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Co-design of water services and infrastructure for Indigenous Canada: A scoping review

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Abstract

There is movement in engineering fields and in Indigenous communities for enhancement of local participation in the design of community infrastructure. Inclusion of community priorities and unique cultural, spiritual, and traditional values harmonize the appearance, location, and functionality of developments with the social and cultural context in which they are built and contribute to holistic wellness. However, co-design processes that align community values and the technical needs of water facilities are difficult to find. A scoping review was conducted to explore the state of knowledge on co-design of water infrastructure in Indigenous Canada to build a knowledge base from which practices and processes could emerge. The scoping results revealed that articles and reports emerged only in recent years, contained case studies and meta-reviews with primary (qualitative) data, and involved community members in various capacities. Overall, 13 articles were reviewed that contributed to understanding co-design for water infrastructure in Indigenous Canada. Barriers to co-design included funding models for Indigenous community infrastructure, difficulties in engineers and designers understanding Indigenous worldviews and paradigms, and a lack of cooperation among stakeholders that contribute to ongoing design failures. A working definition of co-design for Indigenous water infrastructure is presented.

Key words: co-design, water infrastructure, Indigenous, First Nations, Canada, water

Background

Co-design and value sensitive design are established approaches to development and technology that include engagement with end-users, reflection by designers, and incorporation of human values throughout the design process (Friedman 1996; Friedman et al. 2013). Originally introduced as a process for including human values in computer software and information systems, co-design's principles are applicable across a range of contexts such as pharmacology (Timmermans et al. 2011), design of health care centers (Walton and DeRenzi 2009), military applications, and as a pedagogical tool for university students for directing their learning (Cummings 2006). A new context in which use of co-design is growing is in the design of water and wastewater infrastructure. In Canada, there is a trend towards increasing the inclusion of culturally unique values and local priorities in the design of community infrastructure and services (Nelson-Barber and Johnson 2016). Researchers have noted that co-design processes benefit all through capacity building; increased motivation, confidence and trust; alignment of goals among community members and service providers, and enhanced holistic health (Donetto et al. 2015; Robert et al. 2015). Examples include the building of the Gordon Oaks Red Bear Student Center at the University of Saskatchewan, and the Justice Institute of British Columbia's Aboriginal Gathering Place (Charbonneau 2016).

Projects that incorporated community values and input in the design process exist in several countries. Both the National Museum of the American Indian in Washington, D.C., and the First Peoples Hall in the Canadian Museum of History in Gatineau, Québec, include style, aesthetics, character, and materials that reflect Indigenous values, and were designed by Indigenous architects (Phillips 2006). Memorials built within the last three decades in Cambodia, Rwanda, and Germany worked to connect tourists and other visitors to the "memory scapes" of local people (Davis and Bowring 2011). The Meulwater Water Treatment Works in South Africa is lauded as a water treatment plant with advanced design and technical efficiency. However, it is also recognized for enhancing heritage and cultural values of the Drakenstein Municipality through its alignment with, and sensitivity to, the local social, ecological, and cultural environments (Meulwater WTW 2013).

Though these projects have shown success in the co-design process across tourism, recreation, housing, and community service projects, outside norms are not always validated in water and wastewater treatment design (Martín 2014; Black and McBean 2017). Infrastructure design textbooks and manuals, for example, sporadically contain reference to the inclusion of cultural values and rarely contain guidelines for engaging with Indigenous communities (Sandercock 2003; Grant 2010). It is recognized that stakeholder priorities should be integrated into the decision-making process for community infrastructure to promote successful project outcomes, but this inclusion has not been advanced in work with Canadian Indigenous communities (Martin et al. 2007; Richardson et al. 2012; Daley et al. 2015; Black and McBean 2017).

As a part of Canada's commitment to reconciliation and within the calls to action of the Truth and Reconciliation Commission, resources for improvements to existing services and infrastructure, and the development of new infrastructure for health care, education, housing and other needs on Indigenous lands are being discussed (Anaya 2015; Truth and Reconciliation Commission of Canada 2015; Reading et al. 2016). One prominent need is access to safe drinking water across reserves in Canada. As a step in understanding the barriers to incorporating co-design and value sensitive principles into the design of water infrastructure for Indigenous communities in Canada, this scoping review sought to discover descriptions of these projects in the Canadian context. The goal of this paper is to describe the academic and grey literature on community co-design of water infrastructure on reserves in Canada.

Co-design defined

Definitions of co-design (and its related terms: value-sensitive design, co-creation, collective creativity; co-evolutionary design; empathetic design: user-centered design, participatory design) are bounded by disciplinary and contextual factors (Winschiers-Theophilus et al. 2010; David et al. 2013). Co-design can mean the development of ideas from the party being serviced; a collaborative process with knowledge sharing towards building a product; the move towards user involvement as a means for ensuring higher product quality and consumer relevance; and, in global development, it is the evolution towards participatory methods framed by discourses on social embeddedness and the importance of local factors in technology appropriation (Sterling and Rangaswamy 2010; Davidson-Hunt et al. 2012; Winschiers-Theophilus et al. 2012). Put simply, co-design means that local people are active in the creation of products ranging from coding for software to the design of large buildings and political or economic systems.

Co-design processes include common steps: stakeholder consultation, problem definition, idea generation, concept testing, prototype testing, product manufacturing, and evaluation (Sanders and Stappers 2008; Staunstrup and Wolf 2013; Frow et al. 2015; Deo et al. 2016). Different levels of participant involvement in co-design processes across various fields include being informed, consulted with, involved, actively collaborative, given empowerment opportunities, and also being central driving units and performers of co-design work (Nyerges et al. 2006; Bovaird and Downe 2008; Pini 2009; Sanders and Simons 2009).

Collaborative process in co-design projects have had positive effects on community health, economies, biodiversity, conservation and stewardship practices, and sustainability (Kambil et al. 1999; Botero and Hyysalo 2013; Marin et al. 2016; Moser 2016). In some co-design projects, stakeholders build capacity by performing tasks for themselves through coaching (Sampson et al. 2015; Galvin et al. 2016; Thorpe et al. 2016). Although the benefits provide ample argument for using co-design processes, some constraints have been reported. First, the ad hoc use of co-design processes for products means that architectures for engagement are often missing or unequally balanced among the project teams. Secondly, the tyranny of participant decision-making results in lengthy project timelines and project management challenges. Along with budgetary limitations of collaborative processes, these are the most frequently cited constraints (Hickey and Mohan 2004; Ramirez 2008; Frow et al. 2015).

As a practice, co-design in the engineering and infrastructure design fields has progressed, but the uptake is only now growing across Canadian and Indigenous contexts (Walsh et al. 2015; Schäfer and Scheele 2017). With a focus on developing sustainable water treatment systems resilient to impacts and on reconciliation in Canada, incorporating the principles of co-design in Indigenous communities offers an opportunity for empowerment and capacity building vital to ensuring drinking water security.

The research gap and its importance

Little has been published on processes of co-design specifically for water infrastructure. In design principles for the civil and environmental engineering fields, there is a heavy focus on treatment technologies and efficiencies and reducing impacts in water treatment processes (Zhou and Smith 2002; Palit 2014). Emphasis is also given to measuring the performance of water utilities, the sustainability of infrastructure, and customer satisfaction (Haider et al. 2015; Han et al. 2015). Calls for more holistic evaluation of water and wastewater infrastructure, processes, and performances for community wellbeing have been made (Haider et al. 2015; Ojuondo 2015).

Case studies in Indigenous Canada describe little flexibility in the way that infrastructure can be designed. For example, the guidelines from government agencies promote the replication of existing models of water treatment facilities at different sites (Mirosa and Harris 2012). Water infrastructure is imposed on community members by engineers and contractors, and Chief and Council members are left to manage infrastructure based on priorities arising from federal programs (Murphy et al. 2015). Even in cases where research on novel systems is positive, the federal process limits a community's ability to adapt the design to one that meets their cultural needs (Walters et al. 2012).

The development of water infrastructure, regardless of the design process, is associated with improving the health and quality of life of communities, but problems can arise with ongoing operation and maintenance (McCullough and Farahbakhsh 2012; Basdeo and Bharadwaj 2013; Black and McBean 2017). Current policies on the design and installation of water infrastructure reinforce ongoing colonization and strain communities financially and operationally (Black and McBean 2017). For example, in Weagamow First Nation in northern Ontario, the community water treatment plant was unable to operate for long periods at the capacity needed for the growing community. The heavy operation stressed the system causing malfunctions that the community did not have the capacity to address leaving them without water for weeks (Troian 2016).

Looking forward, the goal of this research is to identify examples where co-design of community water infrastructure on reserves has occurred in Canada, key principles that guide the process of co-design in that context, and lessons learned. A scoping review was deemed most appropriate given the recent emergence of literature and the relatively new movement towards participatory infrastructure design in Canada.

Study context

In Canada, there are more than 600 First Nation communities that were, in whole or in part, relocated from traditional territories to reserves set aside for their use (AANDC 2014). Reserves are often in remote areas with low population densities, which creates hurdles for access to reliable drinking water (AANDC 2011). The climate, especially in northern reaches, provides challenges for the development of infrastructure; some communities experience short construction seasons with limited accessibility by road. Others have requirements for more expensive water systems to supply water through the cold winters without freezing and damaging infrastructure, or to improve very low quality source water (Smith et al. 2006; Maal-Bared et al. 2008; Grover 2011). Most of the drinking water systems in these reserves are classified as small drinking water systems (serving fewer than 5000 people) (National Collaborating Centres for Public Health 2009). These systems are plagued with technical and management problems: treatment plant age and suitability; inadequate training of operators and high turnover of staff due to poor working conditions; inadequate treatment of source water due to calculation difficulties, depletion of chemical stock, and difficulty repairing and maintaining equipment; lack of emergency preparedness; limited technical support when needed; and spatial and seasonal factors that exacerbate the problems (Edwards et al. 2012).

Other human factors and historical inequities compound the problem. Each reserve community is unique, with varied social, cultural, political, and economic systems. Top-down and one-size-fits-all approaches to fixing water problems on reserves have left a legacy of mistrust and contributed to little measureable progress (Daley et al. 2015; Morrison et al. 2015; Black and McBean 2017). Introducing new approaches including co-design and resulting trust and commitment to collaborations for enhancing water infrastructure on reserves are needed (Castleden et al. 2017).

Approach and methodology

The Safe Water for Health Research Team (SWHRT) is a conglomerate of members from 10 academic departments, four government agencies, three non-governmental agencies, the Federation of Sovereign Indigenous Nations, and 11 independent First Nation community representatives in Saskatchewan. The team has been collaborating since 2008 towards community-based participatory research projects around water issues. The need for the research discussed here arose from the team's desire to follow evidence-based approaches for co-design in communities on upcoming projects. Few articles that directly encouraged or described co-design processes could be found by the network of researchers on the team; hence, a scoping review was deemed appropriate given the need to discover and map the extent of research, and categorize findings but not extrapolate data across a variety of cases as in a systematic review (Arksey and O'Malley 2005).

The procedure for this scoping review was informed by Arksey and O'Malley's (2005) framework with new developments (Joanna Briggs Institute 2015). Eight steps were completed concurrently by two researchers: defining the question, creating a search protocol and criteria, identifying relevant articles, selecting the sample, tabulating data, engaging with other experts for consensus over themes, collating, summarizing and reporting the results of this sample (**Table 1**).

Next, article screening was completed and eligibility criteria applied to determine the in-scope articles; duplicate articles and articles deemed irrelevant were removed. Eligibility for inclusion in the study was determined by three criteria: articles had to be peer-reviewed articles, reports, or government documents; articles had to be published no earlier than the year 2000; and articles had to be published in English or English and French.

The two scope reviewers met with SWHRT members to come to a consensus on the summarized results. Feedback from the SWHRT also provided a framing for the recommendations arising from the work.

Results

Articles were retrieved and analyzed from June 2016 to March 2017, and are summarized in **Table 2** by design, relevant findings, and limitations (article ID is indicated by an uppercase letter).

Overview of selected studies

A total of 1551 were returned (**Fig. 1**). These articles were managed in a commercial database for easier processing. Most articles were removed as duplicates ($n = 966$) before being screened for inclusion. Thirteen articles remained for this review after the removal of duplicates, screening for inclusion criteria, and exclusion of irrelevant articles. This included four articles that were relevant to the element of co-design but that were not conducted in Canada.

Table 1. Key words (with synonyms) and syntax used for literature search.

Search term(s)	Synonyms
Water	Drinking water OR water quality OR potable water OR healthy water OR drinkable water OR drink water OR drink OR safe water OR water OR suitable water OR palatable water OR edible water OR tap water OR fresh water OR water supply OR source water OR raw water OR wastewater OR waste water
Indigenous communities	Indigenous people OR Indigenous OR Aborigine OR Aboriginal OR Indigenous community OR Native(s) OR Indigen* OR Indigenous people OR First Nations OR Métis OR Inuit OR Inuk
Co-design	Co-design OR collective creativity OR co-creation OR empathetic design OR user-centered design OR participatory design OR Value sensitive design
Infrastructure	Infrastructure OR system OR building OR structure OR treatment plant OR plant OR piped distribution system OR water pipe(s) OR water system OR cistern OR tank
Canada	Canada OR North America
Water AND Indigenous Communities AND Co-design AND Canada	—
Water AND Indigenous Communities AND Co-design AND Canada AND Infrastructure	—

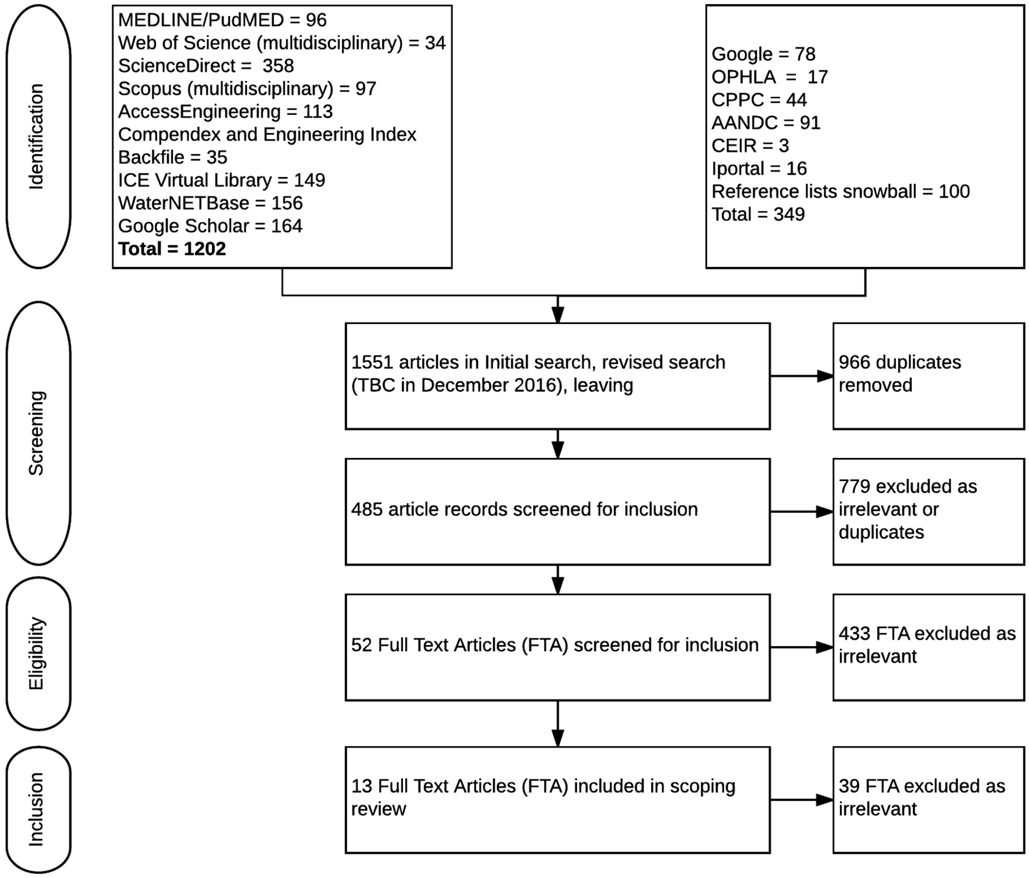

Fig. 1. Scoping review process and step-by-step results.

Study characteristics

Descriptive summaries of study characteristics

General attributes of the articles resulting from the scoping review are summarized in Table 3. Many of the articles were published in the last 5 years (9 of 13) and in academic journals (10 of 13). The collection also included government guidelines and sets of annual reports. The studies involved First Nation communities and groups in Canada (6 of 13) and Indigenous groups outside of North America (4 of 13). Hereinafter, articles included in Table 2 are referred to by article ID. Most of the sample articles did not have definitions for design or co-design, but those that did (B, J, and M) had a definition for both design and co-design (Table 3). The definitions for co-design were similar in the three articles but were not as specific as academic definitions, which focused on process steps (problem definition, idea generation, concept evaluation, lab research, experimentation & analysis, detail design, fabrication, testing, and evaluation in both lab and field). One article (B) defines the process of co-design as when stakeholders are consulted on problem definition and then are engaged to some degree throughout the project, and defines engineering design as "the use of heuristics to cause the best change in a poorly understood situation within available resources" (Halbe et al. 2015, p. 272), suggesting a common sense approach to problem solving. Another article (M) described co-design as relational, knowledge-sharing learning process meant to enhance "design for the common good" and involving foreign and local experts and an understanding of the environmental context in which design was sought. For comparison, the Canadian Engineering Accreditation

Table 2. Summary of articles in scoping review.

Article ID	Reference	Topic	Site(s)	Design			Summary of relevant findings	Limitations
				Method	Data type	Response rate		
Canada								
A	Horning et al. (2016)	Social network analysis of watershed planning and water governance configurations in Canada	Similkameen Valley and Kettle River, British Columbia	Case study	Primary data using semi-structured survey	Two networks explored; $n = 59$ 80% response rate, and $n = 54$ 69% response rate	Both case networks demonstrated that collaboration is not supported. Centralized power brokers exist resulting in power asymmetry. In Similkameen, a small number of First Nations actors provide key bridging services. Missing links to industry and federal levels of government hinder policy progress.	Two case studies in one province, not longitudinal
B	Halbe et al. (2015)	Roles of paradigms in engineering practice with particular attention to "community involvement"	Flood case study: Hungary; education case studies McGill University Montreal, Quebec, Canada and University of Osnabrueck, Germany	Case Study	Primary, qualitative data; two cases: one on flood management, one on incorporating new paradigms into university-level engineering pedagogy	—	Application of solutions from one paradigm only is not enough to address the multiple aspects of sustainability problems. Both engineering and local community members have difficulty acknowledging the value of each other's paradigm. Teaching paradigms in engineering education could sensitize engineers to the value of diversity leading to "integrated management" paradigm.	Cases only in Westernized Nations (Hungary, Germany, Canada), small sample.
C	McCullough and Farahbakhsh (2015)	Refocusing the lens: drinking water success in First Nations in Ontario	First Nations in northern and southern Ontario that were stratified across remote and accessible areas	Qualitative interviewing: grounded constructivist approach	Primary data	16 from snowball, stratified sample; recruited at a technical tradeshow in Toronto, Ontario, Canada	Locally driven actions enhanced First Nations pride, capacity, and OCAP principles. Better infrastructure achieved through sidestepping Federal programs and processes to attain a desired goal. Satisfaction due to reduced bureaucracy.	No inclusion of negative findings. Single province examined
D	White and Leblanc (2015)	Report on initial improvement to water and wastewater systems in 2013–2014 in Pikangikum First Nation, northern Ontario	Pikangikum First Nation, Ontario	Case report	Primary qualitative data	$n = 10$ family dwellings that had received piped water systems	Community members should be included in water infrastructure projects to build capacity, enhance health outcomes, and enhancement to water systems improve other issues in remote reserve communities through interconnectedness of water, health, energy, and social services.	Small sample, remote community, singular event

Table 2. (*continued*)

Article ID	Reference	Topic	Site(s)	Design			Summary of relevant findings	Limitations
				Method	Data type	Response rate		
E	McCullough and Farahbakhsh (2012)	First Nations drinking water infrastructure policy, and its translation, and action areas for reserves	16 First Nation reserves across Ontario	Case study	Primary qualitative data (interviews)	*n* = 13 interviews with 16 First Nations technical practitioners recruited voluntarily from trade-show	INAC accountability to external agents restricts its ability on technical challenges. INAC perceived as gatekeepers dominated by macro- and micro-control measures with no flexibility and too much frugality. Federal control interferes with accommodating diversity among First Nations. Northern FN's have limited capacity to execute a major capital works process, and retention of technical stuff is poor. Northern communities have more challenging construction logistics. Engineers and workers not equipped to coordinate direct involvement of community leadership and navigate social structures of remote communities. INAC inflexible and incompatible with the diversity of First Nation communities—sharply contrasting INAC's mandate.	Small sample size, one province, not representative. Lack of comparable research to draw from.
F	Simeone (2010)	Reviews roles, responsibilities and progress of federal, provincial, territorial and First Nations governments for safe drinking water on reserves up to May 2010	Federal, provincial, territorial, and local policy landscape	Content review and gap analysis	Secondary data	N/A	Water infrastructure on reserves is obsolete, absent, inadequate, or of low quality. Reserve communities have no mechanism to provide input on regulations. The focus of the federal government is on legislation, however, making legislation while infrastructure is inadequate to meet current requirements is questionable.	Data sparse. Poor consultation Failure to consider cultural dimensions of First Nations water use in legislation. Gap analysis found no pathways forward
G	Smith et al. (2006)	Public health evaluation of drinking water systems in First Nation communities in Alberta, Canada	56 treatment plants in Alberta First Nations	Risk analysis site evaluation survey	Survey conducted with environmental health officer and water treatment plant operator: Primary data; mixed quantitative and qualitative	*n* = 56 systems	The process of design for small water treatment plants limited by funding. Systems are not user-funded and are constrained by the agencies who make decisions, reinforcing hierarchies. Needs to be locally determined and culturally relevant water sources, monitoring and treatment programs, and addressing of cultural, political, social, and economic environment	Conservative approach to questionable situations in the study

Table 2. (*continued*)

Article ID	Reference	Topic	Site(s)	Design: Method	Design: Data type	Design: Response rate	Summary of relevant findings	Limitations
H	AANDC (2010a, 2011, 2012, 2013)	Investment reports and national assessment of the federal government infrastructure development for First Nations water on reserves	First Nations across Canada	Government reporting	Includes background, enforceable standards, protocols, investments, and evaluations of systems across Canada	*n* = 3	Annual report on water and wastewater infrastructure highlights success stories and lists spending on projects. The partnerships are defined as financial support from the government with First Nations planning submitted for approval	Does not provide a definition for design or descriptions for design process
I	AANDC (2010b)	Design Guidelines for First Nations Water Works: policy statements and appendices	—	Content Analysis of Policy statements	—	N/A	Plans for engineers to carry out successful design of water and wastewater infrastructure. It focuses on meeting technical standards for operation.	Lacks a component for community consultation
Global								
J	Ambole et al. (2016)	Designing for informal contexts: a case study of Enkanini sanitation intervention	Western Cape, South Africa	Case study	Participant observation and cross-case synthesisprimary data	*n* = 3 cases; 2 snap-shots, 1 longitudinal	Inclusivity and human-centered design are concerns in design fields, especially for vulnerable populations. Capacity to participate and social pressures interfere with creativity and agency. Generative methods of co-design such as design ethnography allow for engaging transdisciplinary success. Socio-technological reciprocity approach allows reduction in power asymmetries. A co-design sanitation system was implemented, but social system to support the infrastructure failed due to poor communications, and reflection by team.	Singe lase study, convenience sampling. No comparative research available.
K	Tinoco et al. (2014)	Literature review, project reports, and field studies in Nicaragua	Nicaragua and Caribbean coasts	Meta-review and participatory action research in six communities	—	*n* = 185 articles; 100 project reports; and stakeholder dialogue, transect walks, focus groups, interviews and mapping in six communities	Poor socio-cultural understanding of water and sanitation interventions abound. There is rejection of infrastructure and non-functioning solutions due to clashes with cultural preferences and local relevant knowledge. Results in inactive management organizations, and incomplete infrastructure installation. Lack of capacity to integrate Indigenous worldviews exists among designers. Wasted investments because facilities are not used/fall into disrepair	Field study limited to one country. Participatory, but no Indigenous methodology.

Table 2. (*concluded*)

Article ID	Reference	Topic	Site(s)	Design			Summary of relevant findings	Limitations
				Method	Data type	Response rate		
L	Jiménez et al. (2014)	Review of water and sanitation services across global Indigenous populations	Global	Meta-review	Secondary data; 185 articles	N/A	Analyses of power struggles and conflict appear often, while legislation and institutions, though increasing in their acknowledgment of the rights of Indigenous people, are failing at practice. Differences in values for water and health contribute to disparities. Indigenous participation in planning processes is increasing, however need more tools to facilitate. Awareness needs to increase. Researchers need to find processes that respect both the requirements of the external agents, and local structures and workflows.	Sample over-represented by political ecology papers focusing on conflicts. Literature lacking in success stories. Omitted large selection of articles on TEK. Few papers from Africa because of Indigenous-Colonial reversal
M	Murcott (2007)	Co-evolutionary design for development: influences on engineering design and implement	Nepal	Case study	Study of household water filter co-development and experimental testing in Nepal to develop a 10-step framework for co-evolutionary development project	—	Co-development and experimental testing had four positive effects: increased public awareness of the problems, enhanced local entrepreneurship, innovation due to constraints of local material availability, and economic development. Other benefits included enhanced networking, empowerment of women, and better water.	Tech requires instruction or is dismissed thus experts need to be available. Small sample, unsustainable funding and no diversified funding sources, no long-term data.

Note: INAC, Indigenous and Northern Affairs Canada.

Table 3. General attributes of publications included in the scoping review ($n = 13$).

Characteristic	Number ($n = 13$)	Percentage (%)	Article ID[a]
Publication year			
2006–2011	4	31	F, G, I, M
2012–February 2017	9	69	A–E, J–L
Publication type			
Journal article	10	77	A–G, K–M
Thesis or academic report	1	8	J
Technical report	2	15	H, I
Level of participation			
Inform	2	15	B, G
Consult	2	15	C, E
Involve	2	15	A, K
Collaborate	3	23	D, M, J
Empower	0	0	—
None	4	31	F, H, I, L
Indigenous community			
First Nations	6	75	A, C, D, E, G, H
Other	4	13	J, K, L, M
None	3	13	B, F, I
Definition			
Design	3	23	B, J, M
Co-design	3	23	B, J, M
Both	3	23	B, J, M
None	10	77	A, C–G, H, I, K, L

[a]Article ID as per Table 2.

Board uses the following definition of engineering design: "Design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs" (Canadian Engineering Accreditation Board 2016, p. 31). It is significant that Engineers Canada indicates that complementary studies are important for design, but no official definition, policies, or practices for co-design were found within Engineers Canada resources.

Reported methods

Articles in this sample primarily used qualitative (7 of 13) and quantitative data (1 of 13), although two used mixed data (2 of 13) (Table 4). Other articles were theoretical or practical in nature and did not use data in the analyses. Articles were mostly case studies (A, B, D, E, J, and M), but also included meta-reviews (F, K, and L), participatory research (C and G), and government reports (H and I). One qualitative case study (J) focused on a project initiated by a community in which the co-design process was used to plan out the collaborative effort needed for the study. The parties

Table 4. Methodological characteristics of publications included in the scoping review ($n = 13$).

Methodological characteristic	Number ($n = 13$)	Percentage (%)	Article ID[a]
Research design			
Participatory research	2	15	C, G
Case study	6	46	A, B, D, E, J, M
Meta-review	3	23	F, K, L
Report	2	15	H, I
Research data			
Primary data	8	62	A–E, G, J, M
Secondary data	3	23	F, K, L
Not reported	2	15	H, I
Study type			
Quantitative	1	8	A
Qualitative	7	54	B, C, D, E, J, K, M
Mixed	2	15	G, L
N/A	3	23	F, H, I
Participatory process			
Survey	1	8	A
Education	1	8	B
Interview	3	23	C, E, K
Working Group	3	23	D, M, J
None	5	38	F, G, L, H, I

[a]Article ID as per Table 2.

involved worked together to produce the principle outcome of the study: prototypes for wastewater infrastructure. Another case study (B) used a literature analysis of paradigms in engineering practice and Integrated Water Resource Management (IWRM) examples to build content for educational tools to improve student's skills in engagement. The literature analysis uncovered six paradigms to which students needed to be sensitized prior to teaching practical approaches for community involvement.

A mixed data review (G) of water infrastructure in First Nations communities was included as the authors conducted the review to determine trends in the state of drinking water facilities. In the review, water treatment plants were examined with data inputs in the form of water quality testing, risk assessment survey results, and qualitative assessments by environmental health officers of treatment plant operators in 56 systems. Overall concern with the condition of treatment plants was high and attributed to an inhibitive funding framework and poor local consultation.

The variety of methodologies and data types in the sample give evidence of the potential data available for examination across complex systems, but none of the studies in the scoping review used the same methodologies that would allow for cross-sectional evaluation of systems of water infrastructure. Only four studies in this review included arguments for their methodology (A, C, E, and G) and none presented alternative methodologies.

Reported data collection approach

Primary data were gathered in eight studies (A–E, G, J, and M), whereas three (F, K, and L) used secondary data and two were unreported (H and I) (**Table 4**). The sample was categorized by level of participation: informed, consulted, involved, collaborated, empowered, or not reported/none (based on the definitions from Nyerges et al. (2006); Bovaird and Downe 2008; Pini 2009; Sanders and Simons 2009). The sample included two studies that described the informed level (B and G), two consulted (C and E), two involved (A and K), and three studies reported collaborating with communities (D, M, and J). Four articles/guidelines did not report any community involvement (F, H, I, and L).

Articles reporting participatory approaches used educational sessions (B) and working groups (J, K, and M), and used local people as community coordinators, data collectors, or other project personnel (J, K, and M).

Methodological limitations

Articles were examined for limitations or biases that would impact credibility. The most consistent limitations were the sample sizes and difficulty in generalizing the results (A, D, E, and J). Further, for the articles that focused on Canadian Indigenous populations, studies were limited to a single community. No treaty areas were identified as study sites, giving further evidence to the lack of contextualized information among researchers and contractors serving Indigenous Canadian water infrastructure needs.

Two articles that described infrastructure and policy (F and G) failed to execute any consultation or explain the rationale for not consulting with Indigenous groups on Indigenous policies as a part of building the guidelines or implementing them. In the qualitative perceptions and mixed data reviews of infrastructure and operators (C, E, and G), the researchers involved water treatment operators in the examination process but did not involve them in the analyses or the formation of conclusions. A lack of review of the cultural dimensions of Indigenous water use was found in most studies included in the review (except J and K). A lack of reporting on procedures that employed cultural methods or tools for gathering or analyzing information was consistent throughout the sample. In summary, only one study (K) examined the relationships between Indigenous culture and water infrastructure.

Results of the government guidelines and documents (H and I) and a perception study (C) focused on the success stories of water projects in Indigenous Canada, but lessons learned were underreported except in the case of the South African wastewater sanitation project (J) whose failure led to community and research team reflection.

Thematic analysis and study findings

Themes arising from the scoping review included the poor state of the water infrastructure on Indigenous reserves in Canada, the co-design processes themselves, difficulties in the process that interfered with implementing co-design, and a belief that a major challenge to the success of these projects is the lack of cooperation and willingness to understand other paradigms when it comes to engineering and design.

State of water infrastructure and design on First Nations

The condition of existing water infrastructure was discussed in some of the articles along with the challenges involved in the process. Some studies (C, E, F, and G) reviewed the infrastructure and stated that it is often obsolete or inadequate and leads to a loss of access to clean drinking water. The difficulty in resolving the state of repair was suggested to be a product of risk- and engineering-centered guidelines and a funding structure that is difficult to navigate (C–G). Authors described the current systems as not value sensitive and therefore missing the element of ownership required for successful upkeep (C, E, and M). Authors also perceived that as a result of government funding formulas, projects lack the uniqueness necessary to address social, technical, cultural, and political factors that are specific to the target community (B–G). When a system fails to meet these needs its success is limited (C, E, and J–L). Among the guiding documentation for the design and implementation of water infrastructure on reserves (H and I), there were no policy statements or standards on respecting cultural values or protocols for collaboration. There are, however, policy statements on ensuring the security of the infrastructure to threats in addition to the technical specifications for each type of water treatment system suggesting a risk-based and engineering-centered approach.

Co-design processes presented

Four processes were presented in the included articles as methods of co-design. Six articles looked specifically at the challenges of federal (central government) control of design, where funding agencies specifically mandated Indigenous consultation and local implementation of water infrastructure for Indigenous people (C–I in Canada, K in Nicaragua). The process includes Indigenous communities submitting applications to federal agents, often through consultants. Federal agency power over the design process has been critiqued as lacking in financial accountability, and being too frugal and controlling on both micro and macro scales (C–E, and G). In addition, the process has been minimally effective in only the most vulnerable communities (D and E). Poor dialogue between central government agencies and local Indigenous people also results in unsuitable institutionalization and poor maintenance and operational functioning of water systems (K). Although the requirements of the federal application system include physical aspects such as expansion potential, plant and building layouts, location, power source, and controls (H and I), guidelines for community engagement, community involvement in the design, and the inclusion of social and cultural considerations are lacking.

The collaborative watershed planning process in British Columbia (A) was evaluated in two First Nations communities, as through B.C.'s new *Water Sustainability Act* watershed planners are encouraged to seek out the meaningful involvement of all water actors including water purveyors, (e.g., irrigation districts), First Nations, industry, government institutions, and nongovernment organizations to develop sustainable watershed plans. The process of creating a watershed plan was evaluated through social network mapping. The authors concluded that the planning networks "evolved a distinct core–periphery structure, which has a tendency to reinforce the dominance of centralized power brokers in framing the dialogue, controlling information flow, and privileging certain outcomes over alternatives" (Horning et al. 2016, p. 9). Further, they describe that bridging actors are not sufficient to overcome the problems of disconnection between diverse stakeholders and, at minimum, more funding is required to include First Nations in the planning process.

The co-evolutionary design for the development process was examined in the context of the design and implementation of an innovative arsenic and microbial remediation filter for households in Nepal (M). The process includes ten steps: problem awareness through partnership; problem co-definition; idea co-generation; concept co-evaluation; experiment/analysis in cultural context; prototyping from local materials; design refinement; piloting; implementation and scale-up; and reiteration and reinvention (M). Although the approach was deemed successful through the implementation in this case study, the authors caution that more time is needed to evaluate the long-term uptake of the technology they co-created, as well as more global awareness of the time their processes take to implement and follow-through (M).

The methodological approach of "infrastructuring", design ethnography, and core design competencies as a unit was explored over the course of a 2 year case study in South Africa (J). Within the frame of infrastructuring, where collaborative design exercises can be sustained to achieve long-term social change, the change agent (i.e., the designer who works from both professional design and anthropological/ethnographical lenses) facilitates the emergence of ideas from the collective imagination. The agent also provides expert design advice, thereby supporting the creation of contextualized solutions (J). The specific social, cultural, ecological, communication, and economic needs become part of the core design competencies that are sought from the ultimate solution. The case study authors caution that although infrastructuring, design ethnography, and competency development can serve to enhance transdisciplinary problem solving, effort needs to be made to ensure that participants from vulnerable communities have clear exit strategies, the pace of research is fluid and is guided by community participants, and the design ethnographer is accepting of poor participation, conflict, and design failure.

Challenges to evolving the design process/merging paradigms

A common theme of discussion is the potential for successes that accompanies co-design processes, but also the difficulties adjusting paradigms among partners (A–E and J–L). It is suggested (B) that it is not enough for only one paradigm to be used when addressing community-based problems. The involvement of co-design processes is becoming more prevalent (A, C, D, J–L, and M), but networks of partners involved in the co-design process are hierarchical in nature and not equal in membership among local, government, and industry partners (A). There is recognition among study authors and their participants that active collaboration is critical to creating human-centered infrastructure (J–M), but there is difficulty bridging the gap between a conventional understanding of the design process and the collaborative approach. Differences in expectations for involvement among actors is cited as an obstacle for consulting engineers, designers, and government agencies (A, B, and J). The normal measure of success was defined by articles in the sample as meeting technical standards (C, D, E, H, and I). Some allude to the need to include social, cultural, ecological, and economic standards (D, E, J, K, and M). The paradigms where communities are involved at meaningful levels and traditional knowledge is recognized equally go deeper to address the broader needs of communities (E, and J–M).

Discussion

A pool of 1551 articles was narrowed to 13 relevant articles. Many of the articles made reference to the numerous challenges faced when designing and implementing water projects on Indigenous reserves. Challenges included the funding framework; whether to employ a design process that addresses the unique situation of a community's needs or a conventional approach to meet the funding requirements; difficulties bridging paradigms of conventional design processes with community social, cultural, and political values through co-design processes; and unequal hegemony and networks of partners involved in water infrastructure design. Although there was the impression within the sample and in the literature that a collaborative process was best for a successful outcome (i.e., Marin et al. 2016; Moser 2016), few articles in this sample defined what that process would be and no actual examples of non-hierarchical approaches were found from within Canada. Further, most of the articles did not describe the need for, or actually involve, increased community participation beyond the level of being informed. Only three of the studies involved stakeholders in an engaged or collaborative effort to find a community-based solution to address a water problem as defined by the community, and these studies were not completed in Canada.

A lack of examinable cases in Canada prevents the assessment of whether the tyranny of participant decision-making affected the outcomes of projects; however, the ad hoc use of co-design processes is occurring globally and may be contributing to the impromptu uptake of co-design for water infrastructure. A lack of guiding documents, a critical mass of work for review, and lessons learned for practitioners from academics means that little progress has been made towards reconciling definitions, processes, and worldviews related to water infrastructure co-design. In contrast, a grassroots movement among Indigenous water experts and some academic partners has developed a three-stage conceptualization of how community co-design for water could work (Aboriginal Water and Wastewater Association of Ontario 2014). The stages include knowledge sharing, grounded guidance, and solution formation, and community values acting as the standards by which proposals are evaluated.

At present, the co-design processes for water infrastructure occurring in Canada have yet to move beyond perfunctory stakeholder consultation, with little contextualized problem definition and co-creation of solutions grounded in community values (Frow et al. 2015; Deo et al. 2016). Without flexibility in government guidelines or funding there is little incentive for co-design by local people, civil engineers, and architects. The Indigenous and Northern Affairs Canada (INAC) (2016) website promotes safe water by indicating that the Federal Budget earmarked $1.8 billion CAD over 5 years for on-reserve water and wastewater infrastructure "to address health and safety needs, ensure proper facility operation and maintenance, and end long-term drinking water advisories on INAC-funded systems on reserve" (INAC 2016); however, individual reserves are dependent on the use of external consulting engineers to design infrastructure in accordance with established INAC standards. The hierarchical nature of the overseeing agency means that the level of engagement, capacity building, and opportunities for empowerment among reserve communities is controlled by consultants and federal agencies, and is limiting collaboration at the decision-making level. This control also limits ethnographic research opportunities that may advance the field. No opportunities for local empowerment on co-design processes as the reconciliatory ideal have been reported.

Although attention has been paid to the need to reduce risks from drinking water in Indigenous communities in Canada solutions have been focused on improving operator training programs, providing more funding for federal government agencies to distribute, and improving the technology for small water treatment systems (Simeone 2010; Kayser et al. 2014). Recurrent calls from researchers that these foci have been identified through misinterpreted evidence have not yielded changes in approaches (McCullough and Farahbakhsh 2012; Cave and Plummer 2013; Castleden et al. 2017). This scoping review points to the need for solutions driven by mindset changes among professional engineers, scientists, architects, and others involved in the design of water infrastructure as well as providing a pathway for Indigenous voices to be heard. The human dimensions of drinking water systems need consideration to reduce not only technical risks, but cultural risks (Kot et al. 2014). To this end, we suggest the prioritization of research towards understanding how Indigenous Canadians want to proceed for the provision of drinking and wastewater services on reserves.

The gap between trust in conventional design versus co-design is wide in this study context as it is in other contexts (Forlano and Mathew 2014; Nelson-Barber and Johnson 2016; Khovanskaya et al. 2017). Evidence also supports the idea that communities do not believe that infrastructure controlled by outside sources and not informed by the community can succeed (Boyd 2011; Martín 2014; Dyck et al. 2015; Black and McBean 2017). Similarly, there seems to be a reluctance by industry to adapt their procedures to include listening to the voice of the community at all stages in the design process, let alone supporting community members to drive the co-design process in a decolonized way (Bhat 2015; Black and McBean 2017; Joyce 2017). The evidence of successes and lessons learned from water infrastructure implementation in Indigenous communities that we came across were researcher-driven and used novel co-design processes (Ambole et al. 2016; Wang et al. 2016). In this sample, case studies provided advice for Canadian co-design sites to avoid rejection of water infrastructure. By focusing on relationship building, open and reflexive communications with local people with a dedicated social scientist/ethnographer, and encouraging flexibility and humility in co-design through using intercultural approaches, co-design of water infrastructure has the potential for success.

Given the need for new water infrastructure on reserves in Canada, researchers, engineers, industry, and government networks could make progress in developing co-design processes with the advantage of learning from other contexts (J–L).

A first step towards this would be calling for more pilot projects and examples of infrastructure co-design in Canada to be shared among mobilization pathways such as in journals, other online publications, and at conferences. Specific topics could include progress in integrating cultural values in design processes for all sorts of community infrastructure on reserves, problems with the current designs of Canada water and wastewater infrastructure on reserves from the perspective of those living and working with these systems, and methods for engineers and designers to reflect on their practices and encourage co-design among their peers. Other recommendations include:

1. Creating an infrastructure co-design working group involving government, industry, Indigenous, and academic partners to examine potential processes.
2. Working towards the inclusion of co-design principles and processes into textbooks, training, degree programs, and other pedagogical material to encourage the next generation of civil and environmental engineers.
3. Increasing the flexibility in the federal guidelines and policies so that co-design processes for water infrastructure on Indigenous lands are supported.

Conclusion

This review highlighted the effectiveness of co-design by way of the Canadian literature and cases of co-design for water infrastructure from around the world. The scoping review also revealed obstacles to current water infrastructure co-design paradigms. As in education provision, health services, and social services, a reliance on hierarchical decision-making and patronizing approaches from the federal government continue to create barriers for Indigenous people to gain services equal to non-Indigenous people in Canada and build capacity and sovereignty. Practitioners require more training to overcome discomfort with accepting local perspectives and knowledge relevant to water infrastructure design and accepting that processes to co-create infrastructure solutions can be inclusive.

Water infrastructure in Canada has proved unreliable in delivering safe water to Indigenous communities. International examples of co-design processes that supported the emergence of innovations provide some lessons for Canadian researchers and practitioners. The issues with the Canadian system begin with the funding, guidelines, and design processes, but also includes overcoming the challenge of co-designing from different worldviews. Although the scoped articles showed reflexive initiatives internationally, the Canadian sample is limited. There is a need for more reporting on and evaluation of Canadian projects in Indigenous communities to be able to build on results. Future research should include studies from multiple regions in Canada for comparison.

A generally accepted definition of co-design for Indigenous communities in Canada would serve the engineering community well, and examples of protocols beyond hierarchical, watershed planning, co-evolutionary design, and infrastructuring are needed. This would help industry practitioners understand co-design. To this end we put forward the following definition for Indigenous co-design for water services: Indigenous co-design for water services is a process where local Indigenous people, their social, cultural, spiritual, and other values associated with water, and engineers and their values associated with water come together in respectful, reflexive, and equally represented ways to co-create and implement a shared process to design, test, and build infrastructure that sustains local environments, holistic health, communities, and cosmologies. Further debate and research is required to inform a collaborative design process for water infrastructure projects on reserves in Canada.

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Author contributions

LEAB, TV, K-EL, KM, GEHS, TAF, and LAB conceived and designed the study. LEAB and TV performed the experiments/collected the data. LEAB, TV, GEHS, and LAB analyzed and interpreted the data. LEAB, TV, K-EL, KM, TAF, and LAB contributed resources. LEAB, TV, K-EL, KM, GEHS, TAF, and LAB drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data accessibility statement

All relevant data are within the paper.

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