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Evaluating the use and intent of drinking water advisories in Atlantic Canada

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Abstract

Drinking water advisories (DWAs) are used as a tool for identifying water safety concerns in many jurisdictions. Evidence from previous research demonstrates a lack of improvement in water system operations over time, with an increase in the total number of DWAs in place. DWAs are predominantly issued due to operational concerns within a water system, implying a lack of proactive management measures for preventable issues. Therefore, DWAs represent a chronic issue for many water systems, particularly those lacking resources to implement operational improvements. This study explores DWA characteristics in Atlantic Canada, including frequency and duration, focusing on municipal and private water systems. Seasonality was identified as a trend in DWA issuance in Nova Scotia, and reasons for DWA issuance are largely unchanged over time. Neither of these identified concerns has led to a change in DWA reporting or issuance procedures. Additionally, this study identifies a lack of a common reporting format, leading to the proposal of a template of minimum characteristics for future DWA reporting. Overall, this study highlights deficiencies in the DWA issuance process as a water safety measure and suggests alternative methods for risk management in water systems to alleviate the persistence and prevalence of DWAs in Canada.

Keywords: Boil order; Drinking water advisory; Rural water system; Water safety; Water management

Highlights

- The drinking water advisory (DWA) lacks necessary information about water system risk.
- DWAs are largely issued as a result of operational or process-related concerns.
- There is a disproportionate DWA burden in small and rural water systems.
- Advisory issuance shows clear seasonality.

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Introduction

In Canada, the drinking water advisory (DWA) is used as a tool to communicate concerns with water quality safety both to consumers and government agencies that regulate drinking water systems (Environment & Climate Change Canada, 2018). DWAs can be precautionary (related to operational challenges, treatment failures or adverse water quality results) or emergency advisories (issued as a result of microbial contamination) (Environment & Climate Change Canada, 2018). Previous studies have shown that the majority of advisories issued are precautionary (Galway, 2016; Murphy *et al.*, 2016; Black & McBean, 2018; Post *et al.*, 2018). DWAs are most often issued for operational or process-related concerns; according to a 2018 report specifically on Boil Water Advisories (BWAs), 83% of all advisories are related to these issues, with only 4% of BWAs issued as a result of *Escherichia coli* presence in drinking water (Environment & Climate Change Canada, 2018). Several studies have shown the prominence of operational concerns in First Nation DWAs specifically: 40% of advisories are related to operational concerns in these water systems (Thompson *et al.*, 2017).

The prevalence of precautionary DWAs is not the only concern revealed by previous studies. The lack of a consistent and uniform DWA reporting method is a common theme observed in the literature. Each province or territory has a different agency in charge of reporting advisories and the information presented with each advisory lacks a uniform format (Miller & Watson, 2011; Murphy *et al.*, 2016; Post *et al.*, 2018). Inconsistencies in reporting format, both across provinces and over time, make it difficult to compile an accurate and complete data set for analysis (Eggerston, 2008; Harvey *et al.*, 2015; Murphy *et al.*, 2016). As a result, several previous studies have censored DWA data sets, limiting the effectiveness of DWA characterization (Thompson *et al.*, 2017; Post *et al.*, 2018). Complete data sets for either municipal, private or First Nation water systems are virtually nonexistent.

Several studies have examined DWAs in First Nation water systems given the federal government's 2015 initiative to end all DWAs in First Nation communities by 2021 (Indigenous Services Canada, 2019). With the current focus the government has placed on removing DWAs in First Nation water systems, several studies have evaluated trends over time (Indigenous Services Canada, 2018). First Nation water systems have experienced a disproportionately high number of long-term DWAs compared to municipal and private water systems (Murphy *et al.*, 2016; Bradford *et al.*, 2017; Thompson *et al.*, 2017). Of the 420 First Nation communities included in a study of advisories from 2004 to 2014, 1773 advisories were reported (Thompson *et al.*, 2017). Galway's study in 2016 found a mean advisory duration of 294 days, while Thompson *et al.* (2017) found a mean duration of 169 days (Galway, 2016; Thompson *et al.*, 2017). The study performed by Galway examined 402 advisories in Ontario First Nations from 2003 to 2014. The commonly observed characteristic is the presence of a large number of long-term advisories, impacting both health and well-being in these First Nation water systems.

Analysis of DWAs has primarily revolved around historical data modeling to formulate predictive tools. Murphy *et al.* (2016) used data from First Nation water systems in a decision tree model to construct a predictive algorithm for future advisories with a 79% accuracy rate. Harvey *et al.* (2015) used data mining to model First Nation water system DWAs with an accuracy rate of 71% overall. Furthermore, the addition of water quality monitoring data (free chlorine, pH, temperature, etc.) has been proposed as a mitigation additional measure for that should accompany DWA reporting to provide context; if implemented, up to 36% DWAs could be removed (Black & McBean, 2018). While the two predictive models have an accuracy rate of over 70%, the operational issues contributing to DWAs are not being addressed; it is broadly acknowledged that the underlying issues causing DWAs need to be

resolved to effectively reduce the total number of advisories in place over time (Harvey *et al.*, 2015; Murphy *et al.*, 2016; Black & McBean, 2018; Post *et al.*, 2018).

The focus on First Nation water systems is important for Canada to fully address its commitment to the Truth and Reconciliation Commission (Truth & Reconciliation Commission of Canada, 2015). In addition, the emphasis is needed to address registered water systems or private on-site systems that also struggle to provide safe drinking water. Small or registered water systems face DWAs as often or more frequently than municipal water systems and often lack the proper resources to adequately address the advisory (Eggerston, 2008; Kot *et al.*, 2011; Eggerston, 2015); this can include lack of technical expertise, inadequate financial resources and lack of advanced water quality knowledge needed to address concerns (Butterfield & Camper, 2004; Boag *et al.*, 2010; Kot *et al.*, 2011). The combination of one or more of these factors can create inequalities associated with access to *public* drinking water.

This study examines the characteristics of DWAs in the Atlantic Canadian provinces for both municipal and registered (private) water supply systems. The objective was to understand DWAs over time, considering both the duration of advisories and trends in issuance. Furthermore, the reason for DWA issuance over time was examined to understand changes needed in water systems to remove current DWAs. In addition, patterns in DWA issuance including seasonality and populations impacted were examined. Using the results from these analyses, this study also focused on understanding the changes needed to improve DWA reporting and examined how DWAs can inform alternative water management strategies.

Methods

Data collection

In order to better understand DWAs and their utility as a water management and planning tool, DWA data were reviewed from three of the four Atlantic provinces: Nova Scotia, New Brunswick and Newfoundland and Labrador. No data are currently reported publicly from Prince Edward Island and as a result, this province was excluded from the analysis of the Atlantic region.

Nova Scotia. Data from Nova Scotia were collected from the Nova Scotia Environment website, where both municipal and individual system DWAs are reported on a weekly basis. A municipal system is one that holds municipal water works approval for 'collection, production treatment, storage, supply or distribution of potable water to the public' (Nova Scotia Environment & Labour, 2019). A registered or individual system is a public water supply system, such as an apartment building, school, rural development and campground, not connected to a municipal water system (Nova Scotia Environment & Labour, 2019). Both types of systems are considered public water systems: a water system operating for more than 60 days per year, serving at least 15 service connections or 25 people (Nova Scotia Environment & Labour, 2019).

Historical DWA data from Nova Scotia were made available to the public in October 2019. Data were downloaded from: https://data.novascotia.ca/Environment-and-Energy/Boil-Water-Advisories/7t68-9xmm for data issued between 2001 and 2019 (Nova Scotia Environment & Energy, 2019). Data were transferred from portable document format to a comma-separated variable Excel file and analyzed in the R software language. Prior to 2019, data on DWAs were generated on a weekly basis in portable

document format and needed to be saved as individual documents, similar to the method employed in Newfoundland and Labrador.

New Brunswick. New Brunswick data are available online through the Office of the Chief Medical Officer of Health (Government of New Brunswick, 2019) and are updated as DWAs occur. The data on this website were emailed to researchers, who then copied the data to a table format in Excel. Data were available from 1 January 2006 to Summer 2019 when the data were compiled.

Newfoundland and Labrador. Newfoundland and Labrador reports are uploaded weekly to the Municipal Affairs and Environment website under the Water Research Portal, similar to the Nova Scotia format (Municipal Affairs & Environment, 2019). The Water Research Portal provides detailed information on the issuance and removal of DWAs, both by community and date in portable document format. As past reports are not available on this platform, data from Newfoundland and Labrador were only collected from Spring to Summer 2019. Data were obtained online and translated to an Excel document for analysis in R software.

Data analysis

Data from each Atlantic province were analyzed to determine (1) what characteristics are being reported in each jurisdiction, (2) the duration of DWAs over time, (3) the reason a DWA was issued and (4) if any patterns exist in the data over time that are useful for water management decision-making. The purpose behind each goal is to determine what features in these water systems make a system or community vulnerable and thus susceptible to future water quality concerns. Substantial evidence reporting DWA prevalence has been supplied; however, more studies are needed to link the reasons behind the occurrence of a DWA or to identify system characteristics that make a water system vulnerable. This study focuses on the reason a DWA was issued over time to determine changes in water system operations and monitoring.

Results

Reported characteristics of DWAs

Review of the reporting mechanisms utilized in Nova Scotia, New Brunswick and Newfoundland and Labrador indicates that there is no common acceptable format for reporting DWAs in the Atlantic provinces. The only features all three reports have in common are the start date of the advisory and the reason the advisory was issued. Duration date (start date to end date) can only be calculated for Nova Scotia and New Brunswick. Furthermore, system size (as represented by population) is only available in Newfoundland and Labrador, although Nova Scotia differentiates between registered (private) water systems and municipal water systems. Neither of these statistics is available for New Brunswick. No system contains all the characteristics analyzed, which leads to a fragmented data set for analysis at a federal level.

DWA trends over time. The largest data set available for this study came from Nova Scotia. Figure 1 shows the number of DWAs issued each week over the 10-year study period. The red bars represent the number of DWAs issued each week, while the blue bars represent the number of DWAs removed each week. Seasonality is represented on the graph by the colored bands across the background, each band representing 3 months. Winter is represented in blue, spring is represented in green, summer is represented in red and fall is represented in yellow.

Evidence from Nova Scotia presented in Figure 1 demonstrates that drinking water issuance over time shows periodicity and predictability. In Figure 1, each bar represents a month of DWA data. More DWAs were removed than were issued in 70 months out of 132 months total. There are 10 months where the number of DWAS issued is equal to the number removed. However, in 52 of the months, the number of new DWAs issued was higher than the number of advisories removed. In 39% of the

Fig. 1. (a) Trend in private system DWA occurrence over time in Nova Scotia. (b) Trend in DWAs in New Brunswick from 2009–2019. Seasonality is represented on the graph by the colored bands across the background, each band representing 3 months. Winter is represented in blue, spring is represented in green, summer is represented in red and fall is represented in yellow. Please refer to the online version of this paper to see this figure in color: https://doi.org/10.2166/wp.2020.029.

months where data were collected, more DWAs were issued than removed, indicating that overall, the situation in the province is not improving. Most reports available on DWAs indicate the number of DWAs removed; the results in Figure 1 indicate that keeping track of DWAs issued each month is important as it gives a net output for how effectively water systems are being managed. Based on the data presented herein, it is clear DWAs are a largely unresolved issue.

Figure 1(b) shows DWAs over time in New Brunswick, summarized by month. The lowest number of DWAs issued by month was zero and the highest was 11 DWAs. There are 8 months where no DWAs were issued out of 96 months total in the data set. In 55 months, more DWAs were removed than issued. In the remaining 32 months, more DWAs were issued than removed, representing 33% of the total data set. Overall, the summer and fall months predominantly had more DWAs issued than removed, similar to the trend observed in Nova Scotia (areas colored in red and yellow, respectively). To further explore DWAs issuance, Figure 2 shows the number of DWAs issued versus removed in Nova Scotia (Figure 2(a)) and New Brunswick (Figure 2(b)). Figure 2 confirms that overall the number of months with more DWAs issued than removed is similar to the number of months where DWAs removed is greater than issued.

Seasonality of DWAs is examined in Figure 3. Month is represented numerically on the x-axis, duration is represented in days on the y-axis and Figure 3(a) shows data from Nova Scotia, with Figure 3(b) representing data from New Brunswick. The majority of new DWAs are issued in the summer and fall months, between May and October. In the winter months, DWA issuance is the smallest. Figure 3 shows a clear seasonal trend in DWA issuance and removal in Nova Scotia. In New Brunswick, seasonal trends are not well-defined; however, the longest duration DWAs are issued in June, July, August and September. Seasonality plays an important role in Nova Scotia, predominantly due to registered system characteristics. Seasonal businesses and a yearly sampling requirement lead to a large portion of total coliform and E. coli testing in late summer months, accounting for the sharp increase in DWAs issued during the summer. Water quality testing in these private systems is only required once a year (Health Canada, 2014).

Reasons DWAs are issued. To further understand DWAs in the Atlantic provinces, Figure 4 presents the reasons DWAs are issued. Emergency DWAs are represented in red and precautionary DWAs are represented in blue. DWAs in New Brunswick and Newfoundland and Labrador are primarily issued due to operational concerns. Municipal systems in Nova Scotia shared this characteristic; however, registered system DWAs are predominantly emergency DWAs, issued due to the presence of total coliforms.

In Newfoundland and Labrador, less than 12.5% of all DWAs are emergency advisories. The remaining 87.5% of DWAs issued in 2019 were operational concerns, ranging from concerns with chlorine disinfection effectiveness to the lack of disinfection procedures and water quantity issues (loss of flow in the distribution system or change in source water inflow). DWAs are predominantly issued as a result of a failure within the chlorine disinfection system. In New Brunswick, 26 emergency DWAs were issued out of 324 total DWAs over a 10-year period. Therefore, 92% of DWAs in New Brunswick were precautionary DWAs related to operational concerns. Water main breaks and power outages are the two most frequent reasons DWAs are issued. Available reasons in Newfoundland and Labrador focus mainly on disinfection as a barrier to preventing microbial contamination, while New Brunswick reporting revealed concerns with infrastructure failure and water quantity concerns.

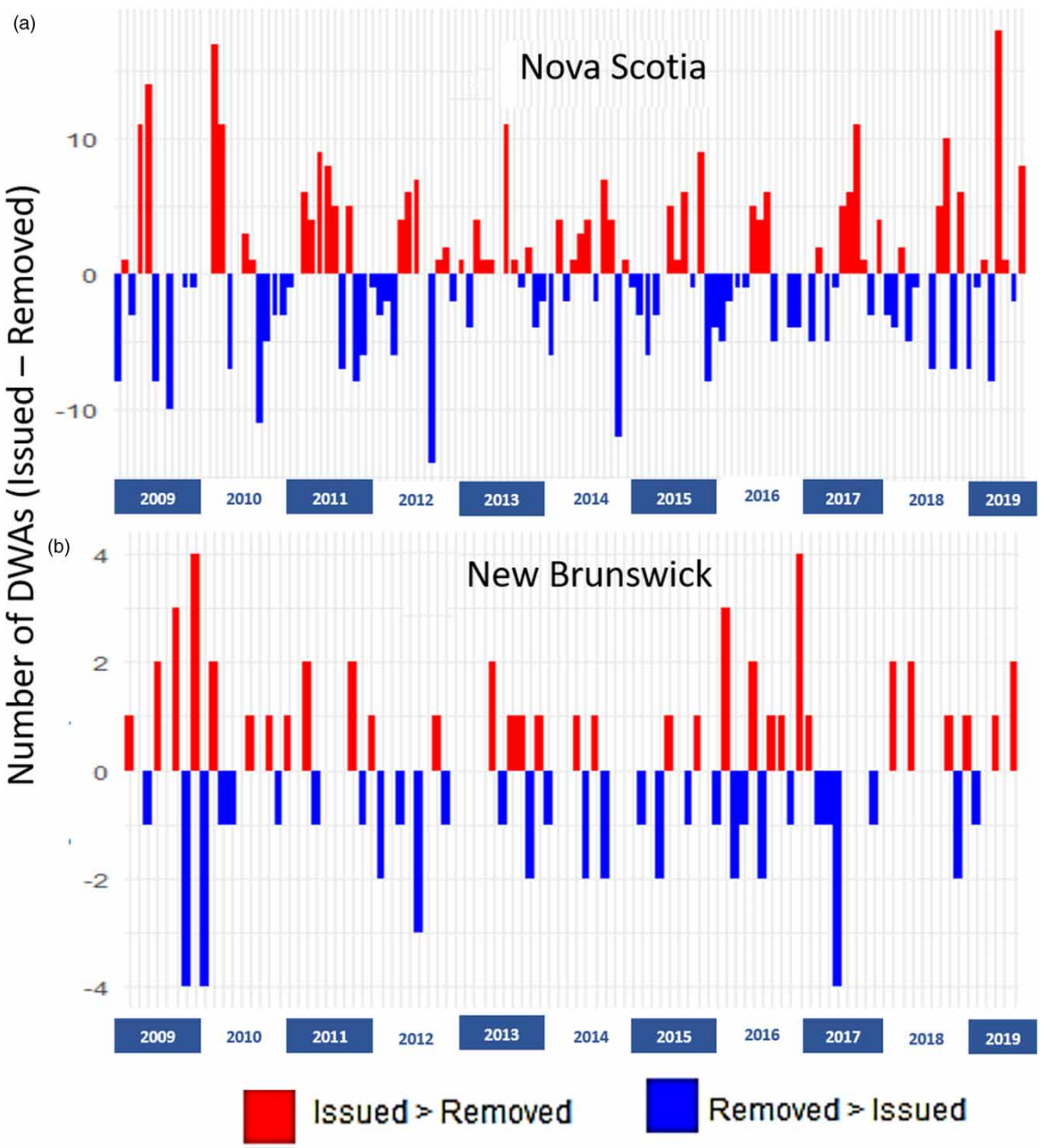

Fig. 2. In both Nova Scotia (a) and New Brunswick (b), there are few months where the number of DWAs issued is equal to the number removed. Each bar in this figure represents a month of data. Bars in blue represent months where more DWAs were removed than issued and bars in red represent months where more DWAs were issued than removed. Please refer to the online version of this paper to see this figure in color: https://doi.org/10.2166/wp.2020.029.

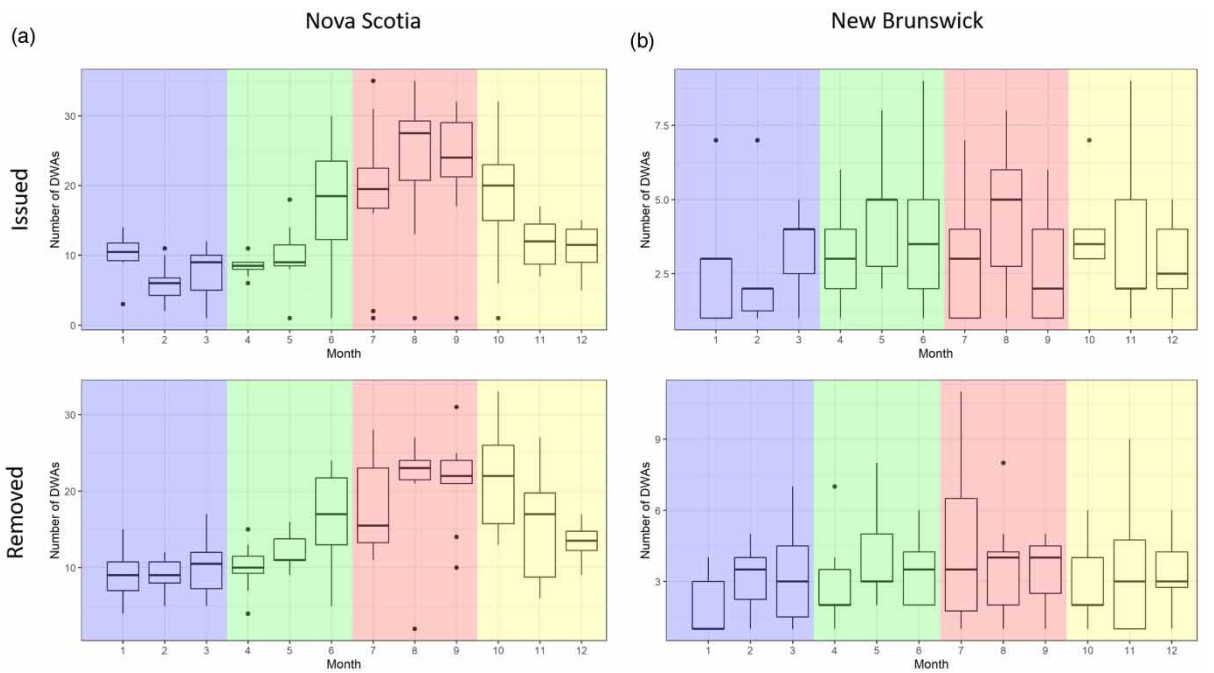

Fig. 3. DWA issuance and removal by month revealed clear seasonality in DWA issuance in Nova Scotia. The majority of DWAs is issued in summer and fall months, with the most DWAs issued in August.

In Nova Scotia, approximately 50% of municipal DWAs are precautionary DWAs. In registered systems, there were 1,442 emergency DWAs representing 76.9% of advisories issued. Of the 1,876 DWAs reported in Nova Scotia, only 28 were in municipal systems, indicating 98.5% of all DWAs issued in Nova Scotia were in registered systems. The main reason DWAs are issued in registered systems is the presence of total coliforms in water samples. Figure 4 clearly demonstrates the unequal water quality and health burden experienced in registered systems. Registered systems experience the majority of DWAs in Nova Scotia, with DWAs issued as a result of unsafe water quality.

Population impacts by DWA. The number of people served by a water system was only available from Newfoundland and Labrador. Small systems represent water systems that serve a population of less than 5,000 people. Figure 5 reveals that DWAs are predominantly issued in small water systems, with large systems having DWAs for one specific reason (D1, distribution system undergoing repairs). The only reason a DWA was issued for a large system represented a precautionary measure, while the water distribution system was undergoing repairs. The number of advisories in small systems was largest for reasons E2 and E1, both representing water with a low disinfectant chlorine residual. Reason C1 represents the absence of disinfection as a result of repair or mechanical failure and reason A represents a water system with no disinfection system in place. The full suite of reasons defined by Municipal Affairs & Environment (2019) is presented in Supplementary Table S1. As seen previously in Figure 4, the four predominant reasons that DWAs are issued in small systems are due to operational concerns, specifically related to disinfection. Population data were only available from Newfoundland and

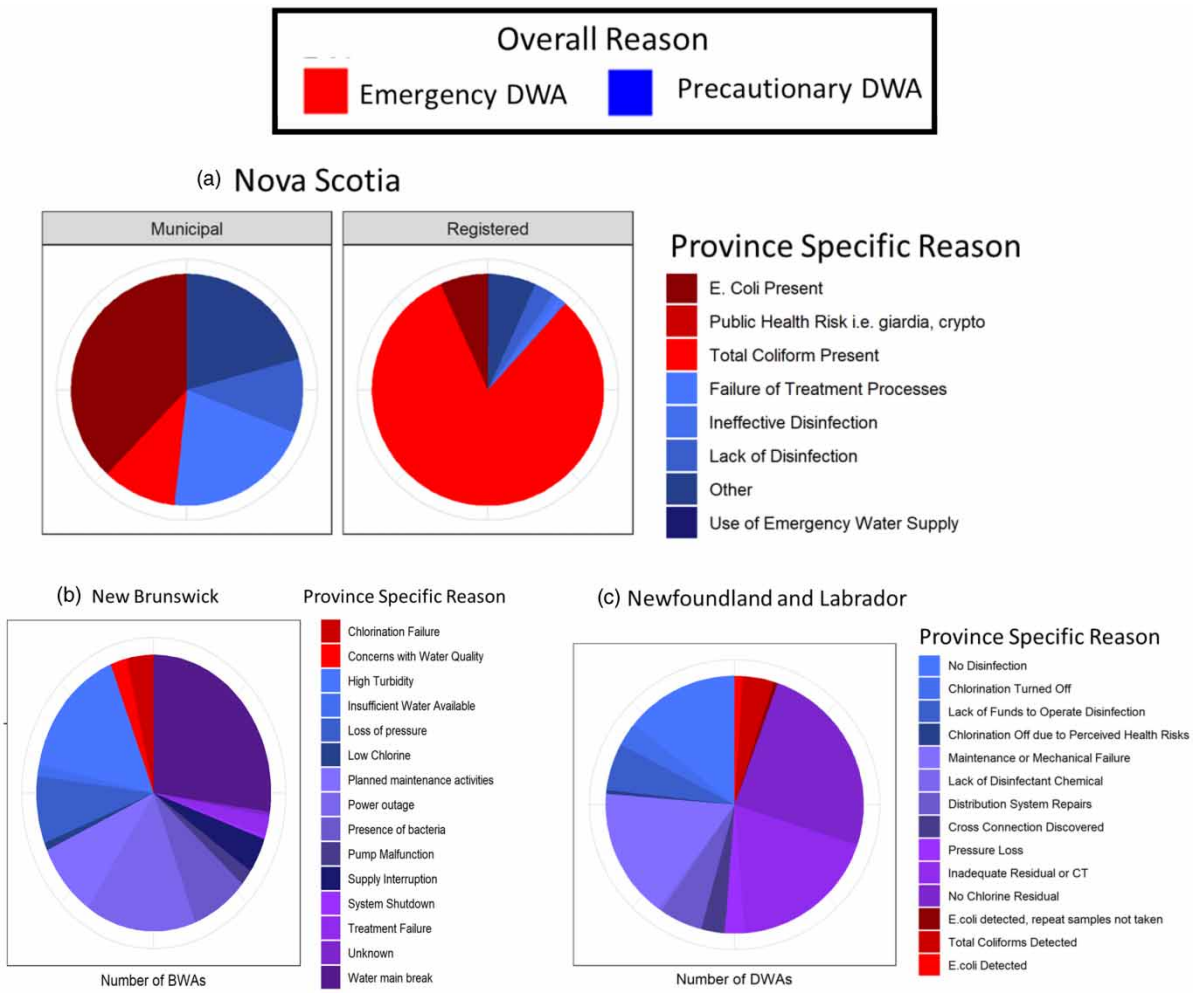

Fig. 4. Data from the Atlantic provinces reveal operational concerns are the primary reason that DWAs are issued in municipal water systems. DWAs considered emergency DWAs are represented in red and precautionary DWAs are represented in blue. Please refer to the online version of this paper to see this figure in color: https://doi.org/10.2166/wp.2020.029.

Labrador; however, given the distinction between registered and municipal systems in Nova Scotia, the situation is similar as registered systems service includes hotels, campgrounds and daycares (Nova Scotia Environment & Labour, 2019).

Duration of DWAs. Finally, the review of data from Nova Scotia and New Brunswick demonstrated the presence of long-term DWAs in both municipal and private water systems. Duration data are presented in Figure 6 showing boxplots for the duration of a DWA on the x-axis in days and the reason for the DWA on the y-axis. Failure of treatment systems in Nova Scotia municipal systems contribute to the longest-lasting DWAs. In New Brunswick, insufficient water quantity and high turbidity contribute to the longest DWAs. These data indicate that DWAs were in place for as few as 3 days, but also

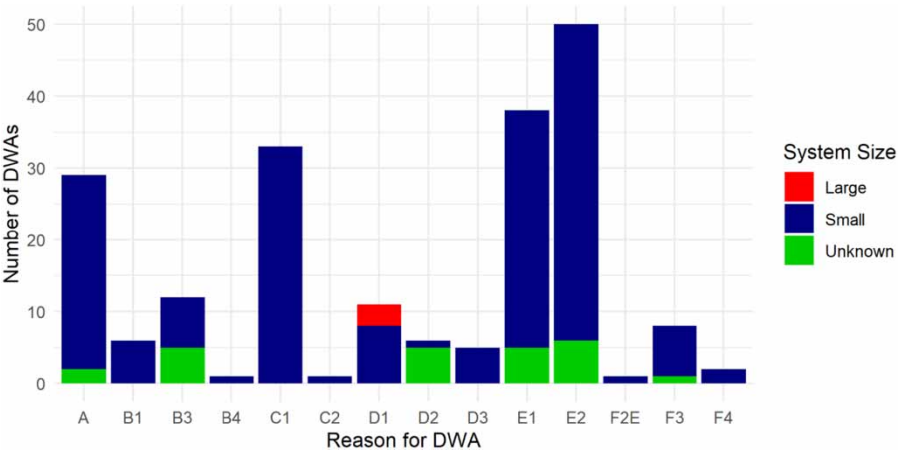

Fig. 5. Data from Newfoundland and Labrador suggest that DWAs predominantly occur in small systems. The definition of the reason codes provided here is specific to Newfoundland and Labrador and can be found in Supplementary Table S1.

highlights several DWAs that have been in place for over 1,000 days. Furthermore, the tails of the box-plots presented indicate that there are water systems where a DWA has been in place for more than 4,000 days. Registered systems experience DWAs that are years long, while the majority of DWAs in municipal systems are under 30 days in length. These data highlight long-term DWAs in non-First Nation water systems, revealing evidence that rural and remote systems in Nova Scotia also deal with long-standing water quality concerns.

Discussion

Current data gaps

Across the three provinces in the Atlantic region, there is no common reporting format for DWAs. Table 1 shows the key characteristics reported for the three provinces currently. This leads to an incomplete data set where all relevant DWA characteristics cannot be accurately compared to discern commonalities. Post *et al.* (2018) noted that DWA data sets needed to be manipulated to have a complete set of variables to construct probabilistic neural networks for First Nation DWAs. Several other studies of First Nation DWAs have noted the same concern, particularly when trying to model future events or understand factors driving DWA issuance (Harvey *et al.*, 2015; Murphy *et al.*, 2016).

This study demonstrates that a lack of consistent reporting for DWA is not a First Nation concern alone. In fact, Dunn *et al.* (2017) noted that this lack of common reporting and data collection is an underlying concern with water governance in Canada overall. Limited data across provincial borders lead to an inability to understand the main drivers behind the waterborne disease and operational and process-related concerns in Canadian water systems, resulting in no clearly defined national trends (Dunn *et al.*, 2017). A common reporting format that is publicly available for consumers to consult is needed to strengthen the DWA as a water safety tool.

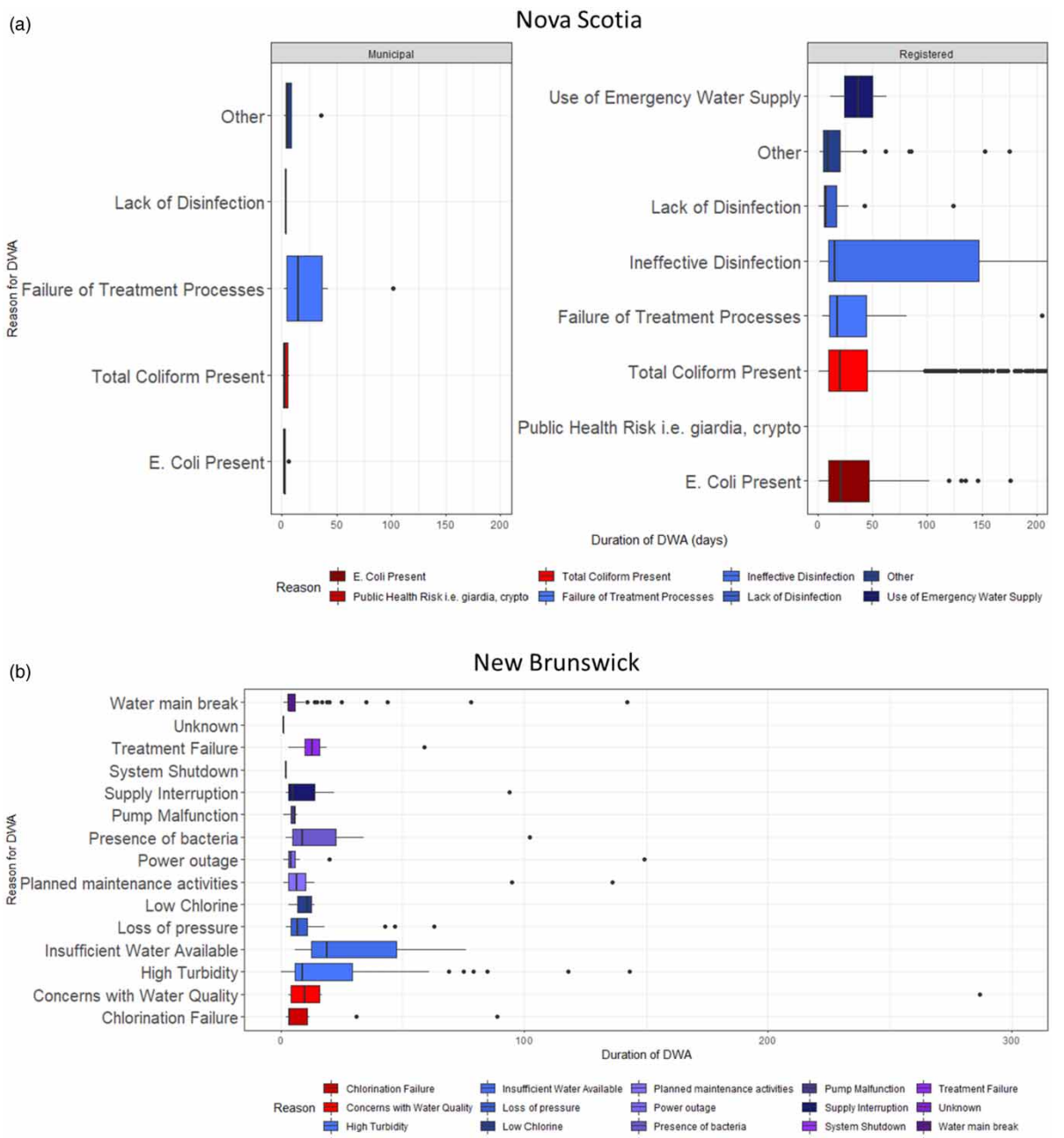

Fig. 6. Review of DWAs in New Brunswick and Nova Scotia revealed the presence of long-term DWAs in registered water systems in Nova Scotia. DWAs are in place for more than 100 days in several instances, with the tails of the boxplots indicating DWAs in place for over 4,000 days or more than 10 years.

Communication of a DWA is also a concern highlighted by the different reporting mechanisms observed in this study and in the literature. Unfortunately, most communication between government agencies responsible for the provision of safe water only occurs when an issue arises, such as the

Table 1. Summary of features reported on DWAs in each Atlantic province.

Province	Start date	End date	Reason	System type	System size (population)	Comments on DWA
Nova Scotia	X	X	X	X		
New Brunswick	X	X	X			X
Newfoundland Labrador	X		X		X	X

issuance of a DWA (Miller & Watson, 2011). While the data utilized in this study were publicly available online through the corresponding provincial authorities, the Newfoundland and Labrador data were collected over a short study period, as there is no historical data available. Trends over time cannot be recorded without constant monitoring of DWA issuance.

To alleviate this reporting concern, Table 2 provides a template for the information that needs to be included in DWA reporting formats across provinces. Using the data currently reported from the Atlantic provinces, this table combines the current DWA characteristics from each jurisdiction and adds two additional characteristics: type of system (municipal, private or First Nation) and water quality parameters measured that led to the issuance of the advisory. Table 2 provides information about location, duration, population, reason and type of advisory from previous reporting formats. Type of system was added to allow for differentiation between water systems; in future studies, this can be used to determine which issues are unique to each system type to better design system-specific solutions. System size contains information not only about the population served but also the number of connections to a water distribution system for clarity.

The data presented in Table 2 are categorical data; accurately understanding trends in DWA data over time relies on proper sample sizes from a full data set to understand how water systems differ. Water safety planning is a system-specific approach: each water system is evaluated based on the unique hazards present in the system (Bartram *et al.*, 2009; WHO, 2012). A first step toward improving the DWA as a water safety tool is to add this element to DWA reporting. This ensures when describing individual DWAs, readers understand these water systems are a subset of a larger, complete data set at a federal level. Instead of grouping all DWAs as the same or generalizing conclusions across several types of systems, a full data set collected using the format in Table 2 better highlights concerns in specific system types and generates more information to inform water governance policy.

At a national level, this information is critical to understanding trends in DWA issuance. At a provincial level, this information is the minimum information recorded for each DWA. Additional characteristics can be added according to provincial regulatory agencies, such as sample location, laboratory analysis location and tests, how the advisory was communicated to the public and source water type. In order to avoid a data collection burden on the agencies reporting this information currently, it is recommended the minimum characteristics should be reported; future studies may reveal the need to include other characteristics.

DWAs in the context of water risk management

Analysis of DWAs in Atlantic Canada reveals a clear seasonality when most DWAs are issued. In Nova Scotia, DWA issuance increased toward the end of June and increases over the later summer

Table 2. A recommended format for communicating DWAs across provinces to allow for a federal database of DWA knowledge.

Location	Start date	End date	Reason	Comments	Type of system	Population/system size	Type of advisory	Water quality parameters measured to issue advisory
System A, County A, Nova Scotia	19 September 2019	29 September 2019	Reason_Code: Water main break in distribution system	Water main break occurred in service lateral on Street Avenue on 19 September	Municipal	3,000 people, 345 connections	Boil Water Advisory	Flow rate, pressure in laterals
System B, County B, Nova Scotia	16 September 2019	Still in place	Reason_Code: Presence of microbial contamination	Sampling staff measured presence of *E. coli* in water system on 16 September	Private	15 people, 10 connections	Boil Water Advisory	*E. coli* (MPN), Chlorine Residual
System A, County B, New Brunswick	3 September 2019	4 September 2019	Reason_Code: Disinfection turned off	Disinfection system was turned off by staff due to lack of chemical available to provide adequate disinfection	Private	35 people, 20 connections	Boil Water Advisory	Chlorine residual, free chlorine, chlorine dose, contact time (CT)

months of August and September. Previous DWA studies have noted this seasonality as well (Galway, 2016; Murphy *et al*., 2016; Black & McBean, 2018; Post *et al*., 2018). When framing the DWA as a safety tool, there is a clear room for improvement in how a DWA informs seasonal risk, particularly considering changes in source water quality in summer months. Several studies have shown how fluctuations in seasonal organic content of lakes or temperatures in aquifers can lead to noticeable impacts in finished water quality delivered to consumers (White & Driscoll, 1987; Granger *et al*., 2014). Since the DWA is a reactionary tool that uses endpoint monitoring, a DWA cannot inform a consumer about changes in source water quality and how that impacts consumers. Despite understanding the seasonality of DWAs, little has been done to mitigate seasonality's effects on private systems. Knowledge of changes in source water characteristics with seasonality is crucial and communicating and educating water systems about this concern is needed.

At a provincial level, several strategies could be employed to reduce the issuance of DWAs given this information on seasonality. An initial strategy for registered systems could consist of sampling more than once per year, with a minimum of two samples, one in the summer months and one in the winter months. Increasing sampling requirements would necessitate increased support for registered systems as well; this can include resources from provincial governments such as a recommended list of accredited laboratories for sample processing, explicit sampling protocols and assistance programs for the cost of sampling and resampling should a microbial parameter be detected. The current availability of these types of resources varies between provinces (Government of New Brunswick, 2019; Municipal Affairs & Environment, 2019; Nova Scotia Environment & Labour, 2019). In general, the authors recommend more resources for registered systems and more communication between these systems and regulators. Workshops educating well-owners and small businesses about the importance of sampling and why certain water quality parameters are included under regulations are one such venue to implement this recommendation. These strategies focus on increased accountability and communication between regulatory agencies (such as Nova Scotia Environment, Newfoundland Department of Municipal Affairs and Environment, and the Department of Health in New Brunswick) and registered systems to decrease future DWA issuance and remove current DWAs.

The need for increased education extends to mitigating operational concerns in water systems to prevent future precautionary advisories. In all Atlantic municipal water systems, the majority of reasons for DWA issuance is operational or related to process control in water treatment and distribution systems. This result has been reported specifically in First Nation communities in several studies (Thompson *et al*., 2017; Black & McBean, 2018; Post *et al*., 2018), in Ontario specifically (Galway, 2016), and across water systems in Canada (Environment & Climate Change Canada, 2018). While current First Nation DWAs are an acknowledged and pressing concern (Indigenous Services Canada, 2018), there is also clear evidence that municipal and private water systems also lack sufficient resources to remove DWAs by addressing the root causes of the advisory. This is not to marginalize the concerns in First Nation systems, where advisories have been in place for as long as 25 years; this study demonstrates that DWA concerns are prevalent across water systems in Canada, pointing to a need for a shift in how water is managed in Canada.

In addition to the concerns presented with DWA issuance and removal, there is also no current evidence available in the Atlantic provinces that suggests DWAs are being adhered to by the general public. Public notice of a DWA is achieved most often by listing the DWAs in effect online; however, little to no information on how DWAs are enforced in communities is currently available (Government of New Brunswick, 2019; Municipal Affairs & Environment, 2019; Nova Scotia Environment & Labour, 2019).

Despite the presence of online reporting formats, there is no data currently available to quantify whether the DWA has been adequately communicated to the public. Given the lack of historical data available from both Nova Scotia and Newfoundland and Labrador, it is difficult to discern how the general public would be expected to know if a water advisory had been previously issued for a water system. A 2011 study from British Columbia demonstrated that for 31 water systems, over 30% of the time, the water authority officials were not aware if a DWA was being complied with (Grover, 2011). Furthermore, over 50% of the time, there was no knowledge about compliance with the DWA or it was known that the DWA was not being complied with (Grover, 2011). Without historical data or data surrounding public compliance, DWA adherence is relatively unknown for the Atlantic provinces; the DWA is designed as a tool to communicate water safety risk to customers only. This demonstrates another drawback of relying on the DWA as a measure for communicating water safety: even if a DWA is issued, there is little data to point to whether the public is aware of the DWA or has complied with the DWA.

A case study of the Toledo DWA in 2014 demonstrated how a water safety plan could have prevented the issuance of a DWA for this large city (Jetoo *et al*., 2015). Water safety plans are risk management tools promoted by the World Health Organization since 2004 that focus on proactive risk management (Bartram *et al*., 2009; WHO, 2012). Jetoo *et al*. (2015) analyzed the events that led to the Toldeo DWA and concluded that the crisis could have been averted with simple risk management procedures. The study concluded that institutional concerns were the most critical threats to the Toledo system; a lack of operator training, standard operating procedures and system monitoring accountability, threats that would lead to a precautionary DWA in Canada (Jetoo *et al*., 2015). A multi-stakeholder, collaborative approach was recommended in the Toledo DWA case study, and the study advised the adoption of proactive measures that limit the translation of future operational issues to the issuance of a DWA (Jetoo *et al*., 2015). This case study presents a potential method for achieving safe drinking water based on a DWA case that could have been averted given proper attention to operational concerns. In the context of Canadian DWAs and water management, the water safety plan provides one potential method for achieving safer water than the DWA alone.

Conclusions

Current DWAs are inadequate as a water safety tool because they lack the necessary information about water system risk. Analysis of DWAs in three provinces demonstrated the clear seasonality of DWA issuance, that DWAs are largely issued for operational and process-related reasons and that there is a disproportionate DWA burden in small water systems. In addition, the number of DWAs is approximately equal to the number of advisories removed in most of the months recorded in Nova Scotia and New Brunswick, which indicates systems that need fundamental improvements.

A DWA characteristic analysis demonstrated the predominance of operational concerns and the need for interventions to improve water systems. Review of DWA data demonstrated the lack of a consistent reporting format across provinces. Inconsistent reporting of DWAs is a symptom of a larger concern for water governance in Canada: the DWA is a metric for water safety but provides incomplete knowledge to make decisions about water system safety at both a provincial and federal level. As a result, a new reporting format is proposed to collect the minimum information needed to begin understanding national trends in water system safety. In particular, proactive risked-based management tools, such as water safety plans, are needed to resolve the operational concerns observed in Canadian water systems.

Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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