Gulf of Maine Council on the Marine Environment
Climate Change Network

Identifying the Possible Effects of Extreme Precipitation and other Climate Change Impacts on Streamflow and Water Quality in the Gulf of Maine – a Background Report

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Introduction

The Gulf of Maine Council on the Marine Environment (GoMC) 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.[1] The Council consists of committees falling under the headings of habitats, maritime activities, services, and cross cutting. Under these general headings there are several sub committees, such as habitat monitoring and IT and mapping initiatives.

The two cross cutting committees consist of the Ecosystem Indicator Partnership (ESIP) and the Climate Change Network. ESIP's activities focus on convening regional practitioners in six indicator areas: coastal development, contaminants and pathogens, eutrophication, aquatic habitat, fisheries and aquaculture, and climate change. ESIP is developing indicators for the Gulf of Maine (GoM) and integrating regional data for a new web-based reporting system for marine ecosystem monitoring. The Climate Change Network strives to bring the latest climate change science, impacts, and adaptation information to the Gulf of Maine community.[2]

The Climate Change Network is currently working toward completion of three sections of the 2007-2012 Action Plan under Goal 1. These include:

- 1.6 Compile and disseminate information on coastal habitats and watersheds at risk due to climate change;
- 1.17 Conduct risk analysis and prioritize the vectors of invasive species and understand the effects of climate change;
- **1.18 Convene stakeholder workshops to identify and promote mitigative and adaptive strategies for dealing with sea-level rise and changes in water quality related to climate change.**

This is the third of three documents addressing the background information available on climate change. The purpose of this document is to identify available research on streamflow measurements, sediment contamination, effects of precipitation changes on watercourse erosion rates, and the consequences to water quality in freshwater and marine environments. Originally, sea-level was to be a major component of this document, however that aspect was covered in the first paper (Horton and McKenzie, 2009) and will therefore only be a small component of this document.

The focus is to bring together the available information in publications and to begin to identify where gaps may exist. Recommendations for further work are subsequently suggested.

[1] http://www.gulfofmaine.org/

[2] http://www.gulfofmaine.org/council/committees/

The Gulf of Maine Overview

The Gulf of Maine is roughly rectangular in shape with approximately 21 basins, the deepest of which include Georges, Wilkinson, and Jordan basins (300-400 m). The Gulf, which has an area covering approximately 93 000 km^2 (36 000 mi^2) of ocean, 12 000 km (7 500 mi) of coastline, and a watershed of 179 000 km^2 (69 000 mi^2) is of significant importance to many species of marine, estuarine, freshwater, and terrestrial origin.

The distinctive topography of peaks and plateaus of the Appalachian Mountains and the rocky coastlines give hints of the icy past. Glaciers cut valleys and shaped coastlines, scouring rock from one area and depositing in others. This created a mosaic of forest types, numerous swamp and lake water basins, and an undersea shelf as diverse as any on Earth. The mountains and plateaus are underlain by granite and metamorphic rocks and are often thinly mantled by glacial till.

The climate is characterized by warm, moist summers and cold, snowy winters. Maritime air masses moderate the extremes and bring precipitation to the area year round and evenly distributed in the forms of either rain or snow with a mean annual rate of 1000-1600mm. This increases towards the Atlantic coast and at higher elevations. Inclusive of areas slightly inland and to the west of the Gulf watershed mean annual temperatures range from 3°C to 6.5°C, rising in the east, and mean summer temperature is 14.5°C. Mean winter temperature within this region ranges considerably, from -7.5°C in the northern New Brunswick Uplands to -1.5°C along the Atlantic coast of Nova Scotia[3].

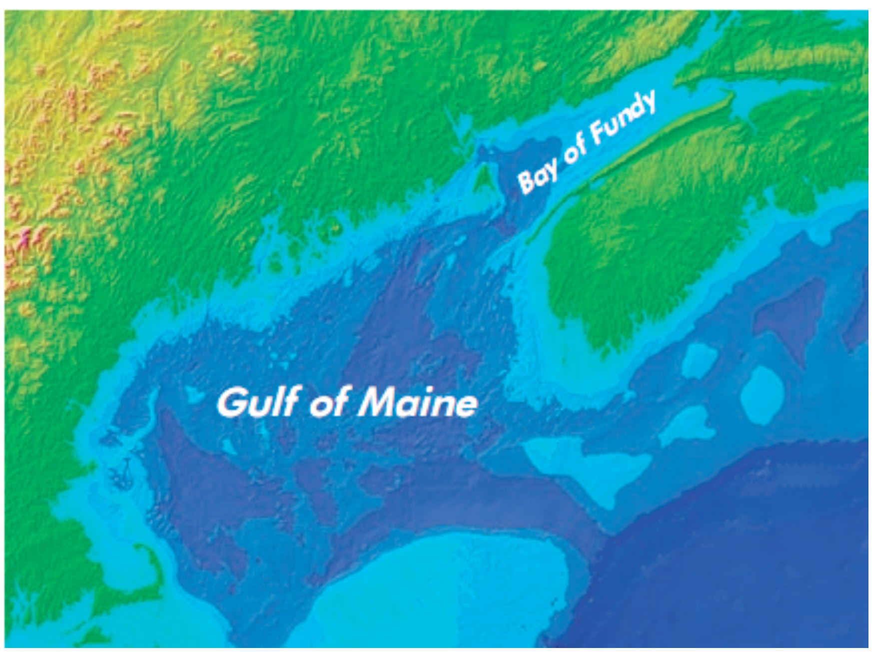

Figure 1: Gulf of Maine.

[3] http://www.nationalgeographic.com/wildworld/profiles/terrestrial/na/na0410.html

The Watershed

The watershed encompasses much of Nova Scotia, New Brunswick, Maine, New Hampshire and Massachusetts, and a small portion of Quebec. Figure 2 shows the Gulf of Maine Watershed including major river basins. There are several significant rivers that drain into the Gulf. The St. John (NB) and Penobscot (ME) have the greatest discharge. Others include, counter clockwise from Nova Scotia to Massachusetts, the Annapolis (NS), Shubenacadie (NS), Salmon (NS), Petitcodiac (NB), Magaguadavic (NB), St. Croix (NB/ME), Kennebec (ME), Saco (ME), Piscataqua (NH), and Merrimack (MA) rivers. The State or province listed is where each river enters the Gulf of Maine, but as rivers cross political boundaries freely there may be more than one jurisdiction in each watershed[4,5]. This is by no means an exhaustive list. There are many watershed groups working toward the betterment of their particular areas. One list of watershed groups can be found on The Gulf of Maine Summit report site[6]. These projects include many of the major river systems and estuaries.

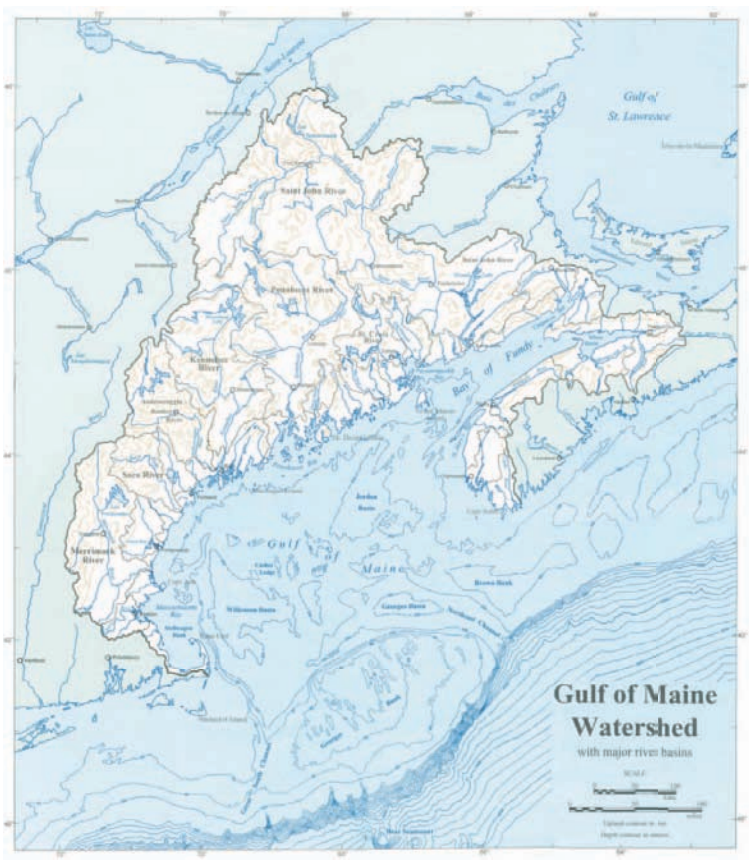

Figure 2: Gulf of Maine watershed map[7].

[4] http://www.nationmaster.com/encyclopedia/Gulf-of-Maine

[5] http://en.wikipedia.org/wiki/Gulf_of_maine

[6] http://www.gulfofmainesummit.org/grouplist.html

[7] http://www.gulfofmaine.org/knowledgebase/aboutthegulf/maps/mapsandphotos.php

The Environments

Terrestrial Environment

The terrestrial environment in the GoM consists mostly of temperate deciduous forests in the New England States changing to mixed deciduous and coniferous forests in northern Maine, New Brunswick and Nova Scotia. Forested areas make up some 91 700 square miles (238 000 square kilometres) and cover about 75% of the land.

The World Wildlife Fund and National Geographic have divided the world into 'ecoregions'. The GoM comprises two of these regions: the Northeastern coastal forests and the New England-Acadian forests. The Northeast coastal forests range from Maryland to Southern Maine. These forests are dominated by oak and have lost almost all native American Chestnut trees to a parasite (*Endothia parasitica*) brought in by Chinese chestnuts in 1904.

The second forest type can be described as a transition zone between the boreal spruce-fir forest to the north and the deciduous forest to the south, with the Atlantic Ocean strongly influencing vegetation dynamics of the ecoregion, especially in coastal areas. Along the Fundy Coast, high winds, cooler summers and strongly broken topography with many areas of shallow soil result in a greater occurrence of conifer-dominated forests.

Freshwater Environment

Freshwater is in abundance in the GoM. The many rivers, lakes, and coastal wetlands in the Gulf of Maine watershed provide productive nurseries for many marine fish; riverine pathways for historically abundant populations of anadromous fish; important habitat for breeding, migratory, and wintering waterbirds and neotropical migrants; and vital habitat for threatened and endangered species[8].

More than sixty rivers with thousands of tributaries make their way through the watershed and drain around 250 billion gallons into the Gulf basin each year. The drainage network comprises 179 000 km^2 (69 000 mi^2).

Freshwater from watershed areas is a major source of drinking water and must be protected in order to provide high quality water for human use. Damage to riparian areas and watersheds has a direct consequence on potable water quality (Smith et al., 2008). Climate change events resulting in flooding or low flow may lead to impairment of freshwater environments.

Riparian Zones

Riparian areas form the transition zones where land meets water: the vegetated habitats such as forests that fringe the shores of rivers, lakes, ponds, and coastlines. They are vital to the ecosystem as they filter water, control flooding, maintain water quality conditions (such as cool water temperatures) and are an important food source for aquatic invertebrates[9]. These

[8] http://www.beginningwithhabitat.org/about_bwh/index.html

[9] http://www.gulfofmaine.org/times/fall2002/science_insights.html

invertebrates in turn support ecologically diverse food webs which in the Gulf of Maine include 12 diadromous fish species (most are anadromous with the American eel being the only catadromous fish species in North America). This is of great ecological importance as only 87 of 24 700 fish species in the world are anadromous[10].

In an ecologically healthy landscape, streams and their riparian areas form the stream corridor. This encompasses the moving river channel, exposed bars and areas of slow moving or still water near the channel, and the floodplain surfaces above and outside the channel banks. In naturally occurring riparian areas riparian plant communities stabilize river banks and regulate sediment deposition on floodplains during overflow events.

Marine Environment – Estuaries

The strength and timing of freshwater runoff affects the delivery of sediment, nutrients, and contaminants to estuaries and circulation within estuaries and continental shelf areas. Increases in runoff add more freshwater to the system and have the potential to increase the vertical stratification and decrease the rate of thermohaline circulation. Salinity gradients are also driven by freshwater inputs and have strong effects on biotic distributions, life histories, and geochemistry (NOAA, 2000). “Ecological processes within estuaries and the types of estuarine habitat are influenced by hydrologic factors of the associated watershed, by the estuary’s surface area and volume, and by its freshwater and marine inputs” (Kennedy et al., 2002). Residence time of water and associated nutrients and contaminants in an estuary are also affected by these hydrologic factors. Freshwater inflow brings particulate material from the watershed that sinks in the estuary as flow decreases and the inflow of seawater from the ocean moves inland along the estuary bottom. This retains these sinking particles and stratifies the water column (Kennedy et al., 2002).

Climate Change

Much work has been done to understand how the world’s climate may change over the next century. Although well known efforts such as the Intergovernmental Panel on Climate Change’s assessments (e.g. IPCC, 2007) have traditionally focused on understanding the science and impacts of climate change at global and continental levels, each subsequent assessment has provided more detail of regional value. Christensen et al. (2007) looked at future climate projections from a number of models and emission scenarios. For the east coast of North America they concluded that over the remainder of the century average annual temperature could rise 2°C to 3°C and average annual precipitation is expected to increase, particularly in the fall and winter.

A major impact of climate change on the marine environment is sea-level rise. Nicholls et al. (2007) estimated average, global sea-level rise by the end of the century, based on a moderate scenario of greenhouse gas emissions, to be 0.35 m. The Gulf of Maine may experience additional sea-level rise over the same period, possibly 0.05-0.1 m, resulting from changes in ocean salinity, density, and circulation (Meehl et al., 2007).

[10] http://restoration.gulfofmaine.org/habitatsandthreats/anadromousfishhabitat.php

Generally speaking, climate change may lead to more storms, greater overall precipitation, and more extreme precipitation events. In the marine environment, increased storminess may result in increased strength and frequency of waves, and an increase in coastal erosion and deposition. Increased water temperatures can lead to lower dissolved oxygen levels. Sea-level rise may drive salt wedges upstream and infiltrate fresh water aquifers with salt-water.

National and sub-national studies have attempted to determine more regional impacts of climate change and can offer more detailed information of use to the Gulf of Maine region. Some recent examples include work by the Union of Concerned Scientists (2006), Environment Canada (Daigle et al., 2006), and Natural Resources Canada (Lemmen et al., 2008). Individual researchers also conduct smaller relevant studies, although their results may not always be published in sources easily accessible by the non-academic community.

Indicators of Past Climate Change

Understanding climate change is not limited to computer-based and other scientific models. Many of the impacts can be readily detected over time, through deliberate observations of current events or data mining of past records. Making such observations and understanding their relationship to climate change can result in the development of climate change indicators. Once identified, these indicators can tell us which aspects of a local system are sensitive to climate change and thus should be monitored into the future to better understand how climate change is driving changes in the local ecosystems.

Wake et al. (2006) examined twentieth century precipitation records for what they identified as the Cross Border Region (Northeastern U.S. and the Maritime Provinces), surrounding much of the Gulf of Maine. By aerial weighting average precipitation records from 133 weather stations in the region, they were able to create a time series (Figure 3) showing an increase in average precipitation over this period of approximately 12%.

Relevant findings of Wake et al. (2006) related to snow and ice include:

- Most stations showed a decrease in total snowfall (1970-2002);
- Overall decrease in snow:rain ratio in New England (1949-2002); and
- Earlier ice-out dates for lakes in New England; on average 4-5 days since 1920.

Wake et al. (2006) also looked at twentieth century volume data for the “17 longest-record, rural, unregulated rivers in the CBR” (Figure 4). They found that the centre-of-volume date (the date on which 50% of the winter/spring water flow passes) became significantly earlier on most rivers; particularly for those that are most heavily influenced by snowmelt.

Changes in timing and volume of fresh water flow in the spring may have ecological consequences for estuaries and coastal waters of the Gulf of Maine, including “timing of nutrient cycling and the inland migration of the salt water” (Wake et al., 2006).

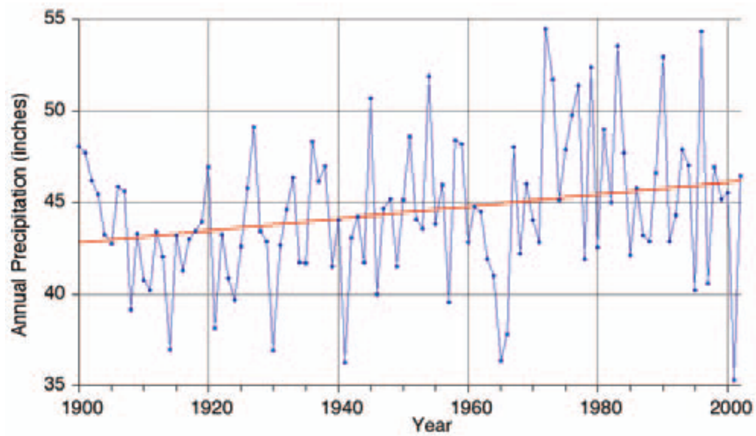

Figure 3: average annual precipitation for the Cross Border Region (Northeastern U.S. and the Maritime Provinces), from 1900 to 2002 (Wake et al., 2006).

Subsequent climate change indicator work for the Gulf of Maine is underway by ESIP[11] (McKenzie et al., 2009). Using a pressure-state response framework, ESIP's climate change sub-committee has chosen three initial priority indicators: air temperature change, precipitation anomalies, and sea-level rise[12].

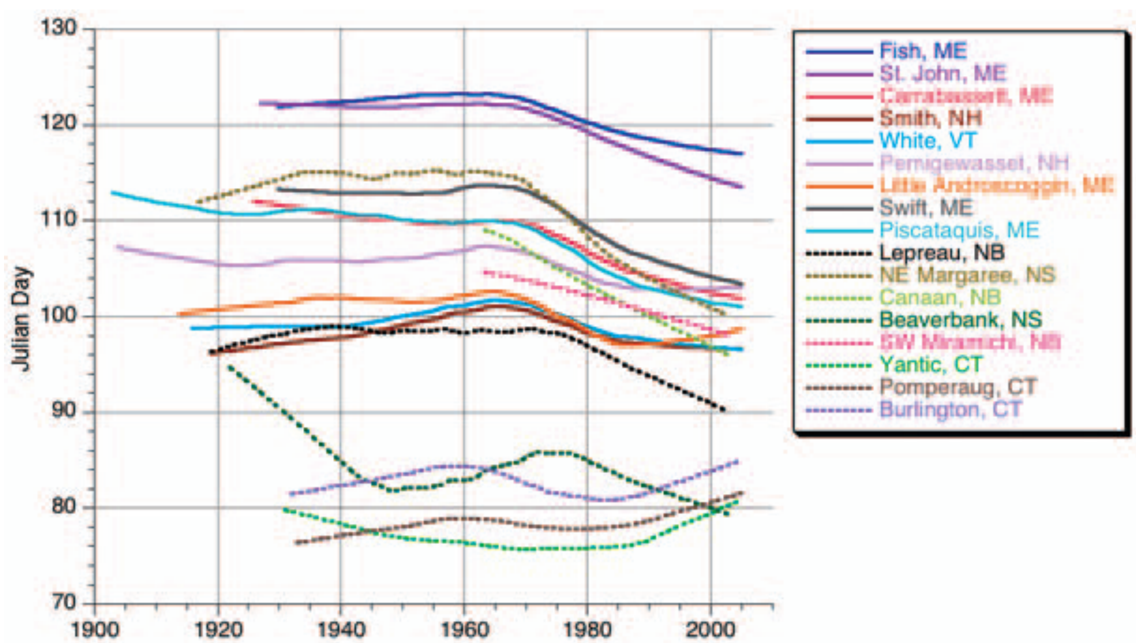

Figure 4: "Smooths of winter/spring (January 1 to May 31) center-of-volume dates for the 17 longest-record, rural, unregulated rivers in CBR." (Wake et al., 2006).

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[11] http://www.gulfofmaine.org/esip/

[12] C. Tilburg, personal communication (2009)

Climate Change Impacts

The Gulf of Maine falls within the area known as the Atlantic Maritime Ecozone as defined by Natural Resources Canada. The area experiences distinct seasons but extremes are moderated by the influence of the Atlantic Ocean. Mean winter temperatures range from -8 to -2°C. Mean summer temperatures range from 13 to 15.5°C, with a mean annual precipitation of 800-1500 mm (Vasseur et al., 2008). In its Fourth Assessment Report (IPCC 2007), the Intergovernmental Panel on Climate Change projects an increase in globally averaged surface air temperatures of 2-4.5°C by 2100. Some worrisome evidence has been seen of a possible effect of increased temperature for the Atlantic Provinces; 2001 for example saw a drought that reached across Canada. The Atlantic region had the third driest summer on record with large areas of the region experiencing only 25% of the normal rainfall levels for July and the driest August on record. The corresponding potential impacts on water resources according to NRCan are shown in Table 1 (Vasseur et al., 2008).

Table 1: Potential Impacts of Climate Change on Water Resources in Atlantic Canada (Warren, 2004).

Potential Impacts	Associated concerns
Decreased amount and duration of snow cover	Smaller spring floods, lower summer flows
Changes in the magnitude and timing of ice freeze-up and break-up	Implications for spring flooding and coastal erosion
Possible large reductions in streamflow	Ecological impacts, water apportionment issues, hydroelectric potential
Saline intrusion into coastal aquifers	Loss of potable water and increased water conflicts

Stream Flow

In the next 100 years mean surface air temperature is expected to increase by 2 to 6°C in Atlantic Canada (Parks Canada, 1999) (El-Jabi et al., 2004). This could potentially lead to great reductions in streamflow (El-Jabi et al., 2004). As highlighted in Table 1 streamflow reductions are of concern in relation to water quantity and quality. Possible reductions in summer stream flow could affect recreation and tourism, freshwater fisheries, hydroelectric power generation, municipal water supplies and agriculture (Vasseur et al., 2008). Worldwide over 50% of total accessible runoff is being used. This is expected to increase to 70% in the next 25 years (El-Jabi et al., 2004) (Postel et al., 1996). In the 1990s many rivers in Eastern Canada experienced low flow conditions and record high temperatures. (Caissie, 1999) (Caissie, 2000) (El-Jabi et al., 2004). Policy makers are concerned as climate change may stress the water resources if adaptive techniques do not take these impacts into consideration. Changes to the hydrological cycle are being studied utilizing climate model output with the most suitable models being chosen for policy development.

According to a water balance model, the projected increase in temperature will result in greater rates of evaporation and evapotranspiration which could cause a 21 and 31% reduction in annual stream flow in the southern and northern sections of the Mid to Northeast USA, respectively, with greatest reductions occurring in autumn and winter (Moore et al., 1997).

Figure 5: High flow, Grand Falls, N.B., Spring 2002 (K. McKenzie).

A study conducted in New Brunswick in 2004 (El-Jabi et al., 2004) focused on low flow characteristics at the river level. It was based on data gathered from 31 hydrometric stations across the province, 20 of which have water that flows into the Bay of Fundy/GoM. Based on the knowledge of air temperature, current flow rates, and precipitation, future changes in air temperature, precipitation and discharge were calculated using statistical downscaling methods. The assumptions are that changes in air temperature and precipitation may lead to changes in future flow rates. Currently, the highest flow rates occur in spring after snowmelt and high rainfall, and low flows in the late summer when precipitation is low and plant consumption and evaporation are high. Low flow also occurs in winter when water is stored as snow and ice. Conclusions drawn are that average annual discharge will increase by as much as 45% due to the significant increases in winter and spring discharge. Warmer temperatures mean that less precipitation falls as snow and therefore less intense flooding from snowmelt. However, mid-winter thaws could become more frequent leading to more ice jam conditions and scouring beds (Beltaos and Burrell, 2003). Summer discharge is expected to decrease, presumably due to greater loss through evaporation (El-Jabi et al., 2004).

In Maine, the Environmental Protection Agency[13] is also taking climate change into consideration. They surmise that a warmer climate would lead to an earlier spring snowmelt, resulting in higher streamflows in winter and spring and lower streamflows in summer and fall. Water quality problems could be exacerbated by warmer summer temperatures especially in rivers such as the Androscoggin, where industry is significant and pollution has traditionally been a problem. Lower summer streamflows could reduce the ability of rivers to assimilate waste. There is no indication as to what possible changes may occur in terms of pollutants. This could be a basis for further study.

[13] http://www.epa.gov/ncea (retrieved 16-03-09)

Figure 6: Low flow, Magaguadavic River, St. George, N.B., October 2006 (K. McKenzie).

Natural Resources Canada[14] projected decreasing trends in renewable water supply over areas in southern Canada with substantial precipitation. The evaporative fraction, or ratio of evapo-transpiration to precipitation, is projected to increase over the 21st century for the Annapolis Valley watershed in Nova Scotia. This implies a decrease groundwater flow in streams.

Floods

Changes in precipitation such as the amount, frequency or type can affect the susceptibility of a waterway to flooding. Atlantic Canada could see more rain-on-snow events with increased precipitation and temperature. This could cause flooding when rainwater cannot infiltrate the ground and subsequently runs off. The Saint John River has already experienced flooding resulting from this type of precipitation change. As the cold and mild spells alternate, the potential for ice jams to occur also increases (Vasseur et al., 2008).

[14] http://sst-ess.rncan-nrcan.gc.ca/ercc-rrcc/theme1/t1_e.php. (retrieved 9-03-09)

Figure 7: River ice on the Tantramar Marsh, Nova Scotia/ New Brunswick border, February 2005 (K. McKenzie).

Precipitation moves through a watershed in many stages. Initially, a large proportion of the precipitation contributes to surface storage. As water infiltrates into the soil, it is stored in one of two types of storage: retention and detention. Retention is storage held for a long period of time and depleted by evaporation; detention is short-term storage depleted by flow away from the storage location. Flow then moves through unsaturated soil near land and as groundwater through aquifers, or as overland flow. Excess rainfall is that rainfall which is neither retained on the land surface nor infiltrated into the soil. After flowing across the watershed surface, excess rainfall becomes direct runoff at the watershed outlet under the assumption of Hortonian[15] overland flow. This saturation can lead to flooding.

There are several mechanisms for flooding. The main types affecting the Atlantic provinces and extrapolated to the Gulf of Maine region are shown in Table 2.

[15] Hortonian overland flow is described as "Neglecting interception by vegetation, surface runoff is that part of the rainfall which is not absorbed by the soil by infiltration" (Chow et al., 1998).

Table 2: Hydrometeorological Flood Mechanisms (Brooks et al., 2001).

Mechanisms	Description
Snowmelt	Snowmelt floods are one of the most common types of flooding in Canada. The magnitude of the flooding reflects, in part, the thickness and density of the snowpack and the rate of melting. Snowmelt floods occur in watersheds of all sizes, often in combination with storm-rainfall runoff and/or ice jams.
Storm-rainfall	Storm-rainfall floods occur directly from rainfall runoff in all regions of Canada. More isolated, but particularly severe flooding can be caused by thunderstorms.
Rainfall-on-snow	Rainfall-on-snow floods occur in all parts of Canada and result from a combination of snowmelt and storm-rainfall runoff. Such floods can be particularly severe during the winter and early spring elsewhere in Canada. Notable examples include flooding along the St. John River, New Brunswick, during March 1936 and April 1973.
Ice-jams	Ice-jam flooding is caused by the temporary obstruction of flow by the build-up of river-ice debris cross the channel. Ice jamming is a significant flood mechanism along rivers in most of Canada. Saint John (New Brunswick) is a large river well known for ice-jam flooding.

During some floods, floodplain areas may be buried with sand and gravel. The thickness of sediment deposited on floodplains varies, depending on the flood location, energy of flow, and amount and calibre of sediment introduced into the river by erosion upstream. In extreme cases, broad sheets of sediment, up to tens of centimetres thick, can be deposited. If agricultural lands flood during spring then planting may be delayed and the growing season shortened. Crops may also be damaged or harvesting delayed if floods occur in summer.

During floods, contaminants in the water (for example, oil, gasoline, raw sewage, chemicals) will enter buildings and coat floors, walls and building contents, compounding the water damage and electrical short-circuits may start fires. When the amount of storm rainfall runoff cannot be handled by storm-sewer drainage systems, sewer backups can flood the basements of otherwise dry buildings introducing pathogens and threatening human health.

The following photographs, from Natural Resources Canada's Atlas of Floods[16], are not of areas in the GoM but are an indication of what may happen of extreme precipitation events lead to flooding.

[16] http://atlas.nrcan.gc.ca/site/english/maps/environment/naturalhazards/floods/1

Figure 8: Photograph of buildings on a terrace undermined by bank erosion, Saguenay area, July 1996 (Geological Survey of Canada, photograph GSC 1997-42DD, taken by G.R. Brooks).

Figure 9: "Photograph of a broad sheet of sand, up to 1 to 2 metres thick, deposited along the valley bottom of the Ha! Ha! River, Saguenay area, Quebec, July 1996" (Geological Survey of Canada, photograph GSC 1997-42CC, taken by G.R. Brooks).

Stream Erosion and Sedimentation

The movement of sediment begins with the process of erosion, where particles or fragments are weathered from rock material and transported. During the erosion processes the energy of the moving water is lost mainly in two ways: overcoming friction and cutting the streambed. Approximately 95% of a stream's energy is used to overcome the friction of water and material coming into contact with the bottom and sides of the channel and internal molecular friction; the remaining 5% is used for vertical and lateral cutting of the streambed. The flowing water erodes the channel by dissolving materials which then contribute to the stream's solution load and through the impact of water, or hydraulic action on the sides and bed of the channel. This dislodges materials and makes them available for transport as part of the stream load. Materials too heavy to suspend, come out of solution and roll across the bed, eroding the channel by abrasion[17].

The volume of water flowing in a river, together with the speed and timing of the flows, determines how a river shapes the surrounding landscapes by eroding the underlying terrain. Rainfall, snowmelt, and groundwater all contribute to the volume of flow, with variations from season to season and year to year. In higher parts of the drainage basin a river can carve steep valleys. In the lower parts of the basin, deposits may create deltas at the river's mouth where the river slope is flatter. This occurs when the river slows down and deposits sediments[18]. Where water is the key agent for erosion, the term fluvial sediment is used[19]. This is what may be of concern with the impact of extreme precipitation events. However, sedimentation is not always associated with negative impacts. Increased sediment transport could alter the amount of sediment available for soil aggradation in wetlands and sands for littoral systems and may be beneficial to many coastal areas by providing material for accretion to coastal wetlands threatened by sea-level rise. A decrease in sediment transport might diminish the ability of some wetlands to respond to sea-level rise. On the other hand, other coastal ecosystems may benefit from reduced sediment inputs, which decrease water clarity or result in rapid infilling (NOAA, 2000).

The concern among climate scientists is that sediments that have been layered and dormant over time will be dislodged in the course of extreme precipitation events if riverbanks and bottoms are scoured. If the sediments have contaminants, perhaps due to industrial pollution or non point sources, this will then cause an increase in contaminated water flowing from rivers and streams into the marine environment. The consequences will influence the water quality of both freshwater and marine environments and subsequently affect the species living within. According to some scientists, it is thought that this situation will not likely occur. The reason may be due to the annual upheaval of sediments in freshwater rivers and streams purging the sediments. Many of these watercourses already experience a thorough scouring each spring, especially in areas where ice jams occur[20]. The lack of literature found on streams and contaminated sediments seems to support this. However, there is evidence of historical monitoring of freshwater courses throughout the GoM states and provinces, with some studies going back at least 60 years (Knox, 1949). Both the United States and Canada have continuing water quality monitoring programmes by such organizations as the National Water Quality Institute and Environment Canada. The monitoring of the physical, chemical, and biological characteristics of water is to ensure limits of substances that may harm the

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[17] http://www.uwsp.edu/gEo/faculty/ritter/geog101/textbook/fluvial_systems/geologic_work_of_streams.html (retrieved12-03-09)

[18] http://www.ec.gc.ca/water/images/nature/sedim/e_map.htm (retrieved 9-03-09)

[19] http://www.ec.gc.ca/water/en/nature/sedim/e_effect.htm (retrieved 9-03-09)

[20] P.G. Wells, personal correspondence (2009)

ecological systems or threaten the health of humans.

Following heavy precipitation events of around 10-15mm (2-3") rain there is often a decrease in water quality. Run-off from roads can contain high levels of hydrocarbons, PAHs, and some heavy metals, depending on the area and the amount of urbanization. In New Hampshire up to 10% of the surface is made of impervious substances[20]. Water cannot infiltrate into soil covered in asphalt and concrete and therefore runs off, often untreated directly into water courses. The amount of development, compounded by extreme precipitation, may lead to higher amounts of water bypassing the soil and groundwater systems and picking up pollutants before entering ecologically sensitive areas.

Monitoring pollutants directly in water is only one of the methods used to track changes. Emphasis is now being put into the study and monitoring of sediments and indicator species. Sediment plays a major role in the transport and fate of pollutants. "Toxic chemicals can become attached, or adsorbed, to sediment particles and then transported to and deposited in other areas. These pollutants may later be released into the environment"[21].

The two following sediment maps show that very little major sediment deposits enter the Gulf of Maine. This could increase with an increase in extreme precipitation events. By the end of the 21th century, runoff aggregated for Atlantic coast drainage basins was projected to increase by 60% for the Hadley model, but decrease by 80% for the Canadian model. For the majority of the Atlantic seaboard, it is uncertain as to whether there will be enhanced or diminished runoff (Vasseur et al., 2008). This is an example of the range of model outputs.

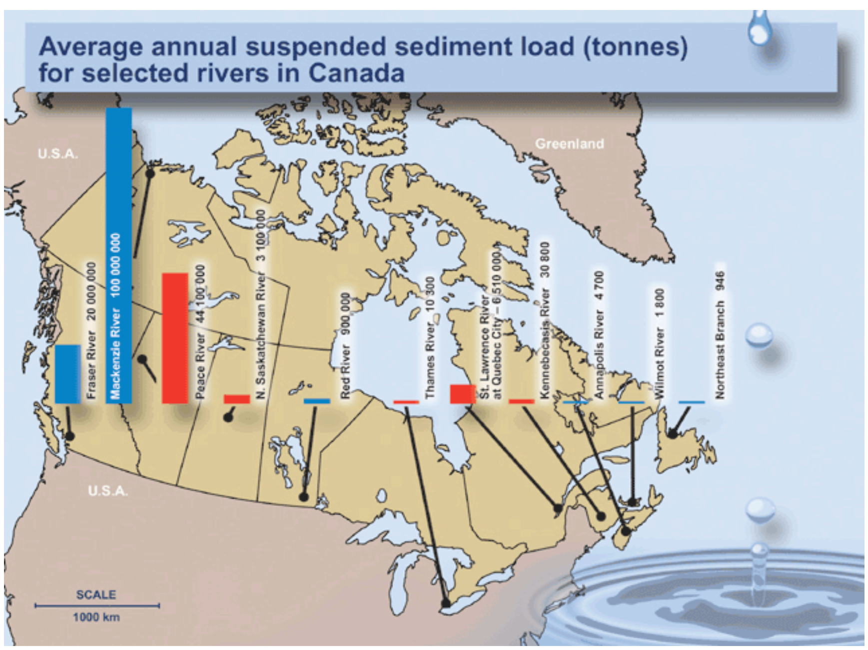

Figure 10: River sediment load map of Canada[22]

[21] http://www.ec.gc.ca/water/en/nature/sedim/e_transp.htm (retrieved 17-04-09)
[22] http://www.ec.gc.ca/water/en/nature/rivers/e_sculpt.htm (retrieved 8-03-09)

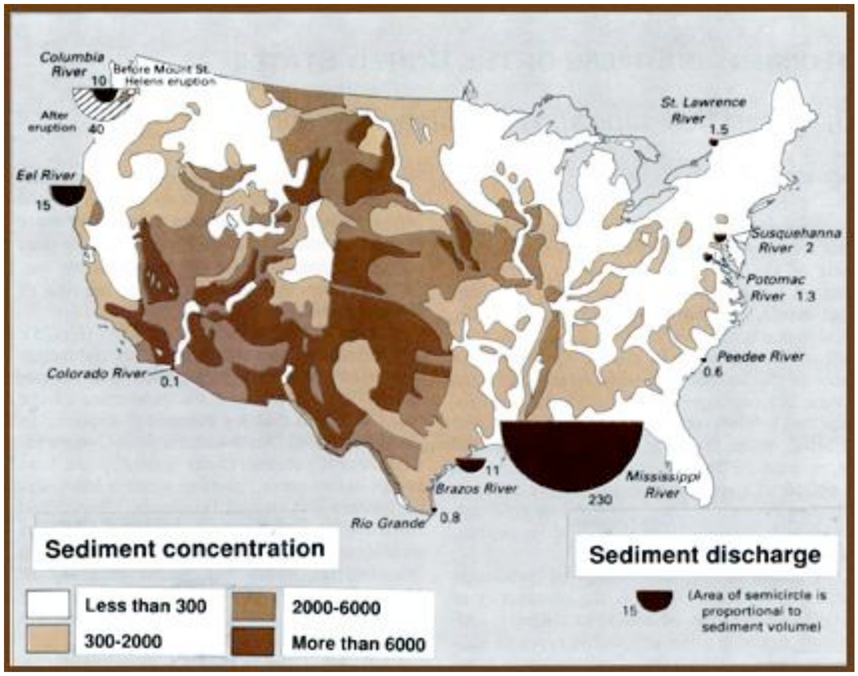

Figure 11: Average concentration of suspended sediment in rivers and average discharge of suspended sediment at the mouths of selected rivers of the conterminous United States. Map was simplified from Rainwater (1962).

Sensitivity and Vulnerability

In 2001 the Geological Survey of Canada produced a research report titled *The Impact of Climate Change on Rivers and River Processes in Canada* (Ashmore and Church, 2001). This document identifies areas of Canada that are sensitive and vulnerable to changes in flow and sediment deposition. The most sensitive river regions include the Atlantic coast. It indicates that the main reason for flooding due to climate change is likely to be more intense rainstorms. Small streams in urban areas may be particularly problematic. Although this study is for Canada it can be reasonably assumed the effects are similar for other areas in the GoM region. The sensitivity projection for Canada's river regions in response to climate warming was based on the effects of projected precipitation changes on landscapes. Climate warming has the potential to cause substantial changes to flow in rivers such as an increase in floods and river erosion.

Climate projections denote that overall precipitation throughout most of Atlantic Canada will continue to increase. However, as mentioned above, increased precipitation does not necessarily lead to more water in rivers, lakes, and wetlands. An increase in summer temperatures will increase the rate of evaporation and transpiration and may exceed the influx of precipitation, causing declines in water levels (Vasseur et al., 2008)

As river morphology and dynamics are controlled by the delivery of water and sediment from the surrounding landscape or watershed, fluvial processes may be affected by changes in the climate and artificially by land use or flow regulation. Climate change can cause widespread alteration of hydrological and erosional processes leading to changes in water and sediment delivery. Rivers have been shown to be sensitive to change in flow and sediment load using case studies and the basic principles of fluvial geomorphology. The magnitude and direction of change can be anticipated with knowledge of change to flow and sediment supply, e.g. increased streamflow causes channel enlargement, increased migration rates, channel incision, and change to channel patterns. Fine-grained, alluvial channels are most sensitive; bedrock and boulder channels are the least. Areas in the GoM have both channel types and would have to be analysed on a local level to predict sensitivity (Ashmore and Church, 2001).

Ashmore and Church (2001) further write, "The areas of greatest vulnerability are the populated areas of Southern Canada where hydrological and stream-channel sensitivity are also the highest. This includes the Atlantic Coast.... where a shift to rainfall-dominated flow regimes could cause substantial increase in flood flows". Calculations made over a range of climate simulations yield precipitation increases due to increased atmospheric energy of around 2.8% per 1°C. The results show that in the absence of temperature changes, changes in precipitation may cause significant changes in runoff. However, temperature change with no change in precipitation produces no consistent change in runoff (Ashmore and Church, 2001).

In Canada, current projected changes to precipitation are the same as recorded decadal fluctuations of the past 50 years. Historical records show that high average annual precipitation = high streamflow and flood discharges. The problem in the GoM is that this situation is extreme in the Atlantic Coast with the projected magnitude of large floods (ten year recurrence interval) increasing by 50-100% for only a 5-15% increase in annual precipitation. These proportional increased flood discharges are larger than those for mean flows. Concerns are great in Eastern Canada if there is a shift to rainfall-dominated (i.e. rain-on-snow) streamflow generation which is a more variable and extreme process than snowmelt. Ashmore and Church (2001) summarized the potential impacts of changes as:

1. Increased discharge- channel enlargement and incision; tendency toward either higher sinousity single channels or braided patterns; increased bank erosion; more rapid channel migration
2. Increased magnitude of large floods – will cause a sudden change to channel characteristics that may trigger greater long term instability of rivers
3. Increased frequency of large floods -will tend to keep river in the modified and unstable state
4. Decreased discharge- often results in channel shrinkage with encroachment of vegetation into the channel; sedimentation in side channels; and channel pattern change toward more stable and single channel patterns

In Maine, more intense rainfall may lead to increased flooding, particularly in steep headwater areas and along well-developed floodplains. Erosion in agricultural and timber-harvesting areas could increase from greater and more intense rainfall resulting in deposition of sediment in lakes and streams. "Less rainfall, particularly during the summer, could reduce streamflow, lake levels, and groundwater levels. Streamflow reduction and warmer temperatures would reduce habitat for cold water fish. This could reduce water supplies in areas such as southwestern coastal Maine, which is experiencing growing water demands..."[23]. Both Canadian and American studies conclude similar outcomes.

Figure 12: Ice out on a lake in northern New England, April 2009 (K. McKenzie).

The Effects of Extreme Climatic Events on Habitats

The effect of extreme climatic events such as drought or intense rainfall can have seriously detrimental effects on the terrestrial, freshwater, and (subsequently) marine environments. High amounts of precipitation and run-off can threaten the survival of species adapted to life within these habitats. Anthropogenic alterations to the environments can further exacerbate any potentially negative effects from climate change. The health of rivers is an indication of the potential health of the marine environment into which they empty. Streamflow characteristics can be informative as to flood and drought conditions that will ultimately impact on fisheries resources. River hydrology also provides valuable information on the capacity of rivers to dilute pollutants during low flow events and is an essential component of environmental impact assessment and instream flow studies. High river discharge, or bankfull discharge, determines many physical characteristics of the river or fluvial morphology (Caissie, 2006).

Effects on Terrestrial Habitats

Moore et al. (1997) focused on the potential changes over the New England and Mid-Atlantic regions. They project that the climate of the New England/Mid-Atlantic Region could become less variable in nature and will probably be characterized by less rapid changes in daily weather rather than in reduced extremes. Convective thunderstorms in summer will most

[23] http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BUT6R/$File/me_impct.pdfEPA236-F-98-007k (retrieved 20-03-09)

likely increase in intensity (similar to those that now occur in the south-eastern US), and there is a suggestion that there may be longer time periods between thunderstorms. This may lead to greater variability in stream flow, especially in summer, with the smaller streams experiencing more flash flooding as well as longer periods of low flow. Forest fires may also increase because of lightning strikes in dry forest conditions (Moore et al.,1997). This may become a serious threat as the possibility of drought disturbance rises in Atlantic Canada with higher temperatures and decreased summer precipitation. Trees with shallow root systems, such as spruce and hemlock, are more sensitive to drought than those with deep root systems and therefore are particularly vulnerable. Increased frequency of ice storms, and increases in the strength and frequency of windstorms and thunderstorms can cause incidental damage of individual branches and annihilation of entire stands. If a period of drought follows an ice storm, the probability of fire outbreak increases. Changes in forest fire characteristics have the potential for critically altering interior forests by changing nutrient cycling (Vasseur et al., 2008).

Poor forestry practices, such as extensive tree cutting in an area, may not only destroy habitat but increase natural water runoff and accelerate soil erosion. They can also release chemical substances occurring naturally in forest soils such as metals like aluminum or iron, and allow them to contaminate rivers or lakes. Both the chemicals and the additional sediment can harm fish and other organisms. Sediment problems resulting from forestry practices are prevalent in New Brunswick.

Effects on agriculture can also have a direct impact on water characteristics. An increase in climate variability and the frequency of extreme events would adversely impact the agricultural industry. A single extreme event such as a later frost, extended drought, or excess rainfall during harvest period, could eliminate any benefits from improved ‘average’ conditions. In the Atlantic provinces the primary environmental issues associated with agriculture are water quality, soil quality, and, to a lesser extent, air quality. Water pollution (52%) and soil erosion (47%) were identified as the most significant environmental impacts of agriculture (Vasseur et al., 2008). This may be particularly relevant to large watershed areas where agriculture is prevalent such as the Annapolis Valley, N.S., which drains into the Bay of Fundy.

Effects on Freshwater

One of the most important and sensitive areas at risk are wetlands. Wetlands are a buffer zone slowing down the influx of water after heavy precipitation episodes. Degradation of the wetland, clearance of forest, and urban development compound the possible effects of episodic extreme precipitation caused by changes in the climate. This can create a greater vulnerability to flooding. The movement of water from precipitation to streams through wetlands is particularly important in the drier summer months. Summer droughts can further impair wetlands. Lowered water levels or decreased river flows, increases in temperature, prolonged summer dry seasons, and heavier rainfall can all lower water quality and increase the risk of contamination of drinking water (Vasseur et al., 2008).

The combined effects of climate change and direct anthropogenic stress will most likely alter hydrological and biogeochemical processes, and, hence, the floral and faunal communities of the region's freshwater ecosystems. For example, an increase in evapotranspiration could eliminate most bog ecosystems, and increases in water temperature may increase bioaccumulation, and possibly biomagnification, of organic and inorganic contaminants (Moore et al., 1997).

Much of the concern related to streamflow and habitats centres around commercially viable species. Salmon, a diadromous fish species, is the focus of many studies of the freshwater and marine environments. The inner Bay of Fundy Atlantic Salmon (*Salmo salar*) (iBoF) was designated by the Committee on the Status of Endangered Wildlife in Canada [COSEWIC] in 2001; and legally listed by the Species at Risk Act [SARA] in 2003. Climate change impacts may mean reduction in freshwater survival (e.g., due to possible adult migration delays and decreased spawning success) because of increased stream temperatures and reduced flows (El-Jabi et al., 2004). The E.P.A. agrees that spring spawning fishes in the Northeast U.S. may be affected greatest by the changes in timing of spring flows which may alter the survival of Atlantic salmon by changing migration timing[13].

Although erosion and sediment transport are natural processes, sediments in excess are harmful to streams in the watershed. Problems with sediments affect both vertebrates and invertebrates. Some known problems, according to Environment Canada[19], are:

- Suspended sediment decreases the penetration of light into the water. This affects fish feeding and schooling practices, and can lead to reduced survival.
- Suspended sediment in high concentrations irritates the gills of fish, and can cause death.
- Sediment can destroy the protective mucous covering the eyes and scales of fish, making them more susceptible to infection and disease.
- Sediment particles absorb warmth from the sun and thus increase water temperature. This can stress some species of fish.
- Suspended sediment in high concentrations can dislodge plants, invertebrates, and insects in the stream bed. This affects the food source of fish, and can result in smaller and fewer fish.
- Settling sediments can bury and suffocate fish eggs.
- Sediment particles can carry toxic agricultural and industrial compounds. If these are released in the habitat they can cause abnormalities or death in the fish.

Any increase in sediment concentrations or duration of suspension as a consequence of increased river flows could potentially reduce biodiversity in the freshwater ecosystem. Depending on the severity of the precipitation events, this damage could be irreversible.

Unfortunately, there are very few studies within the Gulf of Maine area itself; however, one area slightly south of the GoM, which has had numerous studies conducted on sedimentation and therefore can be used as an indicator of what might happen in the Gulf area, is Chesapeake Bay. Problems associated with excess sediment in the Chesapeake watershed and bay have been described as (United States Geological Survey, 2005):

- Excessive sedimentation can degrade stream habitat and bury benthic (bottom-dwelling) plants and animals, such as oysters and clams.
- Suspended sediment clouds the water, preventing light from penetrating to the leaves and stems of underwater grasses, or submerged aquatic vegetation (SAV). Suspended sediment and phytoplankton growth due to excess nutrients have reduced water clarity below the thresholds needed to support SAV.
- Toxic materials, potential pathogens, and nutrients may be transported by sediment and contaminate waterways that affect fisheries and other living resources.
- Commercial shipping and recreational boating are threatened by accumulations of sediment that can fill waterways and ports, making traffic difficult or hazardous, and requiring dredging
- Sediment plays an important role in transporting phosphorus and other contaminants in river systems. The amount of phosphorus depends on the source and on the geochemical reactions affecting phosphorus during transport.
- Most of the sediment from the watershed to the bay is transported when (1) streams reach bankfull conditions, which take place on average every 1-2 years, and (2) during relatively large storm events. Hence, sediment input to the bay potentially can be affected by large-scale patterns of climate change, such as hurricanes and tropical storms.

Not all change may be adverse. For example, a decrease in runoff may reduce the intensity of ongoing estuarine eutrophication, and acidification of aquatic habitats during the spring snowmelt period may be ameliorated.

Acidity in freshwater is a major concern for the eastern seaboard. The GoM region is particularly vulnerable. The eastern Canadian provinces receive more acid rain than any other part of Canada. The area is highly sensitive because of the weak neutralizing ability of granite bedrock and granite-derived soils. Models predict that up to one quarter of the lakes in Eastern Canada will remain chemically damaged after 2010 as many lakes and wetlands in the region receive twice as much sulphate as they can tolerate[24]. Extrapolations need to be made to include the GoM states.

One reason that acid levels remain so high is that there has been a drop in the level of acid-neutralizing bases in the atmosphere. The same is happening in forest soils, where decades of acid rain have leached away calcium and magnesium, leaving them less able to neutralize surface water before it reaches lakes and streams. Another reason is that hot, dry weather, converts sulphur that has accumulated in wetlands and soils over past decades into sulphuric acid. When wet weather returns, some of this acid washes into nearby lakes[24]. It is unclear whether episodic precipitation events will be detrimental or beneficial in this regard.

[24] http://www.ec.gc.ca/science/sandesept00/article3_e.html (retrieved 9-03-09)

Stream acidity could result from less frequent but more severe summer storm events. “Nitrogen appears to leach from forest soils to streams via a `wash-out' process in which deposited or mineralized nitrate is flushed from the watershed during periods of increased run-off.... If climate change causes less frequent, but larger rainfall events, the period of dry deposition and microbial nitrification between storms will increase, and this wash-out process may encourage larger pulses of nitrate to surface water....” (Moore et al., 1997).

Effects on Estuarine and Marine Habitats

The impact of climate change in the watersheds upstream of estuaries in the New England/Mid-Atlantic Region, may affect primary production and eutrophication of estuarine waters. Eutrophication is a major problem in this region, with excess nutrient inputs leading to enhanced rates of primary production and incidences of anoxia and hypoxia in bottom waters (National Research Council, 1993) (Moore et al., 1997).

Figure 13: Mouth of the St. Croix River, Maine/New Brunswick border, October 2006 (K. McKenzie).

Nitrogen, most of which comes from non point sources, is the element that is most limiting to primary production in most estuaries of the northeastern US. Only 25% of nitrogen inputs to the coastal zone comes from sewage, and 75% comes from non-point sources on land, principally from fertilizer and atmospheric deposition (Howarth et al.,1996). Climate change may affect the delivery of nitrogen to estuaries; the projected general decrease in water runoff and greatly decreased snowpack would be expected to result in more nitrogen retention in forests and agricultural lands, and less exported from land to the rivers and estuaries (Moore et al., 1997). This is in contrast to increased nitrogen inputs as a result of increased precipitation. More study needs top be completed before final conclusions can be drawn.

Climate change resulting in increased river flows means more suspended sediments could be transported into the coastal regions, thus increasing the upper layer turbidity and potentially reducing available light to both plankton and submerged aquatic vegetation. This could also increase the flux of nutrients and contaminants into coastal systems, which influence eutrophication and the accumulation of toxins in marine sediments and biota. Increased temperatures and decreased densities in the upper layers might also reduce the vertical convection enough to prevent oxygenation of the bottom waters, further contributing to anoxic conditions in the near-bottom waters (Feltzer and Heard, 1999).

Acidification is a problem in the marine environment as well as freshwater and terrestrial. Shellfish larvae, including those of lobsters, clams, mussels, and scallops, begin their lives in shallow coastal waters where they must begin building their protective shells immediately. They do so by pulling calcium carbonate out of seawater. As seawater becomes more acidic the critical ingredient, aragonite, is in shorter supply as it is used to buffer (make more alkaline) the water itself. If the acidity level exceeds a certain threshold shells begin to disintegrate. Should climate events change prevailing winds and currents “cause a river plume to hug the coastline rather than push it further offshore, the shellfish larvae will be swimming in an acid soup devoid of aragonite”[25].

As scientists place greater and greater emphasis on monitoring toxins in the tissue of living organisms, the Gulf of Maine Council has created a monitoring group called Gulfwatch. The description found on the GoMC website[26] is:

> *Gulfwatch is a chemical-contaminants monitoring program administered by the Gulf of Maine Council on the Marine Environment. Conducted and coordinated by scientists and managers from universities and agencies around the Gulf of Maine, the program uses blue mussels as indicators of habitat exposure to pollutants in coastal waters*.

Since 1993, Gulfwatch has measured contaminants in blue mussels (*Mytilus edulis*) to assess the types and concentration of contaminants in coastal waters. The blue mussel (*Mytilus edulis*) is a species that is common throughout the Gulf of Maine and is used because it is long-lived and sedentary and a filter feeder, which means contaminants in its tissues reflect environmental conditions over time. There are dozens of contaminants monitored, such as metals (aluminum, cadmium, chromium, copper, iron, lead, mercury, silver and zinc); and pesticides such as ppDDD, PCBs and PAHs. Other contaminants of interest are pathogens and nitrogen[27].

An interactive mapping tool can be found on the Gulf of Maine Council website. This shows the levels of contaminants found in blue mussels at the monitored sites.

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[25] http://www.eos.unh.edu/newsl_0309/river.shtml

[26] http://www.gulfofmaine.org/gulfwatch/

[27] http://www.eos.unh.edu/newsl_0309/river.shtml

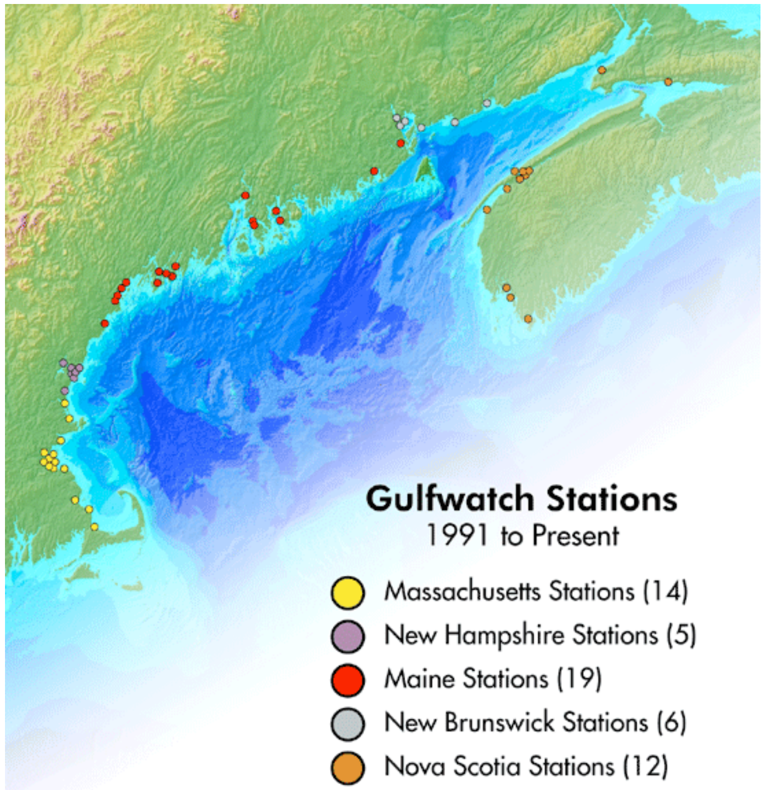

Figure 14: Gulfwatch stations, 1991 to present.

Gap Analysis

Gaps relating to climate change and possible effects on streamflow are not dissimilar to gaps identified in the previous two documents. Similar problems of access to information, fragmentation of information, understanding of government structure and map completeness all occur here. Other more specific gaps include:

1. Lack of focus on the Gulf of Maine region

Once again the Canadian provinces and American states which make up the GoM are under represented in terms research. For example, Environment Canada has produced an abundance of documents on erosion, water levels and climate change in the St. Lawrence River and Great Lakes but this is generally as far east as the study area goes. Natural Resources Canada (NRCan) has also carried out research into water resources and climate change issues in the Central/Great Lakes, western, and Arctic regions with very little in Atlantic Canada. On an NRCan website there is agreement in regards to a lack of regional focus. One statement says: "From a regional perspective, studies based in the Atlantic Provinces, eastern Arctic, and high-elevation mountainous regions are still lacking."[28]

The USGS and EPA are leaders in research and publication of material related to the

[28] http://www.adaptation.rncan.gc.ca/perspective/water_1_e.php

environment. There is information categorized in dozens of headings on each aspect of the environment. However, even with this immense amount of information, there is little specifically on the Gulf of Maine. Frequently there are omissions in data. For example, there are many references to the three states in the GoM, but when refining searches it is not unusual to only have one or two items result. Searches conducted for Region 1 give the most specific information.

2. Regional Boundaries, Disjointed Results, and Lack of Standardization

Following the lack of region-specific information, one problem is that of identification of boundaries. This leads to disjointed results which are not easily comparable. The difficulty partially lies in the classification of an area. For example, a river in Nova Scotia draining into the Bay of Fundy may be found under the heading of Nova Scotia (provincial), the Maritimes, The Atlantic Provinces, the Atlantic Coast, the Atlantic Maritime Ecozone, the Appalachia Region and of course the Gulf of Maine. In the United States a river in New Hampshire could be classified under New Hampshire (state), New England, Northeast or GoM to name a few. If a study was funded by a federal agency then the reports would be found on one of the federal websites or libraries but if the funding was provincial or state then it may be found in an entirely different location. This regionalism is a barrier when trying to understand trends or link results as parameters may not be the same for each study. Saying this, the EPA has released the Report on the Environment (May 2008) which does try to standardize the parameters used, therefore allowing comparisons to be made.

3. Grey Literature and Accessibility

There is excellent scientific research being accomplished and published but subsequently lost to the greater public. Restricted access or lack of promotion is working in opposition to the ethos of sharing scientific knowledge. As mentioned previously there are great difficulties in either locating work that has been accomplished or in accessing that work. There is a slight bias toward a Canadian perspective in this document as the literature was partially procured through access to libraries not available to the public. In this manner, finding information is as much about who you know as what you know.

There must be a significant amount of duplication of research and serious omissions occurring due to the lack of awareness or communication. In this technologically advanced age with international access via the Internet, it is still difficult to find the current publications without a physical presence in some libraries.

4. Out of Date Material

There are two examples from this document of publications or sources of data that require updating. One is the sediment deposition map of the United States; there may be a more modern version but the one used was the most easily accessible. It shows suspended sediment discharge from selected rivers in 1962. There may have been many scientific studies conducted in the last 47 years since the publication of this map. Secondly the monitoring programme by the GoMC Gulfwatch. The last report is dated 2000. The last data on the interactive maps is also from the early 21st century. There has been a continuation of monitoring in the past nine years but the data have not made it into the public realm.

5. Different Model Assumptions

Uncertainty of future climatic trends is one of the biggest problems when trying to project the changes to streamflow. As written in the text, the main climate models used sometimes have differing results. Climate scientists can incorporate different approaches to define physical processes in climate models which allows for a range of outcomes. All projections are equally valid although some situations can give extreme results. This gives policy makers options for decision making i.e at times one model can be chosen over another depending on the greatest concern for that area. One example of how the results may differ is:

> "...runoff aggregated for Atlantic coast drainage basins was projected to increase by 60% for the Hadley model, but decrease by 80% for the Canadian model. For the majority of the Atlantic seaboard, it is uncertain as to whether there will be enhanced or diminished runoff."

Even when there is consensus in the model outcome, there can be contradictions in the consequences to numerous variables. An example of this is found in the report 'Potential Effects of Climate Change on Freshwater Ecosystems of the New England/Mid Atlantic Region' (Moore et al., 1997). It states:

> "the projected general decrease in water runoff and greatly decreased snowpack would be expected to result in more nitrogen retention in forests and agricultural lands, and less exported from land to the rivers and estuaries. This is in contrast to increased nitrogen inputs as a result of increased precipitation. More study needs top be completed before final conclusions can be drawn."

Frequently the uncertainty of projections is a problem when trying to prepare for possible outcomes. Many of the studies used mention this uncertainty. One example is the report titled 'A River Runs Into It'[29]. The author writes "little is known about the relationship between discharge, low aragonite in coastal waters, and the potential negative impact on early stages of early shellfish development". In this case the possible negative effects of river discharge could cost the shellfish industry millions of dollars.

Recommendations

1. Lack of focus on the Gulf of Maine region

Obviously more research focused in the Gulf of Maine region needs to be done. More specifically there are areas where research is lacking such as the potential effects of climate change on the regions freshwater supply, aggregation of data on sedimentation rates in streams and rivers, and the consequences of alterations to these.

In the report 'Potential Effects of Climate Change on Freshwater Ecosystems of the New

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[29] http://www.eos.unh.edu/newsl_0309/river.shtml (retrieved 17-03-09)

England/Mid Atlantic Region' (Moore et al., 1997), many recommendations were suggested in regards to work specific to the Northeast region of the United States. These include:

> (1) extending and improving data on the distribution, abundance and effect of anthropogenic stressors (non-point pollution) within the region; and (2) improving scientific knowledge regarding the contemporary distribution and abundance of aquatic species. Research recommendations include: (1) establishing a research centre(s) where field studies designed to understand interactions between freshwater ecosystems and climate change can be conducted; (2) projecting the future distribution, activities and direct effects of humans within the region; (3) developing mathematical analyses, experimental designs and aquatic indicators that distinguish between climatic and anthropogenic effects on aquatic systems; (4) developing and refining projections of climate variability such that the magnitude, frequency and seasonal timing of extreme events can be forecast; and (5) describing quantitatively the flux of materials (sediments, nutrients, metals) from watersheds characterized by a mosaic of land uses.

More targeted study on the consequences of climate change in relation to current ecological knowledge is essential. More discussion with scientists and policy makers in the region is recommended to highlight target areas for funding.

2. Regional Boundaries, Disjointed Results, and Lack of Standardization

A greater profile of the region and agreement of boundaries for the sake of scientific standardization. This is being undertaken to some extent as international organizations such as National Geographic and the World Wildlife Fund are using ecological boundaries rather than political ones. In North America the Canadian government is undertaking a major compilation of information on ecological zones. These zones cross provincial boundaries, but unfortunately this is another report that will stop at the country border.

3. Grey Literature and Accessibility

Grey literature and accessibility are two issues that all researchers and users come across daily. The amount of material being generated needs to be available in formats that are accessible beyond the doors of the supporting organization. More paper based material needs to be made electronic. Fortunately, there are studies being funded to address these problems. Some large organizations are having inventories performed and are tracking material usage. Perhaps this will shed some light on the vastness of unknown material and give recommendations as to how to make this available to the greater community.

4. Out of Date Material

Part of the problem of out dated material stems from a lack of consistent funding. There are multitudes of excellent initiatives that seem to have funding for finite periods only. Programmes such as Gulfwatch are essential in collecting data in order to analyze trends. It appears that many ecological studies are carried out by passionate volunteers as much as by financially supported teams. This may lead to gaps in information as people move on to other work. The information needs to be updated regularly. This depends on reliable funding.

The technological age has brought information into the public realm that was otherwise not available. However, the information chosen is a selection and may or not be updated and maintained. Antiquated publications may be inadvertently used if superseded work is not removed. Therefore it would be useful to have some indication of the availability of newer versions linked into older documents.

5. Different Model Assumptions

Education for decision makers and general public on the reasoning behind the use of various climate models is recommended in order to decrease the concern over uncertainty and model output differences. All climate models give different outputs with some giving more dramatic results than others. All results are equally valid. The utilization of climate model output can be approached in two ways:

1. Treat results as a range of future scenarios. This approach works best when there is not extreme difference between results

2. Choose the model output closest to scenario of concern- e.g. if more or less heavy precipitation is concern then use model output which best demonstrates this

As for uncertainty and conflicts in interactions with various biotic and abiotic factors, then the suggestion is to commission more research studying a range of variables in order to have better information for decision making.

Conclusion

This report represents a starting point for those interested in understanding the possible impacts of climate change on the various coastal and freshwater ecosystems in the Gulf of Maine Region. Climate change has traditionally been simplified to an increase in temperature, changes to precipitation, or a rise in sea-level, but as scientists study further it is becoming more evident that each region of the globe may have very different effects which will require differing adaption solutions.

These three companion background reports begin to identify what research has been published and which individuals and organizations are conducting research on climate change issues in the Gulf of Maine. These papers have been selective in usage of material available and acknowledge that there is much more information provided by many of the sources cited and many more which have not been cited.

Although it is not an explicit guide on how to incorporate climate change considerations into coastal habitat decisions, it can help such decision makers ask appropriate questions regarding climate change and their particular areas of interest. The authors hope that it will be built upon in the future and grow to become a sought-out source of information for all those concerned about the impacts of climate change on coastal habitats around the Gulf of Maine.

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