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Small systems, big challenges: Review of small drinking water system governance

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TABLE OF CONTENTS

ABSTRACT

Small drinking water systems (SDWS) are widely identified as presenting particular challenges for drinking water management and governance in industrialised nations, due to their small customer base, geographic isolation, and limited human and financial capacity. Consequently, an increasing number and range of scholars have examined SDWS over the last 30 years. Much of this work has been technocentric in nature, focused on SDWS technologies and operations, with limited attention to how these systems are managed, governed, and situated within broader social and political-economic contexts. This review seeks to provide a comprehensive overview of the governance dimensions of SDWS by drawing together existing literature relating to SDWS governance, and exploring its key themes, research foci, and emerging directions. This overview is intended to provide guidance to scholars and practitioners interested in specific aspects of SDWS governance, and a baseline against which researchers can position future work. The review identified 117 academic articles published in English-language journals between 1990-2016 that referred to some aspect of drinking water governance in small, rural, and Indigenous communities in industrialised nations. The articles' content and bibliographic information were analysed to identify the locations, methods, journals, and themes included in research on SDWS governance. Further analysis of SDWS' governance dimensions is organised around four questions identified as central to SDWS research: what governance challenges are experienced by SDWS, and what are their causes, solutions, and effects? Overall, the review revealed that the SDWS governance literature is piecemeal and fragmented, with few attempts to theorise SDWS governance, or to engage in interdisciplinary, cross-jurisdictional conversations. The majority of articles examine North American SDWS, retain a technocratic orientation to drinking water governance, and are published in technical or industry journals. Such research tends to focus on the governance challenges SDWS face, and proposed solutions to systems' performance, capacity, and regulatory challenges. A small but growing number of studies examine the causal factors underpinning these governance challenges, and their socio-spatially differentiated impacts on communities. Looking forward, the review argues for a more holistic, integrative approach to research on SDWS governance, building on a water governance framework.

Key words

Small water systems; drinking water; governance; rural; Indigenous; literature review.

INTRODUCTION

The provision of clean drinking water to small, rural, and Indigenous communities in industrialised nations has been the subject of increasing concern and investment over the last thirty years (see Ford et al. 2005; Christensen et al. 2010; Rickert and Schmoll 2011). Chronic contamination issues, tragedies such as Walkerton disaster in rural Canada , and the compliance burden of new drinking water regulations have placed a spotlight on small drinking water systems (SDWS) in the academic literature and in practice. While improving drinking water quality is typically regarded as a technical endeavour, focused on water treatment and monitoring technologies, research has highlighted that small communities experience severe operational and governance constraints, contributing to high community vulnerability to contamination events (Maras 2004; Edwards et al. 2012; Dunn et al. 2014a). A growing number of studies and policy initiatives have consequently focused on improving the operational and governance capacity of SDWS (see Bergman 2008; Pons et al. 2014). However, this review reveals that research on drinking water governance in small, rural, and Indigenous communities is fragmented across diverse disciplines and topics, with most studies examining individual governance features (e.g. regulatory exclusions) in specific geographic contexts. To the best of our knowledge, no review has attempted to draw together and interrogate the diverse literature on SDWS governance. This article endeavours to bridge this gap by drawing together key themes in the literature, and highlighting common challenges faced by SDWS, alongside discussion of their causes, solutions, and impacts on communities.

Good governance is increasingly recognised as critical to the sustainable and equitable management of water resources, including drinking water (Franks and Cleaver 2007; Bakker 2010). The concept of governance has shifted away from its traditional focus on the exercise of authority by government, to encompass the broader network of relationships among state and non-state, public and private actors that work together to achieve outcomes (Franks and Cleaver 2007; Ansell and Gash 2008). In this review, we use the term water governance to refer to "the range of political, organizational and administrative processes through which communities articulate their interests, their input is absorbed, decisions are taken and implemented, and decision-makers are held accountable for the development and management of water resources and delivery of water services" (Bakker and Cameron 2005: 487 - adapted from Rogers & Hall, 2003). In practical terms, water supply governance is likely to span the range of institutions and processes that surround regulations, system operation and management, financing, risk management, monitoring, and reporting. Governance consequently engages a wide range of actors, from operators, regulators, and public health agencies, to citizens, Indigenous groups, companies, and local governments (Edwards et al. 2012).

In this article we review the academic literature on the governance of SDWS in industrialised countries. We aim to summarise key conceptual foci in the literature, evaluate the scope of research on SDWS' governance, and identify directions for future research. The purpose of this review is to describe the state of knowledge with regard to SDWS' governance, and to provide guidance for scholars and practitioners on the scale and significance of drinking water governance challenges in small, rural, and Indigenous communities.

Throughout this review we use SDWS to refer to the range of capacity-limited drinking water systems (or utilities) common to small or fragmented peri-urban, rural, and Indigenous communities in industrialised countries. Definitions of 'small' systems differ significantly between jurisdictions, from systems that serve less than 500 people in British Columbia, Canada (Cook et al. 2013) to those that serve less than 50,000 people in Japan (Shinde et al. 2013). However, household-level water supplies (e.g. individual wells) are typically excluded from small system definitions, and are often referred to as private systems (e.g. Charrois 2010). Without consistent size-based definitions of SDWS, we follow prominent cross-jurisdictional studies in using capacity limitations as a functional definition of SDWS, reflecting the importance of human and financial resources in the provision of safe drinking water (see Ford et al., 2005).

This paper is comprised of three key sections. Following an overview of the approach employed in the literature review, we briefly summarise research on SDWS according to its geographic setting, system type, publication venue, and methodology. In the fourth section, we describe the thematic emphases and substantive scope of existing research on SDWS governance, summarising key insights from this literature alongside its gaps and possible future research directions. This section is organised around four questions that our review identified as central to SDWS research: what governance challenges are experienced by SDWS, and what are their causes, solutions, and effects? Building on this analysis, we conclude by arguing for a more holistic and integrative approach to governance research, and suggest five key directions for a revised research agenda.

APPROACH

This article reviews English-language academic literature published between 1990-2016 on the governance of SDWS in industrialised countries. Keyword searches of several online databases identified 134 publications that referenced some aspect of SDWS governance (i.e. operational, managerial, institutional, regulatory, economic, social, or political aspects) in their title or abstract; 117 of these texts (most of which are journal articles) were accessible via the University of British Columbia's online and hardcopy collections . Full details of our literature search are provided in Supplement I. An updated list of publications on SDWS governance from 1990-mid 2018 is also available at http://watergovernance.ca/publications/.

The 117 publications were analysed using open-ended coding to identify the range of governance topics featured, followed by inductive analysis of the resulting codes to group similar topics into broader themes (see Saldana, 2016). This iterative coding process produced a list of 14 prominent themes, which are detailed in section 3 following a bibliographic summary of the literature's geographic setting, publication venues, and methodologies. The analysis also revealed that research on governance dimensions of SDWS broadly addresses four high-level questions: 1) what are the governance challenges facing SDWS? 2) what are the causal factors underlying SDWS' underperformance? 3) how effective are various solutions at addressing these governance challenges? and 4) what are the impacts of SDWS' underperformance on communities? Key issues and discussions related to each of these questions are summarised in section 4, with attention to key strengths, weaknesses, and opportunities to expand current work on SDWS governance.

Limitations

This review focuses on SDWS in industrialised countries, examining those issues of greatest relevance in the political-economic context of industrialised development. As such, results are not necessarily relevant for low and lower-middle income countries (cf. issues raised in Cheng 2014; Marston 2014). However, work on water and poverty by Wescoat et al. 2007 suggests that there are also opportunities for cross-pollination of research insights across contexts.

Our search parameters only identified those publications that explicitly address the drinking water infrastructure (systems, utilities, etc.) that supplies small, rural, and indigenous communities. Consequently, the review excludes relevant publications that address drinking water, wastewater, and local or indigenous water governance more generally. For example, there is extensive research on indigenous water ontologies, laws, and histories that would provide context and nuance to work on drinking water supply in different indigenous communities, but is beyond the scope of our review.

Finally, the vast grey literature on SDWS is not included, although a few widely-cited reports are referenced where relevant (Ford et al. 2005; Hulsmann 2005; Rickert and Schmoll 2011). Reviewing the grey literature, as well as non-English language literature, would be valuable next steps in broadening our understanding of key issues.

QUANTITATIVE ANALYSIS OF RESEARCH ON SDWS GOVERNANCE

The majority of English-language academic research on drinking water governance in small, Indigenous, and rural communities over the last 26 years has focused on the USA (60% of all publications) and Canada (30%), with limited contributions examining SDWS in Europe (3%), and the Pacific region (3%) . It is unclear from this review whether the predominance of North American research in this review reflects the scale and severity of SDWS issues in the North American context, or differences in the way drinking water issues are conceptualised and researched outside of North America. The evidence of several agency reports on SDWS issues in Europe (Hulsmann 2005; Rickert and Schmoll 2011) suggests that small systems' governance is not solely a North American problem, and yet far fewer English-language academic publications address European SDWS. Comparative research into the governance of drinking water in these different contexts could provide further insight into whether, how, and why SDWS issues differ across industrialised nations.

Each publication was also coded according to the type(s) of drinking water system the study focused on. Quantitative analysis of these codes revealed that while 56% of publications focused explicitly on small drinking water systems, a further 32% examined a range of drinking water system size classes but made specific mention of SDWS. Among these studies, a quarter of publications focus explicitly on rural SDWS, highlighting the specific issues that rural/remote communities face. In addition, a small collection of publications examine the diverse water system challenges that indigenous communities experience (13%), particularly among Canadian First Nations, Inuit, and Métis communities.

Of the publications identified in this review, the majority come from industry and scientific journals – notably Journal of the American Water Works Association (n = 25), Groundwater Monitoring and Remediation (6), Journal of American Water Resources Association (5), and Journal of Water and Health (5). The predominance of these journals reflects the highly technical nature of research on SDWS, even when the review scope is narrowed to publications referencing governance aspects. While some social science publications were identified through the review (e.g. Kot et al. 2011; Goldhar et al. 2013), they were outnumbered by: a large number of industry-targeted publications detailing the state of drinking water issues in a particular context, and opportunities/strategies to address them (e.g. Rubin 2013b); as well as health science articles seeking to characterise population health determinants and outcomes (Beer et al. 2015); and technical articles examining the efficacy of particular drinking water solutions or proposing methods for performance evaluation (Bereskie et al. 2016). It is notable that of the 117 publications included in this review, 39 percent of studies relied primarily on quantitative data and methods, compared to the 20 percent that used primarily qualitative data and methods, and 13 percent that utilised a mixed methods approach; the remainder of publications were commentaries or reviews of subfields (e.g. benchmarking).

THEMATIC ANALYSIS OF RESEARCH ON SDWS GOVERNANCE

Open-ended coding of the publications identified by this review revealed a wide range of themes relating to SDWS governance. Common themes and their key foci are summarised in Table 1, along with the frequency with which they recur in the literature and examples of representative papers. From this analysis, it is clear that system finance, drinking water regulations, capacity limitations, and assessment and monitoring remain dominant concerns in research on SDWS governance. Despite an increase in epidemiological and social science studies, the conceptual foci of the SDWS literature appear to have changed little over the last 26 years. Early articles on the financing, capacity issues, compliance, and consolidation of SDWS (e.g. Cromwell et al. 1992; Castillo et al. 1997) raise similar concerns and solutions to recent studies (Pons et al. 2014; Kot et al. 2015b). However, the number of publications and sophistication of research methods have increased significantly over this period (Supplement II).

The following subsections provide further insight into existing research on each theme as it relates to the four dominant research questions identified earlier. Some themes recur across multiple research questions (e.g. regulations are a dominant theme in research on SDWS challenges and solutions), while others correspond with a particular research question (e.g. system ownership is largely researched as a causal factor). In each subsection we explain the research question and identify those aspects of SDWS' governance that have been the focus of research on this question, summarising common research approaches and the state of knowledge for each, as well as opportunities to strengthen the scope and rigor of governance research.

Question 1: What are the governance challenges facing SDWS?

First, and most frequently, researchers examine the challenges that water system operators, managers, and regulators face in the management and governance of SDWS. Small systems are notorious for their long-term water quality issues, high levels of non-compliance, and slow progress in addressing water system issues and upgrading infrastructure (Ford et al. 2005). While technical challenges in improving drinking water treatment and distribution remain, experts highlight that the problems underlying SDWS's poor performance are more than technical or operational in nature (Davies and Mazumder 2003; Orru and Rothstein 2015). Indeed, researchers across the social, political, and engineering sciences have sought to explain SDWS's systemic problems through analysis of the ways in which systems are funded, staffed, managed, and regulated, as well as their relationship to communities and decision-makers. Drawing out these concerns, this section explains three key types of SDWS governance challenges that are commonly identified by researchers: 1) financial and capacity limitations; 2) regulatory requirements and compliance; and 3) disjunctures between official and community perceptions of drinking water.

Financial and capacity challenges

Studies highlight that a small customer base and limited external support result in a lack of financial, operational, managerial, and institutional resources with which to run and govern SDWS (Braden and Mankin 2004; Ford et al. 2005; Lebel and Reed 2010; Blanchard and Eberle 2013). Capacity limitations are identified as both a driver of SDWS' underperformance, and a barrier to system improvements. Studies highlight that insufficient funding results in poor system maintenance and repairs, contributing to the hastened degradation of systems with no funding for system replacement (Dziegielewski and Bik 2004; Rogers and Louis 2007). A lack of human capacity in the form of trained, full-time operators and managers has been associated with inefficient system management and increased risk of water system failures (Logsdon et al. 2004; Pons et al. 2014; Scheili et al. 2016), while limited financial, technical, and management capacity prevents systems from installing new treatments, applying for funding, or exploring alternative supply arrangements (Geldreich 2005; Baird 2012). Without adequate operational funds, SDWS are typically run by part-time staff with limited qualifications and experience, who are paid at lower rates than their full-time equivalents and may serve more than one role in the community (Bergman 2008; Baird 2012; Pons et al. 2014; Hanrahan et al. 2014). As such, SDWS are subject to high operator turn-over, and are frequently managed by volunteer and part-time managers (Dziegielewski and Bik 2004; Maras 2004). In the USA, awareness of these capacity limitations has led to a national discourse and set of policies and programs targeted at improving SDWS 'technical, managerial, and financial' capacity (TMF) (Blanchard and Eberle 2013). However, as Balazs and Ray (2014) highlight, program criteria that "define eligibility on the core weakness of resource-poor communities" can act to reduce access to funding and support for SDWS, as "communities that lack resources lack TMF; without TMF, funding is harder to attain; and without funding, TMF cannot be developed" (p.607)

While the majority of studies in this review identify limited financial, operational, managerial, and institutional capacity as the key governance challenge facing SDWS, few examine SDWS capacity concerns in any detail. Among those that do, three trends are visible. First, studies conduct cross-spatial analyses to identify trends in specific forms of SDWS capacity, such as human (Pons et al. 2014; Scheili et al. 2016), managerial (Dziegielewski and Bik 2004), and financial capacity (Geldreich 2005; Rogers and Louis 2007). These studies reinforce the oft-stated assertion that a high proportion of SDWS suffer from significant capacity limitations, and that this is affecting system performance and compliance. Second, studies attempt to characterise SDWS capacity by identifying key elements and indicators; several articles use this information to create analytical or evaluative frameworks (Lebel and Reed 2010; Engle 2013). For example, Blanchard and Eberle (2013) report on the results of a state-wide survey of TMF capacity, intended to identify those aspects of capacity that are most limiting and in need of assistance. These studies demonstrate that SDWS capacity is multifaceted, and signal the importance of human capacity (in the form of operators and managers) in the provision of safe drinking water. Third, a small but growing number of studies have undertaken case study analyses of capacity challenges in particular communities, using both quantitative and qualitative methods (Brown et al. 2005; Kot et al. 2011; White et al. 2012; Balazs and Ray 2014; Hanrahan et al. 2014). These studies have provided rich insights into how capacity limitations manifest in SDWS, with what consequences, and how operators and managers seek to address these challenges. For example, Kot et al. (2011) demonstrate the unequal burden of increased regulatory requirements on SDWS operators in Canada, causing job stress, difficulties recruiting and retaining trained operators, and poor operator-community relations. Such in-depth research into SDWS capacity is important for characterising the scale and outcomes of capacity limitations, directing policy-makers to provide assistance where it is most needed. Indeed, SDWS would benefit from similar research into other aspects of system capacity (e.g. institutional, socio-political, management) that are typically overlooked in favour of financial and technical/operational capacity.

Regulatory requirements and compliance challenges

Second, research into SDWS governance identifies compliance with regulatory requirements as a key challenge facing SDWS, at times exacerbating capacity limitations by placing greater demands on existing operational, financial, and technical capacity. Drinking water regulations vary by country, state, and system type, but typically set maximum contaminant levels; treatment, monitoring, reporting, and public notification requirements; operator training and certification; system and source area protections; and other system requirements (Baird 2012; Gunnarsdóttir et al. 2015). In some jurisdictions SDWS are exempt from specific regulatory requirements. Studies report that regulatory requirements for drinking water systems have increased significantly over the last ~20 years in the USA and Canada, with increased monitoring, reporting, and planning requirements, as well as tougher maximum contaminant levels (Pontius 2004; Brown et al. 2005; Dunn et al. 2014a). Compliance with these strengthened drinking water regulations has emerged as a significant challenge, with studies showing that SDWS are overrepresented in drinking water violations, and subject to a greater ‘compliance burden’ (Kot et al. 2011). For example, Jordan et al. (1996) noted that US regulatory reforms in the 1990s were estimated to have compliance costs of $18 billion per year, with 69% of the costs falling on SDWS. Small and remote rural systems are expected to meet the same regulatory standards as large systems, but with higher marginal service costs and lower revenues (Brown et al. 2005). In many cases regulatory requirements are designed for larger systems with economies of scale, making them impractical, unaffordable, or economically inefficient for SDWS (Cromwell et al. 1992; Jones and Joy 2006; Pontius 2008; Cho et al. 2010). As a result, studies have shown that SDWS have higher rates of non-compliance than larger systems, although most violations are a result of failing to meet monitoring and reporting requirements, rather than water quality standards (Castillo et al. 1997; Job 2011b; Rubin 2013a).

Such findings have spurred debate over whether the benefits of strengthened regulations – in terms of increased protection for public health – outweigh the increased costs of compliance and associated rise in noncompliance (e.g. Cromwell et al. 1992; Pontius 2004; Scharfenaker 2006a; Bennear and Olmstead 2008). Engagement with this question has included quantitative analyses of regulatory costs and benefits (Brown et al. 2005; Jones and Joy 2006), policy analyses of the implications of regulatory changes for different risk and system types (e.g. Pontius 2004), and qualitative research into how systems are affected by and respond to increased regulatory requirements (Geldreich 2005; Kot et al. 2011). This research highlights that while new regulations may promote reductions in public health risks, the costs and benefits of these changes are distributed unevenly, resulting in benefit-cost ratios of <1 for some citizens (Cho et al. 2010). Studies note that increased treatment costs may drive some households to opt out of regulated water systems and rely on private water sources and/or treatment solutions, increasing household-level risks and further eroding the revenue-base of SDWS (e.g. Daniels et al. 2008). Further, in small, capacity-constrained systems, strengthened regulations may simply result in a reallocation of resources to specific risks rather than an overall reduction in public health risk. For example, revised arsenic standards in the USA are feared to have redirected limited public health funds into arsenic compliance (cf. other drinking water needs), even in communities where arsenic levels are traditionally low (Jones and Joy 2006; Cho et al. 2010). Pontius (2004) similarly argues that the USA's complex regulatory framework imposes a significant administrative burden on SDWS, diverting resources away from the provision of treatment barriers (see also Kot et al. 2011). Indeed, Geldreich (2005) found that a regulatory compliance culture resulted in an operational focus on meeting minimum standards – in some cases by selecting 'low risk' test sites – rather than ensuring the safety and efficiency of the whole drinking water system. Some under-capacity regulators are also forced to prioritise which drinking water regulations to enforce, resulting in greater uncertainty in drinking water quality in small communities, and spatial inequalities in the protection afforded by strengthened regulations (Balazs and Ray 2014). However, it is important to note that some regulations – such as public reporting requirements in the USA – have been found to have promoted operational improvements (e.g. adoption of innovative solutions, Kot et al. 2015b) and reduced violations (Bennear and Olmstead 2008).

Indeed, the literature seems torn between a critique of the compliance burden imposed by new regulations, and critiques of inadequate regulation and regulatory exemptions for small systems. Studies have highlighted variability in drinking water regulations within a country according to jurisdiction, system size, system ownership, and community composition (Daniels et al. 2008; Edwards et al. 2012; Dunn et al. 2014a). Some have argued that this regulatory variability results in environmental injustice, as residents are subject to varying levels of drinking water risk depending on where they are located (Balazs et al. 2012). For example, Canada lacks national drinking water standards , resulting in significant differences in the range of contaminants regulated and monitored, and degree of regulatory enforcement across provinces and territories (Cook et al. 2013; Dunn et al. 2014a). Canadian regulations also do not cover drinking water systems on First Nation reserves (Basdeo and Bharadwaj 2013) or private drinking water supplies (Charrois 2010), while some provincial regulations exclude further system categories (e.g. cooperatively-governed systems, see Edwards et al. 2012). In the USA, systems serving less than 25 people or 15 connections are similarly exempt from regulation (Daniels et al. 2008). While often justified with respect to regulatory burden or compliance difficulties, these exemptions also create the conditions for jurisdictional gaps, a lack of oversight, limited knowledge about drinking water risks, and ultimately differences in populations' exposure to risks (Dunn et al. 2014a). Indeed the Walkerton Inquiry identified the lack of binding drinking water standards, and resulting poor monitoring and oversight, as key causal factors in the 2000 public drinking water contamination event (Christensen et al. 2010). Since then Canadian scholars have strongly critiqued the use of guidelines over standards, provincial variability in drinking water regulations, and inadequate regulatory framework for indigenous communities, arguing that consistent, legally-binding minimum standards are necessary to guarantee equality in protection for all Canadians (Hill et al. 2008; Christensen et al. 2010; Dunn et al. 2014a). While allowing temporary exemptions and permanent variances from regulatory standards was intended to ease the compliance burden for small, capacity-constrained systems, critics have argued that it creates two 'tiers' of drinking water protection in the USA (Scharfenaker 2006b; Daniels et al. 2008), in which communities with lower socio-economic capacity are exposed to a higher level of drinking water risk (Balazs et al. 2012). Therefore, while the critiques of 'too much' and 'inadequate' regulation may initially appear contradictory, proponents of both critiques conclude that 1) fragmented, inconsistent, and partial regulation will perpetuate existing inequalities (Jones and Joy 2006; Balazs et al. 2012); 2) regulation should be tailored to address SDWS needs and constraints (Kot 2009; Dunn et al. 2014a); and 3) regulation must be supported by adequate resourcing for SDWS implementation and enforcement (White et al. 2012; Balazs and Ray 2014). Greater comparative analysis of the equity, efficiency, and effectiveness of different regulatory approaches across similar jurisdictions (e.g. EU member states, as in Orru and Rothstein 2015) could help to further refine these debates over the regulation of SDWS.

Drinking water perception and preference challenges

The third set of challenges identified by researchers examining the difficulties SDWS face in managing and governing their water systems relate to drinking water preferences and perceptions. Studies highlight that consumer perceptions of drinking water quality and risk are often out of sync with the measured water quality of SDWS, and that can create risks to public health, barriers to system improvements, and public distrust in water providers (Kot et al. 2011; Goldhar et al. 2013; Castleden et al. 2015). Public perceptions of water quality tend to rely on aesthetic qualities of water – including its colour, smell, and taste – which may not be good indicators of the bacterial, viral, or mineral content of water, and thus weak indicators of the health risk posed by drinking water (Doria 2010; Kot et al. 2015b). Arsenic, for example, is a widespread contaminant of concern that is only detectable via chemical tests; small community residents generally lack access to sophisticated tests and up-to-date water quality data (Stone et al. 2007). Perceptions of water quality are also influenced by a range of extrinsic factors, including attitudes towards particular sources and treatment processes, trust in water providers, and past experiences (Doria 2010). For example, chlorine-based disinfection is often perceived negatively due to the unpleasant taste of residual chlorine, and in some cases, disinfection biproducts (Goldhar et al. 2013). Barriers to management and governance may also arise when public satisfaction and trust in the water treatment process is undermined by issues such as discolouration or smell, which do not necessarily pose a health threat (Kot et al. 2011). Dissatisfaction with the aesthetic qualities of drinking water may result in households disconnecting from the SDWS and using alternative (potentially less safe) sources. For example, operators in a survey of ten rural communities in Eastern Canada estimated that half of consumers in their communities used in-home filtration devices or bottled water (Kot et al. 2011). Consumers who opt-out of SDWS may raise the cost of drinking water supply for themselves and other SDWS users (Cromwell et al. 1992), while also eroding support for and trust in drinking water operators (Kot et al. 2011). As such, perceptions of poor water quality can further reduce the already limited financial and social capacity of SDWS.

The inverse can also be true—at times is it difficult to convey risks to consumers as they simply trust that water is safe and may not concern themselves with specifics of source water protection, microbial risk, and so forth (Dunn et al. 2014b). Where consumers are unable to detect contaminants or risks to their water quality, they may perceive their water to be of better quality than it is, they are less likely to support drinking water system upgrades, or accept increases in their water rates (Cromwell et al. 1992; Kot et al. 2011). This is a significant barrier to improving drinking water safety in SDWS, which as noted previously may already be financially constrained. Overestimating the quality of a water supply can also create a public health risk, as Castleden et al. (2015) found in their survey of eight small communities that had recently been subject to boil water advisories, where most respondents continued to rely on local water sources and did not attribute health problems to their drinking water.

Studies suggest that differences in official and consumer perceptions of drinking water quality may result from a range of factors, including limited awareness of water quality; difficulties communicating risk; (lack of) trust between operators/managers and their communities; and differences in drinking water preferences and perceptions of water health. Frequent, accessible communication is often identified as important to raise consumer awareness of changes in drinking water quality, and improve drinking water literacy and confidence (e.g. Daniels et al. 2008; Kot et al. 2011; Dunn et al. 2014b). However, drinking water quality information is often detailed and technical, making it difficult to communicate risks effectively, particularly across demographically diverse populations (Stone et al. 2007). Castleden et al. (2015) also highlight that how consumers receive and act on such information may depend on the perceived significance of drinking water risks and their relationship to public health, as well as the source of communication. For example, they found that consumers were more likely to trust local sources of drinking water information and advice (e.g. local doctors) than that provided by distant government officials. Flora (2004) and Kot et al. (2011) similarly emphasise the importance of social networks and trust for safe drinking water provision in small communities. Further, research with Indigenous communities in Canada demonstrates that differences in perception of water quality may be the result of different worldviews and understandings of water health (Lebel and Reed 2010; White et al. 2012; see also Yates et al. 2017). For example, Indigenous communities in studies by Goldhar et al. (2013), Daley et al. (2015), and Kot et al. (2015b) expressed a preference for raw water gathered from traditional water sources, and for the use of traditional knowledge and practices in ensuring the safety of the water supply. Drinking water perceptions and preferences may also be place specific, tied to the history, cultural significance, and aesthetic qualities of a particular water source, together with perceptions of various threats to water quality (Hanrahan et al. 2014;Castleden et al. 2015; Kot et al. 2015b). As such, these authors advocate for a more place-based, culturally appropriate approach to drinking water provision, which takes seriously the beliefs, knowledge, preferences, and concerns of communities when designing SDWS.

Question 2: What are the causal factors underlying SDWS' underperformance?

While studies examining the governance challenges associated with SDWS are common, surprisingly few studies engage with the underlying causes of small system underperformance. The overrepresentation of SDWS in terms of compliance violations and drinking water advisories is often accepted as an inevitable outcome of geography and scale that can be mitigated but not resolved. However, critical scholars have challenged these assumptions, highlighting colonialism, neoliberal development, geographic inequalities and structural causes that promote the proliferation of small, under-capacity drinking water systems. In this vein Balazs and Ray (2014) encourage researchers and policy makers to "look beyond the proximate causes and include historical and structural factors in the analysis of exposure disparities" (p.609) in order to address differences in access to safe drinking water. This section summarises the findings of the small collection of papers that discuss the conditions under which SDWS were developed, highlighting the causal forces of 1) underregulated development; 2) decentralised governance; and 3) jurisdictional fragmentation. In the context of Indigenous communities (notably for Canada), 4) colonial dispossession, fragmented landholdings, and a lack of jurisdictional clarity have added to these debates.

Underregulated development of SDWS

Commentators in the United States and some Canadian provinces have highlighted the underregulated development of water systems, and related disincentives to connect to existing systems as key drivers of the growth of SDWS. When the first small systems with their poor economies of scale were developed as part of the ongoing outward spread of settlements across colonized landscapes, government regulation of water supply systems was 'almost non-existent' (Jocoy 2000). Decentralized growth and unregulated development combined to promote the proliferation of SDWS to serve dispersed communities (Cromwell et al. 1992; Jocoy 2000). However, as development has continued apace, the logics of geographic isolation and small community sizes are no longer the only factors driving the development of SDWS. Indeed a study by Castillo et al. (1997) of 227 SDWS across 17 US states found that 45% of small community water systems were located within 5 miles (8km) of another drinking water system, while only

10% of SDWS were more than 10 miles away from another system. These findings suggest that there may have been underutilised opportunities to connect new developments to existing drinking water systems (in the past, and also now).

Scholars argue that this continued proliferation of SDWS can be attributed to the lack of regulation of housing and water system development, and perverse incentives to develop new systems (Cromwell et al. 1992; MacDonald et al. 1997; Collins and Bolin 2007; Lee and Braden 2008). Indeed most states/provinces in the USA and Canada do not have regulations controlling the creation of new water systems that would require new developments to connect to existing systems. While some jurisdictions do attempt to promote such connection (see Baird 2012), in many cases it is assumed that market forces will result in the most efficient system for water provision. For example, Congress assumed that the new US SDWA (1974) would cause small systems to merge with larger systems in order to meet the costs of compliance (MacDonald et al. 1997). However, the division of costs between the developer (system construction) and communities (system maintenance and compliance) create perverse incentives for developers to build new SDWS. It is often cheaper to construct a new system than to pay for connection to the existing system and meet its design standards (Lee and Braden 2008). Thus MacDonald et al. (1997) found that between 1963-93 the number of very small systems in the US multiplied nearly sevenfold, despite the introduction of new legislation, as developers of new suburbs avoided connecting with larger systems to reduce development costs.

Medium-large systems may also resist taking on new or existing small communities due to their added financial and management burden. For example Balazs and Ray (2014) and Vandewalle and Jepson (2015) describe the refusal of US cities to annex neighbouring small, low-income towns to the city supply, due to the added cost and low tax revenues generated from such towns. Selective annexation is shown to be particularly common among private, for-profit utilities; Mann et al (1986) found that private companies were selectively consolidating with high-performing systems, while poor-performing systems were acquired by municipalities (in Lee and Braden 2008; see also Greiner 2016). Such selective annexation not only results in continued reliance on SDWS, but contributes to the further marginalisation of geographically-isolated and low-income communities.

Together, these examples highlight that the combination of expanding residential development, weak regulations, and profit-maximising behaviour by developers and utilities promote the ongoing creation of small, peripheral, capacity-limited systems. Critics have consequently ascribed the large and still growing number of SDWS to the neoliberalisation of development, social and environmental regulations, and public service provision (Collins and Bolin 2007; Patrick 2009; Vandewalle and Jepson 2015; Greiner 2016). They argue that the privatisation of water provision together with a lack of regulatory controls combine to create a culture of community responsibilisation, where individual communities bear the costs of water service provision to enable ongoing development and capital growth. This has the greatest impact on small, poor, and otherwise marginalized communities who typically pay higher rates for their water provision and are exposed to the greatest health risks (Collins and Bolin 2007; Vandewalle and Jepson 2015; Greiner 2016). Consequently, Balazs and Ray (2014) call for stronger regulatory mandates and incentives to promote regional solutions to water supply and system consolidation (see also Cromwell et al. 1992). Examples of such approaches include Iceland, where legislation dictates that municipalities are required to supply water to all areas above a specific density criteria (Gunnarsdóttir et al. 2015); several Australian states (see Hrudey 2008); and Iowa, where the state required applicants proposing system developments to consider a county-wide or multi-county solution (Baird 2012).

Decentralised governance of SDWS

The poorly regulated development of SDWS is also linked to the second causal factor identified by scholars interested in unmasking the endemic challenges facing SDWS: the decentralised nature of SDWS ownership and governance. Whereas large systems are typically owned and/or governed by municipalities or elected boards, SDWS are often owned, operated, and governed by private individuals, businesses, corporations, strata corporations, or groups of private property owners in the form of user communities or homeowner associations (Edwards et al. 2012). Studies consistently describe a disproportionately high rate of private ownership among SDWS in the USA and Canada, with the proportion of systems that are privately owned increasing with decreasing system size (e.g. 72% of very small systems in the USA are privately owned, Baird, 2012; see also Dziegielewski and Bik 2004; Charrois 2010; Blanchard and Eberle 2013). The combination of small size and private ownership is significant, because private SDWS are also found to have higher rates of non-compliance and disease outbreaks than publicly owned systems (Wallsten and Kosec 2008; Charrois 2010; Edwards et al. 2012). Cooperative ownership structures (e.g. water user communities) are also demonstrated to be more likely to be non-compliant and subject to a boil water advisory than publicly- or privately-owned systems (Edwards et al. 2012).

Studies have provided a range of explanations for why private ownership contributes to the poor performance of SDWS, including access to funding; staffing issues; ability to cope with and implement change; poor oversight and accountability; and weaker regulations. In the USA for instance, public systems have access to a wider range of lending and funding options for system improvements (Dziegielewski and Bik 2004; Petersen et al. 2009; Baird 2012). Furthermore private governance structures such as homeowner associations or strata councils typically lack full-time staff; systems are instead managed by community volunteers with limited experience or training (Maras 2004; Lee and Braden 2008). Such governance structures consequently lack the skills and knowledge to cope with performance issues and failing infrastructure, or the introduction of new requirements, resulting in compliance failures when new regulations are introduced (Flora 2004). These decentralised governance structures are also noted to lack the formal oversight and accountability mechanisms that often characterize public systems, whose governing boards are typically democratically elected and/or accountable to state authorities (Charrois 2010; Edwards et al. 2012). Fragmented ownership may exacerbate accountability issues, with different owners responsible for water supply, treatment, and distribution (Bennear and Olmstead 2008).

Furthermore, some private and cooperative governance structures are exempt from regulatory requirements that apply to public systems (e.g. local government regulations), and many lack oversight beyond basic monitoring and reporting requirements. For example, Edwards et al. (2012) identified 11 types of SDWS governance structures In

British Columbia (Canada), each created under and governed by different legislation, and with varying permit requirements and oversight. Private water systems (e.g. household wells) are particularly vulnerable to weak oversight, as they are typically exempt from drinking water regulations, and responsibility is placed entirely on the homeowner (Charrois 2010; Kreutzwiser et al. 2011; Vandewalle and Jepson 2015). The private and decentralised nature of SDWS governance is consequently described as creating two tiers of system protection, where household, private, and cooperative systems may have fewer compliance challenges, but are more vulnerable to changes in water quality.

Research on systemic issues among privately-owned SDWS reveals significant differences from wider critiques of drinking water privatisation (e.g. Bakker 2010; González-Gómez et al. 2013). While a minority of privately owned SDWS operate at a profit (Blanchard and Eberle 2013), the poor economies of small-scale supply mean that SDWS are not typically seen as a significant revenue source – a key driver of privatisation in Greiner's (2016) study of utility behaviour. Thus many of the critiques usually directed at water supply privatisation (e.g. market competition, Wallsten and Kosec 2008) do not translate directly to small systems. Privatisation scholars would do well to attend to these differences, and examine in greater detail the particular dynamics of private ownership and governance in small, rural, and Indigenous communities.

Jurisdictional fragmentation

Beyond weak governance at the system level, SDWS researchers also highlight jurisdictional challenges at state and national levels as a factor contributing to the poor performance of SDWS (Patrick 2009; Dunn et al. 2014a; Castleden et al. 2015; McCullough and Farahbakhsh 2015). Drinking water systems in the EU, Canada, USA, and other industrialised nations are typically governed through multi-level governance arrangements, where authority and responsibility for safe drinking water are divided across multiple scales, agencies, and departments. Small drinking water systems may be subject to greater jurisdictional challenges than larger or publicly owned systems, due to their complex ownership and governance structures, and frequent exemption from regulations and oversight (Dunn et al. 2014a; Gunnarsdóttir et al. 2015).

Both Canada and the EU operate under decentralised systems of drinking water governance, where central authorities set the rules or guidelines for drinking water, which provinces/member states are responsible for implementing through legislation and resourcing (Christensen et al. 2010; Rickert and Schmoll 2011). Responsibility for service delivery and enforcement is typically devolved further to state/province, regional, or local governments. Rationales for such devolution include the constitutional division of powers and respect for member states/provincial autonomy; spatial variability in water resources and issues and the desire for context-specific approaches; and efficiency gains associated with distributed implementation (Daley et al. 2014; Dunn et al. 2014a). Such rationales are sometimes described according to the principle of subsidiarity, wherein action is devolved to the lowest competent scale of governance (Hill et al. 2008). In both jurisdictions this devolution has resulted in significant spatial variability in drinking water regulation, governance, and resourcing. For example, Dunn et al. (2014a) highlight that the lack of national drinking water quality standards in Canada has resulted in significant variability in legislation across provinces and territories, with five jurisdictions using voluntary guidelines while eight set mandatory standards. And whereas the EU does set enforceable water quality standards, the definition and inclusion of SDWS is left to member state discretion. The devolution of authority for SDWS is reported to result in significant variability in: member state regulations; knowledge about SDWS; system monitoring and enforcement; and ultimately drinking water quality/compliance (Hulsmann 2005; Rickert and Schmoll 2011). Critics in both jurisdictions argue that smaller, less wealthy jurisdictions are likely to struggle more with the burden of devolved authority and responsibility, with the potential of exposing those citizens to greater drinking water risks and costs (e.g. Hrudey 2008; Castleden et al. 2015; Orru and Rothstein 2015).

Unclear division of authority and responsibilities across governance scales also creates the potential for inconsistent implementation and gaps in resourcing and oversight, increasing the likelihood that poor system performance will continue undetected and unaddressed (Cook et al. 2013; Dunn et al. 2014a; McCullough and Farahbakhsh 2015). These concerns have led a number of scholars to argue that the devolution of regulatory authority is inappropriate, given equity concerns and the belief that all citizens have the right to the same drinking water quality standards regardless of where they live (Hill et al. 2008; Christensen et al. 2010; Dunn et al. 2014a). Others focus on the need for clear delineation of responsibilities, strong links between levels of government, and appropriate resourcing to enable effective governance at the local level (Patrick 2009; Lebel and Reed 2010). The USA, where federal water quality standards are accompanied by federal and state resourcing to support system compliance, provides opportunities to critically examine the operation and implications of centrally-mandated multi-scalar governance for SDWS (e.g. Daley et al. 2014).

The literature also highlights that jurisdictional fragmentation can also occur within a governance scale, where authority and responsibility are divided across multiple departments or agencies. For example, authority for drinking water provision and source water protection in British Columbia is divided between the Ministries of Health and Environment respectively (Patrick 2009). Navigating this complex multijurisdictional environment requires significant administrative capacity, thus limiting the ability of capacity-poor SDWS to access drinking water information, funds, and programs (McCullough and Farahbakhsh 2015). Fragmented authority can also result in governance overlaps, conflicts, and gaps, as is evident in the disconnected governance of Indigenous communities' drinking water in Canada, where one government agency is responsible for system infrastructure, and another for water quality monitoring (Smith et al. 2006). Patrick (2009) further highlights that fragmentation contributes to a lack of coherence in management approaches across government agencies, and is a particular barrier to holistic source water protection. For example, White et al. (2012) describe the difficulties First Nation governments face in protecting their water quality when they have no authority over other activities that affect drinking water, including industrial and agricultural land uses. As such, these authors argue for the consolidation of authority and responsibility for water in a single government agency, with strong links to local governments and communities.

While many authors identify jurisdictional fragmentation and uncertainty as contributing to poor SDWS governance and management, few have undertaken research to substantiate and contextualise this claim. Studies by Dunn et al. (2014a) and Cook et al. (2013) are among the few to undertake comparative analyses within a devolved jurisdictional context, while evaluations of the EU Drinking Water Directive (e.g. Hulsmann 2005; Rickert and Schmoll 2011) are some of the only studies that examine the consequences of devolution for SDWS. Further research that enumerates the results of devolution and fragmentation for SDWS, compares across and within jurisdictions, and interrogates the effects of devolution at each level of government is needed to examine how multi-scalar institutional arrangements shape SDWS capacity and governance. The EU in particular presents a region with significant opportunities for comparative analysis and multi-scalar case study research, but has so far produced surprisingly few academic studies.

Colonization

Finally, colonization and post-colonial systems of government add a further layer of complexity to SDWS governance, compounding the issues generally experienced by SDWS and increasing drinking water risk among Indigenous communities. While only a small number of authors have explicitly identified the practices and processes of colonization as responsible for the systemic drinking water issues experienced by Indigenous communities (see White et al. 2012; Basdeo and Bharadwaj 2013; Daley et al. 2015), many describe the high rates of non-complying systems/boil water advisories (Patrick 2011); under-provision of infrastructure (Hanrahan et al. 2014; Sarkar et al. 2015); lack of financial, operational, and management capacity for on-reserve systems (Lebel and Reed 2010); limited opportunities for Indigenous participation in decision making (Grey-Gardner 2008); and fragmented governance responsibilities (Dunn et al. 2014a). Many of these studies have highlighted these concerns in the context of settler colonialism in Canada – the review only identified one article that examined drinking water governance in each of Australian aboriginal communities (Grey-Gardner 2008), and Native American reservations (Jones and Joy 2006). This attention is likely due to the considerable imbalance of drinking water issues experienced by First Nation and Inuit communities in Canada (there were 72 long-term drinking water advisories for on-reserve systems as of July 2018), as well as the public attention that drinking water (ine)quality has received since the Walkerton (2000) and Kashechewan (2005) drinking water disasters. However, given the systemic nature of drinking water issues in Native American reservations (Wallsten and Kosec 2008 report that Native American water systems experienced the most frequent contaminant, treatment, and monitoring and reporting violations of all system types between 1997-2003), the lack of comparable research on Indigenous communities outside of Canada is a significant gap in the literature.

Authors examining the causes of drinking water insecurity for Indigenous communities in Canada have argued that these issues are rooted in systemic inequities created by colonialism, overlain by colonial policies and governance frameworks (White et al. 2012; Basdeo and Bharadwaj 2013). In the first instance, colonial dispossession of aboriginal lands and the displacement of Indigenous people onto reserves resulted in the development of small, geographically-isolated Indigenous communities, who now rely on individual wells and very small systems (Basdeo and Bharadwaj 2013). In Western Canada in particular, First Nations were fragmented across a patchwork system of small reserves. White et al. (2012) highlight that reserves were typically created on poor, unsustainable lands with poor water supply, "mak[ing] the attainment of safe drinking water difficult to this day" p.110. Furthermore, reserves are often co-located with large areas of natural resource development, leaving on-reserve water supplies vulnerable to mining, agricultural, and industrial pollutants, and causing recurrent drinking water pollution in Indigenous communities (Basdeo and Bharadwaj 2013). These issues were compounded by the earlier introduction of diseases that had decimated Indigenous populations, creation of residential school systems, and criminalisation of Indigenous practices. Together, these processes contributed to a loss of Indigenous knowledge, social fragmentation, economic marginalisation, and consequently a loss of capacity within Indigenous communities (White et al. 2012).

Postcolonial laws and governance frameworks have further added to these systemic sources of inequity in drinking water provision. Basdeo and Bharadwaj (2013) highlight that the lack of federal recognition of aboriginal water rights, and resulting assumptions of provincial ownership of water, have limited the ability of First Nations to use, protect, and make decisions about water resources within their traditional territories. As a result, drinking water protection and treatment on First Nation reserves typically fails to incorporate Indigenous perspectives and values regarding water, with consequences for community health (Goldhar et al. 2013). Authority over Indigenous nations' drinking water is fragmented across federal government departments and provincial licensing authorities, while responsibility for the creation, operation, and maintenance of drinking water systems is devolved to Indigenous governments. This division of powers and responsibilities, together with limited access to finance, places a large burden of responsibility on capacity-limited communities without adequate support and oversight (Lebel and Reed 2010; Dunn et al. 2014a; Hanrahan et al. 2014). Basdeo and Bharadwaj (2013) argue that "as a result, uncertainties, inconsistencies, and failed systems have been the norm in First Nation communities" p.3. While Canadian governments have made efforts to invest in Indigenous drinking water infrastructure and review governance frameworks in recent years, these interrelated and systemic causes of drinking water problems in Indigenous communities mean that such problems are difficult to overcome (White et al. 2012; Daley et al. 2015). Existing research on drinking water governance in Indigenous communities in Australia and the USA, while limited, suggests that these complex legacies of colonization are not limited to Canada (Jones and Joy 2006; Wescoat et al. 2007; Grey-Gardner 2008). Further work is needed to examine how complex processes of colonialism manifest in different places, and to directly engage communities in developing appropriate policies and programs to decolonize drinking water governance (see Black and McBean 2017).

Question 3: How effective are various solutions at addressing governance challenges?

The third question addressed by publications in this review concerns the effectiveness of various solutions in preventing and mitigating the challenges that SDWS face. Whereas most publications in the wider SDWS literature focus on technical solutions – including novel treatment, distribution, and monitoring systems – studies in this review argue that improvements in technology and processes alone are insufficient, in light of SDWS' capacity, management, and governance challenges. Here we summarise prominent solutions discussed in the literature that are intended to address the governance challenges SDWS face, noting any evaluation of the affordability, effectiveness, and equity these solutions. Prominent solutions discussed in this literature include: 1) financial and management support for SDWS; 2) regulatory changes; 3) system consolidation; 4) planning-based approaches; and 5) (performance) assessment tools.

Financial and management support

Given widespread recognition of SDWS' capacity limitations, many solutions discussed in the literature involve attempts to improve the technical, managerial, and financial capacity of SDWS. Government and non-governmental organisations have invested in a range of initiatives to support local SDWS operators and managers, including the creation of funding opportunities (such as the State Drinking Water Fund in the USA), networks (e.g. rural operators networks), training programs, educational materials, and partnership opportunities (MacDonald et al. 1997; Brown 2004; Maras 2004; Bickel 2006). These initiatives are intended to address capacity shortcomings directly (as in the case of funding and training) or indirectly (as in the case of operator networks that provide peer-to-peer support). Studies on the uptake and effectiveness of these initiatives vary considerably – while numerous articles have been published on SDWS' access to funding (e.g. Bickel 2006; Shanaghan et al. 2006; Daley et al. 2014), few have examined the operation and outcomes of training programs or operator networks in any detail. Relative to the many calls for more funding for SDWS (e.g. Blanchard and Eberle 2013), there are relatively few available evaluations of existing initiatives (but see Jocoy 2000; Bowman et al. 2009). Evaluations of this type are an important contribution to this literature, as they enable detailed analysis of how effective, economically efficient, and equitable investments in SDWS improvements are likely to be. The few evaluations that have been conducted highlight that, paradoxically, low capacity can prove a barrier to SDWS benefiting from funding and similar capacity-building initiatives. For example, in the case of operator training, sole-operators of remote SDWS are often unable to attend training events due to a lack of replacement staff or funding for travel (Geldreich 2005). This has resulted in a push towards online training programs, although internet access can prove a further barrier for some remote and aging communities (Pons et al. 2014). Similarly, a lack of financial capacity can prevent SDWS from accessing funding opportunities; Jocoy (2000) noted that government requirements for improvements prevented small, under-funded communities from accessing the US state drinking water fund. As such, well-intentioned but inflexible assistance initiatives can become complicit in exacerbating the very capacity issues they are trying to resolve (Balazs and Ray 2014). Greater evaluation of these initiatives, particularly environmental justice studies of key differences in access to support and related barriers, would be useful to better tailor initiatives to meet the specific needs of vulnerable communities (see Kot et al. 2015b).

Regulatory changes

Another common set of solutions discussed in the SDWS literature concern revisions to drinking water regulations that govern the design, operation, and management of SDWS. These regulatory reforms are largely targeted at strengthening drinking water standards, and/or tailoring regulations to better meet the needs and constraints of SDWS. While authors are fairly consistent in their critique that 'one size fits all' regulatory standards place an inequitable and often unachievable compliance burden on capacity-limited SDWS, they differ significantly in their recommended approach to mitigating these issues.

Reflecting the diverse regulatory challenges identified in Question 1, most suggested solutions target regulatory reforms, ranging from exemptions and variances for SDWS from mainstream regulation (a suggestion that has resulted in considerable debate, see Daniels et al. 2008); to regulatory frameworks catering specifically to SDWS (Cook et al. 2013); to revising regulatory criteria in line with small system needs (Jones and Joy 2006); to arguments that strong regulation is preferable, but with concurrent investments to support SDWS compliance and implementation (Balazs et al. 2012). Linked to these concerns, there is ongoing debate as to whether regulations should be nationally applicable (in line with harmonization), or whether decentralized approaches are more appropriate (subsidiarity). For instance, some have argued that the patchwork outcomes of drinking water quality regulation in Canada suggests the need for federal drinking water standards (Dunn et al. 2014a), while others emphasize the need for regional autonomy so that place-specific issues can be taken into account (e.g. monitoring contaminants based on historical occurrence, Brands and Rajagopal 2008). As a hybrid approach, the EU provides an example where drinking waters safety requirements are harmonized, but there is some flexibility regarding national and local implementation (Rickert and Schmoll 2011). Even with a range of discussions related to the most appropriate regulatory approaches to support SDWS and ensure the quality and sustainability of these systems, few studies actually evaluate the outcomes of regulatory changes, in terms of their implementation, effectiveness, and equity outcomes for SDWS. Notable exceptions include select analyses of new drinking water legislation (Gunnarsdóttir et al. 2015; Froscio et al. 2016), or the incorporation of novel regulatory tools and approaches (e.g. requirements for water safety plans, Perrier et al. 2014). Nevertheless, the prospective and post-hoc evaluation of regulatory changes remains a significant gap in the literature. Further, little comparative analysis across regulatory contexts is conducted, despite significant potential across provinces/states in Canada, the USA, and Europe (but see Cook et al. 2013; Dunn et al. 2014a; Orru and Rothstein 2015), which could enable analysis of the strengths and limitations of alternative regulatory approaches.

System consolidation

In recognition of the problems that the proliferation of small, under-capacity systems have created, policy makers and scholars advocate for the consolidation or joint management of SDWS (MacDonald et al. 1997; Morgan 2002; Braden and Mankin 2004). Depending on the jurisdiction and geography of the community, consolidation may range from the physical connection to nearby larger systems, to SDWS being operated and/or managed by an external provider with responsibility for multiple systems (MacDonald et al. 1997). System consolidation may involve a transfer of authority, responsibility, and/or ownership away from the small system to another utility or service provider (Morgan 2002), meaning that this is a governance solution as well as a technical one. Consolidation is advocated on the basis that ageing, low-capacity, and/or non-complying SDWS can access greater economies of scale, expertise, and operational and managerial capacity (Braden and Mankin 2004). Where SDWS require expensive upgrades or maintenance, physical connection to an existing system is often perceived by governments as a more affordable and sustainable solution in the long term.

Studies that evaluate consolidation as a solution to SDWS problems suggest that while important, system consolidation may not be as widespread nor as beneficial as expected, and that significant barriers exist (Lee and Braden 2008; Blanchard and Eberle 2013;

Hansen 2013). Studies do report a long-term trend of system consolidation in the USA, based on reductions in the number of SDWS and increases in population served (Job 2011a; Baird 2012); there is also some evidence that consolidation is occurring in Canada (e.g. Woods 2014; Kot et al. 2015b; Lipka and Deaton 2015). However some researchers argue that consolidation remains relatively rare; for example Lee and Braden (2008) report that only 6.6% of community water systems in six US states were acquired by other systems over their study period (see also Hansen 2013). Further, Castillo et al.'s (1997) study of the potential for SDWS consolidation in 17 US states on the basis of geographic proximity and economic feasibility found that physical interconnection between systems would only be feasible for 35% of small systems (compared to US EPA country-wide estimates of 50%), although the potential for remote management of SDWS was much higher. This study also highlighted that distance and costs are not the only barriers to physical interconnection, with landscape features (e.g. rivers), institutional boundaries (e.g. state lines), and socio-political resistance also preventing wider uptake of consolidation. Indeed, Blanchard and Eberle's (2013) survey of small system operators found that few were interested in consolidating or transferring management to a nearby system, and even those that responded positively were interested in taking over another system, rather than being taken over. This resistance is reported to result from reluctance on the part of small, independent communities to transfer authority to an external agent (Cromwell et al. 1992), a lack of trust between communities and even interpersonal conflicts between local politicians (Kot et al. 2015b), as well as uncertainty over who should pay for the upgrades required to expand service (Morgan 2002). Large utilities must also weigh the drawbacks of taking on small systems – Morgan (2002) highlights that ownership of SDWS ensures authority over the system but creates liability issues, whereas assuming management requires greater consultation with SDWS owners and can result in conflicts. Furthermore, while consumers may benefit financially from the economies of scale created by consolidation, it is not always in the economic interests of producers (Hansen 2013). Indeed Lee and Braden's (2008) analysis of systems that have been acquired through consolidation suggests that systems serving low income or declining populations are less likely to be acquired. There are consequently important equity dimensions to promoting consolidation as a solution, as poor, underperforming communities are likely to face greater financial and political barriers in negotiating a consolidation agreement with nearby systems (Balazs and Ray 2014). However, analyses of First Nations' water service contracts in Canada highlight that consolidation – where properly supported by various levels of government – can help to address systemic inequalities in drinking water risk for Indigenous communities (Woods 2014; Lipka and Deaton 2015).

In light of the barriers to consolidation, and potential for inequitable uptake of this solution, a range of scholars argue for governments to use regulations, incentives, and regional programs to promote the uptake and equity of consolidation moving forward (Baird 2012; Balazs and Ray 2014). For example, Kot et al. (2015b) notes that SDWS were more willing to regionalize when this process was supported by a grant. However in general the outcomes of government interventions to promote system consolidation have not been well studied. Important areas for further research therefore include the effectiveness and equity of 1) various government initiatives to promote uptake of consolidation, and 2) consolidation in improving the safety and affordability of drinking water to small, rural, and

Indigenous communities.

Planning-based approaches

Other governance-focused solutions discussed in the literature include the use of planning approaches to improve SDWS performance and prevent drinking water contamination. Planning is advocated as a mechanism to promote a more holistic understanding of the drinking water system and its risks; and to bring operators, managers, regulators, and other stakeholders together to identify sustainable drinking water management strategies (Santora and Wilson 2008; Castleden et al. 2015). Three main forms of planning are advocated in the SDWS literature, although again, there is limited research on their implementation and effectiveness.

First, scholars and practitioners argue for increased uptake of asset management planning and related forms of financial and infrastructure planning (Cromwell et al. 1997; MacDonald et al. 1997; Brown 2004; Jarocki 2004; Alegre 2010). In recognition of the ageing nature of SDWS infrastructure, and limited investments in infrastructure maintenance and replacement, scholars promote the use of asset management tools to identify the age, lifetime, and maintenance and replacement costs of each part of the system (Jarocki 2004; Maras 2004). This information is intended to provide managers with a more realistic sense of the total future cost of the overall system, allowing them to adjust current rates based on expected lifetime costs, and more effectively plan for infrastructure maintenance and replacement (Brown 2004). These planning approaches are often viewed as relatively achievable, even for very small systems, because of the small size and simplicity of their infrastructure (Pontius 2008; Alegre 2010). However, reviews by MacDonald et al. (1997) and Jarocki (2004) indicate low uptake of asset planning and budgeting among SDWS in the USA, contributing to poor financial performance among these systems. Better understanding of the potential for, and effectiveness of, these planning approaches would represent significant contributions to the field, particularly if there is concurrent evaluation of the requirements and benefits of varied approaches for different system types.

The second form of planning frequently advocated involves the preparation of plans to minimise and/or mitigate drinking water risks, in line with a more general focus on risk management in recent decades. These approaches are generally conducted at the system scale and are geared towards improving system knowledge, preparedness and preventative measures (Gunnarsdóttir et al. 2012). Often these efforts involve the identification and assessment of water quality risks; development of strategies to reduce those risks and manage contamination events; and implementation of preventative measures (Hrudey et al. 2006). In recent years this approach has been institutionalised in industrialised countries through regulatory requirements to develop drinking water safety plans and/or emergency response plans, as well as their inclusion in international guidelines and recommendations (Gunnarsdóttir et al. 2015). Drinking water safety plans are a common, proactive form of risk management planning that involve “a comprehensive assessment of present and potential risks throughout a water supply, from water source to the consumer’s tap, and the development of a plan for reducing these risks to an acceptable level” (Kot et al. 2015a: 1). Following their inclusion in World Health Organisation guidelines in 2004, they have been incorporated into the EU drinking water directive, and implemented in Alberta (Canada), New Zealand, Victoria (Australia), and elsewhere . Several academic and policy studies have been conducted on water safety planning, which collectively highlight the benefits of these plans, while noting the challenges SDWS face in developing and implementing them (Gunnarsdóttir et al. 2012; Perrier et al. 2014; Kot et al. 2015a; World Health Organization 2017). Key barriers to successful implementation include financing and time constraints; weak relationships between operators, local decision makers, and regulators; and negative perceptions of water safety planning as a top-down exercise and added burden on operators. However, it was also noted that water safety planning provided an important mechanism for relationship-building and attitudinal change, with the potential for greater community involvement. In terms of key gaps, our review suggests that further research on plan implementation and outcomes across different jurisdictional contexts would improve knowledge of the effectiveness of this approach, including ways that planning processes and resources could be refined to specifically support SDWS (see also Kot et al. 2015a).

Another common form of risk management planning is hazard or emergency response planning, focusing on how to contain and address public health risks during a contamination event. This type of planning typically involves clarifying the roles, responsibilities, and relationships of relevant individuals and institutions in such an event, as well as the appropriate procedures to be carried out. While advocated by several papers (Logsdon et al. 2004; Hrudey et al. 2006), no evaluation of the effectiveness of such planning for SDWS was identified in this review. It is notable however, that as with water safety planning, this approach emphasises improving relationships between system operators, management, regulators, and communities (including communication, clarification of roles and responsibilities, and trust), and thereby directly targets one of the key limitations of SDWS governance (see question 2).

The third planning-based approach identified in the literature is source water protection, which emphasises a source-to-tap approach to ensuring drinking water safety. Source water protection involves the integrated management of land, surface water, and groundwater adjacent to drinking water sources, and throughout the wider watershed. Such an approach is based on the idea that protecting the land and waterbodies that produce drinking water is the best way to reduce contaminants and treatment costs, and ensure drinking water safety (Patrick 2009). In some cases source water protection may involve targeting specific source areas, while in others it involves a collaborative planning process to identify and manage potential pollution in a multi-use watershed. Research with Indigenous communities in Canada highlights that source water protection may be an appropriate solution for Indigenous drinking water governance, as it protects all water (not just drinking water), requires less chemical treatment (a common source of conflict), and reduces the management burden on communities (Smith et al. 2006; Patrick 2011; White et al. 2012). It should also be an effective strategy for SDWS in theory, as source water protection reduces infrastructural and operational requirements (see Icelandic experience, Gunnarsdóttir et al. 2015). Indeed Kreutzwiser et al. (2011) identify source water protection as a key mechanism for drinking water safety among private wells, where limited treatment options are available. However, the literature review indicates that source water protection remains uncommon, limited in scale, and in general, under-studied. In many contexts it only applies to the area immediately adjacent to a well or water collection point, while in others it is implemented as a voluntary initiative (Johnson et al. 2010). Patrick (2009) highlights that even where there have been attempts to increase application of source water protection – for instance in Ontario, Canada following the Walkerton disaster – wider neoliberal regulatory shifts can prevent its successful implementation. However, instances of source water protection (of specific drinking water catchments) do occur—greater analysis of their implementation (cf. Perrier et al. 2014) and economic, water quality, ecosystem service, and governance outcomes could help to strengthen support for SWP. Work on climate-change adaptation planning based drinking water planning (O'Connor et al. 1999; Maier and Carpenter 2015) also highlights the potential to expand the scope and scale of planning interventions further in in the context of large-scale changes to the hydro-social cycle underway and anticipated.

Assessment tools

In addition to more direct forms of support, another set of solutions discussed in the literature is the development of assessment tools for SDWS. Such tools are variously intended to help identify key 'problem areas' or threats to drinking water safety (e.g. Butterfield and Camper 2004; Lee et al. 2009; Summerscales and McBean 2011); and track system performance over time or relative to other systems (i.e. benchmarking, Rogers and Louis 2007; Bereskie et al. 2016; Haider et al. 2016a). Publications in this study propose and trial such assessment tools, including performance indicators and benchmarking, risk assessment frameworks, and data analysis tools. A common theme among these publications is an appreciation of SDWS' capacity limitations, and the need to develop simple, low-cost assessment tools that will allow operators and/or managers to use available data to identify issues and track progress over time (e.g. Jayanty et al. 2008). Butterfield and Camper (2004) and Summerscales and McBean (2011) highlight that existing assessment tools have been developed for large systems, and are either too data- and energy-intensive for SDWS or are not designed to respond to the specific water quality challenges small systems face. While many publications test their model or framework on one or several systems (e.g. Haider et al. 2016b), there is limited wider validation of such tools; no publications in this review tested an externally-developed assessment tool, and it remains unclear whether the tools would work outside of the context in which they were developed. Further, none of the studies describe engaging operators or managers in the testing process, leaving uncertainty as to whether the assessment tools would be applicable in practice. Thus, while authors highlight the importance of assessment tools in identifying issues of concern for SDWS, tailoring operational and management practices to address those issues, and identifying system indicators with which to track progress over time, there remain questions as to whether the application of these tools would be limited by the same issues of capacity and institutional fit that drove their development.

Question 4. What are the impacts of SDWS' underperformance on communities?

Finally, one area of research that received surprisingly limited attention in literature on SDWS governance is the consequences for communities. While many articles used the poor performance of SDWS, and related public health and safety concerns, as the basis for their examination of a particular aspect of drinking water management or governance, few researched the actual impacts of SDWS on community health, behaviours, finances, and dynamics. Perhaps the number of articles on this topic would have been larger had we not sought articles that directly related to water governance. However, given the significance of social and governance factors in mediating the relationship between source water contamination and individual exposure to contaminants (see Balazs and Ray 2014), as well as the consequences of contamination for consumers, it is surprising that so few studies deal directly with community impacts, particularly from perspectives that go beyond public health framing of the issues. Those studies that do undertake such an integrative analysis often have an environmental justice orientation, highlighting disparities in impact according to community size, ethnic composition, and socio-economic status (e.g. Wescoat et al. 2007). In examining the inequitable distribution of impacts on racially and socio-economically marginalised communities, these studies highlight disparities in 1) communities' exposure to drinking water contaminants and disease; and 2) the socio-economic impacts of drinking water contamination, as summarized below.

Exposure to drinking water contaminants and disease

A handful of studies examine the health impacts of SDWS on communities through statistical analyses of exposure to contaminants, regulatory violations, and incidence of water-related diseases. The underperformance of SDWS compared to medium and large systems, often measured through higher rates of compliance violations (e.g. Job 2011b; Rubin 2013a; Oxenford and Barrett 2016), is widely reported. However, compliance data alone tells us little about how non-compliance is manifest in communities' exposure to particular contaminants and consequences for individual or public health. As noted by McCullough and Farahbakhsh (2015), "the potential health impacts of SDWS are neither benign nor evenly distributed" p.274. A subset of studies therefore use spatio-statistical analysis to examine differences in communities' exposure to specific drinking water pollutants and health risks, demonstrating that exposure is related to community demographics (Hales et al. 2003; Collins and Bolin 2007; Stone et al. 2007; Wescoat et al. 2007; Balazs et al. 2011; Balazs et al. 2012). For example, two studies provide evidence that arsenic concentration in community water systems in the US is linked to the racial profile and socio-economic status of residents. A study in Oregon found that drinking water systems with arsenic concentrations above the maximum contaminant level (MCL) served residents that were more likely to be of Hispanic origin, have a lower median household income, and speak a second language in the home compared with state-wide averages (Stone et al. 2007). Similar trends were observed in San Joaquin Valley (California), where communities with lower home-ownership rates and higher proportions of people of colour were more likely to violate the arsenic MCL (Balazs et al. 2012). Researchers also observed associations between communities' racial composition and socio-economic status and drinking water nitrate concentrations (Balazs et al. 2011); drinking water quality grade (Hales et al. 2003); water system security (Collins and Bolin 2007); and household plumbing deficiencies (Wescoat et al. 2007). Others highlight rural-urban disparities and the overrepresentation of Indigenous communities in drinking water contaminant exposure and disease statistics (Castleden et al. 2015; McCullough and Farahbakhsh 2015). These researchers argue that these results constitute evidence of environmental injustice, wherein marginalised sectors of the population are disproportionately exposed to environmental contaminants and related health risks. Access to safe drinking water has therefore come to depend on where you live (Hrudey

2008), which through historical and contemporary spatially-differentiated processes of colonization, immigration, racial segregation, gentrification, and industrial development and decline, is intimately interrelated with who you are.

The causes of the observed over-representation of low income residents, renters, and people of colour in communities with poor drinking water quality are plural and complex. As such, “there is no direct causal path between race and class and disproportionate burdens; rather, race and class are imbricated in almost all the factors and actors that have historically combined, and still combine, to produce this composite burden” (Balazs and Ray 2014, p.609). While a range of causal factors have already been discussed in Question 2, it is worth noting here a few of the forms of procedural injustice that researchers argue contribute to the distributional injustices demonstrated by these studies. First, regulatory variances and exemptions for small systems are argued to create a two-tiered and inequitable system of drinking water protection, where predominantly Indigenous, rural, and low-income communities are permitted by law to receive lower quality drinking water with fewer management requirements (Scharfenaker 2006a; Daniels et al. 2008). Second, small communities with high proportions of low-income residents are inherently capacity constrained, and therefore disproportionately impacted by regulatory changes, as they are forced to either spend a higher proportion of their income on drinking water, or fail to comply due to their inability to afford system improvements (Collins and Bolin 2007; Stone et al. 2007; Balazs and Ray 2014). Third, researchers highlight that English-language reporting and SDWS exemptions to reporting requirements can create barriers to drinking water protection, as households that do not receive or cannot read system performance reports are less likely to hold suppliers accountable when issues are detected, take preventative measures, or demand improvements in systems, regulations, or support from government (Stone et al. 2007; Daniels et al. 2008). Balazs et al. (2011) also suggest that home ownership and citizenship may act as obstacles to consumers speaking out and demanding better protections. Together, these barriers mean that small, immigrant, tenant, and low SES communities are more vulnerable to system performance issues, and have less political agency to advocate for changes in system operations and governance.

Socio-economic impacts of drinking water contamination

Finally, studies highlight that the impacts of SDWS underperformance extend beyond differential exposure to contaminants and incidence of drinking water diseases across communities, to include a wide range of health, economic, social, and cultural outcomes of these disparities. The most commonly identified consequence is the financial strain that poor water quality places on communities, as in the absence of system improvements individual households are left to rely on expensive bottled water or point-of-use/point-of-entry solutions (Balazs et al. 2012; Vandewalle and Jepson 2015). In low-income communities, the high costs of drinking water provision are noted to limit revenues available for system improvements, and divert household funds away from other health care priorities (Jones and Joy 2006). Low household income is also suggested to increase individuals’ vulnerability to drinking water risks, as households are noted to limit their water use (potentially compromising hygiene), use non-treated water sources, and have less access to nutritious foods and health care (Hales et al. 2003; Stone et al. 2007; Balazs et al. 2011; Balazs et al. 2012; Hanrahan et al. 2014; Sarkar et al. 2015). As such, low-socioeconomic status households are argued to experience greater exposure to contaminants, undertake cost-avoidance behaviours that increase health risks, and be more vulnerable to their effects, leading to disproportionate health impacts on these households.

Indeed Sarkar et al. (2015) highlights that drinking water insecurity can result in a wider range of health impacts, including mental stress, chronic back injuries due to carrying heavy water buckets, obesity and diabetes due to consumption of sugary drinks instead of water, gastro-intestinal infections, and stomach cancer. Basdeo and Bharadwaj (2013) further observe that among Indigenous communities, declining water quality can restrict access to traditional water and food sources, disrupt cultural practices, and have wider effects on spiritual and social relations. In the most extreme examples, First Nations' loss of access to safe drinking water has resulted in the closure of schools and relocation of whole communities, with deep-seated and wide-ranging effects for community wellbeing (see Basdeo and Bharadwaj 2013). However, despite awareness of the cascading effects of drinking water insecurity on households and communities, this review identified very few studies that examine or discuss the wider (and differentiated) impacts of SDWS on community health and wellbeing. It is therefore argued that future research in this area could significantly advance existing understanding of the SDWS dilemma through: 1) more rigorous examination of the relationship between SDWS contamination/violation data and SDWS governance, including identification of the causal factors that contribute to drinking water disparities (see Balazs and Ray 2014); and 2) a greater number and range of empirical studies of the social, economic, and cultural consequences of poor water quality and SDWS compliance violations on communities (e.g. Sarkar et al. 2015).

CONCLUDING COMMENTS

A primary finding of this review is that SWDS governance issues remain under-researched. Even as we identified 117 relevant texts and distilled some key governance insights, it is noteworthy that few contributions had a direct focus on governance. In many cases, aspects of system governance were used to describe the context of research, or to explain the findings of a study, rather than being the primary focus of inquiry (e.g. Rahman et al. 2010). Other publications were narrowly focused on a single governance dimension, such as regulation or finance (e.g. Scharfenaker 2006a), with limited attention to how that aspect fits within a wider governance framework. Consequently, the literature as a whole appears piecemeal and fragmented. There are few attempts to theorise SDWS governance, or to engage in interdisciplinary, cross-jurisdictional conversations about the causes, challenges, and directions of SDWS governance (but see Ford et al. 2005; Rickert and Schmoll 2011). There is a similar fragmentation across national boundaries, with most research focusing exclusively on the USA or Canada, and few studies developing cross-jurisdictional analyses.

Nevertheless, this review has highlighted areas where significant progress has been made in the last 26 years. Our thematic analysis demonstrated the depth and breadth of research on SDWS' capacity and regulatory challenges, and that these challenges recur across national and sub-national jurisdictions. Capacity issues have been identified as a seemingly irreducible feature of SDWS governance, particularly with respect to financial constraints; recent qualitative research on SDWS operations has also demonstrated the importance of human and institutional capacity for SDWS performance (e.g. Scheili et al. 2016). While regulatory (compliance) challenges are similarly well-explicated in the literature, debates continue over how to adjust regulatory frameworks to account for SDWS' capacity limitations – through robust regulation and compliance support, or enabling variability in regulatory requirements. This review has identified opportunities to advance evaluation of regulatory frameworks for SDWS through comparative analyses and research in under-studied jurisdictions, particularly the EU.

In line with the prominence of SDWS challenges in the literature, this review identified a multitude of publications promoting solutions to improve SDWS' capacity and performance, and reduce their regulatory burden. Numerous studies have been conducted on the US government's efforts to address SDWS' low compliance rates, including regulatory variances and exemptions, opportunities for financial support and training, and promotion of consolidation and joint management. While many publications discuss weaknesses in these approaches, including unequal access to or impacts from these initiatives, few studies have undertaken systematic evaluations of their effectiveness, efficiency, or outcomes. Research on system consolidation provides some exceptions, including strong examples of how quantitative analysis can be used to evaluate the potential and actual application of a solution. In Canada and the EU, research has focused more on regulatory solutions – particularly the appropriateness of subsidiarity and spatial variability in drinking water management – and the application of risk-based planning approaches, including water safety planning and source water protection. Case study research on the early application of these approaches has provided rich insight into their expected benefits, as well as the challenges SDWS face in developing and implementing plans (e.g. Perrier et al. 2014). As these approaches are institutionalised in an increasing number of jurisdictions, opportunities exist to examine the implementation and long-term outcomes of planning in a more systematic way, across multiple locations.

Our review revealed that significantly less research has been conducted on the root causes of SDWS' governance challenges, and their impacts on communities; too often studies examine the challenges SDWS experience in isolation from their wider political-economic and social context. Only a handful of studies draw on political economy, political ecology, or similar critical scholarship to interrogate the proliferation of small, under-capacity, and underperforming systems in industrialised nations (e.g. Vandewalle and Jepson 2015; Greiner 2016). Nevertheless, case studies in the USA and Canada have demonstrated that geography and remoteness only partly account for SDWS' challenges, highlighting that under-regulated development, decentralised ownership, and market forces play key roles. Governance scholars further argue that jurisdictional fragmentation within and between levels of government has added to the complexities of ensuring drinking water safety across this large, decentralised matrix of SDWS. This is especially apparent in Indigenous communities, where histories of colonial dispossession and post-colonial governance compound the challenges generally experienced by SDWS. Further critical social science research is needed to analyse the institutions, processes, and relationships through which the causal factors identified by these studies contribute to the proliferation and underperformance of SDWS. Additional policy, quantitative, and GIS analysis across different jurisdictional contexts could also help to evidence the outcomes of different regulatory, ownership, and governance frameworks for SDWS.

Within research on the social impacts of SDWS, a focus on marginalised demographics and communities has revealed important connections between the causes of SDWS challenges and inequality in their effects. Quantitative analysis of water quality and health statistics has proven a powerful tool in exposing environmental injustice in access to safe drinking water, demonstrating that socio-economically marginalised communities are more likely to be exposed to drinking water contaminants, and suffer greater impacts as a result (Balazs and Ray 2014; Sarkar et al. 2015). Studies have identified some of the causal factors contributing to these heightened impacts (including language barriers, lack of access to nutritious foods, etc…), although more community-focused research (cf. population health studies) is needed in this area. For example, existing work on drinking water perceptions and preferences indicates that research with communities on the social, cultural, and health impacts of different drinking water sources and treatments could be beneficial.

Looking forward, our review suggests the need for a more holistic, integrative approach to research on SDWS governance. Specifically, we argue that a revised research agenda built upon a water governance framework (e.g. Franks and Cleaver 2007) would enable researchers to more effectively converse across disciplinary boundaries; situate their studies in broader political-economic and institutional contexts; compare findings across contexts; and examine under-recognised but important aspects of SDWS governance. Building on insights gained from our review, we suggest five ways in researchers could advance a more integrative understanding of SDWS governance: (1) By moving beyond case studies and context-specific reviews to examine the types of governance institutions, mechanisms, and processes that facilitate improved SDWS management and performance. (2) By extending the governance framework beyond regulations and capacity, to consider how the organisation of decision-making authority, responsibility, oversight, communication, etc. affect SDWS performance. (3) By engaging a broader range of actors – including regulators, managers, elected officials, and citizens – in research on SDWS' governance. (4) By situating drinking water management within a more holistic understanding of the hydro-social system that integrates water's social, ecological, spiritual, and economic aspects, and considers quantity alongside quality. (5) By undertaking more spatially extensive and integrative research. In particular, this review highlights the potential for more SDWS research in Europe, Australia, and other industrialized nations outside North America; comparative research across jurisdictions; and cross-pollination of research questions and insights between developing and industrialised nations. Collectively, these five research directions emphasise a shift from ad-hoc and technocentric research on SDWS governance, to research that engages governance theory and insights to critically interrogate the current regulation, management, and operation of SDWS.

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TABLES

Table 1. Key themes in the academic literature on SDWS governance (n= 117)

Theme	% publications addressing theme	Key foci in literature, with example citations
Finance & funding	48%	• SDWS' difficulties achieving economies of scale (Male et al. 1991) • Financial capacity limitations - revenue shortfalls & lack of financial reserves (Baird 2012) • Public & political support for raising water rates (Cho et al. 2005) • Need for financial accounting, reporting & asset management (Jarocki 2004) • Funding options (loans & grants) available for SDWS (Bickel 2006) • Barriers to accessing funding (Jocoy 2000; Balazs and Ray 2014)
Regulation	44%	• Regulatory compliance rates among SDWS (Job 2011b; Rubin 2013a; Oxenford and Barrett 2016) • Compliance burden & barriers to implementation (Kot 2009; Kot et al. 2015b) • Affordability criteria for regulations (Jones and Joy 2006; Cho et al. 2010) • Distributional equity of regulatory protection & cost (Balazs et al. 2012; Dunn et al. 2014a) • Regulatory variances & exemptions for SDWS (Daniels et al. 2008) • Water quality standards vs. guidelines (Cook et al. 2013; Dunn et al. 2014a)
Operational & management capacity	39%	• Technical, operational, managerial & institutional aspects of capacity • Impacts of capacity limitations on SDWS performance (Scheili et al. 2016) • Constraints on operator availability, employment & training (Bergman 2008; Pons et al. 2014) • Capacity limitations on SDWS management (Braden and Mankin 2004) • Role of institutional arrangements in shaping capacity (Cromwell et al 1997) • Technical capacity limited by access to expertise & information (Dziegielewski and Bik 2004)
Assessment & monitoring	32%	• Limitations of SDWS water quality monitoring and data (Cook et al. 2013; Balazs and Ray 2014) • Alternative monitoring approaches (Brands and Rajagopal 2008; Roig et al. 2014) • Performance assessment – indicators and tools (Coulibaly and Rodriguez 2004; Bowman et al. 2009; Haider et al. 2014) • Performance benchmarking (Rogers and Louis 2009; Bereskie et al. 2016) • Risk assessment & management tools (Butterfield and Camper 2004; Staudinger et al. 2006; Lee et al. 2009; Summerscales and McBean 2011)

Governance structure	26%	• Opportunities for & benefits of community participation (Flora 2004; Grey-Gardner 2008; Basdeo and Bharadwaj 2013) • Costs & benefits of decentralised drinking water governance (Dunn et al. 2014a; Castleden et al. 2015; McCullough and Farahbakhsh 2015) • Fragmented jurisdiction & unclear division of responsibilities (Patrick 2009; Lebel and Reed 2010; Dunn et al. 2014a) • Governance of private individual systems (Charrois 2010; Kreutzwiser et al. 2011; Vandewalle and Jepson 2015) • Institutional oversight and accountability (Cromwell et al. 1992; Gunnarsdóttir et al. 2015) • Institutional barriers to improvement (Cromwell et al. 1992; Daley et al. 2014) • Importance of strong governance relationships (Perrier et al. 2014)
Assistance & support (non-financial)	26%	• Technical assistance needs of SDWS (Dziegielewski and Bik 2004; Maras 2004; Blanchard and Eberle 2013) • Role of partnership organisations and support networks (Bergman 2008; Kot 2009; Baird 2012) • Training for operators and officials (Brown 2004; Bowman et al. 2009) • Information resources and tools (Brown 2004; Geldreich 2005)
Equity/ environmental justice	25%	• Disparities in exposure to contaminants, compliance violations, and incidence of disease (Hales et al. 2003; Stone et al. 2007; Balazs et al. 2012) • Effects of drinking water insecurity on communities (Basdeo and Bharadwaj 2013; Sarkar et al. 2015) • Structural drivers of inequality in drinking water supply (Balazs and Ray 2014; Greiner 2016) • Procedural injustice – eligibility for assistance, unequal regulatory protection & costs (Daniels et al. 2008; Cho et al. 2010; Balazs et al. 2012)
Planning & management approaches	21%	• Source water planning & protection (Patrick 2009; Johnson et al. 2010; Gunnarsdóttir et al. 2015) • Need for improved asset management & financial planning (Cromwell et al. 1997; Jarocki 2004; Alegre 2010) • Best management practices (Johnson et al. 2010; Baird 2012) • Water safety planning (Gunnarsdóttir et al. 2012; Perrier et al. 2014; Kot et al. 2015a)
Social factors	21%	• Community demographics & dynamics (Flora 2004; Greiner 2016) • Perception, awareness of water quality & risks (Kot et al. 2011; Castleden et al. 2015) • Drinking water perceptions & preferences (Goldhar et al. 2013; Kot et al. 2015b) • Community support & willingness to pay for improvements (Kreutzwiser et al. 2011; Kot et al. 2015a) • Significance of relationships between communities, operators, decision makers & regulators (Kot et al. 2011; Perrier et al. 2014) • Connecting SDWS to social capital, livelihoods & community development (Grey-Gardner 2008; McCullough and Farahbakhsh 2015)

Consolidation/ regionalisation	20%	• Potential for consolidation to address SDWS financial/capacity issues (Cho et al 2005) and improve drinking water outcomes (Lipka and Deaton 2015) • Trends in/uptake of DWS consolidation (Job 2011b; Baird 2012) • Scope of potential application of consolidation (Castillo et al. 1997; Lee and Braden 2008) • Socio-political barriers to consolidation (Blanchard and Eberle 2013; Hansen 2013; Kot et al. 2015b) • Need for regulations & planning to promote consolidation (Baird 2012)
System ownership	16%	• Reasons behind creation of small, privately owned systems (Cromwell et al. 1992; MacDonald et al. 1997; Vandewalle and Jepson 2015) • Trends in ownership among SDWS (Charrois 2010; Greiner 2016) • Relationship between ownership & system performance (Wallsten and Kosec 2008; Rahman et al. 2010; Edwards et al. 2012; Beer et al. 2015) • Effects of ownership on system capacity, access to funding, and ability to implement changes (Dziegielewski and Bik 2004; Baird 2012) • Costs & benefits of private providers (González-Gómez et al. 2013; Greiner 2016) • Non-state solutions to drinking water safety (Vandewalle and Jepson 2015)
Indigenous communities	13%	• Water insecurity & health risks in Indigenous communities (Smith et al. 2006; Sarkar et al. 2015) • Jurisdictional complexity & gaps in drinking water governance (Lebel and Reed 2010; Basdeo and Bharadwaj 2013; Dunn et al. 2014a) • Challenges to safe water provision in Indigenous settlements (Smith et al. 2006; McCullough and Farahbakhsh 2015) • Options for & implications of Indigenous control (Lebel and Reed 2010; White et al. 2012) • Indigenous knowledge, skills & perspectives on safe drinking water (Grey-Gardner 2008; Basdeo and Bharadwaj 2013; Goldhar et al. 2013) • Legacy of colonization (White et al. 2012; Basdeo and Bharadwaj 2013)
Communication	12%	• Inadequate communication of health risks & mitigation strategies to public (Balazs and Ray 2014) • Challenges communicating drinking water quality & risk (Stone et al. 2007; Kot et al. 2011; Castleden et al. 2015) • Relationship between reporting requirements & system violations (Bennear and Olmstead 2008; Daniels et al. 2008) • Communication of system financial & operational status improves consumer confidence & support (Dziegielewski and Bik 2004; Geldreich 2005) • Importance of informal communication networks (Kot 2009) and trusted sources of information (Castleden et al. 2015)

Risk	12%	• Public health risks associated with drinking water (Sarkar et al. 2015) • Public understanding & perceptions of risk (Goldhar et al. 2013; Castleden et al. 2015) • Determinants of community/household vulnerability (Stone et al. 2007; Sarkar et al. 2015) • Risk assessment (Smith et al. 2006; Staudinger et al. 2006; Lee et al. 2009; Summerscales and McBean 2011) • Risk management approaches (Grey-Gardner 2008; Santora and Wilson 2008) • Vulnerability to climate change (O'Connor et al. 1999; Dow et al. 2007; Castleden et al. 2015)

SUPPLEMENT I: FURTHER DETAILS ON LITERATURE REVIEW APPROACH

This article reviews English-language academic publications on the governance of small drinking water systems (SDWS) in industrialised countries. Relevant publications were identified through a two-step approach, beginning with a search of online databases using SDWS keywords, followed by inclusion/exclusion of the resulting publications based on their use of governance terms and concepts.

Search terms for SDWS were initially identified based on their use in key international reports on the state of SDWS (Ford et al. 2005; Hulsmann 2005; Rickert and Schmoll 2011), and refined by trialling search terms in several online databases (Google Scholar and Web of Science). As there is significant variability in SDWS terminology across jurisdictions, it was decided that keyword searches would combine 1) adjectives describing relevant system or community types (small, rural, Indigenous and synonyms), and 2) nouns for drinking water infrastructure (systems, utilities, supplies). Broader terms such as ‘drinking water’ and ‘infrastructure’ were also trialled, but were not used in the final search as a high proportion of their results were out of scope of this review.

The database search was undertaken in October 2016 using Google Scholar, Web of Science (Thomson Reuters), ScienceDirect (Elsevier), and Wiley Online Library (Wiley), which captured a broad range of English-language science and social science publications. Search queries identified relevant articles, books, theses, and conference papers published between 1990-2016 using combinations of the following search terms:

Small OR Community OR Rural OR Indigenous OR Aboriginal OR Native American* OR Maori OR First Nation* OR Inuit OR Metis
AND or NEAR (depending on database Boolean terms)
Water System* OR Water Utilit* OR Water Suppl*

Each database search generated hundreds to thousands of potential publications. The lead author reviewed the title, abstract, and keywords of the resulting publications, and identified relevant publications according to three inclusion/exclusion criteria:

1. *Case study or geographic context*: publications that focused on industrialised countries (i.e. Australia, New Zealand, the USA, Japan, South Korea, Canada, and members of the European Union) or undertook international reviews were included; all others were excluded.
2. *Relevance to governance*: Publications that referenced some aspect of SDWS governance (i.e. operational, managerial, institutional, regulatory, economic, social, or political aspects) were included; all others were excluded.

3. *Relevance to small, rural, and Indigenous systems*: Publications that stated a focus or specific attention to small, rural, or Indigenous systems (among others) were included; those that aggregated all drinking water systems or explicitly focused on medium or large systems were excluded.

All publications that met all three of the inclusion criteria were exported to an Endnote library. Duplicate results from across the database searches were removed.

The resulting list of publications was further refined during analysis of the full texts. 17 publications were not accessible via the University of British Columbia's online and hardcopy library collections,[1] and were excluded from the review. Other texts that appeared to be within scope of the review based on their abstracts turned out to have little relevance to SDWS governance (e.g. their results and discussion focused entirely on technical aspects of SDWS) and were also excluded. A handful of additional relevant texts were identified based on citations in publications included in the review; while reference lists were not systematically analysed, studies that were cited in-text in relation to SDWS governance were sought and included if relevant. A reviewer of the manuscript also identified two further texts that were within scope of the review.

In total, our review approach identified 117 accessible English-language academic publications on SDWS governance in industrialised countries. The majority of texts were journal articles; a smaller number of conference papers and theses were identified. While grey literature was not included in the literature search and analysis, a few widely-cited reports were reviewed during development of the approach, and are cited in the paper where relevant (Ford et al. 2005; Hulsmann 2005; Rickert and Schmoll 2011).

All 117 publications were reviewed using open-ended coding in NVivo to identify the range of governance topics featured, followed by inductive analysis of the resulting codes to group similar topics into broader themes (see Saldana, 2016). This approach aimed to identify the range of themes that represent the diversity of foci in the literature, while minimizing repetition in insights across themes. This iterative coding process produced a list of 14 prominent themes in the literature.

Publications were also analysed according to bibliographic descriptors. Publication dates and venues were analysed using Endnote tools; other descriptors were created through coding of publications:

1. The *geographic setting* of the research (i.e. case study or jurisdictional context analysed) was coded, and then aggregated according to country or region (e.g. Europe), depending on each country's prominence in the literature. Five

1 Almost all of the inaccessible texts were conference proceedings.

publications addressed more than one country/region, and were coded as ‘transnational’.

2. The *type(s) of system* featured in the publication were coded, using the codes small, rural, Indigenous, community (i.e. a range of system sizes), and private/individual (e.g. household wells). While most publications focused on one nominal system type, a subset of the SDWS literature identified systems of interest by both their size and rural location.
3. The *methodology* employed was coded according to statements made by the authors (e.g. this study uses a qualitative approach) and/or review of the methods and data presented. Publications were coded as either primarily quantitative (i.e. relied on primarily numerical data and analytical methods), primarily qualitative (e.g. used interviews, observations, or document analysis as primary data collection methods), mixed methods (i.e. a combination of quantitative and qualitative techniques), or review (i.e. no primary data analysis).

All coding was summarised using basic quantitative descriptors (counts and percentages); excerpts coded by theme were further analysed to identify key foci and the state of research on each theme.