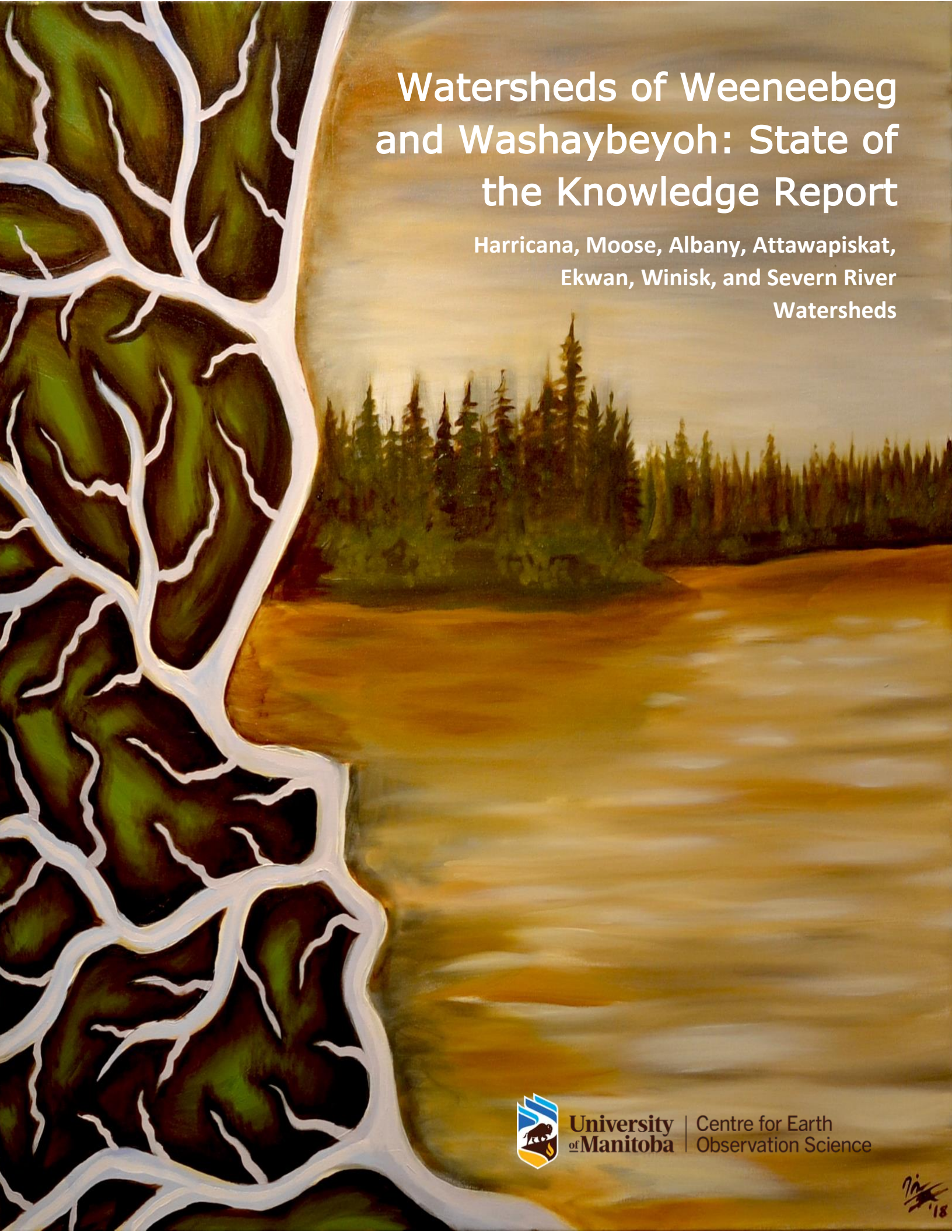
Watersheds of Weeneebeg and Washaybeyoh: State of the Knowledge Report

Harricana, Moose, Albany, Attawapiskat, Ekwan, Winisk, and Severn River Watersheds



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Mushkegowuk Council, Lands and Resources Department

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Cover Page Artwork Acknowledgment

The artwork presented on the front page titled “I am the Land” was created by Gerry McComb. Gerry McComb is a Cree artist from Moose Factory, currently based in North Bay and is a part of the Oshichikesiwuk Nanipek, the Omushkego Artist Collective. Find out more at the link below: https://nanipek.ca/gerry-%D0%BC%D1%81%D1%81%D0%BE%D0%BC%D0%B2/

Foreword

Facing pressures from ongoing climate change and increasing development, the First Nations of northern Ontario are working to protect the vast region of their homelands. They are seeking the best available knowledge for this effort drawing on both Indigenous and Western knowledge systems. This draft report is a first attempt to pull together information about the current state and recent trends in key features of the watersheds of the region including permafrost distribution, land cover and surface water distribution, carbon storage, hydrology, water quality and biodiversity for the region. Many researchers are actively working to add to the knowledge base by collecting new observations and modelling initiatives. Thus, this literature review should be considered a 'living document' with a plan for regular updates into the near future. The next step for this draft report is for peer review by thematic specialists in several of the above-mentioned fields.

Photo Credit: Jeronimo Kataquapit

Summary and Key Messages

The watersheds of seven major rivers (Severn, Winisk, Ekwan, Attawapiskat, Albany, Moose, and Harricana) lie within or adjacent to the Mushkegowuk Council Territory along the west shores of James Bay and southern Hudson Bay. The rivers are generally northward flowing and drain portions of the Precambrian Shield and the Hudson Bay Lowlands (HBL), mostly in northern Ontario. Wetlands are present throughout the watersheds, while representing perhaps 80% of the surface cover across the vast coastal plain of the HBL. Peat is ubiquitous, generally deeper inland where it formed more than 5000 years ago, and thinner near the coast that has only recently emerged due to continued post-glacial isostatic rebound. Across the seven watersheds, there are also large gradients in climate and vegetation, with the northern area (Severn and Winisk watersheds) hosting continuous permafrost and the coldest and driest climates while the southern area (Moose and Harricana watersheds) has warmer temperatures, greater precipitation, and little to no permafrost.

Although large population centres such as Timmins, ON and disturbed areas resulting from mining and forestry may be found in the southern portions of most of the major watersheds, some smaller watersheds are pristine, and notable through their intact habitat for species such as Lake sturgeon, critically endangered elsewhere around the globe. Small, Cree and Anishinabee First Nations communities comprise most of the population across the northern portions of the watersheds with the communities of Fort Severn, Peawanuck, Attawapiskat, Fort Albany, Kashechewan, Moose Factory, and Moosonee (municipality) lying at or near the coast along the major rivers. Community members hunt, fish and trap in the surrounding areas. The coastal area provides globally important migratory bird feeding and breeding grounds and now hosts several bird sanctuaries/protected areas. The region's high biodiversity and long-standing role in carbon capture and storage in the peatlands and coastal salt marshes have attracted national and international attention. Some portions of the southern watersheds support resource extraction and some urbanization, while hydroelectric development is present along some of the major tributaries of the Moose River.

During recent decades, climate change and associated warming has had noticeable effects across the Territory, with community members observing warmer winters, less snow, earlier breakup of ice on the lakes, rivers, and bay, and later freeze up. Although river discharge has varied on decadal time scales, increases in annual discharge are still expected, in general, with continued climate warming. There have been years with unusually low water levels in the rivers and increased frequency and severity of extremes in flow may be seen because of increased variability in precipitation and changes in the precipitation-evapotranspiration balance with warming.

Because wetlands are the defining feature of the territory, including portions within the HBL, Shield and along the coast (salt marshes), current investigations have focused on improving the mapping and sampling of these areas. Researchers at Environment Climate Change Canada (ECCC - Jason Duffe, P.I.) is working on a project entitled "Canadian Wetland Inventory Map Version 3A (CWIM3A)" (Canadian Wetland Inventory Map Version 3A (CWIM3A) - Open Government Portal) in which they utilize remote sensing to map the land cover with emphasis on coastal marshes,

surface water, bogs and fens, etc. at high resolution. Researchers at the University of Toronto (Sarah Finkelstein, P.I.) is working to quantify the carbon stocks in mineral soils of the coastal wetlands (intertidal, supratidal, thicket swamp, and freshwater marsh), which are previously unquantified. Their preliminary results indicate that the coastal wetlands host significant stores of soil carbon comparable to other global salt marshes. Considering the very large spatial extent of the territory's coastal wetlands, this makes them an important component of the region's overall massive wetland carbon store.

Researchers at Natural Resources Canada (NRCAN – Yu Zhang, P.I.) lead permafrost modelling initiatives to augment ECCC's detailed land cover map with permafrost distribution for the HBL. Using a map of snow cover end dates derived for the HBL (Mitchell T. Bonney, in prep.), Zhang's team will study how snow dynamics impact ground temperature and permafrost. Recent studies showed a significant loss of the continuous, discontinuous, and isolated permafrost occurrences within the Moose, Albany, Attawapiskat, Ekwan, and Winisk River watersheds. Permafrost thaw likely is affecting surface water dynamics, river flows, as well as the security of carbon storage.

Future projections from climate models indicate that the region will continue to warm; however, changes in precipitation and the net effect on the wetness of the landscape remain uncertain. The current climate models are not able to accurately predict detailed wind patterns or extreme climate events. Earlier breakup and later formation of sea ice in southern Hudson Bay and James Bay and associated warming of bay surface waters will be felt in more pronounced spring-summer-fall warming in coastal communities and the loss of the cooling 'sea breeze'.

Stream gauges in the region are limited to the major rivers and only represent portions of the watershed areas leaving much uncertainty about how streamflow in the territory is responding to warming. Gauged rivers historically have shown large variations in discharge on decadal time scales, but several major rivers show decreasing trends in discharge during the past few decades. This implies there will be a reversal in discharge trends in the coming decades, because, based on modeling, river discharge right across the pan-Arctic watersheds including James Bay will increase by 2070.

A potential major influence on land cover, surface water dynamics, carbon storage and streamflow within the watershed is increased human activity, particularly new hydroelectric development and industrial expansion associated with the Ring of Fire. Past resource development and industrial activities have influenced the landscape, sedimentation, carbon and nutrient cycles, and aquatic food webs during recent decades but the available data suggest these impacts have been local in scale. The dramatic increase in scale of potential future activities, and the potential for interactions with ongoing climate change make it difficult to extrapolate in time and space based on past impacts. Extreme events, such as heat waves and wildfires, lead to non-linear effects and feedbacks that are difficult to predict. A major impediment for impact assessment is the limited availability or at least accessibility of baseline data for many indicators and much of the Territory, with data scarcity most acute in some northern regions that coincide with critical transitions (e.g., discontinuous/continuous permafrost boundary). Central databases of water quality and water chemistry data analogous to the peat core databases that are being

developed would be very useful. Rivers naturally integrate signals from climate change and environmental disturbances at the watershed scale and thus should be a focus of research and monitoring. Processes controlling water balance and water distribution across and within the watershed also need to be better understood.

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Introduction

Watersheds and data acquisition

A watershed is an area of land that channels precipitation, runoff, and tributary flows into a particular lake, river, bay, or ocean. It includes all creeks, streams, rivers, and lakes within the drainage area, as well as the surface runoff and groundwater that contribute to the flow discharge at the outlet. Watersheds can be unique ecosystems with interconnected biological and physical properties, and thus should be examined holistically (Lotspeich, 1980). Watersheds are delineated by natural boundaries such as ridges and hills that separate one drainage basin from another, although visualizing and delineating watershed boundaries can be challenging in flat landscapes with small differences in relief.

Watersheds shape the landscape and determine geochemical fluxes of elements such as carbon and nutrients to downstream bodies of water (e.g., estuaries and oceans). In turn, watersheds are influenced by natural processes occurring over both long and short time scales, and human activities that impact water flows or surface or subsurface materials. The way we manage streamflow, soils and crops, waste, forests, and wildlife directly impacts the functioning of the watershed. The effects of industrial activities, development projects, including those for hydroelectricity, and urbanization are not limited to local ecosystems but can extend far downstream, influencing water quality, biodiversity, and the sustainability of farther afield aquatic and even marine environments.

Watershed boundaries rather than political or provincial borders are sometimes selected as a framework for addressing hydrological management and challenges, assessing and adapting to climate change impacts, and considering proposed developments. An important factor in successful watershed management is access to data across political or provincial borders, spanning diverse topics (climate, hydrology, environment, geology, biology, economics, etc.), and compiled in such a way that it can be considered collectively. Useful information includes hydrological assessments, maps of surface cover (e.g., vegetation), surface water distribution, information on water quality, land zoning and land use (e.g., forestry), and habitats (terrestrial and aquatic). In a changing environment, it is also important to have access to hydrological monitoring data and projections, water quality assessments, studies of changes in surface cover (e.g., wetlands), and access to a continuous record of climate elements that may be used to detect change in, for example, precipitation, permafrost thaw, and seasonal ice cover. Data may be attributable to many different organizations for a wide variety of purposes but compiling it, and considering it collectively, provides a basis for understanding the present-day *state of the watershed*. This understanding may then inform the design of future research and monitoring efforts and decisions around water management and watershed protection.

Purpose of the study

The watersheds of western James Bay and Hudson Bay are vast and diverse, distributed along a 600 km south-to-north latitudinal gradient between about 47°N and 56°N latitude (Figure 1). Seven major rivers descend from the forested uplands of the Canadian Shield and cross the vast lowlands before discharging to the estuaries and tidal flats of southwestern Hudson Bay and

James Bay. However, the landscape dissected by the rivers is characterized by an abundance of wetlands, and, indeed, proportionally the region has more water than land by area – somewhere between 60% and 80%, depending on how the surface water is measured.

The lands and waters are the homeland of the Omushkego people (Figure 1) and have long provided the resources to support the Omushkego way of life; including hunting, trapping, fishing and gathering. The region has an abundance of wildlife, including freshwater and anadromous fish, moose, caribou, wolves, and polar bears. It also has become known nationally and internationally among conservationists because it provides critical breeding and migration stopover habitat for millions of shorebirds, songbirds and waterfowl (MacDonald et al., 2014). It is also a globally-significant site of carbon storage and capture in peatland soils (Packalen et al., 2014; Harris et al., 2022; Li et al., 2025a).

While interest in mining in the territory is not new (e.g., Peerla, 2012), the past decade has seen an intensification of mining interest and associated activities, specifically within the region that has been coined the “Ring of Fire”. Increasing resource development and industrial activities have, in places, influenced the landscape and modified local water quality (Mosher and Martini, 2002; Ontario Power Generation Inc. and Moose Cree First Nation, 2009). Alongside development, climate change is beginning to impact many components of the watersheds with regional effects including warmer winters, earlier ice breakup and later freeze up, permafrost thaw, and changes in average and seasonal river discharge, in conjunction with changing frequency of extremes (low and high) in streamflow (Kuzyk and Candlish, 2019). Impacts of continued climate change and extreme events (e.g., frequency of wildfires) and increased future resource extraction are expected but not easy to predict.

This report was prepared to support planning by the Mushkegowuk Council and First Nations in the region in the context of ongoing and future environmental change, related to both climate change and development. The report aims to summarize the state of the knowledge across key components of watersheds, including landscape, climate, hydrology (water supply and flow), water quality, health of aquatic ecosystems. Across these sections, the text highlights what is known about recent changes and trends, and identifies areas where information seems (*to the authors*) inadequate for detecting the changes and impacts that may come about from changing climate and development. The summary is based on scientific publications, governmental reports, and indigenous publications complemented by traditional knowledge of the Territory’s watersheds (e.g., Litvinov studies). Consideration is also given to past and present land use activities and potential future threats facing the watersheds from projected climate change and proposed industrial developments. It is important to note that with the broad scope of the report, some topics fall outside the area of expertise of the authorship team. An attempt was made to incorporate the most up to date knowledge, but ongoing work is addressing gaps in the Territory even as this was written.

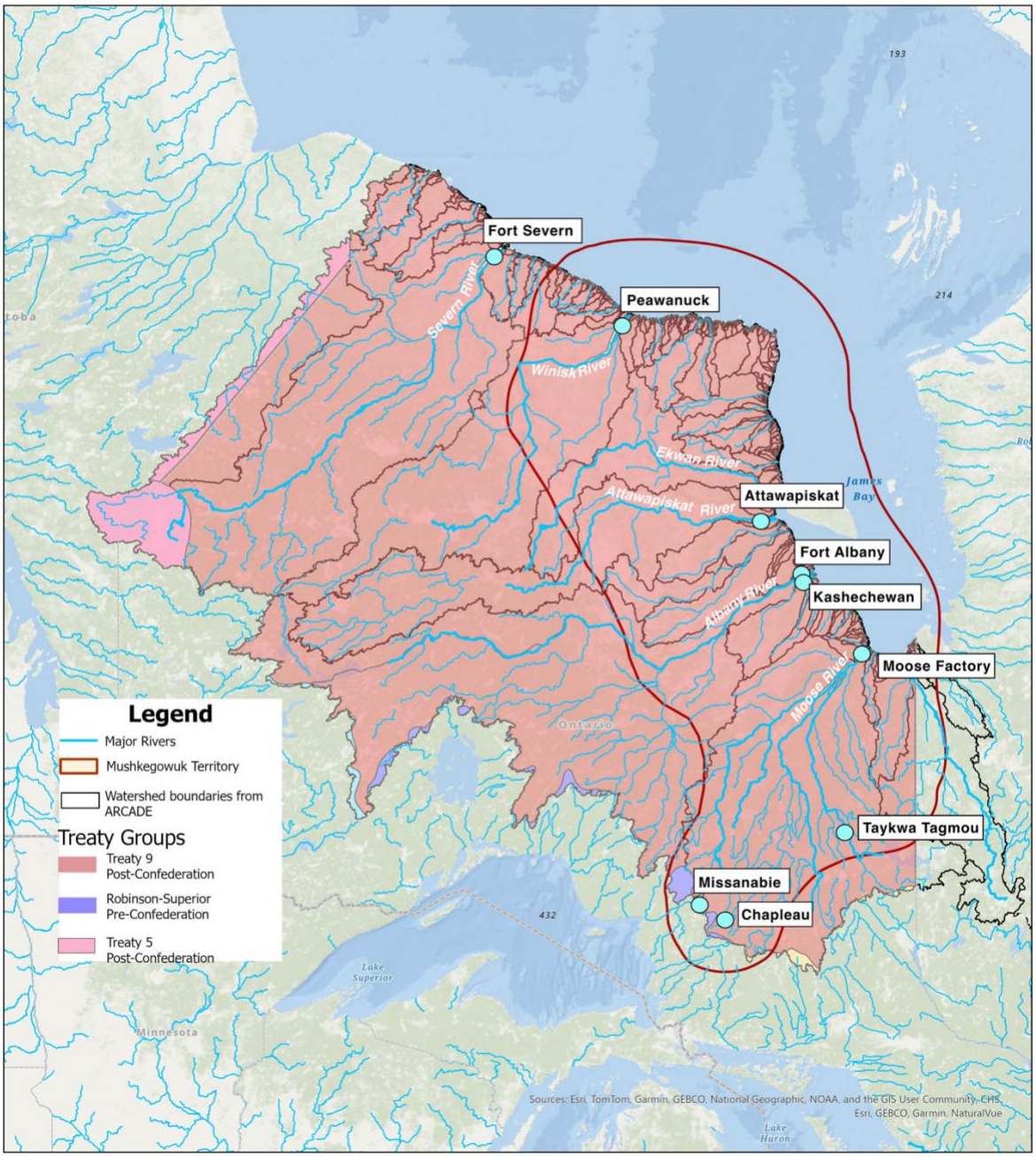

Figure 1. Map of the region of interest for this report, including Mushkegowuk Territory (red smoothed polygon that encompasses water and land), Treaty lands shaded in various colours, major rivers (light blue), and the major western James Bay watersheds outlined in red.

Scope of this report

The geographic scope of this report includes northern Ontario watersheds that drain into Washaybeyoh (Hudson Bay) and Weeneebeg (James Bay), through Mushkegowuk Territory, including Treaty 9 Territory (Winisk, Ekwan, Attawapiskat, Albany and Moose Rivers) and adjacent Territories (i.e., Robinson-Superior in the south of Mushkegowuk Territory and Eeyou Istchee for the Québec side of the Harricana River). The approximate bounds are 47.2-56°N and 77.5-95°W (Figure 1). Located within this area are six Cree Nation communities, including Fort Severn, Weenusk (Peawanuck), Attawapiskat, Fort Albany, Kashechewan, and Moose Cree

(Moose Factory) that lie along the southern Hudson Bay and western James Bay coasts. Taykwa Tagmou, Missanabie, and Chapleau Cree First Nations are located further inland within the Mushkegowuk Territory. Seven major river watersheds are the focus: the Severn, Winisk, Ekwan, Attawapiskat, Albany, Moose, and Harricana Rivers (Figure 2). The report also touches upon several sub-watersheds of these seven major watersheds, some smaller rivers with outlets to southwestern Hudson Bay and western James Bay and select northern Manitoba rivers and watersheds.

Watershed delineation

Watershed boundaries may vary from one information source to another because of different types of data being used and/or strategic decisions to combine the watersheds of specific streams/rivers, depending on the study being conducted. In this report, two data sources were used to delineate watershed boundaries: the pan-ARctic CAtchment DatabasE (ARCADE), which is specific to high-latitude watersheds all around the world, and the Ontario Watershed Boundaries (OWB), which was developed for the province of Ontario. The two databases contain similar watershed boundaries for the seven major river watersheds with slight differences. ARCADE delineated seven major watersheds and numerous smaller watersheds near the coast in western James Bay (black outlines in Figure 2; and see Table 1), providing over 100 properties related to landcover, climate, soil, permafrost, etc. from various datasets for each of those watersheds. The OWB collection represents the authoritative watershed boundaries for Ontario and are based on watershed delineation principles updated with inputs from First Nation communities and various government partners such as the Far North Branch, the Applied Research and Development Branch, and Ontario Geographic Names Board. The OWB approach includes all watershed levels from primary to quaternary, and level 5 and 6 watersheds for select areas of the province. However, there is still room for improvement in adopting finer watersheds, particularly in the coastal region of the western James Bay (OMNRF, 2022a). The watershed delineations used in this report are derived from the secondary level of the OWB collection. For more information about watershed delineations see the *Watershed delineation* section in the *Supplementary Information*.

One particularly challenging area for watershed delineations is the Hudson Bay Lowland watershed between the Winisk and Ekwan Rivers (see those watersheds in Figure 2). In this area, the northeast-trending Cape Henrietta Maria Arch separates the remnants of the two major Phanerozoic sedimentary basins that are present – the Moose River Basin in the south and the larger Hudson Bay Basin in the north. On the Cape, exposed Archean and Proterozoic rocks give rise to complex geologic control of inland water flows, resulting in the Sutton River flowing northward out of Hawley Lake to discharge along the Hudson Bay coast east of the Winisk River and Cape Lookout, and the Ekwan River flowing eastward to discharge into northeast James Bay (Cumming, 1968). That may also explain why there are so many small sub-watersheds separated from the Ekwan and Winisk watersheds in the coastal region, as shown by black boundaries in Figure 2. For more information about the streamflow routing in this area and the hydrology specific to the seven major watersheds, see Appendix A.

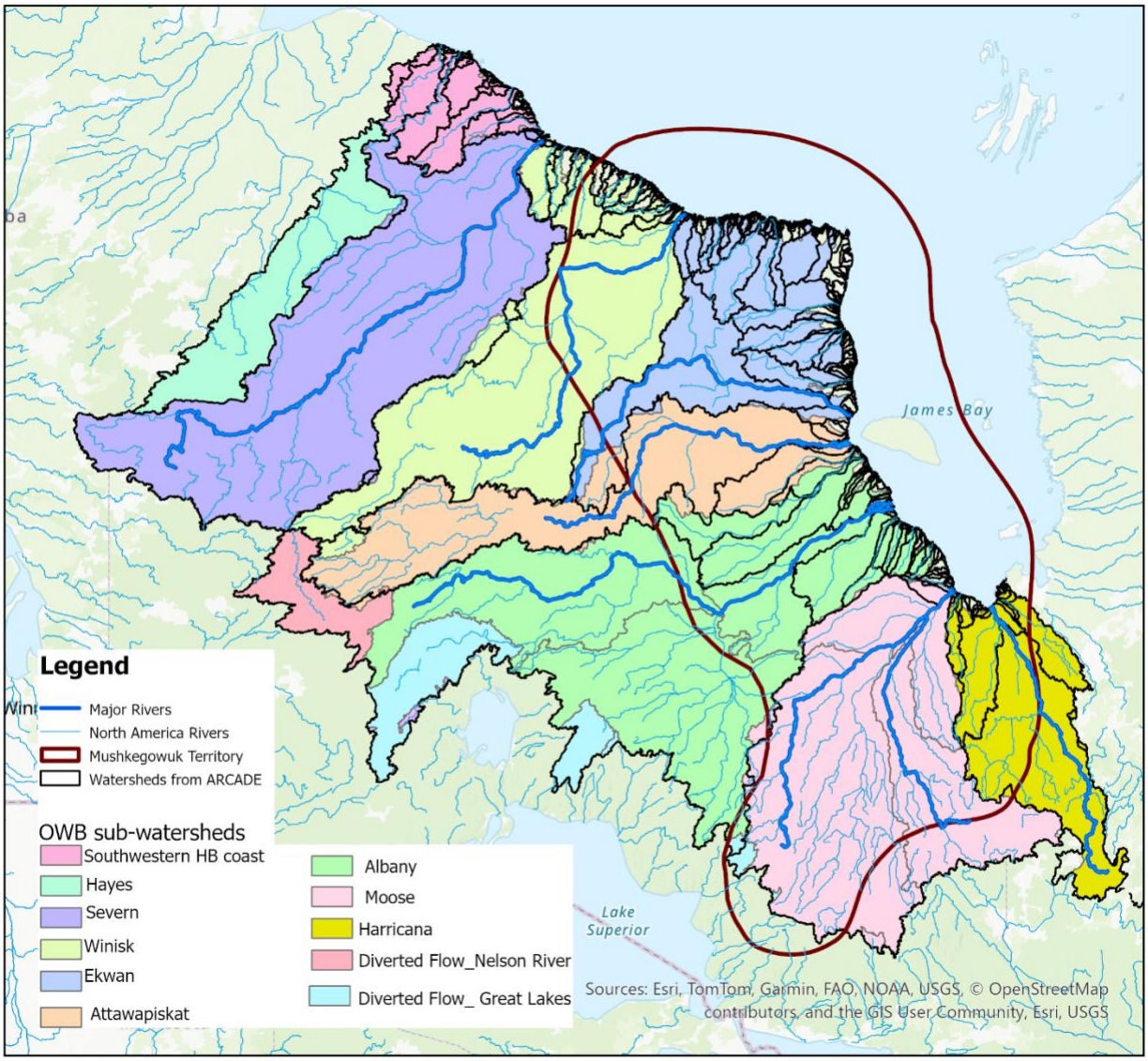

Figure 2. Map of the watersheds that drain into southern Hudson Bay and western James Bay. The bold red line shows the Mushkegowuk Territory boundary. The black boundaries are the watersheds delineated by the pan-ARctic CAtchment DatabasE (ARCADE) while the shaded areas are the major watersheds from OWB database.

Table 1. Characteristics of seven major watersheds in the southern Hudson Bay - western James Bay study area as derived from the ARCADE and OWB databases.

River	Region (outlet)	Province (gauges)	Drainage Area from OWB (km^2)	Drainage Area from ARCADE (km^2)
Severn	HB	ON	98,940	99,884
Winisk	HB	ON	76,868	64,656
Ekwan	JB	ON	44,943	21,871
Attawapiskat	JB	ON	57,027	47,903
Albany	JB	ON	126,262	130,465
Moose	JB	ON	106,522	106,455
Harricana	JB	QC	42,375	30,015

Physiography and climate normals

The major watersheds that drain across northern Ontario into southern Hudson Bay and western James Bay extend across a vast area of about 550,000 km^2 and span large gradients in climate, geology, and ecology. The major rivers originate in the rocky, forested upland areas of the Canadian Shield and flow eastward and northward, descending onto and crossing the broad (150-400 km) lowland plains. The drainage basins of the major rivers thus span two physiographic provinces and two Ecozones, Boreal Shield and Hudson Plain (Figure 3). In the latter Ecozone is the Hudson Bay Lowlands (HBL), characterized by flat-lying (incline of <1 m/km), low-relief (<2 m), poorly drained substrates that overlie sedimentary rocks (Dredge and Dyke, 2020). The poor drainage, combined with a cold climate due, in part, to seasonally ice-covered Hudson Bay and James Bay, have produced the largest wetland network in North America. This wetland is the third-largest wetland globally and the second largest peatland complex in the world, which contains massive stores of carbon (~30 ± 6 Pg) (Li et al., 2025a) as will be discussed later in this report. Within the Shield, a physiographic subregion known as the Clay Belt, is of interest because it modifies the water properties of the streamflow and because it is the most densely populated part of the watershed and the most developed (lumber, agriculture, mining, hydroelectric dams, etc.).

Figure 3. Map depicting the two major Ecozones covering the western James Bay watersheds, shaded in light and dark green. Black lines within the shaded areas indicate watershed areas.

The landscape south of Hudson Bay and west of James Bay has been strongly influenced by the last glaciation, when the Laurentide Ice Sheet flowed in and out of southern Hudson Bay weathering and eroding the underlying bedrock. The Superior Upland, underlain by the Canadian Shield, is mostly covered by glacial, glaciofluvial, and glaciolacustrine deposits, whereas the Mesozoic and Paleozoic limestone bedrock of the lowlands is mostly covered by glaciomarine and marine deposits, typically overlain by peat (Milner et al., 2009). Retreat of the ice was followed by inundation of the lowlands by large proglacial lakes, and later by inundation by the marine waters of the postglacial Tyrrell Sea (Dredge and Dyke, 2020). These processes produced a landscape that has a high rate of post-glacial isostatic rebound and thus falling relative sea level at a rate of at least 1 cm/yr (Pendea et al., 2010). As the land rises, the coasts of James and Hudson Bays evolve rapidly both in space and time. Recently emerged land is initially dominated

by mineral soil wetlands. As these wetlands retreat inland under continued coastal emergence, they transition to peatlands, defined as locations where at least 40 cm of peat has accumulated (Packalen et al., 2014). Rates of isostatic rebound are lower inland to the south, away from the coast (Figure 4). Over long time periods, differential isostatic rebound (higher in the north) affects several landscape features, including stream slope gradient, causing north-flowing streams to adjust, possibly promoting channel aggradation (sedimentation). However, recent rates of isostatic rebound west of James Bay remain uncertain due to low data density (cf., Figure 2 in (Simon et al., 2016), which shows relative sea level (RSL) and GPS site locations).

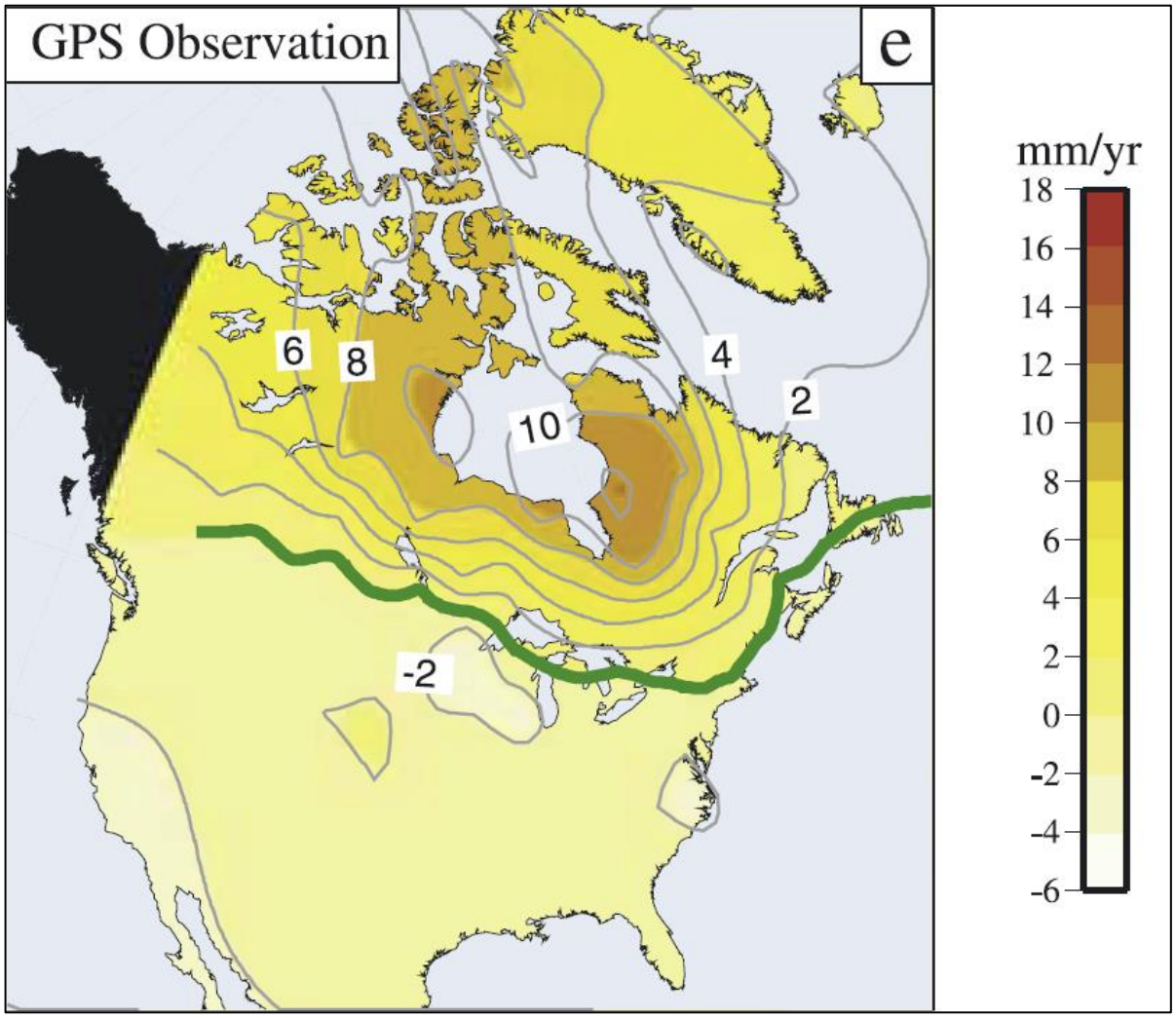

Figure 4. Vertical motion (upwards) based on Global Positioning System (GPS) data mostly caused by glacial isostatic adjustment (GIA) due to ice mass unloading during deglaciation (Source: Sella et al., 2007).

The western James Bay region's climate is influenced by Arctic air masses, specifically alternating influence of cold Arctic air masses and warm southerly airflow (Gough and Leung, 2002; Gough et al., 2004; Gagnon and Gough, 2005), strong winds, and sea ice presence on southern Hudson Bay and James Bay. Large aggregations of thick, slowly melting sea ice can persist off the coast of southern Hudson Bay well into the summer months (Barber et al., 2021). Dates of river, lake, and sea ice formation and breakup differ with position relative to latitude

and proximity to the coast, ranging from early November to mid-December and from mid-May to late July, respectively (Taha et al., 2019; Gupta et al., 2022a).

As can be seen in air temperature records for the communities of Fort Severn and Moosonee (Figure 5), the region experiences short, cool summers and cold winters (Gupta et al., 2022). Based on historical data for 100 years (1901-2000), the mean annual temperature averages -2.5 ± 1.8 and the mean growing season temperature is 10.8 ± 1.0°C over a period of 119-162 days (McKenney et al., 2006; Packalen et al., 2014).

Data averaged over a 30-year period (1990-2019) for each of the seven major watersheds shows regional gradients in air temperature and precipitation, from cooler and drier in the northwest (e.g., Severn River watershed) to warmer and wetter in the southeast (e.g., Moose River watershed) (Table 2). Precipitation is in the order of 400 to 800 mm/yr depending mostly on latitude, and secondarily on proximity to the coast (see *Climate Section* in *Supplementary Information* for more details). The Ekwan is reported to have the lowest mean annual precipitation at approximately 680 mm/yr and the Harricana the highest at 921 mm/yr (Table 2).

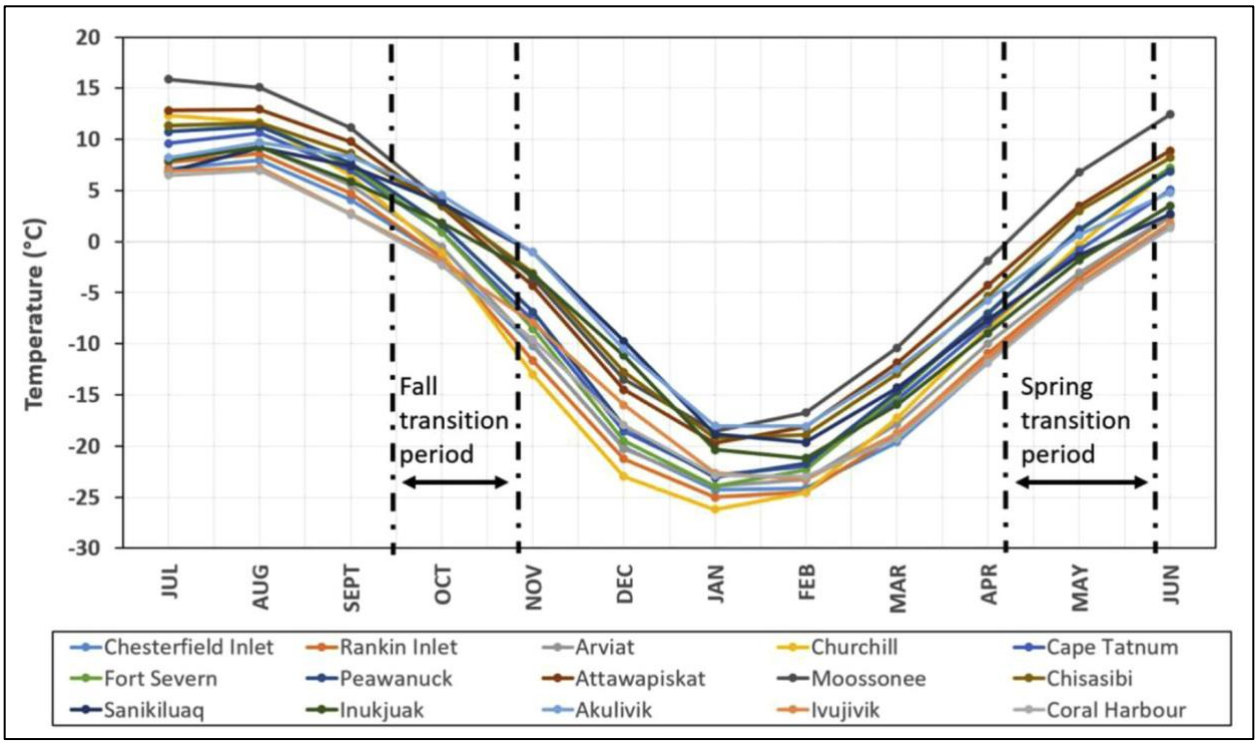

Figure 5. Mean annual air temperature variations at weather stations located around Hudson and James Bays. Data is averaged over the 2000-2019 period. (Figure from Gupta et al. 2022).

Table 2. Summary of air temperature and precipitation for a 30-year period (1990-2019) for the seven major watersheds in western James Bay from ERA5-Land Reanalysis climate data

Watershed	**Max Temp** (°C)	**Mean Temp** (°C)	**Min Temp** (°C)	**Mean Runoff** (km^3/yr)	**Mean ET** (mm/yr)	**Mean Precip.** (mm/yr)		**Max snow cover** (%)	**Max snow depth** (m)	**Max snow fall** (mm/month)	**Max snow melt** (mm/month)
Severn	14.0	-1.5	-16	29.5	-418	669	664	89.9	0.60	589	1182
Winisk	14.0	-1.7	-16	21.1	-417	694	692	89.9	0.63	643	1276
Ekwan	14.5	-1.9	-16	6.9	-384	680	681	96.0	0.64	643	1259
Attawapiskat	16.0	-0.5	-15	16.7	-421	729	728	93.7	0.62	637	1249
Albany	16.5	0.9	-14	47.2	-471	778	777	91.9	0.62	674	1306
Moose	17.5	1.6	-14	41.1	-497	858	855	95.4	0.65	733	1468
Harricana	17.0	1.1	-15	14.4	-467	921	916	89.9	0.63	790	1664

Max/Mean/Min Temp: Gives the 30y averaged annual monthly maximum/mean/minimum temperature
Mean runoff: Gives the 30y averaged annual mean total runoff
Mean ET: Gives the 30y averaged annual mean total evaporation (negative value)
Mean Precip. (first column): Gives the 30y averaged annual mean total precipitation
Mean Precip. (second column): Gives the 30y averaged annual mean total precipitation from ERA5 instead of ERA5-Land in case the latter is not covering the spatial extent of the watershed
Dataset Name: ERA5-Land Monthly Averaged - ECMWF Climate Reanalysis
Source spatial Resolution: 11132 m/ Temporal Resolution Used: 1990-2019
Reference: Muñoz Sabater, J. et al., 2019/ Link: https://doi.org/10.24381/cds.68d2bb30

Drivers of change

Anthropogenic climate change

Northern Canada is warming approximately three to four times faster than the global average (IPCC, 2021). According to a recent report commissioned by Environment and Climate Change Canada (ECCC), the annual average temperature in Northern Canada increased by about 2.3°C between 1948 and 2019, while the global average temperature rose by about 0.8°C (Bush and Lemmen, 2019). Together with these temperature increases, Canada is experiencing increases in precipitation (particularly in winter), extreme precipitation events, heightened risk of coastal flooding, extreme hot, dry, windy weather that promotes forest fires, and water supply shortages in summer (Bush and Lemmen, 2019). Warming brings many changes to all components of the cryosphere and other systems that interact with the cryosphere. Many studies have described the shortening of the season of ice cover on lakes, rivers, and coastal marine waters and the warming of surface waters that results from a longer open-water season.

In addition to warming trends, extremes of warming and variability (i.e., the magnitudes of temperature variations) are increasing. Community members note increased unpredictability of day-to-day weather (Canadian Arctic Resources Committee et al., 1991). There has also been a significant reduction in the number of extremely cold days (-30°C or colder) in the Canadian Arctic since 1950s (Ford et al., 2018; CCA, 2019; Blair et al., 2021). From paleoclimate studies (proxy reconstructions), there is wide consensus that the rate of recent warming in northern areas is exceptional, unprecedented during the whole Holocene (last ~11.7 ka) and possibly also exceptional in the total magnitude of warming, at least for some seasons and some regions of the north (Porter et al., 2019). The loss of cold days, changes in snow and ice, and water warming will impact Arctic marine life, aquatic life, vegetation, the landscape, and northern communities in many ways. Climate models have accurately predicted the decline in extremely cold days observed during recent decades and they project further reductions in cold days throughout the 21st century.

Subarctic Canada, including the Mushkegowuk Territory, is subjected to similar snow-ice-albedo forcings and feedback mechanisms that are responsible for Arctic amplification of warming but also has unique characteristics associated with its more southern location that requires dedicated study. Subarctic regions already experience many freeze-thaw cycles, during which water and soil fluctuates between frozen and thawed conditions (Morison et al., 2023). These fluctuations occur annually, seasonally, and diurnally in subarctic areas, affecting land-surface characteristics, soil properties, hydrologic responses, ecosystem diversity and productivity, and construction and operation of infrastructure components. There is a whole host of responses that may occur when the frequency and duration of these phases is altered. Morison et al. (2023) notes that "*the capacity of the region to maintain a relatively narrow thermal window with upper and lower boundaries creates an environment able to support the presence of organisms that are not found elsewhere*". Because the Territory spans all of the permafrost zones and is at the northern limit of the boreal forest, it is a prime example of a geography poised to experience dramatic rates of climate change in the coming decades (Morison et al., 2023; Morison and Casson, 2023).

Air temperature

As air temperature has warmed globally due to anthropogenic climate change, regional air temperatures in the southwestern Hudson Bay - western James Bay watersheds have increased. Temperature increases in the James Bay Lowland range between 1.5-3.5°C, with accelerated warming over the past 30 years, particularly during fall and winter (Hochheim et al., 2010; Vincent et al., 2015; Litvinov, 2021). Rising surface air temperature (SAT) is most prominent in the fall season (+0.7 to +0.9°C/decade) and more moderate in spring (+0.32°C/decade) (Hochheim et al., 2010; Litvinov, 2021). Community members find that solar intensity appears stronger during winter months, while summers are now longer and hotter. Additional Omushkego observations include state changes in snow and ice conditions, unusual warm days and freezing rains during the winter, changes of heat waves to cold days, longer and more frequent heat waves than previously observed, and unusual cold and hot nights during the summer (Litvinov, 2021).

Extreme temperatures

Air temperature extremes have been changing in the Mushkegowuk Territory, similar to other northern regions. Extremely high summer SAT has been noted in the northern part of the Territory around Peawanuck (Winisk River). Between 1998 and 2007, maximum air temperatures exceeding +30°C (range 30.7°C – 38.1°C) were recorded every year with a complete or near-complete temperature record at the Peawanuck weather station (Gunn and Snucins, 2010). Those years also had between 7 and 20 days with air temperatures above 25°C.

The extremes influence the average SAT and vice versa. According to the Climate Atlas of Canada, which summarizes results from Global Climate Models, the *average* summer SAT in the Peawanuck (Winisk River) region will increase from 11.9°C during 1976-2005 to 14°C (11.8-16.1 for the 10^{th}-90^{th} percentile) for the present and near-future period (2021-2050), assuming greenhouse gas (GHG) emissions continue to increase at the same rate as they have in the recent past. Even if GHG emissions are much reduced, the summer average SAT will likely increase to 13.6°C.

Temperature extremes are also changing in other parts of the Territory. During 1976-2005, Moose Factory/Moosonee in the Moose River watershed had five days on average with maximum air temperatures exceeding +30°C; modelling results suggest they will likely see 11 extremely hot summer days on average during the period 2021-2050 assuming no change in emissions trends. Record high air temperatures were observed during the fall of 2023 and summer of 2024 that ranked second and third warmest in the western James Bay region since 1950, respectively (Ballinger et al., 2024).

Generally, across Arctic and subarctic areas, the strengthening of heat extremes is accompanied by a reduced occurrence of cold events (Ballinger et al., 2024). For example, the average temperatures of the “cold extremes” are warming at twice the rate as pan-Arctic annual temperatures since 1979 (Polyakov et al., 2024). According to the Climate Atlas, the number of very cold days defined by minimum air temperatures below -30°C will decrease from 26 to 12 at Moose Factory/Moosonee and from 38 to 16 at Peawanuck.

Seasonality in air temperature is being reduced with the loss of extreme cold days. The changing frequency of temperature and precipitation extremes can be expected to cause a change in the likelihood of extreme events such as heat waves, wildfires, droughts, and floods. Extreme events affecting streamflow and land cover are discussed in subsequent sections of the report.

Precipitation and snow cover

Scientific studies predict a shift in the form of precipitation from snowfall to rainfall during the late winter and early spring, potentially leading to a higher likelihood of extreme events, such as severe and/or sudden flash floods in the James Bay watershed (Nilsson et al., 2015; Bush and Flato, 2019; Litvinov, 2021). Other extreme events such as freezing rain and rain-on-snow are also expected to increase. These events are more likely when air temperatures near the surface are close to 0°C; thus, with continued winter warming in the Territory, their frequency is expected to rise (Walsh, 2021). Icing events have significant implications for safety of travel and for wildlife.

It is less clear whether the total amount of precipitation (sum of all forms) will increase or decrease in the future within the region. For the global Arctic, there is general agreement that total precipitation will increase (30%-60%) throughout the twenty-first century. The increase is attributed to (i) increased evaporation over northern ocean areas as a result of reduced sea-ice cover, (ii) higher air temperature that increases the atmosphere's ability to hold moisture and (iii) increased poleward moisture transport (McCrystall et al., 2021).

Along the coast of western James Bay, models have predicted there could be a 6-11% increase in mean total annual precipitation under moderate warming conditions by 2050, with summer precipitation increasing 1-3% by 2050 (Bush and Lemmen, 2019; McLaughlin and Packalen, 2021a; Climate Change in Canada | Climate Atlas of Canada, n.d.). However, for James Bay, precipitation and streamflow exhibit high natural variability and different trends compared to many Arctic areas. The HBL had a wet period from 1995 to 2008, which was attributed to a shift in regional atmospheric circulation, specifically an anomalous convergence of atmospheric moisture flux (Champagne et al., 2021). The moisture convergence was possibly driven by the combination of low-pressure anomalies in the East Coast of North America and in western regions of Canada, associated with the cold phase of the Pacific Decadal Oscillation (PDO). Although the wet period did not continue after 2008, since 2009, streamflow has remained high, which may be attributed to more groundwater discharge associated with the degradation of permafrost (Champagne et al., 2021).

The snow cover fraction (SCF), which is defined as the fraction of land area covered by snow, decreased for the period of 1981-2015 due to later snow cover onset in the fall and earlier snow melt in the spring. The decreasing SCF trends align with documented reduction in annual snow cover duration (SCD) across high latitudes of Canada. These reductions are about two to four days per decade, or approximately 1% to 2% per decade. Various studies have noted slightly stronger spring snow cover losses, but all consistently show reductions in spring SCF (Brown et al., 2021). The projection of snow cover changes under a high emission scenario (RCP8.5) and shows decreases in SCF throughout the year, not just during springtime. Specifically, higher

latitudes will remain cold enough to maintain winter SCF and into spring but increasingly there will be snow loss in the boreal forest, subarctic, and high Arctic during the period from April to June. By the end of the century, spring snow loss will stabilize under a medium emission scenario (RCP4.5) but continue under a high emission scenario (RCP8.5) (Bush and Lemmen, 2019).

The snow water equivalent (SWE) quantifies the amount of water contained in the snowpack. Seasonal maximum SWE (SWEmax) decreased over the 1981-2015 period alongside SCF, indicating less accumulated snow available for spring melt (Bush and Lemmen, 2019). SWE was projected to decrease across southern Canada including some parts of western James Bay region (Figure 6). Consistent with this projection, seasonal maximum SWE (SWEmax) indicates significant *reduction* (between 2.5% and 5% per decade through 2050) for the Moose River watershed and eastern parts of Albany River and Attawapiskat River watersheds. However, Morison et al. (2023) showed that over a 25 year timeline, subarctic winters are warming faster than summers but this is not having the expected effects on snowpacks. These workers found trends of thicker and longer-lasting snow on the ground for four distinct subarctic terrestrial ecosystems in northern Canada, which they attributed to changes in the vegetation. Shrub expansion, which is notable along the Hudson Bay coast near Peawanuck, can affect drifting and lead to deeper snowpacks. Discrepancies such as these, resulting from interactions between climate-relevant subsystems, highlight the uncertainty surrounding snowfall and snowpack trends in the southern Hudson Bay – western James Bay watersheds.

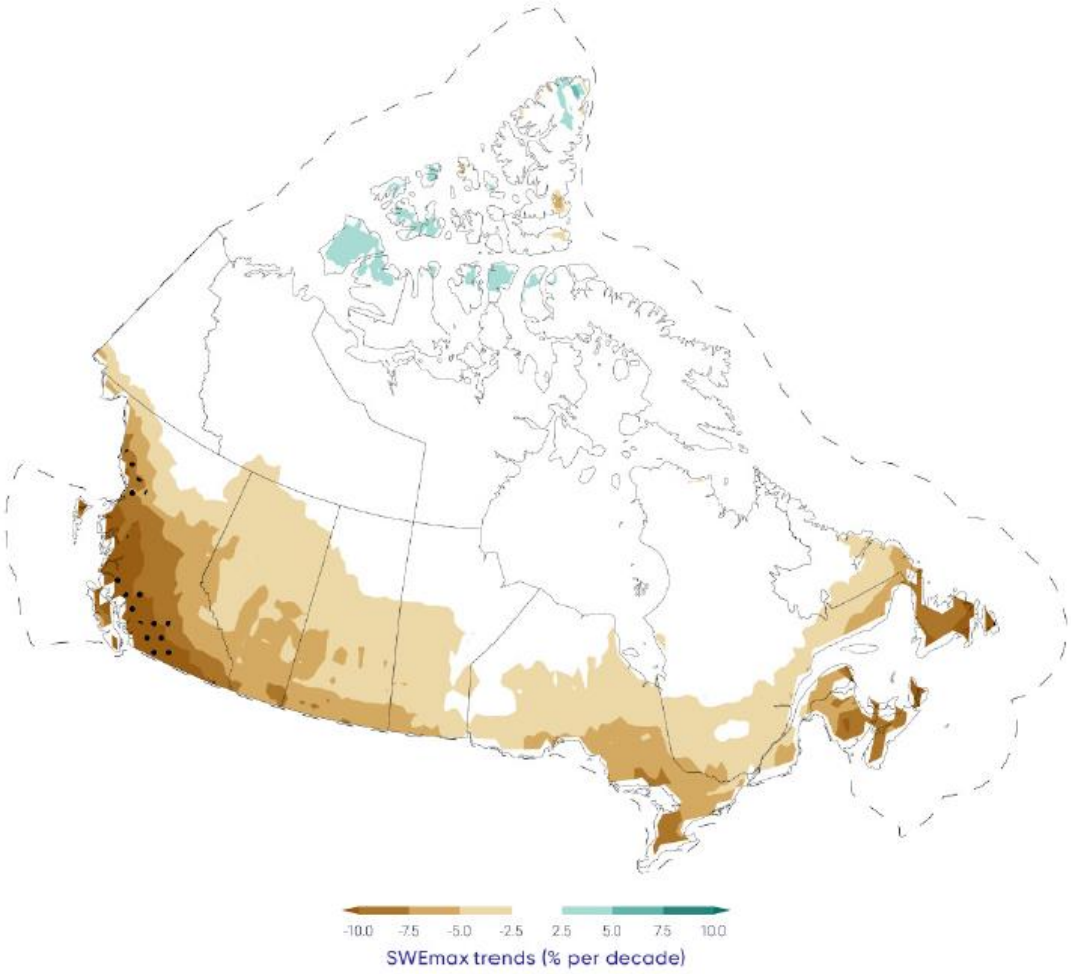

Figure 6. Projected trends in maximum snow water equivalent (SWEmax), 2020-2050. Trends were calculated from the multi-model mean of an ensemble climate models (Coupled Model Intercomparison Project - CMIP5), using a high emission scenario (RCP8.5) (derived from Bush and Lemmen, 2019).

Sea ice and marine climate

The marine climate is important for the local climate, ecology, and hydrology of the HBL, as well as summer air temperatures in coastal communities. Western James Bay experiences prevailing onshore winds, which advect cool, moist air from the bay, westward over the terrestrial land surface. In 1990, observations from a transect extending 100 km inland showed that cooling "sea breezes" developed on approximately 25% of summer days and penetrated up to 100 km inland on occasion (McKendry and Roulet, 1994). However, the marine climate in James Bay and southern Hudson Bay has changed significantly since these observations in 1990. While the 1980s and early 1990s were periods of relatively little warming and sea-ice change, notable ice losses occurred in the late 1990s and thereafter (Gough et al., 2004; Hochheim and Barber, 2014). The marine climate appears to have undergone a 'step change' both in ice and surface water temperatures during the late 1990s (Galbraith and Larouche, 2011). Recently, it was demonstrated that marine heat waves—extended periods of five days or more of exceptionally warm ocean water—are increasing in James Bay. Since 1998, these events have become more frequent, longer, and hotter, potentially impacting ecosystems like the eelgrass

(*Zostera marina*) beds along the east James Bay coast (Bruneau et al., 2025). The season of marine heat waves in James Bay has lengthened both into May and into October/November because of lengthening of the open-water season in James Bay and advection of warm water from Hudson Bay into James Bay during fall (Louis, 2024).

One study compared landfast ice properties in James Bay across two periods, 1980–1997 and 1998–2016, and projected future changes (Taha et al., 2019). Not every parameter related to the fast ice showed evidence of change across these two periods. For example, they found consistency in freeze-up dates, where this is defined as 50% progress of fast ice coverage across the typical area of the fast ice. This extent of ice coverage happens generally around early January, approximately 73 days after the beginning of the freezing season, and around the winter solstice, when solar radiation is at minimum intensity. However, freeze-up dates on rivers (e.g., La Grande and Eastmain rivers, as well as for Rupert Bay) were found to have shifted later because of the warming between 1980–1997 and 1998–2016. They also detected changes in the maximum landfast ice extent. Overall, mean fast ice coverage was found to have decreased by 2.1 km on the east coast and of 2.3 km on the west coast of James Bay between the earlier (1980-1997) and the recent (1998-2016) periods. Some regional variations in the relationship between fast ice coverage and winter temperatures were noted, with the extent of fast ice varying greatly in the areas between Wemindji and Eastmain, south of James Bay in Hannah Bay and along west James Bay's coastline northwest of Akimiski Island. In contrast, they found the fast ice coverage varied little along the coast in the La Grande area and southwest of Akimiski Island near the Moose River region. Future projections based on heat flux calculations for future winters and two greenhouse gas emissions scenarios suggested that around the year 2050, freeze-up is likely to occur on average 1–3 weeks later than during the 1998–2016 period and there may be a recession of the landfast ice coverage of several kilometers, a delay of 1–3 weeks of the freeze-up dates, and an advance of 2–10 days of the breakup dates (Taha et al., 2019).

A recent study examined rates of warming and large-scale sea ice changes across several regions of Hudson Bay in relation to possible impacts on polar bears (Stroeve et al., 2024). They found that annual surface air temperatures over southern Hudson Bay, which includes James Bay, rose by 1°C between 1980-1989 and 2012-2021. This was accompanied by an increase in the ice-free period of between 23 and 34 days depending on the method of analysis. The extension in the ice-free period involved ice loss both earlier and later in the season (i.e., both spring and fall). This study projected continued increase of the ice-free period in southern Hudson Bay with continued warming, with, for example, 3°C warming extending the ice-free period from about 147 days presently to about 210 days.

Sea-ice patterns in Hudson Bay in spring 2024 were unprecedented with a uniquely early opening up of the waters in the southeastern part of the bay, which led to basin-wide sea ice extent five standard deviations below the 1979–2023 average (Soriot et al., 2025). The event was caused by a strong pressure gradient between high pressure over the Canadian Arctic Archipelago and low pressure to the south of Hudson Bay, which led to unusually strong and persistent winds from the east during May 2024. The early retreat of the sea ice led to warmer

than average sea surface temperatures, which, in turn, extended the ice-free period in southeastern Hudson Bay to 202 days.

A separate study examined factors causing low sea-ice extent in fall and winter in Hudson Bay, during which time the sea ice is typically extending from west to east across the bay (Crawford et al., 2025). Focusing on a low sea-ice extent period in December 2010, they showed that a very strong anticyclone, the strongest autumn to *ever* occur over Baffin Bay region (65–80◦ N, 50–90◦ W) between 1979–2023, and record-high atmospheric pressure up to 1043.0 hPa, helped to produce storms and record-strength easterly winds in Hudson Bay, halting and reversing the eastward advance of the ice edge across the bay, and ultimately producing anomolously low sea-ice extent. In December, the ice in western and central Hudson Bay was easier to break up and push back towards the west side of the bay. Consequently, sea ice advance into the eastern third of Hudson Bay did not occur until 2 January 2011—a record 4 weeks later than average (1979–2023) (Crawford et al., 2025).

Lakes, rivers, and inland waters

Lakes, rivers, and other inland waters in the territory are also likely responding to climate change, although not necessarily in a uniform manner. A recent summary report describing research since 2008 concludes that "Aquatic ecosystems of the Hudson Bay Lowlands Ecozone (HBLE) in Ontario are relatively pristine but face growing pressure from human-caused stressors. Lakes and rivers of this region are also among the most poorly studied in Ontario." (Patterson et al., 2020). Emphasis has been put on fish research and monitoring activities as well as research focused on mercury cycling. Overall, research from the Paterson et al. team has included projects conducted on 23 lakes, 15 coastal rivers with outlets on southern Hudson and James Bay, and 20 small inland streams.

Previous studies focused on paleolimnology and other sedimentary proxies have shown marked limnological changes during the past 20 years in shallow lakes in the HBL (Hadley et al., 2019). A study examining 13 lakes in the HBL of northern Ontario concluded that after a relatively cool, stable climate for hundreds of years, the lake ecosystems have been affected dramatically since approximately the 1990s (Rühland et al., 2014). This timeline of change in lake environments matches that in the James Bay marine environment (Bruneau et al., 2025).

Warming temperatures and earlier ice-off dates can lead to lower water levels in a lake, unless balanced by increased mean precipitation (Woolway et al., 2020). A modelling study that considered all the seasonally ice-covered lakes across the Northern Hemisphere found that, on average, the timing of ice-off has changed by −8.1±6.4 days from 1979 to 2020 (Li et al., 2022). Furthermore, they projected that by 2070–2099, lake ice-off dates will be 15–45 days earlier. They linked the earlier ice-off dates to an increase in lake surface temperature during the ice-off month or months, and suggested this effect will be amplified in the future with continued climate change. A global data set containing records on daily landscape freeze–thaw status as determined from satellite (passive microwave) remote sensing is allowing increased study of how ice is changing over lakes and rivers even in remote areas (Kim et al., 2017).

Streams across northern Ontario are likely being affected by warming and will be further affected with continued warming. However, water temperature has not been an element routinely measured in Canadian hydrometric networks (Yang and Kane, 2021). As noted by MNRF (2021), there is a notable lack of stream temperature data in northern Ontario. This poses a challenge for confidently detecting trends. Based on findings from a study that analyzed stream temperature data from 19 sites across the United States and 54 sites from the Water Survey of Canada's hydrometric network within the province of Ontario, confidently detecting stream temperature trends required an average of 12 years of daily data metrics. MNRF has developed temperature models to predict average stream temperature in July across the province of Ontario based on a statistical approach and 30 years of climate data from which they classified streams into five thermal classes (OMNRF, 2021).

Limitations

Current climate modelling and impact prediction efforts are hampered by scarcity of climatological data for the Mushkegowuk Territory, particularly for coastal areas near southern Hudson Bay and James Bay. The only long-term weather station in Moosonee has data spanning over 30 years, but this is not sufficient to capture microclimate variations across the region (Royer, 2016; Niemi et al., 2019).

Beyond data deficiency, multiyear climate variability—driven by natural oscillations such as the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO)—complicates the identification of long-term climate trends. This variability can cause changes in ice cover, snow patterns, and precipitation which further contribute to uncertainty in climate projections (Vincent et al., 2015).

Development and resource extraction

Northern Ontario, including portions of the Mushkegowuk Territory is at the cusp of major industrial development and resource extraction. The discovery of rare minerals (Ontario, 2022; Macklem, 2003; Hjartarson et al., 2014) and the increased demand for hydroelectric power generation (Ontario's Long Term Energy Plan 2017: Delivering Fairness and Choice, 2017; OPG, 2022a) may change the economic picture of the region dramatically in the near future. These industries will profoundly affect ecological processes in development zones and local areas and may have consequences for areas downstream and experiencing cumulative impacts from multiple developments as well as climate change.

Mining

To our knowledge, the first mine in the region was the DeBeers Victor open-pit diamond mine in the Attawapiskat River watershed. Diamonds were discovered in the Attawapiskat River watershed in the 1980s and the mine was in operation between 2008 and 2019. While in operation, it produced 8.3 million karats of diamonds (Our Mines, Canada, n.d.).

In 2003, valuable minerals, namely nickel, a key component in electrical vehicle batteries, and chromite, a rare mineral used in stainless steel production, were discovered in the Winisk, Ekwan and Attawapiskat River watersheds in an area known as the "Ring of Fire" (Canada, 2025). This was the first major chromium deposit discovered in North America; as of 2014, it was considered

enough to sustain the mining industry for a century and generate over $25 Billion GDP for Ontario (Hjartarson et al., 2014).

Currently, within the “Ring of Fire”, the Eagles Nest Mine is the first mine to undergo environmental assessment. This underground mine owned by Wyloo will be in operation for 12-20 years. This mine is designed to have a minimal footprint and to keep all tailings underground to reduce its environmental impact. Once in operation it will produce nickel, copper, palladium and platinum. Several other junior mining companies, in particular Juno, are increasing exploration in the area.

As the push to extract the rare minerals in the “Ring of Fire” increases, protective legislation is being amended in ways that many consider to be weakening environmental protections and the influence of First Nations over development. For example, in 2023, the Bill 71: Build More Mines Act was put into place. While the stated intent was to increase the feasibility of mining in Ontario, many feel it came at a cost of reduced oversight, First Nations’ involvement, and financial assurance of remediation at mine closure (Benoit, 2023; Linklater, 2023; Proposed Building More Mines Act, 2023). In early 2025, Bill 5: Protect Ontario by Unleashing our Economy Act was proposed and enacted. This Bill grants exemptions to projects in ‘special economic zones’ from complying with existing regulations, including environmental protections and consultation of local communities (Stephen Lecce, 2025). This Bill could be detrimental for the environment, not only at sites of development, but also downstream, impacting communities and First Nations that call this Territory home. There is concern rising due to the reduction of restrictions on regulations and responsibilities that are not only in place to ensure the environment is protected, but that proper consultation with local leadership and First Nations is conducted.

Figure 7 shows recent information about mining claims made in the Territory as compiled and shared by Wildlife Conservation Society (WCS) Canada (Meg Southee). In Ontario, mining claims can be made on First Nation territory through an online portal without consultation or consent of First Nations. These claims give mining companies the rights to any minerals found in that claim and, with an early exploration permit, they are allowed to clear areas, build buildings, and drill for minerals (Southee et al., 2023). The mining claim process is currently under questioning in court for being unconstitutional led by several First Nations (Hercus, 2024; Law, 2024).

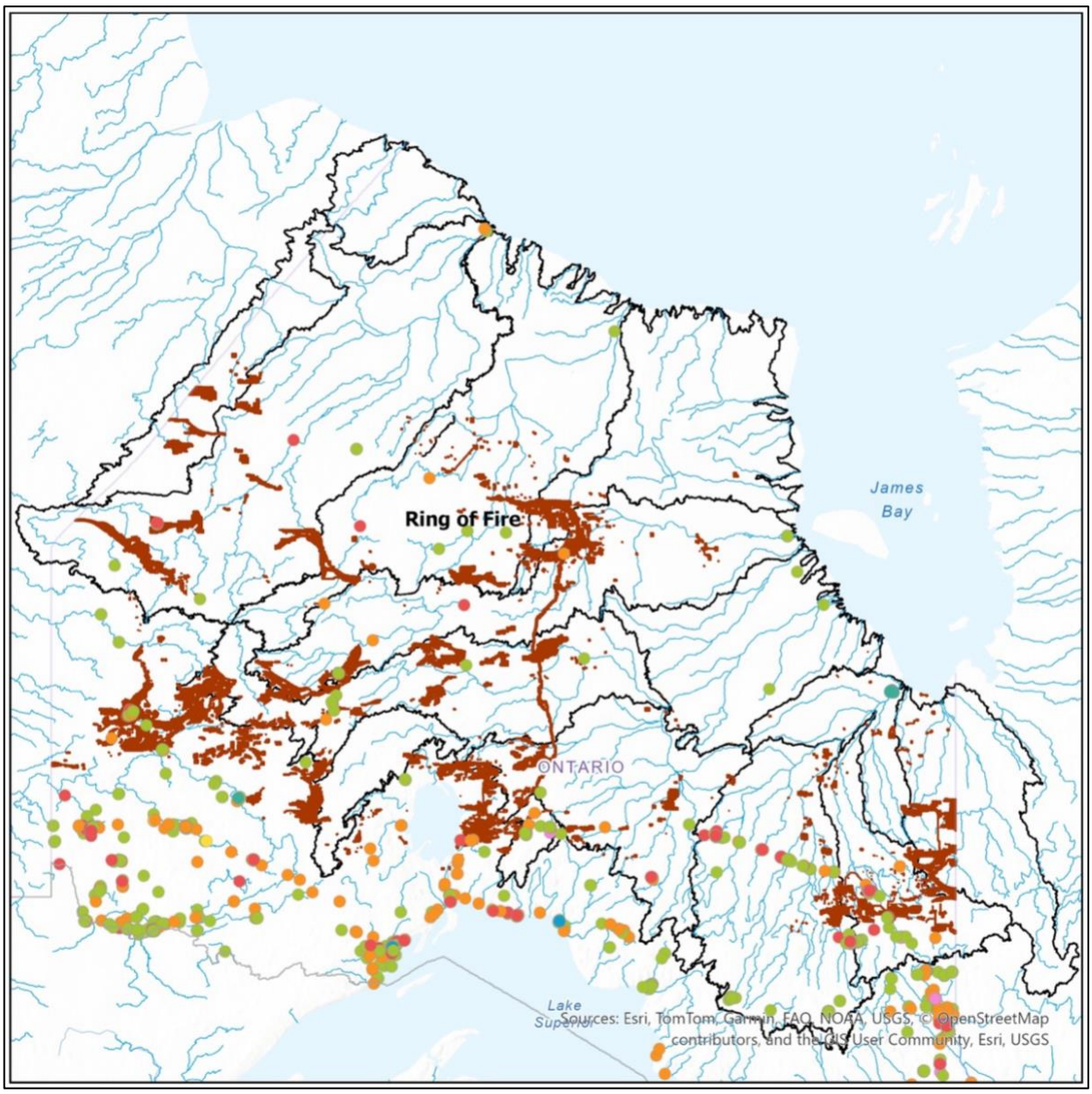

Figure 7. Mining claims shown in dark red shades and key infrastructure shown in colorful circles representative of communities (green circles), education (blue circles), roads and bridges (orange circles), and recreation (red circles) across northern Ontario. Data sources: WCS Canada (Meg Southee) and Ontario Builds: our infrastructure plan | Ontario.ca.

Water diversions and hydroelectric power developments

Of the rivers flowing into western James Bay, only the Albany and Moose Rivers have extensive water control structures. The Albany River has had three water diversion projects, the Long Lake diversion completed in 1939 and the Waboose Dam on the Ogaki river completed in 1943 which both reroute flow into the Great Lakes (Day et al., 1982) and the Lake St. Joseph Dam constructed in 1957, which reroutes the water into the English and Winnipeg Rivers (Root River Control Dam, n.d.). These projects were completed with little preventative remediation (i.e., not clearing trees) and led to significant ecological (fish population effects due to increased turbidity and sedimentation), geological (erosion) and social impacts (navigation, low aesthetic value), while providing profit through increased hydropower downstream and easier pulp wood

transportation (Day et al., 1982). Currently, the Moose River watershed is the only watershed in the Mushkegowuk territory with major hydropower development (Figure 8). It contains 14 hydropower stations built between 1911 and 2016. These power generation stations have 1436 MW of collective power capacity and produce 3.5% of the province's energy annually (ieso, 2025).

Several watersheds in northern Ontario may see further hydroelectric power development in the coming decades. Several studies were conducted 15-20 years ago to identify locations with high hydroelectric power potential (Hatch Acres, 2005; Hatch, 2013), but the current 25 MW minimum limit in place for much of northern Ontario (OPG, 2022a; Renewable Energy Program, Biodiversity Branch, 2010) reduces the feasibility of hydro development in most of the Mushkegowuk territory. The threshold, 25 MW of power, is often unable to make up for price of construction. As it is excluded from this limit, the Moose River watershed may be of interest for further development in coming decades to meet rising energy demands. OPG has suggested 9 locations within the watersheds of the Abitibi, Mattagami and Moose Rivers, which if constructed would lead to 640-1250 MW of additional power (ieso, 2022; OPG, 2022a). As of April 2025, OPG has announced two locations in the Moose River watershed they are pursuing; Nine Mile Rapids Generating Station on the Abitibi and the Grand Rapids Generating Station on the Mattagami Rivers that would provide an additional 430 MW of power capacity (Lower Mattagami River Redevelopment Project, n.d.; Ontario Pursuing New Hydroelectric Stations in Northern Ontario, n.d.). Additionally, 2 smaller sites on the Severn and Windigo Rivers with up to 35 MW of collective potential power have been suggested as their proximity to the Wataynikaneyap transmission line project significantly decreases their cost of construction (ieso, 2022; OPG, 2022a). With increased energy demands from mining development and southern populations (Ontario's Long Term Energy Plan 2017: Delivering Fairness and Choice, 2017), pressure is increasing to remove the 25 MW limit (OPG, 2022a). If lifted, development of 8 additional suggested sites along the Albany and Attawapiskat Rivers could lead to an additional 680-1300 MW of power production (OPG, 2022a).

Dams and reservoir construction, and subsequent flow control on regulated rivers have many environmental and social impacts (Ligon et al., 1995; Rosenberg et al., 1997; Maavara et al., 2020). Dams change stream flow regimes, fluvial geomorphology, and sedimentation patterns both upstream and downstream of the structure (Brandt, 2000; Mosher and Martini, 2002; Schmidt and Wilcock, 2008). Dams impede historically used transportation routes of people and impact fish migratory movement. Large dams and reservoirs alter contaminant concentrations in aquatic food webs and important fish species (Lescord et al., 2024), as well as altering carbon and nutrient cycling (Maavara et al., 2020; De Melo et al., 2022). Dam and powerplant construction causes an influx of people and jobs during and after construction and requires construction of additional infrastructure for long term operation and maintenance.

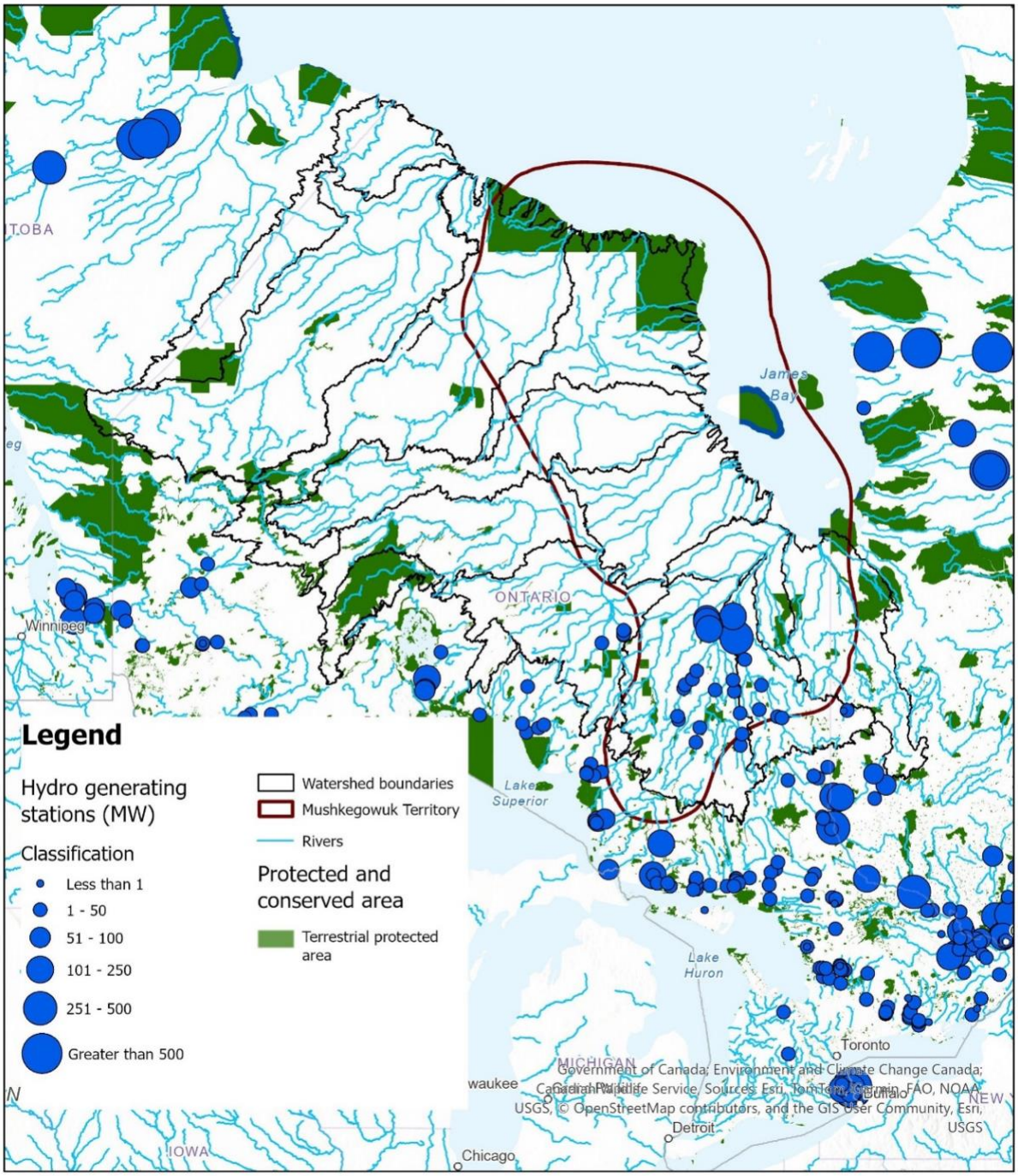

Figure 8. Map of hydropower dam locations, protected areas, watershed boundaries, and Mushkegowuk Territory. Source: Energy/clean_energy_dams_reservoirs (MapServer)

Transportation infrastructure – Roads and transmission lines

Transportation infrastructure connects communities allowing for easier flow of people and goods. Currently, the communities located along the southern Hudson Bay and James Bay coasts are without year-around roads. A winter road connects Moose Factory, Moosonee, Albany, Kashechewan, and Attawapiskat. A second winter road connects Fort Severn and Peawanuck to Gillam, MB, where the all-season road begins. Two rail lines go through the Lowlands, one reaching the Hudson Bay coast at Churchill, MB and the other ending at Moosonee, ON (Abraham

and Keddy, 2005). Several road construction projects are under various stages of proposal including Martin Falls Community Access Road, Webequie Supply Road and The Northern Road Link. These proposed roads will run to the Ring of Fire and increase access to communities and mining sites year around.

Transmission lines transport power between where power is generated to where it is used at communities and industrial areas. Currently, the only transmission lines in the region connect Moosonee, Moose Factory, Fort Albany, Kashechewan, and Attawapiskat to the Moose River hydroelectric power generating stations and the southern power grid. As of the end of 2024, the Wataynikaneyap Transmission Project completed construction and begun powering 4 communities (Wataynikaneyap Power Completes Construction of "the Line that Brings Light," 2024). In the future, this project will connect 17 communities to Pickle Lake township's electrical grid, transitioning these communities from diesel fuel power generation (Wataynikaneyap Power Completes Construction of "the Line that Brings Light," 2024).

The price of large infrastructure projects such as mines and hydroelectric dams increases with remoteness in part because the project is then responsible for building the supporting infrastructure to connect it to the larger supply chain. Once roads and transmission lines have been constructed, locations that were once too remote to be cost effective become feasible and attractive. Socio-economically, building roads in these remote areas can accelerate development by increasing access, despite environmental consequences.

State of Knowledge for Key Indicators and Recent Trends

Selected Indicators and Sources of Information

A literature search was conducted for peer-reviewed literature and other studies and reports providing information on selected indicators of watershed change. The search largely focused on natural science studies related to the regions' watersheds, with a more limited review of relevant social science articles pertaining to Cree land use and involvement in participatory research (e.g.,

. Additional information was available from reports created by local organizations, development companies with reporting obligations, and scientific staff conducting work in the region (e.g., Litvinov, 2017; Litvinov, 2021). Additionally, information was found in baseline studies of rivers flowing toward Hudson and James Bays conducted by Mushkegowuk Council and associated Nations, for example, the Aquatic Baseline Study Report for Attawapiskat River (prepared by Litvinov, 2016), reports attributed to the WWF (2020), Dr. Nicole Balliston (Balliston, 2022), and provincial reports prepared by staff from the Ontario Ministry of Natural Resources. Nevertheless, much of the ongoing relevant research in the region is not yet published or publicly available except in the broadest terms. Thus, this literature review should be considered a 'living document' and is suggested to be updated annually, or as new studies, results, and reports are published. The following sections detail the significance, state, trends, and challenges of specific indicators selected by the authors. The use of the term 'indicator' was chosen to represent a topic that can be used to indicate changes are occurring in the natural environment within this region, in the past, present, or future.

Permafrost

Significance

Perennially frozen permafrost soils form where the ground loses more heat than it gains due to sub-zero air temperature for prolonged periods. Situated on top of the permafrost is an "active layer" that freezes and thaws by season, with its depth depending on characteristics of the surface energy balance and soil moisture (Gough and Leung, 2002). Permafrost, where present, shapes many aspects of the landscape, including vegetation, peatland distribution, surface and subsurface water dynamics, carbon storage and release, etc. It plays an important role in maintaining the storage of carbon in peatlands (Frey and Smith, 2005) and contaminants such as mercury (Thompson, 2023).

Widespread permafrost thaw is one of the most significant impacts of the rapid warming of high latitude areas (nearly four times faster than the global average since the 1980s). Permafrost thaw can alter hydrological systems by changing water flow patterns, raising water tables, and expanding thermokarst lakes. This affects wetland ecosystems, river systems, and the availability of freshwater resources, which are critical for both natural habitats and human communities (Walvoord and Kurylyk, 2016). Permafrost thaw can also support lateral water transport across a larger soil cross section, with the concomitant transport of old carbon, which has been largely shielded from active participation in the global carbon cycle for thousands of years (Vonk et al., 2025). Because Hudson Bay and James Bay are strongly integrated with their surrounding watersheds, changes in river delivery of carbon and freshwater will have biogeochemical and

ecological impacts on the receiving marine ecosystem, including the possibility of increased greenhouse gas emissions, and increased vulnerability to ocean acidification.

Past permafrost studies include attempts to map permafrost extent in the region. Field data can be used to map spatial distribution of permafrost and active-layer thickness where available, but data is often limited as it is difficult to monitor the changes in the field over a large area. Consequently, satellite imagery has become popular for regional scale mapping. This technique delineates permafrost extent by identifying permafrost-related features in satellite images. Indicator features include vegetation types and permafrost-associated landforms such as frost mounds, hummocks, ice wedges, polygons, thermokarst features, etc. (e.g., Duguay et al., 2005; Hachem et al., 2009; Nguyen et al., 2009; McLaughlin and Webster, 2013). Duguay et al. (2005) provides an overview of key satellite remote sensing techniques for mapping permafrost using optical wavelengths, microwave remote sensing, including Synthetic Aperture Radar (SAR). One of the challenges of using remote sensing data to map subsurface permafrost is the need to detect proxy variables rather than the frozen layer directly. Thus, satellite-based classification is at its best when coupled with field measurements.

Permafrost maps also have been created using indirect factors such as Mean Annual Air Temperature (MAAT), soil type and moisture content, vegetation and snow cover, and water bodies that influence thaw depth (e.g., taliks under lakes), together with process-based permafrost models (Zhang et al., 2003; Zhang et al., 2006; Zhang et al., 2008). Over the period 2012-2016, maps of permafrost distribution at 30 m × 30 m resolution were made using a process-based permafrost model (Northern Ecosystem Soil Temperature (NEST)), which had been previously validated, and used to map permafrost at half-degree latitude/longitude across Canada (Zhang et al., 2003; Zhang et al., 2006; Zhang et al., 2008). In 2012, a high resolution map was produced for an area in northwest HBL (Wapusk National Park, Manitoba), which straddled the boundary between continuous and discontinuous permafrost zones and the tree line (Zhang et al., 2012). In 2016, the model was used, for the first time, to map an area further south (central HBL in northern Ontario), where permafrost exists only sporadically or in isolated patches (Ou et al., 2016a; Ou et al., 2016b). Modelling permafrost in this second area was challenging because it is shallow and dynamic, with its extent being sensitive to changes in climate and ground conditions (Ou et al., 2016b).

State and Trends

According to the National Atlas of Canada and data widely used in scientific publications (e.g., Figure 1 in Olthof and Fraser, 2024), Mushkegowuk Territory spans all permafrost zones, from the unfrozen zone in the extreme south (upper part of Moose River basin), through isolated patches, sporadic, and discontinuous permafrost moving northward, and including continuous permafrost in northern James Bay and along the Hudson Bay coast (Figure 9). However, northern permafrost conditions have significantly changed during the past few decades and will continue to change in the future (Zhao et al., 2021). Figure 10 shows permafrost distribution in the territory based on data from a more recent period (2000-2016) as described in Obu et al. (2019) and incorporated into the ARCADE database. In this map, continuous permafrost in the coastal region of northwestern James Bay has almost disappeared having been replaced by discontinuous and

sporadic permafrost. All the permafrost zones show a northward shift in the study region. At most, only about 4-6% for the Ekwan, Winisk and Severn watersheds, and even less in the Moose River and Albany watersheds have permafrost (Table 3). Permafrost databases (e.g., Olthof and Fraser, 2024) have higher spatial resolution than the Northern Hemisphere Permafrost dataset, but may not reflect current conditions because they are based on observations from 1978 to 1997, before major regional climate shifts of the late 1990s. By comparison, the Obu et al., (2019) dataset is based on the period of 2000 to 2016.

Observations of large reductions in permafrost extent are consistent with modelled results (e.g., Zhang et al. (2012) and Ou et al. (2016a)), which show that continuous permafrost on the western side of southern Hudson Bay and James is much reduced relative to the extent shown in Figure 9. Additionally, these studies indicate that there has been a reduction in discontinuous permafrost by area in northern Ontario.

The current distribution of permafrost and its future fate in the region remain important areas of research. Natural Resources Canada (NRCAN Principal Investigator Yu Zhang) is working to improve model permafrost estimates in the region based on newly available data for land cover, ground temperatures, snow cover and other properties and previously tested models. Some previous projections of permafrost fate are available. For example, Gagnon and Gough (2005) assumed mean annual air temperature (MAAT) and mean annual ground temperature (MAGT) equilibria would result in a 35 to 67% loss in permafrost by 2100 in the Hudson Bay region, while Zhang et al. (2008) assumed non-equilibrium between MAAT and MAGT and reported only minor losses (~16%) in permafrost occurrence in the HBL during the 21st century (McLaughlin and Webster, 2014).

(Ou, LaRocque, et al., 2016; Ou, Leblon, et al., 2016) used the Northern Ecosystem Soil Temperature (NEST) model to map permafrost conditions in the Attawapiskat River watershed within two different time periods, 1961-1970 and 2001-2010. They showed that permafrost declined from ~ 9.8% of the study area to ~9.4% between the two time periods, associated with warming. Additionally, the active layer thickness deepened by 20.5% in response to a 1.9°C increase in air temperature and a 2.4% increase in precipitation. Uncertainties associated with the modeling included: (1) poor spatial and temporal resolution of weather data, (2) estimation of regional scale Leaf Area Index, (3) outdated land cover and surficial material maps (some dating back to 1932), (4) lack of direct water table levels and flow-rate measurements, and (5) reliance on one-dimensional (vertical) water and energy balance modeling without consideration of lateral water flow.

Figure 9. Permafrost distribution (in various shades of purple) in the study region of the southern Hudson Bay - western James Bay watersheds (black outlines) based on data from the 5th Edition (1978 to 1995) of the Permafrost dataset, National Atlas of Canada: Permafrost, Atlas of Canada, 5th Edition - Open Government Portal).

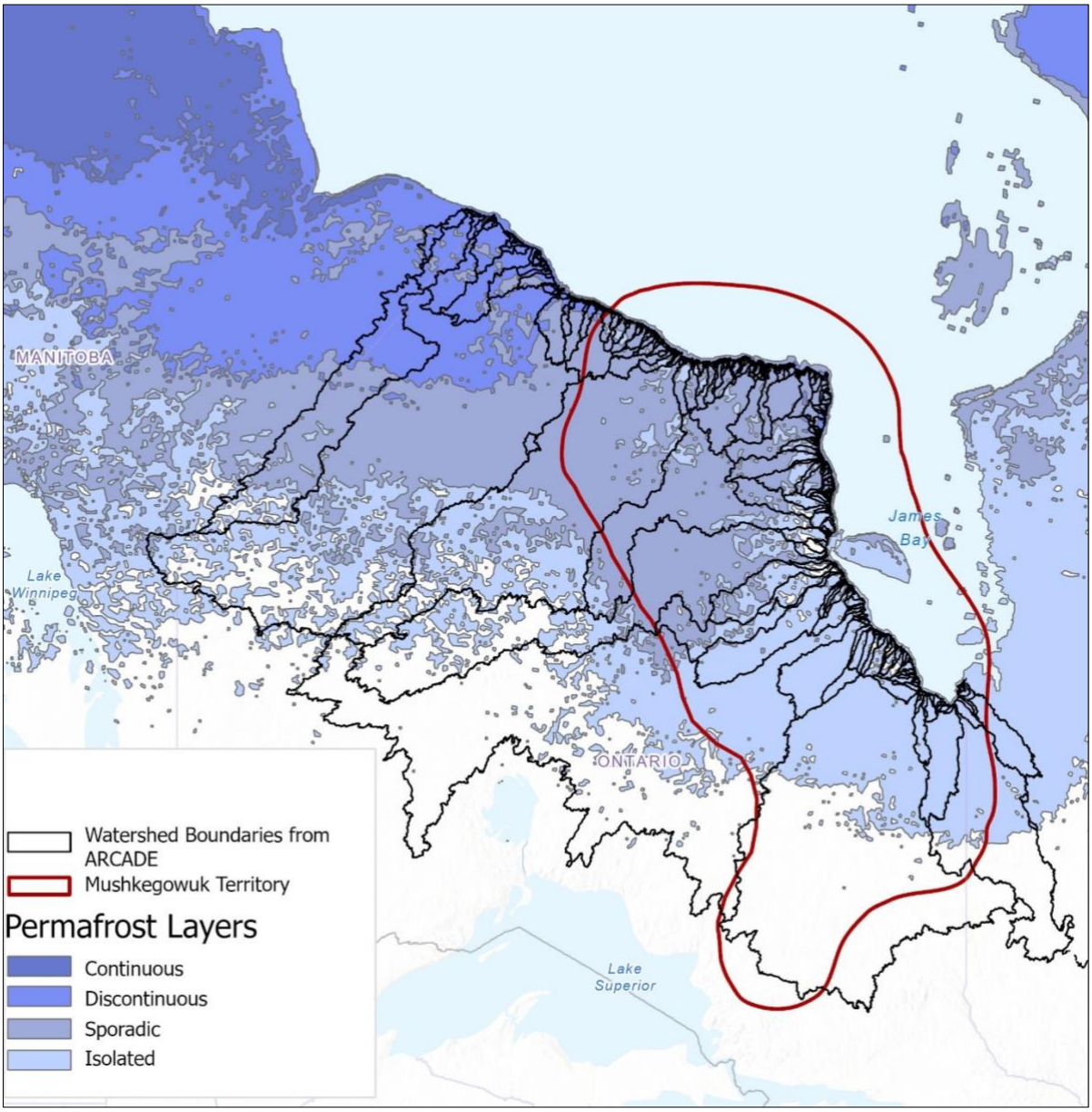

Figure 10. Permafrost distribution in the study region based on the Northern Hemisphere Permafrost dataset (Obu et al., 2019; source spatial resolution: 926.7 m; https://doi.pangaea.de/10.1594/PANGAEA.888600). White shading represents no permafrost

Table 3. Fractional permafrost coverage for the seven major watersheds estimated from the Northern Hemisphere Permafrost dataset (Obu et al., 2019), as shown in Figure 10.

River	Watershed area (km^2)[1]	Total coverage of permafrost	Continuous	Discontinuous	Sporadic	Isolated
Severn	99,884	0.058	0	0.005	0.243	0
Winisk	64,656	0.044	0	0	0.211	0
Ekwan	21,871	0.053	0	0	0.2950	0
Attawapiskat	47,903	0.005	0	0	0.030	0
Albany	130,465	0	0	0	0.0002	0
Moose	106,455	0	0	0	0	0
Harricana	30,015	0	0	0	0	0

[1]Watershed area derived from ARCADE database (2023)
Total coverage of permafrost: Fractional permafrost coverage (all types)
Continuous: Fraction of watershed area underlain by continuous permafrost (>90%)
Discontinuous: Fraction of watershed area underlain by discontinuous permafrost (50% - 90%)
Isolated: Fraction of watershed area underlain by isolated permafrost (10% - 50%)
Sporadic: Fraction of watershed area underlain by sporadic permafrost (<10%)
Dataset Name: Northern Hemisphere Permafrost Probability Fraction, Source spatial resolution: 926.7 m
Link: https://doi.pangaea.de/10.1594/PANGAEA.888600, Reference: Obu et al., 2019

Challenges

Studies cited above have emphasized the need to continue and expand the monitoring and modelling of the permafrost variables, particularly ground temperature and active layer thickness. In terms of modelling, a comparison of observations and models shows that ground temperature profiles can vary in proximity under the same annual air temperature regime. Typically, permafrost models take a one-dimensional approach considering only heat fluxes between the air and the ground, however heat can also flow laterally within the ground. This can happen for example between an unfrozen lake surrounded by frozen soils, and thus should be represented in model thermodynamics (Zhang et al., 2024).

Observations from the northern HBL (zone of continuous permafrost), as recently begun at Churchill, MB by Laure Gandois and co-workers, are needed to improve understanding of the ultimate fate of the carbon stores when permafrost thaws. While it is generally accepted that ground subsidence and changes in hydrological pathways will gradually transform permafrost peatland mounds (palsa) to thermokarst bogs, then larger bogs, and ultimately to inundated fens, the carbon balance is hard to assess; increased fluxes of CH_4 from the fen's waterlogged soils may be partially compensated or even outweighed entirely by increased CO_2 sequestration in the newly productive ecosystem and accumulating peat. Nutrient availability and microbial communities may influence the outcome. Furthermore, carbon releases via lateral losses of water-borne DOC need to be considered alongside gas fluxes. (Gandois et al., 2019).

Permafrost thaw also has a destabilizing impact on landforms and infrastructure, and hence land use planning (Schneider von Deimling et al., 2021). Riverbank collapse due to permafrost thaw is widely observed in the region, even in areas without palsas or other obvious permafrost landforms, and warrants study in terms of downstream impacts on aquatic and marine ecosystems. Implications are discussed further in subsequent sections (*Hydrology, Carbon Storage* and *Water Quality)*.

Surface Water Distribution and Dynamics

Significance

Variation in the distribution of surface water remains a key source of uncertainty on the future of the HBL's peatland carbon store under projected development and climate warming. On drying, the peatlands could shift away from the persistent anoxic, water-saturated conditions that have been responsible for the slow decomposition rates of the peat. It is the cool, wet conditions that have supported high peat accumulation rates in boreal and subarctic peatlands during the past 6000 years. With drying, the peat will decompose more quickly in an oxic environment with accordingly higher emission rates of carbon dioxide. A point may be reached where higher carbon dioxide emissions could overwhelm any benefits of reduced methane emissions (Morris, 2021). Drying can also affect plant community composition leading to changes in evapotranspiration and ground temperatures. Thawing permafrost sets up its own feedback with respect to surface water distribution and wetting versus drying of peat.

State and Trends

The HBL is regarded as the wettest ecozone in Canada with 80% of its area covered by wetlands of one form or another. However, only very recently has the distribution of surface water and wetlands been mapped. Previous satellite-derived global water and wetland data sets (like those compared in Tootchi et al., 2019) estimated surface water as covering only between 5% and 21% of the area. On their own these estimates will underestimate the surface water in the HBL as the satellite data will not detect water beneath wetland vegetation (Olthof and Rainville, 2022; Tootchi et al., 2019).

In 2022, dynamic surface water maps of Canada from 1984 to 2019 were produced by Olthof and Rainville (2022), based on Landsat satellite imagery with ~30 m spatial resolution. These maps were "binary" in that they classified each 30 m x 30 m pixel as either land or water. These maps showed on average, 66.3% of the HBL was covered by water. While these estimates were considered an improvement, they noted that many water features in the HBL were smaller than the pixel resolution and missed from the inventory.

In 2024, Olthof and Fraser (2024) combined the existing binary land/water product together with machine learning and physical models to develop a Landsat-based surface water time-series over the HBL from 1985 to 2021, with sub-30 m resolution (Olthof and Fraser, 2024). Following the Government of Canada Open Data initiative, the dynamic surface water maps are available to the public at Annual sub-pixel Landsat surface water maps of the Hudson Bay Lowlands from 1985-2021 - ECCC Data Catalogue. This product showed that across the HBL, there was overall wetting in the HBL over the period 1985-2021. The time series showed widescale drying from

1985 to 1990, followed by progressive wetting to 2021. There were also broad spatial patterns indicating a general drying trend in areas with lichen peat bogs within the interior of Wapusk National Park (Brook and Kenkel, 2002) and bogs located inland of Hudson Bay. Conversely, there were wetting trends in coastal fens near the Hudson Bay coast (OMNRF, 2014a). Inspection of data mapped in Figure 11 suggests drying in the northern part of the HBL, specifically between Churchill and the Nelson River, and between the Nelson and the Severn River. Blue colours suggest wetting near the Winisk, Ekwan, Albany, and Attawapiskat Rivers. In the Moose River watershed, there is a pronounced brown area identifying a drying trend. The thawing of permafrost (i.e., solid to liquid) may have contributed to the wetting trend, however, hydrologic changes resulting from permafrost thaw are complex.

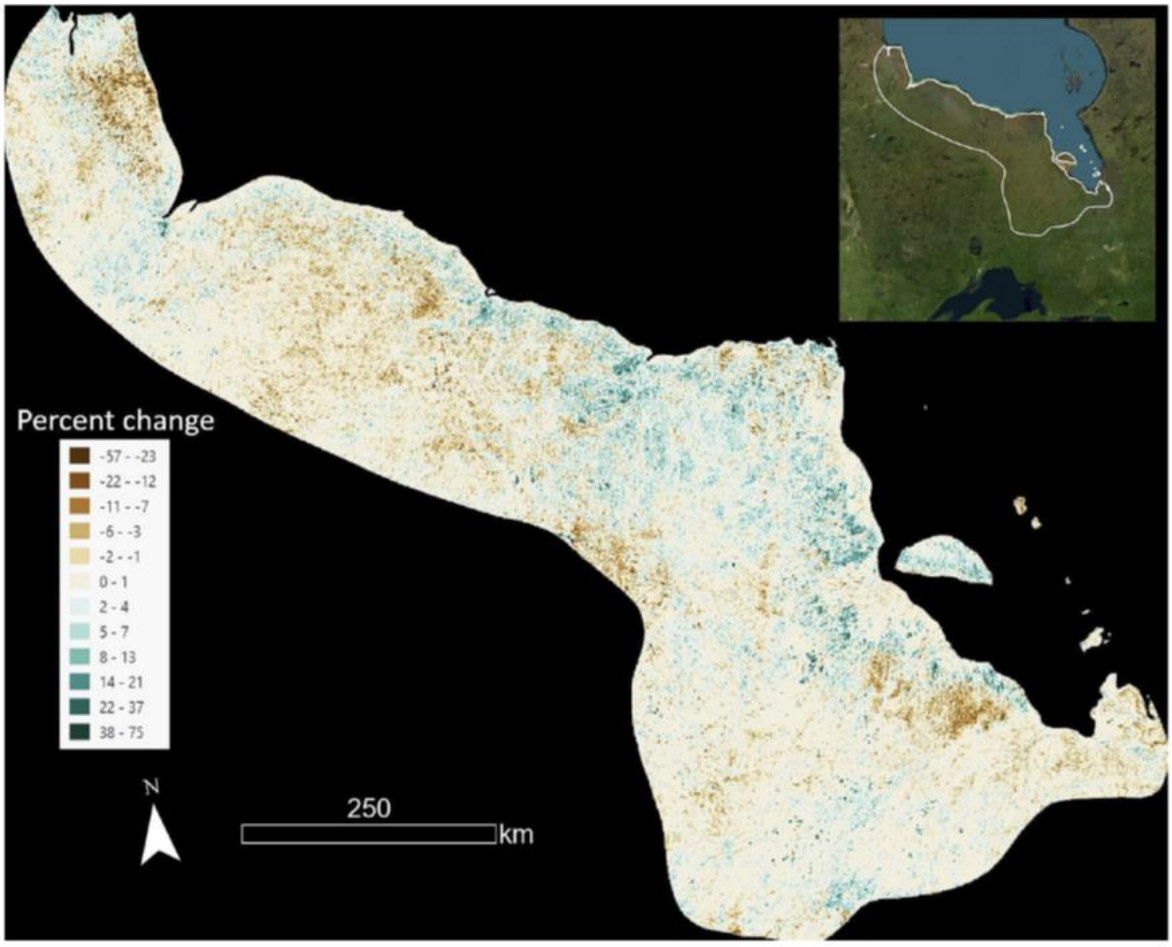

Figure 11. Spatial wetting and drying trends of surface water in the Hudson Bay Lowlands as estimated by Olthof and Fraser (2024).

Challenges

The future trajectory of soil moisture of the HBL remains uncertain, but speculation points to overall drying due to climate change. In general, precipitation in the Mushkegowuk territory is expected to rise (Fekete et al., 2010; Bush and Lemmen, 2019; McLaughlin and Packalen, 2021a; Climate Change in Canada | Climate Atlas of Canada, n.d.). Simultaneously temperatures are

rising, increasing evapotranspiration (ET). The current thought is that increases in ET will outpace an increase in precipitation, which will lead to drier conditions overall (Fekete et al., 2010; Bush and Lemmen, 2019; McLaughlin and Packalen, 2021a; Zhang et al., 2021; Elmes et al., 2024a). Indeed, global models and data analyses show annual ET over the northern regions has already begun to rise (Zhang et al., 2021). Although drier conditions appear to be the overall future trajectory of the HBL, it is likely some parts of the HBL will become wetter while other parts become drier, especially when factoring in permafrost thaw (Walvoord and Kurylyk, 2016).

Land cover and wetlands

Significance

Wetlands are a defining feature of the territory. They are responsible in large part for the massive carbon stock in the region and support a high degree of biodiversity. Additionally, the distribution of wetlands impacts travel across the expansive landscape.

Wetlands are defined as areas of land that are saturated with water for all or much of the year (Mitsch and Gosselink, 2007). They are broadly classified into organic wetlands (peatlands), which include bogs and fens, and mineral wetlands such as shallow open water wetlands, marshes and swamps, many of which do not accumulate peat. Historically, wetlands were often drained to repurpose land for development or agriculture, but with the 1971 Ramsar Convention, and recognition of the importance of wetlands in the United Nations Sustainable Development Goals (Indicator 6.6.1), the rate of wetland loss has slowed globally (Fluet-Chouinard et al., 2023). Scientific research has shown the importance of wetlands in terrestrial water storage, quality, and supply; evapotranspiration; land-to-ocean carbon export; emissions of greenhouse gases, including carbon dioxide, nitrous oxide and methane; nutrient dynamics; flood regimes; and groundwater recharge (Fluet-Chouinard et al., 2023). In the HBL, wetlands of various types are found (e.g., bogs, fens, salt marshes) and known to be important to varying degrees for bird habitat, biodiversity conservation, and other services, including water purification and carbon storage (Harris et al., 2022; Finkelstein et al., 2023).

State

Mapping the spatial distribution of wetlands and forests has been prioritized by governments interested in land use planning and by researchers seeking to scale up site-specific measurements to quantify the region's carbon stocks. Efforts to generate more detailed maps of land cover and various wetland types are underway by ECCC. Currently available land cover information however, as it relates to open water, wetland and vegetation types is provided in Figure 12 and summarized in Table 4 based on data from the Ontario Land Cover Compilation V.2 map/dataset that was published in 2014. It is one of the most extensive land cover products in the area to date. The area of relevance to this report is contained in the Far North Land Cover V1.4 map. This map indicates that wetlands are the dominant ecotype in the region's watersheds with bogs, fens and swamps covering about 55% of the surface across the western James Bay watersheds (Table 4). This region also has significant amounts interspersed open water (10%) and, in the south-west, coniferous forest (13%) (Table 4). In the northern HBL, the landscape is defined by permafrost features including palsa-bog-fen-pool/pond complexes and small lakes (Martini, 2006).

Notably absent from the land cover maps are coastal wetlands (Figure 12). With only 30 m resolution in the satellite imagery used for the mapping, coastal fens and marshes are hard to distinguish (M. Pellatt, pers. comm). Higher resolution mapping and drone imagery are being used to improve the representation of coastal marshes on the region's land cover maps. This involves collaboration between ECCC, Parks Canada, and university researchers.

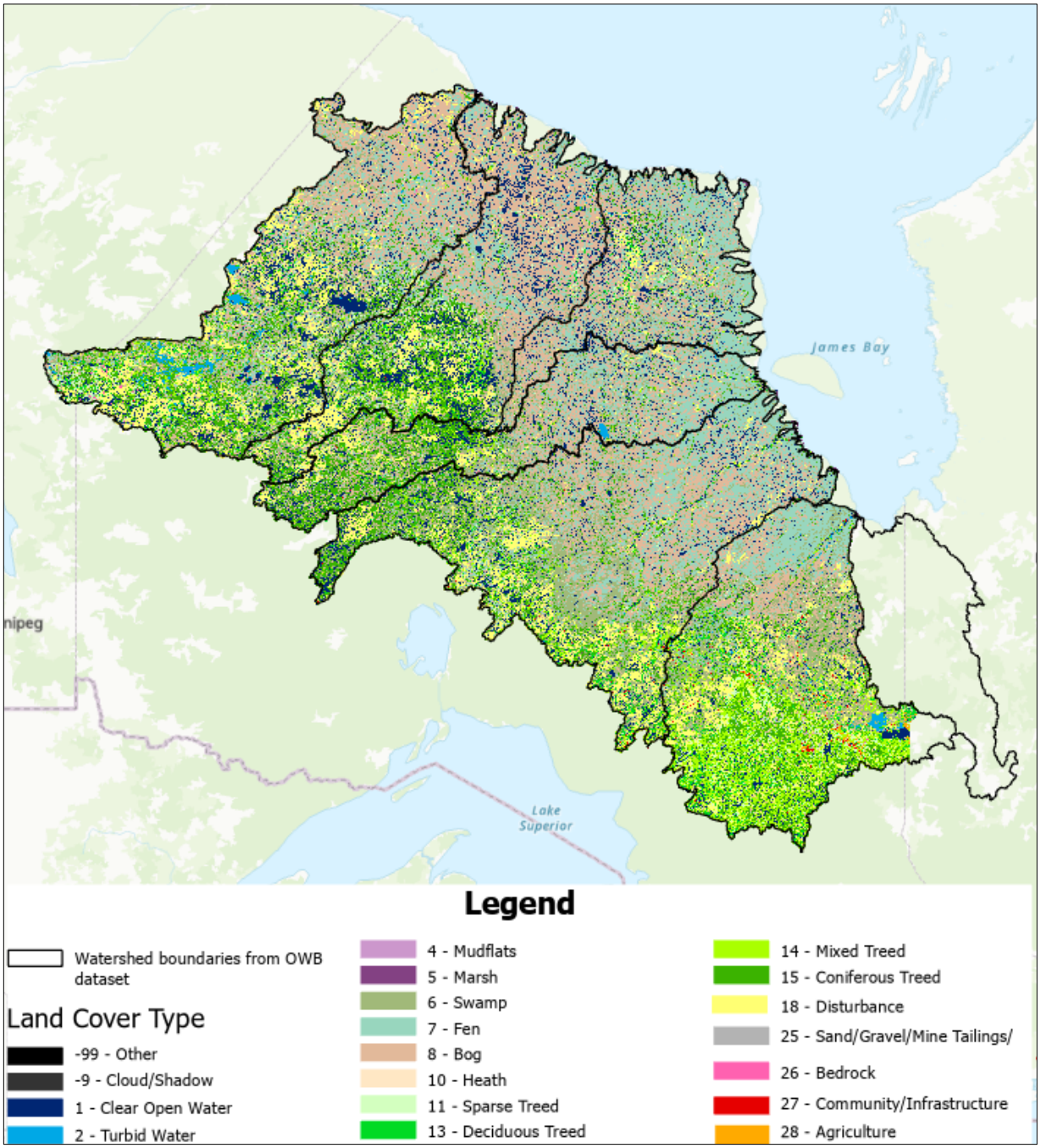

Figure 12. Land cover map for the seven major watersheds (portions located in the province of Ontario and Manitoba) (modified from OMNRF, 2014)

Table 4. Summary of land cover types in the southern Hudson Bay - western James Bay watersheds study area based on data from the OWB data set and province of Ontario Far North Land Cover database (OMNRF, 2014).

Land cover type[1]	Area (km^2)	Percentage (%)
Clear Open Water	60,078	9.9
Turbid Water	3,608	0.6
Marsh	589	0.1
Swamp	85,562	14.2
Fen	105,784	17.5
Bog	138,761	23.0
Sparse Treed	16,546	2.7
Deciduous Treed	13,417	2.2
Mixed Treed	35,081	5.8
Coniferous Treed	79,220	13.1
Disturbances	61,906	10.3
Sand/Gravel/Mine Tailings/ Extraction	236	0.04
Bedrock	391	0.06
Community/Infrastructure	1,027	0.2
Agriculture and Undifferentiated Rural Land Use	537	0.1

[1]The Far North Land Cover consists of 26 land cover types and was updated in 2014 from an object-oriented classification of Landsat-5 TM satellite images acquired between 2005 and 2011. The FNLC was produced as 3 overlapping raster maps, one for each UTM zone in northern Ontario, with a pixel resolution of 15 meters. Some of land cover types with very low percentages (<0.05) have been removed from the list.

Wildfires impact surface cover and are monitored closely and publicly reported by the Ontario Ministry of Natural Resources (OMNR) (Figure 13). There is concern that the frequency of wildfires is increasing because of climate change, although for many regions a direct causal link has not been established. Increasing human activity can inadvertently lead to increased forest fire frequency when combined with hot and dry conditions. Regardless of the causes of the increase in forest fires, they have massive direct human impact (loss of infrastructure, wildlife, and human lives, etc.). The frequency of forest fires is also believed to erode a region's carbon sink capacity as discussed by Virkkalla et al. (2025). Wildfires lead to increases in lateral water-borne carbon release, both in dissolved and particulate forms. They also increase erosion and transfers of other elements such as trace metal contaminants like mercury. Details are provided in subsequent sections.

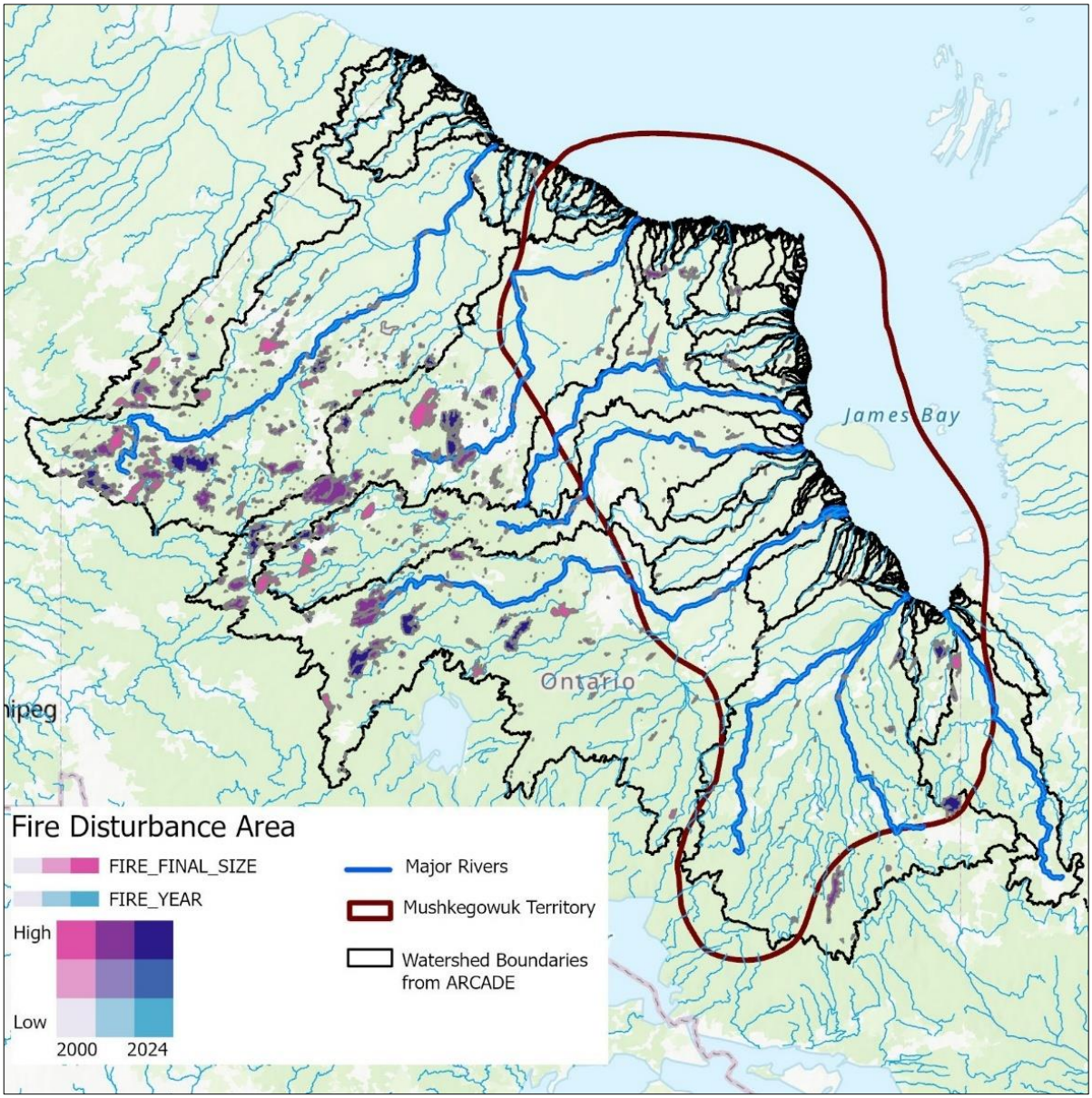

Figure 13. Fire disturbance areas between 2000 and 2024 based on the final burned areas created from the data source: [Fire Disturbance Area | Ontario GeoHub]

Trends

Currently, research has been focused on mapping high resolution and accurate land cover maps. There is too much uncertainty to assess temporal trends in particular types of cover across the region. However, we can speculate on some expected changes in cover due to changes in climatic and industrial conditions.

The vast HBL wetlands are considered mostly intact (Keller et al., 2014; Dredge and Dyke, 2020; Li et al., 2025a); however, warming, coupled with thawing and potential drying of permafrost, pose regional and local threats to the wetlands and their services, including carbon storage. Wetland extent and properties are sensitive to: 1. wetting and drying; 2. changes in the marine environments – storminess or eustatic sea level rise; 3. climate-driven changes in water properties, including within the lakes and rivers, such as changes in temperature and

colour/clarity (e.g., browning of rivers); 4. water level fluctuations in response to river and stream discharge, including changes with river regulation; and 5. northward advances of southern vegetation (McLaughlin and Webster, 2014). Large scale industrial development, such as mining, and associated activities (e.g., road building) are also considered potential threats to the HBL wetlands (Harris et al., 2022).

Water level has one of the largest influences on cover class in the subarctic peatlands. Several studies using remote sensing and ground surveys have identified that surface water is the main driver of shifts in vegetation; increased drying leads to increased tree and shrub vegetation ("greening"), while increased wetting leads to sphagnum moss dominated bogs and fens ("browning") (McLaughlin and Webster, 2013; Myers-Smith et al., 2020; Li et al., 2021). This relationship between water and cover class can be observed as the permafrost melts. Peat plateaus create a dry, well-draining habitat that support black spruce dominated forests. As permafrost thaws, the plateau collapses and the whole ecosystem undergoes a community shift from black spruce dominated forest to peat and sedge dominated wetland (Baltzer et al., 2014). This begins a feedback loop as the permafrost melts at a faster rate along the edges of these 'forested islands' due to decreased shading and insulation from trees (Baltzer et al., 2014). As current climate models predict overall drying in the Mushkegowuk territory (McLaughlin and Packalen, 2021b), we can expect an increase in forested areas in the future, though this shift may not occur for many decades or even centuries (Lloyd, 2005; McLaughlin and Packalen, 2021b).

The relationship between water level and shifts in cover class is not always straightforward. For example, in areas where flooding has occurred due to infrastructure projects, widespread tree die off has not always occurred (Bocking et al., 2017; Elmes et al., 2022). This may be due to the presence of sphagnum moss which can modulate the effect of water table level on other vegetation in the ecosystem as the surface of the peat rises and lowers with the water level (i.e. "mire breathing";(Roulet, 1991; Nijp et al., 2019)). This process can protect other vegetation from the effects of draining or flooding (Elmes et al., 2024), slowing changes in cover class due to changes in water levels. This suggests there is a threshold of water level changes that peatlands can withstand, and, if that threshold is met, either through drainage for mining or long-term drying due to increased evapotranspiration, the resilience of the ecosystem is significantly reduced. This leads to decreased carbon storage, increased wild fires and reduced primary production (Harris et al., 2020) and ultimately a shift in cover class (McLaughlin and Webster, 2013).

Coastal wetlands are a special case and require dedicated study. They are vulnerable to changes in inland hydrology as well as the marine climate (e.g., loss of sea ice, increased storminess) and nearshore productivity. Past work in the coastal wetlands of the HBL includes biological and physicochemical observations of coastal wetlands along coastal transects of the James Bay coastline (Martini et al., 1980; Glooschenko and Martini, 1983). Plant communities associated with brackish vs more saline conditions and sedimentary deposits have been described. Impacts of increased numbers of lesser snow geese (*Chen caerulescens caerulescens*) on vegetation and soil erosion in the HBL's coastal marshes were also studied (Jefferies et al., 2006).

Coastal geomorphology was described in detail in several areas by Martini and colleagues (Martini et al., 1980; Glooschenko and Martini, 1983; Martini, 1986; Mosher and Martini, 2002). They documented a number of coastal landforms related to sea ice, including jig-saw puzzle marshes, boulder push ridges, shallow circular depressions, boulder pavements, scours generated by moving ice floes, ice pressure ridges, and drop stones ranging from large boulders to gravel. They also noted how ice scour caused vegetation damage (Martini, 1986). The dramatic changes in sea ice in southern Hudson Bay and James Bay since the late 1990s (Galbraith and Larouche, 2011; Bruneau et al., 2025) may have impacted these processes and consequently coastal landforms and vegetation. Kaushik Gupta, a University of Manitoba PhD student with Dr. Jens Ehn who studies landfast ice in Hudson Bay and James Bay, is further documenting the evolution of ice-related coastal landforms using drone and satellite imagery.

In other regions, studies have looked at how coastal salt marshes will respond to rising global sea levels and concluded that the marshes can continue to accumulate in step with the pace of sea-level rise provided the rate is not too great (Chmura and Hung, 2004). Along western Hudson Bay and James Bay, the falling relative sea level and consequent emerging landscape can evolve into coastal marshes of various types with diminishing marine influence over time; this process leads to wetland succession where salt-tolerant vegetation is replaced by freshwater wetland systems such as bogs and fens (Pendea et al., 2010). Pendea and Chmura (2012) caution that while wetland succession generally follows a transition from nutrient-rich to nutrient-poor and/or ombrotrophic communities, wetland communities can also undergo shifts due to changes in environmental conditions regardless of the successional trend.

Glooschenko and Martini (1983) proposed successional sequences for the coastal vegetation as a way of thinking about how vegetation could be impacted by rivers, and climate change, especially changes in storminess or the rate of local sea-level rise responding to the balance between future global eustatic sea level rise and isostatic uplift. For example, the wetland ecosystems of the lower reaches of the Attawapiskat River are influenced by several important local environmental controls including water salinity, tides and storm surges, geomorphology of riverbanks, and soft-sediment drainage. Any river flow regime modifications would therefore induce successional changes. If, for example, the river flow was decreased due to flow regulation (dams or diversions), or prolonged periods of drying (evapotranspiration in excess of precipitation), the saline waters of James Bay could reach further upstream possibly increasing the areal extent of salt and/or brackish marsh development.

Table 5 shows the surface area (km^2) and percent contribution of various land cover types for six of the major sub-watersheds (those draining land mostly in Ontario) based on data from the Ontario Land Cover Compilation. Swamp, fen, bog and treed cover classes dominate across all the watersheds but there are notable differences among the watersheds. For example, the 'mixed treed' class is dominant in the Moose River watershed whereas the swamp, fen and bog classes are dominant in the Albany River watershed. The 'bog' cover class is very dominant for the Winisk (>30%) and Severn (>25%) River watersheds. In Table 6, percent contribution of various land cover types for seven major sub- watersheds are summarized based on the ARCADE database. The Severn, Winisk, and Ekwan have more herbaceous wetland (10%-22%) than the

other watersheds and lower proportions of 'treed' cover. It is interesting to compare among the databases and consider the potential strengths and limitations of each one. Although these data provide good baseline characterization, they are not suited to detecting changes over short time scales (e.g., years) because of challenges with classifying some cover types at lower resolution.

Table 5. Percent contribution of various land cover types in six major sub-watersheds mostly in Ontario (OMNRF, 2014).

Land cover Type [1]	Moose	Albany	Attawapiskat	Ekwan	Winisk	Severn
	%	%	%	%	%	%
Clear Open Water	5.8	8.1	9.7	9.6	15.1	11
Turbid Water	0.7	0.1	0.4	0.4	0.2	1.9
Mudflats	0	0	0	0	0	0
Marsh	0	0.1	0	0.2	0	0
Swamp	16.5	20.2	13.3	8.8	8.6	9.8
Fen	11.0	22	23.8	36.9	15.1	14.9
Bog	11.8	21.5	25.3	33.7	30.5	25.5
Heath	0	0	0	0.2	0	0
Sparse Treed	4.9	0.7	1.2	1.6	3.3	3.6
Deciduous Treed	4.8	2.1	0.9	0.8	1.5	1.9
Mixed Treed	18.5	3.8	2.3	0.1	2.8	3.4
Coniferous Treed	13.9	10.9	16.8	3.9	13.6	14.6
Disturbance	10.8	10.3	6	3.6	8.9	13.1
Sand/Gravel/Mine Tailings/Extraction	0.1	0.02	0	0.1	0	0
Bedrock	0.0	0.02	0	0	0	0.2
Community/Infrastructure	0.6	0.16	0	0	0	0
Agriculture and Undifferentiated Rural Land Use	0.5	0	0	0	0	0

[1]The Ontario Land Cover Compilation includes 29 land cover categories, created by merging the Provincial Land Cover Database (2000 Edition), Far North Land Cover Version 1.4, and the Southern Ontario Land Resource Information System (Version 1.2). Each of these databases was adjusted to have a uniform pixel size of 15 meters, transformed to the NAD83 Lambert Conformal Conic projection, and reclassified into a standardized class structure. Details of the reclassification process can be found in section 2.3 of the Ontario Land Cover Compilation Data Specifications Version 2.0 document published by OMNRF in 2014.

Table 6. Percent contribution of various land cover types in seven major sub-watersheds based on the ESA WorldCover 10 m v100 database for the years 2020-2021.

	Land Cover Type								
Sub-Watershed	**Trees (%)**	**Shrubland (%)**	**Grassland (%)**	**Cropland (%)**	**Built-up (%)**	**Barren / sparse (%)**	**Open water (%)**	**Herbaceous wetland (%)**	**Moss and lichen (%)**
Harricana	73	6.6	15	0.11	0.09	0.32	3.9	1.0	0.03
Moose	79	7.6	6.2	0.11	0.06	0.15	5.0	2.4	0.03
Albany	69	10	8.4	0.00	0.01	0.04	8.8	3.7	0.05
Attawapiskat	50	20	13	0.00	0.01	0.03	7.5	9.1	0.24
Ekwan	19	37	16	0.00	0.00	0.01	6.4	22	0.80
Winisk	37	26	10	0.00	0.01	0.02	12	16	0.25
Severn	48	25	6.9	0.00	0.00	0.06	10	10	0.16

Dataset Name: ESA WorldCover 10m v100
Source spatial Resolution: 10 m
Temporal Resolution Used: 2020-2021
Reference: Zanaga et al., 2021
Link: https://doi:10.5281/zenodo.5571936

Challenges

The remote sensing imagery used to make the Far North Land Cover map V1.4 was created using Landsat imagery from 2005-2011 (OMNRF, 2014a). This methodology can cover large areas relatively quickly, but in comparison to slower and more rigorous field observations and classification, it is less accurate, especially when classifying wetlands. Due to its resolution, remote sensing classification can miss small sparse forest stands. Additionally, in instances when classification of wetland type relies on indicator species, errors may result when the indicator species are undetected based on resolution. In heterogenous wetland landscapes like the HBL, these limitations often cannot be overcome using other physical characteristics (OMNRF, 2014a). Researchers at ECCC are working on a revised wetland classification for the region which have largely overcome some of these limitations – CWIM3A has a higher resolution (10 m^2 instead of 30 m^2) and has shown to be able to identify fens and bogs with 0.75-0.82% accuracy (OMNRF, 2014a; Merchant et al., 2023).

There is currently not enough data to determine regional scale changes in land cover classes over time. As methodologies continue to shift and improve, they become incomparable. Differences in cover between maps may be due to either actual change or due to differences in accuracy or categorization definitions (OMNRF, 2014a; Bartsch et al., 2016).

Carbon Storage in Peatlands and Coastal Wetlands

Significance

Peatlands are widespread in the territory and have been important sinks for atmospheric carbon dioxide for millennia, which means they have mitigated a proportion of the rapid and on-going build-up of atmospheric carbon dioxide (CO_2) that has occurred since the start of the industrial revolution (Schuur et al., 2015; Natali et al., 2021). The inland peat of the territory, in some instances, could have been first formed as far back as 5000 years ago (Packalen et al., 2014). The status of CO_2 sink results from primary production (uptake of CO_2) exceeding ecosystem respiration (release of CO_2), mainly due to low degradation rates of organic carbon in saturated and seasonally or permanently frozen (permafrost) soils of this flat-lying poorly drained landscape.

In addition to peatlands of the HBL, coastal marshes may be more important than previously recognized for providing ecosystem services such as carbon storage (Chmura, 2024). They release negligible amounts of greenhouse gases and store more carbon per unit area compared to freshwater wetlands and peatlands (Chmura et al., 2003). Coastal marshes may capture both autochthonous organic matter (salt marsh vegetation) and allochthonous organic matter from marine sources and nearby river outlets while protecting the carbon from decomposition both by maintaining anaerobic conditions and brackish to saline conditions. Detailed work on coastal wetland carbon has been completed near Moosonee and Peawanuck, ON as well as further north near the mouth of the Hayes River and Laperouse Bay, MB (M. Pellatt, pers. comm).

The fate of the enormous carbon stock in northern soils is a growing global concern in response to climate change that has elevated temperature, rates of permafrost thaw, and resulted in changes to wildfire regimes and local and regional water budgets (Schuur et al., 2015; Natali et al., 2021; Hugelius et al., 2020; McGuire et al., 2012). On thawing, organic carbon is subject to degradation that leads to the production and evasion of CO_2 (in the presence of oxygen) and methane (CH_4, in absence of oxygen). Carbon originally fixed from the atmosphere by vegetation can also be transported with flowing water and carried seaward along a land to ocean aquatic continuum. While in transit the carbon can be buried (organic and inorganic), and/or the organic component can be degraded by microbes and light, producing CO_2 (and to a lesser extent CH_4) that underpin aquatic emissions. All else equal, warming will increase the decomposition rate in unfrozen soils. Generally, emissions of greenhouse gases from aquatic systems are not well represented in Earth System Models, largely because it has only been relatively recent that their role as a key source of atmospheric greenhouse gas concentration has been recognized (e.g., Cole et al., 2007, among others).

State

Early work on carbon storage suggested that peatlands in Canada contain ~147 Pg C (Tarnocai, 2006) with the HBL specifically containing ~30 Pg C (Packalen et al., 2014; Gonsamo et al., 2017). However, a central focus of more recent research has been to improve

quantification and reporting of the HBL's peatland carbon stocks (Harris et al., 2022), and associated carbon cycling (e.g., Humphreys et al., 2014).

In regard to carbon stocks, the distribution of peatland (from Xu et al., 2018) is shown across the HBL in Figure 14. The distribution of soil organic carbon is summarized by depth in Table 7 for the seven watersheds (derived from SoilGrids database). Near surface (0-30 cm) total storage is largest in Albany, followed closely by the Severn and Moose River watersheds. All the watersheds contain an excess of ~ 60 t/ha of soil organic carbon.

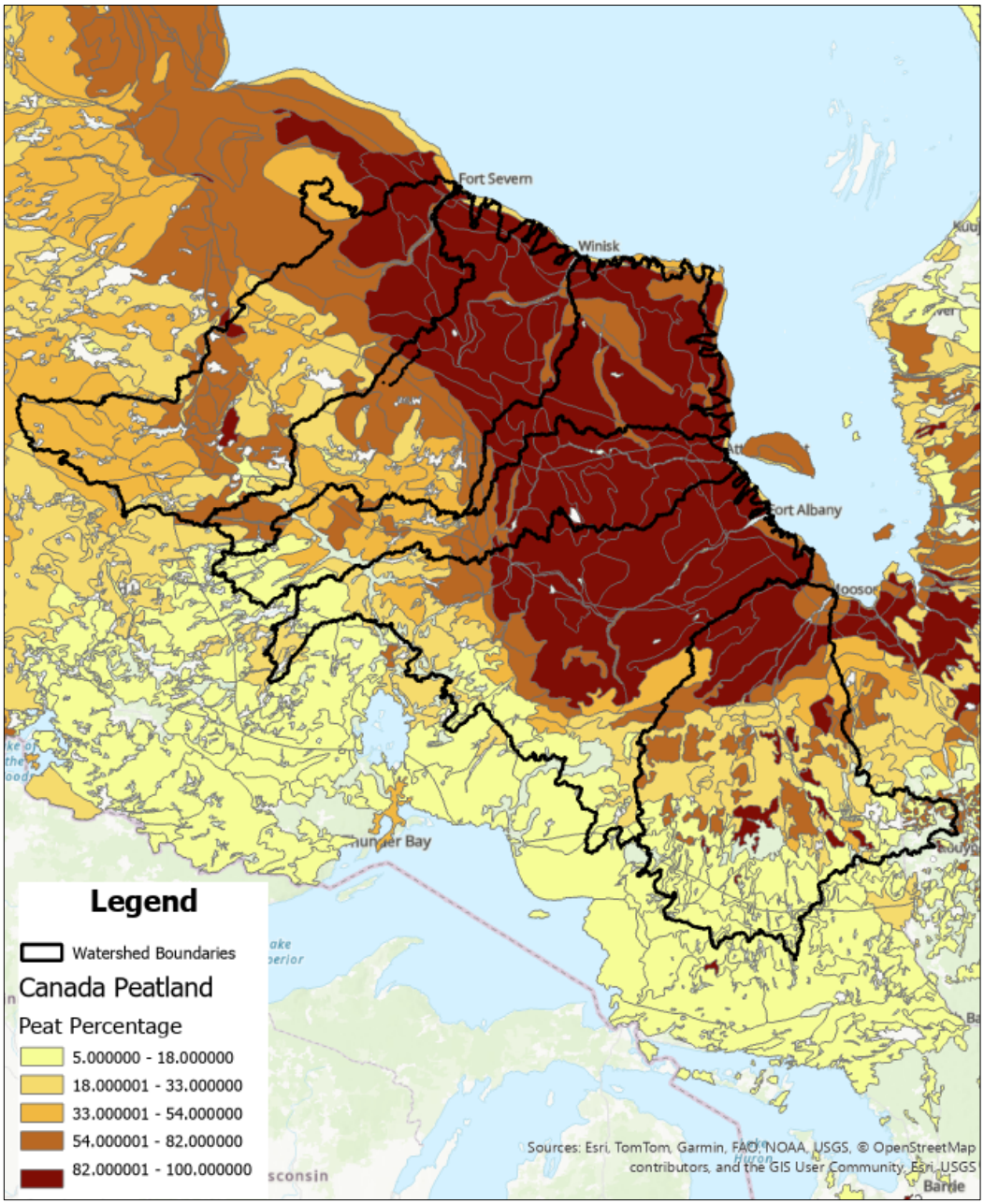

Figure 14. Peatland percentages across the study area (derived and modified from Data Packages – PeatDataHub)

Table 7. Soil organic carbon content for seven major watersheds derived from SoilGrids database[1].

River	Watershed area	Mean soil organic carbon content in different depths (cm)						Organic Carbon Stock in 0-30 cm depth				
		0-5	5-15	15-30	30-60	60-100	100-200	Max	Mean	Min	Std	Total
	km^2	g/kg						t/ha				gt
Severn	99,884	115	116	138	139	144	238	100	69	42	6.96	0.61
Winisk	64,656	114	114	129	129	132	201	97	70	49	4.83	0.39
Ekwan	21,871	144	147	177	175	184	232	87	69	55	3.44	0.14
Attawapiskat	47,903	93	88	98	97	100	176	89	69	51	4.43	0.30
Albany	130,465	60	56	55	53	53	100	97	65	43	5.77	0.77
Moose	106,455	57	49	39	34	33	41	110	59	33	6.19	0.59
Harricana	21,200	46	43	34	27	25	34	90	61	41	5.22	0.18

[1]Dataset Name: SoilGrids
Source spatial Resolution: 250 m
Temporal Resolution Used: 1905-2016
Reference: de Sousa et al., 2020
Link: https://doi.org/10.17027/isric-soilgrids.713396fa-1687-11ea-a7c0-a0481ca9e724

More recently, (Li et al., 2025a) updated estimates of peat depth and carbon storage specifically for the HBL. The average peat depth of the HBL was 184 cm, 90% of which has a depth ranging between 89 to 184 cm, and 99% of which has a depth falling between 0 and 300 cm, while very deep peat (300-600 cm) makes up only 1% of the HBL soil organic carbon store. They describe how peat depth varies by peatland type. Bogs typically have deeper peat (average 230 cm) compared to fens (average 160 cm). In the HBL, peat depth increases inland, influenced by isostatic uplift and climate conditions (Li et al., 2025b), with coastal areas containing younger, shallower peat (about 100 cm depth). The oldest peat formations are found near the Boreal Shield interface where peat accumulation has occurred for thousands of years (Li et al., 2025b), although uncertainties in carbon accumulation are highest in these areas as in-situ data are sparse (Sothe et al., 2022). Field-based validation is required in underrepresented peatland regions such as wetland pools, inland peatlands, and high elevation areas due to water cover, fewer ground measurements, and variable peat accumulation, respectively.

Large carbon stocks are also contained currently in the territory's coastal marshes (Forbes-Green, 2024). These first estimates suggest that coastal marshes store very significant amounts of carbon even though the fraction of organic matter in the soils is lower than in peat. The coastal marsh soils were found to be comparable in carbon density to other global salt marshes. Given the very large spatial extent of the coastal area across the territory, this makes the overall carbon stock in these coastal marshes very important. The average carbon stock in the top 21 cm of soil across all studied coastal marsh sites (n = 41) was 4.6 kg C m^{-2}. There was no statistically significant difference in carbon stocks between any of the four wetland types studied (intertidal, supratidal, thicket swamp, and freshwater marsh) but there was a trend toward rising organic matter content and declining bulk density offsetting each other moving inland.

Authors acknowledge, e.g., (Harris et al., 2022; Li et al., 2025b) that gaps exist in our understanding of the pathways of peatland carbon export. Over roughly the past 20 years there has been coordinated monitoring of vertical greenhouse gas exchange in circumpolar boreal and Arctic peatland systems, including within the HBL, which is providing an improved understanding on the magnitude, trends, variability and ecosystem drivers of greenhouse gas exchange budgets. Researchers have developed a better understanding on the role of temperature, length of growing season, water table depth and soil moisture, vegetation, and the respective roles of photosynthetic uptake and respiration on the regions' CO_2 source/sink status (e.g., Humphreys et al., 2014; Helbig et al., 2019; Valkenborg et al., 2023; Virkkala et al., 2025). Insights have supported the development of models of net ecosystem production (remote sensing and numerical) in peatland and boreal systems (e.g., Beaver et al., 2024). Average annual gross primary production (GPP as g C m^{-2} y^{-1}) has been shown to vary by more than a factor of two across sites within the HBL, with the lowest GPP (153 ± 17 g C m^{-2} y^{-1}) observed at a northern-most station in Wapusk National Park (on Cape Churchill) and highest GPP (462 ± 14 g C m^{-2} y^{-1}) over a fen in the Attawapiskat watershed at the southernmost station (Beaver et al., 2024). Only five greenhouse gas flux stations were used to characterize variability over an extremely large and diverse territory. The average annual GPP can differ by ~ 25% over different wetlands in close proximity, as was the case for sites at a bog (dominated by coniferous trees) and fen (dominated by deciduous trees) in the Attawapiskat watershed (Beaver et al., 2024). The differences in carbon uptake were attributed to differences in vegetation physiology (affecting GPP) and ecosystem respiration (affecting net ecosystem production) between the two systems, and results suggest that warmer temperature would likely reduce CO_2 uptake by these peatlands (Helbig et al. 2019).

Relative to our understanding of air-surface vertical exchange budgets of carbon associated with peatland and boreal systems we know less about the lateral carbon losses associated with transport from soils and through the aquatic continuum. This remains a critical knowledge gap as globally it is estimated that the land to inland water flux is ~ 2.9 Pg C y^{-1} which represents ~ 72% of total uptake by terrestrial systems (Regnier et al., 2022). Vonk et al. (2025), based on a comprehensive carbon cycle for the Arctic across the land-ocean continuum, suggests that the fluvial flux of carbon across the circumpolar Arctic is ~ 50% of total terrestrial uptake, and closer to ~ 46% for Hudson Bay. Zolkos et al. (2022) suggests that the permafrost landscape history impacts the fluvial carbon export, and that in watershed affected by thaw-induced wasting, the fluvial carbon export approached 60% of net ecosystem production, and much lower (6%-16%) in watershed not affected by thaw-induced wasting. Clearly the lateral carbon loss from watersheds is large, and remains unquantified for the HBL, which constitutes a significant knowledge gap. Government agency, and community-partnered programs are underway to address this gap.

Trends

Most research on the carbon balance of peatlands has focused on permafrost regions, and specifically the changes due to permafrost thaw. As mentioned above, permafrost thaw supports higher rates of respiration and influences water balance, which in turn influences carbon storage.

Although the extent of permafrost in these watersheds is limited, the research reflecting the changes in carbon fluxes due to water balance can be extrapolated, to a point, to non-permafrost peatlands. Overall, there is consensus that the peatland carbon storage will weaken with permafrost thaw, warming, and drying, though these changes are not easy to predict (Swindles et al., 2015).

Already, the circumpolar permafrost zone has become nearly carbon neutral, with large swaths now serving as net sources of CO_2 to the atmosphere (Virkkala et al., 2025). With continued warming and loss of sea ice in Hudson Bay and James Bay, continued thawing of remaining permafrost is almost guaranteed. Experiments conducted in discontinuous permafrost peatlands in western Canada showed large carbon losses averaging ~33 g C m^{-2} $year^{-1}$ after permafrost thaw; these losses were not offset by limited new plant growth and peat capture at the thawed surface (Harris et al., 2023). During initial thawing of permafrost, enhanced decomposition of associated peat is expected, increasing CO_2 emissions; carbon turnover rates are lowest when soils are frozen, therefore carbon turnover will increase with thaw regardless of whether the peatland is well or poorly drained.

After permafrost thaw, carbon turnover rates and pathways depend on whether the peat is waterlogged, in which case its degradation could lead to increased CH_4 emissions. Cooper et al. (2017) found that the source of significant CH_4 emissions from thawing peatlands in northern Canada was primarily anaerobic decomposition of recent carbon inputs, and not previously frozen carbon. Therefore, they concluded that changes in surface wetness and wetland area due to permafrost thaw may influence CH_4 emissions from northern peatlands to an extent greater than the anaerobic decomposition of previously frozen carbon (Cooper et al., 2017).

For regions with seasonally unfrozen peat and no permafrost, reduction in the carbon sink status with continued warming is also expected. Recently, Virkkalla et al. (2025) showed, using models and observations from long-term flux stations, that the circumpolar Arctic boreal zone remains a CO_2 sink largely due to increased summertime primary production; however, the increased frequency of forest fires in the region erodes the carbon sink capacity. Parts of the subarctic boreal and permafrost zone, including the HBL, show increasing net CO_2 emissions driven largely by an increase in respiration in response to warming (Figure 15). Natali et al. (2019) caution that wintertime warming within northern permafrost regions will increase CO_2 emissions that in the future could offset summertime uptake associated with increased seasonal primary production. In fact, recent work (e.g.,Helbig et al., 2022), including research in the HBL (Helbig et al., 2019) has shown that the response of the net CO_2 exchange in sign and magnitude for peatlands is sensitive to the seasonality of warming (e.g., warmer early summer favours increased uptake), and vegetation physiology. In that study it is suggested that warmer temperature would likely reduce CO_2 uptake by these peatlands.

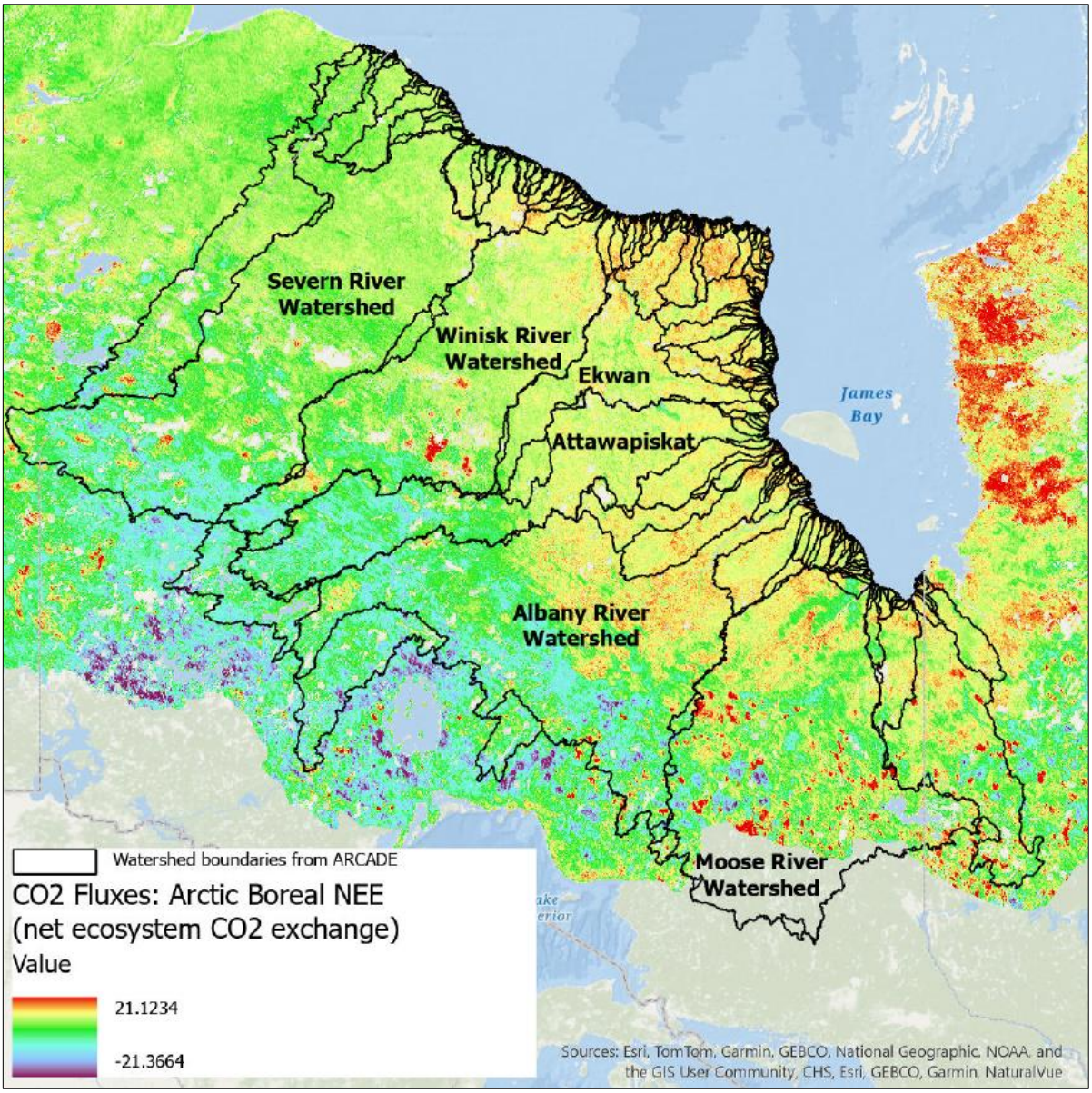

Figure 15. Temporal trends of CO_2 fluxes for the period of 2002-2020 (modified from the database of Virkkalla et al., 2025). Negative values mean increasing net ecosystem CO_2 uptake (purple, blue and green shading) while the positive values indicate increasing net ecosystem CO2 emissions (red and yellow shading).

Water stress (drought and waterlogging) has also been shown to impact GPP in northern peatland systems, including the HBL (Valkenborg et al., 2023). In western James Bay, simulations under severely warmer climate scenarios show that peat drying leads to a 20% reduction in net ecosystem carbon exchange and the strength of the peatland carbon sink. Methane emissions decreased slightly, and peat carbon sink strength was 27% lower due to peat combustion (McLaughlin and Packalen, 2021a).

Less studied than changes in the direct land-air fluxes of carbon with permafrost thaw and peatland warming is the impact of permafrost thaw on lateral losses of water-borne carbon. Plant-derived carbon is also removed from a landscape through entrainment by moving water, from soils, and along an aquatic network (streams, rivers, ponds, lakes, etc.) ultimately to the

ocean (see Regnier et al., 2022; Vonk et al., 2025). The amount of carbon entering a water-borne phase and being transported laterally via the aquatic network can be quite large (Regnier et al., 2022). Rates of lateral peatland carbon loss will be affected by water table shifts, influenced by river channel migration, accelerated river incision and shifting interfluvial divides (Glaser et al., 2004). While in transit, the organic portion of the carbon (living or dead plant matter) carried along the aquatic network is subject to degradation by microbes and light, producing CO_2 (and to a lesser extent CH_4). Some portion typically survives transport downstream and eventually is buried in a receiving body of water (e.g., coastal marine ecosystem). Turetsky's (2020) study found that more than half of the particulate and dissolved organic carbon (POC/DOC) released from peat after permafrost thaw and transported in water-borne phases along the aquatic network may be degassed as CO_2, further increasing the total net atmospheric carbon emissions from permafrost thaw in peatlands.

The Hudson Bay region ranks second in the circumpolar Arctic for drainage, third in total soil organic carbon, second in the delivery of dissolved inorganic carbon by rivers, and third in the delivery of dissolved organic carbon (Vonk et al., 2025). The largest export of the river carbon fluxes is during the spring freshet. Fluvial fluxes of carbon are affected by changes in hydrological cycles, widescale permafrost thaw, land surface change including that associated with human intervention (e.g., regulation of rivers), and the processing of organic matter on land and within stream. However, while increased river discharge has increased the pan-Arctic dissolved inorganic carbon fluxes since 2003, the fluxes of dissolved organic carbon have remained fairly constant (Drake et al., 2018; Tank et al., 2023).

Challenges

Projecting the fate of the carbon stored in the peatlands and the coastal marshes of the territory remains challenging because of the uncertainty around carbon quantities and distribution. Furthermore, the impact of warming and development on these carbon stores is uncertain (Harris et al., 2022). There is uncertainty in global estimates of the magnitude of the total carbon losses from permafrost thaw (see, for example, Hugelius et al. (2020), who gives estimates that are 5 to 10 pentagram (Pg) higher than those given in Turetsky et al. (2020)). The differences can be attributed to a larger projected thaw area and the inclusion of carbon loss from active layer deepening (Hugelius et al., 2020). Additionally, uncertainty about the current distribution of permafrost casts doubt on the relative importance of this thaw-driven carbon release vs. increased rates of carbon degradation resulting from drying due to increased evapotranspiration with warming. Future assessments would benefit from improved characterization of fire-related carbon losses and carbon losses due to other types of disturbance. More data are needed on soil moisture, impacts of water table changes, and understanding of landscape heterogeneity. Additionally, long-term flux measurements from directly within the HBL would reduce uncertainty on the regions evolving CO_2 source or sink characteristics.

The Hudson Bay area is one of a number of Arctic basins where data are scarce, and thus the river flux totals summarized by Vonk et al. (2025) relied heavily on extrapolation. The relative contribution of carbon delivery through the Hudson Bay Lowlands and from James Bay rivers are not known. Both the transport of carbon and its degradation products can have downstream

ecosystem impacts in marine environments, including acidification, primary production, and greenhouse gas budgets (Semiletov et al., 2016; Terhaar et al., 2019; McGuire et al., 2009; Macdonald et al., 2015; Regnier et al., 2022); however, there have been only a few studies examining these impacts in Hudson Bay (e.g., Deschepper et al., 2023; Lee et al., 2023) and none specific to James Bay. Ongoing work by University of Manitoba researchers aims to address these gaps, while also assessing the impacts of fluvial carbon delivery on coastal ecosystems.

A major challenge for the HBL is the poorly known hydrology (see next section) because the carbon releases in aqueous form from the peatlands will go where the water flows (Ward et al., 2017). Second, the age and lability of carbon released from the HBL peatlands are poorly known but critically important for the region's overall carbon balance (Capelle et al., 2020). Some permafrost carbon is highly labile because it contains high contents of aliphatic (straight-chain) and small organic acids that bacteria can consume within days, whereas in other settings, permafrost carbon may contain aromatic compounds that are resistant to breakdown (Gandois et al., 2019). The differences may depend on the geological context, permafrost history, peatland type, and history of permafrost formation. A future large-scale study of the lateral carbon losses from the HBL peatlands spanning the whole thaw gradient could address some of these questions.

Webster et al. (2025) highlight critical knowledge and data gaps in Canada's peatland science and policy. They emphasize the need for standardized data collection, Indigenous knowledge integration, and long-term monitoring. Their study stems from the Global Peatlands Initiative workshop held in June 2023 that identified seven critical data categories and proposed solutions to improve peatland conservation, carbon accounting, and land-use planning as summarized in Table 8.

Table 8. Seven critical data categories to improve peatland management as described by Webster et al. (2025).

Data Category	Key Measurement Priorities	Recommendations
Peat Coring & Depth	Peat depth, bulk density, nutrient concentration	Establish standardized coring protocols across all regions.
Hydrometeorological Sensing	Water table depth, soil moisture, precipitation	Expand climate stations in remote peatlands.
GHG Monitoring	CO_2 & CH_4 fluxes, primary productivity	Integrate peatland GHG accounting into national inventories.
Vegetation & Biomass	Peatland type, tree biomass, plant cover	Improve peatland classification for carbon models.
Biodiversity	Habitat assessment, vegetation inventory, species diversity	Increase long-term biodiversity monitoring.
Traditional Knowledge	Peatland use, ecosystem changes, cultural values	Strengthen Indigenous partnerships in monitoring.
Water Quality	Dissolved organic carbon (DOC), pH, nutrient levels	Establish a national peatland water quality database.

Hydrology and Streamflow

Significance

Water levels and flows are among the most fundamental pieces of information for managing a watershed and activities therein including hydroelectric power generation. They are also critical for risk assessment and mitigation related to extreme events (droughts and floods). Freshwater discharges to ocean systems are also critically important pieces of information because they impact many processes including circulation, sea-ice formation, water column structure and mixing, and primary production.

Hydrometric (water-level) gauges remain relatively sparse across the northern regions of Canada (Stadnyk et al., 2020; Stadnyk and Déry, 2021). As of 2013, approximately 27% of the Hudson Bay drainage basin had never been gauged and the available hydrometric stations collectively covered only 60% of the basin (Coulibaly et al., 2013). Hydrological modeling has filled in some of the spatial and temporal gaps in the observational record and has been used to make future streamflow projections (Stadnyk et al., 2020). However, hydrological modeling is not without challenges, such as getting the storage-discharge dynamics right for watersheds that have a large number of lakes and wetlands, or with changing permafrost distributions.

In the territory, there are numerous small rivers that start within the lowlands having shallow channels and becoming marshy at their mouths. There is still work to do to delineate some of these watersheds. Additionally, there are lots of small and interconnected lakes and ponds within the peat that covers the lowlands, including some small waterbodies that are in depressions in glacial drift. This is a complicated landscape for evaluating water flow pathways, which may change seasonally with deepening of the active layer, and may exhibit preferential flow pathways beneath the surface.

The larger rivers such as the Severn, Winisk, Attawapiskat, Albany, and Moose originate beyond the lowlands and have origins dating back to before the last glaciation. Drainage over the flat lowland plains is very poor, which can increase the risk of flood for the Indigenous communities living on those lands (Dredge and Dyke, 2020). The seasonal hydrograph, which indicates the variation of streamflow over a one-year period, has a nival regime for all the rivers flowing toward James Bay, with relatively low flow for most of the year and high flows during the spring snow melt period (freshet) (Mosher and Martini, 2002). Most of the rivers experience major spring flooding during ice break-up and freshet, which can advance from the upper reaches towards their mouths because of their northward-flowing orientation (Glooschenko and Martini, 1983).

State

In 1977, Prinsenberg (1977) developed the first freshwater budget for Hudson Bay including James Bay and estimated that the Winisk and Severn Rivers contribute about 7.8% of the total annual mean runoff to the Hudson Bay system, while the combined contribution of all rivers with outlets on James Bay is about 44.6%, despite this region representing only 22% of the drainage area. He noted that the high runoff per unit area is due to the large amount of precipitation that occurs when warm and humid air is cooled by the cold surface waters of James Bay. All major rivers, except for La Grande River, are situated in the southern half of James Bay, south of Akimiski Island. Subsequent literature made the approximation that James Bay receives almost half of the total freshwater input to the Hudson Bay basin (Déry and Wood, 2004; McCullough et al., 2019; Eastwood et al., 2020). A more recent study reported that James Bay contributes 38.0% of the total annual river water input to Hudson Bay, with the majority (26.3%) from the east coast of James Bay (Évrard et al., 2023). The average contemporary discharge of rivers in eastern James Bay was estimated at 227 km^3 yr^{-1} based on historical discharge data, hydrometric stations currently operated by Hydro-Québec, and eight newly installed hydrometric stations (De Melo et al., 2022).

Discharge of rivers in western James Bay is not precisely known because of ungauged watershed areas and data gaps in historical discharge data. Comparing gauged areas (Déry et al., 2016) and watershed areas from the ARCADE database, it appears that about 25% and 23% of the Attawapiskat and Ekwan watersheds, respectively, are ungauged and about 15% of the Winisk and 10% or less for each of the Albany, Moose, and Severn Rivers. There are major data gaps in historical hydrometric data as well, including the Ekwan River (1964–1966 and 1996–2010), Severn River (1995–2006), Albany, Winisk and Attawapiskat rivers (1996–1998), and the main stem Moose River (1998–2001) (Déry et al., 2016). According to a Baseline Hydrology

Statistics Report (OMNRF, 2014b), there are 56 hydrometric stations (including southwestern Hudson Bay and James Bay) currently collecting streamflow data (Figure 16). The Moose and Albany Rivers have the highest number of hydrometric stations reflecting their large tributary networks. The Attawapiskat, Winisk, and Severn Rivers have moderate monitoring coverage for capturing seasonal flow variations. The Ekwan and Harricana Rivers have the fewest stations indicating potential data gaps in streamflow monitoring. There is limited data in the Government of Ontario databases for the Harricana River; more hydrometric data is accessible via Quebec Hydrological Data Centre (CEHQ). For the Attawapiskat River watershed, some streamflow discharge data were collected associated with environmental monitoring of DeBeers Canada Inc. for their Victor Diamond Mine (Orlova and Branfireun, 2014).

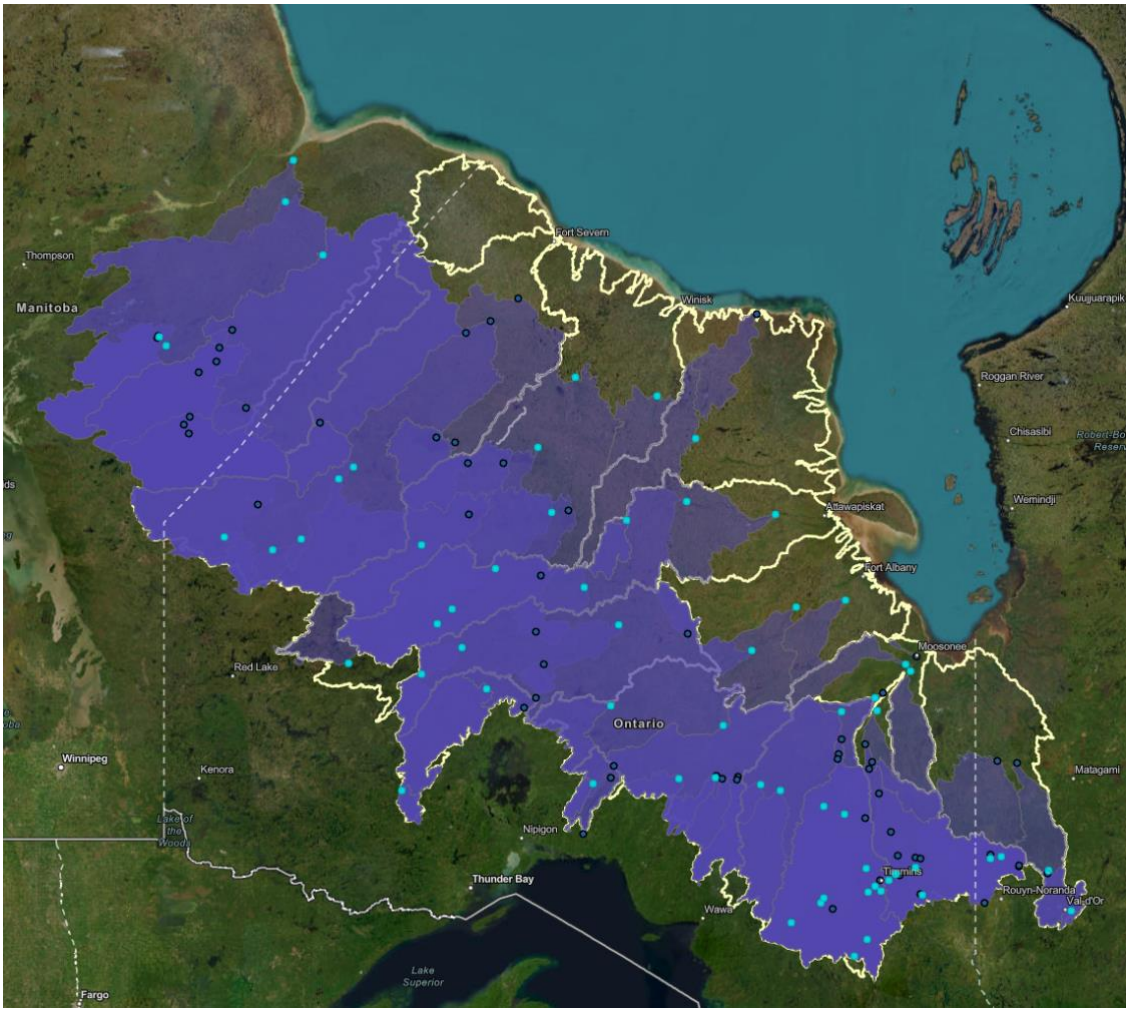

Figure 16. All the active (light blue circles) and discontinued (dark blue circles) HYDAT stations obtained from National Water Data Archive: HYDAT - Canada.ca. Purple shades boundaries are representative of drainage basins of HYDAT stations and yellow boundaries are from OWB; Ontario Watershed Boundaries - Dataset - Ontario Data Catalogue.

In addition to total streamflow, it is also important to know the relative contributions of surface water and groundwater across different watersheds and the variation associated with wet and dry conditions. The Baseline Hydrology Statistics Report, Appendix A (OMNRF, 2014b) presents Base Flow Index (BFI), the ratio of long-term mean baseflow to total streamflow, which

generally increases with increasing groundwater contribution. The reported BFI values suggest that groundwater contributions are highest in the Severn and Winisk Rivers (BFI > 0.73) and lowest in Mattawishkwia and North French Rivers (BFI > 0.39), as well as the Moose River mainstem (BFI > 0.5). A study that used a chemical mixing model approach in the Attawapiskat River watershed also found a significant groundwater contribution to streamflow (Orlova and Branfireun, 2014). They found that groundwater contributes more to streamflow as the watershed size increases, ranging from less than 20% to over 40% during dry periods, with groundwater importance declining during wet periods. According to their data, surface water from the peatlands contributed up to 53-67% of streamflow regardless of time and location. However, they note that the year of their study (2010) was exceptionally dry with low spring, summer, and fall flows, compared to typical years. Nevertheless, their results suggest that streamflow and source water dynamics will be significantly impacted by warmer and drier future conditions.

Peatlands in headwater streams contributed up to 50% of the discharge for the higher order tributaries of the Attawapiskat River (Orlova and Branfireun, 2014), while also accounting for a significant portion of the baseflow in both low and higher order tributaries (Richardson et al., 2012). Working in the same region, Balliston and Price (2022) showed water table and streamflow connectivity thresholds in patterned bog-fen-tributary systems. The hydrological connectivity of the bog-fen-tributary complex was observed to be highly seasonal and influenced by variable meteorological conditions (Balliston and Price, 2022). During winter, snow accumulates and the near-surface peat freezes, leading to increased lateral hydraulic flow at the expense of drainage from deeper layers. Snowmelt runoff can be influenced by snowpack properties such as highly heterogenous snow cover, variable snow depths and densities, and the energy budget during the melt period (R Brown et al., 2021). Some portion of snowmelt runoff in the spring replenishes groundwater storage and contributes to peak runoff. Summer drying disconnects aquatic nodes, while in the early fall connectivity is restored before winter freeze- up and snow accumulation. Abnormally warm or cold spring periods significantly impact landscape connectivity, affecting the timing of snowmelt, peak runoff, and overall water table dynamics. Greater temperature fluctuations and longer unfrozen periods may lead to increased evapotranspiration, desynchronized snowmelt and frost thaw, and greater peatland drainage. These changes could influence frost table dynamics, species composition, and decomposition rates, potentially limiting the system's ability to buffer other changes like drought.

A comprehensive evaluation of flood frequency and low-flow conditions for the river systems was completed in 2013 (OMNRF, 2013). They used historical streamflow records from the Water Survey of Canada HYDAT database and applied statistical methods to assess flood magnitudes and drought severities across different recurrence intervals. Based on the flood and low flow analyses, the Hudson Bay Lowlands dominated by low relief and poor drainage of wetlands and peatlands have slow response to rainfall and snowmelt which can affect both floods and droughts. However, the Canadian Shield Areas characterized by greater relief and rapid runoff due to thin soil cover over bedrock show more variations in flood magnitudes and seasonal discharge patterns.

Table 9. Streamflow characteristics and trends for major rivers in the Territory (study area).

River	Drainage Area[1] (km^2)	Length (km)	Hydrological Regulation Status	Mean Annual Flow (km^3/y)	Historical Streamflow Trend[4]	Modelled Streamflow Trend[5]
Harricana	21,200	498	Unregulated	7.75	Less than 1% increase	Poor model performance
Moose	98,530	607	Highly regulated[2]	39.01	~17% decrease	Slight increase (especially during winter)
Albany	118,000	982	Partially regulated[3]	31.77	~7% increase	
Attawapiskat	36,000	748	Unregulated	11.43	~13% decrease	Significant increase, almost double that of regulated rivers, except poor model performance for Ekwan River
Ekwan	16,900	545	Unregulated	2.76	No trend observed	
Winisk	54,710	582	Unregulated	15.24	~15% decrease	
Severn	94,300	982	Unregulated	21.9	Less than 1% increase	

[1]Drainage area is based on the HYDAT database, which is different from ARCADE or OWB-OLRRP datasets, as well as the scientific literature, including Déry et al. (2016).
[2]Hydroelectric dams on Abitibi and Mattagami Rivers regulate streamflow.
[3]Upstream hydroelectric dams impact flow patterns.
[4]Streamflow trend is based on historical data between 1964-2013. See Déry et al. (2016) for more information.
[5]Streamflow trend modelled via A-HYPE for 2021-2070 time period (Stadnyk et al., 2021).

Trends

According to a large-scale, pan-Arctic summary, freshwater discharge from Canada's northern rivers showed an increase in annual discharge of 36 km^3 between 1964 and 2015 (Shiklomanov et al., 2021). Seasonal trends included increases in winter and spring but may reflect a combination of climate-related changes, alteration by human activities and reservoir regulation (Shiklomanov et al., 2021).

A more comprehensive analysis of historical trends in Canadian Arctic streamflow was conducted by Déry et al. (2016), based on discharge data from 42 downstream gauging stations between 1964 and 2013. Figure 17 illustrates these results according to season. The snow-dominated river systems in western James Bay showed strong seasonality, with minimal flows in winter when discharge averaged ~50 km^3/year. Peak flows occurred in spring (approximately 120 km^3 per year) due to snowmelt and remained relatively high into summer (~100 km^3 per year). River flows were lower in fall than summer at about 90 km^3/year, influenced by synoptic-scale storms and associated rainfall. In terms of temporal trends over 1964-2013, differences were noted between regulated and unregulated rivers. Regulated rivers (e.g., Moose and Albany) showed positive discharge trends in winter, possibly due to controlled release from hydroelectric reservoirs. However, unregulated rivers (e.g., Attawapiskat and Severn) also exhibited small positive increases in discharge in winter (Figure 17). Several rivers in the territory showed small negative trends in discharge for the summer period.

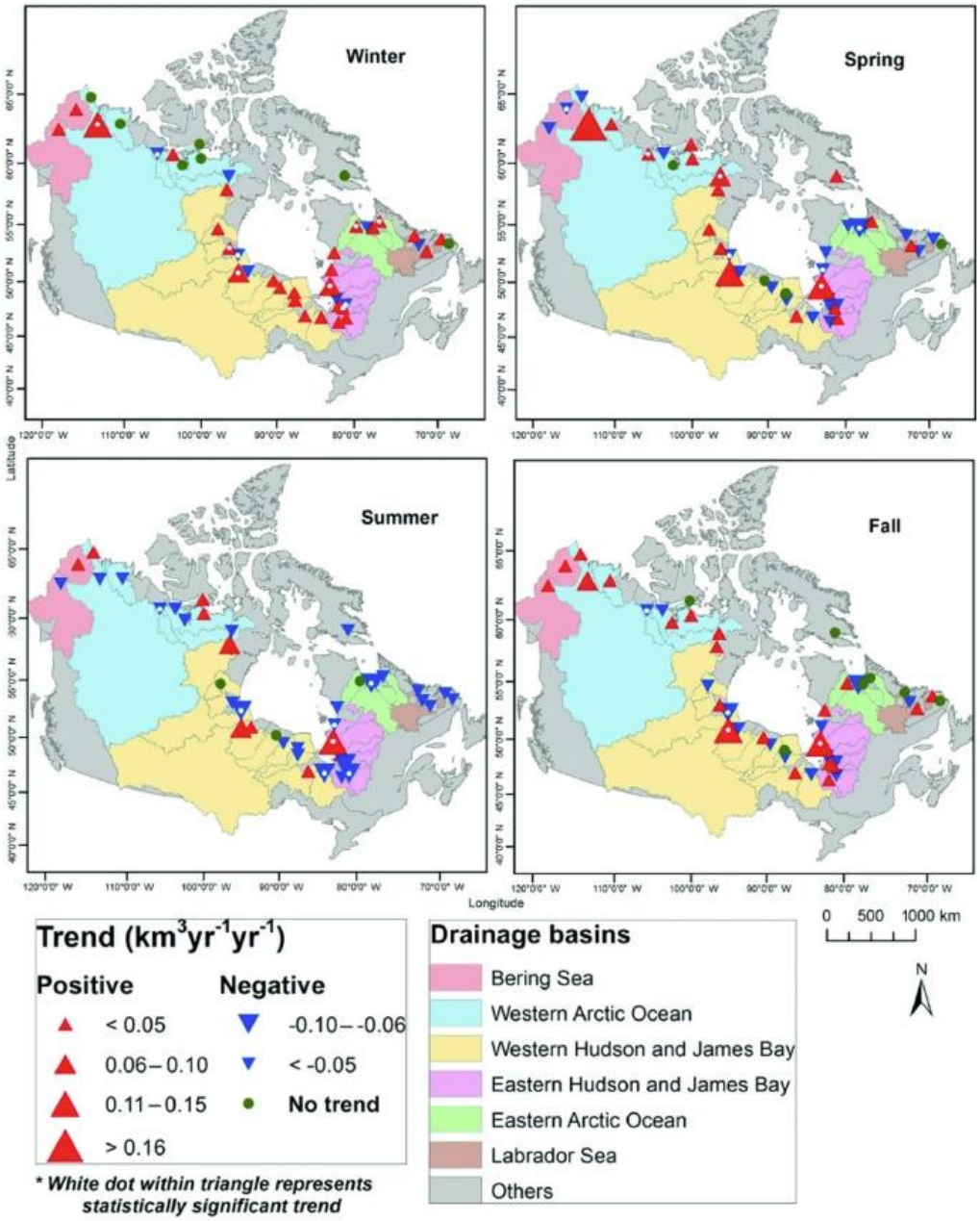

Figure 17. Seasonal discharge trends for select drainage basins flowing toward northern Canada (modified from Déry et al., 2016).

Anthropogenic water management tends to flatten the hydrograph, decreasing discharge differences between winter and summer. Interannual differences in water discharge are also flattened by flow regulation (Déry et al., 2018). Two regulated complexes, the Nelson–Churchill River Basin and the La Grande River Complex, have been subjected to more explicit regulation modeling in cooperation with industrial partners (Manitoba Hydro and Hydro-Québec, respectively) (Stadnyk et al., 2021). To our knowledge, the same kind of modelling effort has not been completed for the Moose River basin. According to Déry et al. (2016), the reservoir volume (as of 2013) in the Moose River system was only 2.1 km^3, which is small compared to the river's

mean annual discharge of 39.01 km^3/yr and may thus partially alleviate the flattening of the hydrograph seen for other regulated rivers.

Increases in terrestrial freshwater discharge from pan-Arctic watersheds are projected by most studies, with some trends almost doubling by 2070 and an overall average increase in streamflow of 22% (Stadnyk et al., 2021). This implies a trend reversal for rivers in the western James Bay watershed that showed decreasing trends during recent decades.

Extreme events related to hydrology

Drought

Drought conditions in western James Bay are variable, with some basins showing greater resilience due to wetland storage. However, the decreasing moisture flux convergence from 2009 to 2018 which consequently reduced precipitation may have included drought events with increased evapotranspiration, particularly during the warm season (Champagne et al., 2021; Champagne et al., 2023). Peatlands, which are divided into fens and bogs, can show different responses to drought in terms of the position of water table, photosynthesis rate, root respiration, and the decomposition of organic matter. Prolonged drought can cause plant moisture stress, reduced microbial activity, and increased fire risk (McLaughlin and Webster, 2014).

Flooding

Climate simulations indicate that inland flooding is primarily linked to rapid spring ice melt, elevated river water levels, and intense rainfall. Floods are relatively frequent in the flat coastal landscapes; a 100-year flood event of the Moose River in spring 2018 occurred just three years after another 100-year flood in the same watershed. According to Indigenous Knowledge, spring flooding occurred seasonally over many generations in Kashechewan First Nation within Mushkegowuk Territory. However, the timing and extent of spring flooding has changed in recent years with warming temperatures in the region. These changes include earlier spring, snowmelt, and rapid runoff. The flooding risks for coastal communities has become more severe in recent decades in part due to anthropogenic factors (Litvinov, 2021). In Kashechewan, community members have described factors contributing to flood risks including inadequate infrastructure, a substandard ring-shaped dyke wall, and the downriver winter ice road. Kashechewan has seen elevated flood risks with the increased frequency and scale of spring ice breakup-related ice jams. As a result, the community has faced 14 evacuations since 2004, with consecutive evacuations from 2004-2008 and 2012-2019 (Khalafzai et al., 2019).

Information about the ice regime on the rivers with outlets in western James Bay and southern Hudson Bay is very limited in comparison to eastern and southern James Bay. Historically, the minimum monthly runoff rates for all James Bay rivers occurred during the winter months and maximum values happened during the spring freshet. The rivers in western James Bay experienced a secondary runoff maximum during the late fall as well (Prinsenberg, 1977). However, human disturbances and climate change may intensify flood events due to regulating river discharge and shifting precipitation patterns, respectively, especially for the rivers with Q10/Q90 ratio over 10 indicating high variability and risk of flood such as Albany, Pagwachuan,

Shamattawa, Kwatabohegan, Kapuskasing, and North French (See Hydrological characteristics in major sub-watersheds in Appendix A for more details).

Snow hydrology

Seasonal snow covers the Territory's watersheds for about 6 to 7 months of the year and plays a critical role in energy and water exchanges. For example, large energy inputs during the thawing season cause the snow water storage to melt over a short period of time. This generates a rapid pulse of fresh water within the watersheds with effects on lake ice melt, surface hydrology, ground thermal regime, permafrost, carbon cycling, and many ecosystem services (Brown et al., 2021).

As warmer temperatures affect snowfall-rainfall partitioning, promoting Rain-On-Snow (ROS) events, the ROS events may amplify the snowmelt-driven peak flows. Additionally, the occurrence of mid-winter river-ice breakup events and ice-jam floods may increase (Shrestha et al., 2021). Therefore, Flood frequency estimates are critical for infrastructure planning, including culverts, bridges, and water supply management.

Challenges

Watersheds are not well delineated

Watersheds can be defined and delineated in many ways. Prominent within the Territory are the seven major rivers: the Harricana, Moose, Albany, Ekwan, Attawapiskat, Winisk, and Severn - that drain watersheds of between 418,440 and 471,233 km^2 and discharge into the marine environments of western James Bay and southern Hudson Bay. Other data sources distinguish the Upper and Lower Albany Rivers, and the major tributaries to the Moose River, including the Abitibi and Missinaibi-Mattagami (WWF, 2020). According to the ARCADE database, there are as many as 400 separate sub-watersheds of various sizes within the Mushkegowuk Territory (Speetjens et al., 2023). To compile this database, researchers used several global and Northern Hemisphere databases such as ERA-5, GLMS, CGLS-LC100, SoilGrids, etc. They then extracted data for more than 300 variables. Some of these data have been used in different sections of this report to represent the most updated conditions of the watersheds within the western James Bay region and Mushkegowuk Territory. However, it is a caveat regarding whether the data sources are well validated by in situ observations.

Physical processes driving hydrologic change

With a view to better understanding the hydrology in these watersheds, there is a need to consider the physical mechanisms driving hydrological changes. These processes that drive hydrologic change are not well understood. Six possible studies to improve understanding of the implications of these processes were proposed by Yang and Kane (2021). The first suggestion is the experimental investigation of interaction between surface and groundwater, particularly in the permafrost and transition zones. The second is to extend in-situ monitoring networks for water discharge and water quality. The third is to apply and expand the scale of remote sensing efforts in these remote regions. The fourth is to apply, calibrate, and evaluate hydrological models for better representation of physical processes at different scales. The last two proposed studies are to conduct a set of coupled experiments with atmospheric, oceanic, and

hydrological/permafrost models to better quantify causes of changes in river flow to the James Bay; and to propose a model to include human activities such as hydroelectric development into all those natural interrelated elements discussed in previous objectives (Yang and Kane, 2021).

Water Quality in Rivers and Lakes

Significance

Water quality is a general term used to describe the state of water in a water body (lake, river, or stream) as it relates to human, organism and overall environmental health. Various water properties can be measured to assess water quality depending on the specific question or concern, including water temperature, dissolved gases, nutrients, carbon content, turbidity or concentrations of suspended sediment, water colour, water clarity, and contaminant levels. Climate and geological characteristics of the drainage basin, which determine flow regime, land cover and soils, influence a river's water quality in a natural system. Land use patterns and development may also alter aspects of water quality.

Water quality information may be collected as part of required reporting for developers or for baseline studies aiming to characterize natural or current states of river and lake ecosystems. The Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 1999) were created to protect all aquatic life and provides toxicity benchmarks for various elements and chemicals. These guidelines are useful when comparing results from water quality reports that may be required as part of operating licences issued to developers. Context of the natural and geologic condition is needed to identify levels of elements that are naturally occurring in the environment to understand the impact of disturbance. For example, some elements can naturally occur in the environment above the recommended guidelines because of the soil and bedrock. Baseline datasets and continual monitoring can be helpful in identifying changes in the environment and help anticipate what trends are expected in the future. Water quality analysis is recommended to be included in aquatic ecosystem assessments of rivers in Ontario (Metcalfe et al., 2013).

The term 'water quality' sometimes is used to refer to parameters that are not a particular concern for the health of the water body, per se, but are monitored primarily because of their importance for downstream marine receiving water bodies, or because certain parameters act as good indicators of changes in a watershed that might be otherwise impossible to detect. Because streams and rivers are the major transporters of carbon, nutrients, sediments, and other materials from land to the oceans, water quality data is often used to quantify land-ocean fluxes (Syvitski and Milliman, 2007; Rosa et al., 2012a). Water quality parameters can provide evidence of carbon release due to permafrost thaw (Wauthy et al., 2018) and also provide insight into stream processes, such as organic matter production, destruction, and burial, and other important reactions (Cole et al., 2007; Ward et al., 2017).

State of water quality as it relates to environmental health

There is limited water quality data available for the Territory's lakes and rivers, and the distribution is biased towards sites of past and present development. The data sources include

peer-reviewed research, pre-development baseline and performance monitoring completed by industry, and river and stream water quality monitoring collected by the Province of Ontario.

Community- and regional-based monitoring

Community initiated water quality monitoring is invaluable when it comes to filling data gaps in both time and space. For example, a monitoring program for water quality has been developed by Moose Cree First Nation within the Moose River watershed. Water samples for a suite of water properties have been collected at rivers and streams within the Moose Cree First Nation Territory. Seasonal water sampling has been a priority, especially along the winter roads, to monitor for potential contamination. In addition to contamination, seasonal sampling for water quality at these rivers may indicate natural seasonal shifts, or a changing environment. The more data points that are available at a location, the more likely it is to identify important environmental events.

Reports have been commissioned by Mushkegowuk Council since the 2010s in order to establish a baseline for the environment and the major rivers within the Territory (Litvinov, 2016; Litvinov, 2018; Litvinov, 2019; Litvinov, 2020; Litvinov, 2021; Litvinov, 2022; Litvinov, 2024). These reports are a primary step to establishing baseline information prior to and during development in the region, especially with regards to the Ring of Fire area in northern Ontario.

Other community-based or community-led programs to assess and establish baselines for water quality have been started in recent years. Peawanuck (Weenusk First Nation) and the University of Manitoba have been collecting baseline water quality data and developing a sustainable community-based monitoring program since the summer of 2023. Interest for monitoring programs has become more prevalent in recent years with the ongoing discussions of development and what impacts it may have on the water quality in the region (as heard during events such as the Mushkegowuk Research and Knowledge Sharing Summit, November 2024).

Provincial monitoring and reporting

Figure 18 shows the distribution of all river and stream water quality stations and associated data that is available for extraction from the Provincial (Stream) Water Quality Monitoring Network - Dataset - Ontario Data Catalogue. The data span 2000-2019; historical data files prior to 2000 (i.e., 1964-1999) have been removed as of May 2025 while there is ongoing work on the site. Of about 60 stations (sampling sites) within the greater watershed region, only data from eleven are presently available and none from the Winisk or Severn watersheds. The water quality parameters in the data set include nutrients, inorganic and organic carbon, alkalinity, chloride, conductivity, and metals such as aluminium, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, molybdenum, nickel, strontium, vanadium, and zinc. Although, each station does not necessarily include results of all the listed properties above. The data are very sparse considering each station on the map represents typically a one- or two-time collection of samples, most often in the 1980s. There are no stations where regular systematic sampling took place nor currently take place. All but three stations in the region (located near Timmins) are inactive. Another shortcoming is methods/detection limits for some elements. For example, mercury and selenium are below detection limits (5 ug/L and 1.67 ug/L) in all the available reports

on the website. The detection limit is reflective of the scientific instruments in use to analyze samples, and often, for some elements such as mercury and selenium, more specialized equipment is needed to properly assess concentrations.

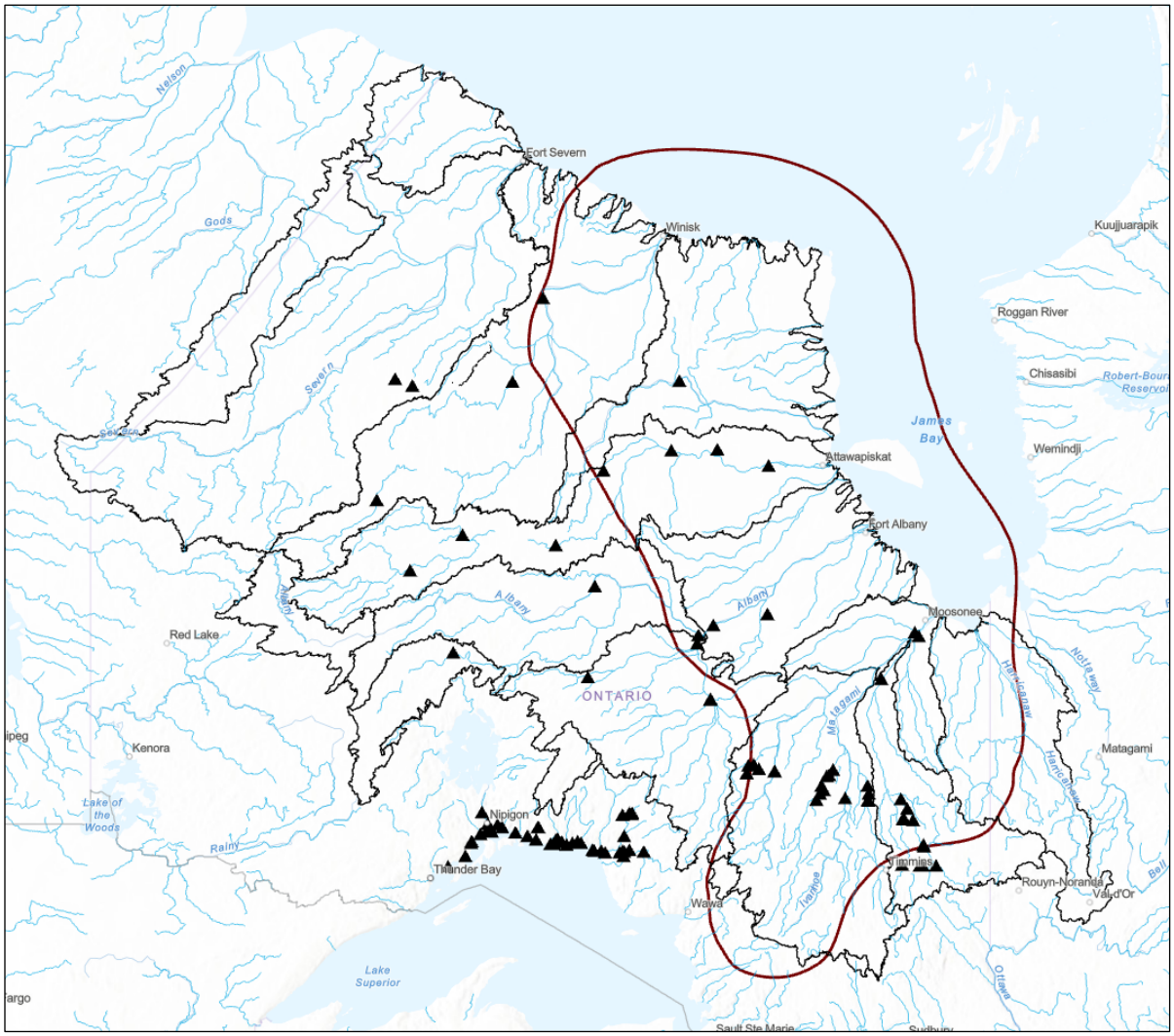

Figure 18. Location of active and inactive river and stream water quality stations (black triangles) within the western James Bay region in the Provincial (Stream) Water Quality Monitoring Network: [Map: Provincial (Stream) Water Quality Monitoring Network | ontario.ca]

Peer-reviewed scientific research

Comprehensive studies of water quality from the perspective of environmental health in this region have scarcely been published in the scientific literature. However, the literature that has been published offers a glimpse at the overall water quality of the region and encourages further studies to be pursued, especially with looming development activities that may alter the water quality of lakes, rivers and streams.

General water quality

Studies that focus on topics such as benthic biodiversity, or contaminant levels in wildlife (particularly fish), often have some form of simple water quality sampling to complement their study such as recording conductivity, alkalinity, pH, water temperature, dissolved oxygen,

dissolved organic carbon, and nutrients (Jones et al., 2014; Lennox et al., 2018; Lescord et al., 2019). These results, despite not being large datasets, provide some context for the associated studies, but also provide potential comparison data for other dedicated water quality studies.

Macronutrients

Macronutrients, such as nitrate, phosphate, and silicate, are essential for photosynthetic growth. Thus, measuring nutrient concentrations in water bodies can inform on the productivity of a system and potential export of production to the food web or harvestable resources.

Watershed characteristics, such as underlying geology, climate differences, and the seasonal flow cycle have been highlighted as important influences to nutrient concentrations and water quality in general (McCrea and Merriman, 1981; Lee et al., 2023a). Nutrients tend to be found in higher concentrations on the western side of James Bay because of limestone bedrock, rich organic soil and presence of wetlands/peatlands, compared to the eastern side that has Canadian Shield characteristics (Lee et al., 2023).

There have been few studies focusing on macronutrients in rivers and lakes in the Territory, however, studies with a larger geographic scope have been published. For example, Lee et al. (2023) presented nutrient inputs from subarctic rivers into Hudson Bay. The Severn and Winisk Rivers were included among nine rivers discharging into Hudson Bay and James Bay chosen to assess nutrient fluxes. Models were used in this specific study to estimate average seasonal and annual discharge and associated nutrient fluxes (nitrate plus nitrite, phosphate and silicate)(Lee et al., 2023b). Lee et al. (2023) suggests that in comparison to La Grande River, which has the second highest annual discharge, and nitrate flux to the Hudson Bay system, the Severn had larger annual phosphate and silicate fluxes.

More locally, nutrient concentrations of the Moose River, some of its tributaries and other streams within the Moose Cree Territory have been seasonally monitored in recent years by Moose Cree First Nation technicians, and with added support from the University of Manitoba. Some of the first nutrient (particulate nitrogen, total Kjeldahl nitrogen, and total phosphorus) data for this area came from work done in 1977-1978 (McCrea and Merriman, 1981). This report established that in this area, nutrient concentrations were strongly impacted by flow of the rivers and streams, where spring runoff diluted concentrations and associated bank and bottom erosion resulted in increased concentrations, dependent on the sediment composition (McCrea and Merriman, 1981).

Carbon

Many forms of carbon can be measured in lakes and rivers. Carbon can be transported in different forms and impact ecosystems differently, e.g., as particles, or dissolved in the water, which can alter the colour and taste of the water.

Early work (e.g., Lapierre and del Giorgio, 2012) showed that there is a complex interplay between geographical gradients, lake trophic status, and the associated metabolic balance in determining dissolved organic carbon (DOC) and partial pressure of CO_2 (pCO2) dynamics in northern lakes. Lake position in the landscape determined the contribution of terrestrially

derived CO_2 to total lake pCO_2 but the pCO_2-DOC relationship was variable and related in part to relative concentrations of total phosphorous.

Rodríguez-Cardona et al. (2023) showed widespread browning of northern lakes is associated with long-term increases in DOC and colour. They believed that these two carbon components should also reasonably be linked to changes in surface water carbon dioxide levels (pCO_2). They found that the highest rates of change in colour and carbon dioxide were in lakes with increasing DOC trends. Lakes with low water retention showed greater increases and a stronger relationship between the three parameters, along with terrestrial carbon being the dominant source of carbon. They suggested that increases in coupling of the three components, DOC, colour, and surface carbon dioxide depend on the hydrology and watershed connectivity.

Contaminants

Contaminants in water most often refer to the presence, in amounts that make the water unsafe, of heavy metals such as mercury (Hg) and arsenic (As), or other materials like pesticides, chemicals, gasoline, and oil, among many other substances. Contaminants may be either naturally occurring in the environment or may be a result of anthropogenic pollution. Metals are naturally occurring, however, natural or human disturbance to an environment may increase concentrations which in turn may have negative implications for animal, plant, and human life. Some elements, that are viewed as contaminants, may naturally occur in the environment at high levels because of the geologic condition. This reinforces the need to investigate and understand baseline concentrations in specific areas, especially if it is a place where animals and people are using the water. Baseline measurements are also important for monitoring and identifying environmental change with development and environmental disturbances.

Lescord et al. (Lescord et al., 2019) documented Hg patterns across the Attawapiskat River watershed, sampling 43 rivers and lakes within the watershed. Their sites varied from boreal shield lakes, Hudson Bay Lowland lakes, and rivers. It was determined that aqueous and biotic Hg concentrations were strongly linked to DOC and nutrient concentrations. Total phosphorus was shown to be a positive predictor in some aqueous and biotic mercury concentrations. It was also suggested that there is an indirect relationship between Hg concentrations and nitrogen cycling and thus they suggest that monitoring programs and studies consider spatial differences in physicochemical properties when assessing trends in Hg cycling. In the Moose River watershed, among other common water quality properties, Hg and other contaminants are seasonally measured through the Moose Cree First Nation monitoring program.

Despite limited peer-reviewed literature about water quality in this region of interest, there have been studies conducted in the adjacent areas of Eeyou Istchee and the area of the Hudson Bay Lowlands located within Manitoba. Recent publications describe nutrient, sediment, and carbon concentrations and loads in rivers draining into the eastern side of James Bay in boreal Québec (De Melo et al., 2022; Évrard et al., 2023). Major ions, strontium (Sr), neodymium (Nd), uranium (U), and dissolved organic and inorganic carbon concentrations were measured in the Nelson River in Manitoba and the La Grande and other rivers in Québec (Rosa et al., 2012a; 2012b). Rosa et al. (2012b) found that rivers from boreal Québec had dramatically different

concentrations of most elements compared to those draining the HBL owing to regional differences in watershed geochemistry. For example, the rivers of the Canadian Shield had concentrations of major cations ranging between 62 and 360 µmol L^{-1} and Nd of 0.57–4.72 nmol L^{-1}. The Nelson River had higher major cation concentrations (1200–2276 µmol L^{-1}) than the Shield rivers but lower Nd (0.14–0.45 nmol L^{-1}). Spatial variations in riverine uranium (U) concentrations were also attributed to lithological control, with rivers draining sedimentary rocks (with abundant carbonates) having overall higher U contents and lower 234U/238U variability than the rivers of the Canadian Shield (Rosa et al., 2012b). Dissolved organic carbon (DOC) was an exception as concentrations varied widely among the studied watersheds (241–1777 µmol L^{-1}). The Nelson River had intermediate DOC concentrations (753–928 µmol L^{-1}) indicating that lithology was not a primary control.

Another study, primarily in the Eeyou Istchee, presented concentrations and yields of total mercury (THg) and methylmercury (MeHg) of 18 boreal rivers draining watersheds in northern Québec, including the Harricana River (Fink-Mercier et al., 2022). Samples were collected seasonally from summer 2018 to summer 2019. They found that variability was largely explained by land cover, specifically wetlands, where higher Hg concentrations and yields were associated with higher water and wetland coverage in the watersheds. Seasonality modulated the relationship between landscape properties and Hg forms (Fink-Mercier et al., 2022). They used data from de Melo et al. (2022) to estimate annual mercury fluxes for the whole eastern James Bay set of watersheds at 441 kg Hg and 14.6 kg MeHg, and average landscape yields 1.24 g Hg km^{-2} y^{-1} and 0.041 g MeHg km^{-2} y^{-1}. The Harricana River had mean concentrations of 0.13 ng L^{-1} MeHg and 3.75 ng L^{-1} total Hg, which was within the range of the other rivers measured along the eastern coast of James Bay. They also reported the mean flux of MeHg (1.97 kg yr^{-1}) and total Hg (65.71 kg yr^{-1}), as well as the yields of MeHg (0.072 g km^{-2} yr^{-1}) and total Hg (2.40 g km^{-2} yr^{-1}). Overall, these rivers are not fully comparable to what is seen in major Arctic rivers, which are often higher in total Hg and MeHg because of elevated concentration of particles and permafrost thaw. Permafrost thaw is, however, much more prevalent in the Hudson Bay Lowlands than the area of this Fink-Mercier et al. (2022) study.

Trends

Water quality properties measured in rivers and lakes typically have natural seasonal cycles, depending on the property, however changes in water quality can also occur as a result of environmental changes such as warming of the climate (implications for permafrost, the ice season, wildfires), and industrial development that physically disturbs the HBL.

Contaminants are a widespread concern both in terms of present-day distribution and sources and possible future changes due to climate change or development. Considering permafrost stores a significant amount of natural mercury, estimated to contain two times as much Hg as the rest of all soils, ocean and atmosphere (Schuster et al., 2018), thawing and physical disturbance will accelerate the release of Hg (Mu et al., 2019; Kirkwood et al., 2021). Wildfires, which have been increasing in frequency and intensity, are also a type of disturbance to be considered. Fires can mobilize mercury or other elements stored in soil and permafrost that alter the bioavailability and toxicity of mercury. While there are currently no specific peer-reviewed

studies that take place in the Territory regarding fire impacts on water quality, some studies have been conducted to assess these impacts in similar landscapes. In the boreal region, and areas where permafrost is present, larger and more frequent fires are affecting watershed biogeochemical processes by changing the chemistry of streams, lakes and groundwater (Turetsky et al., 2011; Tank et al., 2018). Permafrost thaw, as a result of fire, releases previously frozen porewater, and resultant runoff, that contains nutrients, dissolved organics, and contaminants into streams and other water bodies (Gordon et al., 2016; Tank et al., 2018). Studies have shown that impact of fires on stream chemistry will decrease over time (i.e., a stream's water quality may be impacted by a fire 5 months after the initial incident, but after a year there is less evidence of the fire) however, with more frequent fires, water quality will be altered more frequently (Holloway et al., 2020). In terms of peatlands, peatland wildfires ultimately impact the natural Hg mass budget on an annual or even decadal scale, essentially shifting burned areas into a net Hg source, although this has not been studied in detail within the HBL (Zolkos et al., 2024). Mining activities may also mobilize various elements or alter the interactions of elements (e.g., via changing pH or dissolved organic carbon concentrations in water bodies). Consideration of water quality impacts downstream of these initial disturbances is also crucial to understand the full extent of these changes.

The 'browning' of water bodies has been a noted trend globally, especially in the boreal regions of the world. The term 'browning' here refers to the colour intensification of freshwater bodies, including rivers, streams, and lakes, linked to increasing dissolved organic carbon concentrations (Fork et al., 2020; Rodríguez-Cardona et al., 2023). Research on carbon balance and water colour has been conducted in northern Québec boreal lakes by the del Giorgio research team based out of Université du Québec à Montréal, UQAM) (pers. comm.). A larger scale study, analyzing more than 58,000 water samples from Swedish and Canadian boreal and hemiboreal regions, documented an ongoing browning trend, related to changes in iron cycling with faster passage of water through landscapes (Weyhenmeyer et al., 2014).

Other environmental events in boreal regions such as droughts and floods, brought about by both climate change and development, have been known to flush out nutrients from peatlands and may alter the timing of when nutrients are replenished in these systems, ultimately changing the macronutrient cycles, including the carbon cycle (Lescord et al., 2019). Lescord et al. (2019) suggests that a warming climate may mean reduced nitrogen fixation and lower N concentrations which could lower Hg concentration bioaccumulation within the HBL.

Challenges

The main limitations of assessing the water quality of rivers and lakes within the HBL and the Territory are the lack of data, and the biased distribution of sampling locations. Data collection is biased towards areas where development has occurred or will occur, for obligatory environmental monitoring, and Environmental Impact Assessments. For example, Attawapiskat has more water quality reports from industry due to the DeBeers Victor Diamond Mine operations, however these are not typically accessible by the public. In terms of drinking water, water quality should be monitored regardless of development, but environmental work is not usually prioritized by industry unless it must be done for reporting purposes.

More community-based or -led monitoring programs for environmental water quality would help reduce the disparity of data. A study from 1981 (McCrea and Merriman, 1981) highlighted the need for bi-weekly sampling done by qualified locals on the Moose River to generate meaningful baseline water quality data and identify seasonal variations and long-term trends. This suggestion would benefit community-based monitoring programs within the seven major watershed areas being examined in this report, or any water bodies with locally identified importance.

Baseline information would need to be gathered in areas where there has been no sampling in the past, to help identify future changes, related to climate change and development activities. Seasonal sampling is needed, at a minimum, to understand how water quality changes between seasons. For example, Hg has a natural seasonal cycle where baseline concentrations will change throughout the year, this is why it is crucial to have baseline measurements throughout the year and over many different years. This would allow comparisons to be made between seasons and years. Sampling water more consistently throughout the year would be beneficial to identify isolated pollution events that may occur with increased development in the area. Consistency of properties measured, and seasonal sampling, at the very least, are necessary for water quality monitoring programs moving forward. It is worth noting that community capacity is often a challenge in maintain water quality monitoring programs, as such, partnerships with universities and other organizations have been increasing in recent years to support local initiatives.

Fish and Aquatic Invertebrates

Significance

Western James Bay and southwestern Hudson Bay aquatic ecosystems are currently relatively free from disturbance. Many sensitive habitats have remained intact, creating refuges for species that are otherwise endangered (i.e. Lake Sturgeon; Chu et al., 2015; Haxton and Cano, 2016; COSEWIC, 2017; Haxton and Bruch, 2022). Biodiversity encompasses the diversity of species, genetics and ecosystems within a region (Oliver et al., 2015; Vasiliev, 2022) and preserving it is a common target for management (Southee et al., 2021). Benefits of high biodiversity includes reduction of disease spread, improvement of an ecosystem's resilience to stress and invasive species, and can improvement of an ecosystem's ability to respond to and recover from change (Oliver et al., 2015; Vasiliev, 2022).

Human-caused disturbances are increasing on the landscape. Increased air temperatures in turn increase water temperatures, in some cases beyond what organisms in the environment can adapt to (Gunn and Snucins, 2010). The construction of infrastructure such as hydroelectric dams fundamentally changes aquatic habitats and creates barriers for migration (Browne, 2007; COSEWIC, 2017; Cooke et al., 2020). Additionally, as roads increase the human accessibility to previously remote areas, introduction of invasive species that cause ecological harm are expected to expand (Kaufman et al., 2009; Kizuka et al., 2014). For successful management, biodiversity hot spots and key habitats must be identified and protected before disturbance occurs. Without this baseline research, it will be impossible to identify changes in populations and behavior of aquatic organisms (Haxton et al., 2018; Kessel et al., 2018; Farrell et al., 2024).

State

Biodiversity of fish and aquatic invertebrates

Ecosystem wide inventories of freshwater fish species are limited. Some recent efforts in describing the Hudson Bay lowland fish diversity have been completed by the Cooperative Freshwater Ecology Unit (CFEU) based at Laurentian University in Sudbury, Ontario (summarized by Patterson et al., 2020) and by the Ontario Ministry of Natural Resources and Forestry (Goertz and Phoenix, 2015; Lennox et al., 2018). These datasets provide a baseline for fish populations within the James Bay watersheds.

As fish inventories are still limited, we can attempt to estimate freshwater fish diversity and distribution through modeling to inform management decisions. By combining the few available fish diversity data sources, such as those within the Royal Ontario Museum records and Ontario Ministry of Natural Resources and Forests databases, with physical ecosystem properties, such as air temperature, precipitation and landforms, the habitat conditions for various species can be approximated. These habitat conditions can then be used to project the current and future distribution of fish species (Southee et al., 2021). Southee et al. (2021) created models to identify key areas for protection targeting several management goals: preserving lake sturgeon, lake whitefish, brook trout, and walleye populations or total biodiversity. The model's ideal protection areas for total biodiversity overlapped significantly with lake sturgeon, lake whitefish and walleye, but the model for brook trout, a cold-water fish, targeted more northern areas than the other models. Therefore, targeting total biodiversity may miss cold-water fish, so these populations may need to be targeted independently of total biodiversity.

Although modeling can be a helpful management tool, further data is needed to improve accuracy in the southwestern Hudson Bay and James Bay watershed. The handful of physical ecosystem characteristics used by Southee et al. (2021) may miss species specific ecosystem requirements, such as key spawning grounds or juvenile habitat, that, if lost, may irreparably influence that species population. To inform management decisions, further widespread systematic monitoring of distribution and habitat use is required. These studies can identify biodiversity hot spots, such as the Moose-Abitibi River confluence (Lennox et al., 2018), that can focus protection efforts.

Benthic invertebrate biodiversity can be used as an indicator of water body health and has been monitored systematically through the CABIN database (Figure 19). CABIN is a Canada wide standardized methodology and database used as a tool to monitor Benthic invertebrate community changes due to disturbances. As it is most frequently used by hydropower or mining industries to meet ecosystem assessment requirements, the locations in the CABIN database are usually highly disturbed habitats such as the Attawapiskat and Moose River watersheds. Ecosystems with lower industrial disturbance such as the Winisk and Ekwan River watersheds have very limited/no data reported within the CABIN database, leaving holes in the understanding of the biodiversity of the freshwater benthos diversity throughout the HBL.

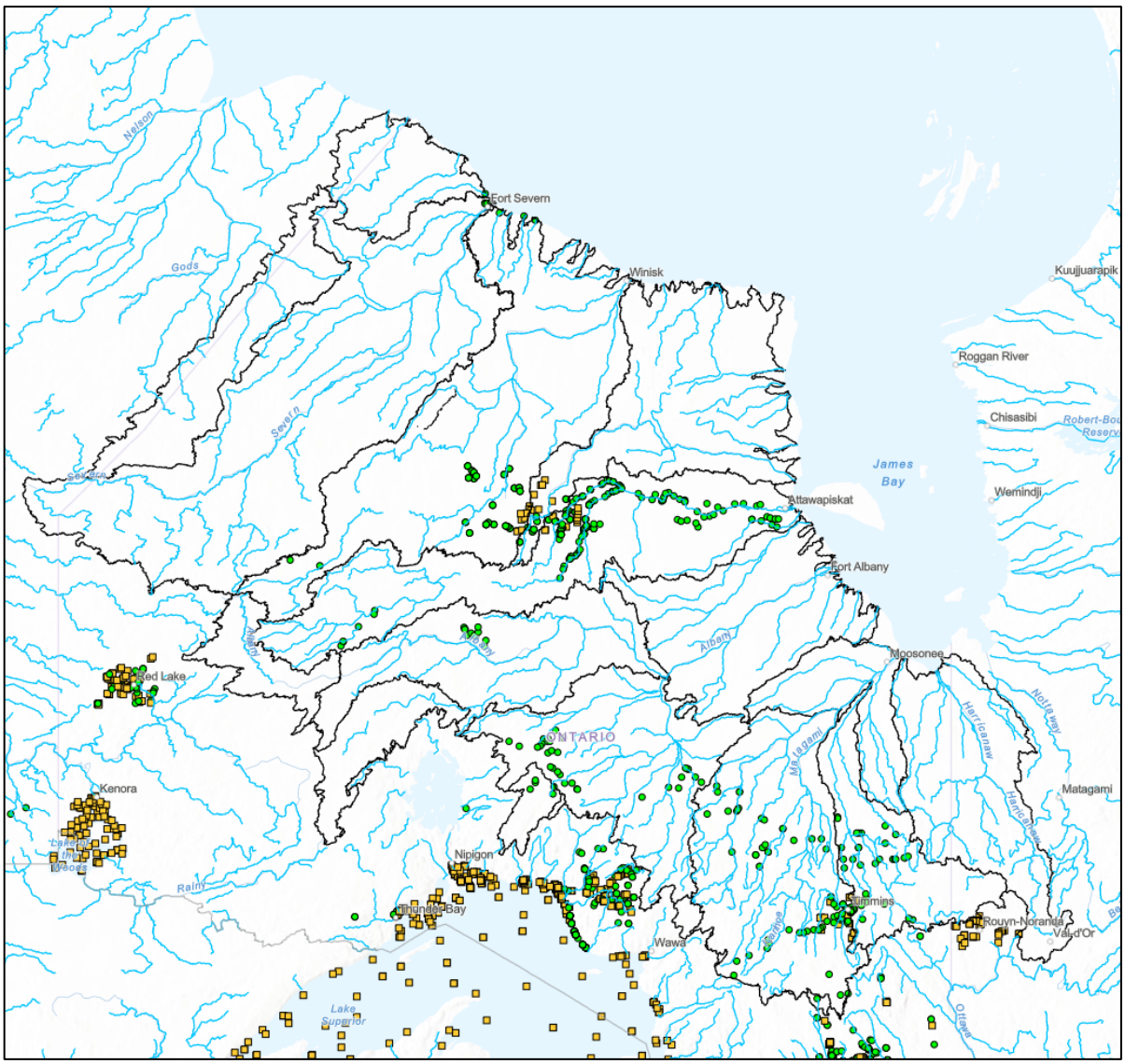

Figure 19. CABIN biomonitoring stations within the western James Bay watersheds: https://open.canada.ca/data/en/dataset/13564ca4-e330-40a5-9521-bfb1be767147 Green circles represent stream sites, and yellow squares represent lake sites.

Contaminants in fish

Fish harvest is a key component of the traditional diet and culture of the Omushkego (Skinner et al., 2013; Tam et al., 2013). Fish within the territory are known to have higher than typical levels of heavy metals such as mercury (Hg), arsenic (As) and chromium (Cr), which may cause significant impacts to human health (Moriarity et al., 2024). Understanding what influences the levels of contaminants in fish and monitoring contaminant levels can empower communities to continue traditional harvest without fear of health risks.

Patterson et al. (2020) compiled the results of several studies completed between 2008 and 2018 by the Cooperative Freshwater Ecology Unit (CFEU) based at Laurentian University in Sudbury, Ontario that examined the concentration of Hg in fish tissue in the HBL. In these studies, large body fish tissue samples were taken from fish in 6 major rivers and 23 lakes to determine differences in the concentration of Hg in fish tissues temporally, spatially and between species.

In all water bodies sampled, some fish were not safe for consumption. They found at a standard size of 1000 g, the differences in mean predicted total muscle Hg concentration between species were as follows: the lowest concentrations were found in anadromous (river spawning) species (brook trout, cisco, and lake whitefish) and in lake sturgeon. Mercury concentrations were slightly higher in benthivores (white sucker, longnose sucker and shorthead redhorse) and piscivorous fish, such as northern pike and walleye. Walleye had by far the highest mercury concentrations of any species in the study, with a predicted total muscle mercury concentration more than double that of northern pike. In comparison to historical data, Patterson et al. (2020) found that the level of mercury in the muscle tissue of lake whitefish, white sucker, and northern pike had not changed substantially since the 1980s, but the concentration in walleye tissue decreased by nearly 27%. As only 3 rivers, the Albany, Moose, and Harricana Rivers, had historical tissue mercury data from 1980, this analysis was restricted to the lower James Bay watersheds.

The difference in fish tissue total Hg concentrations between river stations was dependent on species, specifically for some species, the concentration of total Hg increased along the northwest-southeast trajectory. For others it decreased and for others there was no distinct pattern. This indicates that the concentration of Hg in the waterways themselves may have a smaller influence on the concentration of total Hg in fish tissue than diet shifts between rivers. For instance, trophic analysis showed that sturgeon shift between being detritovores and being piscivores depending on location. As Hg bioaccumulates, small shifts in trophic level can have a large influence on concentration of total Hg in tissues. Along individual rivers, the distance from the coast influenced concentration of total Hg in fish tissue, but the trajectories were dependent on river. For example, in the Attawapiskat River, concentrations of total Hg in fish tissues were higher near the coast than in the boreal ecozone. The reverse was true for the Albany River, where concentrations of total Hg in fish tissues were lower near Fort Albany than 200 km upstream.

There has also been increasing research on other toxic elements in fish tissue. In a study sampling 12 rivers that flow into James Bay of the 10 elements sampled, only Hg, Arsenic (As) and Chromium (Cr) concentrations were found to be above advisory levels (Lescord et al., 2020). They found evidence for the bioaccumulation of Hg, As and selenium (Se) in this region, but not for Cr. Cr concentrations were highest in the Albany, Attawapiskat, and Winisk river mouths. The Attawapiskat and the Winisk River watersheds are known to have Cr deposits (Lescord et al., 2020). It will become increasingly important to track the concentration of Cr in fish tissue as it may increase with increased mining activity. The As concentration in fish tissue was higher in fish collected near the Hudson Bay and James Bay coast compared to inland Ontario, which may be due to the higher background As concentration in marine water and algae (Lescord et al., 2022; Ponton et al., 2022; Kluke et al., 2023). How toxic As is depends on its form – inorganic As is much more toxic than organic As. Current recommendations for safe As levels for consumption assume 10-20% of As is inorganic (Lescord et al., 2022). In fish collected along the Attawapiskat River, there was no inorganic As detected, rather all As that was detected was organic (Lescord et al., 2022), indicating that fish may be safe for consumption even if high levels of total As is detected.

It is well documented that Hydroelectric dams increase bioaccumulation of Hg in fish for the first several years after impoundment before returning to background levels (Bilodeau et al., 2017). In the Moose River, it was found that the concentration of Hg was below what they would expect to impact sturgeon health and, when comparing impounded versus reference sites, that the hydro impoundment did not significantly affect total Hg or methylmercury (MeHg) concentrations in sturgeon blood. In fact, sturgeon from the undisturbed North French River had the highest mercury concentrations. Instead of impoundment, fish length, and to some extent trophic level, was a stronger predictor of Hg concentrations (Lescord et al., 2024). Because of the large ranges of sturgeon, comparing Hg levels to a baseline before the dams were built would have been more informative. Patterson et al. (2020) found that large, bodied fish from the Moose River (the most hydroelectrically developed river in this region) did not have notably higher levels of Hg than the other the rivers in the James Bay watershed.

Climate impacts

Particularly warm years or events (heat waves) are known to have impacted aquatic species including fish populations in the HBL. For example, in 2001, increased water temperatures within the Sutton River and its headwater lake (Hawley Lake) led to the mass mortality of anadromous brook trout (*Salvelinus fontinalis*). This fish die off was attributed to thermal stress caused by abnormally high summer air temperatures which caused unusually warm waters (Gunn and Snucins, 2010). This finding aligns with the abrupt marine climate shift reflected in ice loss and marine heat waves described above. Indeed, Gunn and Snucins (2010) note that the Sutton River mouth is influenced by heavy onshore winds and currents throughout much of the year that force cold seawater to the mouth of the river, making the lower reaches of the river susceptible to southern Hudson Bay surface water temperature variability. The southwestern coast of Hudson Bay can be the first or the last area to have sea ice and correspondingly exhibits high variability in sea surface temperatures (Galbraith and Larouche, 2011). In spring 2001, snow and ice disappeared early, air temperature at Peawanuck, ON exceeded 25°C for at least 17 days and reached a maximum of 30°C during the week of the observed brook trout mortality. Along with changing marine conditions, such as reduced ice and warmer coastal waters, the fish die-off may also have been partly caused by thermal stratification in the historically cool, wind-mixed waters of upstream Hawley Lake. The remaining fish were only observed in the cooler waters near the river mouth. This example shows the impact a shift in climate, or a sudden, unpredictable weather event can have on vulnerable species that are not able to adapt quickly enough.

Habitat fragmentation

For Lake Sturgeon, which is an endangered species (Haxton and Bruch, 2022), dam construction can cause separation from or destruction of key spawning habitat and cause injury or death due to entrainment and impingement (Haxton and Cano, 2016; COSEWIC, 2017; Cooke et al., 2020). Due to their life history strategy, sturgeon are particularly sensitive to fragmentation (Haxton and Cano, 2016; Arantes et al., 2019; Cooke et al., 2020). They have long migrations with specific habitat requirements for reproduction and recruitment (Browne, 2007; Haxton and Cano, 2016; COSEWIC, 2017; Cooke et al., 2020). Additionally, they are periodic (i.e. large, long lived, late sexual maturity, lots of offspring with low parental care) and therefore are particularly

slow to recover from population decline (especially with loss of larger individuals) and fragmentation (Browne, 2007; COSEWIC, 2017; Arantes et al., 2019).

Northern Ontario has one of the last and largest un-fragmented populations (Browne, 2007; Haxton and Cano, 2016; Haxton and Bruch, 2022), but much is not known about their population and behavior. Although they are present, there is no data on the population size in the Winisk, Severn, and Harricana Rivers (COSEWIC, 2017). Although population estimates exist for the Attawapiskat, Albany and Moose Rivers, these records are overall dated and trends in their population sizes are not confidently established (Browne, 2007; COSEWIC, 2017). Additionally, much is unknown about the migrations and key spawning grounds unique to each waterway (Browne, 2007; COSEWIC, 2017). As behavior and population size changes with fragmentation, identifying baseline lake sturgeon behavior and population levels is necessary in order to identify, and correct changes after fragmentation due to dam construction occurs (Haxton et al., 2018; Kessel et al., 2018; Farrell et al., 2024). Some recent studies in the region have begun to fill these knowledge gaps. In these undisturbed rivers, such as the Attawapiskat River, sturgeon have been observed using a variety of habitats covering long distances over their lifetime (Haxton et al., 2018). Additionally, the "Learning from Lake Sturgeon" project, a collaboration of WCS and The Moose Cree First Nation, has found that sturgeon movement rates and daily distances in the undisturbed North French River was higher than that of the nearby, highly fragmented Mattagami River (Farrell et al., 2024). This research group plans to continue monitoring the populations in these two rivers.

Invasive species

Invasive species are species that are non-native and cause economic or ecological damage. The tracking of the spread of invasive species is currently done through the Early Detection and Distribution Mapping System (EDDMapS) in Ontario (OMNRF, 2023). This program relies on reports from volunteers and therefore most of its data is incidental observation. Provincial level systematic and risk based sampling is lacking (OAGO, 2022), therefore many high risk species are spreading unnoticed, especially in more remote areas such as the southwestern Hudson Bay and western James Bay Watershed.

Fish invasive species are often introduced intentionally as game species or unintentionally as bait species. In fact, accessibility (i.e., to fishers) is one of the main predictors for fish invasions (Kaufman et al., 2009; Kizuka et al., 2014) and over exploitation (Kaufman et al., 2009; Wilson et al., 2020). In studies completed by Goertz and Phoenix (2015), Lennox et al. (2018) and Patterson et al. (2020), there were no invasive fish species captured, but there have been reports of smallmouth bass (*Micropterus dolomieu*) and rainbow smelt (*Osmerus mordax*) in the Territory's watersheds. Rainbow smelt are present in the Hudson Bay drainage basin including the Nelson River system in the Manitoba portion of the HBL (Rooney and Paterson, 2009). According to Ontario government sources, these species have been captured in several locations in the this area (Figure 20) (https://www.ontariofishes.ca/home.htm), and are predicted to become an anadromous population in Hudson Bay (Coad and Reist, 2018). Although rainbow smelt can serve as an important forage species for piscivores, they are also believed to compete with and prey on juveniles of some native species such as cisco, lake whitefish, and walleye (Loftus and

Hulsman, 1986; Evans and Loftus, 1987; Mercado-Silva et al., 2007; Patterson et al., 2020). Smallmouth bass could have negative effects, both through predation and competition, on important food and forage species (MacRae and Jackson, 2001; Van Zuiden and Sharma, 2016). As access increases in these major watershed areas, invasive species will become an increasing issue. This includes invasion by species that are present within the Laurentian Great Lakes through unintentional introduction via boats and other anthropogenic activities within the water system. Several models have shown that this region is at moderate risk for Zebra and Quagga mussel establishment if invasion occurs (DFO, 2022). Additionally, with such a broad range of acceptable environmental conditions for survival, spiny water flee (*Bythotrephes longimanus)* is well suited to invade many northern lakes which themselves include a wide range of pH and humic conditions, as well as a wide range of maximum summer temperatures, largely dependent on depth and latitude (Johannsson, 2007). Further work is necessary to determine the species of high concern for each river's watershed and to monitor the introduction and spread of those species.

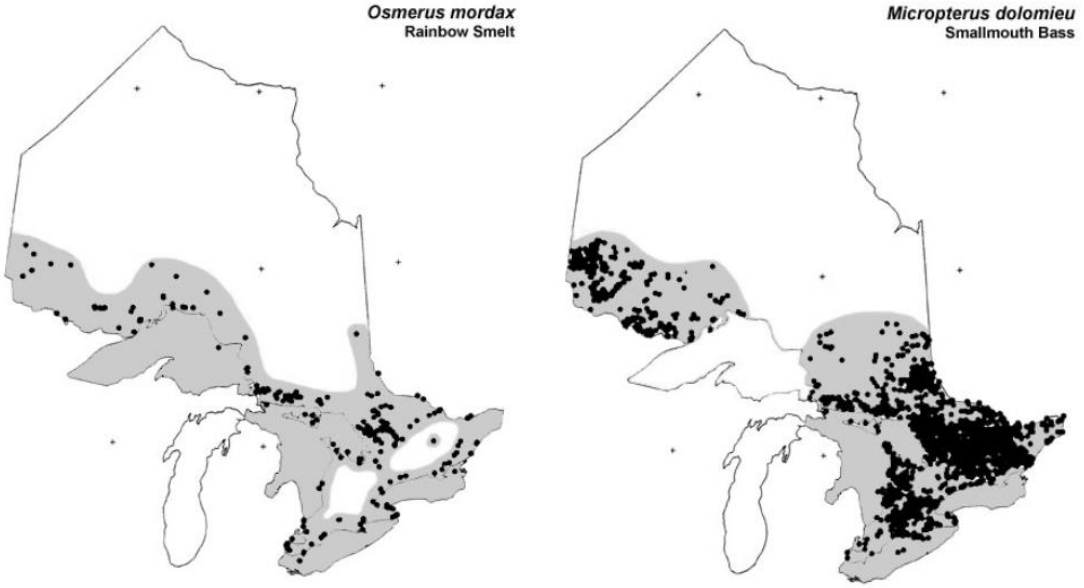

Figure 20. Capture locations of Rainbow Smelt and Smallmouth Bass in Ontario. (https://www.ontariofishes.ca)

Appendix A: Hydrology for Specific Watersheds

The structure and hydrology of all the major watersheds in the Territory reflect typical shield-to-bay drainage transitions with a strong lake influence in the headwaters. However, the hydrology of the region's major watersheds is distinct. The surface areas of the watersheds vary from 16,900 km^2 for the Ekwan to 118,000 km^2 for the Albany (Table 10; adapted and modified from data presented in Déry et al. (2016) and Kuzyk and Candlish (2019)). The Moose River is ranked second largest in terms of watershed area behind the Albany River but the Moose River has the largest flow discharge (39.0 km^3/year) indicating higher yield. This appendix contains brief descriptions of the hydrology of the seven major watersheds. Maps show the stream networks and designated protected areas.

Table 10. Characteristics of seven major rivers in the southern Hudson Bay - western James Bay study area (adapted and modified from data presented in Déry et al. 2016 and Kuzyk and Candlish, 2019).

River	Region (outlet)	Province (gauges)	Drainage Area (km^2)	Drainage Area Rank	Discharge (km^3/year)	Discharge Rank
Severn	HB	ON	94,300	3	21.9	3
Winisk	HB	ON	54,710	4	15.2	4
Ekwan	JB	ON	16,900	7	2.8	7
Attawapiskat	JB	ON	36,000	5	11.4	5
Albany	JB	ON	118,000	1	31.8	2
Moose	JB	ON	98,530	2	39.0	1
Harricana	JB	QC	21,200	6	7.8	6

Severn River Watershed

The hydrology of the Severn River watershed (Figure 21) reflects a complex river-lake system transitioning from Canadian Shield to Hudson Bay Lowland, with a mix of steep- and low-gradient channels and river basins. The Severn River drains the large Hudson Bay sedimentary basin and consequently has a large-scale radial drainage system (Cumming, 1968).

The Severn River watershed can be divided into three major sections, the Upper, Middle, and Lower Severn, reflecting the Sachigo River entering from the west about 170 km upstream from Fort Severn and the Fawn River draining out of Big Trout Lake and entering the Severn from the east about 65 km downstream from the mouth of the Sachigo River (Cumming, 1968). The community of Fort Severn is situated along the bank of the Severn River, 9 km from the coast of Hudson Bay and is home to about 400 people with another 250 Fort Severn First Nation

community members living elsewhere (Gibson et al., 2012). Fort Severn is a member of the Keewaytinook Okimakanak (KO) Tribal Council and the Nishnawbe-Aski Nation (Treaty #9 area). The Fawn River was used frequently as a fur trade route to Big Trout Lake (now known as Kitchenuhmaykoosib Inninuwug or KI for short). also known as Big Trout Lake First Nation or KI for short, is a First nations community in Northwestern Ontario. They are part of Treaty 9. This Oji-Cree community is one of the largest First Nations communities in the region, with the 2016 census identifying the population as more than 1000 people. During the 1970s, the community worked with researchers to understand and address the causes of eutrophication of Big Trout lake (Jackson and Mckay, 1982). The community successfully opposed mining in their territory in 2006, which some suggest was instrumental in having the Ontario Mining Act "modernized" in 2009 (Peerla, 2012).

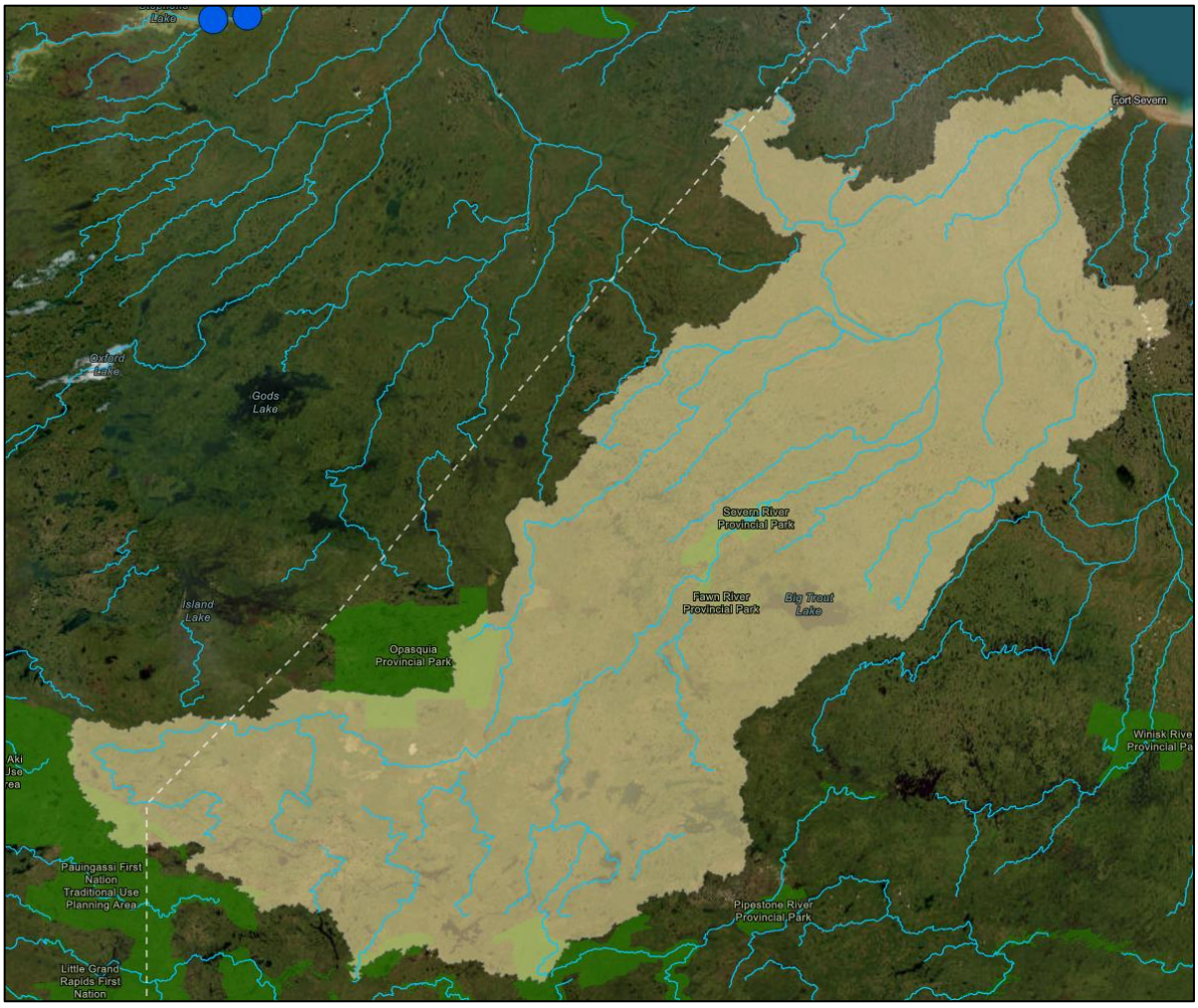

Figure 21. Severn River Watershed shaded in yellow. Rivers are represented by light blue lines. Green shaded areas on top of the basemap are protected areas. The dashed line represents the border between Ontario and Manitoba.

Winisk River Watershed

Similar to the Severn River watershed, the Winisk River watershed (Figure 22) is shaped by complex lake-river interactions and can be divided into three major sections, the Upper, Middle, and Lower Winisk. Extensive large, interconnected lake systems dominate in the Middle Winisk section. Major sub-watersheds include the Asheweig River, which joins the Winisk about 300 km from Hudson Bay. The Shamattawa River joins the Winisk about 35 km from the outlet and the confluence is where the community of Peawanuck is located (Weenusk First Nation).

The Watershed Hydrology Lab, Aquatic Research and Monitoring Section (ARMS), Ontario Ministry of Natural Resources (OMNR) has recently developed a dashboard to support the Weenusk First Nation's Community Based Monitoring (CBM) initiative in the Winisk River Watershed (Bob Metcalfe, pers. comm., March 2025). This dashboard combines traditional ecological knowledge (TEK) with data from long-term streamflow and climate monitoring and modeling to help the community understand current and historical watershed conditions, identify trends, and anticipate future changes. It provides insights into the watershed's hydrological cycle and the First Nation's deep understanding of the interconnectedness of land and water. The dashboard complements traditional ecological knowledge (TEK) in a two-eyed approach, recognizing the importance of watersheds to the cultural, spiritual, and physical well-being of First Nations and their role in sustaining traditional ways of life that can be accessible here: Winisk River Watershed Dashboard v1.1. Since 1971 there has been a positive trend for annual total precipitation within all gauging stations in the Winisk River Watershed (Figure 23a); however, the trend is not evident across all months (Figure 23b). Additionally, the trend of annual streamflow is likely positive as is also shown for monthly streamflow in several months (Figure 24).

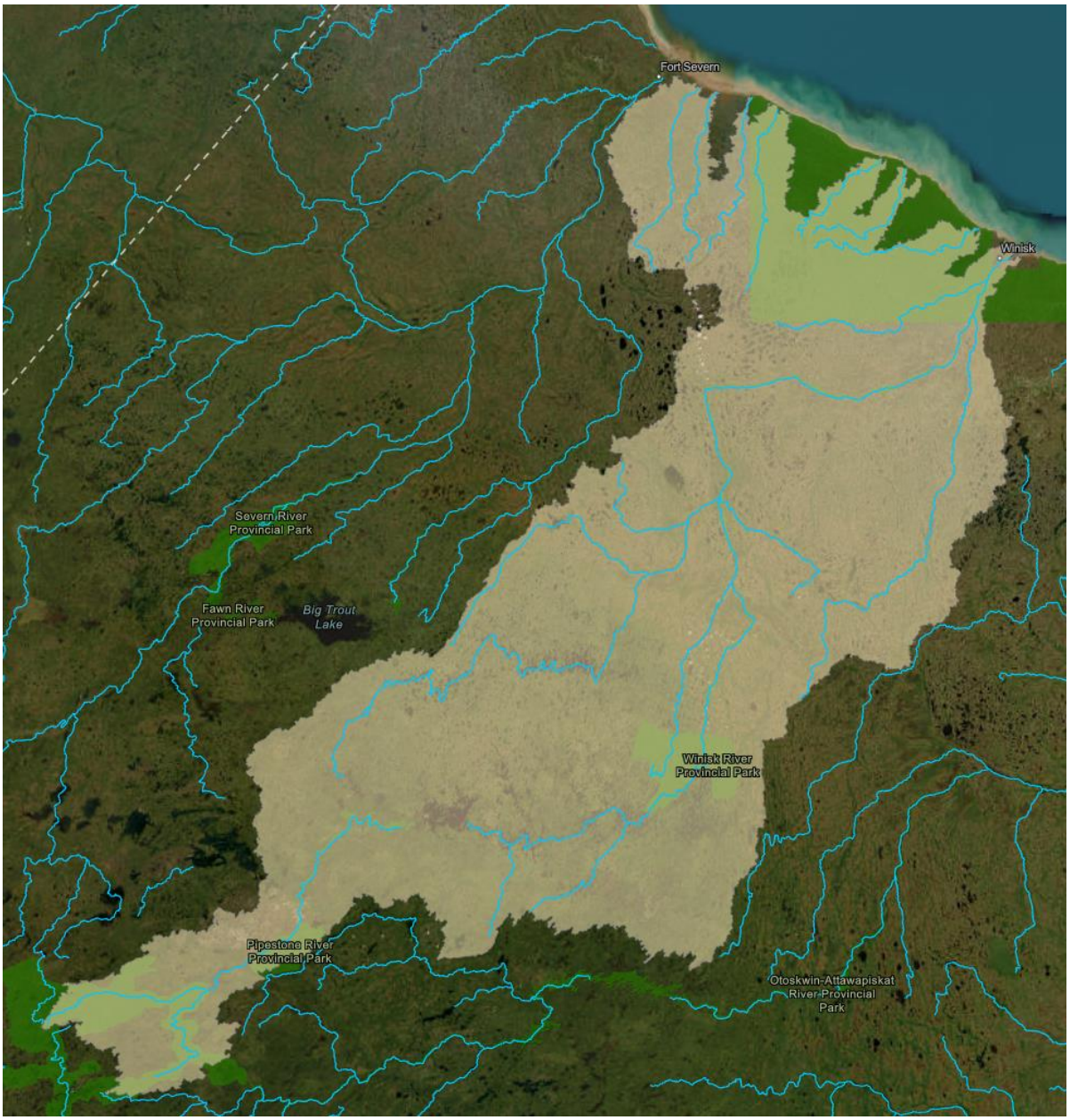

Figure 22. Winisk River Watershed shaded in yellow. Rivers are represented by light blue lines. Green shaded areas on top of the basemap are protected areas.

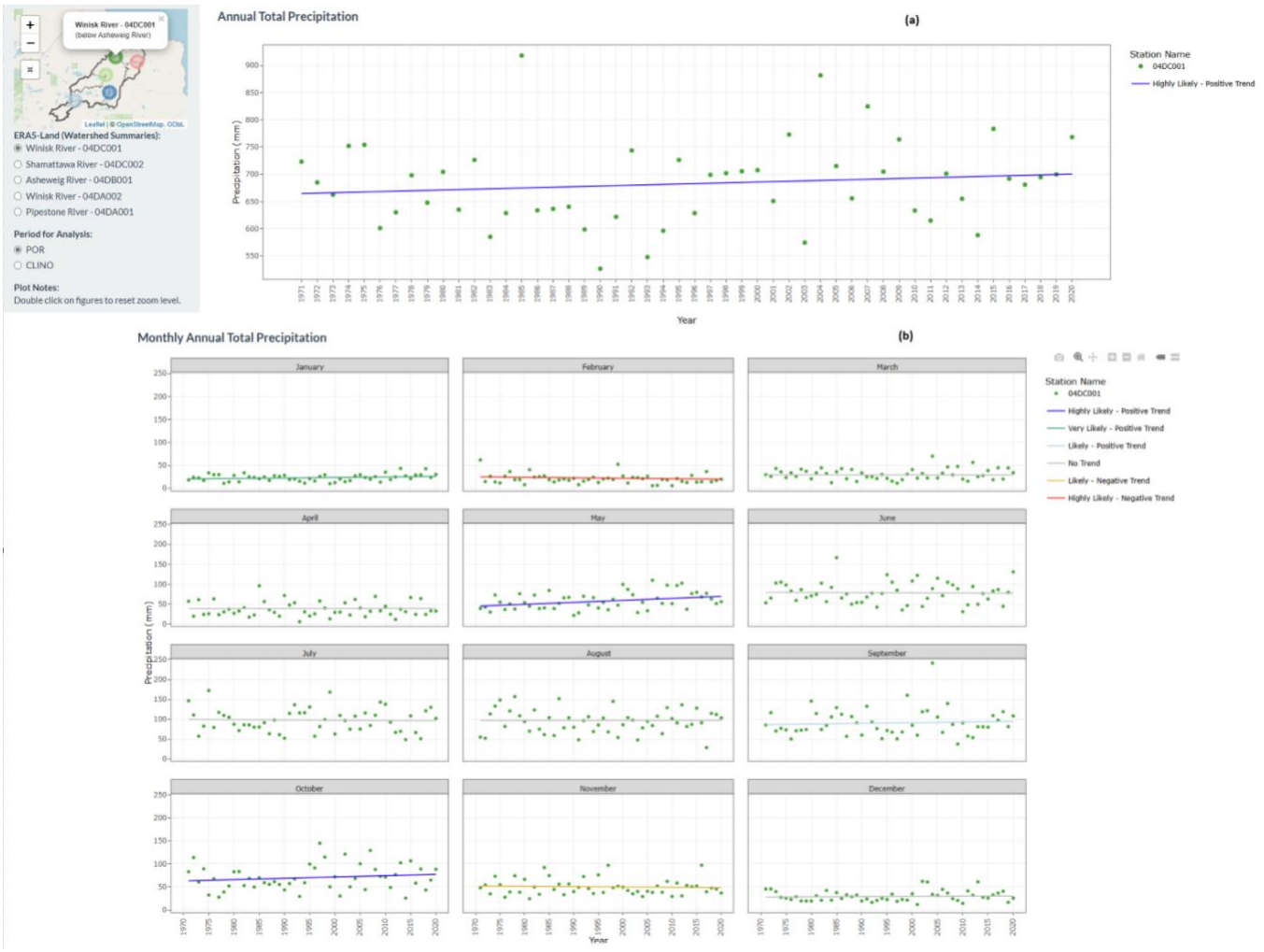

Figure 23. (a) Annual total precipitation and (b) monthly annual precipitation for Winisk River, dervied from Winisk River Watershed Dashboard v1.1.

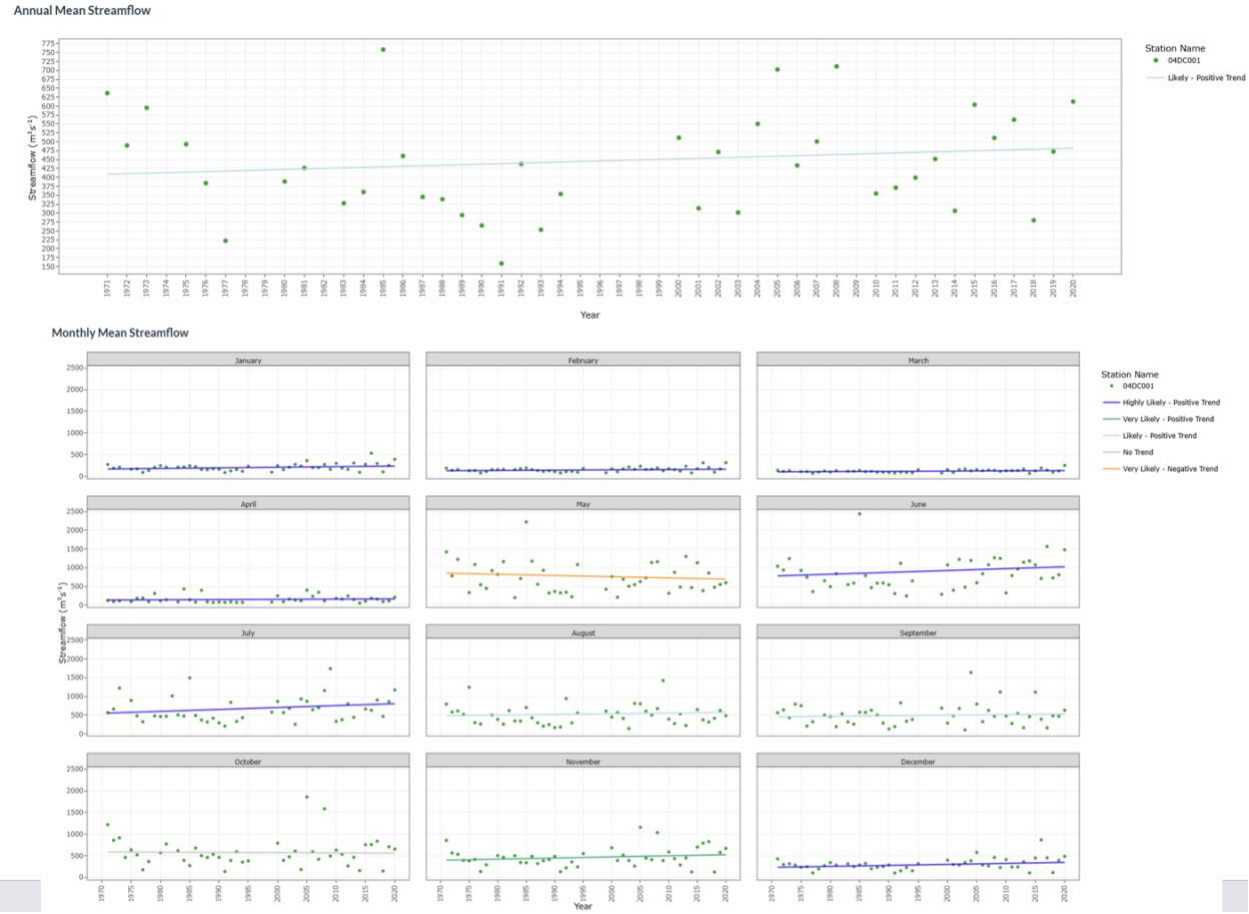

Figure 24. Annual and monthly streamflow trends for Winisk River-04DC001 gauging station, derived from Winisk River Watershed Dashboard v1.1.

Ekwan River Watershed

There is a very limited data about the structure and hydrology of the Ekwan River watershed despite the river channel forming, in places, the southern boundary of Polar Bear Provincial Park (Figure 25). The Ekwan River watershed as delineated on most maps including those issued by Ontario encompasses a number of smaller watersheds that are not tributaries to the Ekwan River such as the Sutton River. Archean and Precambrian bedrock outcrops, which are associated with the Cape Henrietta Maria Arch that divides the Moose River and Hudson Bay sedimentary basins, control water flow routing in the lowland area between the Winisk and Ekwan Rivers (Figure 26) (Cumming, 1968). In the northern portion of the Ekwan River watershed, an area of Precambrian bedrock called the Sutton Ridges extends about 50-km long and rises 120 m above the extensive bogs and fens of HBL. Hawley Lake lies in this area and feeds the Sutton River, which flows northward approximately 138 km (river length) through Polar Bear Provincial Park before discharging to southern Hudson Bay. Recent reports (e.g., Litvinov, 2021) and TEK (Omushkego in addition to Attawapiskat First Nation) suggests that the Ekwan River watershed is more vulnerable to impacts of climate change relative to neighbouring Attawapiskat and Albany River watersheds. The Ekwan watershed is largely contained within the Hudson Bay Lowland ecozone.

Figure 25. Ekwan River Watershed shaded in yellow. Rivers are represented by light blue lines. Polar Bear Provincial Park is considered as a protected area within the watershed (green shaded area at top of map).

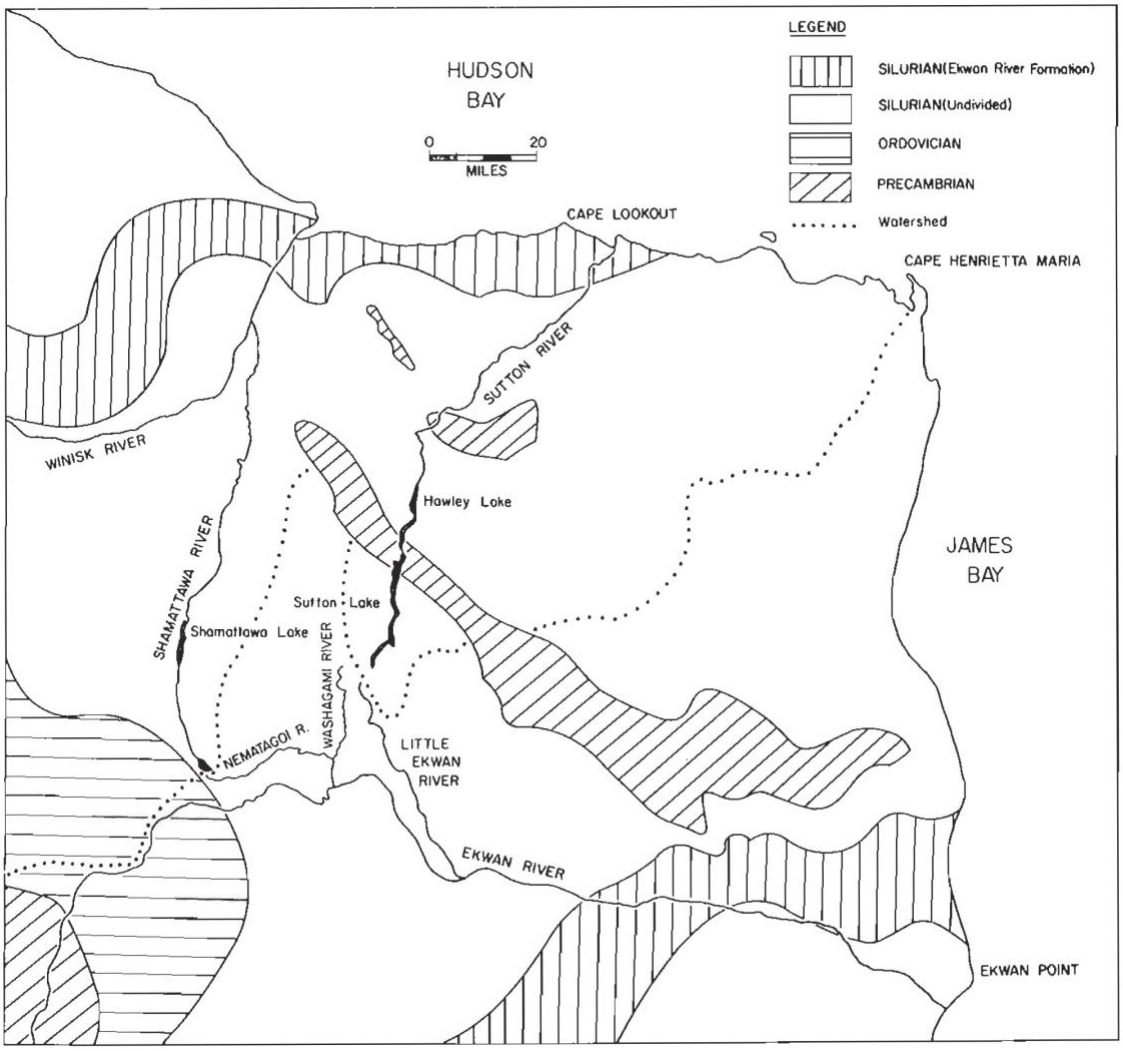

Figure 26. Sketch map of the lowland watersheds between the Winisk and Ekwan Rivers showing outcrops of Precambrian rocks on Cape Henrietta Maria and the Sutton River flowing northward to Hudson Bay while the Ekwan River flows eastward to James Bay. Source: Cumming (1968)

Recent streamflow modeling by Stadnyk et al. (2021) showed poor performance for the Ekwan River attributed to the relatively small drainage area and the potential for complete freeze up during parts of the winter season. Also, this river may be influenced by aufeis (overflow ice), which can contribute to late-summer flow (Makarieva et al., 2019).

Earlier sediment core work in lakes within the Ekwan River Watershed indicated that increased MeHg production was linked to increased sediment organic carbon concentrations due to increased algal primary production. Total Hg in their samples increased over time since the industrial revolution due to atmospheric deposition, but MeHg was not linked to inorganic Hg concentrations, indicating that MeHg production was limited by organic carbon, not inorganic Hg, in this system (Brazeau et al., 2013).

Attawapiskat River Watershed

As with the other watersheds, the Attawapiskat River watershed can be organized into an Upper, Middle, and Lower section. This watershed features a lake-dominated upper system, a moderately broad middle corridor with key tributary inflows, and a low-gradient lower reach flowing toward coastal wetlands into the James Bay. The Attawapiskat watershed is approximately 56,589 km^2 in area and drains northeast into James Bay, across from Akimiski Island.

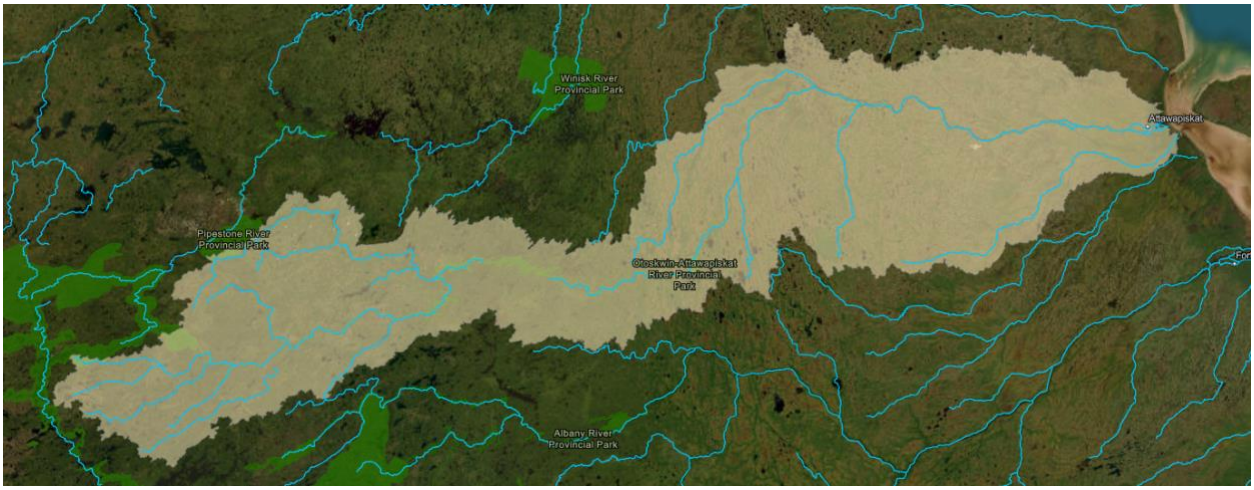

Figure 27. Attawapiskat River Watershed shaded in yellow. Rivers are represented by light blue lines.. This watershed is considered unregulated watershed without any hydropower dams whereas mining activities would be one of threats for this watershed. Green shaded areas represent protected areas.

As with the Ekwan River watershed, the Attawapiskat River watershed may be negatively impacted by proposed mining activity within the Ring of Fire. Since 2009 the Canadian Aquatic Biomonitoring Network (CABIN) has initiated the assessment of Attawapiskat River watershed. CABIN is based on the networks approach that promotes inter-agency collaboration and data-sharing to achieve consistent and comparable reporting on freshwater quality and aquatic ecosystem conditions in Canada.

The data from monitoring streamflow gauging stations of Water Survey of Canada (WSC), climate stations of Meteorological Service of Canada (MSC), and ERA5-Land reanalysis climate data from the Copernicus Climate Change Service (C3S) Climate Date Store (CDS) have been used to create Attawapiskat River Watershed Dashboard v1.1: Attawapiskat River Watershed Dashboard v1.1. Figure 28 shows the streamflow status for more recent years (2021-2025) for the Attawapiskat River-04FC001 station which is the last station before the mouth of river following to the James Bay. There are some concerns about the data especially during the thawing season, due to ice jam conditions, missing data, and potential inaccuracies in measurements caused by fluctuating water levels.

By looking at the long-term annual streamflow data (1970-2020), the Attawapiskat River-04FC001 station showed a slightly positive trend while the fluctuations are considerable (Figure 29a). However, the long-term monthly data did not show any strong trends for several months of all four seasons except strong positive trends for June, November, and December and a strong negative trend in August (Figure 29b).

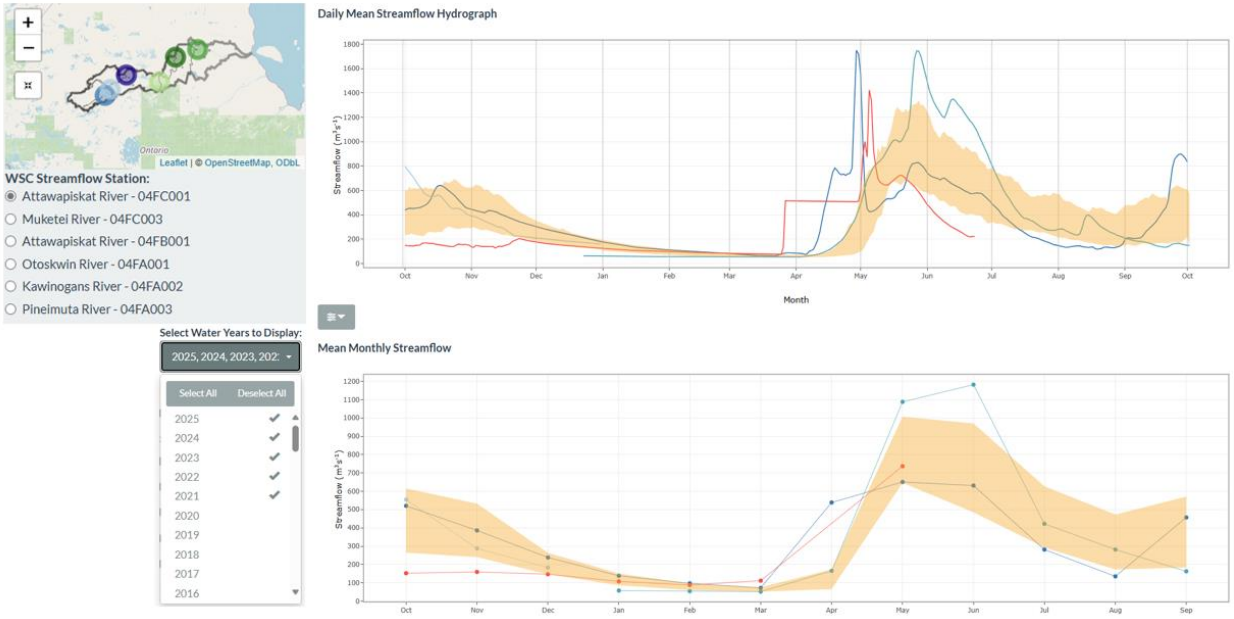

Figure 28. Daily mean and mean monthly streamflow hydrographs of Attawapiskat River (04FC001) station (derived and adapted from Attawapiskat River Watershed Dashboard v1.1). Orange shade shows the interquartile range.

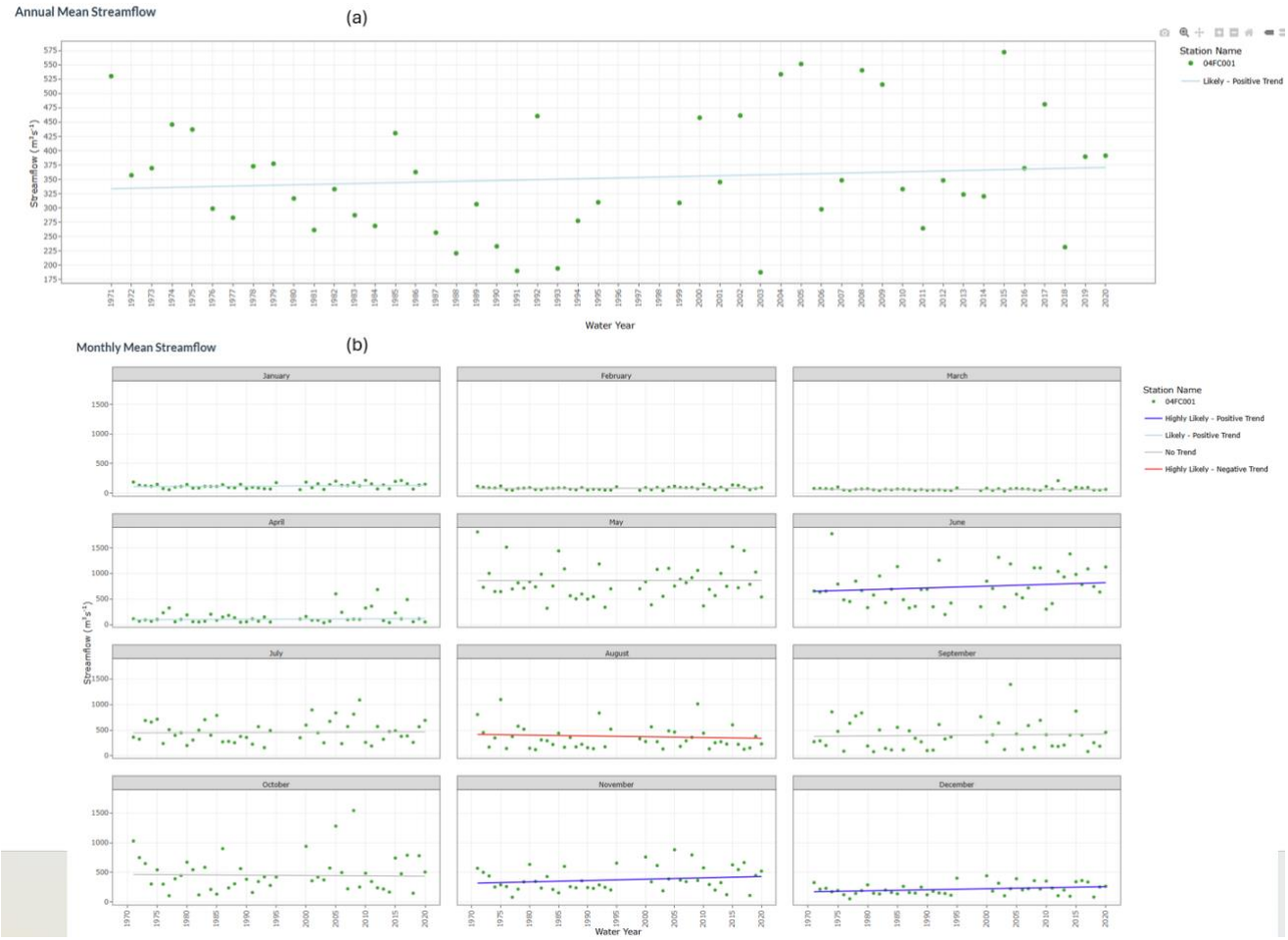

Figure 29. Trends of annual and monthly mean streamflow for the Attawapiskat River-04FC001 station.

Albany River Watershed

The Albany River, with an approximately discharge of 31.8 km^3/year (based on the mean annual discharge from 1964 to 2013) ranks 7th among the rivers draining into Hudson-James Bay system. The Albany River watershed (Figure 30) ranks 4th in terms of drainage area size which is the largest watershed among the western James Bay watersheds (Kuzyk and Candlish, 2019).

Waters from three regions within the headwaters have been diverted outside the basin. Lake St. Joseph has been diverted to the Nelson River watershed. The Ogoki River has been diverted to Lake Nipigon and Long Lake which has been diverted to Lake Superior (Day et al., 1982; Root River Control Dam, n.d.). These interventions make the Albany River system one of the most hydrologically modified rivers draining into James Bay.

The Albany River watershed received approximately 700 mm of precipitation annually and the annual evapotranspiration accounted less than half of that for the study period from 2002 to 2015, with the surplus water contributing to aquifer recharge and sustaining winter baseflow (Wang, 2019). The early winter baseflows varied widely from 350 m^3/s to over 4600 m^3/s (i.e.,

0.26 mm/day - 3.37 mm/day). The baseflow were more stable in the late winter ranging from 200 to 700 m^3/s (0.15 mm/day - 0.51 mm/day), with the overall mean of 430 m^3/s (0.31 mm/day) (Wang, 2019).

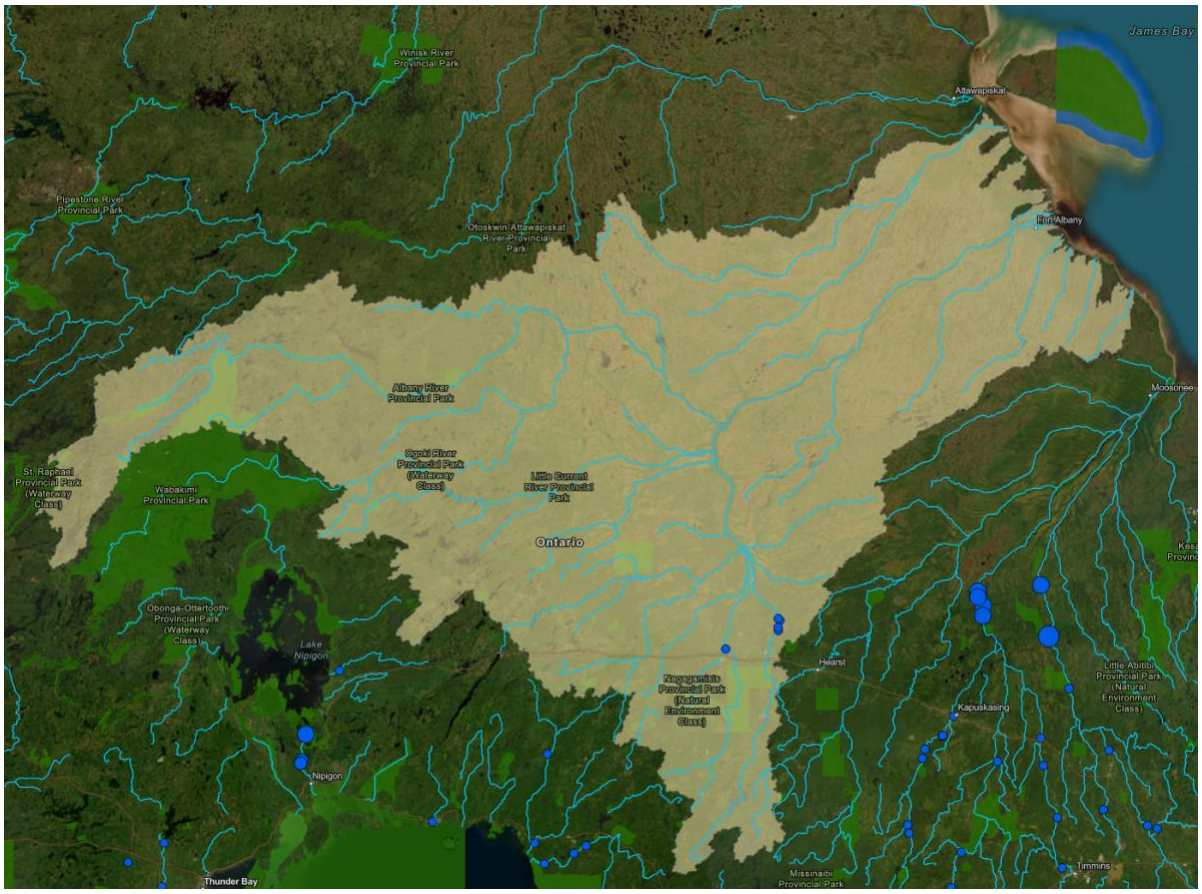

Figure 30. Albany River Watershed shaded in yellow. Rivers are represented by light blue lines. Blue circles show hydropower dams on tributaries within the watershed. Green shaded areas represent protected areas.

In Kashechewan (based on a 30 year average), mean daily minimum temperatures for each month, December through April, are −7°C, −23°C, −23°C, −15°C, and −6°C, respectively, while maximum daily temperatures for the same months are −9°C, −13°C, −11°C, −5°C, and 3°C (Khalafzai et al., 2019). The area receives 200–240 cm of snowfall annually. During June, July, and August, maximum temperatures often reach 31–32°C. Precipitation averages over 50 mm monthly between May and October, with 38 mm in April, a critical month for triggering spring flooding (Khalafzai et al., 2019).

Moose River Watershed

The Moose River is the fifth largest contributor (~ 39 km^3/yr) of freshwater discharge to James Bay flowing from the Precambrian Shield through the Hudson Bay lowlands entering James Bay at Moose Factory across the Hudson Bay system (Kuzyk and Candlish, 2019). The Moose River Watershed (Figure 31) ranks as the 7th largest drainage basin (98 530 km^2) of the Hudson Bay system with significant tributaries including the Abitibi, Mattagami, and Missinaibi Rivers. The Moose River watershed has the 1st, and 2nd ranks of drainage area and drainage discharge, respectively, among the seven watersheds within western James Bay system. Four major hydroelectric developments by Ontario Power Generation that initiated in the mid-1960s affect the Moose River on the upstream Mattagami and Abitibi Rivers. Compared to the Nelson and La Grande Rivers, regulation of the Moose River has a more localized impact on freshwater-marine coupling and cycling.

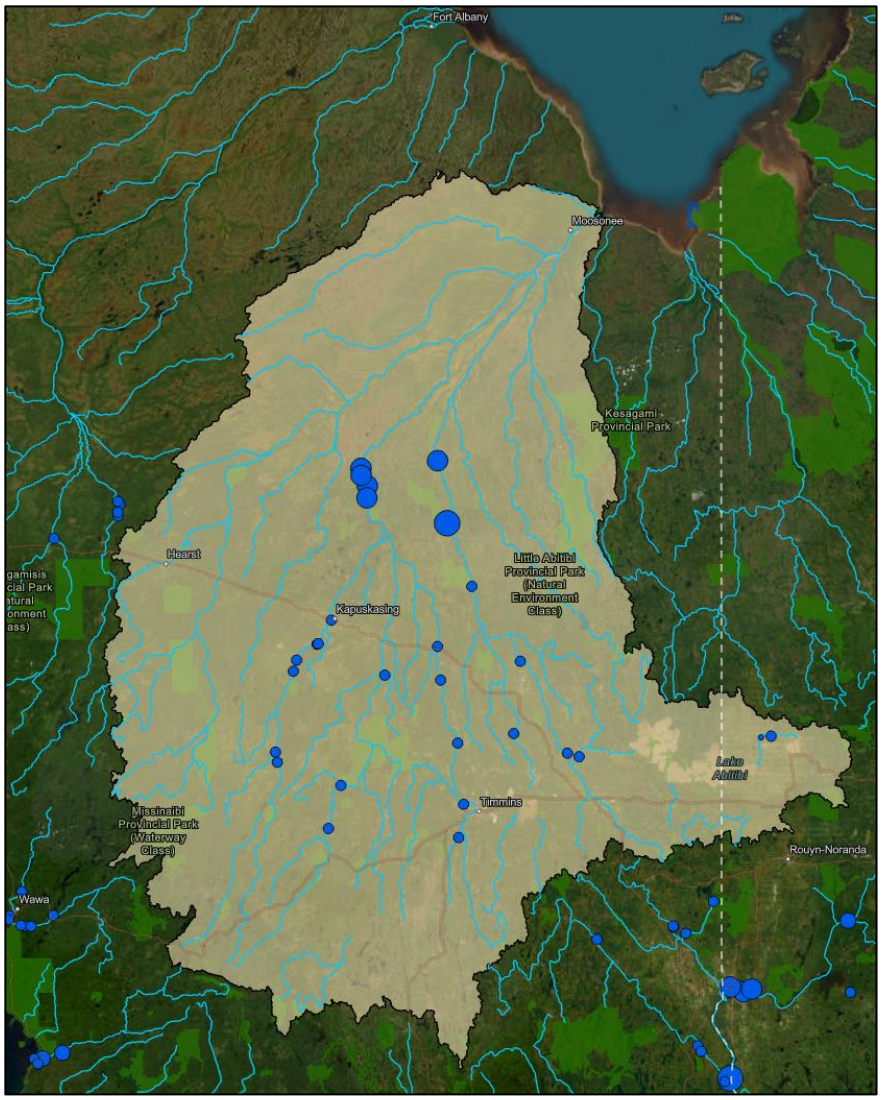

Figure 31. Moose River Watershed shaded in yellow. Rivers are represented by light blue lines. Blue circles show the hydropower dams on several tributaries within the watershed. Green shaded areas represent protected areas.

The Moose River forms at the confluence of the Mattagami and Missinaibi Rivers of north-eastern Ontario with the Abitibi, Kwetabohigan, and North French Rivers augmenting downstream flows prior to discharging into James Bay.

Discharge from the Moose River into James Bay from its combined gauged stations for the year 2023 was 34.4 km^3 (Government of Canada, 2024) with strong seasonal variation as shown in Figure 32. The Mattagami River and Missinaibi River combine ~105 km from the mouth of James Bay (or ~110 km accounting for the meanders of the channel). The combination of the Mattagami and Missinaibi forms the point in which the Moose River begins. Closer to James Bay, the Moose River flow is augmented by flow from the Abitibi, Kwetabohigan, and North French Rivers.

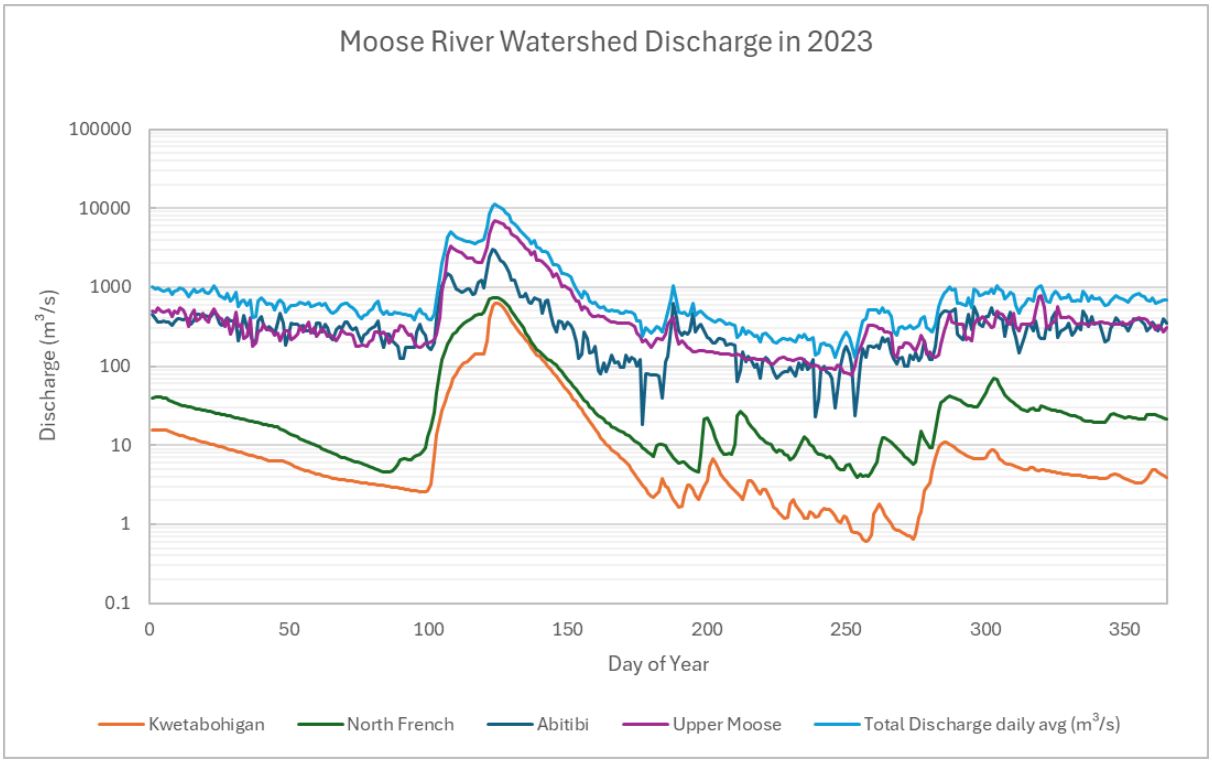

Figure 32. Streamflow of major tributaries in Moose River Watershed in 2023 based on the flow data from four HYDAT stations within the watershed.

Within the Moose River watershed, the roughly 500 km span inland from the tributaries' sources down to James Bay accounts for an elevation loss of approximately 500 m (McCrea & Merriman, 1981). There are three main forest cover designations that exist within the Moose River watershed: the headwaters exist in the eastern forest/boreal transition region, the midsection of the watershed in the Canadian shield forests, and the lower reaches in the southern Hudson Bay taiga (Milner et al., 2009). The majority of the Moose River watershed and its tributary rivers are located in the Humid Mid Boreal region, with only the lower reaches located in low subarctic (Milner et al., 2009).

The Abitibi River is one of the major inflow rivers into the lower stretch of the Moose River basin. The Abitibi River drains a land area of 27,500 km^2 and in the year 2023 had an annual discharge of 132,002 m^3/year (Government of Canada, 2024), accessed in 20242025-10-17 4:09:00 PM). Local knowledge (Moose Cree First Nation) suggests that the Abitibi is considered to be the most "contaminated" (modified or disturbed) of the rivers in the basin. The reason for this perception is that the river has seen more development than any other river. The Abitibi contains 3 hydroelectric stations (Otter Rapids, Peter Sutherland Sr., and Abitibi Canyon) along with a pulp and paper mill operating along the river at Iroquois falls that began operation in 1914 and only recently closed in 2015 (Wells, 2015; OPG, 2022b)

The Kwetabohigan River drains a land area of 4,250 km^2 over its roughly 230 km span. The Kwetabohigan River is the only gauged river that drains a land area north of the Moose River main stem.

The North French River is another major river that discharges into the lower reaches of the Moose River and is another area of particular interest for the Moose Cree First Nation. The North French River over the span of 270 km drains a land area of 7,445 km^2 (MCFN, 2023). North French is notable for being one of the only rivers in the watershed that does not have industrial development. The lack of development along with the traditional hunting and fishing that occur on this watershed make this river one of importance to the Moose Cree First Nation. In 2021, the Moose Cree reaffirmed its commitment to the establishment of the North French River watershed as an Indigenous Protected and Conserved Area (MCFN, 2023).

Although the population density of the Moose River basin is quite sparce at less than 1 person per square kilometer (Milner et al., 2009), the region is still subject to development (Figure 33). Within the watershed basin, there are mining, forestry, logging operations, and hydroelectric power generation. Most operational mines are located in the southern tributary regions of the watershed, primarily within Ontario's borders and concentrated near Timmins, with only two gold mines in Quebec falling within the watershed. The lower Moose River watershed contains 17 mines, including 13 gold mines, 2 nickel mines, 1 base metal mine, and 1 talc mine (OGSEarth, accessed in 2024).

Mining samples were collected in 2021 for the potential creation of a mine in the South Bluff Creek watershed, which drains land to the south of the Moose River mainstem; however, a survey vote by the MCFN voted 55% to never support a mine in this area and instead support its protection. This has since led to the MCFN applying for protected status of the South Bluff Creek watershed with the Ontario and Canada governments. This marks the second watershed preservation effort being attempted, following the MCFN's efforts to preserve the North French River watershed (MCFN, 2023).

Forestry operations within the Moose River watershed are ongoing, with forestry operations occurring in 8 forest management areas within the Moose River Watershed (OMNRF, 2022b). All forestry regions exist south of the Moose River mainstem. Forestry operations include harvesting

of timber, building and decommissioning of roads and infrastructure for harvesting and processing timber, and planting and reforesting processes.

In addition to the three generating stations along the Abitibi, the Lower Mattagami Hydroelectric Complex is made up of four generating stations on the Mattagami River. The four stations are (from south to north): Little Long, Smoky Falls, Harmon, and Kipling. They are about 70 kilometers northeast of Kapuskasing and about 150 kilometers upstream of Moose Factory and the Town of Moosonee. Recent retrofitting and renovations were completed in 2015 on the 4 hydroelectric generating stations on the lower Mattagami River, where three stations were supplied an additional turbine to generate more power while one stations was completely rebuilt adjacent to the old station to increase power generation efficiency (OPG, 2025)

Harricana River Watershed

The headwaters of the Harricana River are primarily located in Québec (Figure 33). The river discharge into James Bay is approximately 7.8 km^3/year which ranks 25th of the rivers draining the Hudson Bay System from a watershed ranking 24th by area (Déry et al., 2016). Hydrometric data for the Harricana River can be obtained from a monitoring station located approximately 480 km upstream from the river's mouth. The data can be accessible via Quebec Hydrological Data Centre (CEHQ) at (De Melo et al., 2022). Harricana River has natural seasonal flow pulses which mobilize organic carbon from the peatlands and organic-rich soils into streams. Nutrient and sediment export dynamics in the eastern James Bay rivers showed higher yields from Harricana River compared to the La Grande River due to geological context (Clay Belt region) and unregulated, simpler, and faster river systems (De Melo et al., 2022).

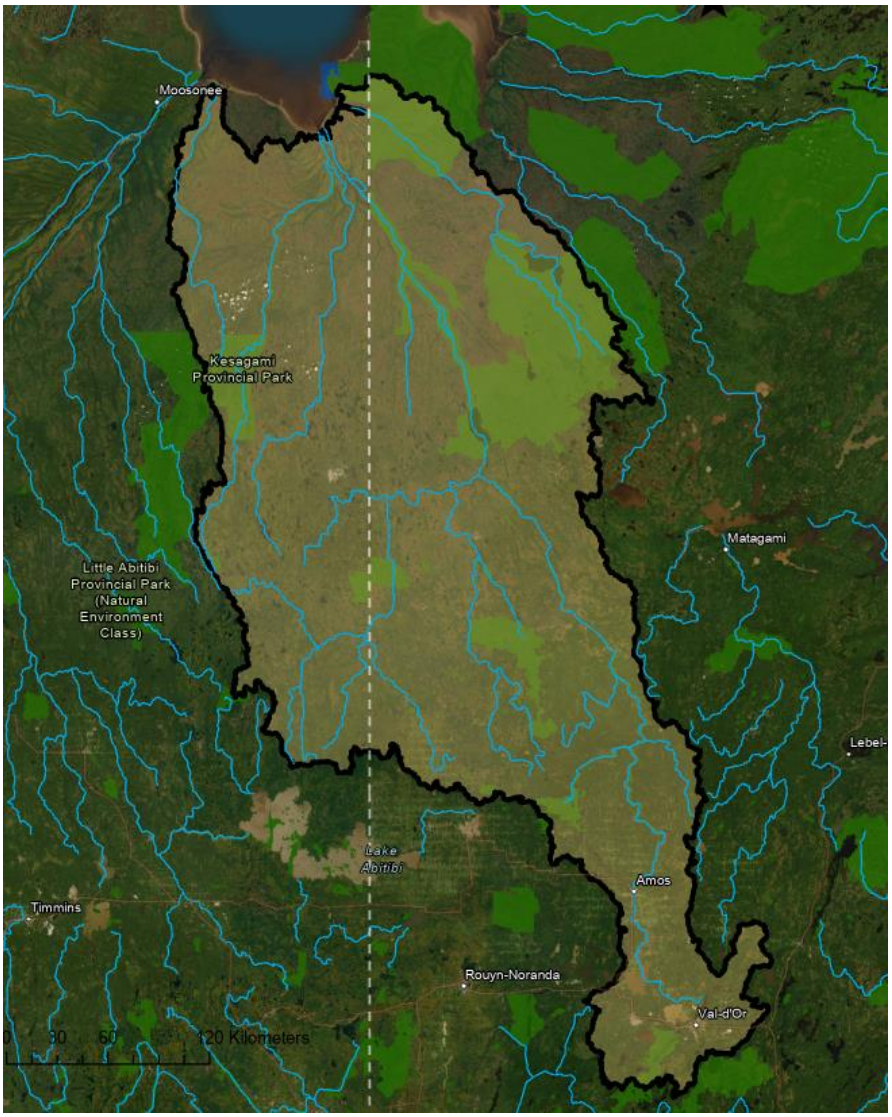

Figure 33. Harricana River Watershed shaded in yellow. Rivers are represented by light blue lines. Some portions of the watershed considered as protected areas, shaded in green. The dashed line represents the border between Ontario (left) and Québec (right).

Appendix B: Land Cover Maps for Specific Watersheds

This appendix includes land cover maps analogous to Figure 12 in the main body of the report but specific to the six major watersheds located in Ontario. (Modified from OMNRF, 2014).

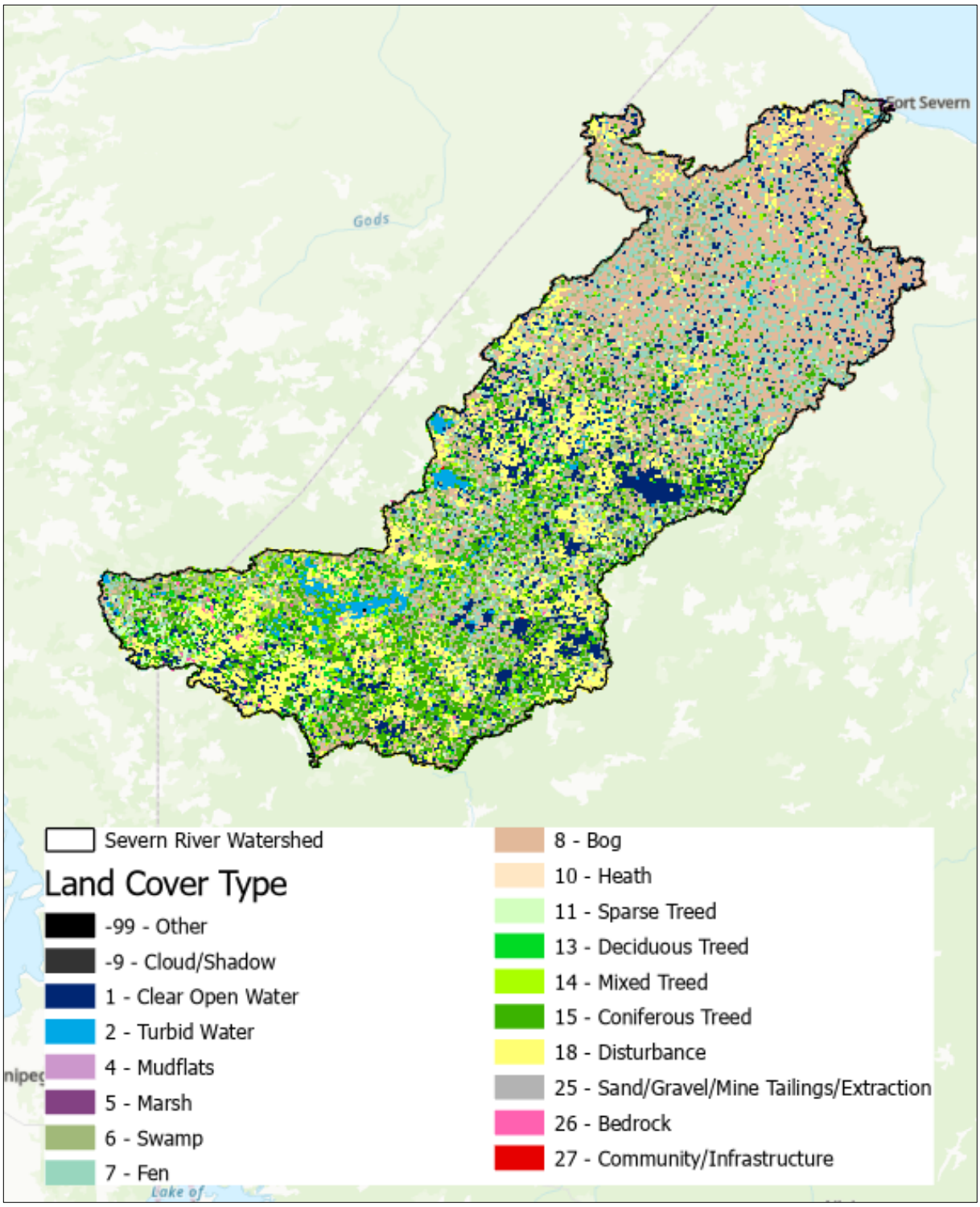

Figure 34. Land cover map for Severn River Watershed.

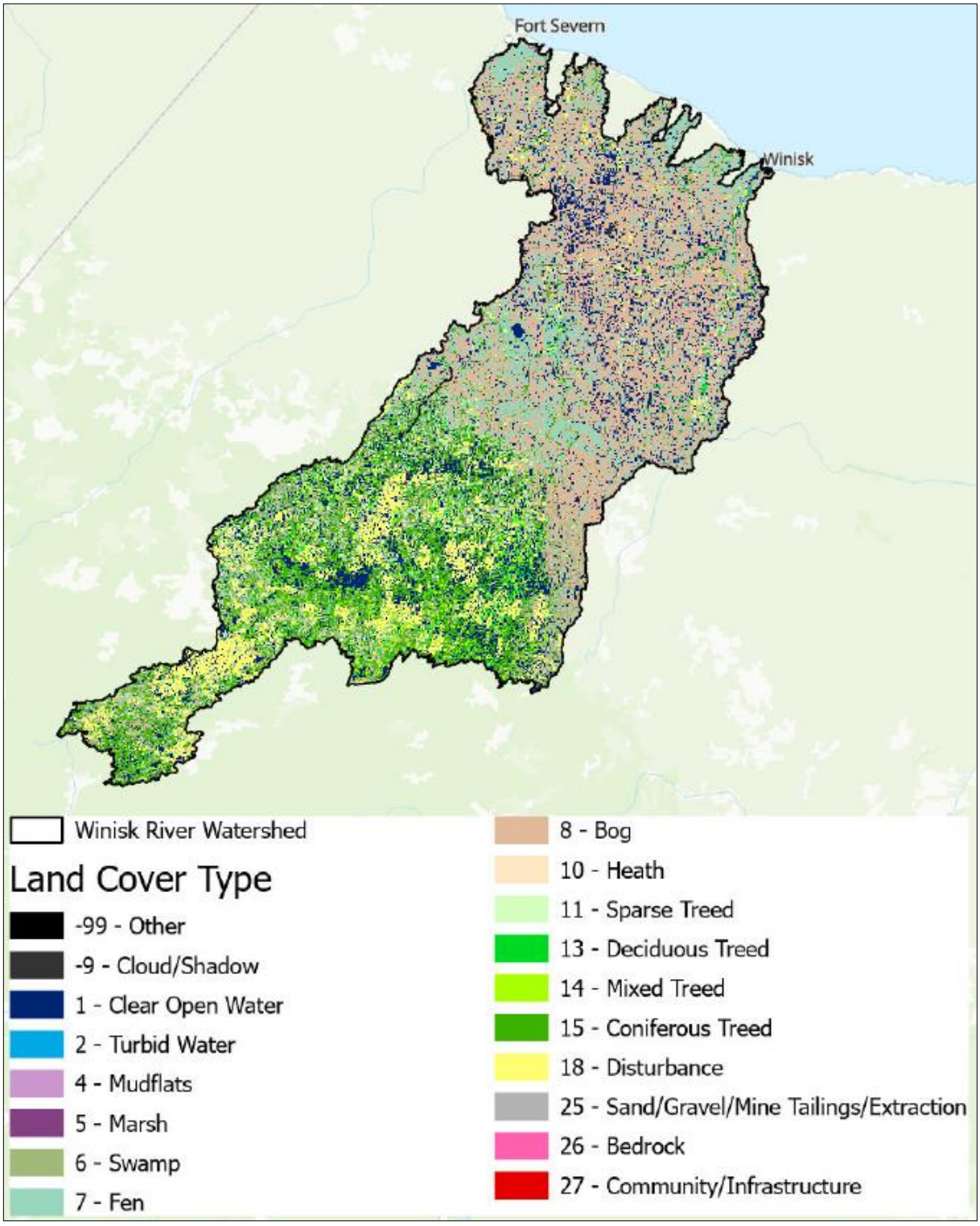

Figure 35. Land cover map for Winisk River Watershed.

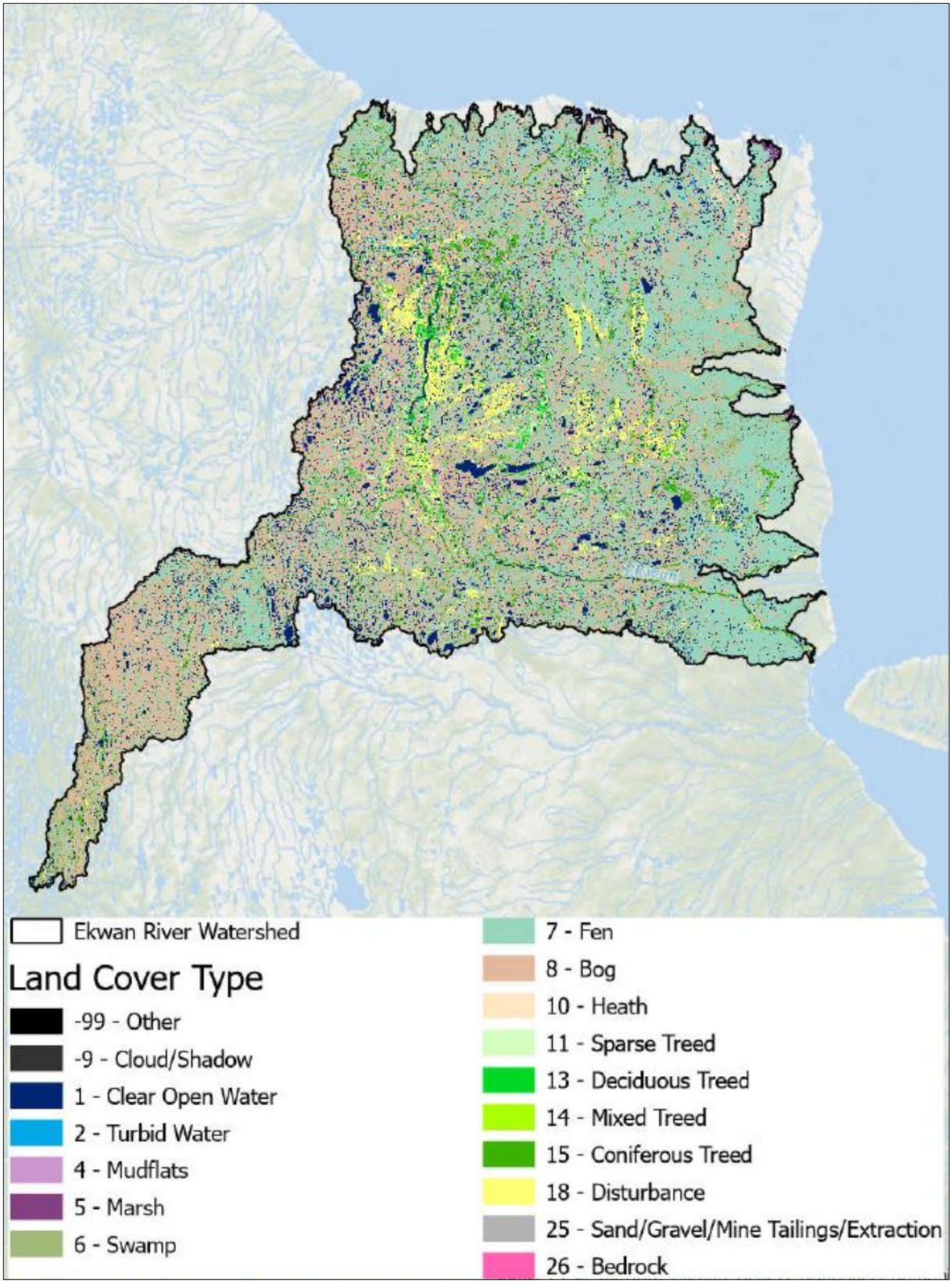

Figure 36. Land cover map for Ekwan River Watershed.

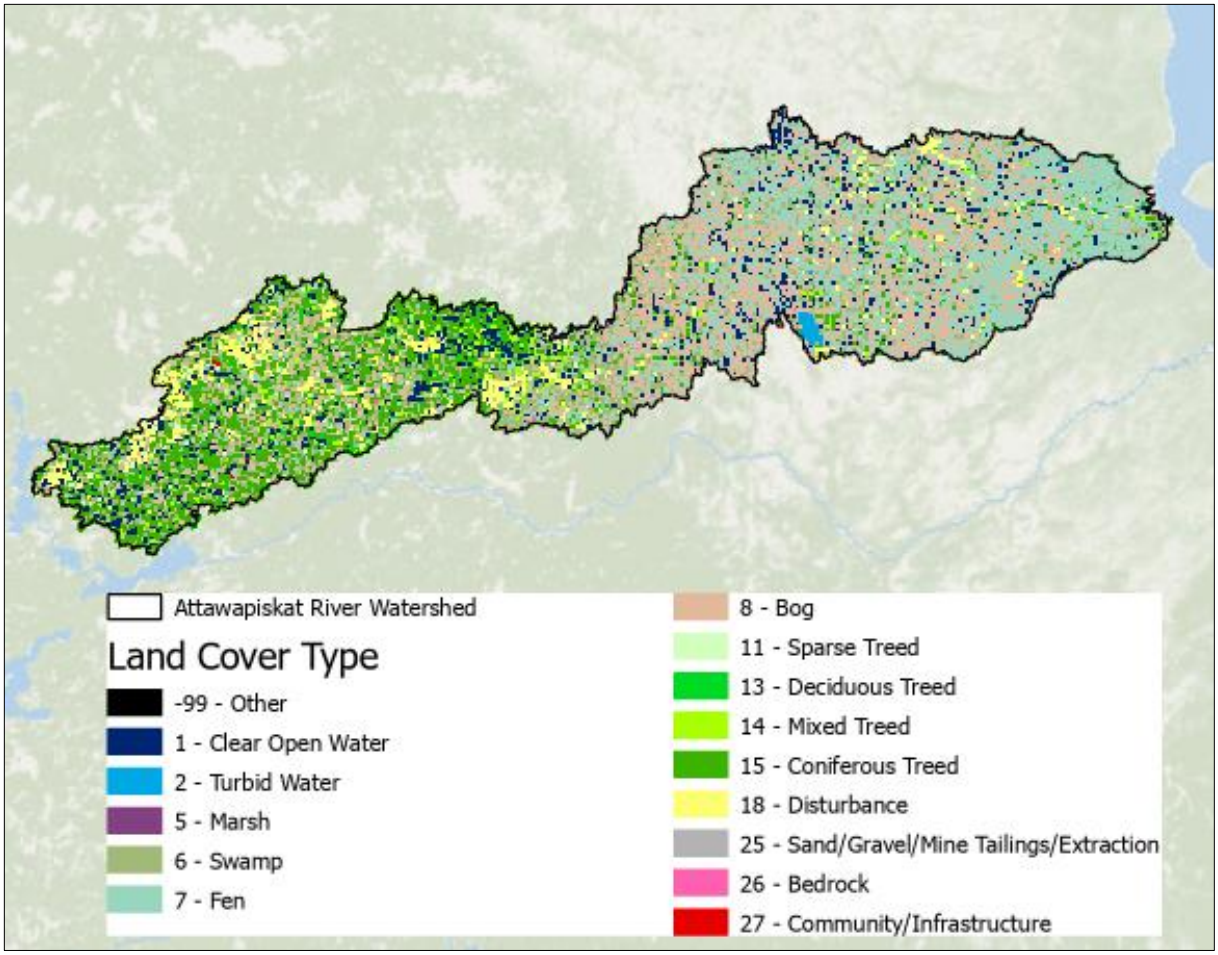

Figure 37. Land cover map for Attawapiskat River Watershed

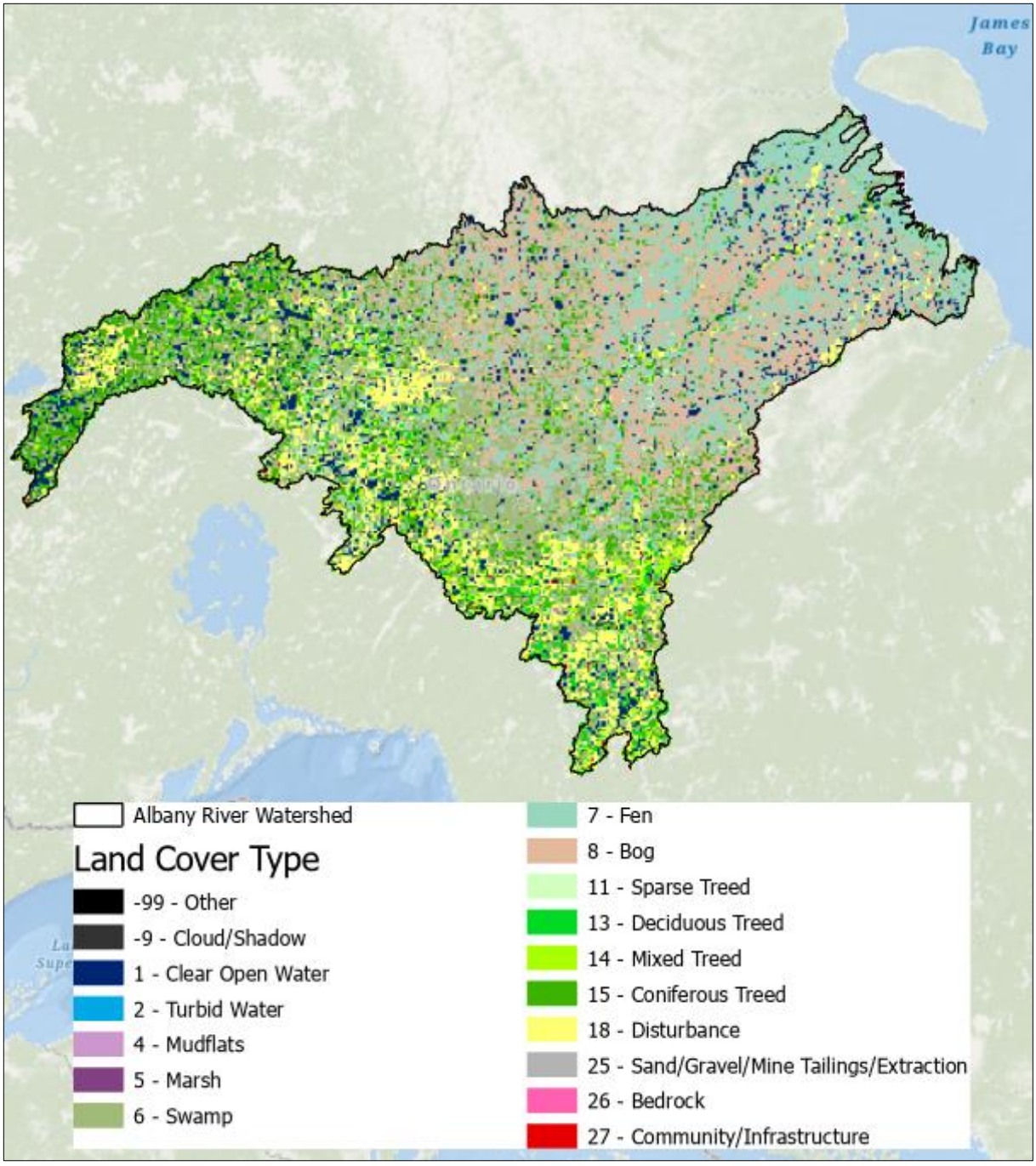

Figure 38. Land cover map for Albany River Watershed.

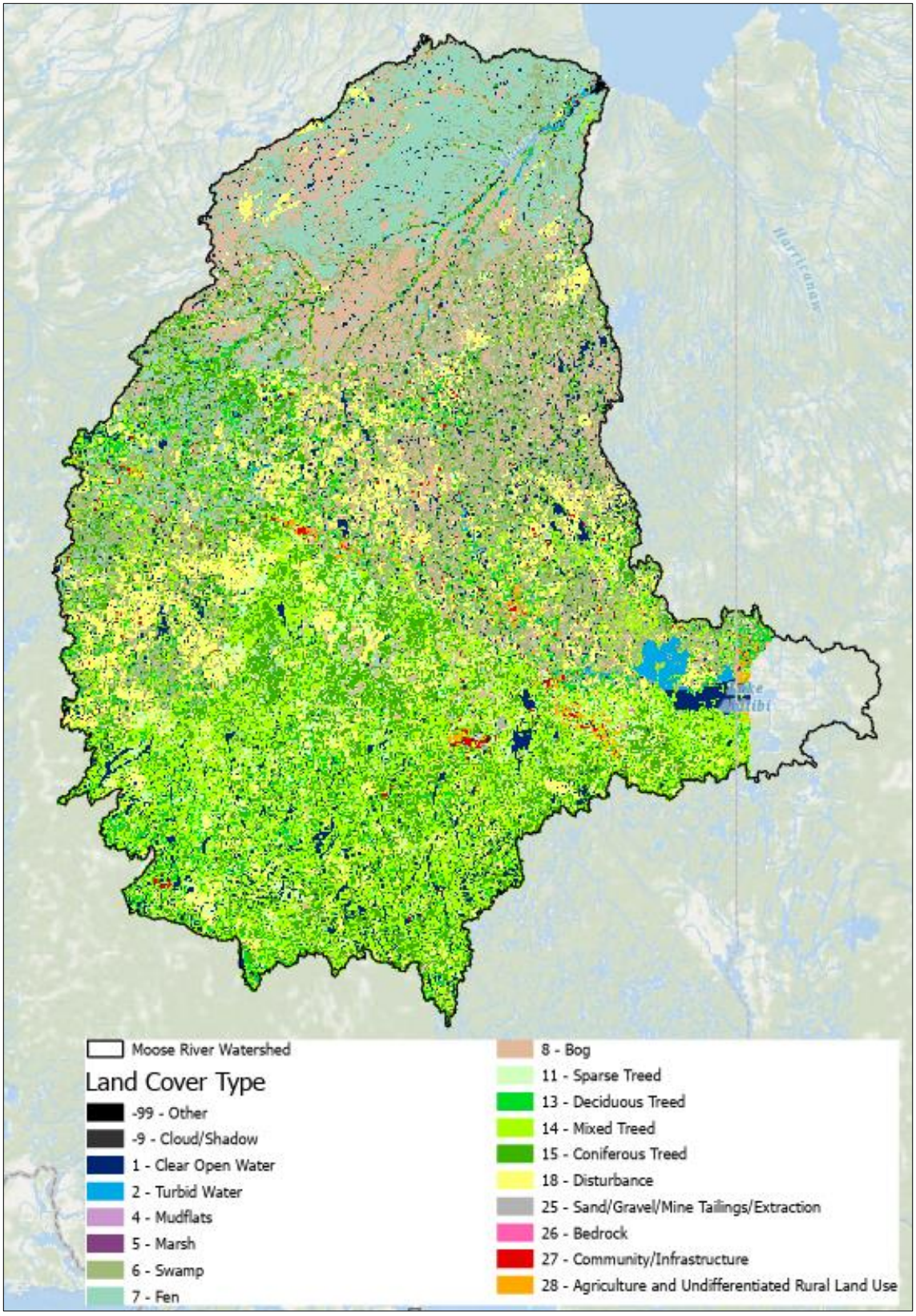

Figure 39. Land cover map for Moose River Watershed. The original Land cover map is derived from Ontario MNRF that is showing southeastern part located in Quebec without information.

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