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Warming Arctic and its Cascading Impacts on Water, Energy, and Food (WEF) Systems: A Case Study of Iqaluit, Nunavut

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ABSTRACT: This paper draws on a case study of Iqaluit, Nunavut, to exemplify the conceptual utility of the water–energy–food (WEF) nexus as a starting point in better understanding the cascading nature of climate change impacts. The case study demonstrates that damage to Iqaluit's main fuel storage tank caused by instability in the permafrost layer induced a series of cascading impacts that affected Iqaluit's water, food, sanitation, and health care services. Because of the non-linear nature of cascading impacts, the response was largely reactionary, rather than anticipatory, leaving Iqaluit residents exposed to heightened and extended periods of WEF insecurity. Given the relatively weak state of WEF security in Arctic regions, coordinated policy action is needed to increase the resilience of Arctic WEF systems. We suggest the WEF nexus can support those coordinated efforts by avoiding siloed responses.

Keywords: disaster; climate change; infrastructure; Canada; Arctic

RÉSUMÉ. Cet article s'appuie sur une étude de cas portant sur Iqaluit, au Nunavut, qui vise à illustrer l'utilité conceptuelle du nexus « eau-énergie-alimentation » comme point de départ pour mieux comprendre les effets en série du changement climatique. L'étude révèle que les dommages subis par le principal réservoir de carburant d'Iqaluit, dus à l'instabilité de la couche de pergélisol, ont déclenché une série d'événements touchant l'eau, l'alimentation, l'assainissement et les soins de santé d'Iqaluit. Les effets en série non linéaires ont entraîné une situation réactive plutôt que proactive, ce qui a fait que les habitants d'Iqaluit ont vécu des périodes prolongées et exacerbées d'insécurité en ce qui concerne l'eau, l'énergie et l'alimentation. En raison de l'insécurité relative en matière d'eau, d'énergie et d'alimentation dans les régions arctiques, il est essentiel d'adopter une approche politique coordonnée pour renforcer la résilience des systèmes d'eau, d'énergie et d'alimentation dans l'Arctique. Nous suggérons que le nexus eau-énergie-alimentation est en mesure de soutenir ces efforts concertés pourvu que les réponses ne soient pas isolées.

Mots-clés : catastrophe; changement climatique; infrastructure; Canada; Arctique

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INTRODUCTION

Arctic regions are being disproportionately affected by climate change. Although contributing negligibly to global greenhouse gas emissions, the Arctic receives some of the most severe climate-related impacts (IPCC, 2022). For example, the Arctic has warmed at more than twice the global rate over the past 50 years and will almost certainly continue to experience more pronounced surface warming than the world average over the current century (IPCC, 2021). These warming conditions have resulted in a myriad of effects, including changes in precipitation, flooding, erosion, and alterations in snow and sea ice cover (Gutiérrez et al., 2021).

While propagating significant changes in key ecological systems (Lawrence et al., 2020), the cascading impacts of climate change are simultaneously disrupting the social and economic conditions of Arctic communities. Cascading effects can be understood as a consequence of direct climate impacts that generate secondary changes in social and ecological systems (Pescaroli and Alexander, 2016). For example, rising temperatures intensify permafrost thawing, which affects transportation networks and, in turn, constrains the mobility of Arctic residents. Permafrost thaw also affects the integrity of Arctic infrastructure, including airports, railways, buildings, and pipelines (Hjort et al., 2018). The instability of permafrost has caused school closures in Yukon and has contributed to runway damage

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at airports in Nunavut (Clark et al., 2022). Climate change is also projected to increase the frequency and intensity of storm surges, causing coastal erosion and damage to community water and sanitation services (Oldenborger and LeBlanc, 2015; CCA, 2019). While the cascading impacts from climate change are already threatening the integrity of critical infrastructure (WSP, 2021) and have caused subsequent disruptions in the delivery of community services, these events are projected to increase exponentially by the middle of the century. For Arctic communities, this will likely result in magnification of existing inequalities (Crépin et al., 2017) and widening of social and economic disparities (Ford et al., 2015).

In light of these conditions, Arctic communities are in urgent need of effective and comprehensive strategies to dampen, if not mitigate, the impending climate crisis (Ford et al., 2014). However, the cascading effects of climate change are not easily anticipated, as they follow complex and dynamic pathways (Chang and Bonnette, 2016), and therefore, effective interventions and adaptive societal responses have been elusive. To date, the implementation of adaptive strategies has been uneven; too often these strategies are also siloed in design (Daher and Mohtar, 2015).

One approach that has shown promise in overcome siloed climate responses has been the water–food–energy (WEF) nexus. The WEF nexus originally garnered attention following the 2011 Bonn Conference as a framework for advancing the integrated management of water, energy, and food systems (Hoff, 2011; Biggs et al., 2015). Whereas the analytical value of the WEF nexus has been debated (Huntington et al., 2021), its effectiveness as a means of interrogating the complexity and contextual nature of WEF systems has been championed, given changing climate conditions (Boluwade, 2021). Because climate change and its cascading impacts do not adhere to sectoral boundaries, the multidimensionality of the WEF nexus (Mpandeli et al., 2018) has proven effective at stimulating systems thinking that guides more anticipatory societal responses (Medinilla, 2021; Kellner, 2023), particularly in regions prone to high rates of WEF insecurity (Radmehr et al., 2021).

While the WEF nexus has been used effectively in other climate-sensitive regions of the world (e.g., Conway et al., 2015; Romero-Lankao and Norton, 2018; Herrera-Franco et al., 2023), its application in the Arctic has yet to be tested. This oversight is surprising given the high rates of water, energy, and food insecurity that currently exist in Arctic communities (Ingram et al., 2021; Natcher and Ingram, 2021; Schmidt et al., 2022; Madani and Natcher, 2024), which are expected to be exacerbated by the projected impacts of climate change (Ford et al., 2021). It was with these conditions in mind that the Arctic Council's Sustainable Development Working Group (SDWG) endorsed research (including the investigations on which the current paper is based) that would examine the nexus between climate change and the security of WEF systems in the Arctic (SDWG, 2021).

In this paper, we draw on a case study of Iqaluit, Nunavut, to demonstrate the conceptual utility of the WEF nexus in making visible the cascading impacts of climate change. What started as instability in the permafrost layer resulted in damage to Iqaluit's main fuel storage tank, and subsequently, a water crisis in the city. From this climate-induced event, a series of cascading impacts ensued that affected Iqaluit's water, food, sanitation, and health care services. Because these cascading impacts occurred through non-linear pathways, the response was largely reactionary rather than anticipatory, leaving Iqaluit residents exposed to heightened and extended periods of WEF insecurity. As concerning as the Iqaluit crisis has been, the situation is indicative of the challenges other Arctic communities are experiencing in the context of the current climate crisis (Schmidt et al., 2022; Smith Lopez et al., 2024).

Rather than offering a blueprint for community response, our objective in this paper is to encourage iterative and non-linear approaches to problem solving that anticipate the cascading nature of Arctic climate change. In doing so, we intend to show that the situation in Iqaluit was not a water, energy, or food crisis alone, but rather, a systems crisis that demanded equally complex and integrative responses.

Background

Cascading impacts occur when the effects of a climate-related hazard progress over time, generating unexpected secondary effects (Pescaroli and Alexander, 2016). These secondary effects result from interdependencies between sub-systems (Walker and Meyers, 2004), where changes experienced in one domain induce and accelerate widespread changes in others (Kinzig et al., 2006). Because of their interconnectedness, a disaster event in one WEF sector can affect others in unpredictable ways that together result in cascading hazards. For example, in southern Africa, a region classified as a climate change hot spot, a 20% reduction in annual rainfall is projected by 2080 (Conway et al., 2015). While reduced rainfall will directly and negatively impact agricultural output (Emediegwu et al., 2022), reduced access to water and sanitation services will have cascading impacts on nutrition, human health, and well-being (Parikh et al., 2021). Countries in southern Africa are already experiencing an upsurge of vector- (malaria and dengue fever) and water- and food-borne diseases (cholera and diarrhea), which will likely be exacerbated by climate-induced changes in regional WEF systems (Mpandeli et al., 2018). Similar conditions exist in southern Asia (Rehman et al., 2024) and eastern Mediterranean countries (Albatayneh, 2023) where the cascading impacts of climate change are bringing multiple and unforeseen hazards that affect the social, economic, and human health conditions of regional populations.

The Arctic is also exposed to cascading climate hazards on WEF system services. For example, climate change is projected to influence the hydrological systems of the

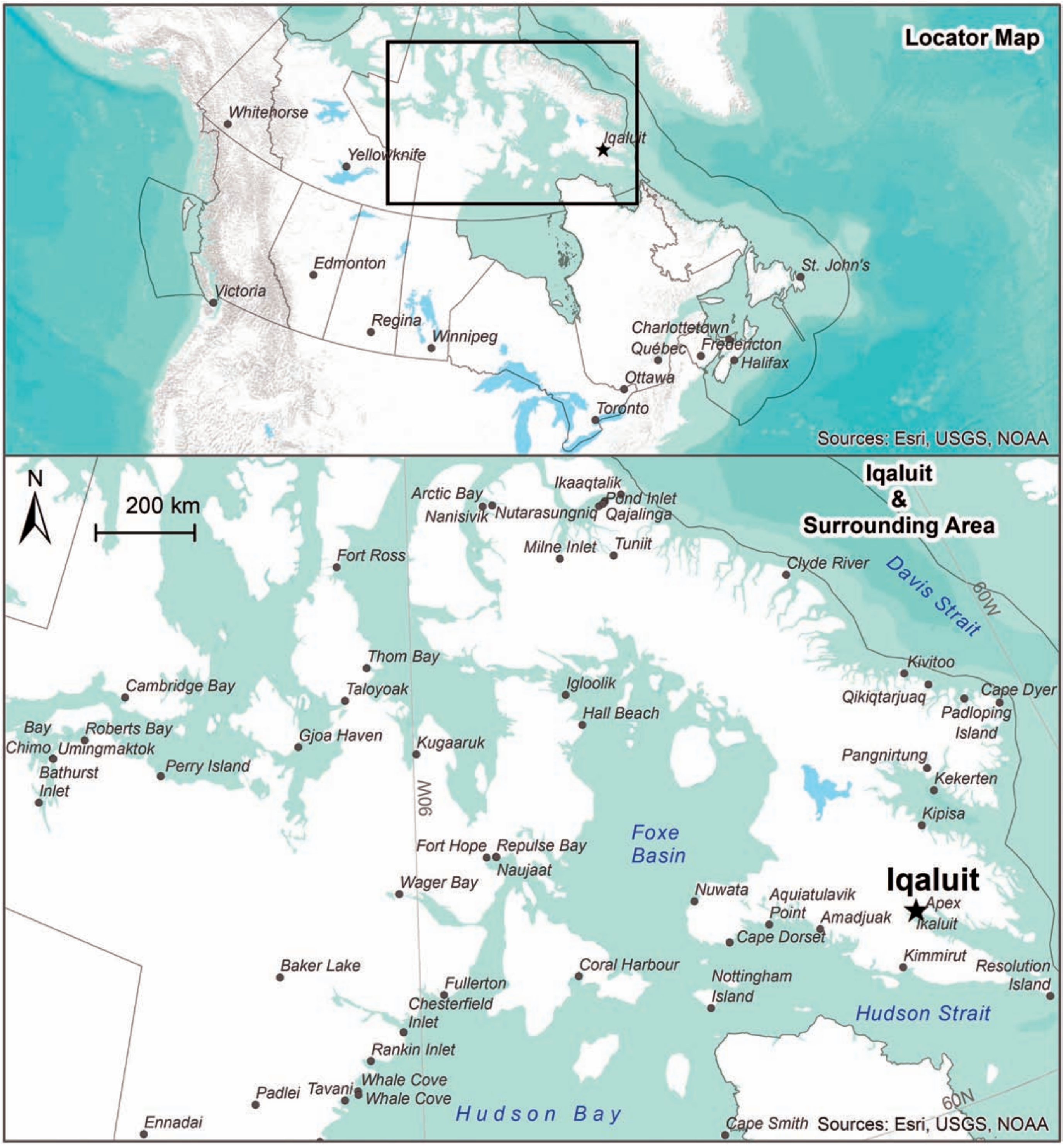

FIG. 1. Study area, Iqaluit and surrounding region.

Arctic by altering surface-water distribution and drainage (Rawlins and Karmalkar, 2004). This is problematic for Arctic communities that rely on precipitation runoff during summer to replenish freshwater supplies (Bakaic and Medeiros, 2017). In Nunavut, these conditions have resulted in territory-wide water shortages, which are expected to intensify by 2050 (Medeiros, 2024). Climate change is also threatening the already strained integrity of community water systems. Due to warming conditions, the active layer of permafrost, which consists of the layer of topsoil that thaws during the summer and freezes again during fall, has deepened in many parts of the Arctic. As the active layer deepens, water pipes that were previously held in place by permafrost begin to shift, causing pipes to break, disconnect, and freeze underground (George, 2019). As recently as 2019, the City of Iqaluit spent $330,000 to thaw frozen sub-surface water pipes (Little, 2022). As the impacts of climate change become more pronounced, the strain on water infrastructure is expected to intensify, with water outages becoming ever more frequent (Swanson et al., 2021).

Climate impacts are having similar effects on the energy systems of Arctic communities. For communities connected to electrical grids, permafrost thaw and increased storm intensity are causing damage to power lines and routine service disruptions (The Firelight Group, 2022). Communities that not connected to electrical grids (including all of Nunavut), meanwhile, are forced to rely almost exclusively on stand-alone diesel generators to meet their energy needs. This is problematic, forcing these locations to rely on imported diesel to power local microgrids (ACEP, 2022). Energy access is also subject to climate-induced delays that, in turn, can be exacerbated by climate-related damage to transportation and holding (i.e., storage) infrastructure (The Firelight Group, 2022).

A warming Arctic climate is also a driving force behind environmental changes that have disrupted access to, and availability of, commercial (i.e., store-bought) and subsistence (i.e., locally sourced, gathered, hunted, or fished) food resources (Natcher et al., 2021). For example, food supply chains are negatively impacted by infrastructure damage caused by frequent extreme weather periods (Tchonkouang et al., 2024). Changes in the Arctic climate are also impacting terrestrial and marine wildlife that Arctic peoples depend on for nutritional and cultural sustenance. In coastal regions, greater unpredictability in sea ice thickness, breakup, and freeze-up dissuade the use of ice-edges and creates more dangerous hunting and fishing conditions. Sea-ice retreat is also contributing to the displacement and range contraction of some critical food species, such as seals and other marine mammals (Meier et al., 2014). In these and other ways, Arctic climate change has triggered a myriad of cascading impacts that are further threatening WEF security of Arctic communities.

Study Area

Located on the southern coast of Baffin Island, Iqaluit is the capital and largest populated community in Nunavut (Fig. 1). Meaning "place of many fish," Iqaluit has been used for centuries by Inuit during their seasonal round of harvesting activities (Newbery, 2020; Arctic Kingdom, 2024). However, it was not until the 1940s that a permanent settlement was established. In 1941, the US began construction of a network of northern airfields to transport short-range military aircraft from North America to Europe. With the Canadian government's approval, Iqaluit was selected as a suitable and strategic location for an airbase. This airbase served as the cornerstone of the northern air defense, and by the end of 1942, an airfield, hospital, workshops, warehouses, and a small tent city were constructed (Eno, 2003). In 1944, the Canadian government purchased the airbase from the US and began to increase its own presence in the area. This involved the later establishment of a Department of Indian Affairs and Northern Development (now Indigenous and Northern Affairs) regional office, with accompanying expansion of civilian housing and accommodations for government employees, medical staff, and teachers (Eno, 2003; City of Iqaluit, 2024). With new employment, education, and health care services becoming available, Iqaluit began attracting a growing number of permanent residents. By 1957, Iqaluit's population had grown to approximately 1200 permanent residents, 489 of whom were Inuit. Iqaluit continued to expand, officially being recognized as a settlement in 1970 and a village in 1974 and receiving town status in 1980. Iqaluit was then selected to be the capital city of the newly formed territory of Nunavut in 1999. By 2001, Iqaluit received its order of official status as a city (City of Iqaluit, 2024), with a population of 7429 residents (Statistics Canada, 2022), making it the largest of Nunavut's 25 communities.

METHODS

We conducted an online document review of public health declarations, government policy papers, safety guidance release, and media coverage. Our analysis was informed by Atkinson and Coffey (1997), who characterize documents as social facts that can be used to produce rich descriptions of a single phenomenon or hazard event. We also reviewed non-technical literature, such as media reports. This literature provided valuable empirical data that helped us identify connections, timelines, and new insights (Mills et al., 2006). We used a systematic keywords-based search protocol to identify the secondary documents using Google's web browser. Our search terms included: "Iqaluit water crisis," "fuel contamination," and "food crisis." After a careful screening of the web-based documents that was guided by relevance and publication date (between 2018 and 2023), we identified: 21 newspaper articles, 12 government reports/press releases, nine peer-reviewed articles, and nine grey literature or other. We thoroughly reviewed all of these to construct the case study. All the selected documents were published in English. Among the documents, the newspaper articles and government reports specifically mentioned the case of the Iqaluit water crisis, while the gray literature and peer-reviewed articles focused on the effects of the climate crisis in Iqaluit and its infrastructural vulnerability. While the newspaper articles and government reports contributed to developing the case study, the grey literature and peer reviewed articles were used in the validation of the case study.

Despite following a systematic procedure for analyzing public documents and publications, the use of secondary documents is not without risk, particularly in cases where the documents obtained are incomplete or not written objectively. In these cases, researchers should maintain a critical eye and not assume the content is unquestionably reliable or unbiased (Bowen, 2009). They should look for additional sources of evidence to corroborate or refute divergent data sources (Stake, 1995). In our case, this involved taking notes first-hand and observing representatives of the Nunavut Government during a closed session we attended at the 2024 Arctic Frontiers conference where they offered their own interpretation of events.

Together, these sources were used to inform a collaborative mind mapping exercise, which allowed members of the research team to visualize the direct and indirect cascading impacts that followed the initial crisis. Mind mapping has been used in previous research to stimulate discussion on the human dimension of climate change and visualize its inter-related impacts (Eggert et al., 2017). We developed the mind map following the synthesis of reviewed documents, which facilitated a more critical discussion of the multiple, integrated, and in some cases, seemingly disconnected nature of events that transpired following Iqaluit's putative water crisis. A preliminary draft was reviewed by staff members at the Nunavut Research Institute, who critically evaluated the mind map and provided additional information not available from secondary sources. The explicit inclusion of emic and etic perspectives allowed us to describe and visualize how cascading impacts were experienced during and after the crisis.

RESULTS

Fragility of WEF Services

While Iqaluit's population has experienced considerable growth in recent decades, its supporting WEF services and infrastructure have failed to keep pace. For example, Iqaluit's water treatment plant was first built in the 1960s, with most of the water and sewer lines installed over 26 years ago (Inuit Tapiriit Kanatami, 2020). Much of the piped water infrastructure is now in a poor state, with aging and dilapidated pipes causing frequent disruptions in water service (Inuit Tapiriit Kanatami, 2020). Households that are not connected to the city's piped water system (due to permafrost and other geographic challenges that make it prohibitively costly or impractical to install) must rely on trucked water services. However, truck delivery is also subject to disruption during frequent periods of disrepair or hazardous weather-related conditions. There is concern that the dilapidated state of Iqaluit's central and in-home potable water services may hasten the spread of enteric diseases and other waterborne diseases and pathogens (Harper et al., 2015). Iqaluit's water source has also become a concern. Iqaluit's freshwater supply is drawn primarily from precipitation runoff that recharges water levels in the summer, making the city susceptible to water shortages in dry years (Bakaic and Medeiros, 2017). This has been the case recently, as water emergencies were declared in 2018, 2019, and 2022, when Lake Geraldine, the city's primary potable water reservoir, dropped to historically low levels (Venn, 2022). Increasingly, the Apex River has been used to supplement Iqaluit's water supply amidst shortages, but this is considered a short-term response that cannot provide long-term stability (Bakaic et al., 2018). Under current water-supply conditions, water use efficiency will need to be substantially improved, or water consumption will have to decrease to avoid a perpetual state of drawdown (Bakaic and Medeiros, 2017).

Iqaluit's energy supply is proving equally vulnerable to disruptions in supply and distribution. The Qulliq Energy Corporation, which is owned by the Government of Nunavut, operates Iqaluit's diesel power plant and is responsible for electricity generation, transmission, and distribution (QEC, 2023). Nunavut has no shared transmission grids between communities or with outside jurisdictions, meaning Iqaluit (as well as every other Nunavut community) operates as a micro-grid that is solely dependent on imported diesel to generate electrical power. Annually, Iqaluit imports over 60 million liters of diesel fuel, transported between July and November, then stored in tanks for annual use (CBC, 2017). Lacking a deep-water port, fuel shipments are received from vessels, anchored roughly 140m offshore, that pump fuel through a mainland pipe to the city's tank farm. The precarious nature of this system poses very high social and environmental risks. As noted by Franco Buscemi, general manager of Iqaluit's fuel plant, "If we ran out of fuel … there would definitely have to be an evacuation" (CBC, 2017:2). Further, in the case of a spill, Iqaluit has limited capacity to respond quickly to avoid environmental impacts on fish and other wildlife that residents rely on for food and cultural sustenance, a situation of grave concern to city managers and Iqaluit residents.

If access to country foods were to be affected, residents would be forced to rely even more heavily on imported commercial foods. Yet, there are significant transportation costs associated with flying commercial foods into Iqaluit, which contribute to extremely high food costs (Naweed, 2022). Food in Iqaluit can cost two to three times as much as the national average, and recent inflation has further increased food prices. For example, a 4.5 kg bag of potatoes can sell for $15, a kilogram of ground beef can cost nearly $25, and a one-liter bottle of water can cost as much as $18 (Numbeo, 2024). These conditions have contributed to Nunavut having the highest rates of food insecurity in the country, with roughly 50% of households being moderately (26%) to severely (24%) food insecure (Statistics Canada, 2020). Due to these conditions, many Iqaluit residents must rely on community food programs, including the local food bank, soup kitchens, and community centres, to help meet their most basic household food needs (Statham, 2012).

The pre-existing insecurities in Iqaluit's WEF systems made the events of 2 October 2021 even more distressing to its residents. That's when Iqaluit residents reported a fuel-like odor coming from the city's piped water system (City of Iqaluit, 2022). After numerous reports, the municipal government conducted a smell test in homes and in the city's only water treatment plant, results of which were inconclusive. As complaints from residents continued over the next 48 hours, city officials collected residential water samples that were sent to southern Canada for laboratory testing. The results again came back inconclusive. City officials then tested the concrete holding tank at Iqaluit's water treatment plant. On 12 October, tests confirmed that a fuel contamination in the city's water supply had occurred (Jamal, 2022). The retested water samples from the treatment plant also confirmed exceedingly high concentrations of various fuel components in the city's water supply. At this point, and 10 days after first being reported by residents, Iqaluit declared a city-wide state of emergency and issued a "do not consume" water advisory (City of Iqaluit, 2022; Little, 2022).

Upon investigation, city officials determined that the source of contamination was an underground fuel tank that had been installed near the water treatment plant when the plant was built in 1962. At the time, engineers had installed a structural void to prevent contamination. The void was an open underground space designed to act as a barrier between the water treatment plant and the surrounding environment (City of Iqaluit, 2022). However, after 60 years of operation, the void ultimately failed, resulting in a fuel contamination of the city's water supply. Once detected, city officials were able to isolate and bypass the contamination point, but it took until 10 December, more than two months after the first reports of a fuel smell, for the "do not consume" advisory order to be lifted, and for Iqaluit residents to be able to resume domestic water services, albeit with considerable trepidation.

Based on our analysis, our team found surprisingly complex, interlinked impacts in our case study of Iqaluit, all of which cascaded from original, climate change effects, and which touched local water, the environment, health care, and food systems. We describe these impacts in detail below.

Water

The federal government, approaching the leak as a water crisis, dispatched members of the Canadian military to Iqaluit (Driscoll, 2021). The central responsibility of the military was to operate a water purification system on the Sylvia Grinnell River (Little, 2022). Once treated, potable water was trucked to designated filling depots, where residents could fill containers for personal use. In addition to centralized depots, residents also gathered at the Sylvia Grinnell River to fill containers for personal use (Tranter, 2021). It was not uncommon for long lines to form, with residents filling anything from five-gallon containers to buckets and pop bottles. As residents collected water for their own personal use, individuals and community organizations mobilized to distribute water to those in need. Despite these efforts, many households still faced water shortages. At particular risk were elderly, physically challenged people, and citizens lacking motorized transportation or support networks to access centralized depot sites. Although members of the community worked tirelessly to ensure those who were in need were cared for, the situation nonetheless created considerable anxiety among residents.

Concerns arose about using the Sylvia Grinnel River as a water source. For example, due to the river's proximity to Iqaluit's airport and runway, there were concerns about the risk of contamination from petroleum and residual runoff from increased aircraft activity. Also, before leaving Iqaluit in 1963, the US military bulldozed thousands of kilograms of hazardous waste off a cliff near this same Sylvia Grinnell River (CBC News, 2017). Previous studies conducted by Transport Canada determined that the soil, surface water, and sediment in the area were still contaminated with petroleum hydrocarbons, pesticides, asbestos, and polychlorinated biphenyls (PCBs) (CBC News, 2017). In 2017, several hundred cubic meters of hazardous material was removed and flown south for proper disposal, but the rest was compacted in an on-site landfill that was covered, with a commitment by government to conduct regular monitoring (Hossack, 2017). Notwithstanding these commitments, Iqaluit residents remain concerned about the impact on the environment and the associated effect on their own health (CBC News, 2017). These concerns were, however, set aside during the fall of 2021 by the more immediate need for potable water.

The use of the Sylvia Grinnell River ended with the onset of colder temperatures, which made pumping operations difficult and posed a threat to equipment and community safety. With local pumping and treatment efforts halted by weather, the federal government began shipping bottled water by air. Between October and December 2021, over 1.5 million liters of bottled water were transported by 39 chartered air flights to Iqaluit (Jamal, 2021; Tranter, 2023). Canadian North airlines alone shipped over 900,000 liters of bottled water (Morritt-Jacobs, 2021). Considering that producing just one bottle of water requires between 5.2 and 10.2 million joules of energy per liter, 2000 times the energy needed to produce tap water (Gleick and Cooley, 2009), the energy demand to supplement Iqaluit's water needs during this three-month period was significant.

Environment

Another residual, yet unanticipated, impact of shipping bottled water was plastic waste. Iqaluit does not have a recycling facility, which means much of the plastic bottle waste was deposited into the city's open-air landfill, which has long surpassed its holding capacity, resulting in a situation characterized by former mayor Madeleine Redfern as an "environmental disaster" (McKay, 2022:4). It took until July 2022 to transport eight shipping containers full of plastic bottles for recycling to Montreal, thereby preventing roughly 265m^3 of plastic from entering Iqaluit's landfill (Jamal, 2022). Yet this amount is well short of the total amount of plastic that was shipped into Iqaluit during the crisis. In the absence of adequate disposal systems, much of the plastic refuse inadvertently ended up dispersed across the city and surrounding land and sea. Romeyn Stevenson, chair of the Engineering and Public Works committee, acknowledged that even the best-designed landfills sometimes allow litter to be blown away and into the surrounding environment, but “we [Iqaluit] have been weirdly accustomed to allowing it to just go out onto the ice and go out onto the road and stay in the ditch and carry on in storms.” While communities in southern Canada have government-funded programs for garbage cleanup, Iqaluit receives no such support, which means the waste that enters Iqaluit will rarely leave, unless on the outgoing tide.

Health Care

The water crisis also affected Iqaluit’s already stressed health care system. Iqaluit was already challenged by having the fewest staffed and operational hospital beds per capita in Canada (NTI, 2020). Because of this, it is not uncommon for Nunavut residents to travel outside of the territory for health care services. However, during the water crisis, the number of patients needing health care outside the territory increased significantly (Somos, 2021). Also due to the water crisis, there were concerns that proper sterilization of surgical and health care equipment could not be assured. This resulted in delays and rescheduling of all non-emergency surgeries and procedures. Those in need of more urgent care were transported to hospitals in southern Canada at an estimated per patient transport cost of $40,000 (Grant, 2021; Tranter, 2021). Less observable was the anxiety and strain placed on the mental health of Iqaluit residents. Although the government assured residents that water was safe to use for laundry, washing dishes, showers, and general household cleaning, Iqaluit residents had their doubts. These doubts included distrust in members of the local leadership who were perceived by some residents to have mishandled the crisis when first reported; these perceptions were later confirmed in a report released by Nunavut’s Department of Community and Government Services, that identified disagreements between the city and territorial government. These disagreements resulted in delays in enacting a response to the crisis (Tranter, 2023).

Food Systems

Since Iqaluit is serviced largely by air transport, flying in thousands of liters of bottled water caused disruption in the shipment of food and domestic necessities. During this time, airlines were operating at maximum capacity, with the delivery of bulk water supplies taking precedence (Morritt-Jacobs, 2021). Even when families and organizations outside Nunavut tried to assist by sending water and personal care items to Iqaluit, the cost of shipping was simply too prohibitive. For example, the cost of sending $300 worth of bottled water from Yellowknife to Iqaluit was quoted to be in excess $3000 (Morritt-Jacobs, 2021). These conditions both limited the availability of food and contributed to considerable price inflation, which had negative impacts on the availability of commercial foods for Iqaluit residents.

Food security was further affected by the water advisory, which cautioned residents against using untreated water in meal preparation. Many residents would not cook or wash food during this time because of their concern over contaminated water. With restrictions placed on water use, the already high rates of food insecurity worsened. Under these conditions, the community food bank experienced a notable increase in users (Gallagher and Yun, 2021). During the crisis, the Qajuqturvik Community Food Centre, which typically served 245 residents (QCFC, 2024), was providing meals five days a week to between 450 and 500 residents, many of whom were young families and elderly people. The cascading impacts described above are captured in the mind map (Fig. 2).

DISCUSSION

Arctic climate change is having cascading impacts across and between multiple service sectors (Cradock-Henry et al., 2020). Because of a higher mean temperature, which is increasing four times faster than the global average (Rantanen et al., 2022), the Arctic is experiencing increasing climate variability and more frequent weather extremes (Hartmuth et al., 2023). These conditions are, in turn, placing additional strain on the already aging and stressed infrastructure in Arctic communities (Hjort et al., 2022). For example, Hjort et al. (2018) estimate that 69% of pan-Arctic residential, transportation, and industrial infrastructure will be negatively affected by near surface permafrost thaw by 2050.

In the case study presented here, a warming climate induced instability in the permafrost layer between a fuel holding tank and Iqaluit’s water treatment facility. While the direct cascading impact, originating from energy infrastructure, was the contamination of Iqaluit’s water supply, a myriad of other cascading impacts ensured, which had significant impacts on the delivery of critical community services.

Recurring WEF Impacts

Evaluating the cause and cascading effects of the water crisis illustrates the interlinkages between Iqaluit’s WEF systems. Climate change will continue to reduce the effectiveness and lifespan of Iqaluit’s critical infrastructure, a situation that will become more pronounced as climate change impacts worsen. In fact, since the 2021 water crisis in Iqaluit, there have been at least two other water advisories issued. The first occurred in February 2023, after a break in the sewer system of the city’s legislative building caused a sewer back flow, which contaminated the

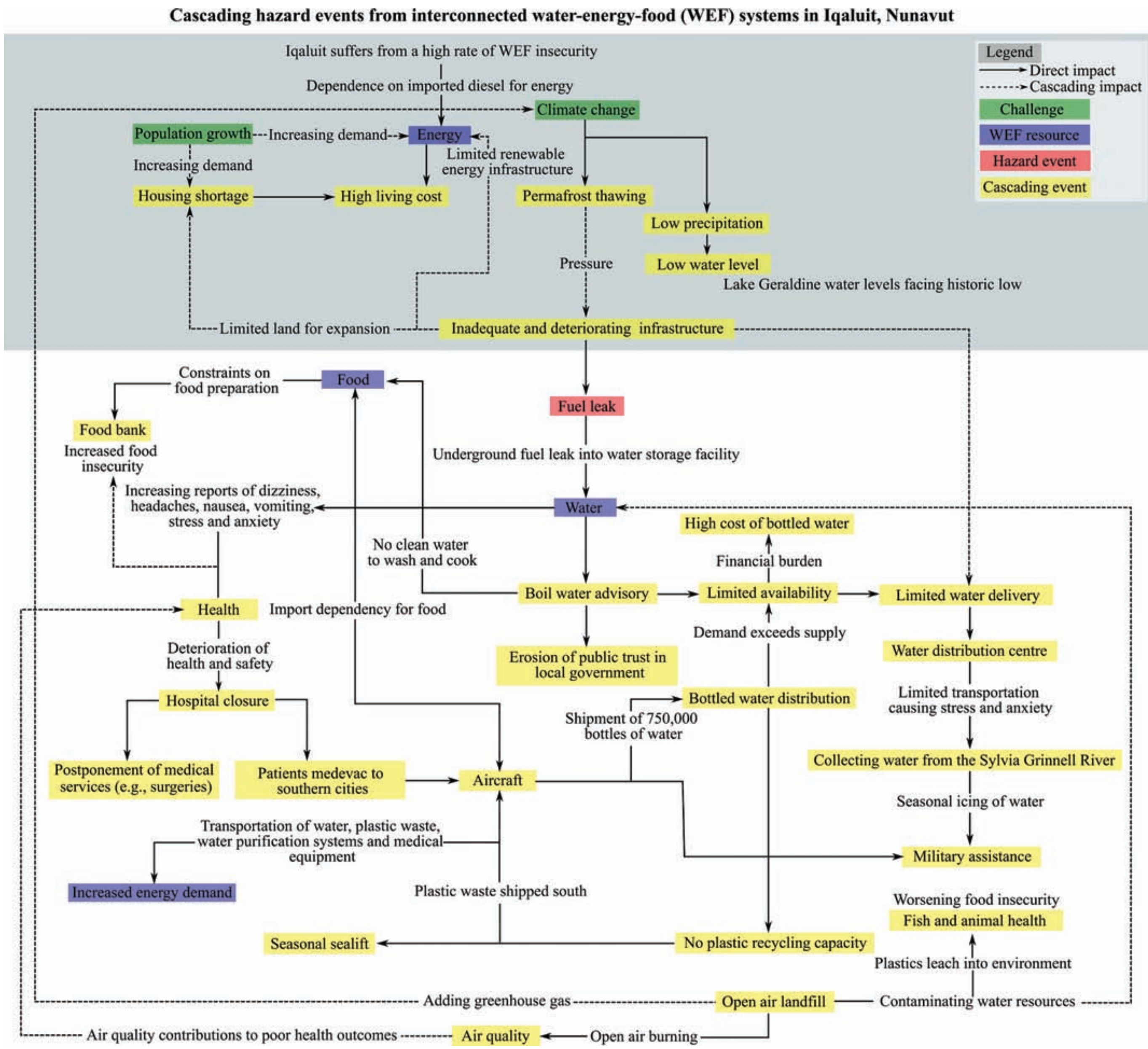

FIG 2. Iqaluit WEF crisis mind map. Note: the blue shaded section represents the general properties of climate change impacts in Iqaluit, and the white background section explains the cascading impacts of the fuel leak.

city's piped water system. One month later (March 2023), the Qajuqturvik Community Food Centre discontinued services due to a rupture of their own water pipes. In this case, the Centre's in-house fuel-storage tank ran dry during the weekend, which caused pipes to freeze and rupture. This damage resulted in the discontinuance of food services for 450 – 500 residents who have come to rely on its services (Venn, 2023). In both cases, the cascading impact of climate change hastened subsequent disruption in community services, which compounded existing insecurities.

While the effects of climate change on Iqaluit's critical WEF services are ominous, other Arctic communities are facing similar challenges. A state of emergency was declared in Kinngait, Nunavut, when a power outage halted water treatment, which interrupted water delivery services (CBC News, 2023). In the community of Arviat, a winter storm with winds exceeding 119 km/h (the highest ever recorded in the month of November) caused a loss of power for four days (Taylor, 2023). During this time, the Arviat airport was closed because of the loss of runway lights, thereby delaying food shipments. The loss of power also resulted in pipes freezing and bursting, which caused flooding in public buildings and homes. The Arviat gas station was also unable to dispense fuel, which caused disruptions in the delivery of trucked water services, requiring residents to ration domestic water use (Taylor, 2023). The increasing occurrence of extreme weather events, coupled with growing populations and inadequate infrastructure, are leading to dire conditions in many Arctic communities (Instanes et al., 2016).

System-based planning

We need more adaptive and anticipatory responses to today's climate-induced disasters. Notwithstanding this need, WEF systems continue to be conceptualized, regulated, and governed by separate institutions, with tenuous coordination (Bazilian et al., 2011; Miralles-Wilhelm, 2016). A greater understanding of the nexus between climate change and WEF systems will be integral to developing timely, equitable, and effective climate change response strategies. Our case study demonstrates just how useful these strategies would be. Yet, too often, government responses are reactionary and fail to consider the potential consequences, regardless of how well-intended the responses may be. For example, during the time when the water advisory order was in place in Iqaluit (October to December 2021), Nunavut's Department of Government and Community Services spent $9 million in emergency funds, with $6.9 million spent on bottled water alone (Tranter, 2023). While bottled water was a necessity, the cascading impact was the accumulation and uncontrolled dispersal of plastic debris entering the environment, which has local and regional implications (Bergmann et al., 2022). Had city and territorial officials conducted a full life cycle assessment of bottled water imports (i.e., evaluating the environmental impact over a product's lifespan), an alternative emergency supply chain could have been implemented (Khourchid et al., 2024). In the absence of this, responses were typically reactionary and aimed at fixing the water crisis without anticipating the subsequent risk to other services. In contrast, a scenario-planning process (a tool for exploring potential future options) drawing on the interlinkages of WEF systems could have been useful to avoid some of the negative impacts experienced across sectors (Khourchid et al., 2024).

As the impacts of climate change and its impacts widen, well-maintained infrastructure will be increasingly important for the continued supply of WEF services (Khourchid et al., 2024). Conversely, failing to invest in maintenance and upkeep ensures continued deterioration and dilapidation of community infrastructure, which will result in service disruptions and compounding WEF insecurities. For example, Iqaluit receives roughly $2 million annually from the Nunavut Government for maintenance and improvement of the city's water infrastructure. However, the city has chosen to use that funding as a subsidy to help offset the high cost of water for residential customers. Although this subsidy was revoked in 2017, it was reinstated in March 2024 and resulted in residential water rates being cut by more than half. This meant that the rate for an average single-family home on trucked service went from $146/month to $51/month after subsidy. For households with piped water service, rates dropped from an average of $200 and $240/month to $70 and $84/month with the subsidy (Pelletier, 2024). City Councilors celebrated this unanimous decision and some, like Kyle Sheppard, encouraged Iqaluit residents to conserve as much water as possible for the health of the city's supply (Pelletier, 2024). Similar subsidies are provided to offset the high cost of residential heating. Electricity rates throughout Nunavut are among the highest in the country due to the territory's low population density and the high cost of importing fuel. However, to offset the true cost of energy, the Nunavut government spends an estimated $60.5 million per year on average subsidizing the cost of diesel fuel, much of which goes towards reducing the electrical bills of low-income households (Thompson, 2018).

The subsidies provided to offset the high costs of water and energy services are certainly justified. It can easily be argued that, without these subsidies, Iqaluit households could not afford these services or direct cost savings to satisfy household food needs. Nonetheless, by choosing to use government funding as consumer subsidies puts critical community infrastructure and the delivery of community services at risk. Although needed, subsidy is a sector-specific strategy, which is contingent on government funding. In contrast, interlinked and redundant WEF-based infrastructural planning and development can help enhance local resilience to climate disasters (Haji et al., 2024; Romero-Lankao et al., 2018).

CONCLUSIONS

Arctic regions are particularly vulnerable to the cascading effects of climate change, which will simultaneously pose threats to WEF security. Infrastructure damage will hinder reliable transportation and delivery of WEF services, particularly to remote communities, imposing significant costs to maintain, repair, or replace existing infrastructure. Given the projected rate of climate change in the Arctic, our aim in this study was to make visible the interrelated impacts that occur from a hazard event and the compounding effects placed on residents who already experience high rates of WEF insecurity. By highlighting the interactions that occur in WEF systems, as well as other socio-economic and health-related impacts, we sought to demonstrate that the events that transpired in Iqaluit were not a water, energy, or food crisis but rather a systems crisis that warrant equally complex and integrated responses. Our case study of Iqaluit, where permafrost instability resulted in a fractured fuel tank, demonstrates that climate-induced events are rarely sector specific. Rather, they have cascading impacts across social and ecological systems. In Iqaluit, the fuel-tank incident cascaded into several impacts, including contamination of the city's water supply, plastic waste pollutants entering the environment, stresses on health care systems, and compounded food insecurity among Iqaluit's most vulnerable residents. Less visible have been the psychological and mental health effects brought about by the WEF crisis, and the anxiety felt among some residents about future crisis events. Justified or not, these conditions have also led to a deterioration of trust in public officials, with concern that self-interest and institutional dysfunction may limit effective and timely responses when the next crisis occurs. To avoid similar outcomes in the future, we encourage coordinated actions and policies. Systems-based decision-making bypasses challenges like institutional redundancies, overlap, and competing mandates.

Iqaluit is the largest community in Nunavut and, as the territorial capital, has greater relative capacity to respond to climate hazards than the other small and more remote Arctic communities. Given the relatively weak state of WEF security in northern Canada, remote communities require coordinated policy action to increase the resilience of WEF systems and effectively adapt to impending climate impacts and ecological changes. We hope this case study can be used to help inform those efforts by preparing community leaders to anticipate how the cascading impacts of climate change might affect WEF system services in the future.

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REFERENCES

ACEP (Alaska Center for Energy and Power). 2022. Alaska microgrid innovation and commercialization & workforce development. University of Alaska, Fairbanks.
https://zenodo.org/records/8045089

Albatayneh, A. 2023. Water energy food nexus to tackle climate change in the eastern Mediterranean. Air, Soil and Water Research 16: 117862212311702.
https://doi.org/10.1177/11786221231170222

Arctic Kingdom. 2024. Explore Iqaluit, Nunavut.
https://arctickingdom.com/destination/iqaluit-nunavut/

Atkinson, P.A., and Coffey, A. 1997. Analysing documentary realities. In: Silverman D., ed. Qualitative research: Theory, method and practice. Thousand Oakes: Sage Publications Ltd. 45 – 62.

Bakaic, M., and Medeiros, A.S. 2017. Vulnerability of northern water supply lakes to changing climate and demand. Arctic Science 3(1):1 – 16.
https://doi.org/10.1139/as-2016-0029

Bakaic, M., Medeiros, A.S., Peters, J.F., and Wolfe, B.B. 2018. Hydrologic monitoring tools for freshwater municipal planning in the Arctic: The case of Iqaluit, Nunavut, Canada. Environmental Science and Pollution Research 25(33):32913 – 32925.
https://doi.org/10.1007/s11356-017-9343-4

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., et al. 2011. Considering the energy, water and food nexus: Towards an integrated modelling approach. Energy Policy 39(12):7896 – 7906.
https://doi.org/10.1016/j.enpol.2011.09.039

Bergmann, M., Collard, F., Fabres, J., Gabrielsen, G.W., Provencher, J.F., Rochman, C.M., van Sebille, E., and Tekman, M.B. 2022. Plastic pollution in the Arctic. Nature Reviews Earth & Environment 3(5):323 – 337.
https://doi.org/10.1038/s43017-022-00279-8

Biggs, E.M., Bruce, E., Boruff, B., Duncan, J.M.A., Horsley, J., Pauli, N., McNeill, K., et al. 2015. Sustainable development and the water – energy – food nexus: A perspective on livelihoods. Environmental Science & Policy 54:389 – 397.
https://doi.org/10.1016/j.envsci.2015.08.002

Boluwade, A. 2021. Impacts of climatic change and database information design on the water-energy-food nexus in water-scarce regions. Water-Energy Nexus 4:54 – 68.
https://doi.org/10.1016/j.wen.2021.03.002

Bowen, G.A. 2009. Document analysis as a qualitative research method. Qualitative Research Journal 9(2):27 – 40.
https://doi.org/10.3316/QRJ0902027

CBC. 2017. 5 quick facts about fuel in Iqaluit: New series "True North Calling" features dependence on fuel in Nunavut's capital. 16 February.
https://www.cbc.ca/2017/truenorthcalling/iqualit-fuel-5-facts-1.3970962

CBC News. 2023. State of emergency declared in Kinngait, Nunavut, over water problems: An electrical issue at the community's pumphouse is limiting water deliveries. 17 May.
https://www.cbc.ca/news/canada/north/kinngait-water-emergency-1.6537774

———. 2017. Hazardous material from 1960s finally getting cleaned up near Sylvia Grinnell Park in Iqaluit: $5.5 million cleanup project expected to begin before the end of the month. 24 July.
https://www.cbc.ca/news/canada/north/metal-dump-transport-canada-sylvia-grinnell-1.4218867

CCA (Council of Canadian Academies). 2019. Canada's top climate change risks: The expert panel on climate change risks and adaptation potential. Ottawa: Council of Canadian Academies.
https://cca-reports.ca/wp-content/uploads/2019/07/Report-Canada-top-climate-change-risks.pdf

Chang, H., and Bonnette, M.R. 2016. Climate change and water-related ecosystem services: Impacts of drought in California, USA. Ecosystem Health and Sustainability 2(12): e01254.
https://doi.org/10.1002/ehs2.1254

City of Iqaluit. 2022. City of Iqaluit water quality emergency: Summary report for distribution. City of Iqaluit, Nunavut.
https://www.iqaluit.ca/sites/default/files/211-12497-00_city_of_iqaluit_water_quality_emergency_summary_report_for_distribution_en.pdf

———. 2024. About Iqaluit: History and milestones. City of Iqaluit, Nunavut.
https://www.iqaluit.ca/visitors/explore-iqaluit/history

Clark, D.G., Coffman, D., Ness, R., Bujold, I., and Beugin, D. 2022. Due north: Facing the costs of climate change for northern infrastructure. Canadian Climate Institute.
https://climateinstitute.ca/wp-content/uploads/2022/06/Due-North.pdf

Conway, D., van Garderen, E.A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., et al. 2015. Climate and southern Africa's water–energy–food nexus. Nature Climate Change 5(9):837–846.
https://doi.org/10.1038/nclimate2735

Cradock-Henry, N.A., Connolly, J., Blackett, P., and Lawrence, J. 2020. Elaborating a systems methodology for cascading climate change impacts and implications. MethodsX 7: 100893.
https://doi.org/10.1016/j.mex.2020.100893

Crépin, A.-S., Karcher, M., and Gascard, J.-C. 2017. Arctic climate change, economy and society (ACCESS): Integrated perspectives. Ambio 46:341–354.
https://doi.org/10.1007/s13280-017-0953-3

Daher, B.T., and Mohtar, R.H. 2015. Water–energy–food (WEF) Nexus tool 2.0: Guiding integrative resource planning and decision-making. Water International 40(5-6):748–771.
https://doi.org/10.1080/02508060.2015.1074148

Driscoll, K. 2021. Canadian military sets up filtration system to distribute Drinking water in Iqaluit. APTN News, 12 November.
https://www.aptnnews.ca/national-news/canadian-military-sets-up-filtration-system-to-distribute-drinking-water-in-iqaluit/#:~:text=The%20Canadian%20Armed%20Forces%20have,make%20it%20drinkable%20without%20boiling

Eggert, S., Nitsch, A., Boone, W. J., Nückles, M., and Bögeholz, S. 2017. Supporting students' learning and socioscientific reasoning about climate change—The effect of computer-based concept mapping scaffolds. Research in Science Education 47(1):137–159.
https://doi.org/10.1007/s11165-015-9493-7

Emediegwu, L.E., Wossink, A., and Hall, A. 2022. The impacts of climate change on agriculture in sub-Saharan Africa: A spatial panel data approach. World Development 158: 105967.
https://doi.org/10.1016/j.worlddev.2022.105967

Eno, R.V. 2003. Crystal two: The origin of Iqaluit. Arctic 56(1):63–75.
http://www.jstor.org/stable/40512159

Ford, J.D., McDowell, G., and Jones, J. 2014. The state of climate change adaptation in the Arctic. Environmental Research Letters 9(10): 104005.
https://doi.org/10.1088/1748-9326/9/10/104005

Ford, J.D., McDowell, G., and Pearce, T. 2015. The adaptation challenge in the Arctic. Nature Climate Change 5:1046–1053.
https://doi.org/10.1038/nclimate2723

Ford, J.D., Pearce, T., Canosa, I.V., and Harper, S. 2021. The rapidly changing Arctic and its societal implications. WIREs Climate Change 12(6): e735.
https://doi.org/10.1002/wcc.735

Gallagher, K., and Yun, T. 2021, October 22. Food insecurity and tainted water: Iqaluit grapples with dual crises. CTV News.
https://www.ctvnews.ca/canada/food-insecurity-and-tainted-water-iqaluit-grapples-with-dual-crises-1.5635375

George, J. 2019. City of Iqaluit says climate change is contributing to its water pipe woes. Nunatsiaq News, 18 March.
https://nunatsiaq.com/stories/article/city-of-iqaluit-says-climate-change-is-contributing-to-its-water-pipe

Gleick, P., and Cooley, H. 2009. Energy implications of bottled water. Environmental Research Letters 4(1): 014009.
https://iopscience.iop.org/article/10.1088/1748-9326/4/1/014009

Grant, K. 2021. In Iqaluit, Nunavut's only hospital feels the ripple effects of the ongoing water crisis. The Globe and Mail, 30 October.
https://www.theglobeandmail.com/canada/article-in-iqaluit-nunavuts-only-hospital-feels-the-ripple-effects-of-the/#:~:text=All%20surgeries%20resumed%20after%20further,department%20said%20in%20a%20statement

Gutiérrez, J.M., Jones, R.G., Narisma, G.T., Alves, L.M., Amjad, M., Gorodetskaya, I.V., Grose, M., et al. 2021. Atlas. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., eds. Climate change 2021—The physical science basis. Cambridge: Cambridge University Press. 1927–2058.
https://doi.org/10.1017/9781009157896.021

Haji, M., Namany, S., Al-Ansari, T. 2024. Strengthening resilience: Decentralized decision-making and multi-criteria analysis in the energy-water-food nexus systems. Frontiers in Sustainability 5:1367931.
https://doi.org/10.3389/frsus.2024.1367931

Harper, S.L., Edge, V.L., Ford, J., Thomas, M.K., Pearl, D.L., Shirley, J., IHACC, RICG, and McEwen, S.A. 2015. Acute gastrointestinal illness in two Inuit communities: Burden of illness in Rigolet and Iqaluit, Canada. Epidemiology and Infection 143(14):3048–3063.
https://doi.org/10.1017/S0950268814003744

Hartmuth, K., Papritz, L., Boettcher, M., and Wernli, H. 2023. Arctic seasonal variability and extremes, and the role of weather systems in a changing climate. Geophysical Research Letters 50(8): e2022GL102349.
https://doi.org/10.1029/2022GL102349

Herrera-Franco, G., Bollmann, H.A., Pasqual Lofhagen, J.C., Bravo-Montero, L., and Carrión-Mero, P. 2023. Approach on water-energy-food (WEF) nexus and climate change: A tool in decision-making processes. Environmental Development 46: 100858.
https://doi.org/10.1016/j.envdev.2023.100858

Hjort, J., Karjalainen, O., Aalto, J., Westermann, S., Romanovsky, V.E., Nelson, F.E., Etzelmüller, B., and Luo-to, M. 2018. Degrading permafrost puts Arctic infrastructure at risk by mid-century. Nature Communications 9: 5147.
https://doi.org/10.1038/s41467-018-07557-4

Hjort, J., Streletskiy, D., Doré, G., Wu, Q., Bjella, K., and Luoto, M. 2022. Impacts of permafrost degradation on infrastructure. Nature Reviews Earth & Environment 3:24–38.
https://doi.org/10.1038/s43017-021-00247-8

Hoff, H. 2011. Understanding the nexus. Background paper for the Bonn 2011 conference: The water, energy and food security nexus. Stockholm: Stockholm Environment Institute,
https://www.sei.org/publications/understanding-the-nexus/

Hossack, S. 2017. Hazardous material from 1960s finally getting cleaned up near Sylvia Grinnell Park in Iqaluit. CBC, 24 July.
https://www.cbc.ca/news/canada/north/metal-dump-transport-canada-sylvia-grinnell-1.4218867#:~:text=North-,Hazardous%20material%20from%201960s%20finally%20getting%20cleaned%20up%20near%20Sylvia,will%20soon%20be%20cleaned%20up.

Huntington, H.P., Schmidt, J.I., Loring, P.A., Whitney, E., Aggarwal, S., Byrd, A.G., Dev, S., et al. 2021. Applying the food–energy–water nexus concept at the local scale. Nature Sustainability 4(8):672–679.
https://doi.org/10.1038/s41893-021-00719-1

Ingram, S., Bogdan, A.M., Shah, T., Lu, X., Li, M., Sidloski, M., and Natcher, D. 2021. Unpacking the WEF nexus index: A regional and sub-regional analysis of northern Canada. Sustainability 13(23): 13338.
https://doi.org/10.3390/su132313338

Instanes, A., Kokorev, V., Janowicz, R., Bruland, O., Sand, K., Prowse, T. 2016. Changes to freshwater systems affecting Arctic infrastructure and natural resources. Journal of Geophysical Research: Biogeosciences 121(3):567–585.
https://doi.org/10.1002/2015JG003125

Inuit Tapiriit Kanatami. 2020. Access to drinking water in Inuit Nunangat. ITK Quarterly Research Briefing.
https://www.itk.ca/wp-content/uploads/2020/12/ITK_Water_English_07.pdf

IPCC. 2021. Summary for policymakers. Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
https://www.ipcc.ch/report/ar6/wg1/chapter/summary-for-policymakers/

———. 2022. Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

Jamal, M. 2021. Canadian Armed Forces now providing potable water to residents of Iqaluit. CBC, 9 November.
https://www.cbc.ca/news/canada/north/iqaluit-water-canadian-armed-forces-emergency-1.6243307#:~:text=X-,The%20Canadian%20Armed%20Forces%20is%20now%20providing%20potable%20water%20in,the%20city's%20treated%20water%20supply

———. 2022, July 28. Plastic bottles from Iqaluit water crisis bound for recycling in Montreal. Nunatsiaq News.
https://nunatsiaq.com/stories/article/plastic-bottles-from-iqaluit-water-crisis-bound-for-recycling-in-montreal/

Kellner, E. 2023. Identifying leverage points for shifting water-energy-food nexus cases towards sustainability through the networks of action situations approach combined with systems thinking. Sustainability Science 18:135–152.
https://doi.org/10.1007/s11625-022-01170-7

Khourchid, A.M., Mahmood, F., Al-Ghamdi, S.G., Ayyub, B.M., Al-Ansari, T. 2024. National level resilience: Innovative framework for energy-water-food nexus evaluation. Sustainable Production and Consumption 49:589–605.
https://doi.org/10.1016/j.spc.2024.07.013.

Kinzig, A.P., Ryan, P., Etienne, M., Allison, H., Elmqvist, T., and Walker, B.H. 2006. Resilience and regime shifts: Assessing cascading effects. Ecology and Society 11(1): 20.
http://www.ecologyandsociety.org/vol11/iss1/art20/

Lawrence, J., Blackett, P., and Cradock-Henry, N.A. 2020. Cascading climate change impacts and implications. Climate Risk Management 29: 100234.
https://doi.org/10.1016/j.crm.2020.100234

Little, K. 2022. Iqaluit's water crisis highlights deeper issues with Arctic infrastructure. The Arctic Institute Center for Circumpolar Security Studies. 2 May.
https://www.thearcticinstitute.org/iqaluits-water-crisis-highlights-deeper-issues-arctic-infrastructure/

Madani, Z., and Natcher, D. 2024. Water, energy and food (WEF) nexus in the changing Arctic: An international law review and analysis. Water 16(6): 835.
https://doi.org/10.3390/w16060835

McKay, J. 2022. Water contamination and ravens spreading garbage: Concerns linger over Iqaluit's new landfill. CBC, 23 February.
https://www.cbc.ca/news/canada/north/landfill-iqaluit-tender-1.6361572#:~:text=North-,Water%20contamination%20and%20ravens%20spreading%20garbage%3A%20Concerns%20linger%20over%20Iqaluit's,sustainability%2C%20litter%20and%20contamination%20concerns

Medeiros, A. 2024. Water security in a warming Arctic. WWF Global Arctic Programme.
https://www.arcticwwf.org/the-circle/stories/water-security-in-a-warming-arctic/

Medinilla, A. 2021. An adaptive and context-driven approach to the water, energy and food nexus: Briefing note. Brussels: Ecdpm.
https://ecdpm.org/application/files/5216/5546/8566/Adaptive-Context-Driven-Approach-Water-Energy-Food-Nexus-ECDPM-Briefing-Note-135-2021.pdf

Meier, W.N., Hovelsrud, G.K., van Oort, B.E.H., Key, J.R., Kovacs, K.M., Michel, C., Haas, C., et al. 2014. Arctic sea ice in transformation: A re-view of recent observed changes and impacts on biology and human activity. Reviews of Geophysics 52(3):185–217.
https://doi.org/10.1002/2013RG000431

Mills, J., Bonner, A., and Francis, K. 2006. The Development of constructivist grounded theory. International Journal of Qualitative Methods 5(1):25–35.
https://doi.org/10.1177/160940690600500103

Miralles-Wilhelm, F. 2016. Development and application of integrative modeling tools in support of food-energy-water nexus planning—A research agenda. Journal of Environmental Studies and Sciences 6:3–10.
https://doi.org/10.1007/s13412-016-0361-1

Morritt-Jacobs, C. 2021. Donor 'flabbergasted' at the cost of shipping water from Yellowknife to Iqaluit. National News, 2 November.
https://www.aptnnews.ca/national-news/donor-flabbergasted-at-the-cost-of-shipping-water-from-yellowknife-to-iqaluit/#:~:text=Katherine%20Mackenzie%20of%20Yellowknife%20organized,%E2%80%9CI%20was%20flabbergasted

Mpandeli, S., Naidoo, D., Mabhaudhi, T., Nhemachena, C., Nhamo, L., Liphadzi, S., Hlahla, S., and Modi, A.T. 2018. Climate change adaptation through the water-energy-food nexus in southern Africa. International Journal of Environmental Research and Public Health 15(10): 2306.
https://doi.org/10.3390/ijerph15102306

Natcher, D., and Ingram, S. 2021. A nexus approach to water, energy, and food security in northern Canada. Arctic 74(1): 1–11.
https://www.jstor.org/stable/27088551

Naweed, N. 2022. The heavy price tag on food security in northern Canada. Rising sun food drive foundation. 22 March.
https://www.risingsunfd.com/post/the-heavy-price-tag-on-food-security-in-northern-canada

Newbery, T. 2020. Obituary: Nick Newbery, 1944–2020. Nunatsiaq News, 28 February.
https://nunatsiaq.com/stories/article/obituary-nick-newbery-1944-2020/

NTI (Nunavut Tunngavik Incorporated). 2020. Nunavut Tunngavik Incorporated: Annual general meeting, 16 Octobe.
https://www.tunngavik.com/news/nunavut-tunngavik-inc-annual-general-meeting/

Numbeo. 2024, March. Cost of living in Iqaluit.
https://www.numbeo.com/cost-of-living/in/Iqaluit-NU-Canada

Oldenborger, G.A., and LeBlanc, A.-M. 2015. Geophysical characterization of permafrost terrain at Iqaluit International Airport, Nunavut. Journal of Applied Geophysics 123:36–49.
https://doi.org/10.1016/j.jappgeo.2015.09.016

Parikh, P., Diep, L., Hofmann, P., Tomei, J., Campos, L.C., Teh, T.-H., Mulugetta, Y., Milligan, B., and Lakhanpaul, M. 2021. Synergies and trade-offs between sanitation and the sustainable development goals. UCL Open Environment 2: e016.
https://doi.org/10.14324/111.444/ucloe.000016

Pelletier, J. 2024, March 14. Iqaluit council backs cutting residential water rates in half. Nunatsiaq News.
https://nunatsiaq.com/stories/article/iqaluit-council-backs-cutting-residential-water-rates-in-half/#:~:text=Iqaluit%20city%20councillors%20say%20residents,at%20its%20meeting%20Tuesday%20night

Pescaroli, G., and Alexander, D. 2016. Critical infrastructure, panarchies and the vulnerability paths of cascading disasters. Natural Hazards 82:175–192.
https://doi.org/10.1007/s11069-016-2186-3

QCFC (Qajuqturvik Community Food Centre). 2024. 2023–24 annual report. The Qajuqturvik Community Food Centre, Iqaluit, Nunavut.
https://cdn.prod.website-files.com/60914bd5457b5061c3131bc2/671ab589ec0baf17ebd0506c_QAJUQTURVIK%20Annual%20Report%2023-24%20EN%20FINAL.pdf

QEC (Qulliq Energy Corporation). 2023. 2022–2023 annual report. Qulliq Energy Corporation. Iqaluit, Nunavut.
https://www.qec.nu.ca/sites/default/files/annual_report_2022-23_-_qulliq_energy_corporation_-_final-_english.pdf.

Radmehr, R., Ghorbani, M., and Ziaei, A.N. 2021. Quantifying and managing the water-energy- food nexus in dry regions food insecurity: New methods and evidence. Agricultural Water Management 245: 106588.
https://doi.org/10.1016/j.agwat.2020.106588

Rantanen, M., Karpechko, A.Y., Lipponen, A., Nordling, K., Hyvärinen, O., Ruosteenoja, K., Vihma, T., and Laaksonen, A. 2022. The Arctic has warmed nearly four times faster than the globe since 1979. Communications Earth & Environment 3(1): 168.
https://doi.org/10.1038/s43247-022-00498-3

Rawlins, M.A., and Karmalkar, A. 2004. Arctic rivers face big changes with a warming climate, permafrost thaw and an accelerating water cycle—The effects will have global consequences. The Conversation, 5 March.
https://theconversation.com/arctic-rivers-face-big-changes-with-a-warming-climate-permafrost-thaw-and-an-accelerating-water-cycle-the-effects-will-have-global-consequences-224869

Rehman, A., Batool, Z., Ma, H., Alvarado, R., and Oláh, J. 2024. Climate change and food security in South Asia: The importance of renewable energy and agricultural credit. Humanities and Social Sciences Communications 11(1): 342.
https://doi.org/10.1057/s41599-024-02847-3

Romero-Lankao, P., and Norton, R. 2018. Interdependencies and risk to people and critical food, energy, and water systems: 2013 flood, Boulder, Colorado, USA. Earth's Future 6(11):1616–1629.
https://doi.org/10.1029/2018EF000984

Schmidt, J.I., Johnson, B., Huntington, H.P., and Whitney, E. 2022. A framework for assessing food-energy-water security: A FEW case studies from rural Alaska. Science of The Total Environment 821: 153355.
https://doi.org/10.1016/j.scitotenv.2022.153355

SDWG (Sustainable Development Working Group). 2021. Finding the nexus between water, energy and food in the Arctic. Arctic Council Secretariat.
https://arctic-council.org/news/nexus-between-water-energy-and-food-in-the-arctic/

Smith Lopez, C., Bogdan, A.M., Belcher, K., and Natcher, D. 2024. Advancing a WEF nexus security index for Alaska: An informed starting point for policy making. Polar Geography 47(2):71–89.
https://doi.org/10.1080/1088937X.2024.2311785

Somos, C. 2021. Iqaluit forced to medevac patients out of territory as water crisis hits hospital. CTV, 21 October.
https://www.ctvnews.ca/canada/iqaluit-forced-to-medevac-patients-out-of-territory-as-water-crisis-hits-hospital-1.5632461

Stake, R.E. 1995. The art of case study research. Thousand Oaks: Sage Publications.

Statham, S. 2012. Inuit food security: Vulnerability of the traditional food system to climatic extremes during winter 2010/2011 in Iqaluit, Nunavut. MSc thesis, McGill University, Montreal, Quebec.
https://escholarship.mcgill.ca/concern/theses/6682x7587

Statistics Canada. 2020. Household food insecurity, 2017/2018.
https://www150.statcan.gc.ca/n1/en/pub/82-625-x/2020001/article/00001-eng.pdf?st=ZIvNThjx

———. 2022. Population and dwelling counts: Canada, provinces and territories, and census subdivisions (municipalities).
https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810000202

Swanson, D., Murphy, D., Temmer, J., and Scaletta, T. 2021. Advancing the climate resilience of Canadian infrastructure: A review of literature to inform the way forward. International Institute for sustainable development.
https://www.iisd.org/system/files/2021-07/climate-resilience-canadian-infrastructure-en.pdf

Taylor, J. 2023. In Arviat, Nunavut, residents start recovering from fierce blizzard. CBC, 25 November.
https://www.cbc.ca/news/canada/north/arviat-state-of-emergency-power-outage-blizzard-1.7040198#:~:text=After%20a%20blizzard%20tore%20through,without%20power%20for%20four%20days

Tchonkouang, R.D., Onyeaka, H., and Nkoutchou, H. 2024. Assessing the vulnerability of food supply chains to climate change-induced disruptions. Science of The Total Environment 920: 171047.
https://doi.org/10.1016/j.scitotenv.2024.171047

The Firelight Group. 2022. The impacts of permafrost thaw on northern Indigenous communities. Vancouver: Firelight Research Inc.
https://climateinstitute.ca/wp-content/uploads/2022/06/Impacts-permafrost-thaw-Climate-Institute-Firelight-Report.pdf

Thompson, J. 2018. Nunavut spends $60M annually to subsidize diesel. Nunatsiaq News, 24 February.
https://nunatsiaq.com/stories/article/65674nunavut_spends_60m_annually_subsidizing_diesel/

Tranter, E. 2021. “We’re all tired”: Iqaluit residents unable to drink tap water for nearly 2 months. CTV News, 3 December. https://www.cbc.ca/news/canada/north/iqaluit-residents-tap-water-2-months-dec-3-1.6273006

———. 2023. Disagreements between city, territory slowed Iqaluit water crisis response: Report. CBC, 3 October. https://www.cbc.ca/news/canada/north/iqaluit-water-crisis-review-report-1.6986832#:~:text=North-,Disagreements%20between%20city%2C%20territory%20slowed%20Iqaluit%20water%20crisis%20response%3A%20report,review%20commissioned%20by%20the%20territory

Venn, D. 2022. Iqaluit declares local state of emergency over water drought. Arctic Today, 15 August. https://www.arctictoday.com/iqaluit-declares-local-state-of-emergency-over-water-drought/

———. 2023. 500 people in Iqaluit go without daily meal as food centre deals with burst pipes. Nunatsiaq News, 3 March. https://nunatsiaq.com/stories/article/500-people-in-iqaluit-go-without-daily-meal-as-food-centre-deals-with-burst-pipes/

Walker, B., and Meyers, J.A. 2004. Thresholds in ecological and social–ecological systems: A developing database. Ecology and Society 9(2): 3. http://www.ecologyandsociety.org/vol9/iss2/art3

WSP (William Sale Partnership). 2021. Assessment of climate change impacts on infrastructure in all NWT communities. Montreal: Government of Northwest Territories. https://www.maca.gov.nt.ca/sites/maca/files/resources/gnwt_pievc_report_final_released.pdf