WATERSHED STATUS

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

October 2016

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Gulf of Maine Council on the Marine Environment

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The Gulf of Maine Council on the Marine Environment was established in 1989 by the Governments of Nova Scotia, New Brunswick, Maine, New Hampshire and Massachusetts to foster cooperative actions within the Gulf watershed. Its mission is to maintain and enhance environmental quality in the Gulf of Maine to allow for sustainable resource use by existing and future generations.

Photo credits: Lowell Canal (p. 7) Tim Grafft; Merrimack River (p. 8) PSNH; Penobscot River (p. 17) Josh Hall; chain pickerel (*Esox niger*), Ken Hammond, U.S. Department of Agriculture; purple loosestrife (*Lythrum salicaria*), U.S. Fish and Wildlife Service; variable water-milfoil (*Myriophyllum heterophyllum*), Leslie J. Mehrhoff, University of Connecticut, available through Wikimedia Commons; rainbow trout (*Oncorhynchus mykiss*), Eric Engbretson, U.S. Fish and Wildlife Service (p. 18); Garvin Falls (p. 26) PSNH; Veazie Dam (p. 27) USFWS.

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1. Issue in Brief

The Gulf of Maine watershed extends from Cape Cod east to the Bay of Fundy and north to the St. Lawrence River valley. The land mass draining into the Gulf encompasses all of Maine and portions of Massachusetts, New Hampshire, New Brunswick, Nova Scotia and Quebec. Its total land area is 179,008 square kilometres (km²) (69,115 square miles) (Thompson 2010).

The watershed is influenced by a complex mix of climatological and geological forces, tracing back to the last Ice Age when the region was buried beneath glaciers. From that legacy and the dominant bedrock geology of granite and limestone emerged a landscape characterized by abundant lakes, wetlands and river systems.

The Gulf watershed encompasses 27 major riverine watersheds—including those of the Merrimack, Androscoggin, Kennebec, Penobscot, St. Croix, Petitcodiac, Shubenacadie and Saint John rivers. This network of rivers and lakes shaped early transportation routes and settlements, generated hydropower and supported industrial development.

Historically, many of the region's rivers offered fishing and hunting opportunities, and provided habitat for diadromous fish species—like alewife (gaspereau), American shad, Atlantic salmon and eels—that spend part of their lives in fresh water and part of their lives in the ocean.

These waterways have shaped the region's growth. Human activities began transforming watersheds and they continue to affect the Gulf of Maine's ecosystems. This paper focuses on the current status of the region's watersheds, exploring some of the many driving forces, pressures, and impacts affecting their health. It highlights how riverine ecosystems link communities and terrestrial and aquatic habitats inland with the Gulf's estuarine, coastal and off-shore environments.

Some forces shaping watershed dynamics (see Figure 1) are local—such as development and forestry practices. Others are regional—like atmospheric deposition of pollutants such as mercury and acid rain. And some, like climate change, are global forces tied to complex atmospheric and ocean circulatory patterns and the retreat of distant ice sheets and glaciers.

This complex mix of forces generates many pressures on watershed ecosystems, including:

- climate stressors, such as increased temperatures and greater storm intensity;
- changing land uses evident in growing suburbanization and forest fragmentation; and
- pollution from nutrient and contaminant runoff, point discharges and atmospheric deposition.

LINKAGES

This paper links to several other theme papers in the State of the Gulf of Maine Report:

- The Gulf of Maine in Context
- Climate Change and its Effects on Ecosystems, Habitats and Biota
- Climate Change and its Effects on Humans
- Coastal Ecosystems and Habitats
- Coastal Land Use and Development
- Eutrophication
- Microbial Pathogens and Biotoxins
- Toxic Chemical Contaminants
- Species at Risk

Water quality, once degraded by industrial pollutants, has improved in many locations, and efforts are underway to restore fish passage and the connectivity required by aquatic organisms. More recent challenges, such as the spread of invasive species and marked declines in biodiversity, are troubling in terms of their potential long-term impact.

Community-led and governmental initiatives are underway to help revitalize watersheds through efforts to improve water quality, biodiversity and nutrient management. Some promising approaches involve collaborative work that crosses municipal, state/provincial and even national borders. These ecosystem-based approaches often rely on conservation, restoration, stormwater management and monitoring.

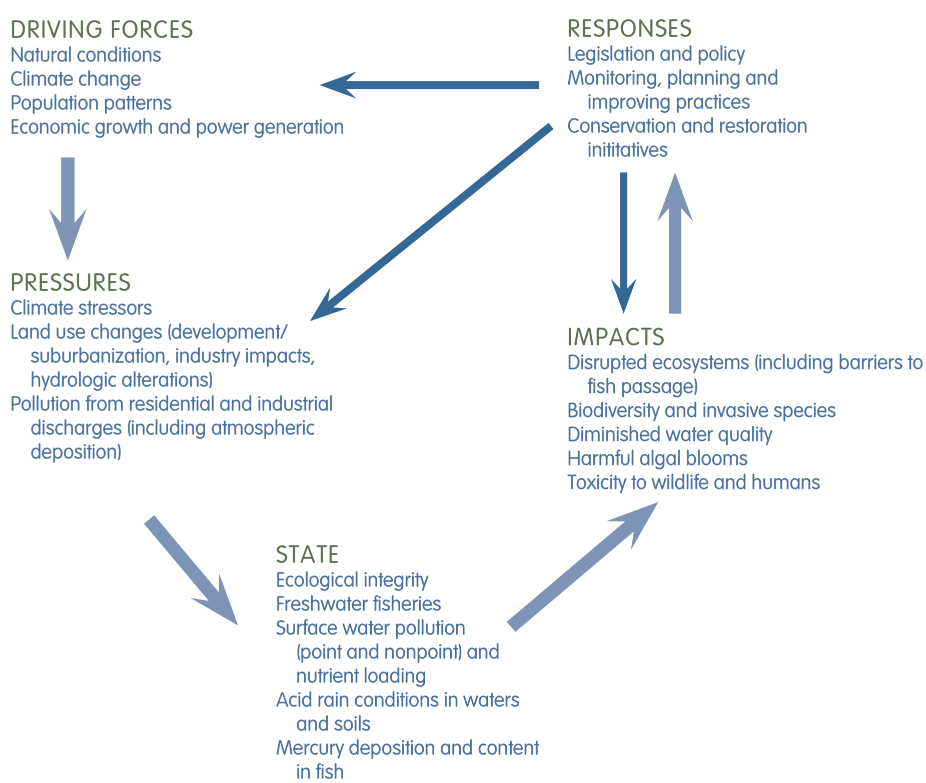


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to watershed status in the Gulf of Maine. The DPSIR framework provides an overview of the relationship between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. The subsequent impacts on the ecosystem, social and economic conditions, and human health may lead to a societal or governmental response that feeds back to all the other elements.

2. Driving Forces and Pressures

The Gulf of Maine watershed and its major basins (Figure 2) have been shaped and affected by geological dynamics, biological systems, the contours and conditions of water bodies, and the weather patterns that characterize the region. Today, these influences are overshadowed by a wide range of anthropogenic factors—including population growth, economic growth, pollution and accelerated climate change.

Figure 2: Map of the Gulf of Maine watershed including the major basins. Watershed boundaries compiled and edited by the U.S. Environmental Protection Agency (EPA) based on the U.S. hydrologic units, the New Brunswick hydrographic network and Nova Scotia watersheds (data sources: U.S. Geological Survey [USGS] and provinces of New Brunswick and Nova Scotia). Prepared by D. Morse, ASRC Federal Vistronix.

Pressures on aquatic ecosystems include increased air and water temperatures, greater frequency and intensity of precipitation, residential and industrial development, habitat fragmentation, hydrologic alterations and pollution of surface water and groundwater from residential and industrial sources (including airborne deposition). These pressures act on ecological processes and biological communities both individually and collectively. Some of these driving forces and pressures are elaborated further in related *State of the Gulf of Maine Report* theme papers (see sidebar, page 1).

2.1 NATURAL CONDITIONS

The Gulf of Maine watershed, shaped by glacial retreat following the last Ice Age, has abundant wetlands, lakes and rivers. Historically, many fast-moving rivers and streams were tapped for hydropower (particularly at sites where dikes or sills within the bedrock produced waterfalls or rapids). The Penobscot River, for example, drops in elevation more than 1,600 metres (5,249 feet) from its headwaters to the Gulf of Maine (Benke and Cushing 2005).

The region's bedrock geology, a mix of metamorphic, igneous (primarily granitic) and sedimentary rock, can influence both surface and groundwater quality (e.g., with many areas naturally high in arsenic and radon). Each watershed's geology can compound or mitigate the impact of other pressures such as climate, land use or pollution. For example, limestone helps neutralize the effect of acid rain, which can have more destructive effects in granitic areas. Certain naturally impervious land covers, such as rock outcrops or clay soils, can contribute to runoff during heavy precipitation.

Surface layers contain "a complex mixture of sand, gravel, silt and clay, sometimes found together as poorly sorted glacial till" (Conkling 1995). Intermixing of sediment and soil types can promote connections among rivers, wetlands and groundwater reserves that help filter water and maintain water flow. However, these linkages can also threaten drinking water in cases where contamination migrates from toxic industrial or landfill sites.

The Gulf of Maine watershed has distinct ecoregions with certain soil characteristics, landforms, climates and biological communities. In southern regions of the watershed, where soils tend to be naturally productive, agriculture and deciduous forests dominate in landscapes that have not been developed. In the northern ecoregions, where soils outside of productive river valley regions tend to be thinner and more acidic, coniferous or mixed-wood forests predominate.

Most of the region is forested: with the exception of the urban southern part of the Gulf of Maine, forests cover more than 70 percent of most watersheds (Table 1). Agriculture ranges from 2 to 12 percent of the area by watershed.

Table 1: Land cover in selected Gulf of Maine drainage areas (compiled from the U.S. National Land Cover database [NOAA 2016]; Garroway, Nova Scotia Environment, pers. comm. June 2016; NBELG 2007a, 2007b, 2007c).

NAME	AREA (SQUARE MILES)	AREA (SQUARE KMS)	FOREST/ SHRUBLAND	AGRICULTURAL LAND	DEVELOPED LAND[1]	WATER AND WETLANDS
Cape Cod and South Shore, MA[2]	643	1,666	39%	2%	37%	18%
Charles, MA	1,013	2,624	33%	5%	45%	17%
Merrimack, MA/NH	5,082	13,164	71%	7%	11%	11%
Piscataqua-Salmon Falls, ME/NH	1,416	3,668	66%	9%	9%	15%
Saco, ME & NH	1,700	4,404	83%	5%	3%	9%
Presumpscot, ME	1,086	2,813	65%	9%	9%	16%
Androscoggin, ME	3,634	9,411	83%	5%	2%	10%
Kennebec, ME	5,949	15,408	78%	6%	2%	14%
Penobscot, ME	8,620	22,326	79%	3%	1%	16%
Maine coastal region including St. Croix to Sheepscot	5,153	13,346	73%	6%	2%	17%
Saint John (ME portion)	5,513	14,279	72%	12%	5%	9%
Saint John (NB portion)	10,850	28,101	83%	6%	2%	7%
St. Croix (NB portion)	639	1,655	81%	3%	1%	14%
Petitcodiac, NB	1,093	2,831	80%	10%	4%	4%
Shubenacadie, NS	1,020	2,642	n.d.	8%	4%	n.d.
Annapolis, NS	872	2,259	n.d.	11%	3%	n.d.
Tusket, NS	825	2,136	n.d.	2%	3%	n.d.

n.d. = no data
[1] For Nova Scotia, this is "urban" land. For New Brunswick, this is "occupied" land.
[2] Portions of the Cape Cod and South Shore drainage area are not part of the Gulf of Maine watershed.

Coastal and southern watersheds, such as the Charles River (Boston metropolitan area) and the Merrimack River watershed (parts of Massachusetts and southern New Hampshire) are heavily developed, while some watersheds in the north, like the Penobscot and St. Croix, have less than 2 percent developed land.

Due to glaciation that was relatively recent in geologic terms, the watershed's aquatic communities have relatively low biodiversity and few species unique to the region, and could be susceptible to invasive species (Curry 2007, Moyle and Cech 2004).

The region experiences relatively high rates of snowfall and rainfall, and the resulting abundant freshwater flow has provided cheap power to spur industrial growth. Prevailing winds from the west and southwest often carry airborne pollution into the Gulf of Maine watershed from the Eastern Seaboard and industries in the midwestern U.S.

2.2 CLIMATE STRESSORS

Regional weather norms are shifting in response to complex influences from global climate change. Climate stressors such as altered temperatures and precipitation patterns can gradually or abruptly transform hydrological, biogeochemical and ecological processes within Gulf of Maine watersheds.

Rising annual air temperatures are leading to less winter snow/ice cover and warmer summers, with an increased frequency of short-term droughts predicted over this century (Frumhoff et al. 2007). Spring runoff is declining, with reduced snowpack and more winter precipitation coming in the form of rain. Changing phenology, with longer growing seasons and leaf-out coverage, could affect water bodies in varied ways (e.g., potentially leading to increased nutrient loads from nitrogen fertilizers being used on lawns more months each year).

Warming of freshwater systems within Gulf of Maine watersheds strains aquatic and riparian ecosystems, changing distribution and abundance of fishes (as many native species are not adapted to warmer water). The warming can also foster the spread of invasive species, including warm water fish species, and promote excessive algal growth (blooms) causing hypoxia (a potentially dangerous decline in oxygen concentrations).

Lake ice-out dates are projected to occur one to three and a half weeks earlier in Canada over the next century, with freeze-up dates expected to be delayed two weeks (Bush et al. 2014). In Maine and New Hampshire, lake ice-out dates have already advanced 16 days from 1850 to 2000 (Wake et al. 2009). The trend toward a shorter ice season will influence how lakes affect "energy, water and biogeochemical processes in cold regions" and will likely change lake ecosystems (Bush et al. 2014).

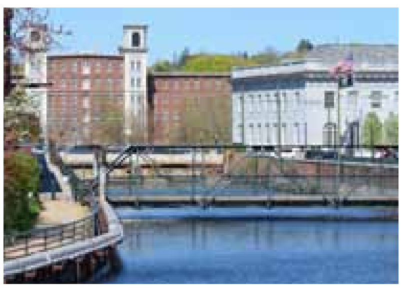
Both the U.S. Northeast and Atlantic Canada are experiencing increased annual precipitation. Canada saw about a 16 percent increase in annual precipitation between 1950 and 2010, with some of the largest changes in Atlantic Canada (Bush et al. 2014).

As land areas and surface waters warm (and the Gulf of Maine warmed faster between 2004 and 2013 than 99 percent of the world's ocean), higher rates of evaporation can increase the amount of moisture in the air (Pershing et al. 2015). Warmer air holds more moisture, creating the potential for more intense precipitation (Bush et al. 2014).

Precipitation falling in very heavy events increased 71 percent in the U.S. Northeast between 1958 and 2010, and is expected to continue increasing in frequency (Horton et al. 2014). Stormwater runoff from the increasingly frequent downpours can carry toxic contaminants and excess nitrogen and phosphorus into local waters—lowering dissolved oxygen (leading to fish kills), stimulating harmful algal blooms, altering ecological communities, and aggravating coastal acidification.

Potential effects of climate change on marine and coastal environments are covered in related papers of the *State of the Gulf of Maine Report* (see *Climate Change and its Effects on Humans* and *Climate Change and its Effects on Ecosystems, Habitats and Biota*).

2.3 POPULATION, ECONOMIC GROWTH AND POWER GENERATION



Population within the Gulf of Maine watershed, particularly in southern portions, is concentrated in coastal regions. More sparsely populated northern and inland areas are losing residents to urban areas and coastal regions that offer more job opportunities (Collins 2004, Index Mundi 2014). Population in the watershed's U.S. states continues to grow (see the *Coastal Land Use and Development* theme paper) while population in the Canadian provinces remains static.

Beyond the few major urban centers, the region's economy relies heavily on natural resources that support forestry, fishing and farming, as well as tourism and recreation that depends on the region's natural beauty and culture of outdoor life.

Historically, rivers powered much of the region's growth. At first, residents built impoundments to store water for household and farm use, and to power water wheels for grinding grain, sawing lumber and carding wool. Later, dams helped facilitate timber transport during log drives, and hydroelectric-generating stations powered paper and pulp processing plants and other industries.

Dams and impoundments can foster recreational uses—such as at the Gulf of Maine watershed's largest dam, which produces 650 megawatts of power, on the Saint John River in New Brunswick. Its headpond, the Mactaquac Dam's reservoir, is a tourist destination with waterfront camping and cottages, beach access, and a robust recreational sport fishery. Similar impoundments along the St. Croix River supply power for a pulp and paper mill while supporting recreational canoeing, camping and a bass sport fishery (ISCRWB 2008).

While fueling economic development, hydropower has reshaped watersheds into a checkerboard of dams, weirs and headponds. The process of creating impoundments and drowning rapids has dramatically altered flow regimes and reduced the diversity and availability of aquatic habitat, particularly for migratory fishes.

Within the states and provinces that border on the Gulf of Maine, there are more than 3000 active dams today—with the majority of them in Massachusetts and New Hampshire (USACE 2016; CDA 2016). Some dams provide for fish passage through fishways or fish ladders, but these vary in effectiveness and require ongoing maintenance.

While dams continue to influence water flow, wildlife and recreation, many of the dominant impacts on waterways today stem from population growth and increased development—particularly in coastal watersheds. These pressures are particularly pronounced in southern portions of the Gulf of Maine watershed.

2.4 LAND USE CHANGES

Beginning with European settlement in the early 1600s and continuing today, the Gulf of Maine watershed has been transformed through timber-cutting, agriculture, and residential and industrial development. Portions of the Gulf of Maine region are experiencing reforestation as once-active agricultural land reverts to woods. Yet larger habitat blocks are increasingly fragmented by road networks, suburbanization and forestry operations. Fragmentation can alter vegetative communities, change established hydrologic patterns, and introduce non-native species (see figures 3 and 4).

Both agriculture and managed forestlands can erode soil, contribute excess nutrients from inorganic fertilizer and manure and contaminate waters with pesticides (Benoy et al. 2012; Weiskel 2007; USEPA 2002). Poor land stewardship practices can diminish water quality and impair biological communities of algae, macroinvertebrates and fish (particularly where streamflow is altered). When native vegetation in terrestrial habitats is destroyed, topsoil can erode—smothering riparian and aquatic habitats downstream.

Road networks can further disrupt habitats fragmented by forestry and agriculture. In urban and suburban areas, impervious cover (from roads, parking lots and rooftops) markedly changes the flow of water within watersheds, and—like dams—can alter streamflow. Studies of urbanization in the Northeast confirm that increased urban runoff and fragmentation erodes biodiversity (Coles and Rosiu 2004).

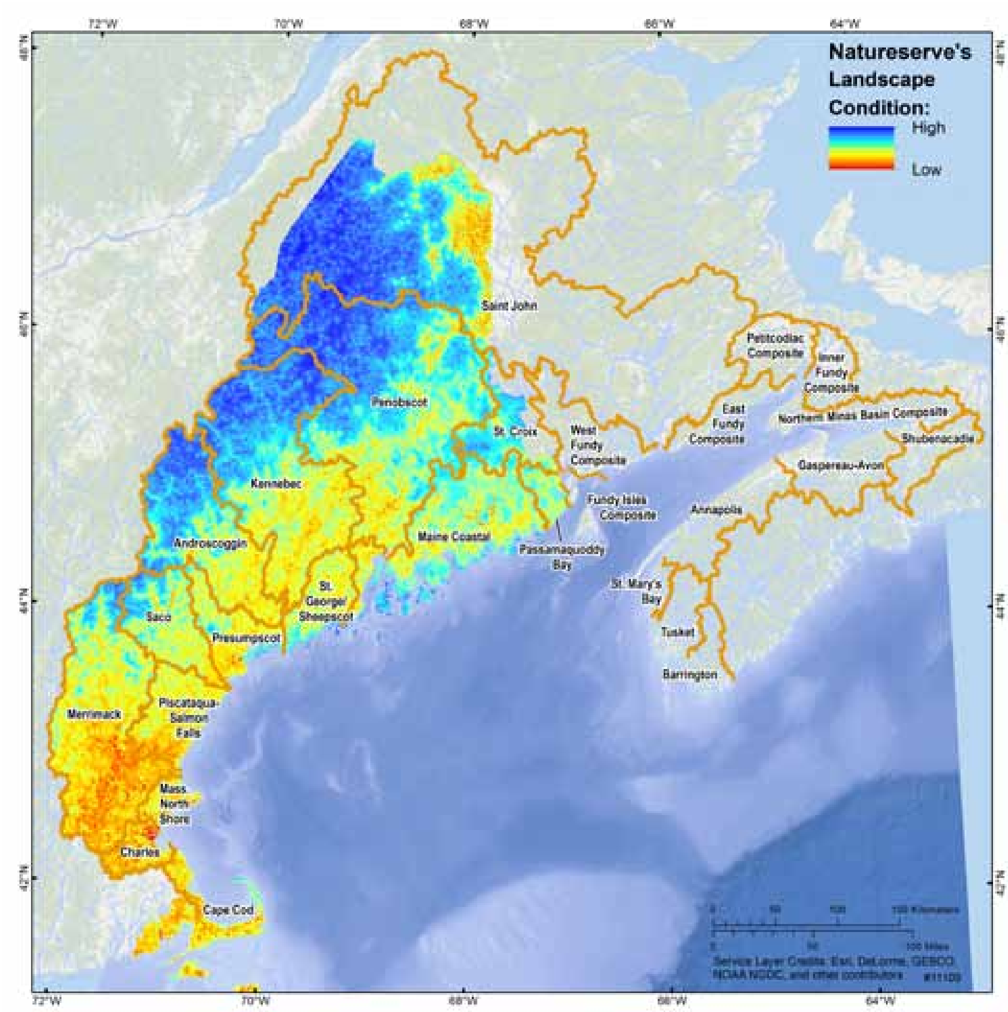


Figure 3: Landscape condition in the U.S. Gulf of Maine watershed, based on the NatureServe Landscape condition modeling tool. This model uses mapped information of human uses that affect ecological condition. Landscape conditions reflect the interaction of physical, chemical, and biological dynamics within natural ecosystems, and incorporate data reflecting human alterations such as vegetation removal or stream alterations. Condition is scaled from 1 to 100; lower numbers represent relatively poor condition while higher numbers represent relatively good condition. Prepared by D. Morse, ASRC Federal Vistronix.

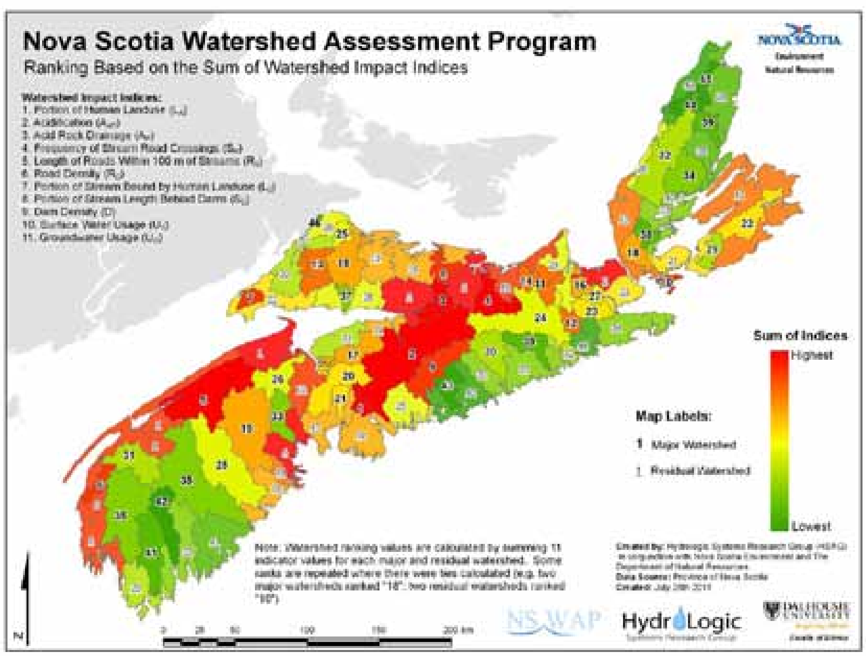


Figure 4: Assessment of watersheds in Nova Scotia based on a sum of rankings of watershed impact indicators. Impact indicators used to calculate rankings are listed on the figure (Hydrologic Systems 2012). Numbers on the map are watershed labels, with bolded numbers indicating major watersheds while non-bolded numbers indicate smaller, "residual" watersheds (see Hydrologic Systems 2012 for more detail of how watersheds were defined). Note that the scale used for this figure is different than Figure 3, with "high" on this figure indicating highly impacted relative to other watersheds.

2.5 POLLUTION

Surface waters in the Gulf of Maine watershed receive pollution both from local sources and from atmospheric deposition of contaminants carried great distances. Regulations have reduced many point sources from industry and wastewater treatment, but nonpoint runoff from impervious surfaces, agricultural fields, forestry operations and lawns is harder to regulate and remains a significant source of nutrients and chemical contaminants within regional watersheds.

Waterways are also degraded by airborne pollutants such as mercury, nitrous oxides and sulfur dioxide from industrial activities and electrical power generation elsewhere in the continent and even overseas. (Trends and impacts of these pollutants are discussed further in Section 3.4.) Power plant emissions contain significant levels of mercury that are deposited in watersheds and transformed into methylmercury which moves up aquatic food chains, endangering fish and wildlife–particularly in areas of high deposition and abundant wetlands (Simcox et al. 2011).

Acid rain forms when air emissions containing sulfur and nitrogen oxide are converted in the atmosphere, and precipitate in the form of sulfuric acid, nitric acid and ammonium nitrate. Emission controls on smelting operations and coal power generation in the U.S. and Canada have lowered rates of acid deposition from sulfur dioxide, but legacy impacts are still evident in terrestrial soils and freshwater sediments—in part because many of the region's watersheds and soils have a low buffering capacity (Likens 2004).

3. Status and Trends

Centuries of human activity have shaped and reshaped the region's waterways, often changing the flow of water and composition of ecological communities, while introducing pollutants and airborne contaminants and affecting human uses.

3.1 ECOLOGICAL INTEGRITY

Most of the waterways in the Gulf of Maine watershed have been markedly transformed by human activities over generations. According to the USGS, 79 percent of streams assessed in the three U.S. states bordering the Gulf of Maine exhibited modified streamflows (a pattern that mirrors national trends). Changes came from a variety of factors such as impoundments, water diversions, urban runoff/impervious cover, wastewater discharges and drinking water withdrawals from both groundwater and surface waters (Carlisle et al. 2011, Carlisle et al. 2013). The most urbanized areas within the watershed displayed the most alterations.

Dams, whether small impoundments or large reservoirs, often regulate flow—removing flood peaks and releasing water during lower-flow periods. These kinds of streamflow modifications can transform communities of algae, macroinvertebrates and fish, changing assemblages to those that flourish in slow-moving currents. Before dam construction on the Saint John River, there was 2379 hectares (ha) (5878 acres) of juvenile Atlantic salmon habitat. Available habitat was reduced to 1347 ha (3328 acres) after construction of the Mactaquac, Tobique and Beechwood dams in the mid-twentieth century (Thrive Consulting 2015).

In coming decades, climate change is expected to markedly alter both streamflow and water temperatures. An analysis by the USGS (based on measurements at gauging stations along 22 Maine rivers that drain to the Gulf) found that for the full period of record (70 years), annual average temperature, precipitation and runoff increased in almost all basins. Annual average temperature typically increased by about 1 °C (1.8 °F) per 100 years at many stations (with a range of 0 to 1.9 °C). Estimates of evapotranspiration for each basin indicated moderate increases in most basins but not as high as expected, perhaps due to other climate change factors such as increased cloudiness. These measurements are consistent with climate change impacts and are expected to continue at an increased rate (Huntington 2014).

While regional data have not yet been compiled, NASA and the National Science Foundation have found that lake summer surface temperatures around the world are warming significantly—at an average of 0.34 °C (0.61 °F) per decade across 235 globally distributed lakes between 1985 and 2009 (O'Reilly et al. 2015). Primary drivers of increased lake temperatures include air temperature, solar radiation, humidity, ice cover and wind, mediated by the water body's area and depth (Huntington 2014; O'Reilly et al. 2015).

3.2 FRESHWATER FISHERIES

Before extensive damming of the region's waterways, rivers like the Penobscot, Kennebec and Saint John supported annual commercial catches of 100,000 to 200,000 Atlantic salmon, and 1,000,000 to 2,000,000 shad and river herring (Saunders et al. 2006).

Stock numbers have plummeted, though, due to diminished fish passage, overfishing and pollution. Today, many diadromous fish populations are at historic lows (Saunders et al. 2006). Fewer than 50 percent of Maine's historic salmon rivers currently have returning salmon populations (Saunders et al. 2006). Despite Atlantic salmon fishery closures dating back to 1984 in Canada, stocks have not rebounded (COSEWIC 2010). Commercial fisheries are also closed in many of the region's jurisdictions for American shad and river herring (alewives/gaspereau) (Saunders et al. 2006).

Like river herring and salmon, the region's eels migrate between fresh water and the ocean. The region's Indigenous peoples have fished this culturally significant species for millennia. While a high-value elver fishery remains, eel populations appear to be dwindling. Stocks in the United States are at or near historic lows and Bay of Fundy rivers show reduced catch rates, with the hydroelectric turbines of dams potentially contributing to mortality (Bradford 2012; ASMFC 2016).

Three freshwater fish species are currently endangered across the region: Atlantic salmon, Atlantic sturgeon, and shortnose sturgeon (for more on other threatened species in the region, see *Species at Risk* theme paper). Populations of shortnose and Atlantic sturgeon have diminished due to overfishing, river fragmentation and pollution (Dadswell 2006; COSEWIC 2015). The dwarf wedge mussel has always been known as an uncommon or rare species of freshwater bivalve. Historically found in 70 locations, it is now found at only 20 sites, a loss attributed to damming and channelization of rivers, agriculture and forestry (Hanson and Locke 1999).

Despite declining fish populations and a consistent decrease in anglers over time (except in New Hampshire), recreational fishing remains a popular pursuit with considerable effort (fishing days), and revenue generated from this activity from food, lodging, transportation and equipment (Table 2).

Table 2: Recreational use of Gulf of Maine lakes and rivers (based on USDOI et al. 1991; USDOI et al. 2014; U.S. Coast Guard 2011; DFO 1990; DFO 2010b).

				RECREATIONAL FISHING IN THE GULF OF MAINE			
STATE/PROVINCE	LAKES	NUMBER OF REGISTERED BOATS (2011)	ECONOMIC VALUE OF BOATING (2011)	YEAR	NUMBER OF ANGLERS	FISHING DAYS	ECONOMIC VALUE OF RECREATIONAL FISHING*
Massachusetts	2,922	186,140	$488,845,724	1991	652,000	9,183,000	$454,240,000
				2011	532,000	8,367,000	$455,403,000
New Hampshire	944	76,952	$42,710,571	1991	319,000	2,894,000	$86,978,000
				2011	228,000	4,370,000	$208,524,000
Maine	6,000	96,918	$125,133,586	1991	448,000	4,643,000	$147,209,000
				2011	341,000	3,873,000	$371,829,000
New Brunswick	2,500	n/a	n/a	1990	93,307	1,009,934	$60,774,626
				2010	67,509	699,226	$95,798,879
Nova Scotia	6,674	n/a	n/a	1990	71,914	1,236,693	$54,752,350
				2010	64,112	830,761	$85,636,538

* Different methodologies used to calculate economic value in states and provinces.

3.3 SURFACE WATER POLLUTION AND NUTRIENT LOADING

By the mid-twentieth century, industrial discharges, municipal wastewater and agricultural runoff had drastically reduced the quality of surface waters through much of the Gulf of Maine watershed. New England's rivers were among the nation's most polluted waters, and stretches of the Saint John River in New Brunswick became anoxic, causing widespread fish kills (CDNHW 1961; Sprague 1964; Robinson et al. 2004).

Legislation and technology have markedly improved wastewater treatment and reduced municipal effluents (USEPA 2002; Chambers et al. 2012). However, in many urban areas antiquated combined sewer overflow systems still prompt beach closures and swimming advisories associated with heavy precipitation events (when sewage enters waterways without treatment). The high-intensity precipitation events associated with climate change exacerbate this problem, carrying both sewage and nutrients into waterways (see theme papers on *Microbial Pathogens and Biotoxins*, *Eutrophication* and *Toxic Chemical Contaminants*).

According to state reports in New England, primary reasons why waters do not attain water quality standards include the presence of nutrients, bacteria and mercury, as well as changes in the number and types of aquatic life. Leading probable sources, according to the most recent data available from the EPA, include atmospheric deposition, urban runoff and stormwater, agriculture and municipal discharges, sewers, and hydrological modifications (D. Switzer, EPA New England, Region 1, pers. comm.). In Massachusetts, the Merrimack River alone has discharges from 46 municipal and privately owned wastewater treatment plants and from 48 industrial dischargers (CDM 2004). The median phosphorus concentration of this river from 1998-2000 was 0.070 mg/L, with every sample exceeding the total phosphorus reference condition of 0.031 mg/L recommended by the EPA for the Eastern Coastal Plain Ecoregion (Campo et al. 2003).

While less urbanization occurs farther north, substantial nutrient challenges remain. The Saint John River is classified as moderately impaired, with several reaches considered areas of concern—due to wastewater treatment plants, food processing plants, pulp and paper mills and potato farming (Culp et al. 2011). Some sub-watersheds of the Saint John River export from 187 to 426 kg of total nitrogen per km^2 per year and from 17 to 70 kg of total phosphorus per km^2 per year (Benoy et al. 2012), yields similar to more urbanized watersheds in the south (Moore et al. 2011) (Table 3).

Table 3: Estimates of total nitrogen and total phosphorus yields for select watersheds in the Gulf of Maine listed from south to north (based on Moore et al. 2011 and Benoy et al. 2012).

WATERSHED NAME	AREA (KM^2)	TOTAL NITROGEN YIELD (KG/KM^2/YR)	TOTAL PHOSPHORUS YIELD (KG/KM^2/YR)
Charles, MA	749	720	35
Merrimack, MA/N.H.	12,950	635	40
Piscataqua, NH/ME	2,574	421	28
Saco, NH/ME	4,389	275	16
Presumpscot, ME	2,574	321	16
Androscoggin, ME	9,129	275	15
Kennebec, ME	15,348	274	16
Penobscot, ME	21,908	224	12
St. Croix, ME/NB	4,269	112	8
Saint John, ME/NB/QC	55,100	290	41

Most rivers that discharge into the Bay of Fundy are considered mesotrophic (moderately nutrient-enriched), with a few considered eutrophic (highly nutrient-enriched) (Environment Canada 2011). The nutrient status did not change appreciably in these rivers between 1990 and 2006 (Environment Canada 2011). See *Eutrophication* theme paper for a more in-depth discussion of nutrient loads to estuaries and coastal waters.

3.4 ACID RAIN AND MERCURY DEPOSITION

The 1991 Canada-U.S. Air Quality Agreement has helped reduce sulfur dioxide and nitrogen oxide air emissions by 50 percent from 1980 to 2007 (EPA website). Decreased emissions have gradually changed the chemistry of surface waters, but depletion of calcium in soils (due to acid rain exposure over time) has slowed improvement in waters and in terrestrial and aquatic ecosystems (Lawrence et al. 2015).

Long-term monitoring at the Hubbard Brook Experimental Forest (HBEF) in New Hampshire and other U.S. sites revealed that acid deposition appears to increase river alkalinity by weathering or eroding calcium and magnesium out of soil and into streams and rivers, potentially affecting biological communities in downstream lakes and estuaries (Kaushal et al. 2013).

First established in 1955 as a National Forest Service study site for hydrologic research, HBEF has provided insights into how watershed ecosystems function through studies of nutrient and pollutant cycling (Campbell et al. 2007). Figure 5,

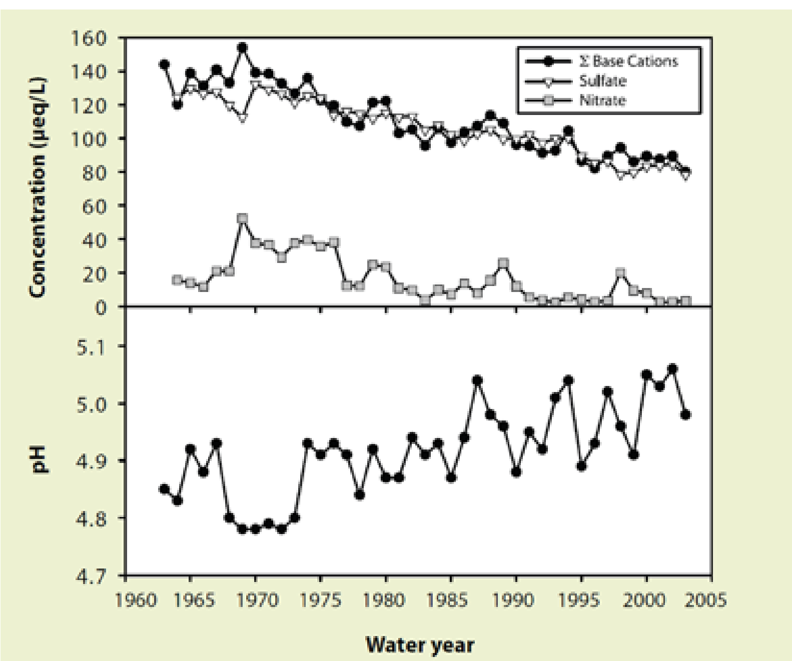


Figure 5: Concentrations of base cations (positively charged ions), sulfate and nitrate, and pH at one location in a stream in the Hubbard Brook Experimental Forest (Campbell et al. 2007).

for example, shows how in one stream gradual reductions over a 45 year period in sulfur and nitrogen pollution from acid rain have led to lowered sulfate and higher pH.

The most recent EPA Report on the Environment found that the percentage of chronically acidic New England water bodies had declined over time (USEPA 2014). In the early 1990s, 5.5 percent of the 57 monitoring sites in New England were considered chronically acidic. By 2012, that percentage had dropped to 2.9 percent. The water bodies sampled were found in areas considered sensitive to acidification.

Almost all of southwestern Nova Scotia is considered a low pH region, with surface waters having a pH below 5.5 (Clair et al. 2007). Despite an apparent decrease in acid deposition from emissions between 1983 and 1997, acidified lakes in Nova Scotia showed no improvement in pH due to their low buffering capacity (Clair et al. 2002).

Airborne deposition of mercury is an ongoing concern in Gulf of Maine watersheds, particularly due to its impact on the food chain of freshwater systems (outlined further in section 4.4).

4. Impacts

4.1 DISRUPTED ECOSYSTEMS

Aquatic ecosystems in the Gulf of Maine watershed are experiencing ecological disruptions, including diminished runs of diadromous fish, due to overfishing, increased temperatures from climate change, multiple impacts of land clearing and urbanization as well as impoundments (the focus of this section).

More than 6,500 river impoundments in the watershed impede migration of diadromous fish, closing off access to freshwater spawning habitats and reducing chances of survival on downstream travels to the ocean. While more than 95 percent of Atlantic salmon smolts moving through reaches of the Penobscot River without dams typically survive, only 52 to 94 percent of smolts survive reaches with dams (Holbrook et al. 2011). Fishways have not worked well for Atlantic salmon, as the fish frequently cannot find their entrances. Less agile swimmers like sturgeon are unable to move past these structures.

Due to impoundments, overharvesting in the twentieth century, and environmental stressors, Atlantic salmon are now listed as endangered in both Canadian and U.S. portions of the Gulf of Maine. Populations are extirpated from New Hampshire and Massachusetts and are critically low in Maine, New Brunswick and Nova Scotia (Saunders et al. 2006; DFO 2010a).

4.2 BIODIVERSITY AND INVASIVE SPECIES

Globally, freshwater habitats occupy less than 1 percent of the Earth's surface yet they support significant biodiversity. Anthropogenic pressures have diminished the range and abundance of many freshwater species, leaving them at greater risk than terrestrial and marine species (Strayer and Dudgeon 2010).

In the Gulf of Maine watershed, as in many other settings, the rate of loss is not easy to quantify because baseline species numbers are not well documented, nor is the potential impact of biodiversity loss on ecosystem function well understood (Higgins 2003). Studies of cyprinid fish populations (minnows) attribute biodiversity losses to urbanization and the introduction of native and non-native predators (Whittier et al. 1997).

In coming decades, freshwater biodiversity loss may be accelerated by climate change, the introduction of invasive species and further landscape fragmentation and nonpoint source pollution. By mid-century, climate change alone could

Photos of non-native species (top to bottom): Chain pickerel (*Esox niger*), purple loosestrife (*Lythrum salicaria*), variable water-milfoil (*Myriophyllum heterophyllum*), rainbow trout (*Oncorhynchus mykiss*).

be responsible for the loss of 30 to 50 percent of all species globally (Thomas et al. 2004). Freshwater fauna in North America could disappear at a rate five times faster than terrestrial fauna (Higgins 2003).

Warmer water temperatures, whether due to global climate change or localized land use (such as urbanization, agriculture and deforestation), reduce populations of cold-water fish species and hasten the introduction or spread of warm-water species—a trend evident in Gulf of Maine watersheds (Robinson et al. 2004).

Regional watersheds are increasingly disrupted by introduced aquatic species, such as *Lythrum salicaria* (purple loosestrife) in wetlands and *Myriophyllum spicatum* (Eurasian water-milfoil) in lakes. Non-native species are introduced to freshwater environments in one of three ways: intentional introductions (such as those made to improve fishing opportunities); accidental releases through human transportation (such as ballast discharge or vegetation carried on boat propellers); and accidental releases from aquaculture operations (Ray 2005). Natural dispersion can further increase the range of these species.

Most ecosystems throughout the Gulf of Maine are already influenced by non-native (nonindigenous)[1] species that were introduced since European settlement. For example, *Micropterus dolomieu* (smallmouth bass), now established in much of the region, were deliberately introduced by the late 1800s to enhance recreational fishing in the New England states and New Brunswick. Other common nonindigenous species include freshwater jellyfish, rainbow smelt, largemouth bass, and brown and rainbow trout (USGS 2014). Even species native to parts of the region can have devastating impacts when introduced to new areas. Chain pickerel, native to the southern Gulf of Maine watershed, has drastically altered native fish communities in Nova Scotia since its introduction in 1945 (Mitchell et al. n.d.).

4.3 NUTRIENT ENRICHMENT AND HARMFUL ALGAL BLOOMS

Excessive loading of nutrients causes eutrophication in downstream waters (see *Eutrophication* theme paper and Section 3.3 of this paper). Ongoing nutrient loads tend to increase primary production (such as algal growth) in watersheds. Increased production can result in increased respiration (oxygen consumption) and reduced concentrations of oxygen, diminishing water quality and making recreational activities less appealing. In severe cases, waterbodies can become anoxic, resulting in fish kills.

Elevated nutrients increase the number of algae, and overgrowth of certain species can reduce the diversity of sensitive macroinvertebrate taxa such as

[1] The USGS defines nonindigenous aquatic species as a member(s) (i.e., individuals, groups, or populations) of a species that enters a body of water or aquatic ecosystem outside its historic or native range, including species native to North America that are introduced to drainages outside their historical range.

Ephemeroptera (mayflies), *Trichoptera* (caddisflies) and *Plecoptera* (stoneflies) (Robinson et al. 2004).

Wildlife and human health are jeopardized by blooms of certain species of cyanobacteria (blue green algae), fostered in part by warmer water temperatures and excess nutrients transported into water bodies by more frequent and intense precipitation events. Blue-green algae blooms are becoming more frequent in the region (including lakes in the Charles, Penobscot, Magaguadavic and Saint John River watersheds). Cyanobacteria concentrations vary enormously in space and time as well as in toxicity—making monitoring challenging (Snook 2015).

Harmful Algal Blooms (HABs) such as blue-green algae blooms can last for several weeks, creating potentially dangerous exposure for humans and animals (including livestock, pets and wildlife) due to the toxins, such as microcystins, produced by certain algae. Microcystins cause allergic skin reactions and intestinal problems, and chronic exposure can lead to liver and nervous system damage. Blue-green algae blooms can temporarily shut down municipal water sources as contaminated waters cannot be used for drinking, cooking or washing. While no drinking water advisories have yet occurred in the Gulf of Maine region, HABs have affected back-up water supplies in New Brunswick and been treated in several New England water supplies.

HABs can also prevent recreational use of waters for several weeks, generating significant economic impacts in communities. During the 2015 season, Department of Health officials issued warnings for seven New Brunswick lakes, while the New Hampshire Department of Environmental Services issued warnings for five lakes and ten lake beaches (NBOCMOH 2016, NHDES 2016b)

4.4 TOXICITY TO WILDLIFE AND HUMANS

While there are many potential sources of toxicity to wildlife and humans caused by changes in the Gulf of Maine watershed, this paper focuses on two examples: acid rain and mercury.

Acidic waters have been a long-standing concern in the Gulf of Maine watershed due in part to the region's native ecosystems and geological substrates. Chronic acidification of lakes and rivers weakens freshwater ecosystems, and can cause problems downstream when acidic and nutrient-enriched waters enter estuaries and bays. Large parts of Nova Scotia have naturally low pH due to an abundance of bogs, while Atlantic Canada in general has low innate capacity to buffer or neutralize the acidity because the soils derive from shale and granitic bedrock parent material with lower base cations (i.e., low alkalinity) (Clair et al. 2007).

Low pH (at values below 6) can negatively affect aquatic communities, decreasing growth and survival rates of fish and other organisms. Eggs and young are more susceptible than adults. Significant mortality of salmon fry occurs at a pH of 5.0, and mortality rates of 72-100 percent occur among parr and smolts at a pH of 4.6–4.7 (Farmer 2000).

Airborne deposition of mercury continues to be a concern in the Gulf of Maine, with methylmercury biomagnifying in the food chain and requiring mercury advisories for fish consumption in all the jurisdictions within the watershed. Mercury concentrations in most biota tested in Atlantic Canada remained unchanged or were increasing in the period 1967-2012, despite reduced mercury emissions (ECCC 2016). Average mercury concentrations in yellow perch fillets across the region exceed the EPA's human health criterion, and concentrations in wildlife that rely heavily on fish are high enough to cause behavioral, physiological and reproductive damage (Driscoll et al. 2007). Evers et al. (2007) identified hotspots and areas of concern where mercury is most concentrated in two indicator species, yellow perch and common loons (Figure 6).

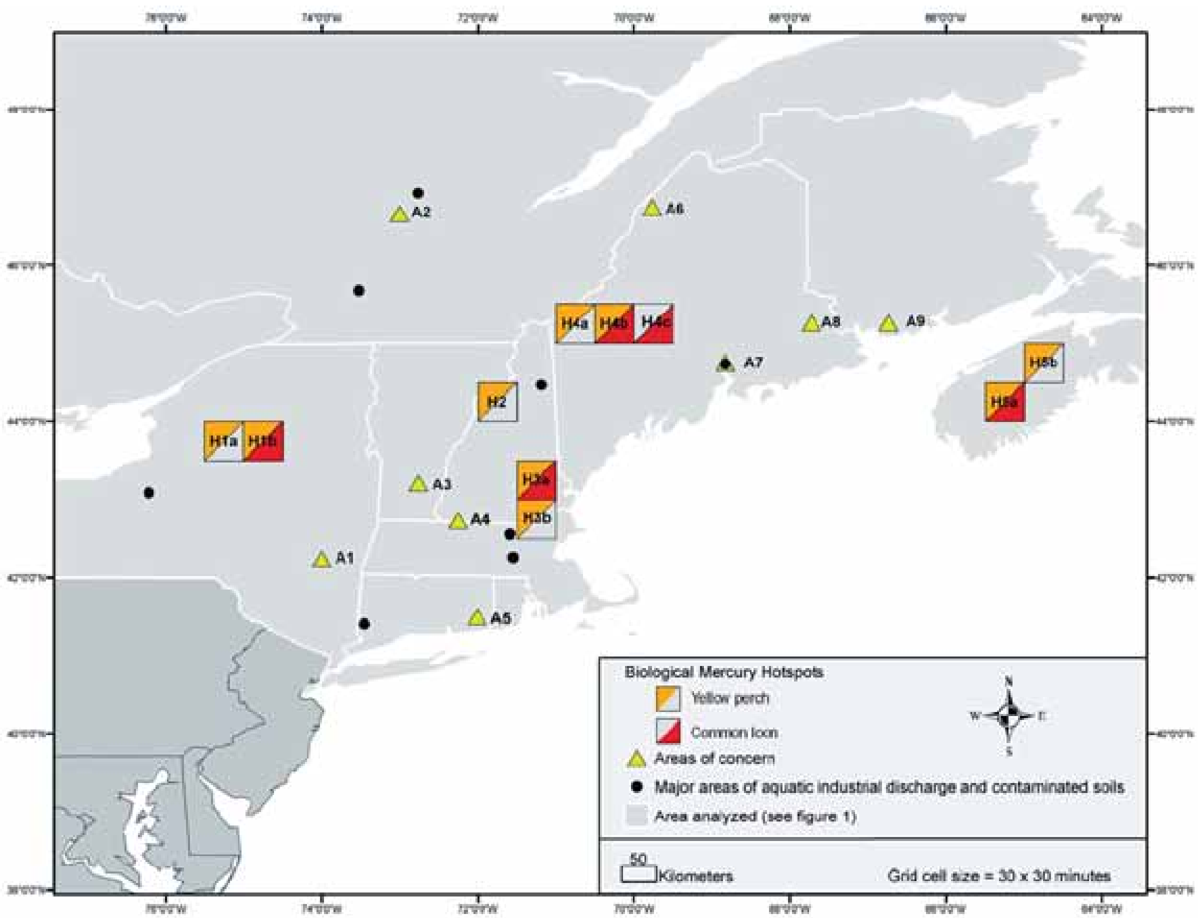


Figure 6: Distribution of biological mercury hotspots (H1a-H5b) and areas of concern (A1-A9). Hotspots and areas of concern that fall in the Gulf of Maine watershed are H3a (middle Merrimack River), H3b (lower Merrimack River), H4A (upper Androscoggin River), H4b (western upper Kennebec River), H4c (eastern upper Kennebec River), H5b (central Nova Scotia), A6 (upper Saint John River), A7 (lower Penobscot River), A8 (Downeast region, Maine), and A9 (Lepreau region, New Brunswick). From Evers et al. (2007), reproduced with permission of the American Institute of Biological Sciences.

5. Actions and Responses

WATERSHED MANAGEMENT REQUIRES CROSS-BORDER COLLABORATION AT every level from local to international. The Gulf of Maine region has good models of this cooperation and some ongoing mechanisms—such as the Gulf of Maine Council on the Marine Environment—to help facilitate this ongoing work. The following examples, while far from comprehensive, illustrate the breadth of ongoing work to protect and restore Gulf of Maine watersheds.

5.1 LEGISLATION AND POLICY

Clean water initiatives

Clean water legislation in both the U.S. and Canada has benefited Gulf of Maine watersheds. Due to the many different policies and pieces of legislation that impact watersheds, this section cannot provide a comprehensive overview of all policy measures. Instead, it highlights several initiatives seeking to address key pressures on regional watersheds.

Ongoing efforts to implement the U.S. *Clean Water Act* have led to markedly improved water quality in the Gulf of Maine's most densely populated watershed. For more than a century, stormwater from urban development and impervious surfaces has carried pollutants such as phosphorus, nitrogen and polycyclic aromatic hydrocarbons (PAHs) into the Charles River in eastern Massachusetts. Sediments in the lower Charles have accumulated high levels of organic contaminants, such as PCBs and metals such as lead, copper, chromium and cadmium. Efforts to eliminate illicit connections between sewer pipes and storm drains began in 1995, when river water quality was rated a "D." After two decades of work, with more than one million gallons of sewage flow per day eliminated, the Charles River had by 2014 achieved a "B+" rating and was reopened for swimming and recreational contact (EPA website).

Through the *Clean Water Act's* National Pollutant Discharge Elimination System (NPDES), federal regulators issue permits for thermal limits to power plants that exploit river water for cooling operations. At Merrimack Station in New Hampshire, for example, cool water native fish species such as yellow perch have significantly declined over time, and the EPA is now issuing a permit to reduce thermal discharge at this location on the Merrimack River.

New Brunswick and Nova Scotia have put in place watershed management initiatives focused on drinking water supplies. In New Brunswick, where 40 percent of the population depends on public water supplies, the province protects watersheds through legislation, limiting activities that may impact water supply

(NBELG 2016). Nova Scotia released its Water Strategy in December 2010, and has 25 protected watersheds where specific activities are regulated throughout the watershed (NSE 2009).

Additional regulatory tools for managing both point and nonpoint sources of wastewater are outlined in the *Eutrophication* theme paper. Efforts to set wastewater guidelines in terms of coastal shellfish beds (such as actions taken by the U.S. National Shellfish Sanitation Program and Canadian Shellfish Sanitation Program) are described in the paper on *Microbial Pathogens and Biotoxins*, while federal and international legislation governing endangered and threatened species is covered in the *Species at Risk* theme paper.

Atmospheric deposition

Gulf of Maine watersheds are subjected to a wide array of toxic contaminants, many of which are discussed in the theme paper on *Toxic Chemical Contaminants*. Chemicals transported through the atmosphere and deposited through rainfall and snowfall—such as mercury and acid rain—pose a particular challenge in terms of legislation and policy.

More than two decades ago, the New England Governors and Eastern Canadian Premiers (NEC-ECP) adopted a comprehensive regional Mercury Action Plan, setting aggressive goals for emission reduction and pollution prevention among the signatories. By 2005, the region had attained a 55 percent reduction in anthropogenic mercury releases (Smith and Trip 2005). The region's success in reaching targets relied heavily on scientific monitoring of indicators (such as fish tissue), deposition sources and releases (Smith and Trip 2005).

While regional limits have helped reduce mercury concentrations near localized sources such as incinerators and coal-burning facilities, reduction of longer-range transport has remained a challenge. In 2011, the EPA issued new national standards to limit mercury and other toxic pollutants from coal and oil-fired power plants, using existing technology. With these new regulations, less mercury is expected to cycle through the region's watersheds.

Invasive Species

Provincial, state and federal legislation aims to prevent the introduction of invasive species in the Gulf of Maine watershed. For example, Nova Scotia's Live Fish Possession Regulations place strict limits on the possession of live fish to minimize the potential for invasive fish species being introduced. Regional efforts are underway to create a more coordinated approach among different jurisdictions. New Canadian regulations aim to fill gaps in the existing patchwork of federal and provincial legislation, while the Northeast Aquatic Nuisance Species Panel (NEANS) helps coordinate actions to control aquatic invasive species in the northeastern states and provinces.

5.2 MONITORING, PLANNING AND IMPROVING PRACTICES

Citizen science

Throughout the region, dedicated corps of volunteers are monitoring water quality in numerous watersheds, creating baseline data to help track long-term change. Among the earliest to form in eastern Canada was the Clean Annapolis River Project. Across the Bay of Fundy, the Petitcodiac Watershed Alliance has compiled more than 12 years of monitoring data that formed the basis of an Integrated Watershed Management Plan (St-Hilaire et al. 2001; Petitcodiac 2012). Their findings indicate that water quality tends to be worse in areas with the most intense land uses and where riparian zones and wetlands have been damaged.

To improve cyanobacteria monitoring within the region, a New England work group formed in 2013 under the auspices of the EPA's New England Regional Laboratory. It comprises lake and watershed associations, citizen monitoring groups, state and federal environmental water quality and beach monitoring programs, departments of public health, tribes, public water suppliers, non-governmental organizations, university extension agents and academic researchers. The pilot monitoring project employs consistent monitoring kits (with field fluorometers), an image-based "Dirty Dozen" taxonomic key and smartphone apps to report results from more than 100 water bodies. Organizers are finding that this more focused and coordinated effort is yielding better understanding of cyanobacteria's potential impact in the region (Snook 2015).

Standardizing data across watersheds

One consistent challenge for watershed management is the disparity across jurisdictions when it comes to collecting, storing and displaying data. Resource managers in the St. Croix watershed, for example, historically had two different methods of treating geographic information system (GIS) data, hampering efforts to form an integrated view of the river basin. Through the International Joint Commission (IJC), hydrologic data from both Maine and New Brunswick portions of the river basin were harmonized into a unified set of maps and data sets in 2007. This collaboration has served as a model for data integration in other transboundary watersheds (ISCRWB 2008).

Within Canada, two networks help support the growth and integration of community-based water monitoring and management: the Canadian Aquatic Biomonitoring Network (CABIN) and CURA H_2O. CABIN helps partners make formalized scientific observations and assessments using nationally comparable standards, promoting collaborative data-sharing to achieve consistent and comparable reporting on water quality and aquatic ecosystem conditions. CURA H_2O, a community-university research partnership in Nova Scotia that seeks to increase community capacity for integrated water monitoring and management, supports local work on water monitoring and watershed education outreach.

Over the past decade, the Gulf of Maine Council's EcoSystem Indicator Partnership (ESIP) has collaboratively developed and tracked indicators such as impervious surface cover, precipitation trends and nutrient and phosphorus loading through a reporting system that includes factsheets and web-based tools.

Groups such as the Canadian Rivers Institute, Maine Rivers, World Wildlife Fund (Canada), the New Hampshire Rivers Council and the Massachusetts Rivers Alliance also help facilitate training and sharing of watershed-related research.

Long-term monitoring

Throughout the region's watersheds, efforts are underway to conduct long-term monitoring of variables affecting both water quality and the health of aquatic communities. Some of these efforts focus on headwaters while others assess the output of tributaries entering the Bay of Fundy and Gulf of Maine. Environment and Climate Change Canada has been monitoring more than a dozen locations in the Bay of Fundy watershed for a decade, and has tracked long-range transport of atmospheric pollutants in many lakes for more than three decades. Long-term monitoring, such as that done at Hubbard Brook Experimental Forest (see section 3.4), is critical to evaluating the success of watershed management strategies.

Long-term planning

Since 1992, the Atlantic Coastal Action Program (ACAP) has worked to improve environmental conditions in New Brunswick's Saint John River basin. Its flagship project lies along Marsh Creek, a tributary that "forms the spine of a 4200-hectare (10,378-acre) watershed […] that drains directly into the Bay of Fundy" (ACAP Saint John website).

Due to development in a former marsh area, the creek had become renowned for sewage discharge and extreme flooding. In 2007, ACAP Saint John began an ambitious initiative to restore the Creek, eliminating all untreated wastewater discharges. Water-quality sampling in 2014 confirmed marked improvements in water quality, with fecal bacterial counts 95 to 99 percent lower than those recorded the previous year (ACAP Saint John website). Water clarity has improved as well, and there are no longer public complaints about offensive odors.

The Piscataqua Region Estuaries Partnership (PREP) is one of three National Estuary Programs in the region affiliated with the EPA (the other two are the Massachusetts Bays National Estuary Program and Casco Bay Estuary Partnership) that takes a collaborative regional approach to watershed management and education. PREP works with 52 communities that lie within the watershed of the Piscataqua River, which marks the border between Maine and New Hampshire.

Each municipality participates in the Piscataqua Region Environmental Planning Assessment, an exercise undertaken every five years. Municipal staff members and regional planners complete a detailed assessment of each municipality's regulatory and non-regulatory approaches to challenges such as wetland and shoreland protection, floodplain management, drinking water source protection, stormwater management, erosion control and land protection. PREP's resulting report card indicates how each municipality is doing and how well they're working to address common challenges. Their collective data help inform watershed-scale planning for threats such as nitrogen loading, impervious cover and climate change.

Participating communities are eligible for grants to help implement actions such as completing a natural resources inventory or climate vulnerability assessment, increasing shoreland setbacks and buffers or adopting model regulations for stormwater management or subdivisions that incorporate conserved lands.

5.3 CONSERVATION AND RESTORATION INITIATIVES

Indigenous peoples

For centuries, Indigenous groups in Canada and the United States have depended on the cultural and natural resources of the Gulf of Maine watershed. Today, many are engaged in watershed protection and restoration efforts, including some that span the international border between Maine and New Brunswick.

Passamaquoddy tribal members in the St. Croix River watershed are working with federal agencies in Canada and the U.S. to ensure that alewife and other anadromous fish can successfully access spawning habitat using fish ladders adjoining dams on this boundary river. Both the Maliseet Nation Conservation Council in Canada and the Houlton Band of Maliseet Indians in the U.S. are working to restore Atlantic salmon in the Meduxnekeag River, a tributary of the Saint John River that straddles the border and lies upstream of New Brunswick's Mactaquac Dam.

Land conservation

Throughout the region, local land trusts and other conservation organizations are protecting undeveloped lands that buffer local waterways (with two cross-border examples highlighted here). These efforts can provide relatively cost-effective means of protecting water quality, particularly for drinking water supplies.

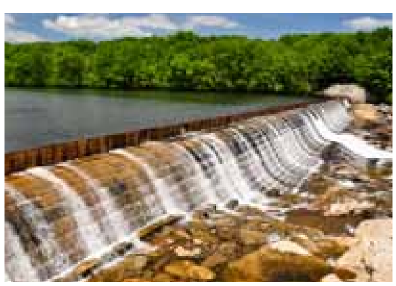
Along the border between Maine and New Hampshire, for example, the U.S. Department of Agriculture's Forest Service found that the Piscataqua-Salmon Falls watershed—where 28,000 people rely on public water systems—was particularly vulnerable to forest fragmentation and diminished water quality (Stein et al. 2009). The Salmon Falls Watershed Collaborative, formed in 2009 to help municipalities, land trusts, water suppliers and landowners protect lands critical to preserving clean water, has to date conserved more than 1,200 acres (K. Jacobs, EPA New England, Region 1, pers. comm.). In addition, the National Resource Conservation Service has funded more than $1 million to implement best management practices on more than 6,000 acres.

In the St. Croix watershed, where developed land makes up just 1 percent of land cover, forests and wetlands help filter waters and limit erosion and downstream flooding, supporting relatively good lake water quality (ISCRWB 2008). Through the efforts of numerous nonprofit organizations such as the Downeast Lakes Land Trust, as well as state, provincial and federal agencies, approximately 42 percent of watershed lands are now permanently protected (ISCRWB 2008).

Between 1996 and 2006, the area of protected land in the St. Croix watershed increased twenty-fold (ISCRWB 2008). Much of this land is in sustainably managed community forests that support the resource-based economy, offer recreational opportunities and provide wildlife habitat. Since 2001, the watershed has seen more than 13,641 ha (33,708 acres) of community forests protected.

The land protection successes of recent decades complement the ongoing planning work of the St. Croix International Waterway Commission, jointly formed by New Brunswick and Maine in 1993 to develop a plan fostering collaborative management of the shared river resource. The latest update in 2014 confirmed that the joint effort has helped to inventory resources, setting cooperative water-quality goals and creating a shoreland greenway (Pond 2014).

Habitat and fish passage restoration



Many watershed associations, state and provincial agencies, federal agencies and nonprofit conservation organizations are collaborating on efforts to restore river flow and revitalize anadromous fisheries. Opportunities can arise when a hydropower energy license is up for renewal, either when dam removal is considered mitigation for a license or when dams no longer provide sufficient energy. With smaller barriers like culverts, even local community efforts can have a large impact.

Along the Bay of Fundy coast of Nova Scotia, the Clean Annapolis River Project (CARP) Broken Brooks Project has worked since 2007 to assess habitat connectivity within the watershed (Freeman 2013). Many culverts in the area are poorly designed, incorrectly installed or inadequately maintained, creating problems such as insufficient water depth, high water velocity or large outflow drops

(Freeman 2013). CARP found that among 777 waterways in its preliminary assessment, 55 percent had barriers. Based on these assessments, CARP targets waterways with full-barrier culverts each year for restoration actions such as debris removal.

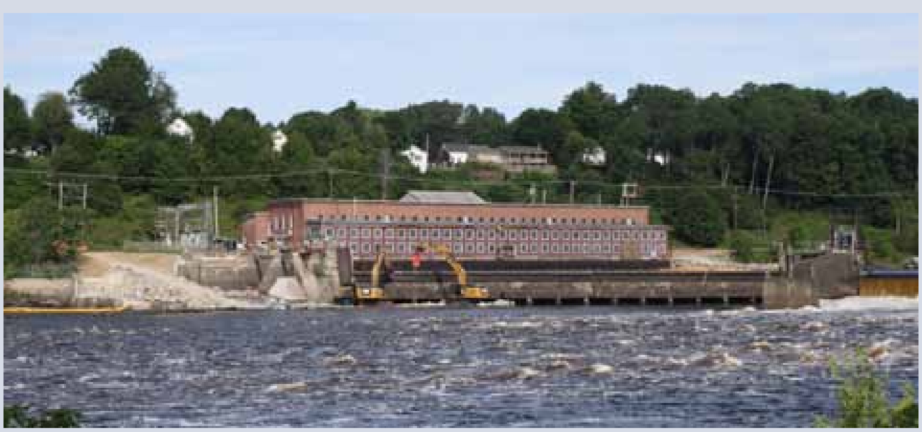
Many other groups are doing similar work replacing culverts, and in Queen's County, Nova Scotia, the Mersey Tobeatic Research Institute and partners have created a fish passage culvert demonstration site.

Restoring Fish Passage

At numerous settings around the Gulf of Maine region, projects to restore aquatic connectivity and runs of diadromous fishes are helping repair past hydrologic alterations. Along the Petitcodiac River in southeastern New Brunswick, the provincial and federal governments conducted an environmental impact assessment on the Petitcodiac Causeway. The 1036-metre installation, built in 1968 along a tidal stretch of the river, restricted saltwater flow into upper portions of the river and severely limited fish passage.

The assessment concluded that a bridge would improve tidal flow upstream of the site, reduce loads of sediment, and foster better fish passage for species such as Atlantic salmon, American eel and Atlantic sturgeon. While construction of the bridge has not yet begun, a decision to keep the causeway gates permanently open has realized many environmental benefits already, including an increase in the numbers of striped bass, American eel, rainbow smelt and tomcod using the river (Redfield 2016).

An evaluation of returning fish runs in Maine's Penobscot River following removal of the Great Works and Veazie dams (in 2012 and 2013) confirmed full accessibility to historic freshwater habitat for four diadromous fish species. After removal of a dam on the Sedgeunkedunk Stream (a tributary of the Penobscot), the upstream abundance of spawning-phase sea lampreys increased four-fold, and the number of nesting sites experienced a three- to four-fold increase (Hogg et al. 2013).



6. Indicator Summary

The table on this page includes a subset of possible indicators based upon the authors' and editors' assessment of relevant status, trends and available data. The indicators listed were those deemed to have the greatest potential impact on Gulf of Maine watersheds.

INDICATOR	DPSIR FRAMEWORK	STATUS	TREND
Storm intensity and frequency	Pressure	Fair—Precipitation events are growing more intense and more frequent	Worsening—Higher intensity precipitation is exacerbating erosion, runoff pollution and water quality degradation
Warmer water temperatures	Pressure	Fair—Water temperatures are gradually increasing	Worsening—Consistently warmer temperatures are likely to alter seasonal timing (phenology) and disrupt aquatic ecosystems and fisheries
Habitat fragmentation	Pressure	Fair—Human uses (agriculture, forestry, development) are fragmenting habitats at a rate that far exceeds population growth	Worsening—Projections are that this trend will increase, particularly in populous coastal counties
Dams and other hydrologic modifications	Pressure	Poor—The region has more than 6,000 barriers in watercourses, but widespread efforts are underway to restore flow	Improving—Many groups are working systematically to improve or remove existing barriers
Modified stream flows	State	Poor—79 percent of the streams assessed in the three U.S. states exhibit modified stream flows	No trend—Both positive and negative influences
Diadromous fish populations	State	Poor—Populations of many diadromous fish have fallen markedly and restoration efforts have not yet prompted a significant rebound	Worsening—Populations already suffering from habitat loss are experiencing pressures from climate change, invasive species and other ecological disruptions
Acidity of freshwater bodies	State	Fair/Poor—In many parts of the region, acidification has affected populations and health of biota	Improving—Studies indicate that fresh water bodies in New England may be decreasing in acidity while there is no apparent trend in the Canadian portion of the watershed
Number of lakes and rivers with introduced species	Impacts	Fair—Many Gulf of Maine aquatic species are influenced by non-native species	Worsening—Invasive species are expanding in range
Number of harmful algal blooms	Impacts	Fair—Nutrient loading is contributing to more outbreaks of potentially harmful algal growth	Worsening—Warmer water temperatures will likely increase incidence of these blooms and risks to public health and wildlife
Concentration of mercury in key biota	Impacts	Poor—Mercury is a leading cause of impairment in New England water bodies and mercury levels in most biota in Atlantic Canada are unchanged or increasing	Unknown—Could improve because of reduced mercury deposition
Changes in acreage of permanently conserved land	Response	Fair—Many parts of the Gulf of Maine watershed have seen significant conservation gains	Unknown— Trend data not available by watersheds or for the Gulf of Maine watershed as a whole
Habitat and fish passage restoration	Response	Good—Many efforts are underway around the Gulf of Maine watershed to restore ecological integrity	Improving—Community, nongovernmental and governmental efforts appear to be increasing

Categories for Status: Unknown, Poor, Fair, Good.
Categories for Trend: Unknown, No trend, Worsening, Improving

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