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# Health risks associated with sea level rise

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# Key Messages

- Canadian coastal communities will be exposed to a range of potential health impacts arising from both the direct and indirect effects of sea level rise on the natural and built environment.
- Sea level rise could exacerbate the effects of coastal flooding or storm surge, increasing the potential for deaths due to drowning, and other physical injuries near the sea.
- Sea level rise may lead to contamination of water and land from untreated wastewater or other legacy toxins in inundated coastal areas, which will increase exposure to contaminants or waterborne pathogens, causing disease and illness.
- Coastal communities that depend on groundwater may face reduced water quality and water security with the increasing salinization of drinking water sources.
- Sea level rise will exacerbate coastal flooding and contribute to an expansion of the habitat for mosquitoes, increasing potential exposure to vector-borne diseases, including West Nile virus, which is under surveillance and monitoring by the Government of Canada.
- Sea level rise will exacerbate the effects of coastal flooding and hamper recovery from floods, which could increase the occurrence of mould in homes and public buildings, compromising indoor air quality.
- Sea level rise can cause loss of cultural land, loss of livelihoods, economic hardship, reduced food and water security, and displacement of individuals or whole communities, leading to mental health effects ranging from eco-anxiety and solastalgia to anxiety, depression, or post-traumatic stress disorder.
- Impacts on the social determinants of health such as secure income, safe physical environments, and access to health care and public services are impacted by sea level rise due to damaged infrastructure and transportation routes, and compromise key industries (e.g., tourism and agriculture) due to loss of land or contamination of resources.
- The health of Indigenous coastal communities in Canada is at higher risk due to the geographic exposure to coastal impacts, and sensitivity to risks based on cultural, historical, and systemic inequities affecting food and water security, mental health, and cultural connectedness.
- Not all Canadian coastal communities will be impacted in the same way, and local factors may determine the likelihood and severity of some impacts on health.

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# Introduction

Global sea levels are rising due to meltwater volume added from glaciers, polar ice caps, and ice sheets, and from the thermal expansion of warming ocean waters. Sea level is also changing in some locations (rising or sinking) due to vertical land motion following the last ice age.<sup>1</sup> Sea level rise intensifies coastal hazards such as storm surge and will increase the occurrence and severity of coastal flooding and erosion. Sea level rise also brings longer-term gradual encroachment of the sea into low-lying land. As detailed in the companion report to this one, “Overview of Canadian communities exposed to sea-level rise,”<sup>2</sup> the regions of Canada projected to be most exposed to rising seas include the Atlantic coast, the mainland coast of the Beaufort Sea, the cities of Metro Vancouver, and the many small island and Indigenous communities situated throughout these vulnerable coastlines.

The impacts of various hazards related to climate change such as heat, flooding, and the disruption to natural systems have been studied extensively, and various reports have summarized the significance of climate change to the health and well-being of Canadians.<sup>3-5</sup> However, the specific link between sea level rise and human health, has not been widely discussed, either in national or international works.<sup>6-9</sup> The purpose of this report is to examine the available evidence on the impacts on human health and well-being that may be driven by sea level rise. This information is intended to assist public health professionals and others involved in climate change adaptation to better incorporate health considerations into adaptation planning for affected coastal communities.

## Methodology

The guiding questions for the literature review were: ***what are the potential impacts of sea level rise on human health and who is most vulnerable to those impacts?***

The author searched the scholarly and grey literature for evidence that combined the concepts of human health impacts and sea level rise using the following databases and search engines: PubMed, Science direct, Medline, Ovid, the Lancet, and Google Scholar. To identify grey literature, Google and the websites of government agencies were used to search for sea level rise and human health impacts. Given that “sea level rise” and “human health” are very generic terms in climate and health literature, Boolean searches with additional terms (e.g., saltwater intrusion; drinking water; food security; and waterborne) were also utilized in an attempt to identify topic-relevant literature. Both peer-reviewed and pre-print sources were considered. Papers were excluded if they were published prior to 2010 or in a language other than English. While initial searches resulted in more than 1,900 hits, articles were selected for



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secondary review if they had “sea level rise” and “human health” (or associated concepts) referenced in the title or abstract. A full review of the remaining 110 documents was undertaken and supplementary references were added via forward and backward chaining of those documents. The final selection of documents included 54 peer-review articles, or published conference proceedings as well as 28 websites, articles, and documents from the grey literature including government agencies, having some relevance to the topic. Each publication was assessed by a single reviewer and the results have been synthesized narratively. Complete search terms and the literature review matrix can be provided by request.

## Findings

### What are the potential health risks associated with sea level rise?

While there were only a limited number of publications that specifically linked sea level rise to health outcomes,<sup>6,8,9</sup> international publications established several direct risks to human health from events exacerbated by sea level rise, such as coastal flooding and erosion, as well as slow onset and indirect risks that may lead to significant health impacts for coastal populations around the world.<sup>10</sup>

There is general agreement in the literature that sea level rise poses risks to human health by way of injuries or drownings when combined with extreme weather events, infectious diseases due to increased exposure to waterborne or vector-borne pathogens, health effects from increased exposure to contaminants or airborne pollutants, and multiple impacts on mental health and the social determinants of health.<sup>11-13</sup> Further, sea level rise acts as a “risk-amplifier” for health impacts by exacerbating existing environmental, socio-economic, and health disparities, particularly for more highly exposed coastal communities, and those experiencing historical health and social inequities, compounding the health impacts.<sup>14,15</sup> This includes many rural and remote and Indigenous coastal communities of BC, the Atlantic provinces and the North of Canada. The following sections will examine the major risks to health arising from both the direct and indirect impacts of sea level rise in further detail.

### Physical injury or mortality

Sea level rise is a gradual process, and as such its impact on risk of physical injury or mortality caused by sea level rise alone is poorly understood, due to this slow pace of change. However, it is predicted that rising sea levels will exacerbate impacts arising from extreme weather events affecting coastal areas. As

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the occurrence of weather events such as heavy precipitation, winds, and storms increase in frequency and intensity, there will be a corresponding increase in the occurrence of elevated storm surges, coastal flooding, and coastal erosion, which could lead to an increase in the risk of physical injury or death from damaged infrastructure, buildings or roads.<sup>6,13,16-18</sup> Modelling and simulation studies have indicated that sea level rise could increase injury and mortality (e.g., drownings) associated with coastal flooding,<sup>18,19</sup> which may be linked to the intensity of these events (e.g., water depth and velocity), or failure of protections such as dykes, seawalls, or other barriers.

## Exposure to infectious disease

Waterborne pathogens can impact water used for drinking, bathing, recreation, or food harvesting, leading to human illness. Sea level rise may influence exposure to waterborne pathogens by causing rising water tables, or damaging water and sanitation infrastructure, contributing to contamination of drinking water sources and facilitating the transfer of microbial pollutants into marine environments used for recreation or food harvesting.

### *Exposure to waterborne pathogens due to disrupted infrastructure*

Rising sea levels and the incursion of saltwater can disrupt sewage and sanitation systems, leading to conditions that can increase exposure to pathogens in urban settings and marine and estuarine environments.<sup>20,21</sup> Increased rainfall intensity and sea level rise effectively raise groundwater tables in coastal areas and increase the saturation of soil.<sup>22</sup> This can cause the inundation of combined sewer systems (e.g., those that collect rainwater runoff and wastewater in the same pipes) with surface runoff that no longer drains naturally, and can force untreated wastewater back up into homes and onto streets, exposing some communities to wastewater contamination.<sup>23</sup> Oversaturation can also cause underground pipes to shift, corrode, and crack, impeding the function and capacity of wastewater infrastructure. The unintended release of untreated wastewater can contaminate nearby groundwater wells, surface water sources, or coastal recreational waters and shellfish harvesting sites. Importantly, the disruption of these wastewater services can impact the sanitation services for both coastal and inland communities that rely on this infrastructure.<sup>6,24</sup> Without effective treatment of wastewater, there is a risk of increased exposure to waterborne pathogens and associated illnesses.<sup>23,25</sup> Diseases of concern are those typically caused by waterborne pathogens such as *Campylobacter*, *Giardia*, *Cryptosporidium*, *Shigella* and *E.coli*, as well as enteric viruses.<sup>8</sup>

Elevated water tables will also interfere with the function of septic systems, which pervade all but a few urban areas of Canada's (and the world's) coastline and many rural and remote communities.<sup>26</sup> Failing septic systems can result in increased loading of bacteria, viruses, and nutrients (e.g., nitrogen and phosphorus) into nearby waters, potentially degrading local water quality and fisheries, or contributing to

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harmful algal blooms.<sup>26</sup> The lack of data on the scale of septic system vulnerability is a key gap in the ability to plan for and address potential contamination.

While there are few examples in the literature reporting on increased incidence of health effects from water infrastructure directly impacted by sea level rise, it is apparent that ensuring the proper functioning of infrastructure (both public and private) is essential for maintaining public health.

### *Threats to marine food safety*

Marine pathogens are responsible for approximately 250 million cases of illness a year, primarily due to consumption of contaminated shellfish or other seafoods, or direct exposure to seawater (e.g., recreational waters) contaminated with bacteria such as *Norovirus* or *Vibrio* spp..<sup>27</sup> Sea level rise may exacerbate some of these exposures by increasing the transfer of waterborne pathogens from terrestrial sources (e.g., sewage) into marine or estuarine environments, including seafood harvesting waters.<sup>25</sup> For example, *Vibrio* spp. are a group of hundreds of naturally occurring bacteria, which include *V. cholera* (associated with cholera disease), which thrives in brackish waters, as well as *V. parahaemolyticus* and *V. vulnificus*, both of which thrive in marine waters and are a major cause of seafood-borne illnesses globally.<sup>27</sup> Rising sea level and increased coastal flooding could allow these species to expand further into estuarine areas. Increasing inland salinity levels to those more favourable to *Vibrio* spp. could result in expanded species distribution, and patterns of infection.<sup>28-30</sup> *Vibrio* bacteria can be transmitted through ingestion or transdermally via open wounds to cause mild to severe gastroenteritis, extraintestinal infections, and skin and soft tissue infection.<sup>8</sup> Infection is mainly through ingestion of raw shellfish (e.g., oysters) or by exposing open wounds to contaminated brackish<sup>a</sup> water or seawater.<sup>8</sup> Research from the United States suggests that there may be a significant underestimation of the occurrence of illness caused by waterborne pathogens by as much as 43 times on average, and by up to 143 times for *Vibrio*.<sup>25</sup> Humans may come into more frequent contact with these microorganisms as a result of rising seas and the movement of saltwater farther inland.<sup>31</sup>

## Saltwater intrusion

Water safety and security, and specifically salinization of drinking water, appears to be a significant risk to human health from sea level rise, affecting as many as 500 million people globally.<sup>29,32-37</sup> Saltwater intrusion has been called a “slow poison” as seawater enters groundwater systems from beneath the surface, leading to a continuous invasion of saltwater into freshwater aquifers, particularly during times of drought and low freshwater levels. Sea level rise is expected to allow saltwater to reach further inland and cause increased salinity in the drinking water of coastal communities that rely on groundwater for

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<sup>a</sup> A transitional area that hosts a combination of fresh and sea water.

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their source water.<sup>38</sup> One stark example of the influence of the rising sea on water supply is in Hilton Head, North Carolina, where saltwater is migrating at a rate of 400 feet per year from the Atlantic Ocean into freshwater drinking systems. Of the city's twelve original drinking water wells, six have been abandoned and a further five will be contaminated by 2024.<sup>11</sup>

Coastal populations in countries such as Bangladesh, Kenya, and Nigeria are already confronted with high salinity exposure, which is predicted to further increase as a result of sea level rise and other environmental influences.<sup>34,39,40</sup> Populations drinking untreated river water affected by elevated salinity in places such as Bangladesh can be exposed to elevated sodium intake (e.g., 16 g per day),<sup>36</sup> which is far in excess of recommended maximum levels in Canada (e.g., 5 g per day). Health Canada has established the aesthetic objective sodium level of 200 mg/L for drinking water, the level at which drinking water becomes unpalatable.<sup>41</sup> Exposure to elevated salinity can occur through drinking, cooking, and bathing. At low concentrations, salty water is more of a nuisance than a health threat. However, at high concentrations, individuals can develop hypertension, which exacerbates pre-existing health conditions, puts the elderly at higher risk of stroke, and increases the frequency of hospital visits for cardiovascular disease and abdominal pain.<sup>12,32,33,38</sup> Elevated salinity in drinking water has also been linked to increased risk of preeclampsia and gestational hypertension, infant mortality, cholera outbreaks, renal disease, cirrhosis, and skin and diarrheal diseases.<sup>36,41-43</sup> Communities that are unable to find alternative water sources or implement suitable treatment may face displacement as a result of dwindling water security.

Generally, the situation along Canada's coasts is less critical than in some developing nations that have limited provision of treated drinking water. Highly populated areas like those in the Metro Vancouver and Greater Victoria area have relatively secure water supplies, provided by surface water sources not exposed to coastal influences.<sup>44</sup> However, many people in low-lying coastal areas in the suburbs, rural areas, and islands have onsite wells that are becoming increasingly exposed to inundation due to sea level rise.<sup>24</sup> Groundwater is the primary source of drinking water for 12% of Canadians, many of whom rely on private wells, particularly in rural areas including coastal and island communities.<sup>45</sup> Saltwater intrusion has been an issue for Atlantic Canada for several decades.<sup>46</sup> New Brunswick has recorded incidences in Shippagan, Richibucto and Shediac Bay (Northumberland Strait coastline). In Nova Scotia, the Atlantic coast near Lawrencetown and the Pictou area (Northumberland Strait) have both been areas of concern with regard to saltwater intrusion. With no major lakes or rivers, Prince Edward Island is particularly vulnerable due to its complete reliance on groundwater to supply drinking water to the province. Studies have been undertaken to address the island's susceptibility to saltwater intrusion, which was generally found to be driven by a combination of tidal action, changing recharge rates, and tidal estuaries that lead deep inland.<sup>46</sup> Finally, les Îles de la Madeleine in the Gulf of St. Lawrence have also been found to be highly vulnerable to saltwater intrusion.<sup>46</sup> These areas may require some wells to be abandoned over time, or enhanced water treatment to ensure safe drinking water.

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## Exposure to contaminants

Rising sea levels and coastal erosion are expected to facilitate the release of toxins from contaminated sites and long-buried landfills. Industrial development along coastlines, once a common practice to facilitate marine transportation of manufactured goods, has left some regions with a legacy of coastal soil contamination.<sup>47-49</sup> The Federal Contaminated Sites Inventory lists known and suspected contaminated sites across Canada, many of which are located in coastal areas.<sup>50</sup> Inundation of industrial buildings, storage facilities, hazardous waste sites, wastewater treatment sites, oil facilities, pesticide and chemical plants, as well as abandoned industrial operations and landfills could enable the remobilization of contaminants, ranging from solid materials such as asbestos and plastics, to inorganic and organic water contaminants, to radioactive waste.<sup>51</sup> Underground petroleum storage tanks may also be impacted due to erosion or water inundation causing the tanks to become unstable or damaged, resulting in the release of contaminants into nearby waters.<sup>52,53</sup> Rising groundwater levels in combination with sea level rise, is expected to further exacerbate this issue by releasing legacy contamination, including volatile organic compounds such as benzene, or heavy metals such as arsenic from soil in areas that have been remediated.<sup>42,48</sup> Landfill leachate and many other chemical pollutants may then contaminate local drinking water, recreational waters, agricultural land or food-growing marine areas. These hazards are of particular concern due to the uncertainty of the potential scale, types of contamination, and long-term implications of this waste being released into the environment.<sup>48,51</sup> Exposure to chemical agents can cause a range of impacts from skin and eye irritation and headaches, to cancer, genetic mutations, and organ disease, among others.<sup>54,55</sup> The potential health risks arising from increased chemical exposure due to sea level rise in Canada have not been widely studied and will depend on the likelihood of exposure as well as the type and concentration of chemical exposure, and is an area for further research.

## Exposure to vector-borne diseases

Vector-borne diseases are infections transmitted to humans by the bite of an infected vector, such as a mosquito or tick. Coastal inundation and flooding exacerbated by sea level rise can cause expansion of water-based habitat for vectors such as mosquitoes. Mosquito-borne diseases such as encephalitis (inflammation of the brain tissue) are caused by arboviruses such as West Nile Virus, the most common type in Canada.<sup>56</sup> While not currently threats in North America, Dengue fever, Malaria, and Zika virus are also vector-borne diseases affected by warmer climates and may become more significant issues in tourist destinations in the future.<sup>8,57,58</sup>

Saltwater intrusion and the expansion of areas covered by shallow water have the potential to create new mosquito breeding sites.<sup>8</sup> For mosquito-borne diseases, rising sea levels can modify the local environment to create conditions that are more favourable for vector habitat, allowing the pathogens to thrive, which increases the likelihood of human exposure to them.<sup>8</sup> Further, studies have found that



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some mosquito species, which were traditionally considered to be freshwater mosquitos, have adapted to reproduce within brackish water environments after incidents of saltwater intrusion, thereby expanding the habitat and increasing the density of coastal vectors, all leading to greater risk for disease transmission.<sup>8,9,57</sup>

## Exposure to poor air quality

Few studies have considered the direct impacts of sea level rise on indoor air quality; however, flooding events can be exacerbated by sea level rise and can lead to elevated indoor mould growth that may be associated with a variety of health effects such as congestion, wheezing, red or itchy eyes or skin and possibly asthma.<sup>59,60</sup> Rising water tables in coastal areas, caused by sea level rise, also make it more difficult for the ground and building foundations to dry out following flooding events. As a result, this can exacerbate indoor air quality issues in affected buildings, which may include homes and care facilities as well as workplaces and schools. Health impacts of mould spores can range from a mild allergic response, such as irritation of the mucus membranes, to long-term impacts, such as cancer or bleeding disorders.<sup>59,61</sup> Further, the remobilization of chemicals from flooded contaminated sites, as noted above, could also increase ambient air concentrations of volatile pollutants, such as benzene; however, knowledge gaps remain as to the extent to which sea level rise could exacerbate exposure to air contaminants in Canadian towns and cities.<sup>42</sup>

## Mental health effects

Sea level rise, among other climate change effects, is a creeping change, or an accumulation of incremental changes, which often go unnoticed. Over time, however, these changes can accumulate to cause significant impacts. This can include numerous mental health impacts, including stress from forced displacement, loss of cultural land, and economic hardship.<sup>62,63</sup> Some researchers suggest that climate change is becoming internalized by some as an existential threat that contributes to “psychoterratic” syndromes, such as eco-anxiety and eco-paralysis, where the overlapping threats of the changing climate can incite despair and hopelessness.<sup>63,64</sup> Where nostalgia is homesickness experienced by individuals when separated from home, “solastalgia” is characterized by the distress that is produced by environmental change affecting people while they are still living in their home environment.<sup>65</sup> This can be the experience of peoples who have lived closely with the land for many generations, but are now living through the visible impacts of climate change such as sea level rise, permafrost thaw, glacial recession, and anomalous warm temperatures.<sup>66</sup>

Both subsistence (such as agriculture, fishing, forestry, and hunting) and non-subsistence (such as tourism and hospitality) livelihoods are experiencing these creeping changes associated with climate

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change. If individuals and communities are unable to adapt their livelihoods, then mental health and well-being impacts may be exacerbated by unemployment, economic hardship, and inability to meet basic needs. For many in small coastal communities, these challenges are often layered upon pre-existing vulnerabilities, such as the structural violence of colonialism.<sup>62</sup> International studies have found anxiety and feelings of powerlessness related to sea level rise, which causes fear and worry on a personal and at the community level.<sup>62,67</sup>

### *The impacts of displacement*

A large proportion of the global population presently resides in coastal regions where sea level rise impacts are expected and, in many cases, may influence the migration of millions of people.<sup>68</sup> Kulp and Strauss estimated the current vulnerability of Canadians living on land below annual flood levels to be upwards of 600,000 people.<sup>69</sup> This compares to a projected total of 840,000 Canadians living on land threatened by annual flood events by 2100 as a result of sea level rise.<sup>69</sup> There is no doubt that unrelenting sea level rise will force some coastal populations to move from their current locations. In addition to the physical loss of land, contaminated drinking water and infrastructure impacts could force coastal communities to migrate. Migration from sea level rise is multifaceted and can be influenced by environmental hazards and political, demographic, economic, and social factors embedded within policy incentives to encourage (or obstruct) migration.<sup>68</sup> Nonetheless, some research has suggested that sea level rise this century may induce large-scale migration away from unprotected coastlines, redistributing population density across countries, putting great pressure on inland areas.<sup>70</sup>

Population displacement is a significant contributor to mental health impacts as a result of increased stress and uncertainty. This presents in individuals as anxiety disorder, post-traumatic stress disorder (PTSD), and depression.<sup>63,71</sup> Forced relocation either inland or to completely different places often results in disharmony in these communities, demonstrating that climate change can impact both individuals and communities as sea level rise erodes physical environments and in turn damages social relationships.<sup>67</sup> As a consequence, these so-called climate refugees may suffer substantial health burdens from overcrowding, lack of shelter, and competition for resources, placing additional pressure on inland communities resulting in potential conflicts.<sup>12</sup> In addition, there is a risk of emerging infectious diseases as populations move and urban areas become more densely populated.<sup>3</sup>

## **Impacts on social determinants of health**

The social determinants of health can be significantly impacted by sea level rise.<sup>14,15,72</sup> Many of the health consequences of displacement from sea level rise are manifested through impacts on social determinants of health such as the loss of employment, loss of traditional food sources, and reduced basic amenities that can affect early childhood development, reduce social inclusion, increase conflict, and reduce access to health services.<sup>6,15,73</sup> These changes can further lead to financial and relationship stress, increase risks

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of violence and aggression, and loss of community connections and social capital.<sup>63</sup> Food and water insecurity have been associated with symptoms of depression, anxiety, and other mental health and well-being difficulties in both adults and children.<sup>62</sup>

### *Food security*

Sea level rise and its effects pose serious threats to coastal agricultural land due to both the physical loss of arable land, and due to crop sensitivity to elevated salt concentrations in irrigation water and/or soils. Salt can affect plants through dehydration and stunting, ultimately lowering crop yields.<sup>29</sup> Further, saltwater can affect soil water chemistry, which could cause enhanced leaching of nutrients from impacted soil, leading to eutrophication of nearby water sources.<sup>74</sup> Erosion caused by rising seas is also impacting coastal agriculture globally. In Canada, future coastal erosion rates are projected to increase in various areas – mostly in the north and east - with Prince Edward Island and eastern New Brunswick being of particular concern.<sup>75,76</sup> These impacts on agricultural production will reduce food security in these regions, and across Canada.

Marine food sources may also be at risk due to sea level rise. Ongoing impacts from salinization of coastal freshwater and soil is associated with the risk of species extinctions, and reduced aquatic biodiversity. Sea level rise may also adversely impact important coastal habitats for shellfish and other aquatic species due to physical degradation of intertidal growing areas, eutrophication leading to harmful algal blooms, or contamination of these sites with various chemical or biological pollutants as noted earlier. The reduced availability of coastal foods could potentially decrease the availability of protein-based nutrition, especially among the communities who depend on local fisheries for sustenance.<sup>8</sup> Traditionally harvested seafood is a fundamental component to the diet and health of coastal Inuit and First Nations communities in Canada, and climate change-related impacts like sea level rise may have significant nutritional and health repercussions.<sup>77,78</sup>

From a food system point of view, sea level rise may also pose transportation challenges. If the food supply chain is interrupted due to impacted transportation corridors, delays can affect food safety and reduce the nutritional value of fresh foods once they are eventually processed.<sup>79</sup> Further, loss of critical corridors such as the Chignecto Isthmus connecting Nova Scotia to New Brunswick can severely impact food security in provinces like Newfoundland & Labrador, Prince Edward Island, and Nova Scotia, all of which rely on this principle TransCanada Highway corridor for the transport (by rail and truck) of the bulk of their imported food supplies.<sup>80</sup>

### *Community services and health system impacts*

Historically, many communities were first established in proximity to water as a primary transportation route, and many maintain a close connection to the sea and continue to develop coastal areas. Sea level

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rise, however, presents long-term risks and disruption of daily life in these communities where people live, work, learn, and play. Rising water tables, as a result of seawater intruding into coastal areas, may affect utilities such as natural gas and buried electrical lines, as well as the functioning of other underground systems.<sup>22,42,81</sup> Sea level rise can also magnify the effect of extreme weather events. As an example, the impacts from Hurricane Fiona to Atlantic Canada in 2022 were widespread and devastating, with three deaths, twelve houses washed to sea, and loss of power, phone, and cellular service to hundreds of thousands of people for extended periods of time throughout the region.<sup>82</sup> This disrupted work, school, and commercial activities, and access to health services and grocery stores was impaired due to the loss of power and blocked transportation routes. The long-term mental health impacts that may result are not yet known, as recovery is still ongoing, but such events are recognized to trigger PTSD, anxiety, vicarious trauma, and suicide ideation, among others.<sup>6,63</sup>

Sea level rise may impact the health system and delivery of health services. This may be exacerbated by the fact that many major healthcare facilities have been established in highly populated coastal cities, vulnerable to the impacts of sea level rise.<sup>83,84</sup> For example, in San Francisco, California, there are 15 healthcare facilities at risk of being impacted by a current-day 100-year flood; however, with the projected sea level rise, the number rises to 42 facilities at risk.<sup>85</sup> In British Columbia, it is estimated that much of the existing health infrastructure will require relocation as sea level rise will disrupt health care services not only for those living on the coast but also those who depend on coastal facilities.<sup>86,87</sup> As many as four hospitals, five ambulance stations and 23 fire stations in the Lower Mainland of British Columbia are vulnerable to flood risks, which will only be exacerbated by sea level rise.<sup>88</sup>

## Summary of health risks associated with sea level rise

The potential health impacts of rising seas are diverse, ranging from impacts on individuals such as physical injury or increased exposure to microbial or chemical contaminants, to impacts on the community level such as loss of land, infrastructure, food security or health services. Table 1 summarizes the main health risks linked to sea level rise, as well as the potential health outcomes that may result.



Table 1: Summary of potential health impacts from sea level rise

Health risk	Linkage to sea level rise	Health outcomes	Ref
Physical injury or mortality	Coastal inundation during storm events, flooding, coastal erosion, and failure of coastal protections are made worse by sea level rise and could lead to damaged infrastructure, buildings or roads.	<ul style="list-style-type: none"> <li>Deaths due to drowning, suffocation.</li> <li>Injury such as fractures, concussions, other wounds.</li> </ul>	6,16-19
Infectious disease	Rising seas can impair natural drainage and exacerbate the impacts of coastal flooding, overloading drainage systems, inundating septic tanks or drainage fields, and damaging submerged pipes and drains. This can result in bacterial contamination of recreational waters, drinking water sources, and coastal food harvesting areas with wastewater.	<ul style="list-style-type: none"> <li>Illness caused by waterborne pathogens such as <i>Campylobacter</i>, <i>Giardia</i>, <i>Cryptosporidium</i>, <i>Shigella</i> and <i>E.coli</i> etc.</li> <li>Illness caused by foodborne pathogens (e.g., <i>Norovirus</i>, <i>Vibrio</i> spp.) in coastal seafood.</li> </ul>	8,20-26
	Increased salinity of estuarine areas due to sea level rise that can expand the distribution of microbial communities.	<ul style="list-style-type: none"> <li>Collective increase in: <ul style="list-style-type: none"> <li>Gastrointestinal illness</li> <li>Faecal-oral disease</li> <li>Skin rashes</li> <li>Skin and soft tissue infections</li> </ul> </li> </ul>	8,25,27,29-31
Salt water intrusion of drinking water sources	<p>Rising sea level can cause saltwater intrusion into groundwater used as primary drinking water sources.</p> <p>This leads to reduced water security and displacement if alternative sources or treatment options are unavailable (see <i>mental health</i>).</p>	<p>Chronic illness from exposure to elevated salinity:</p> <ul style="list-style-type: none"> <li>Dehydration</li> <li>Hypertension</li> </ul> <p>Acute illness from exposure to elevated salinity:</p> <ul style="list-style-type: none"> <li>Stroke</li> <li>COPD</li> <li>Diarrhea</li> <li>Abdominal pain</li> <li>Complications during pregnancy</li> </ul>	6,11,29,32-40,44,46
Exposure to water contaminants	Rising water table or flooding of contaminated land (e.g., former industrial sites, landfills, underground storage tanks), can cause chemical pollution to reach groundwater or marine waters	Acute or chronic illness arising from exposure to toxins in contaminated drinking water or recreational waters.	42,47-49,51,52,54,55

Health risk	Linkage to sea level rise	Health outcomes	Ref
Exposure to vector-borne diseases	Coastal inundation and flooding exacerbated by sea level rise can cause expansion of water-based habitat for disease vectors such as mosquitoes.	Acute illness: <ul style="list-style-type: none"> <li>West Nile virus leading to encephalitis</li> </ul>	8,9,56-58
Exposure to mould	Coastal inundation, flooding, and poor drainage caused by rising water tables, exacerbated by sea level rise can cause mould growth in homes and other public buildings.	Acute illness due to mould exposure: <ul style="list-style-type: none"> <li>Congestion</li> <li>Wheezing</li> <li>Irritation of mucus membranes, eyes or skin</li> </ul> Chronic illness due to mould exposure: <ul style="list-style-type: none"> <li>Allergies</li> <li>Bleeding disorders</li> <li>Cancer</li> </ul>	59,61,85
Mental health effects	<p>Rising sea levels causing incursion of seawater, coastal erosion and exacerbating coastal flooding causing physical loss of land and homes, food and water insecurity, loss of employment and subsequent displacement.</p> <p>Displacement may include migration from traditional lands, and loss of historic and coastal archaeological sites.</p> <p>Inward migration by those displaced by sea level rise could cause temporary overcrowding, lack of shelter, and increased demand for services, resources, or employment.</p>	<p>Displacement and loss can result in effects on mental health:</p> <ul style="list-style-type: none"> <li>Psychoterratic syndromes (e.g., ecoanxiety, solastalgia)</li> <li>Anxiety</li> <li>Depression</li> <li>PTSD</li> <li>Suicide ideation</li> </ul> <p>Impacts on social cohesion, increasing risks of conflict or communicable illnesses.</p>	14,62-64,67,68,70,71
Impacts on social determinants of health	<p>Potential loss or contamination of land leading to reduced access to, or safety of traditional subsistence food sources, such as shellfish harvesting, fishing sites, and agricultural land.</p> <p>Reduced access to food during and following extreme events exacerbated by sea level rise (e.g., flooding or damage disrupting supply chains).</p>	<p>Potential increase in mortality and morbidity rates from both chronic and acute illnesses.</p> <p>Compromised food security and associated malnutrition and micronutrient deficiencies.</p> <p>Mental illness:</p>	4,6,14,15,29,34,38,73,74,76-79,83-90

Health risk	Linkage to sea level rise	Health outcomes	Ref
	<p>Potential damage to roads and health infrastructure causing limited access to emergency or health services during an event, or after displacement.</p> <p>Changes in quality of physical living environment, reduced land security, loss of homes, loss of traditional livelihood, disruption of attachment to place, reduced social capital.</p>	<ul style="list-style-type: none"> <li>• Stress</li> <li>• PTSD</li> <li>• anxiety</li> <li>• depression</li> </ul> <p>Chronic stress leading to higher rates of high blood pressure and heart disease.</p> <p>Injuries from domestic violence.</p>	

## Who is most vulnerable to health impacts of sea level rise?

Identifying the people most vulnerable to the health impacts of sea level rise will depend on demographic and geographic factors. Vulnerability is defined as a combination of exposure to the risk from a geographic standpoint; sensitivity to the hazard due to pre-existing health conditions or one's social vulnerability; and the adaptive capacity or ability to cope with the challenges.<sup>4</sup> Generally, people who are more vulnerable to climate change impacts such as sea level rise include the elderly, young children, people with chronic illnesses, low-income individuals, people with disabilities and those facing systemic inequities.<sup>4</sup> The social determinants of health play an important role in the health vulnerability of coastal communities.

While it is important to acknowledge that all coastal communities are vulnerable to health impacts from sea level rise, by far the most significant impacts will be faced by Indigenous coastal communities.<sup>63,77,91,92</sup> These communities are considered to be more vulnerable due to the combination of the geographic exposure to coastal influences as well as the elevated legacy of risks based on colonial, social, and systemic challenges.<sup>92</sup> Coastal communities are expected to face common threats such as increasing salinization of drinking water or damage to wastewater infrastructure. However, given the pre-existing health and social inequities, including issues such as reduced access to safe and secure water supplies, faced by Indigenous communities, sea level rise may lead to greater potential for health impacts from foodborne and waterborne diseases, mental health, chronic and infectious diseases, and injuries, as well as food and water insecurity.<sup>4,77</sup>

A study of the impacts of climate change on drinking water, wastewater, and fisheries in Atlantic First Nations found that 25% of on-reserve drinking and wastewater systems are at high risk to climate change

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impacts, including sea level rise.<sup>92</sup> For example, Lennox Island First Nation, PEI, is highly vulnerable to sea level rise, which is exacerbating coastal erosion and storm-surge events. The community loses up to three feet of coastline depth per year, and access to the island is only one metre above sea level. The sewage system is at risk and sacred grounds are subject to erosion.<sup>93</sup> Indeed, when Hurricane Fiona made landfall on September 24, 2022, the wind and storm surge damaged both the shoreline and existing infrastructure.<sup>94</sup>

Displacement from traditional territories caused by sea level rise, including physical losses of sacred sites such as burial grounds, archaeological sites, and places of significance, could lead to adverse health impacts for Indigenous coastal communities.<sup>4,95</sup> Twenty indicators for monitoring the potential human health impacts of climate change in Nunavut were developed, and researchers found that climate change impacts like coastal erosion contribute to culture-loss vulnerability. Land, culture and well-being are inextricably linked.<sup>96</sup> For that reason, it has been surmised that forced migration or retreat from climate impacts like sea level rise may have different and/or worse impacts on the health of Indigenous communities than other populations.<sup>97</sup> This will be particularly the case for displaced Indigenous coastal communities who rely on subsistence fishing and agriculture.<sup>98</sup> As noted earlier, there are direct health impacts of relocation in relation to food security, water and sanitation, exposure to environmental hazards, injury, and health care services, as well as mental health implications. Forced displacement may trigger mental health problems, such as anxiety, depression, substance abuse, and suicide. Displacement can also be associated with augmented degradation of social capital, especially among residents with a strong sense of place attachment.<sup>98</sup>

## Conclusions

This review assessed the available evidence on the health risks associated with sea level rise and the populations in Canada who are likely to be most vulnerable to such health risks. Findings suggest that sea level rise poses a range of direct and indirect risks to human health, including expanding the potential for injury, exposure to waterborne diseases, vector-borne diseases or other contaminants, reduced air quality, as well as impacts on the social determinants of health that affect everything from mental health to physical well-being. The literature reveals a multitude of health impacts that may be experienced due to sea level rise; however, not all Canadian coastal communities will be impacted in the same way, and local factors may determine the likelihood and severity of some types of impacts on health. Assessing and addressing potential health risks arising from sea level rise in future adaptation planning should consider how local factors may impact health risks:



- Risks of physical injury or mortality may be associated with the susceptibility of local infrastructure, buildings, roads, and coastal protections to damage from sea-level rise.
- All municipalities (large and small) with public sewer and water infrastructure placed near the flood- or erosion-prone areas of the coast may be at risk for damage caused by sea level rise and resulting higher groundwater tables, leading to higher risk of exposure to infectious disease.
- Coastal communities with a higher dependence on groundwater are more susceptible to impacts of saline intrusion of drinking water sources (e.g., Prince Edward Island, les Îles de la Madeleine, QC).
- Coastal communities experiencing saltwater intrusion into drinking water systems will be forced to find new sources of water, invest in expensive desalinization technology, or relocate. This will be a significant challenge for rural communities with limited resources.
- Communities that are home to decommissioned coastal industrial uses and landfills may be exposed to a range of legacy toxins that may be released as a result of rising water tables.
- Some coastal environments will be more likely to experience an increase in exposure to certain vector-borne diseases, which can result in more acute illnesses.
- Sea level rise may exacerbate the impacts of flooding and the extent of mould damage, particularly in communities with more poor-quality housing, compromising indoor air quality.
- Communities or individuals dependent upon coastal agricultural lands affected by salinization will see reduced crop yields and food production, affecting food security and livelihoods.
- Indigenous and other communities who depend on traditional fisheries or food collection activities on or near coastlines may suffer more from health impacts related to food insecurity, malnutrition or loss of livelihoods.
- Indigenous communities, particularly on low-elevation islands, may be more threatened by displacement and loss of land of cultural and historic significance, leading to a range of impacts on the social determinants of health, including mental health.
- Disruption of energy or communications (e.g., cellular) services could become compromised during extreme events, and recovery may be hampered due to the effects of sea level rise.
- Access to health services may be severely impacted in various communities (large and small) due to the flood-prone location of some hospitals and emergency service providers, affecting anyone with emergent care needs during an extreme event.
- Mental health impacts will vary in severity, but will likely be experienced by residents in many coastal communities, particularly following extreme events that have been exacerbated by sea level rise.

While risk of exposure may be pervasive among many communities large and small in Canada, the ability to adapt and mitigate the impacts differ significantly between areas, with the most vulnerable populations being those in rural areas with limited resources as well as those experiencing significant challenges as influenced by the social determinants of health.

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As the understanding of the linkages between sea level rise and the impacts on health becomes clearer, it is important for coastal communities exposed to risk from sea level rise to consider ways to reduce the associated health risks through adaptation and mitigation measures undertaken at the community level. Local tools such as vulnerability assessment studies, climate change adaptation plans, and community planning documents are often used by communities to identify and address key areas of concern with regard to the threat of climate change. The next phase of this study will establish how sea level rise concerns have been characterized by coastal communities in British Columbia, the North, and in Atlantic Canada, and to determine if and how the health impacts from those concerns have been considered in local adaptation plans.

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