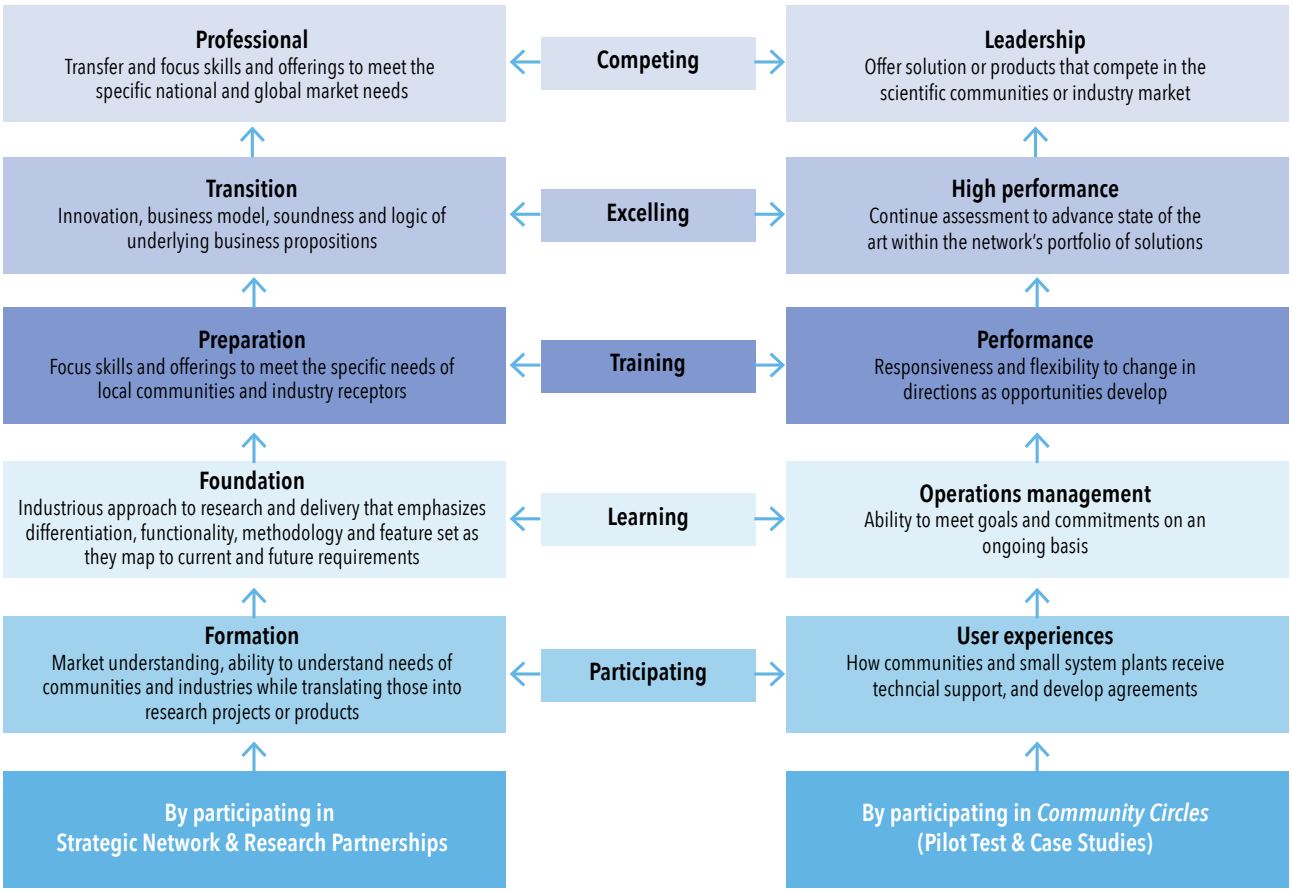

More youth engagement at UBC.


This photo and below: Giving voice to communities' needs shapes the *Community Circles* process.

DEVELOPMENT OF HIGHLY QUALIFIED PERSONNEL (HQP)

Our HQP development plan for graduate students, PDFs and research associates/assistants is outlined in Figure 6 on page 16. Upon completion of their studies, RES'EAU's HQP have been uniquely prepared for a career in the water profession. They will be equally employable in positions in industry and academia, and will serve as ambassadors of the spirit of cooperation between industry and academia that advances Canadian innovation. Our individual researchers have a track record of providing excellent training opportunities for HQP, many of

FIGURE 6: HQP DEVELOPMENT PATH



whom have been recruited by industry, including our partners such as Veolia, Trojan Technologies, Kerr Wood Leidal, BI Pure Water, Urban Systems, Associated Engineering, Opus International, Assembly of First Nations and many other public and private organizations. More than 150 HQP will have been trained by 2018.

YOUTH OUTREACH

The *Community Circles* approach has identified the need to generate meaningful communication within the communities we engage about solving their water challenges, the value of the project to stakeholders and the wider community and building community support for the collaborative project. Engaging youth in these communities through the promotion of the various scientific disciplines related to sustainability and drinking water is an important part of establishing long-term community buy-in.

Examples of RES'EAU youth programs include:

Workshops for First Nations' youth, carried out along with Walkerton Clean Water Centre, to improve awareness of youth in relation to water care and the importance of water security:
A three-day workshop held at the Walkerton Clean Water Centre in Walkerton, ON. Attendees are given a tour of local water treatment systems to understand how water moves through a community. Afterward, a sacred water ceremony is performed, which helps to bridge the divide between traditional and western knowledge. The youths then participate in a fieldtrip to a wastewater treatment plant, improving their knowledge of water handling. Presentations are made on wastewater treatment and the Walkerton incident, giving the youths the chance to learn about the repercussions of untreated or improperly treated water. They also learn about the science and engineering principles behind drinking water treatment, and have guest speakers discuss careers related to water quality.

First Nations' youth video documentary project:
RES'EAU piloted a unique project in Nlaka'pamux territory with the Lytton First Nation via our *Community Circles* framework. Partnering organizations on the project included Nlaka'pamux Nation Tribal Council/ShchEma-mee.tkt Project, Stein Valley Nlaka'pamux School, Lytton Elementary School and Hannah C/Reel Youth Productions.

The goals of this project were to i) engage Lytton First Nations youth to learn about their local water situation, the Nickeyeah IR 25 Project and the broader RES'EAU program; ii) promote the importance of and respect for water quality and management toward increasing community awareness of water sources and

treatment technologies in place that benefit BC communities; and iii) inspire youths to pursue water-related careers.

Fourteen local teens took part in the program. Participants first attended an engagement/project information session with Lytton youth. A full-day workshop was then held for youths to learn about their local water situation, the Nickeyeah IR 25 Project and the broader RES'EAU program. Next, a guided tour of the local watershed and treatment plant was held to provide insights about the challenges of water management and sustainability. Finally, the youths were trained on how to use video cameras, sound recording equipment and video editing software to summarize their experience and learning through the creation of short videos about the community's attitude toward water and the new treatment plant that was being installed. Participants filmed interviews with community members about their opinions on water and the new plant, as well as engineers who were on hand for its delivery and installation. They also captured an important lesson about how even the most carefully planned scientific and engineering project can go wrong with a simple miscalculation or oversight — the treatment plant and the flatbed truck delivering it exceeded the maximum weight capacity of the local ferry. Delivery was delayed for several days until a larger ferry could accommodate the transfer across the river.

One of the videos produced in the program is viewable here: https://www.youtube.com/watch?v=xuXI5UM-i93Q&feature=youtu.be

Water in a Truth and Reconciliation Commission of Canada context:

Since the release of the Truth and Reconciliation Commission of Canada's (TRC's) 94 calls to action, RES'EAU has accelerated collaborations with public- and private-sector partner organizations. Together, we share a common goal — repairing the harm done to drinking water ecosystems attributable to numerous social and economic inequities that First Nations face.

To test our collective understanding of the UN Declaration on the Rights of Indigenous People and the TRC's work as it relates to water, we recently sought the perspectives of local leaders and community members, including professionals and researchers, who influence the implementation of sustainable healthy water solutions within First Nations' communities. The result of these efforts became *Water: The Life of a Community*, an ongoing series of workshops focusing on indigenous people's relationship with water. The results of these discussions will inform the evolution of RES'EAU's *Community Circles* approach to innovation.

A summary of these events will be available in fall 2017. One comment sums up the prevailing lessons learned from the discussions:

"*There are many people who are part of this water community that we have been talking about. The private sector needs to remember that these are real people with families who need to be understood, and heard… And then we have the public sector, and they move at the opposite speed (of business) sometimes — [we need to] balance out the two so they can work together. The community itself needs to remember that there are people that are out there that are willing to help us — to accept them into our community and to be ready to accept that change. We need to hold on as strongly as we can to our language, our culture, our understanding of who we are as a people from the past, but we need to always be ready to adapt and change and move into the future…*" — *Chief Joe Pierre, Ktunaxa Nation.*

RES'EAU'S IMPACT TO DATE

Network investigators have published more than 150 papers in peer-reviewed journals, trained more than 150 HQP and conducted proof-of-concept tests toward the commercialization of several emerging technologies, such as electrocoagulation, vacuum UV, ion exchange and more. Collaborations also grew beyond Canadian borders to include American, Japanese and European partners.

To date, RES'EAU has worked successfully with more than 10 small communities in British Columbia to implement innovative drinking water solutions. Our teams are currently on the ground in six communities performing consultations and proof-of-concept tests. These technology trials are often conducted using one of RES'EAU's state-of-the-art Mobile Water Treatment Pilot Plants, which are equipped with several water treatment technologies, including filtration, ion exchange, activated carbon adsorption and both conventional and vacuum UV. The mobile units are designed to evaluate these processes individually or in combination using a community's actual source waters, often faster and at greater savings versus other methods of technological evaluation.

The *RES'EAU Community Circles Model* was recently honoured with the 2017 *Excellence and Innovation in the Water and Waste Industry Award* from the BC Water & Waste Association. The award recognizes innovation and excellence that advances the water and waste industry in BC and the Yukon. Recipients are selected by an industry judging panel.

Along the way, we:

- Helped to transform the perception of SRCs' drinking water problems from a poorly understood issue of low national priority to a high priority that is economically viable.
- Streamlined market demand by capturing communities' needs, expectations, preferences and dislikes.
- Positively influenced communities' perceptions about the benefits of collaborating with academia (e.g., community outreach, youth education and engagement programs).
- United communities and operators in the solution development process.

- Built strong partnership with First Nations Operators Water Net of BC and Yukon.
- Performed/performing proof of concept for several innovative treatment methods suitable for small water systems.
- Helped three First Nations communities to celebrate the lifting of long-standing BWAs.
- Encouraged better cooperation, communication and collaboration among government departments and agencies (federal and provincial), NGOs, professional associations, communities and academia.
- Provided effective mechanisms to bring researchers and industry together, initiating exchanges between industry professionals and academia and supporting the development of non-technical "innovation skills" involving users and businesses working with engineering and science HQP.
- Developed collaborative proposals and solved significant and complex problems that have important ramifications for Canada.
- Provided small businesses with better access to post-secondary research resources.
- Elucidated cultural barriers between academia and industry through increased knowledge of and appreciation for each other's motivations.
- Streamlined project management approaches.
- Stimulated international research partnership, including the North American Drinking Water Network with U.S. partners (DeRISK, WINSSS & RES'EAU).
- Engaged all stakeholders, potential collaborators, current and future researchers, community members and others via education and outreach activities (e.g., summer school for Aboriginal youth, workshops for First Nations' water operators, professional development for our students); RES'EAU-WaterNET knowledge translation conferences and webinars; panel discussions featuring multi-sector experts; fielding speakers and panelists at national and international water events/conferences; participation on national advisory committees; and more. In this manner, we have helped to shape and amplify a national voice and dialogue for small water systems that did not previously exist.
- Formed working relationships with government agencies and industries, including First Nations Operators Water Net of BC and Yukon, First Nations Health Authority, Aboriginal Affairs and Northern Development, Assembly of First Nations, Peter Wall Institute for Advanced Studies, Walkerton Clean Water Centre, Consulting Engineering Firms (Kerr Wood Leidal, Opus International, Urban Systems, Associated Engineering), Trojan Technologies, BI Pure Water, Noram Engineering and Constructors, Tritech, Veolia, professional associations (BCWWA, CWWA), BC Centre for Disease Control, Health Canada, BC Ministry of Community, Sport and Cultural Development and many others.

Boil Water Advisories are all too common in Canada's small rural communities.

Celebrating the launch of the network's first Mobile Water Treatment Pilot Plant.


RES'EAU-WaterNET, University of British Columbia
www.reseauwaternet.ca
Research:
• Innovative & Integrated Treatment Processes
• Water Health Assessment & Monitoring
• Governance, Risk Management & Compliance
1 University of Victoria
2 University of Calgary
3 University of Guelph
4 McMaster University
5 Brock University
6 École Polytechnique de Montréal
7 Université Laval
8 Dalhousie University
1 University of New Hampshire
2 Rural Community Assistance Partnership
3 University of Alaska Anchorage
4 Arizona State University
Design of Risk Reducing, Innovative Implementable Small System Knowledge (DeRISK), Center University of Colorado Boulder
www.colorado.edu/deriskcenter
Research:
• Assessment and Implementation
• Photon-Based Treatment
• Extended Biofiltration
• Distribution System Technologies
1 University of Texas (Austin)
2 University of Nebraska-Lincoln
3 University of Florida
4 University of Illinois Urbana-Champaign
5 University of South Florida
6 Carollo Engineers
Water Innovation Network for Sustainable Small Systems (WINSSS), University of Massachusetts (Amherst)
www.umass.edu/winsss
Research:
• Evaluation of Mature Technologies
• Non-Treatment Innovations
• Advancing New Technologies: Physico-Chemical
• Advancing New Technologies: Biological

SEVERAL LOCAL, PROVINCIAL AND NATIONAL CO-CREATORS:

Industry Partners

Associated Engineering

BI Pure WATER

IBM

kwl

NORAM

OPUS

TRITECH Water Infrastructure Solutions

TROJAN UV WATER CONFIDENCE

URBAN systems

VEOLIA WATER

Government, Professional Agencies & NGOs

Indigenous and Northern Affairs Canada

BC Centre for Disease Control
An agency of the Provincial Health Services Authority

BRITISH COLUMBIA The Best Place on Earth
Ministry of Community, Sport and Cultural Development

BCWWA
BC WATER & WASTE ASSOCIATION

CWWA ACEPU

Comox Valley REGIONAL DISTRICT

C·V·R·D

EOCP Environmental Operators Certification Program

First Nations Health Authority
Health through wellness

First Nation Operator Water Net of BC & Yukon Territory

Développement durable, Environnement, Faune et Parcs
Québec

Health Canada Santé Canada

Newfoundland Labrador

Okanagan Basin WATER BOARD

Van Anda Improvement District

VILLE DE QUÉBEC

WHITE ROCK
My City by the Sea!

WCWC Walkerton Clean Water Centre
CWAE Centre de Walkerton pour l'assainissement de l'eau