Climate Change Adaptations for Land Use Planners

Project A1209

Birch Hill GeoSolutions

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1.1.1 Introduction

Most scientists now agree that climate change, i.e., global warming, is occurring at a rate much faster than the normal climatic cycles, due to anthropogenic causes of greenhouse gases. Because global warming is changing the ocean currents and wind patterns, climate is changing world-wide. Some of these changes are beneficial, such as a longer growing season for farmers; however, most are harmful. The negative impacts include more frequent and severe weather extremes, such as more intense storms and droughts, more variability in weather, and sea level is rising, putting coastal communities at greater risk. Such climate changes are expected to increase in the foreseeable future; and Land Use Planners need to be prepared for the impacts on their communities. While there are many ways to help *mitigate* climate change, mainly through reduction in greenhouse gas production, our study is concerned with *adaptation* to the adverse impacts of climate change.

This project is intended to provide an understanding of climate change impacts on land uses, and the tools that can be used to assess these impacts and adapt to them. While Land Use Planners deal with municipal land use issues, they receive engineering input from municipal engineers and outside consultants. Thus, the more technical tools in this project are intended for use by engineers and scientists assisting Land Use Planners.

This document is a simplified summary of the main report, which contains an explanation of the tools methodology, as well as additional details on the topics in each chapter.

1.1.2 Project Purpose

The purpose of this project was to research, develop, and test "tools", i.e., methodologies, for Canadian communities to use in: 1) analysing climate change projections and impacts on their communities; and 2) implementing adaptations to these impacts.

We have worked with both traditional and leading-edge existing tools, and have developed new tools, to incorporate climate change impacts and adaptation considerations into Land Use Planning. This toolkit is intended to be used primarily by municipal and consulting engineers, who provide essential input to community Land

Figure 1.1: *We Seek Answers to These Questions:*

- Why is climate change important?
- How will these changes impact our community?
- What tools can we use to assess potential climate changes in our community?
- What tools can we use to assess risks associated with these climate changes?
- What tools can we use to adapt community land uses to these climate changes?
- What tools can we use to implement climate change adaptations in our community?
- Where can we find information and assistance?

Use Planners; with the less technical tools intended for use by community Land Use Planners directly. Our analyses and recommendations are geared toward rural municipalities in the Atlantic Provinces, and southern Nova Scotia in particular, although most of the methodologies and recommendations would also apply to cities and to other areas of Canada.

This study attempts to bridge the gap between the engineering/science disciplines and Land Use Planning, with respect to the emerging community planning issue of climate change impacts analysis and adaptations. The gap between environmental engineering/science and Land Use Planning has begun to close in recent decades, due to increasing understanding of the need for resource-based planning, especially in rural areas not serviced by municipal water and sewer. However, relatively recent environmental planning concepts such as “Sustainable Development”, “The Natural Step”, and “Ecological Footprint” can be clear in objective but quite vague in methodology for accomplishing growth that is compatible with environmental resource protection. Climate change can exacerbate existing environmental issues, such as flooding and drought; and thus, there is an even greater need for more scientific analysis in Land Use Planning practices.

For example, it has only recently been generally practiced that development in rural areas unserviced by public water and sewers needs to be kept within the safe yield limits of the aquifer supplying well water. However, land use planning of lot sizes and population densities for maintaining well water *quality* is still rarely practiced. Similarly, the risks associated with development in coastal and inland floodplains are clear, but this still is not adequately reflected in land use location choices by both municipal governments and private residents.

Climate change is expected to increase this existing need to bridge the gap between science and Land Use Planning. Thus, although there is still much uncertainty regarding climate change projections, policies that take a conservative approach are ‘policies of no regrets', since there is already a need for better resource-based Land Use Planning.

1.1.3 Project Methodology

The format of our project follows the logical progression of the report structure:

Chapter 1 – Introduction
Chapter 2 – Impacts on Land Uses (climate change projections and impacts in Atlantic Canada)
Chapter 3 – Analysis Tools (Theory 1)
Chapter 4 – Implementation Tools (Theory 2)
Chapter 5 – Tools Tests (Theory Application)
Chapter 6 – Recommendations

Our methodology is summarized as below:

Background Review: After reviewing climate change impacts and adaptations literature and case studies, we analyzed how these impacts and adaptations were applicable to rural community and regional land use planning.

Analysis Tools: We then reviewed the *analysis tools* that municipal and consulting engineers, planners, economists and scientists use to inform Land Use Planning decisions, and how climate change considerations could be incorporated into them. Both state-of-the-art and simpler tools were reviewed.

Implementation Tools: We also reviewed *implementation tools* that municipal land use planners use to implement their policies, in consort with other municipal departments and consultants, and how climate change considerations could be incorporated into them.

Test Tools: Our analysis and implementation toolkits were then tested in two test case sites (see Figure 1.1.2 - Test Site Locations):

- **Annapolis Royal:** The small rural town of Annapolis Royal, Nova Scotia was used to test our toolkit in regard to coastal and inland flooding, since flooding is already a problem there, and is expected to be exacerbated by climate change.

- **Pereau Watershed:** Since Annapolis Royal does not have on-site water and septic or significant agricultural land uses, we examined these rural land use factors in the rural watershed of Pereau River in Nova Scotia's Annapolis Valley.

Figure 1.2: *Test Site Locations*

Map Source: NS(Encarta.msn.com)[1]

1.2 Land Use Planners Overview

Land Use Planners, as their name implies, deal with the use and management of land. In Canada, the term 'Land Use Planning' is a sub-sector of 'Planning', which the Canadian Institute of Planners (CIP), defines as, "the scientific, aesthetic, and orderly disposition of land, resources, facilities and services with a view to securing the physical, economic and social efficiency, health and well-being of urban and rural communities" www.cip-icu.ca/ (CIP website). The Canadian Institute of Planners is the professional organization and certifying agency for planners in Canada.

Besides land use planning, the planning sector in North America includes: urban/city planning, regional planning, metropolitan planning, rural planning, and environmental planning, with a lot of overlap among these sectors. In Canada, the majority of planners are government employees, working for municipal planning offices. According to Statistics Canada, there are approximately 10,000 professional planners in Canada. Over half of these planners are members of the Canadian Institute of Planners (Statistics Canada, 2006: http://www.statcan.ca/menu-en.htm).

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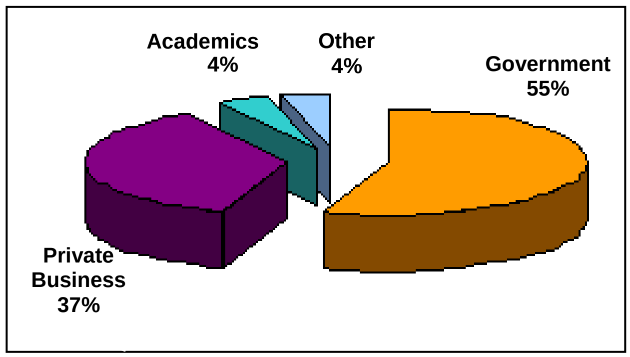
The Canadian Institute of Planners is the primary planning organization in Canada. Planners can obtain certification through CIP; however, this certification does not enable them to "seal" construction plans and documents, which require an engineer's involvement. Planners normally work at the conceptual design stage, in both community and site-specific land use planning. However, close work with other professions from the municipal and private sectors is essential.

Municipal Land Use Planners work with municipal engineers and other municipal staff, as well as private consultants and community residents, to develop long-term and short-term plans to promote the best use of a community's land and resources. They deal with a number of community issues, including environmental, social, and economic. "Planners are concerned with the scientific, aesthetic and orderly disposition of land and resources and the location of facilities, buildings and services over a given territory" www.cip-icu.ca/.

Figure 1.3 *Employment Sectors for CIP Members*



Source: Information provided by Canadian Institute of Planners. Charts based on Statistics Canada and CIP

Land Use Planning Issues and Tools

Rural Land Use Planners are concerned with a variety of community issues, including:

- promoting safe and healthy living conditions,
- conversion of land from its natural state to development,
- protection of natural, cultural, and heritage resources,
- infrastructure development,
- social and community services,
- economic community vitality, and
- emergency measures.

Climate change can be a challenge to these issues, including:

- flooding of coastal and inland development,
- drought stresses on agriculture,
- high wind impacts on structures and infrastructure,
- secondary impacts on property values and insurance,
- impacts on terrestrial and aquatic plants and vegetation, and
- threats to human health and life.

Analysis of these impacts in terms of climate change involves both traditional tools, and tools new to most Land Use Planners and municipal engineers. Traditional analysis tools used by Land Use Planners and engineers include, into which climate change should be incorporated include:

- geographic Information Systems (GIS) tools,
- decision support tools,
- engineering and scientific analysis tools, and
- regulatory analysis.

Implementation of land use climate change adaptations involves primarily working within existing tools to include climate change parameters. Existing implementation tools include:

- planning policies in a community's Strategic Plan,
- land use by-law,
- subdivision by-law,
- other municipal by-laws,
- Best Practices recommendations to other municipal departments, and
- building codes in some municipalities, where planners serve as Development Officers.

This study attempts to bridge the gap between the engineering/science disciplines and Land Use Planning, with respect to the emerging community planning issue of climate change impacts analysis and adaptations. The gap between environmental engineering/science and Land Use Planning has begun to close in recent decades, due to increasing understanding of the need for resource-based planning, especially in rural areas not serviced by municipal water and sewer. However, relatively recent environmental planning concepts such as "Sustainable Development", "The Natural Step", and "Ecological Footprint" can be clear in objective but quite vague in methodology for accomplishing growth that is compatible with environmental resource protection.

Climate change can exacerbate existing environmental issues, such as flooding and drought; and thus, there is an even greater need for more scientific analysis in Land Use Planning practices. For example, it has only recently been generally practiced that development in rural areas unserviced by public water and sewers needs to be kept within the safe yield limits of the aquifer supplying well water. However, land use planning of lot sizes and population densities for maintaining well water *quality* is still rarely practiced. Similarly, the risks associated with development in coastal and inland floodplains are clear, but this still is not adequately reflected in land use location choices. Planning practices such as inadequate development setbacks from water, agricultural districts (in Atlantic Canada) that include soils only arable with irrigation, and land development densities that do not adequately consider well water quality protection are *already* needed. Climate change may increase this existing need to bridge the gap between science and Land Use Planning. While there is still much uncertainty regarding climate change, policies that take a conservative approach are "policies of no regrets", since they are already needed for better Land Use Planning.

1.3 Climate Change Overview

What is Climate Change?

First of all, what is Climate? Climate is the average pattern of weather for a particular region and time period - usually observed over a 30-year time period (IPCC, 2001). Weather describes the short-term state of the atmosphere. The weather changes daily depending on the season and the type of system that is in place at a particular time, however, climate does not vary much in the normal span of a human life time for a given area. Extremes such as hurricanes, heavy snowfall, or torrential rain are duly noted weather events that lend to the overall climatic average. Climatic elements typically include precipitation, temperature, and wind and also take into account humidity, sunshine, fog, frost, and other measures of the weather.

Climate change refers to the variation in the Earth's atmospheric environment through natural processes and the impacts by humans on our global climate due to the release of greenhouse gases (United Nations Framework on Climate Change, 2006: http://unfccc.int/2860.php).
Most climate change scientists agree that it is the unnatural increase in greenhouse gas (GHG) from human activity that is the cause of today's climate change. Naturally occurring greenhouse gases trap solar energy and warm the Earth, enabling it to support life. This is called the greenhouse effect. In reality, all of Earth's flora and fauna owe their very existence to the Earth's ability to generate and retain GHGs. Without the greenhouse effect, the average global temperature would be 30 °C colder than the current average of 15 °C (World Wildlife Fund, 2006: http://www.worldwildlife.org/).

Climate change has been occurring on the Earth since the first wisps of atmosphere were generated hundreds of millions of years ago. There have been countless tropical periods and ice ages in the intervening millennia, but all climatic fluctuations – up until about mid 18th century – were as a result of natural causes such as: stellar and planetary motions, fluctuations in the Sun's energy output, volcanic eruptions, or the bombardment of the Earth by space debris. During the last 400,000 years – through tropical intervals and ice ages – the concentration of carbon dioxide (CO_2) in the Earth's atmosphere has averaged 280 ppm with very little variation. Beginning with the 18th century Industrial Revolution in Great Britain, human activity, through the consumption of coal, oil and gas products, has produced increasing quantities of CO_2. Since 1990 atmospheric CO_2 concentration levels have been recorded at 380 ppm (McElwain et al., 1999).

Eighty-five percent of the world's energy requirement is generated from fossil fuels (Canadian Hydropower Association, 2006). When we burn carbon-based fuel carbon dioxide, water vapour, methane (CH_4), nitrous oxide (N_2O) and other gases are being emitted into the atmosphere. CO_2 contributes two-thirds of the greenhouse gases globally. In addition to the CO_2 concentration increases, atmospheric methane and nitrous oxide levels have increased by 150 and 20 percent respectively (http://www.pewclimate.org/document.cfm?documentID=221). The earth's atmosphere contains about one-percent of GHG. Thus minor increases in the concentration of these gases can cause major changes in our climate.

Scientists have reported that global temperature increased by an average of 0.6 degrees over the past century with the rate of change since 1976 at roughly three times that over the past 100 years. Regardless of our efforts to date, most weather models predict that there will be an average global temperature increase of at least 1.4 ^{0}C by 2050 and as much as 6 ^{0}C by 2100. The decade of the

1990s was the warmest on record (UNFCCC, 2006). Of the past 22 years, 19 have been the warmest since 1880.

Figure 1.4 *Historical Carbon Dioxide and Temperature Changes*

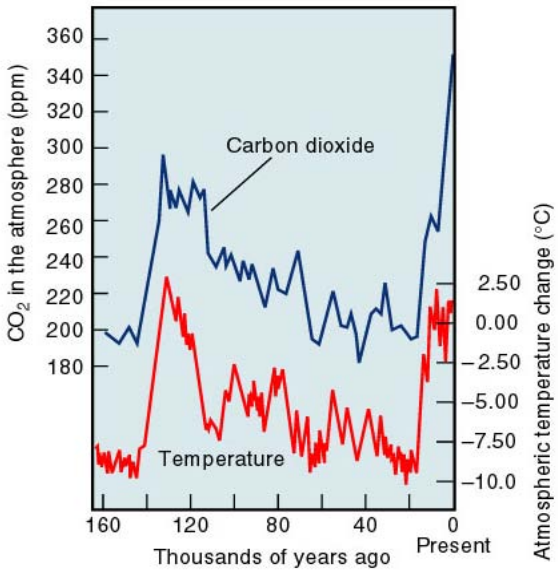
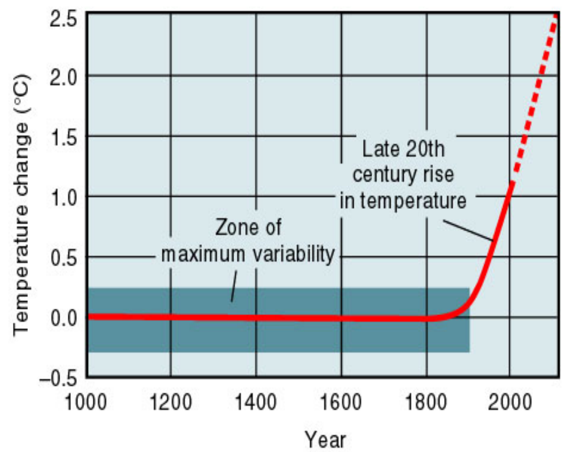


Figure 1.5 *Global Temperature Change During the Past 1,000 Years*



Source: Botkin and Keller, 2003, John Wiley and Sons Publishers

Even if we could completely stop GHG production tomorrow, it would not immediately stop climate change. Atmospheric CO_2 has a lifespan of approximately 100 years, CH_4 12 years, and N_2O 114 years; other gases have much longer life spans. Hence, as long as these excess GHGs exist in our atmosphere, adverse changes will continue. Reducing the causes of climate change by reducing GHG emissions is the objective of the Kyoto Protocol[1].

Increased air temperatures could result in the melting of the permanent polar ice and the world's glaciers; and the thermal expansion of ocean water because of higher water temperatures will cause climate-change related sea level rise. The global mean sea level is expected to rise 50 cm by the year 2100 (IPCC, 2001), causing flooding of low-lying areas and other damage. An increase in precipitation and changes in the severity or frequency of extreme events are expected in many regions. Countries lying in the northern latitudes, like parts of Canada, will tend to experience greater temperature fluctuations. Generally speaking, the more the climate changes, the greater the risk of adverse effects.

[1] The Kyoto Protocol on Climate Change is an international agreement with legally binding emissions targets for industrialized nations that will strengthen the international response to climate change. With its beginning at the1992 Earth Summit in Rio de Janeiro, the Protocol was signed at Kyoto, Japan in December 1997. Simply stated, the world's developed countries have agreed to reduce their emissions of six key greenhouse gases by at least 5% percent below their 1990 levels by the period 2008-2012, with demonstrable progress being made by 2005. Although 150 countries signed the Protocol, it came into effect only when 55 countries representing at least 55 per cent of the world's GHG emissions had ratified it individually. This threshold was surpassed in 2005 when Russia ratified it, although the USA and Australia had opted out. Most countries – including Canada – have not met their targets; in fact, Canada has increased its GHG emissions by approximately 20 percent in the intervening years. Thus we must reduce our GHG emissions by at least 25 percent before 2012.

1.4 Climate Change Impacts Overview

An overview of some of the main climate change impacts in Atlantic Canada is outlined below.

Sea Level Rise is one of the most important climate change factors in coastal communities. The mean sea level is expected to rise between 9 and 88 cm by the year 2100 (IPCC, 2001). This could cause massive coastal erosion and inundation of low-lying areas, such as salt water marshes, potentially destroying ecosystems and reducing crop yield. Salt water infiltration into fresh water aquifers could render them unfit for consumption. Sea surge may have an even greater effect on coastal communities' infrastructure.

Severe weather events, such as an increase in the frequency and severity of severe storms are expected to increase in many regions, causing flooding, wind damage, and ice damage to structures and infrastructure. This could affect human health and safety, property values, commercial property insurance rates (residential flood insurance is not covered under home owner policies in Canada), and bank mortgages.

Inland flooding of river flood plains is another major projected impact of climate change. What is now the 100-year flood plain may become the 50-year floodplain, i.e., the average flooding frequency may double, with higher areas flooded. Large peak flows on rivers in Atlantic Canada are already becoming more common. This should be considered for new construction and infrastructure.

Stormwater management is another environmental factor that may be strongly influenced by climate change. With more severe and frequent storms, stormwater management infrastructure will need to be designed to handle the higher runoff volumes. The flooding of New Orleans showed the potential for catastrophic damage done by storm-related water with inadequate dyke infrastructure.

Wastewater management will also be affected with more frequent and severe storm events flooding sewage treatment lagoons, causing power outages at sewage lift stations, flooding into sewage treatment plant outfalls, etc.

River ice formation and breakup will cause more ice dams, flooding, and scouring, affecting roads, bridges, and other infrastructure.

Aquifers and surface waters will be affected, since evapotranspiration may increase due to temperature increase; and groundwater recharge may decrease (with the increased runoff from more severe storms). Summer stream flows may decline, with a corresponding increase in winter flows, since snowmelt tends to recharge groundwater. In general, shallow unconfined aquifers will be impacted most significantly. Lower water levels could mean higher pollution.

Forest species composition may change as the climate becomes too warm for some of the boreal species. This may put boreal species at the limit of their temperature range, making them more susceptible to wind throw, with the increase in severe storms. Climatic zones could shift poleward and vertically, disrupting forests, deserts, rangelands, and other ecosystems. As a result, many could decline or fragment and individual species may become extinct.

Wildlife species composition may change as their habitats change. There are already noticeable changes in bird species composition in Atlantic Canada, with more southern species occurring in what was the limit of their range. Since insect species adapt more readily to climate changes than their avian predators adjust to new prey species, birds' food sources may be negatively impacted. **Aquatic ecosystems and wetlands** may change, due to increased variability in precipitation and groundwater levels, and altered water temperatures and flow regimes. Vernal pools also will be less stable. Lake temperature and water level fluctuations may effect fish and other aquatic species and ice cover duration will be shortened, or not occur at all in some areas.

Agricultural water shortages and crop damage may occur, since there will be more climate variability (frosts in summer and thaws in winter) and extreme weather events, including droughts and storms, and more evapotranspiration, which will reduce soil moisture. Better water management and cropping practices will be needed to adapt to these changes.

Human health and safety is impacted by climate change in many ways, including an increased level of transmission of pathogens in water and air pollution, and the dangers to human health and safety from an increase in severe weather events.

1.5 Climate Change Adaptations Overview

Since Land Use Planners are concerned with the uses and management of land, adaptations appropriate for them involve adapting the locations of new land uses (such as conversion of natural habitat to development), and adapting the impacts on existing uses, which cannot easily change locations. Locational adaptations for new land uses involve finding alternative locations for particular land uses that will not be prone to the impacts of climate change. For example, locating new development out of flood prone areas, or locating new agricultural uses out of drought-prone soils. Adaptations for existing land uses are more complex, with a multitude of adaptations, appropriate to the specific use. For example, floodproofing existing structures, or finding new irrigation sources for crops on droughty soils.

Climate change adaptations can be classified as reactive, i.e. reacting to an existing problem, or anticipatory, i.e., avoiding a problem before it occurs. An example of an anticipatory adaptation is the Confederation Bridge between New Brunswick and Prince Edward Island, which was built on metre higher than needed today, to accommodate sea level rise over the next hundred years of its designed lifespan. See Chapter 1 of the main report for a summary of other adaptation case studies.

The two major climate change impacts we are addressing in this report involve coastal flooding, primarily from sea level rise, and agricultural drought.

Adaptations to coastal flooding include:

- Protection of the coastline through levees, groins, and 'soft' protection measures such as beach nourishment and wetland restoration;
- Accommodation of sea level rise while development continues to occupy coastal areas, such as flood-proofing of buildings, and better emergency management planning; and
- Retreating from the risk by moving existing development and legislating to prevent future development of vulnerable coastal areas.

Adaptations to agricultural drought include:

- Developing new irrigation resources and water management practices;
- Planting drought resistant crop varieties;
- Reducing the demand side of water use by all water users; and
- Transitioning from agricultural land uses to residential if agriculture becomes less viable.

1.6 Adaptation Case Studies Overview

Climate change adaptation is a relatively new science; with three key ingredients still evolving: downscaling global projections of climate change to specific communities, assessment of potential impacts, and adaptation measures to these impacts. This project has attempted to bridge the gap between the emerging science and community adaptation tools. Each tool addressed in this project in chapters 3 and 4 discusses current state-of-the-art and its application, with additional sources of information contained in the Technical Appendix.

Below is a sampling of climate change adaptation case studies, with respect to community land use planning. The case studies below incorporate certain aspects of climate change adaptation into their by-laws and practices. They are organized according to the two major climate change impacts this study addresses: flooding and drought. References are provided where the information was obtained from secondary sources.

Sea Level Rise

Prince Edward Island (PEI): A major case study of climate change impacts and adaptations with respect to coastal flooding was undertaken in Prince Edward Island (PEI), and served as valuable instruction for this study. The project was carried out by a team from Natural Resources Canada, Environment Canada, Dalhousie University, the Centre of Geographic Sciences of the Nova Scotia Community College and the City of Charlottetown, with other partners. In addition to climate change impacts of accelerated sea-level rise on the PEI coast, an important objective of the study was to consider feasible and effective adaptation measures that might be adopted in PEI to minimize the impacts of these changes. Finally, because this study is one of the first of its kind, it is intended to serve as a template for future studies**.**

One implemented adaptation measure in PEI to build the Confederation Bridge joining New Brunswick to PEI one metre higher than they would have been under today's sea levels to accommodate potential sea level rise.

Increased Frequency and Intensity of Heavy Storms and Flooding

Some Canadian municipalities include floodplain regulation in their zoning / land use by-laws, while others, such as Winnipeg, Manitoba, and Hazleton, British Columbia have separate by-laws or regulations addressing floodplains. Examples of different types of land use regulations are summarized below.

- **Prince Albert, Saskatchewan:** In new subdivisions stormwater infrastructure is designed to drain floodwaters into retention ponds, rather than into the North Saskatchewan River. This method has also been used in other Canadian communities to prepare for the potential increases in stormwater runoff and flooding that are expected to result from climate change.

(http://chapter7.pdf+%22climate+change+adaptation%22,+bylaws,+Canada&hl=en&ie=UTF1/26/03)

- **Grande Prairie, Alberta:** This is an example of Canadian municipalities that are upgrading their infrastructure in preparation for climate change. Originally, Grande Prairie's stormwater infrastructure was designed to accommodate the 1 in 5 years flood; however, it is being redesigned to accommodate the 1 in 100 year flood. (http://chapter7.pdf+%22climate+change+adaptation%22,+bylaws,+Canada&hl=en&ie=UTF1/26/03)

- **Moncton, New Brunswick:** This is an example of existing forward-thinking floodplain policies that already include concerns about floodplain development. The 2001 Municipal Plan for the City of Moncton includes policies for identifying those areas of land subject to flood inundation. Although there is no specific flood risk area by-law, implementation is via a recently enacted zoning by-law states that "no building or structure may be erected on any site ... when, in the opinion of the Commission the site is ... subject to flooding".
- **Saint John, New Brunswick:** The City of Saint John adopted a flood risk area by-law for the 1 in 100 year flood zone, which requires compensatory floodwater storage capacity for any development that reduces the existing floodwater storage capacity of a site. This is enforced through the building permit process, which requires that development may only be permitted if the cross sectional area of the drainage course is not compromised.
- **Charlottetown, Prince Edward Island**: Although the City of Charlottetown does not have a flood risk by-law, flood-prone areas are protected from development impacts via the zoning by-law, which includes flood-prone areas in its Open Space zoning districts. This is supplemented by the subdivision application requirements to include maps of those areas vulnerable to flooding.
- **St. John's, Newfoundland**: The Municipal Plan for St. John's, Newfoundland's municipal plan includes a the statement that land within a 15 metre buffer of the 100-year high water mark of ponds, wetlands, rivers or major tributaries of rivers shall not normally be developed. However, exemptions may be granted if Council determines that the impact of development will be minimal.
- **Winnipeg, Manitoba:** The City has adopted detailed flood-proofing regulations for structures in the designated floodway fringe area, which is enforced through a permit system.

Increased Frequency and Intensity of Drought Events

Some municipalities in North America are incorporating water Best Management Practices into their municipal plans and by-laws to compensate for expected climate change. Such policies are especially needed in agricultural communities where agricultural irrigation competes with aquifer water demands of other land uses. Some examples of water conservation programs are summarized below.

- **Vancouver, British Columbia:** To adapt to the more frequent drought conditions expected to occur with climate change, the City of Vancouver has initiated a program to educate citizens about the Best Management Practices of using natural cultivation to conserve water. (www.city.vancouver.bc.ca/engsvcs/watersewers/water/conserva.../landscaping.htm)

- **Vancouver, BC, Edmonton, AL, and Etobiocoke, ON** have implemented lawn sprinkling restrictions and developed water conservation rain barrel programs for collecting rainwater for gardening watering, since 40% of domestic water consumption in these municipalities is used for lawn sprinkling. (www.tv.cbc.ca/canadiangardener/GardenGuests/053197may3197.htm)

Figure 1.6 *Rain-Barrel*

- **British Columbia** has implemented water conservation by incorporating innovative features in a number of several of its municipal buildings in order to reduce water use. (www.greenbuildingsbc.com/new_buildings/case_studies.html)
- **Regina, Saskatchewan** reduced the demand side of water conservation through public education on low water landscaping and plumbing fixtures, and increased charges for public water use.

  (http://chapter7.pdf+%22climate+change+adaptation%22,+bylaws,+Canada&hl=en&ie=UTF1/26/03)
- **New York, New York:** The New York City Department of Environmental Protection initiated a water conservation program to replace 1.33 million toilets in the city, as well as a program to install water saver showerheads and faucet aerators. "An impact evaluation of project results in multi-family buildings found an average reduction in water use of 29% per apartment per day." (www.greenbuildingsbe.com/new_buildings/resources_guide/4.0_epr_water.html)
- **California**, as well as some African countries, have sponsored research and cultivation of new agricultural crop varieties, such as drought resistant corn, to better withstand the impacts of climate change on agricultural drought.
- **In the Annapolis Valley region** of Nova Scotia, many farmers are already adapting their irrigation practices with water conservation in mind, to avoid 'tragedy of the commons' demands on surface and groundwater resources.

Policies of "No Regrets"

Winnipeg, Manitoba as well as several other Canadian cities, have adopted a climate change policy of "no regrets", in order to cope with the uncertainty regarding climate change. This policy implements cost-effective climate change adaptations that can only *help* the City. Like the stormwater adaptation strategies discussed above, these policies err on the side of the environment, and implement solutions to problems that needed to be solved anyway, in a cost-effective way.
Climate change impacts adaptations for Land Use Planners includes four main elements:

- understanding of climate change impacts,
- recognition of the need to adapt – having an incentive, and
- ability to adapt.

These elements are still not well understood by most communities; and thus, current objectives, such as school budgets, often take precedence over climate change impacts assessment and community adaptations. However, forward-thinking municipalities plan *now* for adaptation to future conditions before they happen. This project is focused on what community Land Use Planners can do to evaluate and adapt now, to be prepared for an uncertain future, with policies and practices that are needed anyway – policies of no regrets.

Chapter 2 Climate Change Impacts on Land Uses

2.1 Introduction

Climate change impacts all sectors of land uses, for both the natural and built environments. The overview of these impacts in Chapter 1 is discussed in more detail in Chapter 2. Since Atlantic Canada is the broader focus of this study, this chapter begins with an overview of impacts in Atlantic Canada in general, followed by impacts in Nova Scotia, where our test cases are located. For summaries of climate change in the rest of the Atlantic Canada provinces, see the full report, which this document summarizes. All of these climate change impacts are of interest to community Land Use Planners, since they affect the use and management of lands and waters, and near-shore marine environments.

Four main climate change impacts on land use planning are addressed in more detail, with additional details provided in the main report that this document summarizes. These topics are: severe weather events, sea level rise, water pollution, and agricultural drought. Agricultural drought is included

2.2 How Will Climate Change Impact Land Uses in Atlantic Canada?

Because of the geographic location, and the fact that the Atlantic Canadian provinces are nearly completely surrounded by water, changes to water temperature and sea level will have the greatest effect on weather and climate. In Atlantic Canada it is projected that the temperature will increase by up to 4 °C over the next 100 years, considered to be the largest and most rapid change in 10,000 years (http://www.climatechange.gc.ca). Although micro-climates within sections of Atlantic Canada are highly variable, in general the region is expected to experience the climate change impacts addressed below. Please refer to the main report for additional details for each Atlantic Canada province.

The following climate change factors are expected to impact at least parts of Atlantic Canada:

- **Increase in Extreme Weather Events:** It is expected that precipitation will occur in more frequent, shorter and heavier bursts (personal communication with Gary Lines, Environment Canada, 2006). An increase in extreme storm events could cause more storm surges and coastal flooding, especially when combined with sea level rise.
- **Sea Level Rise:** An increase in sea level rise will contribute to coastal flooding and erosion.
- **Storm Surges:** Storm surges can raise the water level a metre or more above normal. As sea level is expected to rise dramatically over the next century, storm surges will be able to flood areas never before flooded, impacting near-shore development.
- **Increase in Weather Variability:** Changes, such as occasional thaws in winter and frosts in summer could occur, which would impact agriculture.

- **Increase in Non-Point-Source Pollution:** Pollution from runoff into surface waters would affect human health.

- **Precipitation Distribution:** Changes could affect agriculture, as well as water supplies.

- **Sea Ice:** Changes could affect flooding and ice scouring of infrastructure.

Because of their geographic location, and the fact that the Atlantic Canadian provinces are surrounded by or adjacent to water, changes to the temperature and level of the Atlantic Ocean will have the greatest effect on our weather and climate. All four provinces will experience similar impacts along their coastlines; i.e. increased coastal erosion, inundation of floodplains, and seawater infiltration risk to fresh water aquifers.

These expected climate changes would, in turn, affect land uses, especially land uses that are resource-based, such as agriculture. The main climate change factors expected to impact Atlantic Canada are summarized below. In addition to structure and infrastructure damages caused by an increase in extreme events, especially storms, an increase in sea level rise, and ice changes, there are a number of other land uses in rural Atlantic Canada that are expected to be impacted by climate change. Natural ecosystems are also a "land use", and they will also be impacted by climate change. These impacts on resource-based land uses are summarized below.

Structures and Infrastructure: Structures and Infrastructure are the main human land use expected to be impacted by climate change. Impacts include:

- An increase in extreme weather events, especially wind and precipitation from storms, could cause more damage to structures, infrastructure, and human health and safety.

- When extreme weather events are combined with sea level rise, significant flooding can occur in coastal watersheds.

- Long-term changes in annual precipitation could affect overall electric power generation capability, although electric power systems with dams and reservoirs are likely to be able to adjust their operating practices to accommodate to these changes.

- Transportation land uses could be affected by flooding and wind.

- Public water and sewer systems, as well as private wells and septic systems, could be impacted: Lowered water levels or decreased river flows in some areas could lead to poor water quality; and increases in temperatures, prolonged summer seasons, and heavier rainfall could also increase the risk of waterborne parasites, such as Giardia and Cryptosporidium, contaminating drinking water.

Agriculture: Agriculture is an important land use in some areas of Atlantic Canada, especially in Nova Scotia's Annapolis Valley. Impacts include:

- A longer, warmer summer would lengthen the growing season and increase the yield of warm-weather crops, such as soybeans, winter cereals, corn, and grapes. However, these conditions could also result in more droughts and a greater need for irrigation.

- Warmer winters may benefit agriculture by reducing winterkill of forage and fruit, but could also create problems for farmers by increasing the range and abundance of insect pests.

- An increase in storms, hail, floods, and drought, may be the greatest concern for agriculture, since these events damage crops and livestock.

- The increase in climate variability expected to occur with climate change could affect agriculture adversely if winter thaws reduce the ice protection of late winter buds. Also, frosts in summer could impact agriculture *if* such temperature extremes occur.

Forestry: Forestry is an important land use in some areas of Atlantic Canada, especially for pulp and paper. Impacts include:

- The risk of trees blowing down may increase, as storms become more frequent and intense as a result of climate change.

- Warmer winter temperatures may allow invasive insects, such as the gypsy moth, to become more pervasive. This is because prolonged temperatures at or below -9°C, or short periods below -23°C, are necessary to limit the development and survival of this species. All of these conditions could result in stresses on existing tree species, the elimination of some, and the introduction of others (http://www.climatechange.gc.ca).

- Increased severity of storms may damage crops and forests through erosion, ice, blow-downs or increased forest fires (www.gov.nf.ca).

Fishing and Marine Issues: Since provinces in Atlantic Canada have substantial seacoast, climate change impacts on near-shore marine environments impact fishing, and thus, the economy of coastal towns. Impacts include:

- The distribution and population of key fish species may be affected by climate change, as fish are extremely sensitive to temperature.

- Climate change may increase the range and extent of the organisms responsible for toxic algae blooms, such as red tides. Toxic blooms pose a serious threat to both fish populations and human health.

- Changing temperatures are expected to influence the numbers and distribution of some fish species. For example, cod are strongly influenced by water temperature. Cod size is also affected by temperature, with larger cod found in warmer waters.

- Salt marshes and lagoons that are currently fresh water could be flooded by seawater, affecting the habitat of fish.

Aquaculture: Aquaculture is becoming an increasingly important land use. Impacts include:

- For some shellfish species, such as oysters, a long, warm summer may improve the conditions for growth and reproduction. Oysters hibernate in winter, so warmer, shorter winters may favour their winter survival. On the other hand, species such as mussels prefer cooler water, and warm summer temperatures can be more stressful.

- Warmer, shorter winters may result in poor ice conditions that hamper winter harvest of mussels.
- Erosion of land can result in heavy silt forming in rivers, which can be stressful for cultured fish or, when reaching the estuaries, can smother oysters being grown on the river bottom.
- Storms can damage culture equipment and result in loss of stocks.

Natural Ecosystems: Natural ecosystems are intrinsically important in Atlantic Canada, as well as to residents and the tourist industry. Impacts include:

- Warmer temperatures and changing precipitation patterns are expected to affect the distribution, health, and accessibility of wildlife and fish. Changes in river flow, such as earlier ice breakup, stronger spring runoff and reduced summer flow, could impact several species.
- The higher sea levels expected to result from climate change will threaten this habitat, and place stress on shorebird populations.
- Insect pests of agriculture and forestry are expected to increase, since they can adapt to warmer temperatures faster than their avian predators.
- Significant warming of fresh water bodies could also affect the numbers and distribution of trout and salmon.

Since extreme weather events and sea level rise could have the most serious climate change impacts on land uses in Atlantic Canada, more detail is provided below. More detail is also provided for non-point source pollution, since coastal watershed management has been identified by many Land Use Planners in Nova Scotia, and by the Nova Scotia Department of Fisheries and Aquaculture, as an important Land Use Issue. More detail on agricultural impacts is provided under section 2.4.

2.2.1 Increases in Extreme Weather Events

Increases in extreme weather events, especially storms, may be the most damaging climate change impact. Examples of extreme weather events impacting land use planning decisions are shown in figures 2.1 through 2.4.

Severe weather events include more severe and frequent rain, snow, and ice storms, resulting in:

- wind safety issues and property damage; flying debris, such as floating wharfs lifted out of water and thrown at buildings during Hurricane Juan,
- flooding safety issues and property damage,
- lightning strikes and storm related fires,

- land- and mud-slides,
- safety issue re. power outages and no electricity for heating,
- electric cables down, causing dangerous conditions, and
- more traffic accidents.

Increasing snow precipitation and more frequent winter storms have implications for the annual cost of snow removal, necessary to preserve the integrity of transportation routes, as well as an increase in traffic accidents. A six-day snowstorm in January 2000, for example, impacted the Maritimes with snow, high winds, and storm surge over 1.5 metres, causing serious damage to coastal infrastructure. Severe cold and winter storms may become more extreme in Atlantic Canada with climate change. Electrical power generation will become increasingly strained as residents seek to cope with these extreme temperatures through heating and air conditioning.

Although there is still uncertainty with regard to potential hurricane increases in Atlantic Canada due to climate change, such storms could increase. Waters south of Nova Scotia are usually not warm enough to support a Category 2 hurricane . However, according to Environment Canada, when hurricane Juan swept into the North Atlantic in September 2003, the surface water temperature was 18 °C, or three degrees higher than normal. This increase allowed Juan to retain its C2 strength long enough to make landfall. If, due to climate change, this trend of warmer ocean water continues, Atlantic Canada may be susceptible to more Category 2 and higher hurricanes in the future.

Land Use Adaptations

Land use adaptations to extreme weather events include:

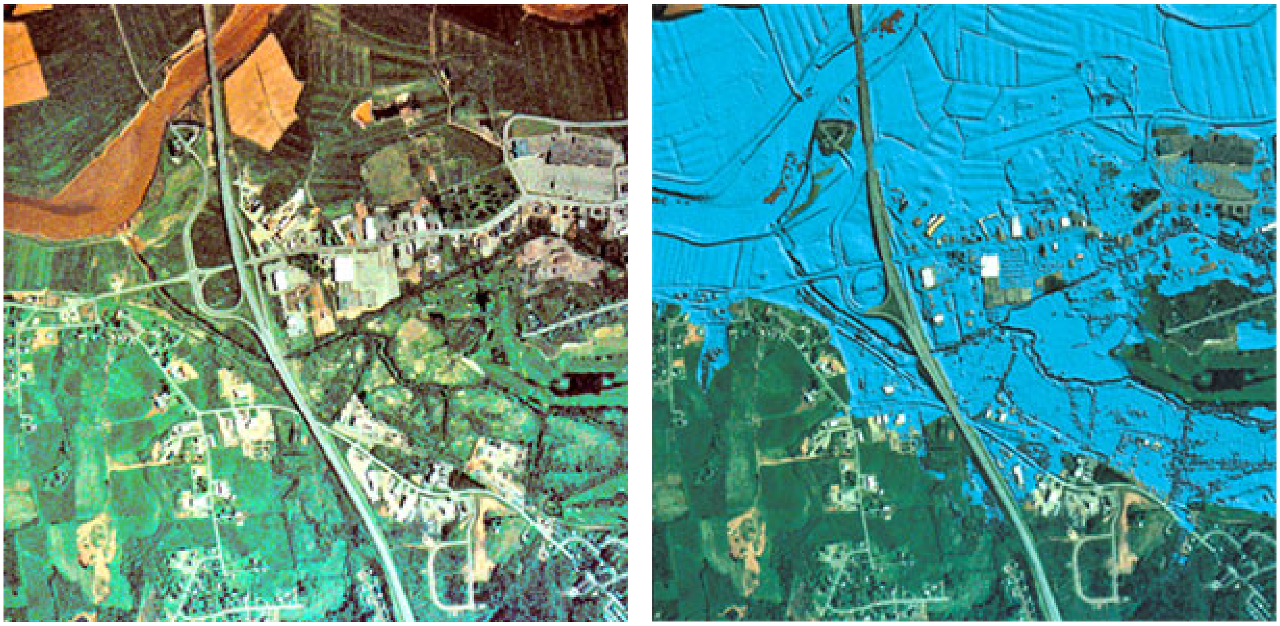
- better future land use location decisions, enforced through municipal policies and by-laws;
- protection or relocation of existing land uses to reduce flooding and storm impacts;
- best Practices for stormwater management;
- structural adaptations, enforced through building and engineering codes; and
- better emergency management response.

The climate change impacts that will affect land use planning the most, are discussed in more detail below.

Examples of Extreme Weather Events Impacting Land Use Planning Decisions

Storm severity and frequency will increase, causing increased flooding and wind damage.

Figure 2.1 ***Simulated Flooding of Truro, NS***



Downtown Truro, NS before simulated flood, left, and after simulated flood, right.

Source: Charles O'Reilly, 2002. From a Natural Resources Canada slideshow, by Ryan Schwartz.

Figure 2.2 ***Actual Flooding of Truro, NS***

Land Use Planning mistakes like locating these roads and buildings in a floodplain in Truro, Nova Scotia will have increased adverse consequences with climate change. Much of Truro was built in the floodplain, and according to Charles O'Reilly, a tidal expert for the Canadian Hydrographic Service, sections of the Bedford Highway may have to be rerouted eventually.

Actual flooding of downtown Truro, NS, as a result of a tropical storm, which occurred on 1 April 2003.

Source: photo by Mark Hingley. See Environment Canada at: http://www.atl.ec.gc.ca/weather/severe/march2003_e.html

2.2.2 Sea Level Rise

Rising Sea Levels are expected to have the greatest impact on coastal flooding. More than 80% of the Maritime Province coastlines are classed as moderate high sensitivity to sea level rise, particularly PEI's North Shore, Nova Scotia's Atlantic Coast, and the Gulf Coast of New Brunswick (Shaw, et al, 1998). Most of Newfoundland's high rocky coast is considered to have a low sensitivity. All four provinces may experience similar impacts along their coastlines, which will likely include:

- increased coastal erosion,
- inundation of flood plains,
- higher tides,
- flooding of dykeland agricultural areas,
- elimination of some low-lying sections of land,
- rapid migration of beaches,
- flooding of coastal freshwater marshes,
- a stronger Labrador Current seawater infiltration risk to fresh water aquifers, and
- changes in fish habitat in the ocean, rivers, and lakes, caused by warmer water temperatures. (http://www.climatechange.gc.ca).

Global Sea-Level Rise

As the climate changes, global sea-level is expected to rise. Past records of tide gauge information in the region show that sea-level has been rising at a near constant rate since we started recording the tides. One of the longest tide-gauge records is in Charlottetown, Prince Edward Island, where water levels have been recorded nearly continuously since 1911. Analysis of these data indicates sea-level has risen at a near constant rate of 32 cm per century. It is expected that sea-level rise will accelerate with climate change. Although the range of sea-level rise varies from model to model, most scientists agree that the rate of global sea-level rise will increase in the future, compared to the past rates. This in part is a result of global warming and the melting of the polar ice caps, as the ice melts, more water is put into the oceans and sea-level rises. The International Panel on Climate Change (IPCC) predicts global sea-level to rise between 0.09 and 0.88 m by 2100. In this study, a modest rate in the centre of the projected range of 0.5 m per century is used to estimate areas of flood risk to long-term sea-level rise.

Dynamics of Earth's Crust

The vulnerability of coastal areas is a combination of global sea-level and local dynamics of the earth's crust. The entire Maritimes was covered by ice during the last glaciation. The load of the ice depressed the earth's crust. As the ice melted approximately 12,000 years ago, the crust rebounded. Even though the ice melted a long time ago the effects of the load on the earth's crust is not expected to end until another 2000 years. This rebound is not uniform across the region, and the effects are still being felt today. The areas where the ice was thickest were depressed the most and peripheral regions where actually uplifted, termed the 'peripheral bulge'. The ice was thickest over Hudson Bay and today this area is still rebounding from the load of the ice and is being uplifted. The Maritimes represent part of the peripheral bulge and the crust in the regions of southern New

Brunswick and Nova Scotia are subsiding. Subsidence rates vary across the region with Nova Scotia sinking at a rate of 20 cm per century. The subsidence of the crust is important for coastal communities in that it compounds the problem of local sea-level rise and must be considered when projecting future flood risk.

In the most sensitive areas much of today's coastal wetlands, barrier beaches and lagoons will be underwater, and coastal structures will become increasingly vulnerable to flood damage. According to Natural Resources Canada, approximately 7,000 kilometres of Canada's coastline are sensitive to sea level rise, as shown in Figures 2.2.3 and 2.2.4. Note that the eastern shore of Nova Scotia is highly sensitive to sea level rise, since it is low-lying; whereas the south-western coast along the Bay of Fundy is less sensitive, due to the higher elevations of the coast. Coastal areas most vulnerable to flooding now, will be the areas most vulnerable to the increased flooding expected from climate change in the future.

Figure 2.3: *Canada's Sensitivity to Sea Level Rise*

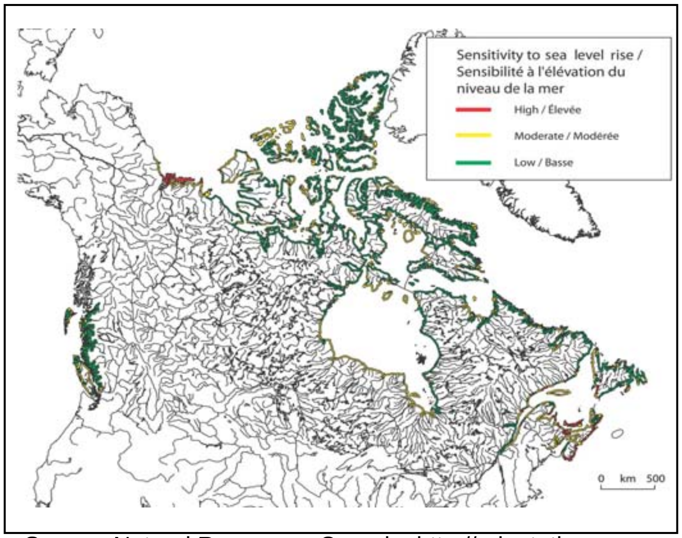
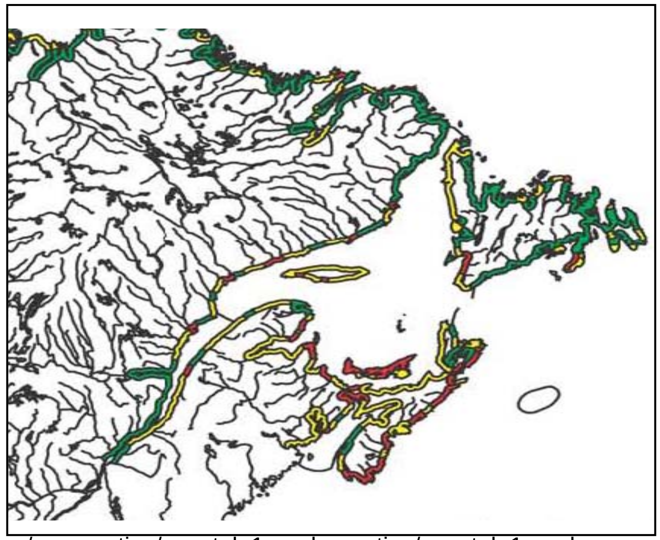


Figure 2.4: *Atlantic Canada's Sensitivity to Sea Level Rise*



Source: Natural Resources Canada: http://adaptation.nrcan.gc.ca/perspective/coastal_1_e.phppective/coastal_1_e.php

Storm Surge

As sea levels are expected to rise over the next century, storm surges will be able to flood areas never before flooded. Storm surges form when low pressure and strong onshore winds combine to raise the water level a metre or more above normal. Low-lying coastal areas will be the most threatened. Sinking of coastal lands from crustal subsidence could compound the problem.

Land Use Adaptations

Land use adaptations to sea level rise include:

- better land use location decisions for future development, enforced through municipal policies and by-laws;
- protection or relocation of existing land uses to reduce flooding and storm impacts; and
- structural adaptations, enforced through building and engineering codes.

Examples of Sea Level Rise (combined with extreme weather events) Impacting Land Use Planning Decisions

Figure 2.5 Vulnerable Infrastructure

Rising sea levels, together with an increase in the frequency and severity of severe storms, will make infrastructure land use locations even more important with climate change. These railroad tank cars were blown off their tracks (and some into the water) into the Bedford Basin in Halifax during Hurricane Juan in 2003. The tracks should not have been located so close to water in the first place.

Source: Environment Canada, 2003: http://www.atl.ec.gc.ca/weather/hurricane/juan/photos_e.html

Figure 2.6 Vulnerable Structures

Some structures along the shores of Sambro Harbour, NS, were devastated during Hurricane Juan in 2003. An increase sea levels and in severe storms will make structural land use location decisions even more important with climate change. Thus, a policy of no regrets, locating structures farther from shorelines, in the face of climate change uncertainties can only improve existing land use problems.

Source: http://www.coastalradio.org.uk/hurricanejuan.htm

2.2.3 Increases in Non-Point-Source Pollution

The projected increase in the frequency and severity of rainfall, which is expected with climate change in some areas, is likely to cause more stormwater runoff. Since stormwater runoff mobilizes non-point-source pollutants[2] on and in land surfaces, there could be increased health risks of non-point-source pollutants entering surface and groundwaters, as well as oceans.

Water-borne Disease in Freshwater

The projected increase in frequency and severity of heavy rainfall can overload septic systems, infiltrate leaky sewer systems, and cause excessive runoff from agricultural fields, all of which can lead to increases in water supply contamination by bacteria, viruses, and protozoa. These microbes can be harmful to human health, and fatal to infants, elderly, and people with compromised immune systems. Contamination of a public drinking water supply by cryptosporidia (a protozoan), lead to 403,000 reported cases of illness in Milwaukee in 1993. The cause of this was unusually heavy rains and snow melt, which caused an increase of over-land runoff, which carried the non-point- source contaminants from the agricultural fields into the streams that fed the reservoir. The same kind of flushing from heavy rains can affect private wells, which are also influenced by surface water runoff. An increase in heavy rainfall events could also cause more rapid leaching of contaminants underground, from hazardous waste landfills, septic fields, and agriculture, since contaminants will be more rapidly leached from saturated soils. This kind of extreme runoff and leaching, and the pollutants it carries with it, will most likely increase with climate change.

Water-borne Disease in Oceans

The warmer ocean waters that will be caused by climate change could increase the growth of toxic organisms, such as red tides, which causes shellfish poisoning. When both warm eddies in the ocean and nutrient rich runoff from the land occur simultaneously, there can be an outbreak of a diatom that produces a toxin that causes shellfish poisoning. In 1987, an outbreak of such shellfish poisoning occurred on Prince Edward Island for the first time, when, in an El Nino year, warm water and heavy rains carrying nutrient-rich runoff occurred.

Land Use Adaptations

Land use adaptations to the threat of increased non-point-source pollution of both fresh and salt-water water-borne disease outbreaks could be greatly curtailed by:

- Prevention of non-point-source runoff, carrying nutrients, microbes, and pollutants into fresh and salt waters, through better land use regulation and 'Best Practices'; and
- Improved water treatment facilities, better septic and sewer designs and technology, "green" stormwater catchment sumps would help.

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[2] Non-point source pollution is pollution that does not originate from a 'point source', such as a pipe; rather it is more diffuse in origin, originating from general urban runoff, septic fields, agricultural pesticides and fertilizers, poor construction practices, poor forestry practices, siltation from erosion, and improper disposal of hazardous wastes.

These adaptations would be policies of “no regrets”, since despite uncertainty about the potential contribution of climate change to non-point-source pollution, such pollution is already a wide-spread problem in many communities.

2.3 How Will Climate Change Impact Nova Scotia?

Nova Scotia is a coastal province where one is never more than 55 km (most areas are less than 40 km) from the coast. Coastal environments are constantly changing due to the effect of winds, waves, tide and ice continuously eroding, transporting and depositing coastal material. Since the last ice age, sea-level change, waves and tides have caused progradation, stability and retreat of the coast (Davis and Brown, 1997). Records at Halifax show an average increase of .35 m in sea level in the last 100 years. If climate change related sea-level change predictions are correct then the Nova Scotia coast will continue to modified, possibly at an accelerated rate.

Climate change related sea level rise is expected to be 0.5 m over the next 100 years, resulting in the erosion of our coastlines, inundation of beaches, flooding of dyked land (head of the Bay of Fundy & Minas Basin), estuaries (Chezzetcook Inlet), and low lying areas (most near coast areas). Global temperature changes will impact climatic patterns, such as the intensity of the wind and type and distribution of precipitation. Over the past several years Nova Scotia has experienced some uncharacteristic extremes in weather events. The water cycle may also be affected.

Scientists have made the following predictions:

- Northern Nova Scotia will be cooler, while the south will be warmer.
- Cyclones may decrease in number, but the frequency of intense cyclones may increase.
- Thermal expansion and melting polar ice will cause sea level to rise in southern Nova Scotia, exacerbated by crustal subsidence.
- Tides are expected to be higher.
- The south flowing Labrador Current is expected to be stronger.
  (source: http://www.climatechange.gc.ca).

Projected Changes in Temperature/Precipitation in Nova Scotia:

Daily maximum temperature (from 1961-1990 normals) to increase:

- 1.8 °C by 2020
- 3.2 °C by 2050
- 5.3 °C by 2080. (Meteorological Service of Canada**,** Atlantic)

Daily minimum temperature (from 1961-1990 normals) to increase:

- 1.1 °C by 2020
- 2.7 °C by 2050
- 4.0 °C by 2080. (Meteorological Service of Canada**,** Atlantic)

Daily precipitation amount (from 1961-1990 normals) to change:

- 12% by 2020
- 12% by 2050
- 10% by 2080. (Meteorological Service of Canada**,** Atlantic)

Fish become more susceptible to disease, their food source could decrease and new predators may migrate to the newly warmed or cooled waters if ocean temperatures were to change as little as 0.5 °C. Slow rates of adaptability to change may cause fishery stocks to decline or for some species to become extinct. Lobster is an important fishery, especially in South-western Nova Scotia. Warmer ocean temperatures may cause lobsters to moult more often causing poor quality lobster during fishing seasons. More moults however cause lobsters to grow to a market size faster and as they age moult less frequently. Increased water temperature may affect this industry by having to change fishing seasons in some cases, and closed in others.

In 2003 Hurricane Juan made landfall in Nova Scotia near Halifax and tracked north through the Province towards Prince Edward Island, a Category 2 (154 – 177 km/hr winds and a storm surge >1.8 m) storm, the likes of which have not been seen in this area for over 100 years. The storm literally flattened large expanses of forests across Nova Scotia. Global changes in carbon dioxide (CO_2) levels and temperature could affect the forests of Nova Scotia causing growth rates to be altered, introduction or extirpation of tree species, and an increase or decrease in carbon and nutrients in the soil. These changes could also affect the ability of the forests to regrow after intense weather such as strong winds or storms. Nova Scotia's forest industry employs over 12,000 people, and lumber, pulp & paper account for 20% of Nova Scotia's total exports (2003 figures).

Climate change will only add to the challenges of the agriculture industry which deals with issues such as farm margins, market, risks associated with weather (temperature and precipitation) weather related events, demands on soil, water quality and availability and pests and disease. For example, if it is too wet in early spring, planting can be delayed. There could also be an increase in the risk of frost damage to plants in the fall because they will reach maturity later in the year. Adaptation mechanisms for agriculture include drought management, proper crop selection and irrigation.

Summary of Climate Change Impacts in Nova Scotia:

- increased frequency and severity of extreme weather events;
- rising sea level and storm surges – increased erosion and flooding of coastal areas, saltwater intrusions as well as impacts on coastal infrastructure;
- increased ocean temperatures affecting distribution and abundance of fish and other seafood stocks;
- Warmer water temperatures may cause lobsters to moult twice a year instead of once a year in more areas than they do now. When that happens, lobsters are of poor quality and the lobster fisheries are usually closed.
- long term shifts in the nature of forests as well as insect infestations and fire;
- increased yield of warm weather crops (corn, soybeans, and grapes) due to a longer growing season;
- more droughts and need for agricultural irrigation; and
- temperature variability affecting agricultural crops.

Additional agricultural impacts in Nova Scotia's Annapolis Valley are discussed in more detail below.

2.4 How Will Climate Change Impact Agriculture in the Annapolis Valley?

The Annapolis Valley is Nova Scotia's major agricultural region (see Figure 1.2 – Test Site Locations). It is 128 km long, with a width of approximately 3 to 11 km, and has some of the warmest temperatures in Nova Scotia. Precipitation wise, it is also one of the driest areas of Nova Scotia, which *may* increase with climate change, although our test case analysis (see Chapter 5) did not prove this. Our test case results did, however, indicate a mild warming trend in the Annapolis Valley, which will extend the growing season, and thus, increase evapotranspiration, which will reduce the soil moisture available to plants.

Agriculture is directly dependent on the weather and climate because these affect such things as temperature, precipitation, and types and amounts of pests and disease. For example, if it is too wet in early spring, planting can be delayed. There could also be an increase in the risk of frost damage to plants in the fall because they will reach maturity later in the year. Early extended thaws, or late springs and early frosts, reductions in sea and river ice, and shifts in rainfall patterns could potentially alter growing seasons.

Figure 2.7 *Annapolis Valley Agriculture*

Agriculture in Nova Scotia's Annapolis Valley, as seen from the look-off on North Mountain, in the Pereau Watershed. The Minas Basin, where the Pereau River empties, is in the background.

Photo by: Tamara Hill

The potential impacts of climate change on agriculture in the Annapolis Valley have been analyzed by the Clean Annapolis River Project (CARP) as follows:

"The Annapolis Valley usually gets plenty of precipitation especially in the fall and winter months, however the rapid drainage and a series of dry summers from 1996 to 2002[3] have caused drought

[3] Since the CARP report was written, the summers of 2003 and 2004 also experienced drought conditions.

conditions for farmers and more generally in the potable water supply. Water supply in the Valley has been a concern for many years. Sea level rise effected by climate change may cause salty contamination of fresh water supplies and aquifers for drinking and irrigation water...

A significant part of the farmland at both ends of the Annapolis Valley lies on dykeland that originates with the Acadian Settlers in the late 1600s and early 1700s. An overtopped or broken dyke from storm events renders the dykeland unusable for agriculture for several growing seasons due to the affects of salty water. Climate change related sea level rise could threaten the Acadian dykelands by increasing the risk of flooding the rich agricultural lands and by causing the requirement for considerable changes to take place the dyke infrastructure to combat the problem." (CARP, 2003)

A report on agriculture in the Pereau and Habitant watersheds in the Annapolis Valley, written in 2003 by CBCL Limited and Jacques Whitford, assessed irrigation needs in this area as follows:

> "Adequate preparation for summer rainfall shortages has clearly been a lacking ingredient for a continued flourishing of the agricultural industry in the last few years. Shortages of rainfall in the growing season have forced farmers to further invest in irrigation systems, and this places additional stress on water withdrawals from streams, lakes, and wells. … Several watershed assessments have resulted in the realization that the largest single water demand within the Annapolis Valley is for irrigation. New water sources and better water management are necessary if domestic and industrial land uses are to continue to expand in the future, and compete with agriculture and the environment (ecosystem, fish) for limited water resources…" (CBCL et al., 2003).

Land Use Adaptations

Land use adaptations for agriculture to the threat of reduced soil moisture during the growing season, and increased potential of flooding of dykeland agriculture with seawater include the following:

- In land use by-laws, do not zone as 'Agriculture District' soils that are only arable with irrigation.
- Develop new irrigation sources for farms, especially using groundwater resources.
- Repair, maintain, and improve (if feasible) dykeland agriculture infrastructure to resist saltwater intrusion from sea level rise. In the long term, climate change could necessitate abandoning agricultural use of some of these lands.
- Plant new varieties of crops that require less water.
- Use Best Practices for agricultural water management.
- Use better land use planning to assess and control competing demands for water from residential, commercial, and industrial land uses.

Chapter 3 Analysis Tools

3.1 Introduction

Tools for analyzing this study's focus impacts of coastal and interior flooding, and groundwater availability to agriculture and development are presented in this chapter. Further details on the more mathematically and scientifically complex analysis methods are presented in the main report.

The analysis tools addressed in this section are aimed at incorporating scientific analysis of climate change impacts into land use planning decisions. Interviews with scientists, federal and provincial administrators, and municipal land use planners during the course of this project have indicated that the science that is known, in terms of climate change impacts, as well as resource-based land use planning in general, is not always getting to community land use planners, or to the general public. Thus, floodplain zoning is inadequate in many municipalities, most building codes do not yet incorporate climate change adaptations, private residents build new homes too close to shorelines, and different land uses compete for increasingly scarce groundwater resources.

Our analysis tools research was based primarily on developing the types of tools that are needed to incorporate more scientific information on climate change into land use planning decisions. Since the most important potential climate change impacts in our test case sites in south-western Nova Scotia are water-related (flooding and drought), the scientific and engineering tools we developed are water related. Where possible, we adapted existing tools to incorporate climate change considerations. However, three of our tools were created for this project, since existing tools proved to be impractical for our purposes. These are: Climate Change Modeling Tools Coastal Flooding Analysis Tool, Climate Change Projection Tool, and Risk and Cost/Benefit Analysis Tool.

Together, these tools provide the scientific bases for informing Land Use Planning decisions with regard to climate change impacts. In Chapter 4 – Implementation Tools, we look at tools that can be used to adapt land use planning to the climate change impacts, once our Analysis Tools have been used to assess these impacts.

3.1.1 Analysis Tools Summary

For all of these tools, explanations of the terminology and methodology precede descriptions of the tools we selected for our project. The methodologies of these tools were then tested at our test case sites, which are covered in Chapter 5. More details about some of these tools are included in the Technical Appendix. The tools follow a linear progression of selection and analysis; and are designed to answer the questions Land Use Planners might pose with regard to climate change impacts and adaptations in their coastal communities.

Tool 1 - Climate Change Modelling Tools
How will the climate change in my community?

The first group of tools we addressed are climate change modelling tools, since projected climate changes on a particular community need to be assessed in order for potential climate change impacts and adaptations to be evaluated. First, existing global and finer scale climate change modelling tools were researched. This lead to the selection of a stochastic model, which was then adapted to the purposes of this project.

Tool 2 – Coastal Flooding Analysis Tools

How will climate change impact coastal flooding in my community, and how far back from the coast is it safe to locate new structures and infrastructure?

The second group of tools we addressed are tools for analysing coastal flooding, since that is perhaps the main projected impact of climate change on land uses in Atlantic Canada. Our primary test case site of Annapolis Royal was selected because it is surrounded by water on three sides, has experienced severe flooding in the past, and is a good example of climate change impacts on flooding. We used LIDAR technology for precise topographic measurements, together with a new tool called Water Modeler to give us flood frequencies, i.e. the probabilities of flood return periods.

Tool 3 – Inland Flooding Analysis Tools

How will climate change impact inland flooding in my community, and what tools can we use to determine how far back from surface water shores is it safe to locate new structures and infrastructure?

There are a number of existing engineering tools currently being used for riparian flood level projections. We examined surveying tools and flood routing analysis tools for their utility with respect to inland flood level projections. Climate change will affect the parameters used in these models, such as precipitation and snow melt. Thus, these tools can include climate change parameters *when* climate changes, such as precipitation changes, are known. However, climate change factors are inter-related, making it difficult to separate out the different factors needed in these models.

Tool 4 – Hydrogeology Analysis Tools

How will climate change impact groundwater quantity and quality in my community, and what agricultural land uses and housing densities can be supported?

The hydrologic cycle, of course, includes groundwater as well as surface water. However, we chose to examine water cycle modelling tools from a groundwater perspective, since in our test case site of the Pereau watershed, groundwater resources have been evaluated for new sources of agricultural irrigation. These existing tools include models used to evaluate the carrying capacity (in terms of supportable population density and groundwater demands) of a rural watershed in terms of both groundwater quantity and quality. Climate change factors can be integrated into these existing tools, once the local climate change factors have been calculated using our stochastic downscaling tool.

Tool 5 – Risk and Cost / Benefit Analysis Tools

Once we know the climate change impacts, how do we assess the risks and cost/benefits of climate change impacts on coastal flooding and agricultural drought?

Existing methods of analyzing risk and cost/benefits were adapted to incorporate climate change factors. The tools were designed specifically to assess risk and cost / benefits of coastal flooding and agricultural drought, which will be exacerbated by climate change factors. These two climate change issues were selected, since coastal flooding is the main climate change issue in our test case community of Annapolis Royal, and agricultural drought is the main climate change issue in our test case site of the Pereau watershed.

Tool 6 – Land Sensitivity and Build-out Analysis Tools

Once we know the localized climate change projected impacts, and the risks and cost/benefits of climate change from the proceeding tools, how can we then incorporate this knowledge into community land use planning *locational* decisions for new land use conversions?

We focused our analysis on tools that can be used in GIS land use analysis and mapping, since such tools are now fundamental for Land Use Planners in developing Future Land Use Maps, which in turn, drive municipal policy and regulatory decisions. We researched existing GIS models, and selected and tested CommunityViz in our test case community of Annapolis Royal. We focused on Land Use Carrying Capacity Analysis, which includes two main aspects of GIS Land Use Planning Analysis: Land Sensitivity Analysis and Build-Out Analysis. Climate change adaptations were integrated into this tool through the results from our coastal flooding tools.

These analysis tools are reviewed in this chapter, with more detail for some of the tools provided in the Technical Appendix, and testing of the tools addressed in Chapter 5 – Tools Tests.

3.2 Climate Change Modeling Tools

3.2.1 Introducton

Climate change modelling tools were reviewed in order to select the most appropriate climate change downscaling tool for use by municipalities in projecting climate changes tailored to their community. Please refer to Technical Appendix 3 for a complete review of climate change background information and models. This is summarized here, with more detail provided for our choice of stochastic model as the basis for our climate change projection tool.

In order to properly investigate these effects, clear definitions of what are meant by *weather*, *climate*, and *climate change* are needed. The term *weather* is defined by the Gage Canadian Dictionary (1983) as the condition of the atmosphere at a particular time and place with respect to temperature, moisture, cloudiness, and/or windiness. Of particular note in this definition is the fact that it refers to an instant in time. That is, weather is essentially a *point* observation which changes from minute to minute and so tends to be highly variable. Because of this high temporal and spatial variability, it is hard to predict its details. For example, there is little point in a weather station attempting to predict the precise temperature and/or precipitation rate at 12:43 pm next Tuesday at Purdy's Wharf, Halifax. However, a weather station might attempt to predict quantities such as the expected (i.e. mean) early morning or mid-afternoon temperatures, the mean hourly windspeeds, or the mean 24 hour precipitation at a particular location. These are *averaged* quantities and since averaging reduces variability, these quantities can be predicted with higher confidence (i.e. averaging reduces variance which in turn reduces the width of a confidence interval on a prediction).

Climate, on the other hand, refers to weather conditions averaged over a much longer period of time, usually on the order of several decades (Barrow, 2004). As discussed above, this averaging smooths out the small-scale weather fluctuations that occur from hour to hour, day to day, month to month, and, to some extent, year to year. Because of this smoothing, the variability of climate is far less than the variability of weather. Nevertheless, the average of the weather over a period of, say, one year will change somewhat from year to year. This scale of change, referred to as *climate variability*, reflects the natural fluctuations in the average weather conditions from year to year. Changes in the sun's output, the variations in the natural composition of the atmosphere, the planetary surface reflectivity, extent of forestation, and so on, will result in the average weather changing from year to year. In the normal course of events, these natural changes tend to be transient so that the weather averages tend to be statistically *stationary* (e.g., the distribution of the weather averages remains the same at all times).

The World Meteorological Organization (WMO), along with Environment Canada (EC) recommends that climate be defined using a *climate normal* which is an average over a 30 year period. The most commonly used climate normal period is 1961 to 1990. However, WMO recommends that the climate normal shift forward at the end of each decade. For this reason, the climate normal now used by EC is from 1971 to 2000. From a practical and human point of view, climate change will be defined here as a change in the average weather which results in humans having to modify their usual behaviour and/or standard practice in order to cope with the change. In other words, climate will be deemed to be changing when the climate normals have a distinct and sufficiently large positive or negative trend over scales approaching a human life-span, e.g. on the order of a century.

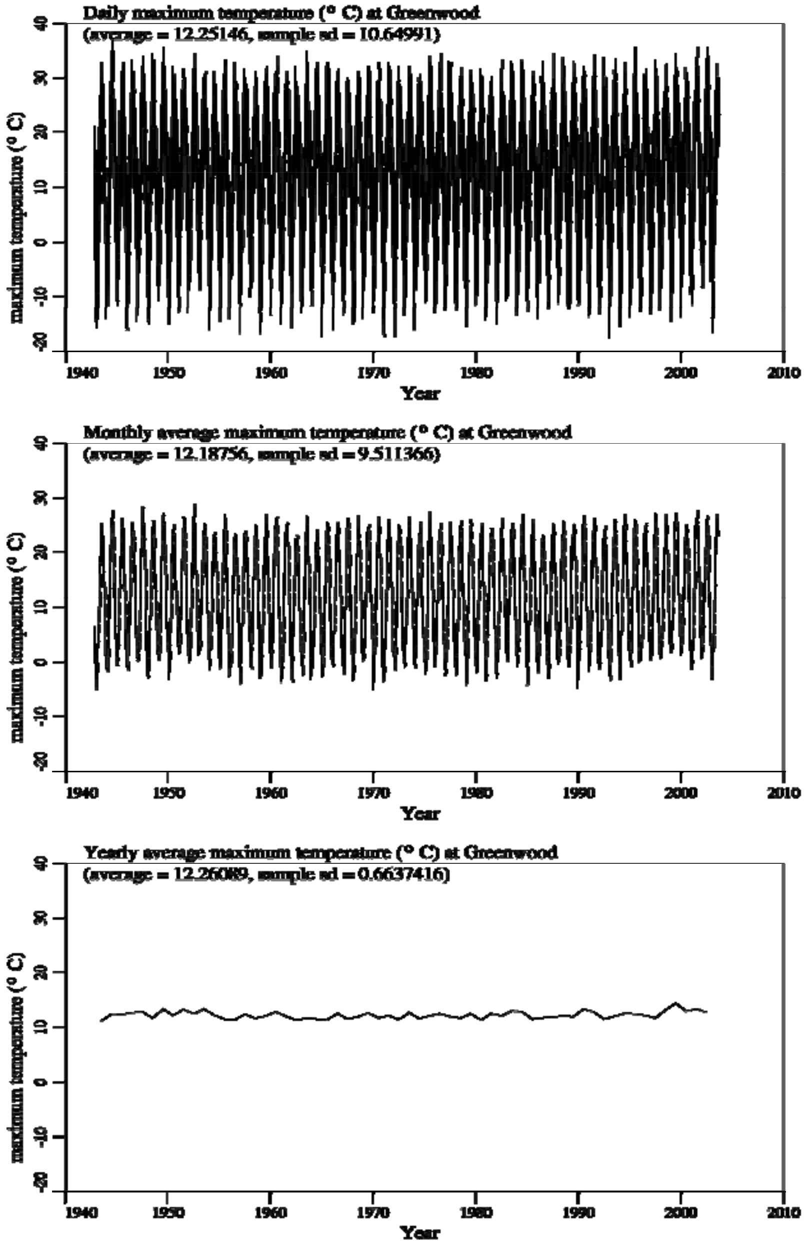


***Figure 3.1 Daily maximum air temperatures at Greenwood, Nova Scotia**, in the uppermost plot. The middle plot averages the daily maximum temperatures over monthly intervals, while the lower plot averages the daily maximum temperatures over yearly interval. The lowermost plot is essentially an estimate of the mean daily maximum temperature at any randomly selected day during a year.*

Figure 3.1 illustrates how averaging reduces variability. The uppermost plot is the daily maximum temperature recorded at Greenwood, Nova Scotia, over the 22,249 day period (61 years) from November 1, 1942 to September 30, 2003. This plot clearly has plenty of variability – its sample standard deviation is 10.6 °C. The middle plot is obtained by averaging the upper plot over monthly intervals (approximately 30 days each). A significant amount of "noise" is damped out due to the averaging, leaving the largely non-random annual temperature cycle. While the overall variability of the monthly average is not too much less than that of the daily observations (the sample standard deviation is now 9.5 °C) the range in extremes has been considerably reduced. In many cases, it is those extremes which are of most importance in disaster planning. The lowermost plot of Figure 3.1 shows the daily maximum temperatures averaged over each year. In this plot most of the variability has been eliminated by the averaging (the sample standard deviation is now reduced to 0.7 °C). The annual average daily maximum temperature can be reasonably well predicted. However, such a prediction is insufficient on its own to characterize the weather extremes experienced at Greenwood, Nova Scotia. One needs to know the mean annual cycle and daily variability to build up a picture of the uppermost plot from the lowermost plot.

Environment Canada defines climate change simply as "a change in the average weather that a given region experiences." Not surprisingly this definition is rather vague – climate change is a concept that depends entirely on the time scale being considered.

Figure 3.2 is a further illustration of climate and climate variability. The solid line from the years 1000 to 1860 represents the temporal 50-year *moving average* of the weather, which in turn is averaged over the Northern hemisphere. This moving average can be seen to be relatively stationary, fluctuating randomly around −0.4 ºC with a relatively small standard deviation. The grey region above and below the line represents the 95% confidence interval on the true annual mean weather – this band can be thought of as representing the hemispheric averaged climate variability (e.g. the 50-year average plus or minus two standard deviations of the annual average). However, it is entirely possible that the inhabitants of the Northern hemisphere considered the significant downwards swing in 50-year average temperature just after the middle of the 1400's to be a *climate change*.

The conclusions drawn from Figure 3.2 are that; there has been no climate change in the Northern hemisphere over the period from 1000 AD to approximately 1900 AD; there is, apparently, a slight climate change taking place from 1900 ─ 2000 AD; and the predicted temperatures from 2000 ─ 2100 AD show a very strong climate change.

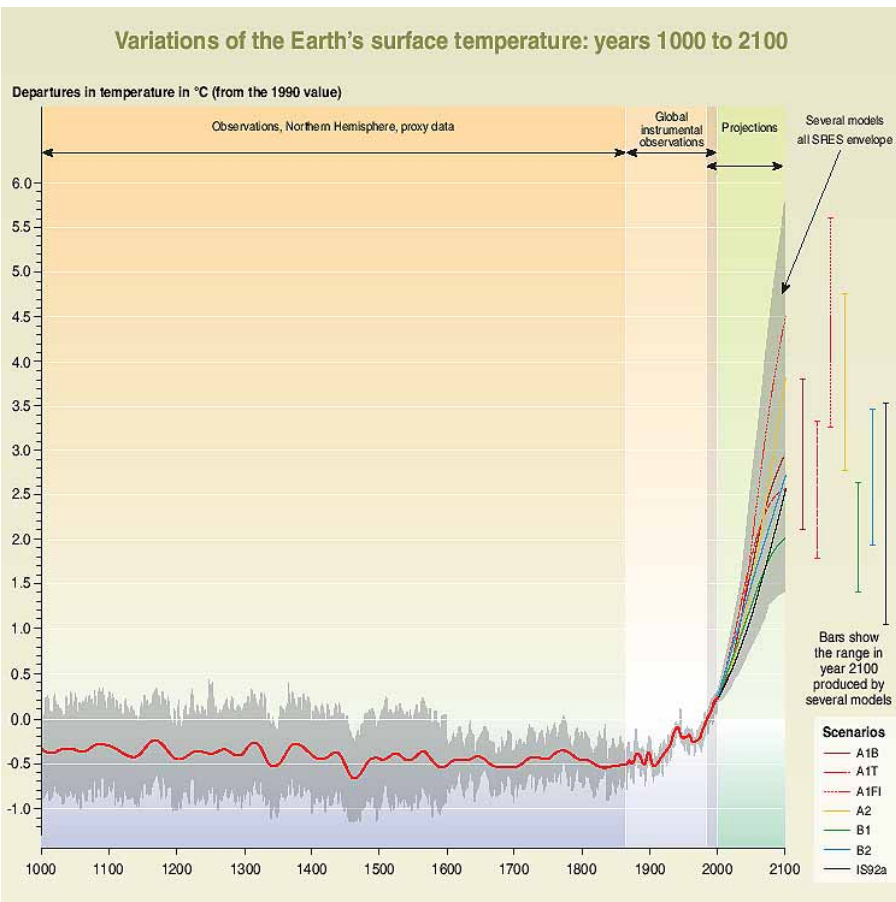


***Figure 3.2 Variations of the Earth's surface temperature**: From year 1000 to year 1860 variations in average surface temperature of the Northern Hemisphere are shown reconstructed from proxy data (tree rings, corals, ice cores, and historical records). The line shows the 50-year average, the grey region the 95% confidence limit in the annual data. From years 1860 to 2000 are shown variations in observations of globally and annually averaged surface temperature from the instrumental record; the line shows the decadal average. From years 2000 to 2100 projections of globally averaged surface temperature are shown for seven illustrative SRES scenarios using a model with average climate sensitivity. The grey region after 2000 shows the range of results from the full range of 35 SRES scenarios in addition to*

The next two subsections will review the methodologies available to predict the climate and its potential for change over the next century.

3.2.2 Summary of Climate Change Models

There were basically two downscaling tools available at the time this research was initiated; the first, and best, approach involves resolving the global climate physics at the site level scale (e.g. downtown Greenwood or Annapolis Royal). This downscaling methodology is called "Regional Climate Modeling". Although we know the physical equations involved with weather description at the local scale, the problem is that these equations require detailed information about the boundary conditions (topography, local water bodies, local land surface emissivity and reflectivity, etc.) at every site in the path of all weather system likely to approach the site. Describing and implementing these details in a finite element GCM model would be prohibitively expensive at this time. The current interim solution of the "Regional Climate Model" involves using the large scale, coarse resolution, GCM results as boundary conditions to a fine scale physical model developed at the local site. However, there is no evidence at this time that this is a particularly successful approach to generating realistic local weather. In fact, this approach is known to not very well represent local weather phenomena. In addition, Regional Climate Models offer only a particular weather realization and little ability to assess weather variability and extremes.

The second approach available at this time (e.g. the StatisticalDownscaling Model developed by ilby) involves developing a regression. The regression is a best fit equation relating the coarse esolution GCMresults to the local weather conditions at the site of interest. This involves "training" the regression to predict future weather using past weather history at the site of interest along with past GCM coarse scale predictions. As is well known regressions give "best fit" mean conditions. While the theory can be used to estimate variances, the underlying assumption is that all variability is normally distributed. In many cases, this assumption is not appropriate. Thus, regression techniques are best suited to estimate mean behaviour, but not extremes, unless all weather variables happen to be normally distributed, which they are not.

When considering risks associated with climate change, we need reasonably accurate estimates of the distributions of weather parameters. For example, if we are to estimate the probability that the maximum daily temperature in July of 2100 will exceed 38 C, we need to know much more than the mean daily temperature -- we need to know the complete temperature distribution. This is not given to us by either of the above two models. Thus, we need a model that goes beyond what is currently available.

The model developed in this report basically says that the future mean behaviour is as predicted by GCM models, but that weather variability is as seen in the past. This model allows for changes in the mean (temperature, precipitation, wind speed) and applies past variability to predict future extremes. This is a "best estimate" approach to predicting future climate risk.

3.2.3 Global Cliamte Models

Global Climate Models (GCM), also called General Circulation Models, are thermodynamic representations of the atmosphere and ocean which employ coupled partial differential equations to model the energy flows and produce equilibrium climate change simulations. The Canadian Centre for Climate Modeling and Analysis (a division of Environment Canada) is currently using a Coupled Global Climate Model called CGCM3. Coupled atmosphere-ocean models have been used for many years now to simulate the Earth's climate. They can reasonably accurately reproduce the seasonal

and regional average values and variations of climate quantities such as temperature, pressure, precipitation, cloud cover, and radiation
(Russell, 2005, aom.giss.nasa.gov/DOC4X3/ATMOC4X3.TXT).

The CGCM3 is comprised of four modules (derived from Hengeveld, H.G., *Projections for Canada's Climate Future*, Climate Change Digest, CCD 00-01 Special Edition, 2000, and Environment Canada www.cccma.ec.gc.ca/models/cgcm3.shtml):

1. **An atmospheric general circulation model** (AGCM3), which divides the atmosphere up into 32 layers vertically. The lowermost layer is approximately 100 m thick increasing linearly to approximately 3 km thick in the lower stratosphere, at a height of about 50 km. Horizontally, the surface of the Earth is divided into a grid of elements each of size 3.75º × 3.75º in latitude and longitude (3.75° is approximately 416 km at the equator). The model takes into account exchanges of heat, moisture, and momentum, solar radiative heating, cloud cover, cloud formation and characteristics, transport of water vapour and heat energy in vertical and horizontal directions, and responds interactively with the Earth's surface. Output from this model includes temperature, humidity, cloud cover, pressure, velocity, all computed as averages over each grid cell layer.

2. **An ocean general circulation model**, known as the *modular ocean model* (MOM), which represents the large scale features of the world's ocean circulation as well as water properties such as temperature and salinity. The modular ocean model is comprised of 29 layers in the vertical direction with a horizontal resolution twice as fine as the atmospheric grid (each atmospheric grid cell is underlain by 4 ocean grid cells).

3. **A thermodynamic sea ice model** that provides for the freezing and melting of ice at the surface in response to heat exchanges with the ocean and atmosphere. The amount of ice and extent of ice cover affects the radiative properties of the surface, as well as the amount of heat energy that can be absorbed.

4. **A land surface model** that includes three soil layers, as well as a snow layer where applicable, and a vegetative canopy treatment. The model calculates runoff and soil moisture on the basis of the balance between precipitation, surface evaporation, permeability, and the water holding capacity of the soil.

As of 2000, Hengeveld indicates that the current GCM models in use world-wide are not without their problems. Errors in the modelled exchange of heat and moisture between the ocean and the atmosphere, through omissions and approximations to the ocean and atmospheric processes, can cause the GCM to drift unrealistically with time. Most modelling groups attempt to remove this drift by making adjustments to the flux of heat and water between the ocean and atmosphere. In addition, many physical processes, such as those related to clouds, occur at scales far smaller than the 400 km grid scale, and so cannot be properly modelled. Such scale discrepancies are handled approximately by averaging the known process properties over the larger model scale in a technique known as *parameterization*.

The need to apply corrections to the model output (e.g. the flux adjustments) highlights the fact that these models are simplified and coarse approximations to a very complex system. For this reason, modelling groups put considerable effort into assessing the reliability of their models. One basic test of a GCM is its ability to reproduce the principal characteristics of the past and present climate changes. Figure 3.6 illustrates such a test – the Hadley Centre Atmosphere-Ocean GCM simulation shown captures the major trend of the global-mean temperature over the past century, but does fairly poorly on variations at scales of less than about 10 years.

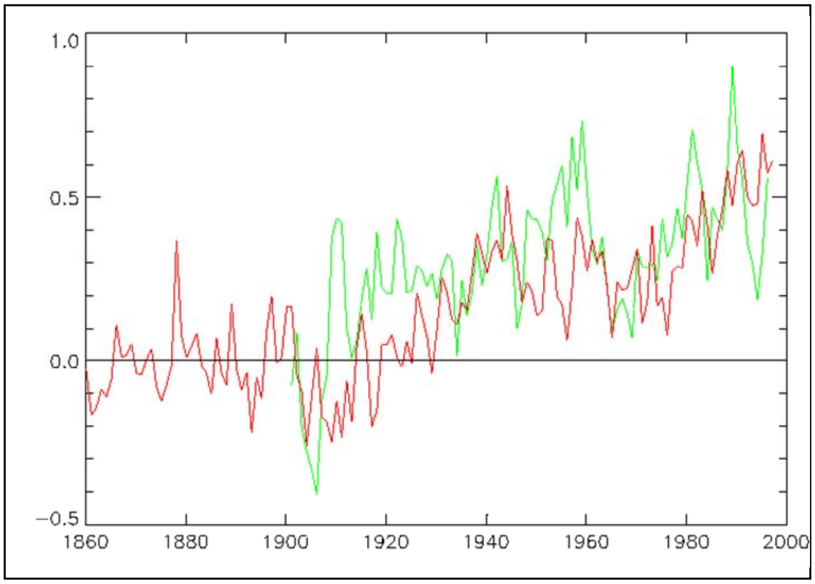


***Figure 3.3 Simulations of the global-mean temperature response**, relative to the 1860-1890 reference period, to historical forcing by greenhouse gases and aerosols. The simulation, in green, is by the Hadley Centre AOGCM (HadCM2, 1997). Observed global-mean temperatures are in red.*

Regarding the accuracy of the GCMs in use world-wide, Russell (2005), one of the prime architects of the NASA GCM, makes the following realistic observations (Russell, G.L., 4x3 Atmosphere-Ocean Model Formulation, 2005, in aom.giss.nasa.gov/DOC4X3/ATMOC4X3.TXT):

> "It has been noted that atmosphere-ocean model simulations, with well mixed greenhouse gases as the only forcing agent, would predict a global surface temperature rise over the twentieth century that is greater than observed, approximately 1.2°C versus an observed change of 0.8 °C. Other forcing agents are also operating including aerosols, volcanoes, ozone changes, and solar luminosity. These have changes in spatial patterns in addition to temporal changes, none of which are known as well as changes in greenhouse gases. Coaxing atmosphere-ocean model simulations to reproduce the surface air temperature for the past century, including the 1940s warming and colder temperatures of the 1950s and 1960s, has become more of an art than a science. You may believe the future predictions of global temperatures by models are valid, but do you trust them more than a statistician with graph paper and a book of past weather statistics?"

The Intergovernmental Panel on Climate Change (IPCC) identify the following three main sources of uncertainty which can lead to errors in GCM climate projections (IPCC-TCCIA, 1999).

1. Uncertainties in future greenhouse gas and aerosol emissions. Changes in government regulations, land use, and social pressures can all lead to significant changes in greenhouse gas and aerosol emissions in the years to come. The IS92 climate scenarios for 2100 have CO_2 concentrations ranging from a low of 471 ppmv to a high of 954 ppmv, corresponding to global annual mean temperature increases ranging from 1.5 °C to 2.6 °C. Uncertainties in aerosol emissions lead to even greater variability in climate projections.

2. Uncertainties in global climate sensitivity lead to differences in the way that physical processes and feedbacks are simulated in different models. This means that different GCMs simulate different global warming per unit of radiative forcing, which leads to an accumulating discrepancy between models over time.

3. Uncertainties in regional climate changes. These are apparent from the differences in regional estimates of climate change by different CGMs for the same mean global warming.

Nevertheless, the GCM's are the best models we have and they are becoming increasingly sophisticated and accurate. The Intergovernmental Panel on Climate Change (IPCC) states that the GCM's are the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations (IPCC-TCCIA, 1999). The IPCC further recommends that "users should design and apply multiple scenarios in impact assessments, where these multiple scenarios span a range of possible future climates, rather than designing and applying a single 'best-guess' scenario." Given the known uncertainties of GCMs, it is also strongly recommended that results from more than one GCM be employed where possible. For example, Figure 3.7 shows annual average temperature and precipitation in the 2050s for a specific region in Zimbabwe as projected by eleven different GCM simulations (experiments). The scatter between results is indicative of the uncertainty in the models and their input. By simultaneously considering multiple scenarios in an analysis, one minimizes the risk that the analysis is merely an opinion about the future (Byer et al., 2001, http://www.ceaa-acee.gc.ca/015/001/025/index_e.htm)

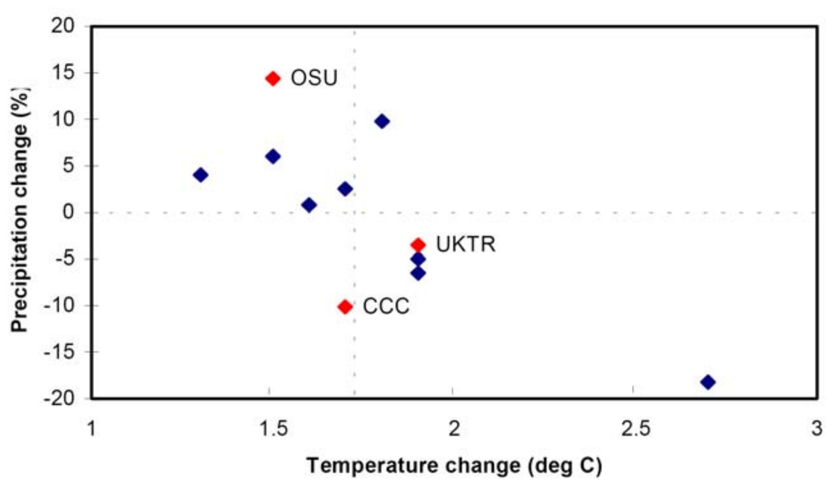


Figure 3.4 Changes in average annual temperature and precipitation *for the 2050s relative to 1961-1990 from eleven GCM experiments for a 10° lat/long region of southern Africa centered on Zimbabwe. Hulme (1996) selected the three experiments in red as representative scenarios.*

The performance of Canada's Coupled Global Climate Model, CGCM1, was reported in some detail by Hengeveld (2000). To test the model, a series of experiments were run:

1. a control experiment, in which greenhouse gas concentrations and other external forces of change were held constant. The purpose of this experiment was to provide a reference (baseline) against which the results of the other experiments could be compared.

2. an experiment in which only greenhouse gases (GHG) were increased with time.

3. a set of three experiments (GHG+A) in which both the concentration of greenhouse gases and sulphate aerosols were varied with time.

Sulphate aerosols are airborne particles, largely created by the burning of fossil fuels. However, unlike greenhouse gases, sulphate aerosols tend to cool the planet by reflecting incoming sunlight back into space. The aerosols also tend to be short-lived, so that they typically concentrate downwind of industrial regions (e.g. North America and Eurasia). Greenhouse gases, on the other hand tend to be much more uniformly mixed in the atmosphere around the world.

The experiment with just greenhouse gases slightly overestimated the temperature change since 1900. The greenhouse gas plus aerosol experiments showed much better agreement with historical records, as seen in Figure 3.5. Figure 3.5 also indicates that the Canadian model is at the high end of projections by other modellers by 2050 and well above them by 2100. This does not necessarily mean that the CGCM1 model is wrong, although it may be on the conservative side. The difference between models illustrates the degree of uncertainty inherent in any current numerical description of the Earth's climate.

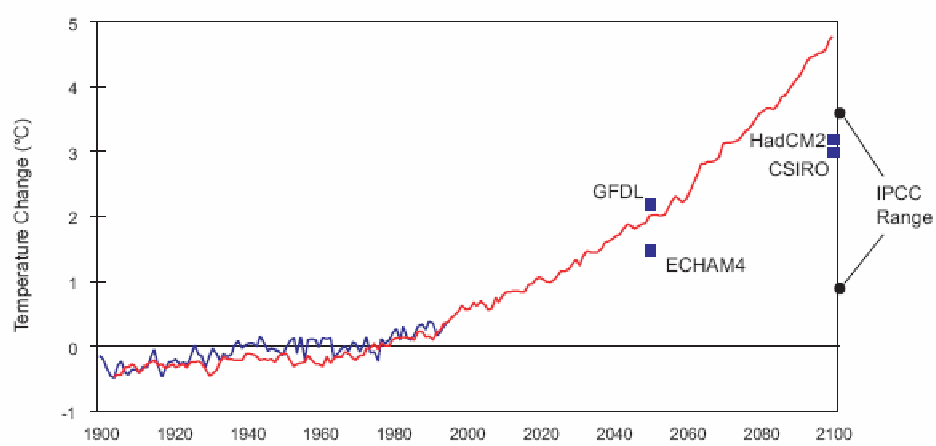


***Figure 3.5 The CGCM1 simulation** (red line) suggests an increased global mean surface temperature of more than 4 °C by 2100. The blue line is the observed global mean temperature while the blue squares are results from other GCM models. (Source: Boer et al., 2000, IPCC Data Distribution Centre)*

Figure 3.6 compares the Canadian (CA) CGCM1 predictions for 2050, over a number of different weather parameters, to three other global models; the UK Hadley Centre (HadCM2), the USA Geophysical Fluid Dynamics Laboratory (GFDL), and the Australian (AU) Commonwealth Scientific and Industrial Research Organization (CSIRO). The UK, USA, and AU global models tend to agree with one another reasonably well at all locations considered in Figure 3.6. The CA model differs significantly from the other three models in a few areas, namely the summer temperature at Ellesmere Island and the summer precipitation in Florida and California.

In the opinion of the authors, agreement amongst predictions for complex behaviour, such as the climate in 50 to 100 years, using independent approximate numerical models, is unlikely unless the models happen to use the same numerical formulation or to have been calibrated to yield similar results. The discrepancy, then, between the Canadian model and the others is more a sign of independence between the formulations than of a model error. It is also to be noted that the CGCM2 and the current CGCM3 models are improvements on the earlier CGCM1 model. However, the authors were unable to find a more recent comparison between the latest models.

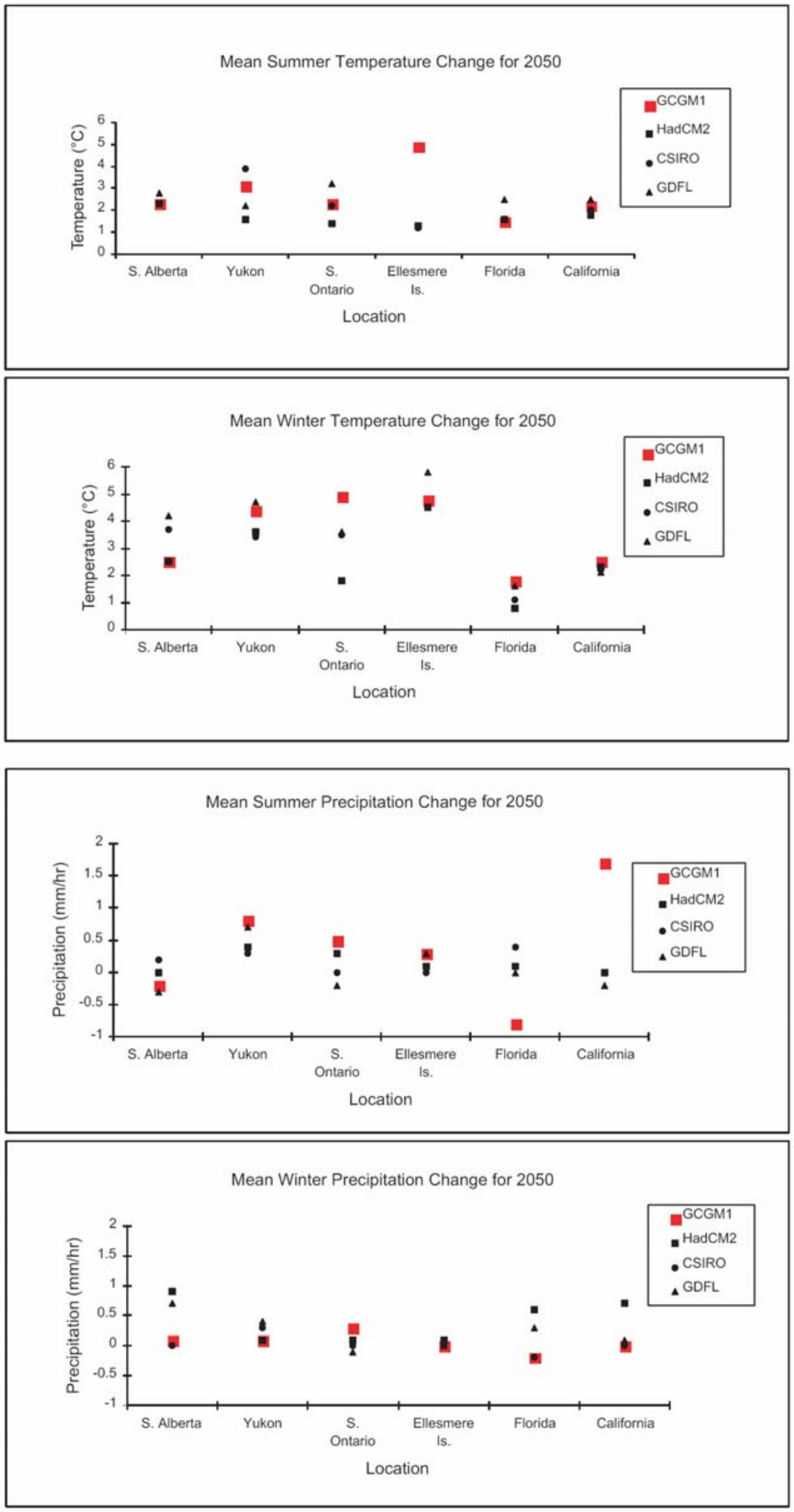


Figure 3.6 Comparison of four specific climate predictions *given by Canada's CGCM1 model with the predictions given by a UK model (HadCM2), a US model (GDFL), and an Australian model (CSIRO). (From Hengeveld, H.G., "Projections for Canada's Climate Future", Special Edition of Climate Change Digest, CCD 00-01, Environment Canada, 2000.)*

The major advancements to the Canadian model implemented in recent years are as follows (Hengeveld, 2000):

1. CGCM2 uses the same atmospheric component as CGCM1, but its ocean component has been improved with the addition of a more realistic mixing scheme.

2. CGCM2 has a more sophisticated sea ice component that simulates the transport of sea ice and the effects of ice transport and melting on the energy flow between the atmosphere and the ocean.
3. CGCM3 has a thicker atmosphere layer (increased from 10 to 32 layers and from 30 km to 50 km) that better represents cloud behaviour and atmospheric turbulence.
4. CGCM3 has a better representation of surface topography.

It is expect that these improvements will improve the predictive capabilities of the Canadian model. In a study of predicted temperature and precipitation extremes (Kharin et al., 2005) shows that the CGCM3 model is now pretty well in the middle of a group of 14 models with respect to 20 year return period temperatures and extremes.

3.2.3 Finer Scale Models

The main drawback to the Global Climate Models is that they have relatively coarse resolutions. Currently, the finest resolution GCMs in use have grid cells in the neighbourhood of 200 km on a side. Within a grid cell of dimension 200 km square, the climate could vary significantly, especially if there are significant elevation differences and/or bodies of open water within or bordering the cell. That is, the forcings and circulations that affect local, or *regional*, climate generally occur at much finer spatial scales than the grid scale and can lead to significantly different regional climate conditions than is implied by the large-scale GCM (Barrow, 2004). Studies assessing the impact that climate changes will have on the environment and on society often require more spatially detailed climate information, e.g. on the order of tens of kilometres, than is currently available from GCMs.

The GCM output is generally an average of the climate variables over the grid cell (for each layer). Fine scale phenomena such as the development of clouds, precipitation, and evaporation are parameterized by linking them physically and statistically to larger scale grid cell averaged variables such as temperature, humidity, and air pressure. To recreate the fine scale details of climate, it is necessary to *downscale* the GCM results. For this reason, there is a need to develop models which can recreate the fine scale climates given the large scale averaged climate predictions.

There are a number of possible approaches to downscaling GCM climate predictions;

Regional Climate Models (RCM): An RCM is essentially the same as a GCM except applied to a small region of the Earth with the output of the GCM acting as a boundary condition. The primary advantage of RCMs as downscaling tools is that they preserve the physics of the climate (e.g. they conserve mass, energy, and momentum according to the rules of physics). The primary disadvantage is that they are approximately as computer intensive, and as difficult to set up, as are the GCMs themselves.

Statistical Downscaling Models (SDSM): An SDSM is a regression in which detailed regional climate variables are predicted from GCM output. For example, suppose that the detailed temperature, precipitation, and wind speeds are required for Annapolis Royal, Nova Scotia. Then these weather variables would be expressed as a linear combination of the output variables from the enclosing GCM grid cell. Using past detailed recorded weather records, along with GCM output over the same past, a regression analysis can be performed to yield the `best' (i.e. least squared error sum) linear relationship between the GCM input and the detailed weather output. This relationship can then be used to predict detailed weather scenarios given coarse scale GCM climate predictions. The major advantage of this approach is that it is relatively simple to implement, and is computationally efficient. The major disadvantage is that the regression coefficients are assumed to remain constant with time and changes in the climate.

Change Factor Model (CFM): The simplest and most straightforward way of obtaining detailed regional weather scenarios is to simply change the mean (and perhaps variance) of a past weather record. The change in the mean (and variance) would be determined by the GCM. For example, suppose that the GCM scenario under consideration suggests that the average temperature at Greenwood, Nova Scotia, over the years 2030 to 2060 will be 2.2 °C higher than the average temperature was over the years 1930 to 1960. Then the detailed temperature scenario at Greenwood from 2030 to 2060 is obtained simply by taking the observed temperature record from 1930 to 1960 and adding 2.2 °C to every observation. A variation to the method might be to use a different `change factor' for each month, if such change detail is provided by the GCM.

Stochastic Climate Model (SCM): In this method, the detailed climate or weather in a particular region is treated as a random (stochastic) time varying process. From the analysis of past weather records for the region, the `random' weather process is characterized by estimating its distribution and time varying nature, along with any deterministic components. The climate predictions of a GCM are then used to specify how the parameters of the random weather process will change in the future (e.g. changes in the mean, variance, correlation model, etc.). The resulting process can then be used to answer probabilistic questions and produce possible realizations (scenarios) of the weather in the region.

3.2.4 Stochastic Climate Model

The *Stochastic Climate Model* (SCM), also called a *stochastic weather generator*, is a representation of the regional weather as a process varying randomly over space and time. The basic idea is that this random process can be broken up into two parts; a deterministic component, which varies in a predictable fashion according to the time of the year and to the current climate mean, and a random component, which incorporates both temporal and spatial statistics of this random process (e.g. mean, variance, spatio-temporal correlation structure, each of which possibly varying in both time and space). Local averaging theory can then be used to relate the regional spatial and temporal scales to the GCM spatial and temporal scales.

Historical weather data at the site or region of interest are used to estimate the deterministic and random parameters of the model. This means that the method can only be used at sites where historical data are available.

Commonly used stochastic climate models (e.g. the *Long Ashton Research Station Weather Generator*, or LARS-WG) generally start by modelling precipitation and then generating temperature and solar radiation values for each day conditionally on whether the day was rainy or not. In detail, the LARS-WG software (available at http://www.rothamsted.bbsrc.ac.uk/mas-models/larswg.html) proceeds as follows:

1. The first step is the statistical analysis of the observed historical data at the site being modelled. The data should include observations on daily precipitation amounts, maximum and minimum temperatures and solar radiation. Frequency distributions for wet and dry day

durations, precipitation amounts on wet days, conditional temperature and solar radiation distributions (depending on whether the day is dry or wet).

2. Information on how the distribution parameters estimated in step (1) are going to change in the future are then read in to the program, which updates the distributions accordingly. The change estimates would have to be determined by the user through an analysis of GCM scenarios of the future climate in the vicinity of the site being modelled.

3. The program can now generate realizations of the weather at the site of interest. Multiple possible realizations can be produced allowing the range of possible weather scenarios to be investigated in the impact assessment.

One complaint often heard about stochastic climate models is that they treat different sites as being independent. The problem with this is that the sequence of dry and wet spells at two nearby sites will also be independent so that one site could easily be getting rain while the other is in a dry spell, or one site could be abnormally cold while the other hot, and so on. In principle, however, this problem is easily fixed simply by adding spatial correlation to the stochastic model and then generating realizations of the climate at both sites simultaneously. A disadvantage of the stochastic climate model is that it requires a large amount of weather data recorded at the site of interest in order to estimate the distributions of the weather variables (although no more so than SDSM).

The stochastic models have a number of distinct advantages over the other models discussed above:

1. they can produce multiple future scenarios of any duration;

2. they can downscale both spatially and temporally. For example, if GCM data is only available monthly, a stochastic climate model can be used to produce daily, or even hourly, data conditioned on the monthly averages, as well as performing the spatial downscaling;

3. they allow for extreme value analysis by virtue of the fact that the climate is described by a distribution; and

4. they allow for the direct computation of risk.

In fact, risk assessments must involve stochastic climate models at some point. For example, in order to compute probabilities associated with the climate, the distribution of the climate must be known. Even if statistical downscaling (e.g. SDSM) is used to create weather scenarios at a site of interest, the weather scenario must then be used to specify the mean, variance, and other parameters of a climate distribution in order to then compute the desired probabilities. For this reason, the stochastic climate model will be adopted in this project to model future climates, and the risk associated with them, in the Annapolis Valley region.

3.3 Tool 2: Coastal Flooding Analysis

Since coastal flooding is most likely the most critical climate change impact in Atlantic Canada, as well as in our primary test case site of Annapolis Royal, it is also the most critical climate change element for land use planning in this area. The flood analysis methodology summarized below, and explained in more detail in the main report, was developed by our team to be used by consultants to municipal Land Use Planners and engineers, in helping them to determine the probabilities of different flood elevations, incorporating climate change impacts. Since the use of this tool involves LiDAR technology, which may not be affordable to smaller municipalities, a simpler, but less accurate, approach is also presented.

3.3.1 Flood Analysis Components

The three main components of coastal flood analysis are: predicted tide water level, additional storm-surge water level, and additional wave runup water level.

Water levels from a storm surge
A storm surge is an increase in the ocean water level above what is expected from the normal tidal level that can be predicted from astronomical observations (i.e. phase of the moon and earths orbit around the sun). In order to map flood risk along the coastal zone from storm surge events different information must be known or approximated. In general this involves modeling the ocean water level associated with storms and projecting this water level on land to determine what areas will be flooded.

Wave Runup Water Levels
In addition to the increased water levels associated with a storm surge (regional scale effect) strong winds associated with a storm blowing on shore can increase wave heights and cause water levels to increase. This is known as wave “run up” and is more of a local phenomenon that is controlled by the wind speed, wind direction and the local offshore water depth. As a wave approaches from the ocean and enters shallower water, the wave will increase in height until it breaks and comes ashore. In order to model wave heights the wind direction and speed must be known in addition to the duration and the local bathymetry. The additional increased water levels associated with high storm waves ride on top of the increased water levels of a storm-surge. Wind and waves change the water level more rapidly and more quickly over shorter distances than storm-surges because of the scale and causes of them. The shape of the shoreline can protect areas from large waves depending on the wind direction and water depth. Wave heights can be predicted with models such as SWAN (Simulating WAves Nearshore) if the bathymetry (water depth) and wind information (speed and direction) is known.

Total Water Levels
Once the three main components are known: predicted tide water level, additional storm-surge water level, and additional wave runup water level, they can be projected onto land to determine what areas are vulnerable to flooding. Tide tables are used to determine what the normal tidal water level ranges are, then the additional storm contributions are added to those. The Canadian Hydrographic Service (CHS) produces the tide tables for Canada. Their mandate is to ensure safe navigation for boats. The water levels for the tides and bathymetry on nautical charts are measured from a reference (datum) known as Chart Datum, so that a mariner can determine how much clearance

there is for their vessel in coastal waters. Water levels on tide tables and water depths on charts (bathymetry) are measured from chart datum. Chart datum is a local reference surface that is determined to be the lowest low water associated with a large tide. However, topographic maps that show land elevations are measured from a different datum. Elevations on topographic maps are measured relative to the Canadian Geodetic Vertical Datum of 1928 (CGVD28) which closely approximates mean sea-level. Therefore in order to determine where a given water level will occur on land from a storm, one must translate the tide level and additional water levels from a storm-surge and wave run-up to the land elevations. This can be accomplished by determining the relationship between chart datum and CGVD28 and simply applying an offset for a local area.

Coastal Protection Barriers

Once a total water level has been determined and translated into land elevations, areas will be susceptible depending on their elevation and relationship to coastal barriers, such as dykes or levees. Many low lying coastal areas have extremely fertile soils and have been claimed from the ocean by building barriers to protect them from flooding. The Acadians back in the 17th century were the first to build dykes to claim these highly productive agriculture areas. In order to drain the low lying agricultural lands behind the dykes, aboiteaus were constructed which act as a one-way culvert allowing water to drain to the ocean, but not allowing the ocean to flow landward. Today, many coastal marsh areas are still protected by dykes with similar drainage structures and are maintained by the provincial agriculture department.

3.3.2 Coastal Flood Extent Mapping - Sophisticated versus Simple Approaches

Topographic Maps

Natural Resources Canada (NRCan) of the federal government is responsible for topographic mapping at scales of 1:250,000 and 1:50,000 (http://www.cits.rncan.gc.ca/cit/servlet/CIT/site_id=01&page_id=1-005-002-002.htmlwebsite). The elevation contour interval at 1:50,000 is 15 m and is too crude to precisely determine the possible extent of flooding from storm-surge events. The provincial mapping agency is responsible for larger scale mapping. For example, Service Nova Scotia produces topographic maps at a scale of 1:10,000 for the entire province with a 5 m contour interval (http://www.gov.ns.ca/snsmr/land/standards/post/manual/default.aspwebsite). The reported vertical accuracy of these elevation contours and spot heights is ± 2.5 m. This level of accuracy is not sufficient to accurately map flood extent areas from storm-surges that are typically on the order of 1-2 m because this additional water level is within the margin of error of the elevation maps. Larger municipalities and cities are mapped at larger scales such as 1:2,000 where the contour interval (2-3 m) and at a higher accuracy (http://www.gov.ns.ca/snsmr/land/standards/post/manual/default.aspwebsite). For example, Belbin and Clyburn (1998) used 1:2,000 paper maps for the town of Annapolis Royal with 2 m contour elevations (accurate to 1 m) and spot heights with stated accuracies of 1 decimetre to determine areas at risk of flooding from storm-surge events.

They essentially used a manual method of drawing the potential flooded areas based on following a set contour interval. All of the above mentioned topographic maps have been acquired through traditional techniques of using aerial photography to manually extract elevations and features (e.g. roads, buildings etc.) and have limits to the amount of detail and precision they can achieve.

LIDAR Technology
LIDAR – Light Detection and Ranging methods of collecting elevation data from an aircraft using a laser has emerged in the last 5-10 years as the most accurate means of topographic mapping. The result of a LIDAR survey is a dense set of elevation points (on the order of cm or m spacing) that include the earth's surface as well as features such as trees and buildings. The points are separated into those representing the earth's surface, known as 'ground' points, and all others, known as 'non-ground'. The points can be brought into a geographical information system (GIS) and used to build surfaces that represent the earth's topography every meter on the ground. The level of detail and the accuracy of the elevation maps, known as digital elevation models (DEMs) are far superior to traditional methods and provide the ideal map to determine flood risk. LIDAR surveys are costly because of the equipment and the requirement for a survey aircraft. Costs vary based on the location of the survey to the service provider and local aircraft landing and fuel sites. In general costs range between \$300 and \$500/km^2, however these are guidelines and will depend on several factors including: potential standby charges during poor weather, size of the area and density of points required, in addition to proximity to the service provider and aircraft (modilization-demodilization charges), and the level of processing required by the user. For example after the LIDAR data are collected and initially processed it is represented by a "point cloud". The client may have the capability to further process these data into 'ground' and 'non-ground' targets and build surface models. Alternatively, the service provider will classify the point cloud 'ground' and 'non-ground' and deliver the points if the client has the ability to further process them into surface models.

Storm surges are typically 0.6 to 2 m in height for this region (Parkes et al., 1997), thus technologies with vertical precision significantly finer than these values must be employed to generate flood risk maps of sufficient resolution. Airborne LiDAR (light detection and ranging) is an emerging technology that offers the vertical accuracy and high spatial sampling density required for this purpose. Many LiDAR systems have vertical accuracies on the order of 30 cm or better. LiDAR technology has been employed for shallow bathymetric charting (e.g. Guenther et al., 2000), although cost remains an impediment to widespread acceptance for the latter purpose. The technology can also be used to image the land and water surface (Hwang et al., 2000), as in the study presented here. A general overview of airborne laser scanning technology and principles is provided by Wehr and Lohr (1999). Applications to coastal process studies in the USA have been reported by Sallenger et al. (1999), Krabill et al. (1999), and Stockdon et al. (2002), among others. Preliminary trials in Atlantic Canada were reported by O'Reilly (2000) and subsequent experience was described by Webster et al. (in press, 2004b). Most of the coast of the conterminous USA has now been mapped using this technology (Brock et al., 2002).

Alternatively, the service provider can do all the processing and deliver surface models in grid format that are compatible with the client's GIS. Another processing step to consider is the vertical datum of the LIDAR points. Since the survey aircraft position is calculated based on GPS, the point heights are referenced to the WGS84 reference system (ellipsoidal heights). For coastal flooding applications, for example, the client may require the heights to be referenced to the Canadian Geodetic Vertical Datum of 1928 (CGVD28) which is a close approximation of mean sea-level (MSL) in order to match other land topographic maps. The more processing required by the service provider the more expensive the survey will be. A quotation can be obtained from LIDAR service providers by providing the minimum information of the location and geographic extent of the survey (GIS polygon), desired point density (e.g. 1 point every 0.5 m on the ground in open areas), and the level of processing and deliverables (e.g. LIDAR point cloud classified into 'ground' and 'non-ground' targets and delivered as ASCII point files consisting of X,Y,Z data).

LIDAR service providers in Canada:
Terra Remote Sensing http://www.terraremote.com/index.html
LaserMap http://www.lasermap.com/laserM/home_en.htm
TerraPoint http://www.terrapoint.com/index.html
LiDAR Services International http://www.lidarservices.ca/

Flood Mapping

In this project we assume the sea level is represented by a flat plane since the scale of storm-surges affects areas of several kilometers. We ensure that the water will only reach low-lying areas inland that are connected to the ocean. In other words, low lying areas protected by dykes are not flooded unless the water has a pathway to get there. There are simpler approaches that simply identify low lying areas below a given elevation that are near the coast and may be at risk. Conversely there are sophisticated flood modeling software programs like MIKE21 (http://www.dhiwae.com/general/m21flood.htm) that estimate friction and other hydrodynamic factors in order to estimate how fast the water will inundate an area. All of these approaches are limited by the quality of the input data, both topographic and other information such as surface roughness that will affect the friction of moving water.

Flood Level Probabilities and Return Periods

For coastal flooding return statistics can be generated by looking at long term water level records. For coastal areas these records would be collected by tide gauges and in Canada this is the jurisdiction of the Canadian Hydrographic Service (CHS) of the Department of Fisheries and Oceans (DFO). The coastal water level records are available from DFO's Marine Environmental Data Service on the internet (http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Home_e.htm). These water level records are referenced to local harbors and chart datum. These represent the observed water levels and the storm surge can be calculated by subtracting the predicted water levels (http://tbone.biol.sc.edu/tide/) and calculating the residuals.

The return periods and probabilities of a given water level or storm surge can be calculated from these time series of water levels. The methods used to calculate the statistics vary and can be complex. Without the statistical software, end users would obtain the most information from a set of flood level return periods curves. These types of curves can incorporate sea-level rise rates associated with climate change. The X-axis represents the return period in years and the Y-axis represents the water level. For a given water level the curve can be read and the expected return period can be determined. Alternatively a given water level, such as that associated with the Groundhog Day storm, can be used and a cumulative probability curve be constructed where the X-axis represents the return period in years and the Y-axis represents the probability from 0-1. For a given return period the probability of that water level occurring can be read from the curve. The probability of the water level occurring increases as the return period increases.

Bernier et al., 2005, used the Dalhousie University storm surge model to reconstruct storm surges for the last 40 years in order to calculate return periods of storm surge water levels and how they might change under climate change scenarios. They plotted the return periods of observed extreme annual water level maxima residuals (observed water level minus predicted) between 1960-1999 for Saint John, N.B. (Figure 5.5).

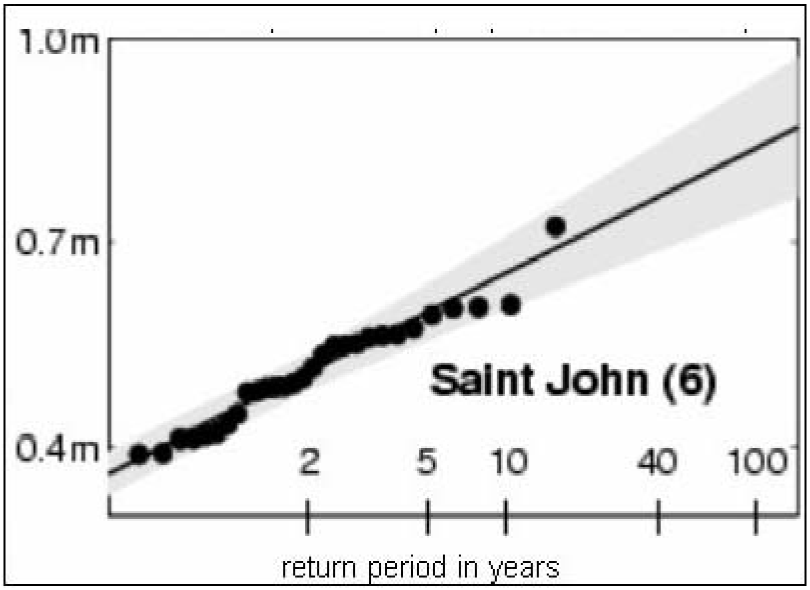


***Figure 3.7 Return Period of Observed Extreme Annual Water Level Maxima Residuals** (observed water level minus predicted) between 1960-1999 for Saint John, NB (from Bernier, 2005).*

Concurrent with the Bernier (2005) study and the CCAF project for Sea-level rise impacts for the southeast coast of New Brunswick, the Applied Geomatics Research Group (NSCC) with partners in the private sector under the leadership of Roger Mosher has been developing tools to facilitate the analysis of coastal areas vulnerability to flooding from storm surges. The project is funded under the Atlantic Canada Opportunities Agency's Atlantic Innovation Fund. Part of the tools that have been developed include a software package known as the "Water Modeler" that allows observed water level records to be analyzed and probabilities and return periods to be calculated based on observed water levels. The approach taken calculates empirical annual probabilities of exceedance of a given water level as well allows a model to be constructed for the prediction of probabilities with relative sea-level changes incorporated to simulate possible climate change effects. The method is based on the "peak over threshold method". Water level records from St. John, NB were acquired from the Marine Environmental Service (http:// www.meds-sdmm.dfo- mpo.gc.ca) for the dates between 1966-2006.

3.4 Tool 3: Inland Flooding Analysis Tools

Inland coastal flooding, (Hydrology Engineering) is also expected to increase with the increase in the frequency and severity of intense storm events, expected to occur in much of Atlantic Canada as a result of climate change. While sea level rise and storm surge will impact inland near-shore rivers, as well as coastal areas, different tools are needed to assess potential flooding of water bodies further inland. Surveying tools, and inland flood-routing analysis tools are currently used to assess potential riparian flooding impacts. These tools are summarized below, followed by summations of incorporating climate change considerations into these tools.

3.4.1 Surveying Tools

Geodetic Control Surveys

A geodetic control survey consists of establishing the horizontal and vertical positions of points on the land. These established control points provide the basic framework from which detailed site topographic mapping, and construction alignment work can be performed. Such surveys are critical in projecting and adapting to climate change impacts on the environment and land uses, since they support a wide variety of engineering applications relevant to climate change, including:

- cross-sections of river floodplains;
- levee profiling, overbank studies, and revetment placement analysis;
- bridge, pier, and other infrastructure design and placement;
- structural grading, design, and placement; and
- navigational safety.

Control surveys are performed by municipal or consulting engineers, and provide important information relevant to municipal Land Use Planners at the site and municipal scales. The information these surveys provide is useful in planning the locations of future structures and infrastructure as part of the Municipal Plan, Future Land Use Map, and Land Use By-law, especially with regard to flooding, which will be exacerbated by climate change.

More information can be found at:
www.waterlevels.gc.ca/ - Website for the Fisheries and Oceans, Canadian Hydrographic Services.
www.geod.nrcan.gc.ca/ - Website for the Natural Resources Canada, Canadian Spatial Reference System.
www.ngs.noaa.gov - Website for the National Geodetic Survey, U.S. Department of Commerce.

Survey Types

Control surveys are completed using either conventional surveying or GPS surveying techniques. Conventional surveying is performed using traditional surveying techniques and instruments, such as theodolites, total stations, and levels. GPS surveying is performed using a minimum cover of four satellites, and is especially useful on large scale projects.

Conventional control and GPS surveying methods can be used to complete any of the above listed applications. Conventional surveying is used primarily to obtain highly accurate positions and elevations under vegetative cover, but is limited by line of site requirements. GPS methods are highly useful in open areas, where the terrain is extreme but are completely open to the sky. GPS surveying techniques are restricted by satellite cover, requiring a clear window to four or more of the 24 orbiting satellites.

Methodology

Both conventional and GPS surveys establish three dimensional point positions of fixed points of interest on the surface of the earth, which can then provide primary reference points for subsequent engineering and construction projects. Conventional total station and GPS surveying methods are discussed in the following paragraphs.

Total Station Surveying Methodologies

When using conventional surveying methodologies, such as a total station, the instrument is set at a known position. Slope distance, horizontal and vertical angles are then measured by sending an electronic signal to a roving target prism, which reflects the signal back to the station. The coordinates and elevation for the prism location are then determined. This method requires a line of site, as such it may require additional set-ups throughout the project.

GPS Surveying Methodologies

The global positioning system (GPS) is a system of 24 orbiting satellites, which continuously transmit positioning information to observers on the ground. A roving GPS receiver collects data about the point of interest from all four satellites, and calculates the unknown x, y and z coordinates by a rigorous triangulation process.

Datums

Both conventional and GPS surveying locate points of interest as defined by a coordinate system, which is in turn referenced to a datum. Existing horizontal and vertical datums as discussed below.

Horizontal Datums: The horizontal positions of the points of interest are defined by a coordinate system, which is referenced to 1983 North American Datum (NAD83) based on the 1980 Geodetic Reference System. Older maps are based on 1927 datum, which is a less accurate model of the shape of the earth. Horizontal measurements in other areas of the world are based on different datums, since the datums are mathematical models representing the shape of the earth, which changes slightly from place to place.

Vertical Datums: The Canadian Geodetic Vertical Datum (CGVD28) is the current orthometric height reference in Canada. The CGVD was adopted in 1935, and constructed using conventional surveying techniques. The datum reference level was defined as mean seal level (MSL) determined from five Canadian tide gauges in 1928. CGVD28 is outdated and not compatible with modern space-based technologies. The current federal Canadian plan is to upgrade the system by 2009.

The alternative approach to conventional surveying for the creation of an updated vertical datum is geoid modeling. Geoid modeling is defined in relation to an ellipsoid that approximates the overall shape of the earth, and the geoid, that corrects for local variations in the Earth's gravity field. The geoid is an equipotential surface, i.e. a level surface where gravity (plumb line) is perpendicular at all points on the surface and water stays at rest. The geoid, by definition, corresponds to the surface that best approximates mean sea level. The geoid surface is determined by analysis of gravity measurements taken on the ground, at sea, from the air and from space.

Vertical data are most commonly referenced to:

- Mean Sea Level (MSL)

- Mean Low Water (MLW)
- Mean High Water (MHW)
- Lower Low Water, Large Tide (LLWLT)

Mean Sea Level: MSL based elevations are used for most construction, geodetic and topographic surveys.

Mean Low Water: MLW based elevations are used on older navigational charts, but for most new Canadian coastal charts a Lower Low Water, Large Tide, water surface has been adopted as chart datum.

Mean High Water: MHW elevations are used in construction projects involving bridges over navigable waterways.

Lower Low Water, Large Tide: For navigational safety, depths on a chart are shown from a low-water surface or a low-water datum called "chart datum". The term "lowest normal tide" (LNT) has been retained on the charts since it encompasses a variety of other choices for chart datum on some older charts.

Incorporating Climate Change Considerations

Impacts on the Horizontal North American Datum: There will be no impact on horizontal datums, since the datums represent the shape of the earth, which will not be affected by climate change.

Impacts on Canadian Geodetic Vertical Datum: Since vertical datums are based on sea level, and climate change (and vertical movement of the earths crust) will impact sea level, there will be an impact on the current vertical datum, CGVD28 and the proposed geoid model. Where the geoid model is determined by analysis of gravity measurements taken on the ground, at sea, and from the air and space, it will be more easily updated. Changes in the accepted vertical datums will affect engineering, surveying, planning, and construction activities.

3.4.2 Inland Flood Routing Analysis Tools

Flood routing analysis is an important tool for municipal engineers to use in assisting municipal land use planners in determining potential locations for interior flooding, and thus, land uses. Basically, this tool enables an engineer to access the amount of water that will run off over land and through watercourses in a particular watershed, to a particular point of interest downstream in the watershed. The size of the watershed that drains a community partially determines the severity of flooding. For example, a storm that recently hit the peninsula of Halifax, Nova Scotia was a 1 in 2 year storm since the watershed is so small, but was a 1 in 200 year storm in a nearby community with a much larger watershed draining into the town downstream. Climate change is expected to exacerbate inland flooding due to the greater volume of precipitation falling in shorter more intense bursts, thus causing more runoff and less infiltration.

Analysis tools used for Flood Routing include: the *SCS Unit Hydrograph* technique, and the Index *Flood Method (IFM)*. In addition, the HEC-RAS flood computer modeling package is used to model large annual flows, such as the 1 in 1,000 year flow. There are expected to be periods of larger flow due to climate change. The application of these tools to our test case site of Allains Creek, which drains the southern half of Annapolis Royal, is discussed in Chapter 5.

Flood Runoff Analysis Methods

The methods of flood run-off analysis will vary depending of the consequences of a flood and the magnitude of a flood. Generally, the larger the drainage area, the greater the magnitude and consequences of a flood. The amount and timing of runoff from a watershed is a function of several phenomena, which have different degrees of importance depending on the nature of the system being studied. The analysis of runoff processes includes the evaluation of precipitation, depression and interception storage, evaporation and transpiration, and infiltration. There are a number of flood runoff analysis methods, which are summarized below. Please refer to Technical Appendix 3 for a summary of flood runoff analysis methods.

3.4.3 Climate Change Adaptations

The effects of climate change are very difficult to predict in a hydrologic analysis. Changes in the climate can influence precipitation patterns, including rain and snow, temperature trends and variance, cloud cover, sea level elevations, ice cover and water quality which in turn affect changes in the hydrologic cycle and the phenomena of depression and interception storage, evaporation and transpiration, and infiltration. Climate change variables are all interconnected. To account for climate changes in a hydrologic analysis, the effect of trend changes in precipitation and temperature must be incorporated into the calculation when using a particular hydrologic analysis method.

Rational Method

The rational method is highly influenced by the runoff coefficient (C) and rainfall intensity (I) (or IDF curves). Because the runoff coefficient accounts for evaporation and transpiration within the drainage basin, the parameter C is influenced by climate change. As well, the method also uses IDF curves which are based on historical rainfall patterns and is subject to changes in climate.

SCS Runoff Curve Number Method

The SCS method for calculating runoff depth over a watershed does not account for rainfall intensity. However, the method is dependant upon the calculation of the curve number (CN) for the drainage basin. The curve number is based on the physical characteristics of the watershed which incorporate hydrologic conditions. The curve number automatically factors evaporation and transpiration into the runoff calculation, parameters which are subject to changes in temperature and cloud cover.

Unit Hydrograph Techniques

Like the SCS method, the unit hydrograph technique is dependant on estimation of the curve number within the calculation of the lag time for the drainage basin.

Index Flood Method/ Frequency Analysis

The IFM is based on historical flow data at observed locations across Nova Scotia. The data alone does not account for future changes in climate but is solely based on past occurrences. Lake levels are extremely sensitive to fluctuations in climate and therefore, when using the method the historical flow data can be scaled to account for climate changes.

Snowmelt Analysis

Both the degree-day method and the energy budget method are highly dependant upon the temperature and the amount of precipitation that accumulates as snow. Parameters such as mean daily air temperature in the degree-day method or snowmelt due to heat, radiation and convection in the energy budget method are highly influenced by climate change.

Examples of Flood Analysis in Conjunction with Dam Safety

Climate change impacts need to be considered during design of any water-related structure. This is especially true for dams, which, if the topography is appropriate, can also serve as flood storage reservoirs, as well as impounding drinking water or generating hydro electricity. However, for any dam, Canadian Dam Association (CDA) Dam Safety Guidelines, 1999 apply.

3.5 Tool 4: Hydrogeology Analysis Tools

While hydrology analysis tools are used to assess surface waters, hydrogeology tools are used to assess groundwater. Hydrogeology analysis tools also already exist; and are summarized here. In Chapter 5 – Tools Tests, they are applied to our test case site of the Pereau Watershed, since climate change impacts on groundwater resources are important in this agricultural watershed.

The objectives of these tools are to allow Land Use Planners to quickly assess an individual site, group of sites, or an entire map area for potential groundwater availability, and to prioritize sites for further investigation, or management of available groundwater resources. A water quantity and a water quality approach are used. Consideration is given to the potential availability of groundwater for various uses, with consideration of ecosystem base flow sustainability, and potential or future changes in groundwater availability due to climate change.

3.5.1 The Hydrologic/Hydrogeologic Cycle

This section describes the standard procedure to estimate a water balance for a watershed, a proposed subdivision development, farming operation, or municipal water supply. An overview of the concept of Hydrologic cycle and Hydrogeological Cycle is provided, followed by procedures for the estimation of a water budget for a specific project. The potential effect of climate change on this process is provided at the end of the section.

The Hydrologic Cycle is the balance of water movement through an environmental system. On a global scale, the overall volume of water is considered to be constant over millions of years. It is the distribution of water, both spatially and temporally, that can lead to shortages and impacts. Because local climate controls the annual distribution of precipitation, climate change is expected to affect the volume and distribution of rainfall, runoff, evaporation and ultimately groundwater recharge.
Water is neither created nor destroyed, but changes state as it moves within the hydrologic cycle. The "hydrologic cycle" within any watershed refers to the balance and fate of precipitation falling within that watershed, and its ultimate disposal as evaporation to the atmosphere, runoff to streams and removal from the watershed by natural or man-made means. In most undeveloped watersheds in the Atlantic Provinces, approximately 60 to 70 % of rainfall falling within a watershed eventually exits that watershed as stream flow on an annual basis. Stream flow includes contributions from both direct overland runoff and groundwater recharge. The remaining approximately 30% to 40% is recirculated into the atmosphere through evapotranspiration of groundwater by vegetation during the growing season, or direct evaporation of surface water from open bodies of water during the summer months.

Superimposed on the hydrologic Cycle is the "hydrogeologic cycle", which conveys rain water and runoff recharge through the subsurface to discharge points at streams, lakes, wetlands and wells. The groundwater component of the hydrologic cycle involves movement of recharging rainwater or surface water though soil, glacial overburden and bedrock at high elevations to points of discharge at springs, seeps, streams or wells at lower elevations. Groundwater also originates locally from percolation of rain, snowmelt, or surface water into the ground. This water fills voids between individual grains in unconsolidated (sand and gravel 'soft rock') overburden materials (surficial geology), and weakly cemented bedrock materials, as well as fractures developed in consolidated ('hard rock') bedrock materials. The upper surface of the saturated zone is called the water table.

On a regional basis, approximately 15 % to 40 % of annual precipitation seeps into the ground to become "groundwater recharge" which ultimately joins the stream flow as base flow. On a local basis, the proportion of groundwater recharge can depend on many factors, including: overburden thickness and permeability which act as reservoirs for subsequent recharge to underlying bedrock aquifers, the hydraulic properties of the aquifer such as porosity and permeability, and local vegetation cover, land uses and topography which collectively affect the proportions of runoff and recharge potential.

3.5.2 Hydrogeology Tool 1 – Water Cycle (Water Budget) Analysis

A hydrologic budget can be prepared for a planning area using published climate normals, and local hydrologic and hydrogeologic assessments, commonly available from the local Environment or natural Resources departments.

The groundwater budget is calculated based on a water mass balance approach, where the change in storage equals the difference between the amount of water added minus the amount of water removed. The storage term (ΔS) is assumed to be negligible over large time periods, assuming no man-made removal of water from the system. Water can be added with precipitation and lost through evapotranspiration, surface runoff, and groundwater discharge. The water budget can be expressed as:

$$P = ET + Rs + Rg \pm \Delta S \qquad \text{[Eqn. G1]}$$

Where:

P	=	Precipitation (mm)
ET	=	Evapotranspiration (mm)
Rs	=	Surface Runoff (mm)
Rg	=	Groundwater Recharge (mm)
ΔS	=	Change in storage within the system (negligible)

Using the values and equation presented above, this translates to:

$$P\ (1173.9\text{ mm}) = ET\ (497\text{ mm}) + Rs\ (449\text{ mm, est.}) + Rg\ (359\text{ mm}) \pm \Delta S\ (0\text{ mm})$$

The above approach can be done on an annual basis (dry, average and wet year), on a monthly basis to assess seasonal effects, and on a seasonal basis (e.g., growing season). For land use planners, the annual approach, using the more conservative dry year climate normals is recommended. For seasonal or monthly analysis, the services of a qualified hydrologist is recommended. Source of the various data components are discussed below:

Precipitation (P)

Rain and snowfall is the source of water for the water cycle. The minimum, maximum and mean annual precipitation is generally obtained from the nearest Atmospheric Environment Monitoring station maintained by Environment Canada (http://climate.weatheroffice.ec.gc.ca/). Data is usually reported as 30-year means, maxima and minimum, and in terms of annual, mean monthly, and mean daily values. Major climate monitoring stations in the Annapolis Valley of Nova Scotia include the Greenwood Airport, Kentville Research station, and several smaller monitoring stations throughout the valley region. The mean annual precipitation is generally used for planning purposes, the minimum precipitation may also be used for more conservative predictions of water availability in drought situations.

Evapotranspiration (E_T)

Evapotranspiration is the total water loss caused by free-water evaporation, plant transpiration, or soil moisture evaporation (Fetter, 2001). Evaporation and evapotranspiration of plants typically removes water from a watershed between June and September, typically during the warmer months. The total evapotranspiration within the study area is typically estimated using the Thornthwaite method (Thornthwaite and Holtzman, 1939). The Thornthwaite equation is an empirical relationship that estimates the amount of evapotranspiration from soil using the mean monthly temperature and a corresponding coefficient to represent the hours of bright sunlight. This component can be particularly difficult to estimate, and requires considerable site specific mean monthly temperature data. Planners may also opt to use published estimates for the general area. If none is available, it will be necessary to retain a qualified hydrologist to calculate this on a monthly basis. This is the component that is most likely to be affected by climate change.

Surface Water Runoff (R_S)

Stream flow runoff is estimated from direct stream monitoring over long periods of time. Long term stream flow data is available from Environment Canada through their website for hundreds of instrumented watersheds across Canada. Information is provided both on-line and on a CD-ROM for all available monitoring stations across Canada:
(http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm).

Where available, a planner would utilize the results of hydrometric studies performed in their immediate area of investigation. If no specific data is available for the watershed under consideration, it will be necessary to retain the services of a qualified hydrologist to estimate mean, minimum and maximum stream flows using data from a nearby similar sized watershed with similar topography. For example, the 546 km^2 Annapolis River monitoring station at Wilmot is commonly used to estimate stream flows in the Annapolis Valley using the rational method.

Surface water runoff varies several orders of magnitude over a water year, and is highest in the spring and fall wet seasons, and lowest in the late summer drought period.

Groundwater Recharge (R_g)

Groundwater recharge is the volume of water that actually percolates through the unsaturated zone (where the interstices between rock particles are not filled with water) to the saturated zone below the water table. Groundwater recharge potential is generally determined through monitoring of precipitation, stream flow and evaporation, and varies seasonally with annual precipitation, and spatially within a watershed due to varying hydraulic properties of the overburden and bedrock aquifers. During periods of low flow, typically occurring in the summer and early fall months, there exists a net outflow from groundwater to stream systems.

Both ground and surface water levels decrease during the summer and are at their lowest (on average) by early fall. Beginning in the fall when leaves fall off the trees and crops are harvested, evapotranspiration (evaporation from vegetation into the atmosphere) stops, and precipitation the surface waters begins to recharge the groundwater. The groundwater level continues to rise until spring, when the leaves come on trees and crops begin to grow, and the combination of reduced rainfall and increased evapotranspiration begins again to draw down the water table.

If published values are available for the study area, the planner may apply these directly to the water balance approach; otherwise, the services of a qualified hydrologist of hydrogeologist will be required to estimate groundwater recharge for an area.

In the Annapolis Valley, groundwater recharge ranges from 10 % in the fractured basalt, granite and metacrystalline bedrock uplands, to over 40 % in the sedimentary lowlands overlain by sandy overburden. Overburden thickness and permeability control recharge to underlying bedrock aquifers. Recent modelling of groundwater flow in the Annapolis Valley by the Geologic Survey of Canada (GSC 2006, in prep) suggests an average groundwater infiltration of about 26 % of long term mean annual rainfall on a watershed basis to overburden, and approximately half of that value (mean 13.5 %) recharges into the underlying bedrock, the remainder being lost directly to adjacent streams.

Storage

Storage is the sum of all available lakes, reservoirs and ponds within a watershed. While the volume of these storage bodies can vary considerably over a water year due to recharge in wet periods, and discharge in drought periods, the net storage is considered to be constant over long periods of time. For example, the Pereaux Watershed study area has an estimated 11,700 m^3 storage (5.85 % of demand) in 5 locations (CBCL et al., 2003). These would fill naturally in the spring and be used as needed later in the summer. Unless lined and covered, some loss to evaporation and groundwater infiltration would occur.

Groundwater-Surface Water Interaction

In most areas of Canada, there is a direct interaction between groundwater and surface water. Groundwater, recharged in higher topographic areas and throughout a watershed, ultimately discharges to surface water as springs and base flow seepage.

In the Annapolis Valley area, a period of aquifer recharge typically occurs during the spring thaw, and the aquifer is expected to provide the base flow to the river and local streams during the summer months when the amount of precipitation is limited and when evapotranspiration exceeds precipitation (except for high precipitation events). In some areas, recharge may also be limited during the colder winter months, when all precipitation resides in the form of snow and ice.

An example of an annual water balance is provided in Section 5.1 for the Pereaux Watershed Test case.

3.5.3 Hydrogeology Tool 2 – Groundwater Quantity Mass Balance

Mass balancing is the process of determining the availability of water quantity and water quality for a specific development project. With respect to water quantity, the supply must exceed the demand. With respect to quality, there musty be sufficient excess infiltration available to adequately dilute septic effluent.

Sustainable land use is a function of water availability and demand. Water demand must be appropriately apportioned to sustain the natural ecosystem, with excess capacity being allocated to various water stakeholders and the natural aquatic ecosystem. The following simplified method is often used by planners to estimate the availability of groundwater supply for subdivisions or light industrial developments. If the development fails to meet these theoretical guidelines, more detailed assessment, including exploration drilling and testing, would typically be requested.

Using a water balance approach, the theoretical number of residential lots or residential water wells (N) that an area can support is based on the estimated annual groundwater recharge and water demand as follows:

$$N = \frac{\text{Theoretical Groundwater Recharge } [m^3/d]}{\text{Theoretical Demand } [m^3/d]} \qquad \text{[Eqn G2]}$$

$$N = \frac{(0.8^{1})\,(\text{area of subdivision } (m^2))\,(\%\, Rg^{2} \times \text{annual precipitation } (m^3))}{(\text{No. persons/lot} * 0.378\ m^3/d \text{ demand/person}^{3})\,(365\ d/yr)}$$

Notes:
1 – 20 % factor of safety to allow for seasonal and spatial variability
2 – recharge coefficient - percentage of annual precipitation that recharges groundwater
3 – assume 100 USgpd demand per capita

The default water recharge value (Rg) can be varied based on site-specific recharge values, either composite, or for specific aquifers (require site specific groundwater modeling), and for an average, wet or dry year; dry year predictions are preferred for long term developments.
The long term mean annual and minimum annual rainfall values are typically obtained from the closest climate station databases. The groundwater recharge coefficients are obtained from local hydrogeological studies, or estimated based on the type of aquifer. Since recharge can locally range from nil (paved areas) to nearly 100 % (coarse-grained sand and gravel deposits), an average value is usually taken for watersheds. In Nova Scotia, general default values for various types of bedrock and overburden aquifers based on groundwater modeling may range as follows:

Aquifer Unit	**Recharge (% mean annual precipitation)**
Overburden:	
Coarse Sand and Gravel	30 to 40 % (>50 % locally)
Medium-Fine sand	10 to 30 %
Silty sand till	10 to 20 %
Clayey silt	<5 to 10 %
Bedrock:	
Sandstone	25 to 35 %
Shale	10 to 25 %
Basalt	10 to 15 %
Fractured crystalline rock with overburden	10 %
Fractured crystalline rock; no overburden	<5 to 10 %

An application of this tool to the Pereaux Watershed is provided in Chapter 5.

3.5.4 Hydrogeology Tool 3 - Assimilative Capacity

With respect to water quality, the supply must meet the water quality standards for the specific water use. For example, public and municipal water supplies must meet Guidelines for Canadian Drinking Water Quality, Health Canada, 2006. The agriculture industry has specific guidelines for various types of crop and animal uses, such as those outlined in the Canadian Council of Environment Ministers (CCEM, 2006) guidelines for Irrigation and Livestock. Other guidelines are stipulated for maintenance of Fresh Water Aquatic Life and for Recreational activities. Some industries and Bottled Water operations may have specific water quality requirements.

Water quality can be adversely affected by land uses, including:

- Urban (road salt, pesticides, pathogens, petroleum chemicals);
- Agriculture (nutrients, pathogens, pesticides, herbicides) ;
- Rural domestic (pathogens and nutrients from septic fields);
- Food processing (nutrients, sediment, pathogens), Etc.

One of the major degraders of rural groundwater quality is from septic disposal beds. Each rural residential lot will discharge an estimated 75 % of their water back to the ecosystem as waste water through on-site septic disposal beds. While most pathogens and bacteria are effectively removed within short distances in properly constructed septic fields, other associated household chemicals and nutrients may be transported from the immediate site.

The numbers of individual lots or persons that a rural area can sustain based on wastewater discharge can also be determined using the following approach:
The assimilative capacity for wastewater flows from a typical residential home are calculated in a manner similar to Method 2. However, wastewater will be discharged to the overburden aquifers, in the Study area. The mean annual infiltration rates for the overburden are used in the calculation.

- Select a dilution ratio (1:3 to 1:4 depending on sensitivity of environment);
- Determine infiltration rate of overburden in area of interest;
- Determine percentage of each overburden unit in study area (estimated)
    - Coarse Sand and gravel (15 %)
    - Fine sand (10 %)
    - Silty till (60 %)
    - Marine clay (15 %)

- Determine infiltration rate from published reports (129 to 430, mean 312 mm/year or 10 to 36.6, mean 26.6 % of annual precipitation);
    - Coarse Sand and gravel 350 mm/yr (30% of P)
    - Fine to sand 250 mm/yr (20 % of P)
    - Silty till 50 to 75 mm/yr (5 % of P)
    - Marine clay <50 mm/yr
- Assume 75 % of water demand is wastewater (e.g., 0.378 m^3/day (75 USgpm)

Method:

1. Calculate effluent per capita:

$0.75 \times 0.3781\ m^3/d$ (100 USgpm) = $0.2836\ m^3/d$ (75 USgpm)

2. Calculate effluent per lot:
   0.2836×4 for four persons = $1.13\ m^3/d$

3. Calculate infiltration volume needed for 4x dilution of domestic septic effluent:
   $1.13\ m^3/d \times 4 = 3.4\ m^3/d$

4. Calculate available infiltration for each overburden unit (bedrock unit if no overburden):

Unit	**Mean Precip (mm)**	**% Area**	**Infiltration (mm)**	**(% P)**	**Area (m^2)**	**Mean Infiltration Recharge m^3/yr**	**m^3/d**	**$m^3/d/ha$**
Sand/gravel	1171.9	15	350	0.299	1173000	410550	1124.8	9.59
Sand	1171.9	10	250	0.213	782000	195500	535.6	6.85
Sandy Till	1171.9	60	75	0.064	4692000	351900	964.1	2.05
Marine clay	1171.9	15	50	0.043	1173000	58650	160.7	1.37
Total watershed					7820000	1016600	2785.2	19.9

Alternate Methods

The Technical Appendix contains a summary of a case study in Massachusetts, U.S.A. of an alternate tool for calculating assimilative capacity (groundwater quality), as well as an alternate tool for calculating mass balancing (groundwater quantity). We chose not to use and test these alternate methods in our test case site for groundwater, Pereau watershed, since the geology in the Annapolis Valley is not well suited to them. They are designed for bedrock aquifer analysis without much glacial overburden (shallow aquifer). While this type of geology is found in sections of Nova Scotia and much of Newfoundland, there is considerable glacial overburden in the Annapolis Valley, except perhaps on the very top of North Mountain which forms the watershed divide. However, they are included in the Technical Appendix since they could be useful elsewhere in Atlantic Canada.

3.5.5 Effect of Climate Change on Groundwater Recharge

Figure 3.1 illustrates the concept of Hydrologic Cycle, which is the balance of water movement through an environmental system. On a global scale, the overall volume of water is considered to be constant over millions of years. It is the distribution of water, both spatially and temporally, that can lead to shortages and impacts. Because local climate controls the annual distribution of precipitation, climate change is expected to affect the volume and distribution of rainfall, runoff, evaporation and ultimately groundwater recharge. The jury is still out on the exact nature and affect of predicted climate changes on the Annapolis Valley region of Nova Scotia. The following discussion is based on an annual water balance approach, with comment on a dry season month (August).

Precipitation
Due to its location near the 45th parallel of latitude, mean annual rainfall in the Annapolis Valley is not expected to change as much as polar or equatorial regions. Based on extensive assessment of the Greenwood climate data, Fenton predicts a small decrease in mean monthly precipitation (about 2 mm on average) in the growing season, and a small increase in mean annual precipitation (2.4 mm) in the winter dormant season, with an overall annual decline of only 1.2 mm between present and the 2061-2100 period. On an annual basis, no changes in groundwater are expected based on precipitation.

However, due to the effects of warming, weather events and periods of precipitation are expected to become more intermittent and intense than the present well distributed average 100 mm per month distribution. Depending on when the rainfall occurs, there could be greater probability of flooding and erosion, and longer periods of drought. With respect to groundwater, the long drought periods could result in decreased water table level and aquifer storage, and associated decreases in stream base flow during the growing season. On an annual basis, this would be expected to be off-set by increased potential for recharge during the warmer winter months. It is possible that the current bimodal (e.g., spring and fall recharge events separated by winter and summer recession) groundwater hydrograph could change to a more unimodel shape with recharge dominant from November through April, and declining water levels from May through October.

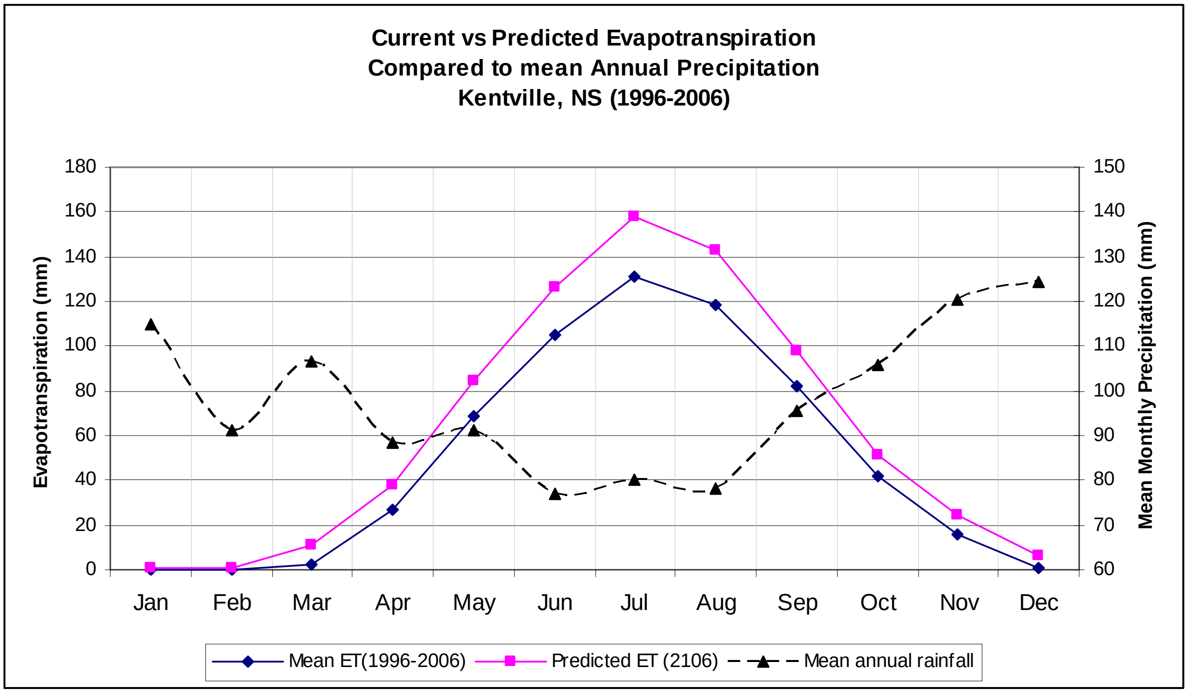
Temperature
Compared to the long term temperature increase trend of one degree Celsius per century, many experts now predict an increase in annual average temperature of up to 4.4 degrees Celsius over the next century (see Fenton, 2006). Significant break-up of the Artic Ice shelf (December 2006) is a fore-runner to this hypothesis. This increase in temperature will be the main driving force to seasonal water balance changes in a study area.

Evapotranspiration
Of the various components of the water cycle discussed in we can assume mean monthly precipitation will remain similar, but evapotranspiration, which is dependent on the temperature, among other factors, would be greater due to rising temperature, thereby removing a greater proportion of water form the system, and extending the period of negligible net recharge farther towards spring and fall.

The Thornthwaite method was used to estimate evapotranspiration for 1996-2006 data and for the 2061-2100 data set calculated by Fenton for this project. Assuming an average 4.4 degrees Celsius temperature rise over the next 100 years, and negligible change in mean annual precipitation, the E_T component can be expected to increase from an average 50.1 % of total annual precipitation (1996 to 2006), to an average of 63 % of total mean annual precipitation for an average water year. Et appears to be increasing over the past 10 years compared to the average 33 % estimated by Trescott (1968) based on 1960s data.

As seen on Figure 3.1.4, the predicted average mean temperature rise of 4.4 degrees C applied across the water year will result in a longer period of potential drought when evaporation exceeds total rainfall, extending the period of no groundwater recharge and reduced runoff into April and late October. A calculation of every mean monthly for multiple years is beyond the scope of this exercise.

***Figure 3.8** Comparison Between 1996-2006 and Predicted 2006 Evapotranspiration for an Average Water Year, Kentville, NS.*



Assuming an annual 4.4 C^{o} mean monthly temperature change (based on Fenton, 2006 calculations), Table 3.1 illustrates the potential effect on the water balance for the Pereaux River Watershed. This assessment suggests an approximate 13 % increase in mean annual evapotranspiration over the next century. However, offsetting this net loss is an apparent 17% increase I means annual groundwater recharge due to additional recharging in the warmer winter months.

Effect of Rising Sea Level on Groundwater

Another potential affect from rising temperature could be an increase in sea level elevation. The effects on stream flow and flood frequency is described in greater detail in. The dyked areas along the eastern end of the Pereaux watershed could be subject to more frequent periodic inundation from storms. A higher mean sea level will also result in a higher mean water table elevation near shore and adjacent to tidal estuaries. However, in consideration of the High tides in the Bay of Fundy, it is uncertain whether of not this would be significant, except on a transient diurnal basis.

With respect to groundwater resources, rising sea level is not expected to cause a significant concern, other than increased potential for saline intrusion in near-shore wells where bedrock aquifer bedding sub-crops under the sea, and to deep sand and gravel aquifers incised into bedrock below mean sea level.

Groundwater and surface water, including sea water, are in direct hydraulic interaction. One possible effect could be a rise in the water table depth near shore and adjacent to tidally-influenced streams. This could cause development of springs and wetlands where water table intersects the surface. Septic fields located in these locations could theoretically become water-logged. Basements could require additional drainage and sump pumps.

Long term monitoring of mean sea level and near-shore shallow groundwater levels is required to further address this issue.

3.6 Tool 5: Risk and Cost Benefit Analysis Tools

3.6.1 Introduction

This document outlines the risk assessment methodology I envisage we will apply to Project A 1209, which I am going to refer to as the "Annapolis Project" (I suppose mostly because its three test sites are in the Annapolis region).

By "hazard" in the following, I mean a possible negative effect, caused by extreme weather and/or ocean conditions, on structures, people, crops, or the environment. Possible hazards include flooding and drought.

I will assume that adaptation alternatives will be hazard specific. For example, one adaptation alternative might be to build a levee of height 2.1 m to avoid damages incurred by flood hazard. This alternative will in general be assumed not help with damages caused by other hazard, such as drought. This assumption allows us to consider hazards separately, at least initially, for simplicity.

3.6.2 The Model

Definitions:
We will denote the hazard under consideration with the letter H. We can now define the following:

Let H_i be the event that the hazard H reaches level i (e.g. 2.0 m flood, 2.1 m flood, etc). This has probability $\mathrm{P}[\ H_i\ ]$.

Let D_{jk} be the event that damage (cost) level j occurs in structure (or area, person, etc.) k. This damage level will have some probability of occurrence that depends on the hazard level reached, H_i, that is $\mathrm{P}[\ D_{jk} \mid H_i\ ]$. The vertical bar means "given that" and this probability may be expressed in words as the probability that damage level j will occur in structure (area, person, etc.) k given that hazard level H_i has occurred. In the following, we will only refer to "structure k", but note that k counts any objects (e.g. people, crops, areas, environments, etc) which may sustain climate induced damage. If event D_{jk} occurs, the cost will be E_{jk}. The overall damage cost for structure k will be denoted E_k.

Let A_l be the l'th adaptation alternative (e.g. build levee to height 2.1 m) having fixed costs B_l (we might set A_0 to be the "do nothing" alternative, having $B_0 = 0$). The total cost of A_l, including damage costs, will be C_l.

The word "impact" probably needs a clear definition, so that when it is used in this study, we all understand it the same way. To my mind, impact is a damage level caused by a hazard, that is, the hazard level i has a certain impact on structure k. There is not a clear equivalent definition in the above. The word impact seems to imply a deterministic damage level, which we only have if uncertainty is ignored (as it might be in simpler analyses). I would recommend that we take impact to mean the expected damage (cost) incurred in building k when hazard H occurs. In terms of the above definitions, this is $\mathrm{E}[\ E_k\ ]$, where E[…] means "expectation of".

Mathematical Formulation:

Given these definitions, we can now compute the following;

1) the probability that damage level j occurs in structure k;

$$\mathrm{P}\left[D_{jk}\right] = \sum_i \mathrm{P}\left[D_{jk} \mid H_i\right] \mathrm{P}\left[H_i\right] \tag{0.1}$$

where the sum is over all possible hazard levels, i = 1, 2, …

2) the expected damage cost in structure k (this is what I am assuming *impact* means);

$$\mathrm{E}\left[E_k\right] = \sum_j E_{jk} \mathrm{P}\left[D_{jk}\right] = \sum_j E_{jk} \sum_i \mathrm{P}\left[D_{jk} \mid H_i\right] \mathrm{P}\left[H_i\right] \tag{0.2}$$

where the first sum is over all possible damage levels, j = 0, 1, … (e.g. from no damage to complete destruction).

3) the expected cost of adaptation alternative A_l;

$$\mathrm{E}\left[C_l\right] = B_l + \sum_k \mathrm{E}\left[E_k\right] = B_l + \sum_k \sum_j E_{jk} \sum_i \mathrm{P}\left[D_{jk} \mid H_i\right] \mathrm{P}\left[H_i\right] \tag{0.3}$$

where the first sum is over all structures, k = 1, 2, …

Risk-Based Goal: to find the adaptation alternative, A_l , having the minimum expected cost E[C_l].

Comments

1) The above formulation is formally only for a single future hazard event (of each type) of uncertain magnitude. The probability distribution of the hazard levels is assumed known. To consider multiple hazard occurrences, we define

$$C_{l_T} = C_{l_1} + C_{l_2} + \cdots + C_{l_N} \tag{0.4}$$

where N is the number of hazard events (this can be random, perhaps Poisson distributed with non-stationary rate to accommodate climate change?). If we can assume that the distribution P[H_i] remains constant in each occurrence of the hazard (which won't likely be true if the climate is changing), we can compute

$$\mathrm{E}\left[C_{l_T}\right] = \mathrm{E}\left[N\right] \mathrm{E}\left[C_l\right] \tag{0.5}$$

and now our task is to find the optimum adaptation alternative, A_l, which minimizes the expected total cost (Eq. 1.5).

If the distribution P[H_i] evolves with time, as would be likely in the climate change scenario, then the expected total cost can be much more difficult to compute, depending on how the probabilities evolve. For the time being, anyhow, we shall assume that we are planning for a single, worst case (e.g. extreme value distributed?), hazard occurrence.

2) To somewhat simplify the risk analysis, the hazard levels can be discretized into a small number of possibilities (e.g. 1.5 m, 2.0 m, 2.5 m flood heights instead of 1.5 m, 1.6 m, etc., flood height, or even ‘low’, ‘medium’ and ‘high’).

3) Similarly, the possible damage levels can be discretized into a small number of possibilities to simplify the analysis (again, ‘low’, ‘medium’, and ‘high’ would be a fairly minimal approximation).

4) A significant simplification occurs if we do not consider structures (people, etc) individually, but rather simply model the “average” structure and write

$$\mathrm{E}\left[C_l\right] = B_l + n_s \mathrm{E}\left[E_{ave}\right] \qquad (0.6)$$

where n_s is the number of structures (people, etc) in the planning domain and E_{ave} is the damage cost of the “average” structure,

The steps followed in the above equations are summarized below:

Step 1. Assess Hazard Levels: Identify the potential hazard levels and their associated probabilities of occurrence as a function of climate change scenarios (e.g. the probability of a flood level in excess of 2.0 m in 2006, the probability of rain levels being less than 2 cm in July, 2009, and so on) at each of the three test communities. Only hazards with a significant probability of occurrence will be considered in this study.

Step 2. Assess Potential Damage Costs for the Null Alternative (i.e., do nothing): For each hazard level arising from climate changes identified in Step 1, list possible damages, their costs, and the probability of the cost being incurred in the case that no adaptation is implemented. For example, at the possible flood level of 2.0 m, building “A” will sustain a damage level of y%, at a cost of $Y, with probability r%.

Step 3. Assess Costs of Adaptation Alternatives: For each potential hazard arising from climate changes identified in step 1, list the possible climate change adaptation design alternatives, along with their fixed implementation costs. For example, this would include the costs of flood adaptation measures, such as levees and floodproofing of buildings in Annapolis Royal; the estimated costs of implementing new irrigation techniques using excess groundwater stored in springtime in the Annapolis Valley watersheds; and the costs of increasing the height of the hydroelectric dam just upstream from the Bear River First Nation settlement to adapt to the possibility of more severe tidal surges.

Step 4. Assess Potential Damage Costs for the Adaptation Alternatives: For each hazard level identified in Step 1 and for each adaptation alternative, list possible damages, their costs, and the probability of the cost being incurred. For example, given that a levee of height 2.1 m has been constructed, building “A” will nevertheless sustain damage level y%, at cost $Y, with probability s%. As in step 2, these damages, costs, and associated probabilities will be estimated for the Annapolis Royal buildings, for the Annapolis Valley crops, and for the Bear River First Nation settlement.

Step 5. Choose Optimal Adaptation Alternative: The total expected cost of each adaptation design alternative is computed as the fixed implementation cost plus the sum of the damage costs times their respective probabilities of occurrence. The adaptation design having the lowest total expected cost is optimal, in the sense that the cost of implementation and the expected "cost of failure" have been jointly minimized.

As an example of the entire process, suppose that the following two hypothetical design alternatives for the Annapolis Royal site are being considered (we note that the numbers are only illustrative at this time):

1. A levee of height 2.8 m is proposed, having a fixed cost of $300,000. Considering the buildings and houses in Annapolis Royal, it is estimated that the expected "cost of failure" is $150,000 over the next 30 years (the design lifespan of the levee). The expected "cost of failure" is computed as the sum over all structures in Annapolis Royal of the sum of the possible damage costs times the probability of each damage cost. The total expected cost of this design alternative is $450,000.

2. A levee of height 5.5 m is proposed, having a fixed cost of $750,000. In this case, the expected "cost of failure" is only $10,000 because only extremely rare events (even taking into account climate change) are expected to result in failure of the levee over the next 30 years. The total expected cost of this design alternative is $760,000.

On the basis of total expected cost, the optimal design is clearly option 1. Performing a similar analysis for a wider variety of design alternatives will allow the optimal design alternative to be refined.

3.6.3 Conclusions

Risk Assessment Limitations

Although the above steps describe what we will strive for in this project, we will need to simplify these analyses to a manageable level in order to complete them within the limitations of the project time-frame and budget. Thus, less important impacts (according to best computational estimates, the test case communities, and stakeholders) will not be addressed in this risk analysis framework. Also, damage costs and alternative costs will be rough estimates only, based on the experiences of our project team. These include team experience in: costs of building and augmenting dams and levees, building and land appraisal, floodproofing costs, etc. Existing recent reports will be used to estimate some adaptation costs, for example, the costs of new groundwater irrigation wells and distribution systems to augment diminishing surface water supplies.

Risk Assessment Model

We will test the procedures outlined above in our three test case sites, with input from community residents and stakeholders in these areas. This will give us a better sense of the difficulties people untrained in risk assessment might have with our model. With this information, we will write a step by step process that municipal land use planners can use for climate change risk assessment, which will include sources of information and outside assistance needed to successfully implement the model.

Risk Analysis as Land Use Planning Tool

Our ultimate goal in this risk analysis is to clearly describe the method and its application to land use planning. Thus, after testing our risk assessment model in our three focus communities, and after peer review comments on our model, we will revise it as necessary. The end result will be a very useful tool that land use planners and other community officials can use, with the help of consultants, to better adapt to the impacts of climate change.

3.7 Tool 6: Land Use Carrying Capacity Analysis Tools

3.7.1 Introduction

Carrying capacity is the ability of a natural or man-made system to absorb growth or development without significant degradation. There are critical threshold limits to a system's capacity to carry growth, beyond which deterioration of the stressed elements of the system will occur. In land use planning, the critical system elements can be environmental, e.g., groundwater, physical, e.g., road networks, fiscal, e.g., tax rebates, or socio-economic, e.g., land ownership and housing. The element in shortest supply is the limiting factor of growth and determines the carrying capacity. The benefits and problems of the carrying capacity concept as applied to land use planning are outlined in Appendix 1 of Part III. (See bibliography for sources for carrying capacity general principles.)

To take advantage of the benefits of the carrying capacity concept, but reduce the problems, a group of researchers at Rutgers University in New Jersey have developed a system called "Current Planning Capacity." They address the *current*, not future, limits of the system, defined by existing infrastructure and natural resource capabilities and the demands placed upon them. They address what can be planned for now, not what the system could ultimately carry based on unknown future conditions. Thus the problems of lack of predictability of future infrastructure, etc., are eliminated. As current threshold limits are overcome, e.g., through the installation of public sewers, the current planning capacity can be recalculated to reflect these changes.

The Current Planning Capacity concept is primarily concerned with *environmental* carrying capacity. It is determined by three factors: water supply, water quality, and air quality. These three factors were considered to be the most important of the environmental factors in setting unambiguous limits to growth for a region for land use planning purposes. They were also considered to be the most critical environmental factors from natural resource, technological, fiscal, and health and safety perspectives (Nieswand and Pizor, 1977).

Calculation methods are described in the Technical Appendix.

3.7.1 Land Sensitivity Analysis

Land Sensitivity Analysis is now a commonly used Land Use Planning GIS tool in most municipal planning departments. Through grant funding, Annapolis Royal has developed a unique use of this GIS tool, in that their maps comprising this analysis are web-based and accessible by any resident on their personal computers. We do not describe this tool in much detail, since most municipal Land Use Planners already use this tool through their GIS analysts. A number of First Nation communities in Nova Scotia also already use this tool as well, although many use it with manual map overlays, without the use of GIS.

There is some debate about whether climate change should be incorporated into the GIS mapping process as a separate element, or integrated into existing elements. Our is to incorporate climate change impacts considerations into the *existing generic* land use planning process, rather than consider them as a separate, detached subject. This tool is used to to analyze spatial relationships (i.e., factors that can be mapped), since environmental impacts maps are such important inputs to resource-based land use planning analysis; and future land use maps are such important tools for proactively planning the uses and management of lands in a community.

Data layers are superimposed, then used to produce higher generations of maps through a series of weighting and scaling, and polygon ascendance. Basically, the tool consists of mapping environmental "constraints" and "opportunities" for different land uses, and then overlaying these maps through "polygon ascendance" to derive a final Future Land Use Map, or any other type of map that is needed to inform Land Use Planning decisions.The end products are interpretive maps used in community land use planning, as illustrated below. The idealized diagram below illustrates our conception of how climate change impacts could be incorporated into the *existing* land use planning "map overlay technique".

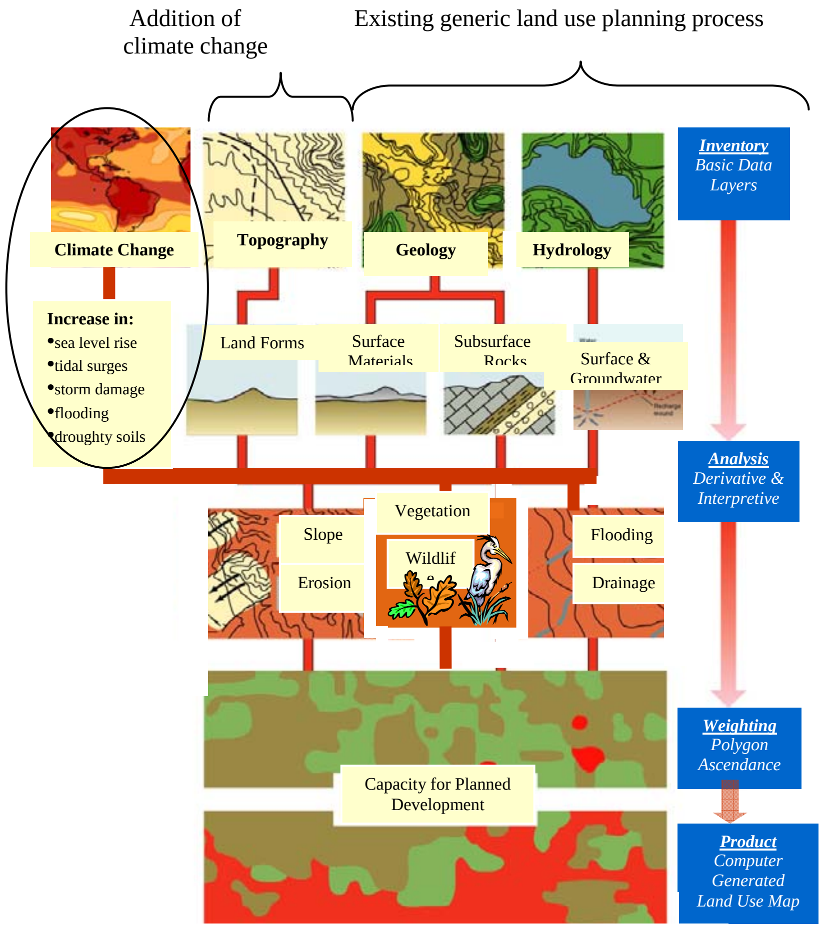
Figure 3.9 Incorporating Climate Change Factors into Land Sensitivity Analysis

Projected climate change impacts that can be mapped include, but are not limited to, land areas vulnerable to the following:

- sea level rise,
- increase in tidal surges,
- changes in low and high tides,
- increase in coastal & riparian flooding,
- changes in high and low water tables,
- changes in water pollutant travel times,
- areas vulnerable to increased wind damage,
- droughty soils,
- air and water temperature changes,
- increased heat and smog,
- impacts on aquatic & terrestrial habitats, etc.

From these maps, vulnerable areas can be identified, and in some cases, associated damages and costs of repairs calculated; and preventative adaptation measures can be accessed.

Some of the "end products" that can be produced through incorporating climate change considerations into the land use planning process are: Future Generalized Land Use Maps for a municipality or a region, or Development Suitability Maps for a specific site.



Adapted from Botkin and Keller, 2003

An example of the use of such a tool is described in the Technical Appendix for a case study of watershed protection analysis in Massachusetts, U.S.A. Incorporating climate change considerations into such an analysis is simply a matter of changing the variables that are mapped. For example, if a floodplain protection zone would normally be 50 metres setback from a river or coast, how much should this variable be increased to include climate change considerations of exacerbated flooding? These questions are answered through our other analysis tools.

3.7.2 Build-Out Carrying Capacity Analysis

Tools

Build-out analyses allow planners to estimate the amount and location of development for an area. Performing a build-out analysis is the step in the community planning process that identifies the holding capacity of the land. Build-out is a supply-side calculation applied to a clearly delineated area that is based on assumptions for density, physical constraints to development, and land-use regulations that define the size and placement of structures for that area. A build-out analysis provides an answer to the question "how many buildings could be built in this area according to current land-use regulations?" A build-out analysis provides a convenient reference for future planning because it represents a theoretical maximum. It does not imply or forecast how many buildings will *actually* be built.

Traditionally, planners have performed build-out analyses by using spreadsheet tables to associate build-out assumptions with a hard copy map. GIS improves this technique by associating the digital land-use plan with a database of associated attributes. The Scenario 360 Build-Out Wizard automates the entire build-out process. The Wizard guides users through the choices and selections that will form the basis of a build-out analysis.

Build-out analysis results will reflect the remaining capacity for an area (they will not include the existing buildings). You can estimate the number, location, and appearance of buildings based on land-use or zoning information. You can set density assumptions in dwelling units per area, minimum lot size per dwelling unit, or floor area ratio. You can also assign design assumptions, including layout efficiency, building offsets, development constraints, layout pattern, and building type to your analysis.

There are many uses for build-out analyses. For example, you can determine:

- What impact changing the zoning classification would have on the number of buildings an area could hold.
- What would happen if you changed the allowed density.
- What impact modifying the efficiency factor based on local conditions would have. For example, the factor for medium density residential might be 80%, but in steep areas it might reduce to 60%.
- How using different constraints would spatially limit where development may take place.

- The build-out process contains 3 separate, but integrated steps: numeric, spatial, and visual. Each of theses has certain data requirements and numerous options. A Build-Out Tutorial is included on the Resource Disk that shipped with your software.

Numerical Build-out

Numeric build-out is the first step in the build-out analysis process. Numeric build-out is a mathematical calculation that measures the holding capacity of land. Numeric build-out provides an estimated building capacity (in numbers) for each polygon in a layer based on its area, permitted or planned density rules, and other factors. The starting build-out calculation is simple: multiply the allowed density (buildings per area) by the area. For example, if an empty area of 100 acres is zoned for 1-acre residential lots, the build-out capacity for that area is 100 units. A zoning or land-use plan might have a combination of density designations (1 acre, half-acre, 10 acre, etc.). In Scenario 360, these are represented by polygons in a land-use layer, where each polygon has a designated land use and each land use has an associated density. With this information, Scenario 360 can easily calculate the area of each polygon, multiply by its density, and produce a resulting number of allowed buildings. From there, additional refinements and variations can be made. You can specify residential, commercial, and mixed-use buildings; prohibit development in certain areas; and transfer or adjust density in specified areas.

Numeric Build-Out Analysis Results

Numeric build-out converts land-use information (like density, design efficiency factors, and constraints to development) into numeric building counts. See also: Tables created during build-out and Numeric calculations.

Running a numeric build-out analysis will produce:

- Two new layers viewable in the Build-Out layer in the ArcMap table of contents. One is called Buildings and the other is Buildable Area.
- A Build-Out LandUses table. You can click the Source tab, right click on the Build-Out LandUses table and click Open on the pop-up menu to view the contents of this table.
- Six indicators. Click the List Indicators button on the Scenario 360 toolbar to view the new indicators.
- A Build-Out report. Click the List Reports button on the Scenario 360 toolbar then click on the report name to view the report.
- Three new charts Build-Out Dwelling Units, Buildings, and Floor Area. Click the View Charts button on the Scenario 360 toolbar to open the charts view.
- A new Buildings Difference Buildable Area alert. Click the List Alerts button on the Scenario 360 toolbar then click Show all alerts to view the alert.

Spatial Build-Out

Spatial build-out places building points on a 2D map. It converts the numeric building counts into points representing individual structures. It then refines the numeric building counts by taking into account the actual geometry of land-use areas and buildings. For example, an oddly shaped lot may have enough total area for two buildings, but because of setback rules or minimum separation distances, it may only fit one unit. You must first run a numeric build-out analysis (to get the numeric building counts) if you wish to run a spatial build-out analysis.

Spatial Build-out Analysis Results

Spatial build-out places building points on your 2D map so that they avoid development constraints, other buildings, and polygon boundaries (land-use areas, zone districts, or lot lines). Potential building points are distributed two-dimensionally into each polygon one at a time. Spatial build-out is not a layout tool (e.g. designing roads, orienting buildings, or accounting for site amenities).

Spatial build-out analysis takes into account factors which cannot be accounted for in a numeric estimate, such as the minimum allowable offset between building or parcel shapes. Therefore, the results of spatial build-out are sometimes lower than the numbers estimated during numeric build-out. In addition, you must always remember that build-out analysis results will reflect the remaining capacity for an area (they will not include the existing buildings for the area).

Running a Spatial Build-Out Analysis:

- Populates fields in the Buildable Area attribute table and the Build-Out LandUses table. You can right-click on the Buildable Area layer in the ArcMap table of contents and click Open Attribute Table to view the contents of this table. You can also click the Source tab, right click on the Build-Out LandUses table and click Open on the pop-up menu to view the contents of this table.
- Adds information to the Build-Out report.
- Updates the Spatial information in the charts created during numeric build-out.
- If your spatial build-out results are did not meet your numeric build-out estimates, the Buildings Difference Buildable Area alert created during numeric build-out will be triggered. Click the List Alerts button on the Scenario 360 toolbar then click Show all alerts to view the alert. If you have triggered the alert, the alerted area is displayed in the map view with a bold outline.

Keep in mind the following when viewing the results of a spatial build-out analysis:

- A new building point will be separated from another new building point in the same polygon by at least the minimum offset distance specified for that polygon’s land-use class.
- A new building point will be offset from its containing polygon’s edge by at least half the minimum offset distance specified for that polygon’s land-use class.
- A new building point will be separated from any existing buildings by at least the minimum offset distance specified for that polygon’s land-use class.
- If a building does not appear in a polygon when you expect one to appear, or if fewer buildings are added than there is capacity, examine the attributes of the polygon. Was an estimated capacity correctly computed? Are there more existing buildings in the polygon already than there is capacity? Also, examine the dimensions of the polygon. Perhaps the minimum offset distance is too large.

- After spatial build-out has been run, you are free to edit the new buildings layer manually. You can add, move, or delete building points. This way you can turn a planning-level building pattern into more of a design-level distribution, with buildings following a uniform frontage line, etc

Visual Build-Out

Visual build-out takes the building points from spatial build-out and associates them with OpenFlight (.flt) building models. Spatial build-out placed the building points onto the 2D map. Visual build-out designates the building model (flight) file for use in the visual 3D scene. Note: You must have access to OpenFlight files (like those that come with SiteBuilder 3D) to run a visual build-out analysis. In addition, you can only view a visual build-out in 3D if SiteBuilder 3D is licensed on your workstation. You must first run spatial build-out (which requires you to run numeric build-out) before running visual build-out.

Visual build-out analysis results

Running a visual build-out analysis will populate the model file field in the buildings layer created during your numeric build-out analysis. Using the CommunityViz Model Library, you can make choices that accurately reflect local architecture, or more complex structures. Note that more complex structures may overwhelm computer system resources and can cause a 3D scene to bog down.

Once you have specified your models and run visual build-out, you must create your 3D view to view your scene in 3D.

Data required to set up a build-out analysis

When following the numeric Build-Out Wizard steps, you will be prompted to specify:

- A land-use layer (like a zoning map, master land-use plan, or a parcel map). This must be a projected coordinate system (as opposed to a geographic coordinate system). For information on coordinate systems, see ArcMap help.

- The attribute in that layer that specifies the land-use designation (like zoning type, permitted use description, or land-use code). This must be a text field (not numeric) and cannot exceed 100 characters. You can convert numeric code to text using the ToString formula function.

- The attribute that specifies the unique identifier of each land-use area (like feature ID or parcel number).

When setting up a spatial build-out analysis, you will be prompted to specify building separation distance rules for your land-use designations.

You must have access to OpenFlight files (like those that come with SiteBuilder 3D) to run a visual build-out analysis. In addition, you can only view a visual build-out in 3D if SiteBuilder 3D is licensed on your workstation.

Chapter 4 Implementation Tools

4.1 Introduction

This chapter provides an analysis of tools that can be used to implement climate change adaptations in sectors of interest to Land Use Planners the municipal and consulting engineers that assist them. These tools include a number of types of legislation, especially building codes "Best Practices" for floodproofing and other climate change adaptations, insurance matters, and emergency management, all which either purposefully or indirectly *could* be used to incorporate climate change adaptations. These tools could not be "tested" at our test case sites, since our study team cannot implement any of them, since they are implemented in numerous ways by government bodies and private parties. However, our research and numerous interviews with stakeholders at our test case sites and elsewhere, helped us to develop recommendations for implementation, which are summarized in Chapter 6 – Recommendations.

In this chapter we have also included recommendations for adaptations to climate change impacts besides our main topics of flooding and agricultural drought. Wind damage to structures from increased frequency and severity of storms, as well as building adaptations to greater extremes of cold temperatures have also been analyzed for climate change adaptations, since such topics are within the purview of municipal Land Use Planners and Engineers.

The analysis tools discussed in Chapter 3 form the scientific basis for determining what the climate change impacts will be on land uses, and thus, what needs to be done for climate change adaptations that affect land uses. These adaptations can then be implemented through the tools discussed below.

Tool 7 – Implementation Tools

Once we have finished our analyses of climate change impacts and adaptations using the above tools, how can we then implement this knowledge into Land Use Planning?

These tools are all existing, and may not normally be thought of as "tools". However, anything that drives implementation of Land Use Planning climate change adaptations, whether they be they regulations, flood insurance practices, floodproofing adaptations, new agricultural irrigation infrastructure, etc., can actually be considered implementation tools. Thus, for these "tools" we summarized existing categories of tool types. While all of our *analysis* tools were tested at our test case sites, "testing" of implementation tools is not possible adaptations to climate change for future development existing development, we summarized a variety of existing tools

4.2 Engineering Codes of Practice

Engineering in Canada is regulated by self-governing professional licensing bodies. These bodies are established by Canada's 13 provincial and territorial governments through Engineering Acts, creating a system of self-regulation. Each provincial or territorial association is responsible for ensuring high standards of engineering practice and education in Canada. They also take appropriate action to prevent the illegal practice of engineering by unlicensed individuals. To govern the profession of engineering in Canada, each and every provincial and territorial government also has an act that:

- Defines the range of activities which may be considered as "engineering," including the scope of practice for engineers, and which professional activities are so critical to public safety and the public good that only a licensed engineer can undertake them;
- Creates or recognizes provincial or territorial engineering licensing bodies, describing how they are to be governed and mandating them to carry out tasks like licensing and regulating the profession; and
- Outlines the regulations pertaining to the profession of engineering, such as who can use the term "engineer," what academic qualifications are required to be a professional engineer and how professional misconduct should be handled.

In Nova Scotia, the Engineering Profession Act was originally incorporated by Chapter 186 of the Acts of 1920. In Nova Scotia, as well as some other provinces and territories, the profession and its volunteers also regulate the practice of engineering at a business level. A number of the Engineering Acts require companies that are undertaking engineering work to be licensed by their provincial or territorial engineering licensing body. The one exception is in the case of sole practitioners, who have the right to practice independently without a license to practice.

To promote consistency in their standards for admission to the profession and licensure as a P.Eng., engineering's licensing bodies created a national organization, the Canadian Council of Professional Engineers (CCPE), in 1936. On behalf of the licensing bodies, CCPE has developed national standards for engineering education in Canada as well as a national accreditation system to evaluate undergraduate engineering programs. Methods of assessing and adaptation to climate change impacts, especially flooding, should be included in the training and licensing programs.

Flood Water Legislation

Flood water control is ultimately regulated by the Nova Scotia Department of Environment and Labour (DoEL) through the Nova Scotia Environment Act. Specific legislation under the Environment Act includes:

- Environment Assessment Regulations (NS Reg. 44/2003)
- Water and Wastewater Facilities and Public Drinking Water Supplies Regulations (NS Reg. 186/2005)
- Activities Designation Regulations (NS Reg. 47/1995)
- Approvals Procedure Regulations ((NS Reg. 48/1995)

All actions identified for flood control are designated activities under Nova Scotia activities designation regulations, and are subject to the Nova Scotia Environment Act. The degree of environmental regulation will vary with each action, generally increasing with complexity. The environmental assessment regulations apply to diversion of any system where the drainage area is greater than one square kilometre. This could have a substantial impact on actions for adapting to flood waters through channel by-pass or flow diversion practices.

In the late 1980's to early 1990's, DoEL decentralized and initiated changes to the water approval process. Currently, DoEL has identified dam safety as a factor to be considered in future renewal of approvals, and has partially endorsed the Canadian Dam Association (CDA) *Dam Safety Guidelines* as a minimum safety "standard". Adoption by DoEL of an industry sponsored guideline as a standard for dam infrastructure is indicative of a deficiency in codes of practice for design of the water course structures. It is likely that levee design would default to the same standard. Currently, there is no best practice or standard methodology for river modeling or even for prediction of flood discharge. There are several models commercially available but the method of use and input parameters are typically at the discretion and judgement of an engineer.

All of the actions described for flood control are dependent on both the magnitude and the duration of a flood event. Most flood model routing that incorporates attenuation from a reservoir will include duration assumptions and antecedent basin assumptions. Engineers bias in making assumptions is that past observations are indicative of future conditions. Provided climate change scenarios prove otherwise, education of professionals will improve long-term performance of flood control structures.

Likewise, in climate change scenarios involving seasonal shifts for events, structural performance may be impacted. Water supply structures are typically designed to retain the spring freshet for the summer dry period. Changes in seasonality may "surprise' operators and cause unsafe practices.
A climate change scenario that involves more drought may render current infrastructure that diverts flood flow non-functional and an inappropriate use of public resources.

Incorporation of Climate Change into Engineering Practices

In many areas of Canada, climate change is projected to change the pattern of precipitation, and/or increase or decrease it. For example, in Fredericton, New Brunswick, it is projected that more precipitation will occur annually, and a greater percentage of it will occur in winter and spring (Lines, 2006). Engineers will need to take this into consideration in designing channels, levees, and other water-related infrastructure. Flood control practices have tended to keep flood flow "in-channel" through a variety of practices. The following practices are used to improve channel capacity, and thus, reduce flooding.

1. **Improving channel capacity** through maintenance by "clearing and snagging" the channel. This simple measure includes clearing excessive vegetation, debris, uprooted trees, etc. It can be effective when only small increases in hydraulic efficiency are needed.
2. **Channel cleanout** can be used when a larger channel is needed or if clearing and snagging will not result in the required hydraulic efficiency improvement.
3. **Channel enlargement** can be used to substantially increase hydraulic efficiency and flood flow capacity of an existing channel. Channels can be either widened or deepened.

However, increased flow velocity from modified channels can cause embankment instability and sediment liberation.

4. **Channel realignment** can improve the efficiency of a meandering river or a river with a constriction. There are habitat considerations and potential for Habitat Alteration and Destruction (HAD) as a result of abandoned streams.
5. **Levees** can be used to provide overbank control of flood waters or to protect critical infrastructure or residents. Levees are less intrusive to the natural channel but they have an environmental footprint.
6. **By-pass flood channels** combine the channel realignment and levee concepts. There are several design options with the simplest being a channel that is normally dry but will fill during a significant flood to by-pass flows around critical infrastructure.
7. **Flow diversions** are similar concept structures to by-pass flood channels except that they also divert part or all of the current drainage area. In other words, they also divert part of the seasonal flow, not just flood flow.

However, other best practices aim at improving infiltration of runoff into the ground, in order to reduce flood volumes and velocities.

4.3 Regulations and Administrative Practices Related to Land Use Planning

The most important federal statutes and programs with regard to water-related legislation, since flooding is the main climate change impacts and adaptations on which this report focuses, are summarized below. (Note, this material has also been used in a report by Terrain, *Government Levels for Climate Change Adaptation in Urban Infrastructure.*)

The Canada Water Act, R.S.C, 1985. c. C-11 provides the statutory authority for the federal government to conduct research, and develop planning, conservation, and development programs for water resources. Water research at the federal level is carried out under the National Water Research Institute and the Nation Hydrology Research Institute. It superseded the Canada Water Conservation Assistance Act as the main statutory authority for federal management of Canada's water resources (Environment Canada, 2006). It provides for a system of federal-provincial Consultative Committees for water issues. Flooding issues have been a primary concern. The approach to water resources management fostered by the Act included the following emerging ideas:

- planning should proceed on a more comprehensive basis by including all water uses and their economic, social and environmental importance;
- views of the people affected should be sought;
- non-structural alternatives should be considered; and
- planning should take place according to river basin or on the basis of other larger geographical areas.

This Act does not address climate change. However, under "Comprehensive Water Resource Management Programs" the Act could be interpreted to indirectly enable federal and provincial governments to include climate change considerations, since such considerations could be interpreted as being part of the type of federal/provincial comprehensive water resource management enabled and fostered by the Act. The establishment of intergovernmental committees, etc. are enabled under the *Federal-Provincial Arrangements* section of the Act.

The lack of a formal federal-provincial floodplain management agreement is largely due to lack of funds, according to federal and provincial sources. The lack of a federal-provincial climate change policy for waterways is most likely due to the recent nature of this issue.

The Flood Damage Reduction Program (FDRP) was established in 1975 in order to identify floodplains and alleviate flood situations, primarily with non-structural measures. The federal FDRP was undertaken jointly with the provinces to map and develop policies to discourage development in floodplains. Through funding by this program, flood risk areas were mapped by the two governments throughout Canada in communities that requested such assistance, including the City of Fredericton.

The federal criterion for defining the flood risk area is the 100-year flood; however, the federal government adopts provincial criteria if they are more stringent. The first province to join the Flood Damage Reduction Program was New Brunswick, signing "General, Mapping and Studies Agreements" in March 1976. The 1 in a 100-year flood was used to delineate and designate flood plains in 13 areas. From the date of signing onward, policies outlined in the General Agreement with the provinces were applied. For instance:

- "neither government will build structures subject to flood damage in that area;
- government agencies such as Canada Mortgage and Housing Corporation will no longer help finance new flood vulnerable developments there; and,
- disaster assistance programs will no longer cover losses due to flooding of new developments in the area." www.ec.gc.ca/water/en/manage/flood/e_delin.htm, 2006
- A flood forecasting centre for the Saint John River in New Brunswick was established through this program, including the required technology development and transfer. "The River Forecast Centre in Fredericton, forecasts river levels along the Saint John River and its main tributaries below Fredericton where the major flood damages are experienced in the province". www.ec.gc.ca/water/en/manage/flood/e_delin.htm, 2006

The FDRP was discontinued in March 2000 after many of Canada's urban areas were mapped. In Fredericton, the Information Technology Department of the Province of New Brunswick is currently digitizing 20 year old flood risk maps created under the Flood Damage Reduction Program.The Federal and Provincial governments had a long-standing agreement whereby (a) hydro-technical studies would be completed to delineate flood-prone areas, and (b) financial disincentives would be applied to control development within such areas. The agreement lapsed in March, 2000.

Environment Canada was created in 1971 to oversee environmental issues, including air, water, soil, renewable natural resources, flora and fauna, and meteorology. Environment Canada is governed by the Department of the Environment Act, and has five regional offices, which administer approximately 15 federal statutes. The most important act Environment Canada administers is the Canadian Environmental Protection Act (CEPA). Environment Canada plays and important role with regard to climate change information and research, and is part of the tri-government level emergency measures responders.

The Canadian Environmental Protection Act (CEPA), R.S. 1985, c. 16 (4e suppl.) which is administered by the Canadian Environmental Assessment Agency, came into force in 1995. This Act governs the Environmental Assessment process for determining the potential environmental impacts of a proposed project, action, or program, where a federal authority is involved. The water related provisions in CEPA include formulation of guidelines and codes of practice. Although this Act does not include provisions for climate change, recommendations for incorporating climate change considerations into CEPA have been developed by ClimAdapt, a public/private partnership committee for research regarding climate change adaptation, based in Halifax, Nova Scotia.

The Fisheries Act, R.S.C. 1985, c. F-14, which is administered by the federal Department of Fisheries and Oceans, regulates habitats and contaminants of waters frequented by fish. This Act provides for the establishment of federal-provincial agreements of joint boards to manage water resources. This Act has bearing on climate change factors since it requires that sufficient flows be maintained in waterways to support fish habitat; and climate change could re*duce low flows in summer.* According to Section 3.8, the City cannot clean sediment out of a stream to mitigate flooding, since this would entail destruction of an ecosystem. There is confusion over interpretation of the *Fisheries Act*, which is being adjudicated in court cases.

The Navigable Waters Protection Act, (NWPA) (R.S., 1985, c. N-22) regulates the building and placement of ‘works’ in navigable waterways. Works subject to approval within the NWPA’s jurisdiction are in Section 3, and include: (a) Any bridge, boom, dam, wharf, dock, pier, tunnel, or pipe … and (d) Any structure, device or thing … that may interfere with navigation.”

Emergency Preparedness Act, (R.S., 1985, c. 6 (4th Supp.) governs all federal agencies and departments in a civil emergency situation. The Act also allows for the development of programs to deal with emergency events. It recognizes the interests of the provinces, territories and municipalities in relation to federal assistance provided during a provincial emergency. Under this Act, the federal government can provide financial assistance to a province when authorized, pursuant to section 9 (d) of the Act when “a provincial emergency in the province has been declared to be of concern to the federal government and the province has requested assistance”. Although there is no mention of climate change factors in the Act, the exacerbating of flooding by climate change could indirectly cause more flood*ing emergencies.*

The Joint Emergency Preparedness Program (JEPP) was established in 1980 to help ensure that all levels of government across Canada are equally prepared to respond to all types of emergencies. Public Safety and Emergency Preparedness Canada (PSEPC) administers this program, which provides funding and support to emergency preparedness and critical infrastructure protection projects and initiatives. Projects are jointly financed by federal, provincial and territorial governments, with the aim to reduce injuries and loss of human life, property damage, and to assure the continuation of our critical services in an emergency. For example, funds from the program have been used for training, the purchase of emergency response equipment, emergency planning and capacity building.

Developing emergency measures and preparedness plans and having available resources for emergency services may become paramount if climate change causes more extreme weather events. Natural disasters and extreme weather events have taxed our systems and resources and threaten lives. Within the emergency management field, there are four generally accepted phases of emergency activity: (1) preparedness; (2) response; (3) recovery; and (4) mitigation.

Flooding, and the damage associated with it, is an ongoing problem in Canada. This originated from early settlement along rivers, resulting in many municipalities being located on flood plains. The consequences of flooding have become more severe with increasing population and development pressures in areas prone to flooding. Recent rising sea levels, more frequent and severe storms, and higher storm surges have added to this problem. Under the Canadian constitution, flood plain management essentially falls under the jurisdiction of the provinces, as they are primarily responsible for water resources and land use matters.

Planning in Floodplains

Adaptive actions can be taken to reduce the likelihood or severity of future flood damage. The selection of appropriate flood damage reduction measures should be based on the characteristics and severity of the flood problem, the physical features of the watershed, the nature and extent of development on the flood plain, and the economic conditions of the region. You don’t necessarily have to build structures to prevent flood damage. The ancient Egyptians had this principle down to a ‘science’. They knew that the Nile was going to flood every year – so they did not build on its flood plain. In retrospect, they were much wiser than we are today!

The federal government has a lead role to play in flood damage reduction efforts in Canada. The reasons for government involvement should be to protect public health and safety, to reduce public expenditures for the repair of flood damage to public and private property, to minimize the contamination of water with hazardous materials or other contaminants present on the flood plain, to reduce expenditures related to emergency response during a flood, and to recognize and protect the environmental and ecological qualities of the flood plain. Non-structural damage reduction, including flood plain delineation, flood risk mapping, and flood forecasting/warning services, should also be a major component of flood damage reduction efforts in this country. Government agencies at all levels should also participate as effective members of multi-disciplinary teams developing land use and financial restrictions with respect to future flood plain development.

In Nova Scotia, the provincial Planning Act, which is contained in the Municipal Government Act, includes appendices called “Provincial Interest Statements”, which provide guidance to Nova Scotia municipalities with regard to topics of interest to Land Use Planners in Nova Scotia. While there is no climate change adaptation Provincial Interest Statement, there already is a Floodplain Provincial Interest Statement. Thus, it would be most appropriate to include climate change adaptations for floodplains in this existing statement.

Municipal legislative tools also already exist throughout the Atlantic Provinces, as well as in the rest of Canada, to which climate change impacts and adaptations for land uses in floodplains could be added. These standard tools include:

- Municipal Strategic Plans, which contain policies which contain land use policies which have the force of law;

- Future Land Use Maps, which guide municipal implementing legislation;

- Municipal Land Use (zoning) By-laws, which implement Municipal Strategic Plans on a municipal-wide basis, and include zones relevant to climate change adaptations, such as floodplain zones and agricultural district zones;

- Municipal Subdivision By-laws, which implement Municipal Strategic Plans on an individual development site basis;

- other municipal by-laws that *could* regulate topics relevant to climate change adaptations, such as floodplain by-laws, erosion and sediment control by-laws, and stormwater management by-laws.

4.4 Engineering Legislation: Building Codes

4.4.1 Introduction

In this section we will investigate the impact that projected climate change has had, or should have, on Building Codes in Canada. While “greener” buildings are a climate change mitigation factor, in terms of burning less fossil fuels, which produce more GHG, they are also an adaptation factor, in that in colder climates like Atlantic Canada (as well as in hotter climates like in southern Ontario), builders and residents will need to *adapt* to more temperature extremes through more energy efficient buildings (see 4.4.4 below).

In many Canadian cities building codes are administered by the Planning and Development Department. In incorporated small towns and villages the same person is often the Planning and Development Officer, administering the building code as well as the zoning by-law and planning regulations.

4.4.2 National Building Code of Canada

The National Building Code of Canada (NBCC) is the end product of a variety of committees made up of practitioners and academics from across the country. The Code is comprised of a set of performance objectives and functional statements, along with a set of acceptable solutions, the latter of which are designed to achieve the performance objectives. In other words, the Code specifies a series of design provisions which result in an acceptable performance level of buildings, with respect to safety, health, accessibility, and fire and structural protection.

In Canada, provincial and territorial governments have the authority to enact legislation that regulates building design and construction within their jurisdictions. This legislation may include adoption of the National Building Code of Canada without change or with modifications to suit local needs, and the enactment of other laws and regulations regarding building design and construction, including the requirements for professional involvement.

The Province of Nova Scotia has adopted the NBCC into legislation. The only significant modification that Nova Scotia has imposed on the NBCC is to use Schedule B: “Design Data for Selected Locations in Nova Scotia” rather than NBCC’s Division B, Appendix C: “Climatic and Seismic Information for Building Design in Canada”. The major difference between these documents is that Schedule B includes more locations in Nova Scotia than does NBCC’s Division B, Appendix C. Where locations coincide, the design data is the same.

In Nova Scotia, municipalities may apply to the provincial government to make specific modifications to the adopted Building Code for their particular requirements. However, provincial governments typically discourage such modifications, preferring instead to consider applications for municipal modifications as candidates for provincial modifications. The last such specific municipal modification in Nova Scotia was made 11 years ago for a site in the historic district of Halifax. However, that specific municipal modification was dropped a couple of years later when the next version of the NBCC was adopted by the province. At the moment, all municipalities in Nova Scotia follow the provincial Building Code legislation, which is essentially the National Building Code of Canada.

Where the NBCC has been adopted into legislation by provincial or territorial governments, a builder, designer, or building owner may deviate from the acceptable solutions described in Division B of the NBCC, as long as they show that their proposed alternative will perform at least as well as the acceptable solution(s) it is replacing. The objectives and functional statements attributed to the acceptable solution(s) identify the areas of performance where this minimal equivalence must be demonstrated.

The Nova Scotia Building Code does not apply to sewerage nor flood control and dams (see Section 1.2.1.2 Exemptions of the Nova Scotia Building Code).

4.4.3 Climate Change Issues in the National Building Code of Canada

The NBCC states the following in Appendix C (Division B), pg. C-2, under "Changing and Variable Climates":

> *Past and ongoing modifications to atmospheric chemistry (from greenhouse gas emissions and land use changes) are expected to alter most climatic regimes in the future. As a result, it can no longer be safely assumed that the climate of the past few decades will be a sufficient guide to the climate of the next few decades. While average climatic conditions may be changing, the frequency and magnitude of extreme climatic events may also be changing in unknown ways. Although consensus is emerging on the long-term trends for some climatic elements, there is no agreement as yet on the changes expected in climatic variability.*

With respect to this statement, the NBCC, in particular the Standing Committee on Structural Design (Part 4) and the Standing Committee on Houses and Small Buildings (Part 9), are planning to address how climate change will affect design provisions in the near future. The NBCC's list of priority projects for the next code development cycle (2006-2010) includes a task on climatic and earthquake loads as they apply to both Part 4 (*Structural Design*) and Part 9 (*Housing and Small Buildings*) of the Code. A brief description of the task is as follows (from private correspondence with Adaire Chown, Senior Technical Advisor, Canadian Codes Centre, February 16, 2006):

> *Climatic and Earthquake Loads - NBCC Parts 4 and 9: Advances in data and methodology should continue to be reviewed and incorporated, where beneficial, into the determination of snow, wind, and earthquake loads on buildings, as should refinements to the analyses.*

The next cycle of revisions are planned to start in May or June of 2006, and the above task will be lead by Cathy Taraschuk, Technical Advisor, Standing Committee on Structural Design. Landslides of natural slopes are not covered by the NBCC, unless the landslide is potentially caused by a building or by an excavation for a building. For example, Section 4.2.4.5 “Sloping Ground” states that

> *Where a foundation is to rest on, in, or near sloping ground, this particular condition shall be provided for in the design.*

while, for excavations, Section 8.2.2.2 “Protection of Adjoining Property” states that

If the stability of adjoining buildings may be endangered by the work of excavating, adequate underpinning, shoring and bracing shall be provided to prevent

1. *damage to, or movement of, any part of the adjoining building, and*
2. *the creation of a hazard to the public.*

There are a few Code provisions regarding floodproofing of individual structures. For example, Clause 5.7.1 “Protection from Surface Water” states

1) *Except as provided in Sentence (3), the building shall be located, the building site shall be graded, or catch basins shall be installed so that surface water will not accumulate against the building.*
2) *Except as provided in Sentence (3), foundation walls shall be constructed so that surface water will not: a) enter the building, or b) damage moisture-susceptible materials.*
3) *Buildings specifically designed to accommodate the accumulation of water at the building or the ingress of water need not comply with Sentence (1) or Clause (2)(a).*

Similarly, Clause 9.14.6.1 “Surface Drainage” states

1) *The building shall be located or the building site graded so that water will not accumulate at or near the building.*

More specifically, Division B, Appendix A, Clause A-5.8.1.1.(1) “Required Drainage”, states:

A wall or floor located below the water table or in the path of a watercourse will be subject to continuous hydrostatic pressure. In such cases, the provision of drainage will be ineffective and the wall or floor must be made waterproof to prevent water ingress.

Clause 9.13.3.1 “Required Waterproofing” clarifies where waterproofing is required,

1) *Where hydrostatic pressure occurs, waterproofing is required for the exterior surfaces of*
   a) *floors-on-ground, and*
   b) *below ground walls, where the exterior finished ground level is at a higher elevation than the ground level inside the foundations walls.*
2) *Roofs of underground structures shall be waterproofed to prevent the entry of water into the structure.*

Regarding drainage code requirements, the following provision is of interest with respect to potential environmental problems: Clause 9.14.6.2 “Drainage away from Wells or Septic Disposal Beds” states that:

1) *Surface drainage shall be directed away from the location of a water supply well or septic tank disposal bed.*

The NBCC Climatic Design Parameters (Division B, Appendix C of the NBCC), and correspondingly, Nova Scotia’s Schedule B: “Design Data for Selected Locations in Nova Scotia” have been evolving over the years, reflecting climate change to some extent. As noted previously, the two documents show the same climatic parameters when the locations coincide (Nova Scotia's Schedule B does include more locations, but not particularly in the Annapolis Valley).

By comparing the climatic design values specified in the 1977 NBCC with those appearing in the 2005 NBCC, the effects of climate change on the Building Code can be roughly assessed. The following climatic design values will be considered:

1) January Design Temperature
2) July Design Temperature
3) Heating Degree Days
4) Snow Loads
5) Annual Total Precipitation (mm)
6) One-Day Rainfall
7) Hourly Wind Pressure
8) Driving Rain Wind Pressure

The following table summarizes these design parameter changes, as presented by the Building Codes in force at the time, at three representative locations in Nova Scotia's Annapolis Valley, over the almost 30-year span between 1977 and 2005. The locations selected are the communities of Digby, Greenwood, and Kentville.

Figure 4.1 *Climatic Design Parameters Specified in the National Building Code of Canada and the Building Code of Nova Scotia*

Municipality	**Temp Jan 2.5%**	**Temp Jul .5% DryBulb)**	**Degree Days < 18^o C**	**1-Day Rain (1/50) mm**	**Ann. Total Precip. mm**	**Snow Load kPa**	**Hourly Wind (1/10) kPa**
Digby, 1977	-15	25	3850	123	1230	2.5	0.40
Digby, 2005	-15	25	4050	139	1275	2.8	0.40
Greenwood, 1977	-17	28	4130	113	1060	2.6	0.36
Greenwood, 2005	-17	28	4300	123	1100	3.3	0.36
Kentville, 1977	-18	28	4240	145	1110	2.8	0.36
Kentville, 2005	-18	28	4200	128	1200	3.0	0.36
Wolfville 2005	-19	28	4200	123	1175	3.0	0.36

The time periods over which the design values were estimated are summarized as follows:

- The 1977 design parameters are based on statistical analyses of records up to 1970.
- The 2005 design temperature parameters are based on temperature records up to 1993.
- The 2005 design degree-day parameters are based on temperature records up to 1990.
- The 2005 design annual total precipitation parameters are based on rain and snowfall records up to 1990.

- The Code does not state the period of time over which the Snow Loads and 1-Day Rain amounts were estimated in the 2005 NBCC.

The following general observations regarding the climatic changes implemented in the Building Code between the years 1977 and 2005 can be made from Table 4.1. The 1977 Code design parameters were based on 1970 statistical analyses.

1. The design temperatures remain unchanged. This does not imply that mean temperatures are not changing, only that this trend was not conclusively observed in Canada by 1993.
2. As of 1990, the design number of degree-days below 18^{o} C has increased by about 5 percent at Digby and Greenwood, and decreased by 1percent at Kentville.
3. The one-day total rainfall amount, for a 1 in 50 year storm, has increased by about 10 percent at Digby and Greenwood, and decreased by 13 percent at Kentville. The time span over which these changes occurred are not reported in NBCC 2005.
4. As of 1990, the annual mean total precipitation had increased by about 4 percent to 8 percent at the three sites.
5. The peak ground snow loads have increased by 6 to 24 percent at the three sites.
6. The hourly wind pressures remain unchanged.

Overall, there is a general trend towards increasingly severe climatic design parameters over the period from approximately 1970 to 1990. The design parameters given in the 1977 Code were often based on only a few years of observations; therefore, some of the changes indicated above may actually be due to the poor quality of the statistical estimates obtained from the 1970 data set. More recent estimates are no doubt more accurate – if the mean and variance of the design parameters are constant – since they include more years of observation. In the face of climate change, a more sophisticated approach to the statistical analysis of data over the past years is required to account for changes in the mean and variance of the parameters being estimated.

4.4.4 Mitigation versus Adaptation in Building Codes

Strategies for dealing with climate change are generally divided into two categories: mitigation or adaptation. When developing a building code with climate change in mind, it is sometimes difficult to determine whether a specific code provision is an adaptation or a mitigation.

Mitigation means to moderate (a quality or condition) in force or intensity. Mitigation in the context of climate change means that we are moderating climate change by removing or diminishing its contributing factors. On the other hand, adaptation means that the system being designed is modified in such a way that the climate change does not affect the system's performance as much as it would have by maintaining the status quo.

For example, a human will adapt to warmer weather by taking off his or her sweater. This is clearly an adaptation and not mitigation (e.g. taking off a sweater does not make the weather cool down). However, if the space in question were air conditioned, that would be mitigation. In analogy, a building code may require improved energy efficient windows, heat exchange systems, and so on, in response to warmer weather. According to the human analogy, this is an adaptation. However, if enough building jurisdictions adopt the code requirements, there will be a reduction in energy usage, leading generally to a corresponding reduction in the contributors to climate change. Thus, the building code provisions regarding energy efficiency might also be viewed as mitigation.

However, since any such code provisions instituted at this point in time will have negligible effect on climate change for at least the next several decades, these provisions can only be considered adaptive at this time. The basic goal of such provisions is to minimize the probability of failure of cooling and heating systems in the face of climate change. Since excessively hot or cold environments are a threat to human health, code provisions to minimize the probability of contributing to such environments should be viewed as adaptations that achieve two of the prime objectives of the National Building Code of Canada, namely that of safety and health of the public.

4.4.5 Recommended Changes to the National Building Code of Canada

Recommendations for future NBCC modifications, taking into account climate change issues, are as follows:

1) Climatic Design Parameters should be reassessed on each revision of the NBCC by a statistical analysis of *up-to-date* climate data, which takes into account possible trends in the mean and standard deviation of the parameters. That is, NBCC climatic design parameters should not be based on data generated 10 to 15 years ago, but rather on ***weather*** data collected ***from the first year of collection.***

2) Climatic Design Parameters should anticipate projected climate change trends, in terms of temperature, wind, rain, snow, and water table levels. That is, environmental loadings should be 'cast forward' to give values anticipated at the end of the current average structure design life. For example, if a structure designed today is expected to have a design life of 50 years and design loads on the structure are based on 1/50 annual probabilities of occurrence, then the climatic design parameters used in the design should be those projected as having a 1/50 annual probability of occurrence in the *50th year of service* of the structure. (Note: this is a *conservative* recommendation, since the intervening years will have a lower probability of design parameter exceedance, assuming the climate quantiles are accurately assessed.)

Do not develop buildings on portions of the sites that meet any of the following criteria (1 & 2):

1) Elevations lower than 1500 mm (5 ft) above the elevation of the 100-year flood plain <u>OR</u> 900 mm (3 ft) above the elevation of the 200-year flood plain.

2) Land within 30.5 m (100 ft) of any wetland. (This is more pertinent to the on-site sewage section.)

3) Energy Efficiency: As suggested above, the NBCC should take a more pro-active stand on prescribing the energy efficiency of buildings and houses. At the moment energy efficiency is largely dictated by market forces, which are based primarily on past experience with energy costs. However, to ensure that risk to human health and safety is maintained at an acceptably low level, the building code should specify design solutions aimed at minimizing the probability that humans in buildings and houses are exposed to extremes in climate, given that these extremes seem to be ever more likely to occur.

Provincial – Nova Scotia

The Province of Nova Scotia has adopted the National Building Code of Canada, with a few minor amendments as indicated in the previous section. The complete set of amendments in the Nova Scotia Building Code can be found at http://www.gov.ns.ca/just/regulations/regs/bcregs.htm.

4.5 Sustainable Buildings Adaptations Tools

4.5.1 Introduction

The number of weather-related natural disasters per decade to hit Canada has increased rapidly in the last 60 years. There was an especially large increase (more than double) from the 1960s to the 1970s. They increased from 29 in the 1950s to 119 in the 1990s. With this dramatic increase in natural disasters, property loss claims have experienced a sevenfold growth – from approximately $10 billion to more than $70 billion – during this same time period. These natural disasters were precipitated by more frequent and extreme weather events. In the short term, these weather events – mainly intense rain storms, tornadoes, or (in Atlantic Canada) hurricanes – have caused massive structural damage, wide-spread flooding, erosion of topsoil or the contamination of fresh water supplies. In the longer term, rising sea levels will cause greater coastal erosion, inundate low-lying lands, and threaten more surface and subterranean fresh water supplies. Heavy precipitation events can also reduce the margin of safety assumed in building codes.

Flooding and its effects vary by time and location. The extent of social and community disruption brought on by flooding, and the cost of flood damage depend on several factors including: the area covered by the flood, the depth and velocity of the floodwater, land-use patterns in the affected areas, the publics' flood awareness, the effective warning time, the rate of rise of the floodwaters, evacuation or rescue procedures in place, and flood-borne debris and sediment.

Flooding in "open water" locations or as a result of ice jams during mid-winter thaws or spring breakup has caused extensive damage. Because of this, we need to do additional research on river ice behavior. This could eventually lead to forecasting when and how river ice will break up and the development of additional means of preventing or mitigating the negative effects of ice jams.

4.5.2 Climate Change Factors to Consider

Floods cause major damage to all types of infrastructure – bridges, dams, buildings, water systems (treatment plants and pumping stations), water supplies (both surface and sub-surface), septic systems (especially on-site), roads and railways.

There have been major floods throughout Canada in the last ten years, ranging from the Sagueney River in 1996 to floods in southeastern Quebec, N&L, and Alberta and BC in 2006. Some of these floods occur almost annually (Red River), while others occur only occasionally. Structural measures to reduce flood damages include levees, dams, floodwater diversion channels, and storage reservoirs. As an example, Winnipeg, Manitoba has reduced its flooding damage costs by building the floodwater diversion channel around the city. However, this diverted water tends to flood the rural areas around Winnipeg instead – thereby affecting fewer people, but still causing extensive flood damage.

Floodproofing should be an integral part of future flood damage reduction efforts in Canada. According to the Canadian Society for Civil Engineering (CSCE), the definition of floodproofing is: Any combination of structural and non-structural additions, changes or adjustments to structures and to our national infrastructure that eliminate or reduce the potential for flood damages. Floodproofing may be an economically viable means of reducing the potential for flood damages where alternative means of flood damage reduction are not feasible. The federal government – in conjunction with knowledgeable professionals (engineers, scientists, architects, and planners) should develop national guidelines for floodproofing all structures – both residential and non-residential. These guidelines should define the approach to acceptable floodproofing practice in Canada and identify commonly applied means of floodproofing specifically suited to the Canadian climate. Similarly, guidelines or standards should be developed for floodproofing water distribution and wastewater collection systems.

Although providing some benefits, the overall cost-effectiveness of simply building more dykes and dams is questionable. Projects of this kind are expensive to build and maintain and are no sure guarantee against disaster. Dykes and dams can be overtopped and channel capacities exceeded making the inevitable flood worse. Structural measures often inspire a false sense of security, thereby encouraging further development in flood prone areas. Moreover this approach, as well as disaster assistance payments, has the general public paying for the benefit of the few who choose to live in known flood risk areas.

'Smart Concrete' Could Improve Levees

The failure of levees in the wake of Hurricane Katrina emphasizes the need for new technologies to strengthen levees and monitor their reliability. Deborah D. L. Chung, Ph.D., a Niagara Mohawk Professor of Materials Research and director of the Composite Materials Research Laboratory in the University at Buffalo School of Engineering and Applied Sciences has proposed a solution to strengthen levees.

"The technology used to build levees is really very primitive – sometimes it involves just the piling of dirt. Surely there's a lot of room to use higher technologies than that," says Chung, the inventor of “smart concrete”, patented in 1998.

Smart concrete contains short carbon fibers, which are added to a conventional concrete mixture. This modification gives the concrete the ability to detect stress and tiny deformations in the concrete. In the presence of structural flaws – within a levee made of smart concrete, for example – the concrete's electrical resistance increases. Electrical probes placed on the outside of structures can detect this change. Chung, who also has studied the use of continuous carbon fibers in the form of composites, suggests that some levees could be encased in a shell composed of such composites. According to Chung, using smart concrete would increase construction costs by 30 percent, which apparently is the major reason industry has not adopted its use. Of course, reconstruction costs after a disaster can run much higher, she points out.

Costs

Structural measures involve high construction and maintenance costs, and may frequently give a false sense of security so as to encourage continuing development on the flood plain. The major flood mitigation solution is to build dykes or levees to hold back the floodwaters. However, before expensive dykes or dams are built, several questions must be answered. 1) How high will the floodwaters rise? 2) How high should the dykes be built – to the height of the average flood, or to the height of the 50- or 100-year flood? The kicker here is that with rising sea levels and increased height of storm surges caused by CC, the 50- or 100-year floods tend to be compressed into 10- or 20-year storms. 3) How much damage will the flood waters of a certain height cause? Is it worthwhile to spend an extra dollar in dyke construction to prevent an extra dollar of damage every

10, 20, 50 or 100 years? The answers to these – and other – questions can change the cost-benefit equation drastically.

In California, the cost to repair levees has increased dramatically. Over the last twenty years, the cost of levee repair has risen from an average of $300 per linear foot to $5,000, with some projects approaching $9,000. When compared to the costs – in both structural and human terms – of Hurricane Katrina, it would appear that almost any cost would be justifiable.

Wind-Proofing (need for and costs)

In 2003 Hurricane Juan caused $100 million worth of damage to Nova Scotia and PEI. Even so, this price tag pales in comparison with Katrina's astronomical *$200 billion* (US) legacy of 2005. Although Nova Scotia is not in "hurricane alley", our experience with Juan, and last year's record hurricane season in the Caribbean and the United States should prompt us to prepare ourselves for more of the same in the next few years.

The two most common types of damage incurred during high winds (and especially hurricanes) are from the force of the wind itself – which can damage structures outright or cause trees and utility poles to fall on structures – or from the debris driven by the winds. The former can be reduced by anchoring all the various parts of a structure ultimately to the foundation; the latter by using hurricane shutters (mainly for windows and doors) and more resilient cladding materials.

The major components that require anchoring are:

Foundations: Uplift forces from hurricane winds can sometimes pull buildings completely out of the ground. Anchoring buildings to their foundations is critical for lightweight structures.

Structural Frame: Connections are usually the weakest part within structural frames. It is imperative that all the components of a building envelope be securely interconnected. Masonry buildings usually withstand hurricanes better than timber houses. Strong connection details are the key to safe construction of timber houses. Lightweight timber houses, coupled with poor connections, are a potentially dangerous combination.

Other factors that influence the severity of wind damage to structures are:

Location: When you buy a house, you usually have little choice as to location. However, if you build in a more vulnerable area, it would make sense to build a stronger-than-normal house. Vulnerable areas include open-ended valleys and exposed hillcrests. Both locations lead to acceleration of wind speeds with the corresponding increase in damage potential.

Shape: We can control the shape of new buildings and shape is the most important single factor in determining the performance of buildings in hurricanes. Simple, compact, symmetrical shapes are best. The square plan is better than the rectangle; the rectangle is better than the **L**-shaped plan.

Roof Geometry: Roof geometry helps determine a building's shape. For lightweight roofs it is best that they be "hipped" (sloping in all four directions, usually), steeply pitched (30 to 40 degrees), with little or no overhangs at the eaves and with ridge ventilators where practicable.

Construction Materials: The strengths and durability of materials are important characteristics to consider.

WindowShutters: These are similar to Storm Panels, except they are permanently attached to the window or door. The cost is between $13 and $14(US) per square foot.

These shutters attach above windows and doors. They roll up and store in a box when no in use. Roll-down shutters offer the best protection and are the easiest to use, but cost $26 to $40 (US) per square foot.

Landslides (need for and costs)

Landslides are generally not covered by insurance. Landslides are relatively rare in Nova Scotia, with the Cape Breton Highlands being the most prone region. They usually occur on steep slopes (> 30°) where heavy rain has saturated the overlying clay-rich or highly permeable soil. There's probably not enough of a risk to even mention landslides in the report.

4.5.3 Energy Efficiency (colder cold and hotter heat) (need for and costs)

R-2000

The R-2000 Standard includes requirements related to energy efficiency, indoor air quality and the use of environmentally responsible products and materials. It does not, however, specify exactly how a house must be built. Rather, the R-2000 Standard sets criteria for how an R-2000 home must perform. This leaves the designer and builder free to choose the most effective and economical way to build it. Typically, an R-2000 home consumes 30 percent less energy than a comparable conventional home.

The R-2000 (voluntary) standard applies to low-rise, semi-detached and row houses covered by Part 9 of the *NBCC* that do not share heated areas, ventilation systems or heating systems between dwelling units. They must meet the requirements of the R-2000 Compliance Procedures for Multi-Unit Buildings.

R-2000 features include 2x6 walls with fibreglass insulation and 1" sheathing on the outside; this gives R-25/26. It also includes an insulated foundation, and low-E Argon windows – R-4; (Regular double glazing is R-2). The roof has approximately 20" thick blown-in cellulose insulation for R-50. On an Energuide scale of 1-100, R-2000 = 80; conventional housing in NS is 77; just meeting code is 63-67.

Nova Scotia has by far the highest residential R-2000 participation rate in Canada. This is mainly because Heat Recovery Ventilators (HRVs) are a standard requirement in all residential construction. The cost premium for a new R-2000 house over conventional construction is only about 2-4 percent.

Terry Waters (President and founder of Sustainable Housing) – July 2006, provided the following information. Because each house in Nova Scotia is almost unique – different size, style, building materials, heating system, fuel, insulation, orientation, etc. – it is impossible to state with any accuracy how much it would cost to upgrade a house to the R-2000 standard. However, a typical range would be $15,000 to $50,000, depending on which upgrades were installed. A heat pump system – which would give the 'biggest bang for the buck' in a heating system – would cost $12,000. Adding insulation to the walls, ceiling, and basement, new windows and doors, and a general ‘tightening’ up of the house could add another $30-40,000. For a typical 2,200 sf house, the upgrade would cost $10-20 per sf.

4.5.4 LEED® Implications for Climate Change

One of our recommended methods to incorporate our GIS site analysis methodology into subdivision design will be to incorporate our data layers and methodology into the LEED® Analysis process. Leadership in Energy and Environmental Design (LEED®) is a rating system for green buildings, described on the LEED® website as “a voluntary standard for developing high-performance, “green” sustainable buildings. The LEED® Canada-NC (New Construction) 1.0 Rating System …provides a voluntary, consensus-based, market-responsive set of criteria that evaluates project performance…for what constitutes a “green building” in the Canadian context.” This system currently does not include housing or subdivision design in its leading edge sustainable development analyses. Such considerations would be very appropriate to include in the system’s “Sustainable Sites” category, and we will put forth recommendations accordingly.

Design and implement an erosion & sedimentation control plan that conforms to EPA Document 832/R-92-005, Storm Water Management for Construction Activities (Chapter 3), or local standards, whichever is more stringent.

Do not develop buildings on any portion of a site where:

1. The ground surface elevation is lower than 1500 mm above the elevation of the 100-year flood plain or 900 mm above the elevation of the 200-year flood plain, or
2. The building would be within 30.5 m of a wetland.

Supply at least 5 % of total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.

Provide at least 50% of the building’s regulated electricity from renewable sources by engaging in at least a two-year renewable energy contract. Renewable sources are those that meet the Environment Canada Environmental Choice programs’ EcoLogo requirements for green power supplies.

According to Ian Theaker of CaGBC (Vancouver – May 2006), there are no programs underway presently to incorporate CC implications into LEED® credits. However, in the summer of 2006 CaGBC will be starting a new round of information gathering – leading to the next revision of LEED® Canada –NC Version 1.0.

4.5.5 Insurance Matters

ICLR is an independent, not-for-profit research institute based in Toronto and London, Ontario. We are affiliated with the University of Western Ontario. The Institute for Catastrophic Loss Reduction (ICLR) was established by Canada’s property and casualty insurers. They are working to reduce disaster deaths, injuries and property damage.

According to ICLR's website: http://www.iclr.org/: Worldwide, natural disasters killed more than 650,000 people over the last ten years, and caused more than C$1 trillion in damage. Disaster damage has been doubling every five to seven years since the 1960s. There are many pertinent reports, presentations, and studies noted on their website.

Insurance coverage has been available since the early 19th century in what is now Canada. As far as can be determined, residential flood insurance has never been available here. Insurance coverage was usually offered on a peril-by-peril basis: i.e. – only those items requested were covered. Approximately 50 years ago, 'All Risk' (or perils) policies were introduced. These policies covered all perils – except those excluded. Flooding has always been excluded from residential policies. Wind Damage is one of the "Named Perils". Catastrophe Coverage includes Earthquake & Flood. For earthquake coverage, the deductible is the greater of 3% of value or $50,000. Sewer backup has a $2,500 deductible. "Mould", as a result of flooding, is excluded.

Two tenets of Insurance: 1) The premium is commensurate with the risk; 2) Losses of the few are paid by the many. Building insurance is generally carried to protect against 'Sudden and Accidental' events: i.e. – they cannot be predicted. The definition of an accident is: Something not expected and occurring at a point in time. Because CC is happening VERY slowly, damage caused by the gradual rise in sea level will probably not be covered by insurance.

Flooding is a huge issue with the insurance industry. For flooding – other than sewer backup or sprinkler malfunction – is covered by a separate policy. When asked to underwrite a policy, insurance companies do a risk assessment survey (questionnaire). Risk Assessment is based on past experiences, not level of water. This assessment includes questions such as: Is the property located on a flood plain? Does it have a history of flooding? (Truro and the Saint John River valley are examples of regions prone to flooding.) What are the physical attributes of the site? What is next door? Is it beside a lake, river, etc? One way of covering this uncertainty is to make the deductible much higher – $25,000-$100,000. Rising sea levels due to CC is inevitable and happening on a more-or-less predictable time scale, so it would not be covered. Extreme weather events – i.e. hurricanes – could cause storm surges, wind-blown waves, and ice floods. None of these events would normally be covered. Some locations on the southeast coast of the US cannot get flood insurance of any kind – mainly because of 2005's hurricane damage.

ING Insurance doesn't offer flood coverage for residential policies. Their general Commercial policies don't cover flooding either, but you can get a "Broad Form" Flood Extension 'rider'. It has an average $50,000 deductible for a $50/yr premium. Because of the high deductible, they have few claims. They determine the rate and coverage by Postal Code. Wind damage is also covered by BF-02: Form EO-23 – Flood Extension. Coverage is based on building and content value.

4.6 Emergency Management

4.6.1 Introduction

Developing emergency measures and preparedness plans and having available resources for emergency services may become paramount if climate change causes more extreme weather events. Natural disasters and extreme weather events have taxed our systems and resources and threaten lives. Within the emergency management field, there are four generally accepted phases of emergency activity: (1) preparedness; (2) response; (3) recovery; and (4) mitigation.

In Nova Scotia, events such as the Hurricane Juan in 2003 and the subsequent winter storm known as White Juan, left an indelible mark on many Nova Scotians. Storm surges along the Atlantic coast, have put stress on the public and have required agencies and utilities to revisit contingency plans in the face of these events. It is estimated that an average of $40 billion (US) in property damage has occurred worldwide due to natural disasters over the last 10 years. Although geophysical hazards (earthquakes, volcanic activity) contribute to this number, 80 percent of the impacts are weather related.

In Canada, natural hazards may include geophysical hazards such as earthquakes in many regions and extreme weather (tornadoes / hurricanes, heat waves/cold snaps, snow/ice storms, hail) causing hazards like storm surges, flooding, and drought. Although they may be unpredictable, the number of geohazards that occur have remained fairly constant (< 4 events per year) over the last one hundred years. Weather related events, on the other hand, have been increasing steadily for the last 60 years from 2-4 events per year to 8-16 events per year in the last two decades.

4.6.2 Agency Coordination and Responsibilities

At the federal, provincial and municipal levels, planning is the key to emergency preparedness through well established and tested emergency plan to ensure a prompt and co-ordinated response by responsible agencies in a time of an emergency. In Nova Scotia, a municipality is responsible for establishing an emergency response plan to potential risks. Input in the form of assistance – technical, monetary – may come from higher government departments and agencies and non-government institutions. The consequences of an emergency may be very localized, affecting a single person or only a small group of people. The impact may be broader, affecting a community, several communities, an entire municipal unit, the entire province, or even several provinces.

Federal Legislation and Responsibilities

In an emergency situation, federal responsibility (all departments and agencies) is governed by the Emergency Preparedness Act. The Act also allows for the development of programs to deal with emergency events. It recognizes the interests of the provinces, territories and municipalities in relation to federal assistance provided during a provincial emergency

Public Safety and Emergency Preparedness Canada (PSEPC) develops national policy, response systems and standards for emergency management in Canada. Timely alerts and similar products from PSEPC help protect Canada's critical infrastructure. Emergency management organizations across Canada are supported with funds, tools and training for emergency response.

The Joint Emergency Preparedness Program, established in 1980, helps to ensure that all levels of government across Canada are equally prepared to respond to emergencies response to all types of emergencies. PSEPC administers this program which provides funding and support to emergency preparedness and critical infrastructure protection projects and initiatives. Critical infrastructure consists of physical and information technology facilities, networks, services and assets that are critical to the well-being, operations and continuity of our country. Projects are jointly financed by federal, provincial and territorial governments, with the aim to reduce injuries and loss of human life, property damage, and to assure the continuation of our critical services in an emergency. For example, funds from the program have been used for training, the purchase of emergency response equipment, emergency planning and capacity building.

Provincial Legislation and Responsibilities

In Nova Scotia the *Emergency Management Act, 1990, c.8, s.2; 2005, c.48, s.1,* is the governing legislation dealing with emergency management and emergency powers legislation. The act creates and gives powers to the Emergency Management Office (EMO) to act on the government's behalf in an emergency, such as flooding or as in the case of the adverse storms that hit Nova Scotia in the fall and winter of 2003-04. The EMO's mission is to ensure the safety and security of Nova Scotians, their property and environment by providing for a prompt and coordinated response to an emergency. To that end they may approve, authorize and implement provincial and municipal emergency management plans; survey or study potential or actual hazards that may cause an emergency; conduct public information programs, facilities assessments and training programs; and procure goods and services of any nature for the purpose on an emergency.

The Emergency Management Office's work is intended to mitigate the effects of emergencies of any size or type. This is accomplished by providing assistance in planning before an emergency occurs, and by coordinating the provision of provincial resources when an emergency occurs and by assisting with analysis and evaluation after an emergency. EMO works at both provincial and municipal levels to ensure that Nova Scotian communities are protected by emergency response plans. The Office also administers the Emergency 911 Act which is the legislation for Nova Scotia's emergency telephone reporting system.

Municipal Legislation and Responsibilities (Annapolis Royal)

Each Nova Scotia municipality is required under the *Emergency Management Act,* to establish and maintain an emergency measures by-law, an emergency measures organization and appoint a coordinator, establish an advisory committee consisting of members of the municipal council, and prepare and approve an emergency measures plan. The act also outlines the powers and protection afforded police, peace officers and those who aid these groups that may fall under municipal jurisdiction.

The Town of Annapolis Royal has a *Regional Emergency Measures Bylaw* which outlines the responsibilities of Committees and Coordinators defined by structure of the Regional Emergency Measures Organization during a declared state of local emergency. A state of emergency is can be called by the municipality when the council is "satisfied that an emergency exists or may exist in all or any area of that municipality, declare a state of local emergency in respect of that municipality".
The By-law enables the REM Coordinator to prescribe necessary duties to be fulfilled by employees, servants and agents of the municipalities during a state of local emergency.

Agency Coordination – Current Practices

NGOs are primarily responsive, mobilizing after an emergency occurs, with emphasis on putting people at ease and assisting in the recovery aspects of emergency management. The core emergency services provided by NGOs include: financial donations, fund raising, provision of food and clothing, trauma and stress counseling, and long-term recovery assistance.

Chapter 5 Tools Tests

5.1 Introduction

In this chapter we test the tools developed or adapted to this project, by applying them in our two test case sites in south-western Nova Scotia: Annapolis Royal for coastal and interior flooding tools, as well as sustainable buildings; and the Pereau watershed for tools related to agricultural drought and residential water demand in an unserviced (no public water or sewers) watershed. For a complete description of the methodology used for the mathematical and engineering tools, see the Technical Appendix, which explains the methodologies in detail.

5.2 Climate Change Projections Test

5.2.1 Introduction

In this section we develop random weather models for temperature, wind, and precipitation. The models make use of past observed weather records to calibrate site specific weather characteristics (e.g. deterministic annual variation, residual variability, and day-to-day inter-dependence), and future climate trends are incorporated by using the output of global climate models (GCMs).

The proposed model involved first of all analyzing past data and deciding what distribution would best model the data. For example, precipitation was best modeled using a Markov Chain model for the sequence of dry and wet days, and a Weibull distribution was best to represent daily precipitation amounts. The "best fit" distributions were found by considering various alternatives and assessing their fit to the data using goodness-of-fit tests. The final proposed weather distribution models were calibrated by assessing the distribution parameters of the various climate parameters (e.g. temperature, precipitation, and wind speed) using past data.

Our choice of sites is constrained to those for which Environment Canada weather data are available and to those sites we believe are representative of our two test cases, Annapolis Royal and the Pereau Watershed in the Annapolis Valley. Greenwood, NS, was selected as representative of the Annapolis Valley because it is in the Valley and because Environment Canada has made daily precipitation and temperature records available from 1942 to 2003 (http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html). In addition, Environment Canada has recently posted hourly weather records at Greenwood extending back to 1953 (http://www.climate.weatheroffice.ec.gc.ca/climateData/hourlydata_e.html?timeframe=1&Prov=CA&StationID=6354&Year=2006&Month=12&Day=12). The hourly data is useful for extracting daily maximum (hourly averaged) wind speeds.

The weather records for Annapolis Royal include daily precipitation and temperature values (http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html) from 1914 to 2003. Unfortunately, no windspeed data were available for Annapolis Royal and so the windspeeds recorded at Brier Island (at the tip of Digby Neck) were used as a very conservative proxy (being at least representative of the windspeed felt over the Bay of Fundy, where storm surges are developed). (http://www.climate.weatheroffice.ec.gc.ca/climateData/hourlydata_e.html?timeframe=1&Prov=CA&StationID=10859&Year=2006&Month=12&Day=4)

At the time this weather research was being carried out (summer, 2006), Environment Canada's CGCM3 weather projections were unavailable, at least at the temporal resolution (i.e. daily) and for the weather types that we desired. However, the CGCM2 projections for temperature, wind, and precipitation were available in daily increments from 1961 to 2100 for both the A2 and B2 scenarios. For this reason, the CGCM2 projections are used in this study. The methodology set up here will remain valid for future GCM results – we need only modify the GCM related trend functions in the following weather models to reflect advances and improvements in global climate modeling.

The details of the following temperature, windspeed, and precipitation models are given in Appendix 5. In this section we summarize the results, discuss the relative merits and shortcomings of the models, give examples of their use, and discuss who should use the tools and how.

5.2.2 Daily Maximum and Minimum Temperatures

The predictive model (i.e. an equation that allows us to predict temperature) for the daily maximum (or minimum) temperature has three components:

1. a climate change, or trend, component which captures the change in the mean annual daily maximum (or minimum). In other words, how much is the mean annual temperature changing from year to year? This is the component that we can predict with a reasonable level of confidence in the future using the results of the Global Climate Models (GCMs).
2. an annual sinusoidal component that follows mean temperature changes over the seasons. This component can be estimated from past records.
3. a residual random component which characterizes natural daily temperature variability. The statistics of this component (e.g. variance and correlation structure) can be estimated from past records.

While the mean trend (item 1 above) in the future is reasonably predicted by the GCM, it will be assumed that the sinusoidal and random components (items 2 and 3) will be also applicable to the future even though these are estimated from the past. In other words, it will be assumed that the length of the year, the time at which the annual minimum and maximum mean temperatures occur, and the mean temperature amplitude (difference between the annual minimum and maximum temperatures) will remain the same in the future. Also, we are assuming that the daily temperature variability will not change in the future. Although the assumptions of constant mean temperature amplitude and daily variability are somewhat questionable, we have no predictive models capable of resolving the level of detail necessary to establish how these might change (note that although the GCM does predict a sinusoidal temperature variation in the future, it necessarily differs from the site specific temperatures because the GCM gives an average over a very large planet area which includes significant ocean moderation).

We propose the following model to represent daily temperatures in the past;

$$T(t) = b + c\left(t - t_o\right) + a\sin\left(2\pi t + \frac{\pi}{p}\right) + \varepsilon(t) \tag{5.1}$$

where t_o is the year in which past records begin and $b + c\left(t - t_o\right)$ is a linear trend fit to the past data.

The model proposed to represent daily temperatures in the future is quite similar, except that the linear trend given in Eq. (5.1) is replaced by at trend predicted by CGCM2, $\Delta G\left(t\right) + m_f$;

$$T(t) = \Delta G(t) + m_f + a\sin\left(2\pi t + \frac{\pi}{p}\right) + \varepsilon(t) \tag{5.2}$$

where:

- $T(t)$ is the (minimum or maximum) daily temperature on day t,
- m_f is the annual average (min or max) daily temperature estimated from observed temperatures at the beginning of the future period (e.g. 2006). For example, if the annual average temperature is estimated from historical records to have the linear form $m(t) = b + c\left(t - t_o\right)$, where t_o is the first year of the records, then if the future starts in 2006, then, m_f will be defined as $m_f = b + c\left(2006 - t_o\right)$.
- $\Delta G(t)$ is the amount that the GCM mean annual temperature in year t has changed from that projected at the beginning of the future period using the same GCM run over past years. Suppose that the first year of the future prediction is assumed to be 2006 and that GCM past predictions are available for the period from 1961 to 2006, and from the period from 2006 to 2100. The GCM past predictions would then be analyzed to fit a mean annual trend to the period from 1961 to 2006, say $d + e(t - 1961)$, and the future projections would be analyzed similarly for the period 2006 to 2100 to produce a trend, say $f + g(t - 2006)$. Then $\Delta G(t) = f + g(t - 2006) - \left[d + e(2006 - 1961)\right]$. Note that both the "hindcast" and "future" projected averages can be more complicated functions of t, so long as they don't descend below a temporal scale where the local site averages start to deviate significantly (in terms of variability) from the GCM scale averages. Probably a 10-year based average would be a reasonable minimum. One disadvantage to just using two linear trends is that the two trends will not predict the same temperature at the future starting time (e.g. 2006), so that there will be a small initial offset. However, this offset does result in the straight line of best fit to the future projections.
- a is the amplitude of the site specific annual sinusoidal temperature variation. We assume here that this is as specified by past records and will not change in the future (in any case, the GCM projections are unable to say anything about the site scale variability, so this is our "best guess" at this time).
- p is the phase angle parameter. Because peak summer and winter temperatures may occur at different times, on average, at inland and coastal locations, and over large scales, we must allow for changes in these peak locations. This parameter specifies the size of this phase change as a portion of π.
- $\varepsilon(t)$ is the *residual* daily temperature. This is a random variable having zero mean, standard deviation σ (assumed constant), and some temporal persistence specified by a temporal correlation function. $\varepsilon(t)$ captures the local variability of daily temperature at the site in question over and above that specified by the deterministic components that precede it in Eq's 5.1 and 5.2.

To employ Eq. 5.2 as a random temperature model for the future, we need to estimate m_f, a, p, and the random characteristics of the residual, $\varepsilon(t)$. We will do this by fitting Eq. 5.1 to past weather records, as shown in Figure 5.1. After removing the sinusoidal component and the mean trend, the residual is $\varepsilon(t)$, which has mean zero and some variability. Details regarding all of these estimates are given in the appendix.

To use Eq. 5.2 in a risk assessment, we must be able to answer questions such as, what is the probability that the maximum daily temperature on July 12, 2080 in Greenwood, NS, will exceed 36 °C? To compute this probability, we first need to determine what t corresponds to July 12, 2080. Since 2080 is a leap year, July 12 is the 193'rd day of the year, so that $t = 2080 + 193.5/366 = 2080.5287$ (assuming we are computing for 12 noon on that day). According to Eq. 5.12 of the appendix, the mean temperature at that time is predicted to be:

$$\mu_T = 11.949 + 0.04499(2080.5287 - 2006) + 11.9\sin\left(2\pi(2080.5287) - \pi/1.6\right)$$
$$= 26.93\ ^\circ\mathrm{C}$$

where we include all terms except the mean zero random $\varepsilon(t)$ term. The appendix tells us also that the random component of the maximum daily temperature is normally distributed with mean given above and standard deviation $4.98\ ^\circ\mathrm{C}$. The probability we are looking for is thus

$$\mathrm{P}\left[T > 36\right] = 1 - \Phi\left(\frac{36 - 26.93}{4.98}\right) = 1 - \Phi\left(1.82\right) = 0.034$$

If the maximum temperatures on each day were independent, then this result would tell us that out of 100 similar days (e.g. the July days in 2079, 2080, and 2081) we would expect 3 or 4 of them to have maximum daily temperatures exceeding 36 °C. However, since daily temperatures are not independent, the 'hot' spells may extend for much longer periods of time. The model given in Appendix 5.2.3 allows us also to estimate probabilities relating to durations of 'hot' spells.

5.3.3 Maximum Daily Windspeeds

Maximum daily windspeeds will be assumed to be lognormally distributed and predicted by (the equation numbers correspond to those given in Appendix 5.2.3);

$$\ln W(t) = c_w + b_w\left(t - t_o\right) + a_w \sin\left(2\pi t + \pi / p_w\right) + \varepsilon_w(t) \tag{5.25}$$

Future windspeeds will be predicted by assuming that mean windspeed changes in the GCM will be seen in the site specific mean windspeeds. Our prediction equation for the future becomes

$$\ln W(t) = \Delta G_w(t) + m_w + a_w \sin\left(2\pi t + \frac{\pi}{p_w}\right) + \varepsilon_w(t) \tag{5.26}$$

where

- m_w is the annual average daily maximum log-windspeed estimated from observed windspeeds at the beginning of the future period (e.g. 2006). For example, if the annual average daily maximum log-windspeed is estimated from historical records to have the linear form $m(t) = b + c\left(t - t_o\right)$, where t_o is the first year of the records, then, if the future starts in 2006, m_w will be defined as $m_w = b + c\left(2006 - t_o\right)$.
- $\Delta G_w(t)$ is the amount that the GCM mean annual daily windspeed in year t has changed from that projected at the beginning of the future period using the same GCM run over past years. Suppose that the first year of the future prediction is assumed to be 2006 and that GCM past predictions are available for the period from 1961 to 2006, and from the period from 2006 to 2100. The GCM past predictions would then be analyzed to fit a mean annual trend to the period from 1961 to 2006, say $d + e(t - 1961)$, and the future projections would be analyzed similarly for the period 2006 to 2100 to produce a trend, say $f + g(t - 2006)$. Then $\Delta G_w(t) = f + g(t - 2006) - \left[d + e(2006 - 1961)\right]$. Note that both the "hindcast" and "future" projected averages can be more complicated functions of *t*, so long as they don't descend below a temporal scale where the local site averages start to deviate significantly (in terms of variability) from the GCM scale averages. Probably a 10-year based average would be a reasonable minimum. One disadvantage to just using two linear trends is that the two trends will not predict the same mean log-windspeed at the future starting time (e.g. 2006), so that there will be a small initial offset. However, this offset does result in the straight line of best fit to the future projections.
- a_w is the amplitude of the site specific annual sinusoidal log-windspeed variation. We assume here that this is as specified by past records and will not change in the future (in any case, the GCM projections are unable to say anything about the site scale variability, so this is our "best guess" at this time).
- p_w is the phase angle parameter. Because peak summer and winter windspeeds may occur at different times, on average, at inland and coastal locations, and over large scales, we must allow for changes in these peak locations. This parameter specifies the size of this phase change as a portion of π.

- $\varepsilon_w(t)$ is the *residual* daily maximum log-windspeed. This is a random variable having zero mean, standard deviation σ_w (assumed constant), and some temporal persistence specified by a temporal correlation function. $\varepsilon_w(t)$ captures the local variability of daily windspeeds at the site in question over and above that specified by the deterministic components that precede it in Eq's 5.25 and 5.26

The appendix gives all of the windspeed model details. Probabilities associated with windspeeds can be found similarly as with the temperatures in the last subsection. So, for example, if we are interested in computing the probability that the maximum windspeed on July 12, 2080 in Greenwood, NS, will exceed 80 km/hr, we make use of all but the $\varepsilon_w(t)$ term in Eq. 5.33 (again, $t = 2080 + 193.5/366 = 2080.5287$).

$$\begin{aligned}\mu_{\ln W} &= 3.1963 - 0.0004175(2080.5287 - 2006) + 0.1186\sin\left(2\pi(2080.5287) + \pi/3.4\right)\\ &= 3.05926\end{aligned}$$

The appendix tells us also that the random component of the maximum daily log-windspeed is normally distributed with mean given above and standard deviation 0.3749.. The probability we are looking for is thus

$$\begin{aligned}\mathrm{P}\left[W > 80\right] = \mathrm{P}\left[\ln W > \ln 80\right] &= \mathrm{P}\left[Z > \frac{\ln 80 - \mu_{\ln W}}{\sigma_{\ln W}}\right]\\ &= 1 - \Phi\left(\frac{\ln 40 - 3.05926}{0.3749}\right) = 1 - \Phi\left(1.68\right) = 0.046\end{aligned}$$

Using the distribution given in the Appendix, we can also use a type II extreme value distribution to estimate the probability that the maximum annual windspeed in 2080 will exceed a certain amount.

5.2.4 Daily Precipitation

Precipitation is the hardest to model, both statistically and numerically (e.g. via the GCMs). One significant problem is that days are divided into 'dry' days and 'wet' days, meaning that probabilistically, precipitation is a mixture of a Bernoulli trial (dry vs. wet) and a continuous distribution governing the amount of rainfall occurring on that day, should it be 'wet'. We have developed a Markov Chain model (a generalization of the Bernoulli trial), which governs the sequence of dry vs. wet days, combined with a Weibull distribution for rainfall amounts on wet days. As shown in Appendix 5, the model is extremely successful at representing both past observations and future projections. We can relatively easily predict the probability of a drought or wet-spell exceeding a certain length with this model. In fact, the random models developed in the Appendix can be used to answer most probabilistic questions regarding past and future precipitation issues.

Another significant problem with precipitation is that if we are to divide days into 'dry' and 'wet' days, we need to decide what constitutes a 'dry' day. As an extreme example, the CGCM2 gives average daily precipitation over a 300 by 420 km grid cell. As can be expected, this average is very rarely exactly zero, even in the midst of an ongoing drought so long as at least one (computed) rain-drop falls somewhere in this region. Thus, according to CGCM2 there are hardly any droughts, even if the rainfall amounts in a particular location lead to crop failures.

A discussion of the minimum significant daily rainfall amounts with farmers in the Annapolis Valley led to the conclusion that any daily rainfall amount under 0.5 mm was deemed to be insignificant from the point of view of a crop and so the following analysis will assume that daily rainfall amounts less than 0.5 mm will be consider to be 'dry' days.

So far as farmers in the Annapolis Valley are concerned, the lengths of droughts in the future are of concern. If N_d is the number of 'dry' days in a row (i.e., the drought length), then Eq. 5.43 gives us its distribution. Suppose that we want to find the 100-year return period drought length, k_{100}, which has a probability of 0.01 of occurring in any one year, for the projected future Greenwood, NS (2061 – 2100). One hundred years consists of 36,500 days, so we are looking for k_{100} such that

$$\mathrm{P}\left[N_d = k_{100}\right] = p_d\, p_{11}^{k_{100}-1} = \frac{1}{36,500}$$

which can be solved for k_{100} as follows:

$$k_{100} = 1 - \frac{\ln\left(36500\, p_d\right)}{\ln\left(p_{11}\right)} = 1 - \frac{\ln\left(36500 \times 0.0707136\right)}{\ln\left(0.65376\right)} = 19.5 \text{ days}$$

In other words, the 100-year return period drought length in Greenwood during the second half of this century is almost 20 days. Note that in the above, we used the combined summer and winter statistics. Note also that other return period drought lengths are easily computed simply by changing the number of days corresponding to the drought length. The corresponding 100-year return period drought length during summers in Greenwood in the period from 2061 – 2100 (which is probably of more interest) is obtained by using the summer statistics and noting that the number of summer days in 100 years is 36500/2,

$$k_{100} = 1 - \frac{\ln\left(36500\, p_d / 2\right)}{\ln\left(p_{11}\right)} = 1 - \frac{\ln\left(18250 \times 0.05435\right)}{\ln\left(0.71528\right)} = 21.6 \text{ days}$$

We note that the same Markov Chain model can be used to compute the lengths of 'wet' spells having certain return periods. Exceedingly long 'wet' spells are also of concern to farmers since this may also lead to crop failure (for example, due to root rot, or soil erosion, etc.).

The amount of rainfall received during a 'wet' day is well modeled using a Weibull distribution, as illustrated in the Appendix. For example, Eq. 5.37 can be used to estimate the probability that a wet summer day in Greenwood, NS, during the years 2061 – 2100 will have rainfall amount exceeding 30 mm as follows

$$\mathrm{P}\left[P > 30\right] = \exp\left(-\left(30\lambda\right)^{\beta}\right) = \exp\left(-\left(30 \times 0.1727\right)^{0.7108}\right) = 0.04$$

Where the distribution parameters were obtained from Eq. 5.62.

From the point of view of recharging aquifers, we are often interested in total amounts of rainfall over longer periods of time, e.g. a month. For example, if X_{30} is the total precipitation amount over a 30 day period during the summer in Greenwood in the future (2061 – 2100), then X_{30} is approximately normally distributed and we can compute the probability that this total rainfall amount is less than, say, 20 mm,

$$\mathrm{P}\left[X_{30} < 20\right] = \mathrm{P}\left[Z < \frac{20 - \mu_X}{\sigma_X}\right] = \Phi\left(\frac{20 - 30\left(1 - p_{dry}\right)\mu_p}{\sigma_p\sqrt{30\left(1 - p_{dry}\right)}}\right) = \Phi\left(\frac{20 - 30(1 - 0.6749)(7.8984)}{9.9169\sqrt{30(1 - 0.6749)}}\right)$$
$$= \Phi\left(-1.84\right) = 0.032$$

In other words, if we assume that 30 days constitutes a month, then this result is saying that, on average, once every $1/0.032 \approx 30$ summer months we will have a month with total rainfall amount less than 20 mm. Monthly precipitation quantiles for Greenwood are listed in Appendix 5.2.3.

5.2.5 Conclusion

The tools given in Appendix 5.2.3 and discussed above allow land use planners to assess the likelihoods of certain climate outcomes. The future predictions are only as good as the GCM results on which the statistics (particularly the mean) are based. It is expected that as the GCMs improve over the next few decades, the better mean predictions will replace those used in Appendix 5.2.3 to yield better estimates of the future statistics. The tools also employ the following fundamental assumptions:

1. the site-specific weather variance (and correlation structure) will remain unchanged in the future – this is our best available estimate at this time,
2. because the GCM results are averages over a GCM grid cell, the GCM results are believed to reflect mean weather changes at a specific site,
3. daily precipitation amounts on wet days are assumed independent.

Now that we have developed and tested this model, we could use it to project climate change at a new site in about two days. However, it would take someone unfamiliar with the model considerably longer. Utility of the model also depends on whether Environment Canada has a weather station with regular records near the site.

Risk assessments must involve stochastic climate models at some point. For example, in order to compute probabilities associated with the climate, the distribution of the climate must be known. Even if statistical downscaling (e.g. SDSM) is used to create weather scenarios at a site of interest, the weather scenario must then be used to somehow specify the mean, variance, and other parameters of a climate distribution in order to then compute the desired probabilities. Since this is not generally possible with common statistical downscaling tools, the stochastic climate model was adopted in this project to model future climates, and the risks associated with them, in the Annapolis Valley region. This stochastic model has the added advantages of needing only a personal computer for the calculations, using readily obtainable weather data from Environment Canada (without need of the more difficult to obtain physical parameters, e.g., barometric pressures), and can be run by a person familiar with statistics. Thus, if municipalities want to down-scale global climate change models to their community and assistance from the federal government is not available, they can hire a consultant or use their municipal engineers to run the model themselves, with assistance from the model's author, Dr. Gordon A. Fenton, to obtain climate change data that is tailored to their community. Dr. Fenton can be reached by e-mail at: Gordon.Fenton@dal.ca mailto:Gordon.Fenton@dal.ca.

5.3 Flood Risk Mapping Test

5.3.1 Summary

Many coastal communities in Canada are at risk to flooding from storm-surge events. A storm-surge is an increase in the ocean water level above what is expected from the normal tidal level that can be predicted from astronomical observations. Storm surges are caused by the winds and low pressure of atmospheric storms. Global sea-level rise, as predicted by climate change models, will increase this problem making more coastal areas vulnerable to flooding. A set of tools that can be applied within a Geographic Information System (GIS) have been developed to assist coastal municipalities identify areas at risk from coastal flooding as part of this project.

Communities around the Bay of Fundy, including Annapolis Royal, are vulnerable to coastal flooding from storm-surge events of the past including the Saxby Gale of 1869 and the more recent Groundhog Day storm on Feb. 2, 1976. Newspaper articles from the Annapolis Co. Spectator describe the flooding in Annapolis Royal by the Groundhog Day storm and eye witnesses have described the spatial extent of the flooding in the area. Unfortunately neither the Annapolis Royal nor the Digby tide gauge was operating during this storm and could not be used to assess the height of the storm-surge. However, water levels from the tide gauge at Saint John, New Brunswick, nearly directly across the Bay of Fundy were used to determine the height of the storm surge during this event. The storm-surge level determined at Annapolis Royal is within 40 cm of that estimated in St. John. This storm provides us with a benchmark of the flooding that can occur in the region under current water levels and climate conditions.

In order to incorporate climate change effects into the model we increased the sea-level by 80 cm over the next 100 years, and determined the flood extent of the same storm if it occurs in the next century. The relative sea-level rise estimate of 80 cm in the next century is a combination of global sea-level rise taken to be 50 cm, local crustal subsidence of 20 cm, and an increase in the tidal amplitude taken to be 10 cm.

The application of LIDAR (Light Detection and Ranging) to construct high-resolution digital elevation models (DEM) to build flood inundation maps for given water levels from storm surges and longer term sea-level rise. This remote sensing technique involves an aircraft equipped with a laser rangefinder that shoots pulses of light towards the earth, and by measuring the two way travel time, determines the distance or range from the aircraft to the earth’s surface. By knowing the precise location of the aircraft by GPS and the distance to the earth’s surface, land elevations can be determined. The LIDAR measures the earth’s surface every 1-2 m on the ground with vertical accuracies within plus or minus 0.15 m.

We have calculated return periods of the Groundhog Day storm and water levels for return periods of 50, 100, 150, and 200 years based on 40 years of water level records from St. John, NB. Because it has one of the longest water level records (via a tide gauge) in the region. A software package developed at the Nova Scotia Community College, Applied Geomatics Research Group known as the “Water Modeler” was used to analyze the observed water level records and calculate water level probabilities and return periods. The approach taken calculates empirical annual probabilities of exceedance of a given water level and allows a model to be constructed for the prediction of

probabilities with relative sea-level changes incorporated to simulate possible climate change effects. The probability statistics are based on the “peak over threshold method”.
In order to evaluate the relationship of water levels observed in St. John with those in the Annapolis Basin, the tide gauge water level record were examined for Annapolis Royal, Digby, and St. John to find times when all three sites were operating simultaneously. Unfortunately there is no time in the past when this condition is met; however in 1970 Digby and St. John were operating simultaneously for three months (Jan.-March). These water level records were downloaded and analyzed in order to estimate how similar the two sites are (Digby and St. John), in order to give some estimates on using the long term water level predictions at St. John in the Annapolis Basin. Generally the storm-surges observed in St. John are observed in Digby nearly concurrently. This is not surprising, considering the scale of the weather systems (low pressure and associated wind) that drive storm-surges. The mean of storm-surge levels in St. John are 1 cm higher than observed in Digby, although there is a high degree of variability as indicated by a standard deviation of surge levels of 39 cm, thus water levels calculated at St. John should be considered as estimates of water levels in Annapolis Basin within 40 cm.

The Groundhog Day storm in Annapolis Royal had a predicted high tide water level of 4.1 m with an estimated maximum increased water level (storm-surge & wave setup) between 5.2 and 5.6 m based on flood extents described by eye witness and newspaper reports. This corresponds to a storm-surge and wave setup of up to 1.5 m. This level floods some key areas including the road near the former location of the Tourist Bureau, lower George Street and over tops the governments wharf. The observed high water level of 4.95 m during the Groundhog Day storm in St. John resulting in a 1.28 m storm-surge. Based on the St. John observed water level records, the current relative sea level (RSL) rise rate is 22 cm per century and the expected RSL rise in the next century due to climate change impacts is 80 cm. The cumulative flood probabilities were plotted for the Groundhog Day storm in St. John using these two relative sea level (RSL) rise rates. The water levels expected for return periods of 50, 100, 150, and 200 years at variable RSL rates for St. John were also calculated. Flood inundation maps were constructed for the water levels presented above to show what is vulnerable to coastal flooding in the future if sea-level rises as predicted or if storm-surges raise the sea-level during storms.

Several new tools were employed in mapping areas at risk to flooding near Annapolis Royal under future climate change effects (storm surge and se level rise). A new remote sensing technology, known as LIDAR (Light Detection and Ranging) was used to construct high-resolution digital elevation models (DEM) in order to build flood inundation maps for given water levels from storm surges and long term sea-level rise. This technique generates elevation models with sufficient quality to accurately predict low-lying areas vulnerable to raised water levels of 1-2 m. Another new tool employed in this study is the “Water Modeler” software package developed at the Nova Scotia Community College, Applied Geomatics Research Group that was used to analyze the observed water level records from a tide gauge and calculate the return periods and probabilities of raised water levels associated with storms and sea-level rise. Currently, there are limited tools for planners to determine return periods of raised water levels and this in an area of active research. We utilized research conducted by Bernier and Thompson of Dalhousie University to compare with the results of the water modeler tool. The Dalhousie study focused on validating their storm surge model and smoothed the hourly water level records to a 6 hour period, thus under estimating some short lived weather events such as hurricanes. It is for this reason that we have used the results of the new “Water Modeler” software for determining the return periods of water levels associated with the Groundhog Day storm and other levels projected in the future with climate change.

5.3.2 Flood Extent of the Groundhog Day Storm in 100 Years

Many coastal communities in Canada are at risk to flooding from storm-surge events. A storm-surge is an increase in the ocean water level above what is expected from the normal tidal level that can be predicted from astronomical observations. Storm surges are caused by the winds and low pressure of atmospheric storms. Global sea-level rise, as predicted by climate change models, will increase this problem making more coastal areas vulnerable to flooding. A set of tools that can be applied within a Geographic Information System (GIS) have been developed to assist coastal municipalities identify areas at risk from coastal flooding as part of this project.

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In order to incorporate climate change effects into the model we increased the sea-level by 80 cm over the next 100 years, and determined the flood extent of the same storm if it occurs in the next century. The relative sea-level rise estimate of 80 cm in the next century is a combination of global sea-level rise taken to be 50 cm, local crustal subsidence of 20 cm, and an increase in the tidal amplitude taken to be 10 cm.

The application of LIDAR (Light Detection and Ranging) to construct high-resolution digital elevation models (DEM) to build flood inundation maps for given water levels from storm surges and longer term sea-level rise. This remote sensing technique involves an aircraft equipped with a laser rangefinder that shoots pulses of light towards the earth, and by measuring the two way travel time, determines the distance or range from the aircraft to the earth's surface. By knowing the precise location of the aircraft by GPS and the distance to the earth's surface, land elevations can be determined. The LIDAR measures the earth's surface every 1-2 m on the ground with vertical accuracies within plus or minus 0.15 m.

We have calculated return periods of the Groundhog Day storm and water levels for return periods of 50, 100, 150, and 200 years based on 40 years of water level records from St. John, NB. Because it has one of the longest water level records (via a tide gauge) in the region. A software package developed at the Nova Scotia Community College, Applied Geomatics Research Group known as the "Water Modeler" was used to analyze the observed water level records and calculate water level probabilities and return periods. The approach taken calculates empirical annual probabilities of exceedance of a given water level and allows a model to be constructed for the prediction of probabilities with relative sea-level changes incorporated to simulate possible climate change effects. The probability statistics are based on the "peak over threshold method".

In order to evaluate the relationship of water levels observed in St. John with those in the Annapolis Basin, the tide gauge water level record were examined for Annapolis Royal, Digby, and St. John to find times when all three sites were operating simultaneously. Unfortunately there is no time in the past when this condition is met; however in 1970 Digby and St. John were operating simultaneously for three months (Jan.-March). These water level records were downloaded and analyzed in order to estimate how similar the two sites are (Digby and St. John), in order to give some estimates on using the long term water level predictions at St. John in the Annapolis Basin. Generally the storm-surges observed in St. John are observed in Digby nearly concurrently. This is not surprising, considering the scale of the weather systems (low pressure and associated wind) that drive storm-surges. The mean of storm-surge levels in St. John are 1 cm higher than observed in Digby, although there is a high degree of variability as indicated by a standard deviation of surge levels of 39 cm, thus water levels calculated at St. John should be considered as estimates of water levels in Annapolis Basin within 40 cm.

The Groundhog Day storm in Annapolis Royal had a predicted high tide water level of 4.1 m with an estimated maximum increased water level (storm-surge & wave setup) between 5.2 and 5.6 m based on flood extents described by eye witness and newspaper reports. This corresponds to a storm-surge and wave setup of up to 1.5 m. This level floods some key areas including the road near the former location of the Tourist Bureau, lower George Street and over tops the governments wharf. The observed high water level of 4.95 m during the Groundhog Day storm in St. John resulting in a 1.28 m storm-surge. Based on the St. John observed water level records, the current relative sea level (RSL) rise rate is 22 cm per century and the expected RSL rise in the next century due to climate change impacts is 80 cm. The cumulative flood probabilities were plotted for the Groundhog Day storm in St. John using these two relative sea level (RSL) rise rates.

Orthometric height (m) CGVD28 (4.19 m above CD)	Return Period (Years) Absolute Probability (1.00)	Return Period (Years) Average Prob./most likely
4.95 m Groundhog Day Storm (RSL = 0.22 cm/yr)	121	43
4.95 m Groundhog Day Storm (RSL = 0.80 cm/yr)	55	23

The water levels expected for return periods of 50, 100, 150, and 200 years at variable RSL rates for St. John were also calculated and presented in the table below.

Return Period (Years)	Water level elevations on land (m)	Relative Sea level Rise (RSL) = 0.0 cm/yr	RSL = 0.22 cm/year (observed rate)	RSL = 0.36 cm/year (Desplanque & Mossman, 1999)	RSL = 0.80 cm/year (climate change)
50		4.6	4.7	4.7	4.9
100		4.7	4.8	4.9	5.3
150		4.8	5.0	5.1	5.7
200		4.8	5.1	5.3	5.7

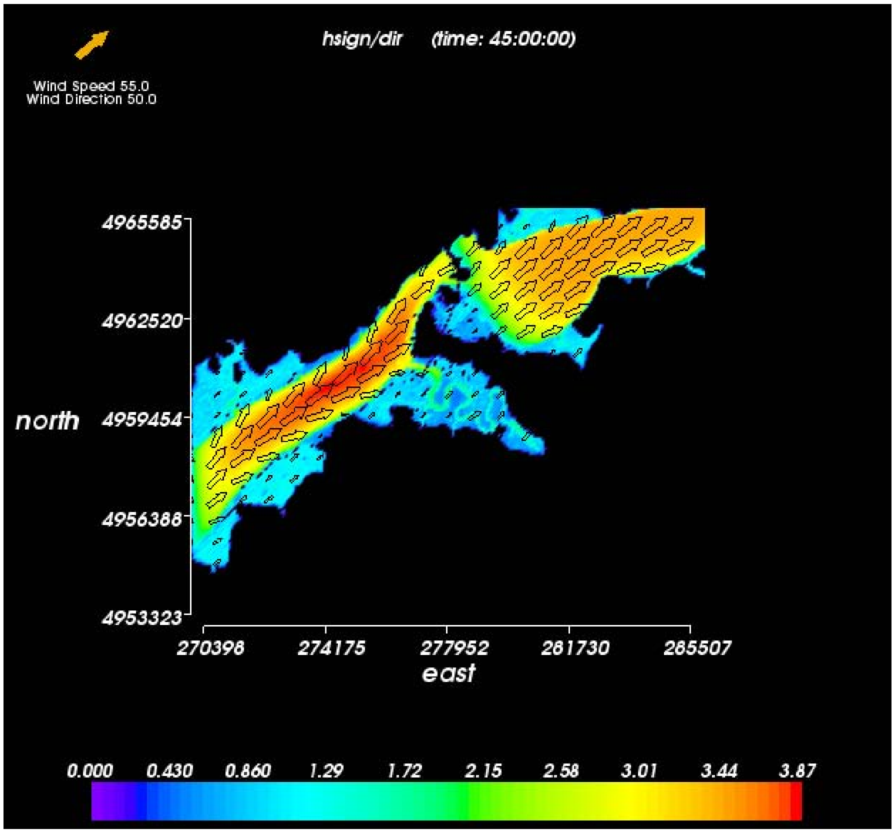


Figure 5.1 Result from the SWAN wave model. *Model generated for winds from Greenwood weather station Feb 1-3, 1976. Bathymetry and land elevation (from LIDAR) merged and water level set to 5 m orthometric height, which represents the predicted tide and a 1 m storm surge. The direction and size of the arrows represent the significant wave direction and magnitude.*

Flood inundation maps were constructed for the water levels presented above to show what is vulnerable to coastal flooding in the future if sea-level rises as predicted or if storm-surges raise the sea-level during storms. Because of the uncertainties involved with predicting water levels in Annapolis Royal, in part because of the lack of long term water level records, flood inundation areas have been calculated for every 10 cm increment in water level from -4.4 m to 8.8 m to cover all possible reasonable conditions in the future.

If we take the Groundhog Day storm and assume a high water level of 5.4 m (median of estimated range 5.2 – 5.6 m), then the same storm in 100 years with an assumed RSL of 88 cm would reach a level of 6.3 m. This level could be even higher if such a storm occurred on a higher tide than occurred in Feb. 1976. For example, the current highest predicted astronomical tide is 4.97 m without any storm surge and in 100 years will be 5.85 m at a RSL rate of 0.8 cm per century, thus a storm surge of 1.3 m would result in a worse case high water level of 7.15 m.

5.3.3 Wave Model

The results of the wave modeling for the Groundhog Day for Annapolis Royal show that significant wave were generated in the Annapolis Basin that impacted the shoreline. The water level used for this run corresponded to an orthometric height of 5 m which represents the occurrence of the highest astronomical tide or the Groundhog Day storm predicted tide (4 m) plus a conservative 1 m storm surge. The modeled significant wave height along the shore of Annapolis Royal was approximately 2 m, with the largest waves occurring in the channel, calculated to have peak heights greater than 3 m (Figure 14). When the water level is set to 5 m, much of the low lying area landward of the dykes are flooded and waves generated. This model does not consider connectivity of the basin to low lying areas separated by dyke structures. Thus the wave heights landward of the dykes should not be considered to be accurate because according to our flood inundation mapping, the dykes on the east and west side of the basin southwest of Annapolis Royal were not overtopped by a 5 m water level.

5.3.4 Conclusions

Annapolis Royal is vulnerable to storm surges and sea level rise. Although the Bay of Fundy has some of the largest tides in the world and the probabilities of a significant storm surge occurring on a high tide may be lower than some other regions of the Maritimes, past events such as the Groundhog Day storm of 1976 proof that this region is not immune to such events. Climate change will impact sea levels on a global scale and the local crustal conditions in this region will add to the problem as a result of subsidence, thus increasing the relative sea level rise. Currently the lower sections of the town particularly lower George St. near Kings Theatre and the government wharf, experience flooding at extreme high tide events in the absence of storms. When storm surges and high winds and waves occur with higher than usual tides, this area of the town is most vulnerable to flooding. The occurrence of these extreme high tides can be predicted based on astronomical conditions. The most significant high tides occur on Soras cycles, of which the most famous storm to cause coastal flooding in the Bay of Fundy region occurred; the “Saxby Gale” of 1869. The predicted water level at Annapolis Royal during the next Soras cycle will peak at 9.14 m CD (4.75 m orthometric) on May 7, 2012. Other time periods where the predicted water level will be above 9 m CD occur at April 8-9, May 6-7, June 5, Oct. 16, Nov. 14-16, and Dec. 14-15.

If coastal development is planned to take place in any of the regions that were impacted during the Groundhog Day storm, or only decimeters above this elevation (e.g. 5.2 – 5.6 m), then significant protective structures such a dykes must be constructed to prevent water from basin or Annapolis River from flooding these areas.

The tools that have been employed for this case study should be transferable to other coastal locations. The main requirements are a detailed elevation model, accurate to 30 cm in height and water level records from a local tide gauge. If detailed elevation data do not exist for the coastal zone, then a LIDAR survey could be carried out. For an area of similar size to the Annapolis Royal site a LIDAR survey could be carried out in 1 day with the processing and separation of LIDAR points into ground and non-ground targets done within 1 month. A Geographic Information System (GIS) could then be used to process the LIDAR points into different surface models representing the terrain (e.g. DEM) that will be used to generate the flood risk areas. This could be accomplished within 1 week. Ideally the tide gauge information represents decades of water levels close to the area of interest. The tide gauge water levels can be read into “Water Modeler” and the past sea-level rise rate calculated along with the return periods of high-water events. In addition to past events, one can also calculate the return periods of water levels in the future under different sea-level rise rates. Once familiar with the software this could be accomplished within 1 week. Based on the analysis of water levels and return periods, specific areas at risk to flooding can be mapped for the terrain model for further impact and adaptation actions. The flood risk mapping could be done in 1 week.

5.4 Inland Flooding Analysis Test

5.4.1 Application of Flood Routing Tools

The Allains River drainage basin, located to the immediate south of the Town of Annapolis Royal, was selected as a test case for our flood routing analysis. Drainage area for the inlet of Allains River is 63.15 km^2. An additional drainage area of 19.43 km^2 is obtained by routing the flow through the river to the outlet of Allains Creek at Annapolis River.

Drainage starts at the inlet of Baillie Lake and Cranberry Lake. The flow runs from these two lakes to Grand Lake through Baillie Lake Brook. Additional tributaries are obtained from Beelers Lake and Little Grand Lake. Grand Lake drains into Grand Lake flowage which has tributaries of Skull Lake and Saunders Brook. From Grand Lake Flowage, drainage enters Allains River, then routes through Allians Creek which outlets flow at the Annapolis River. A map of the drainage basin is attached.

Allains River drainage basin is approximately 21 km long with an average width of 4 km and has a perimeter of 51km. Elevations at the inlet and outlet are approximately 200m and 5m, respectively. Slope of the watershed is 0.93%. The basin is composed of 76.25 km^2 of forest, 5.66 km^2 of lakes and 0.68 km^2 of swamps which totals 92.3% forest, 6.9% lakes and 0.8% swamps. From aerial photography, there is no farmland located within the watershed. Total length of all streams is estimated as 72.9 km, while the length of the main divide measures 24.2 km.

Total estimated annual precipitation for the area is 1275mm (NBC) and the mean annual runoff is 800mm (MacLaren). The drainage density of the watershed is 0.88 km/km^2 with a circulatory ratio of 1.59. The estimated curve number is 62, assuming an average antecedent moisture condition, with a combination of soil groups B and C, and estimating that the forested area is in a fair condition.

Flood EstimatingTools

Flood estimating was performed through the use of two methods: SCS Unit Hydrograph technique and the Index Flood Method (IFM). Using the relationships of the SCS method the following parameters were estimated for the Allains River Basin.

Figure 5.2 SCS Parameters

t_l	16.0	hours	*Catchment Lag Time*
t_p	17.8	hours	*Time-to-peak*
t_r	3.6	hours	*Effective rainfall duration*
t_c	26.7	hours	*Time-of-concentration*
T_b	88.9	hours	*Unit hydrograph base time*
Q_p	9.66	m^3/s	*Unit hydrograph peak flow for 1cm of effective rainfall*

Figure 5.3 Allains River Map

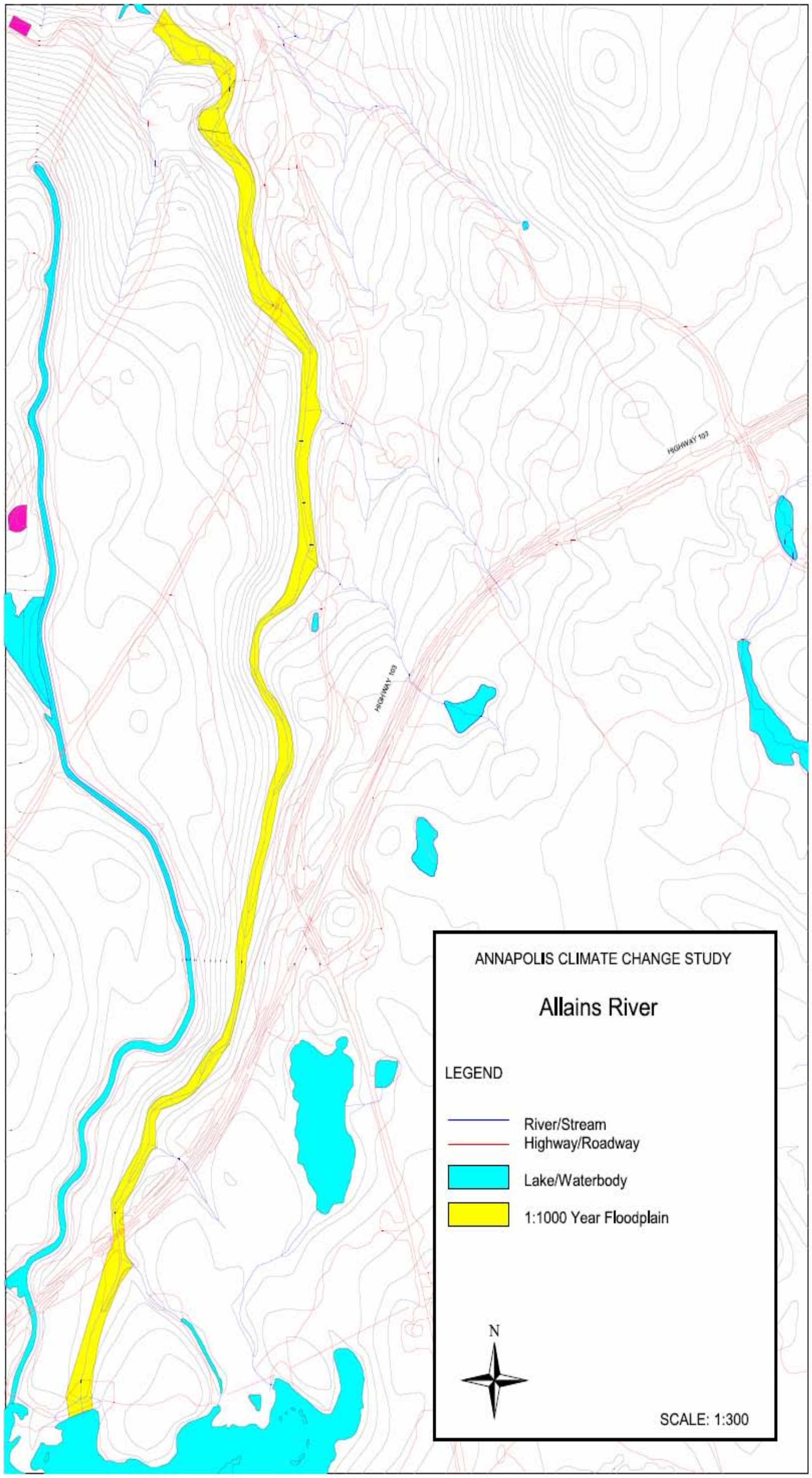
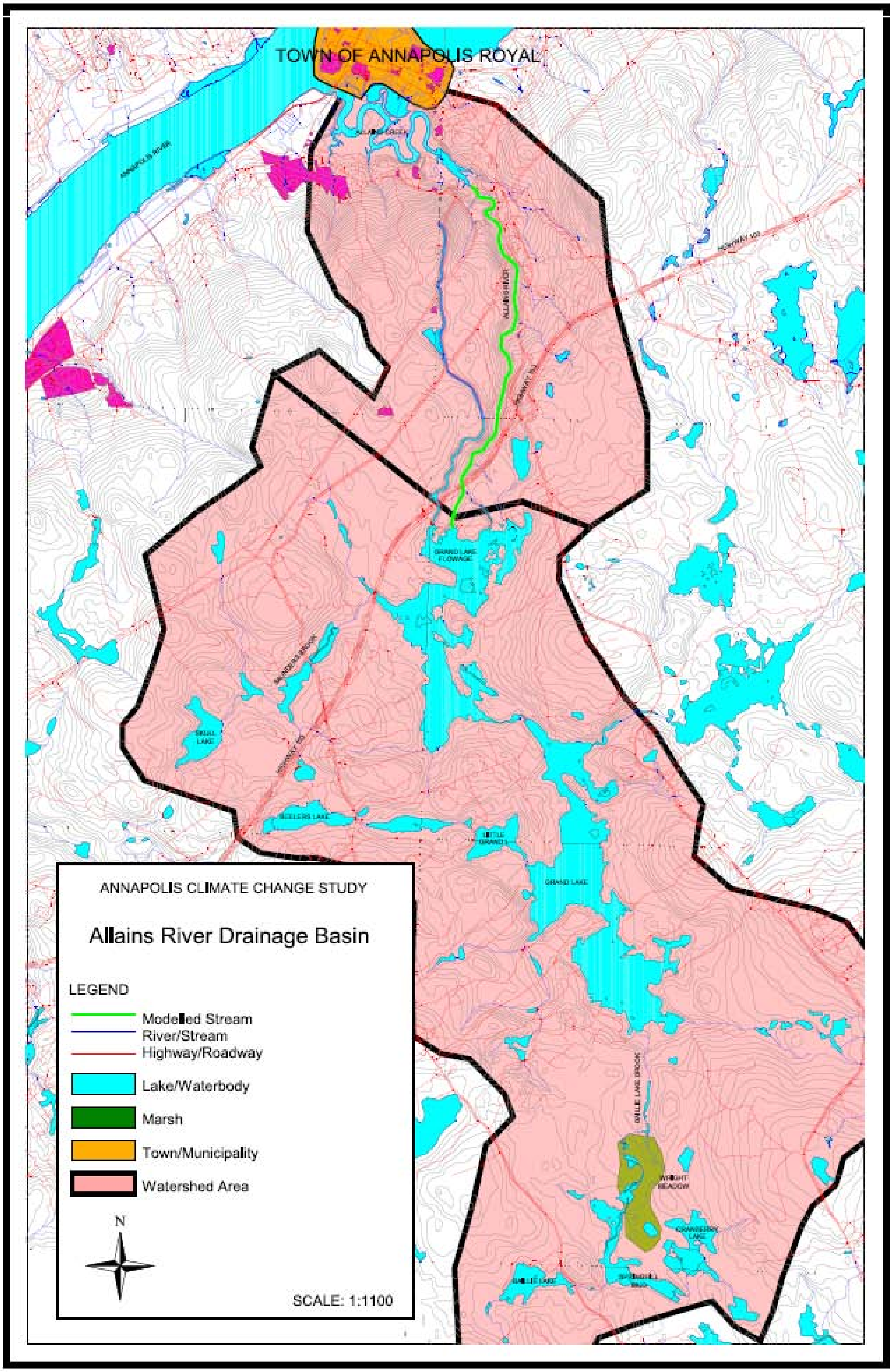
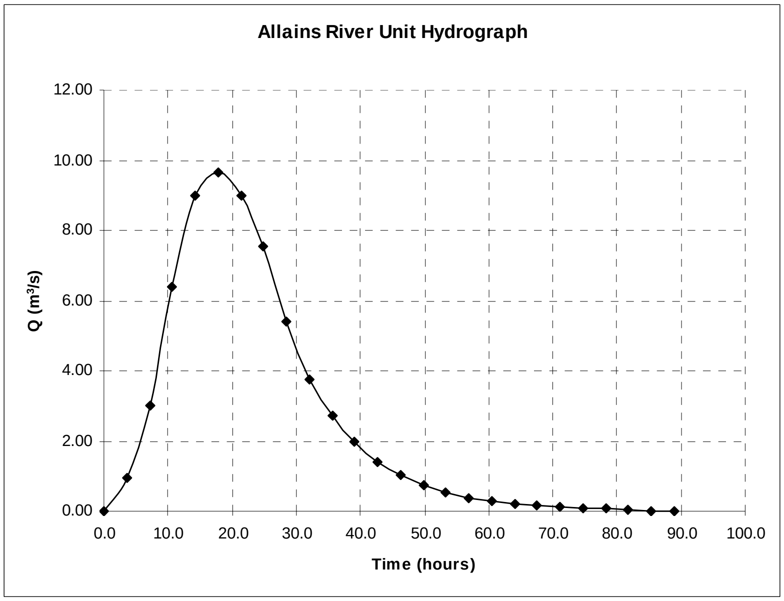


Figure 5.4 Allains River Watershed Map



Using the table above for SCS unit hydrograph ordinates, the unit hydrograph was constructed.

Figure 5.5 Allains River Unit Hydrograph



The IFM was used to estimate peak flood flows for the watershed. Based on the area of the drainage basin, the average flood flow was estimated as 28 m^3/s using the mean annual flood equation. Index factors of 1.6, 2.33, 2.68 and 4.11 were estimated for the 1/10, 1/50, 1/100, and 1/1000 year storm from the regional frequency curve. The following table presents the flood flows for the Allains River drainage basin.

Figure 5.6 Allains River Flood Flows

Q_{10}	45	m^3/s
Q_{50}	65	m^3/s
Q_{100}	75	m^3/s
Q_{1000}	115	m^3/s

5.4.2 Computer Modelling

The HEC-RAS flood modelling package by the USACE was used to model the 1/1000 year flood flow in the Allains River. The peak 1/1000 year flow was modelled in a steady flow simulation. A total length of 5300m of river was analyzed from the inlet at Grand Lake Flowage to the intersection of Allains River with Allains Creek. Eleven sections were taken in the reach at various intervals from 1:10,000 mapping from Service Nova Scotia with 5m contour intervals.

The following table presents the output from the HEC-RAS model. An attached map highlights the floodplain area.

Figure 5.7 HEC-RAS Output

Section #	Spacing (m)	Distance (m)	W.S. Elev. (m)	Velocity (m/s)
1	0	0	123.33	0.41
2	982	982	101.12	3.07
3	680	1662	86.56	3.33
4	538	2200	76.52	3.38
5	900	3100	60.77	1.90
6	662	3762	50.84	2.80
7	200	3962	45.53	2.48
8	191	4153	36.33	4.41
9	268	4421	30.68	2.53
10	570	4991	11.11	4.86
11	309	5300	7.16	0.67

The effects of obstructions such as bridges, culverts and weirs in the floodplain were not modelled because of lack of data. No survey or site investigation was taken to gather pertinent information. Therefore, the water surface elevations in Table 1.3 represent the minimum water surface elevations and backwater effects from structures may create an increase in water surface elevation if the structure can not pass the 1:1000 year flood flow efficiently.

5.5 Hydrogeology Tools Tests

5.5.1 Method 1

Method 1 - Water Balance for the Pereaux Watershed

The Pereaux River watershed has a watershed area of approximately 7.81 km^2. The land uses are dominated by agriculture (65 %) and forest (35 %), with a small urban area centred around Pereaux Village. No central water supply well fields or central wastewater collection services are present. There are also no major groundwater users in the watershed.

The main water usage and demand is agriculture (85%). The estimated 308 residents (CBCL, 2003) utilize approximately 116 m^3/day or 11 % of the water total demand, with agriculture using the remainder. With the exceptions of small wet areas along the stream, and the steep forested slopes of North Mountain, most of the watershed (est. 65 %) is cleared agricultural land. Stream flows range as low as 5% of mean annual flows in the summer dry periods (CBCL, 2003).

Information for the water balance was obtained as follows:

- Obtain minimum, maximum and mean annual precipitation (Kentville CDA 1961-2006 was 837.9, 1575.6 and 1171.9 mm respectively);
- Mean annual evapotranspiration has historically been taken as 25 to 44 %, mean 33 % (Trescott, 1968). Estimates using mean monthly temperatures from Kentville climate Station for the period 1996 through 2006 infer an average evapotranspiration of 596.5 mm (50.9 % of mean annual P). Since the methods utilize differing time periods, the method of differences (e.g., subtract total surface water and groundwater runoff from total precipitation);
- is used in equation G1 to estimate probable evapotranspiration (e.g., about 486.5 mm or 41.5 % of total P);
- Mean annual runoff (CBCL 2003) for the Pereaux River based on extrapolation of runoff from the Annapolis River at Wilmot (CBCL 2003) was 443.5 to 1048.2 mm, mean 685.4 mm (58.5 % of P);
- Groundwater recharge determined by 3D groundwater modelling of the eastern Annapolis Valley (GSC 2006, in prep) suggests an infiltration range of 129 to 430 mm, mean 312 mm (26.5 % of mean annual P) for Pereaux Watershed. Of this, approximately 50 % is expected to reach the underlying bedrock, with the remainder being lost to horizontal drainage from overburden to streams. Groundwater recharge reaching bedrock is therefore estimated to be in the order of 65 to 215 mm, mean 156 mm (13.3 % of precipitation), which is similar to previous estimates in the valley region (mean 12.3 %, Trescott, 1968).
- Direct runoff (Rs) is determined as about 373.4 mm by subtracting the estimated groundwater infiltration from the total runoff value.

Using Equation G1, and the results of the 2003 investigations for the Pereaux Watershed, the mean annual water balance for the Pereaux Watershed would be:

$$P = ET + Rs + eRg \pm \Delta S$$

$$1171.9 \text{ mm} = 486.5 \text{ mm} + 373.4 + 312 \text{ mm} \pm 0 \text{ mm}$$

The above water balance, expressed in terms of mm of equivalent precipitation, may also be expressed as water volume by extrapolating over the entire 7.82 km^2 watershed, a standard area such as hectare or acre), or a subdivision development.

	(mm)	% of P	m^3/day	m^3/hectare	Igpm/acre
Mean Annual Precipitation	1171.9	100.0%	25,108	32.1	2859.4
Evapotranspiration	486.5	41.5%	10,423	13.3	1187.0
Total Runoff (Rs + Rg)	685.4	58.5%	14,684	18.8	1672.3
Direct Runoff	379.4	32.4%	8,129	10.4	925.7
Groundwater Infiltration*	306	26.1%	6,556	8.4	746.6

* total infiltration based on overburden (actual recharge to underlying bedrock about half of this)

The above approach provides a general indication of water availability in an average year over a long period of time. As discussed in Section 3.x, the effect of climate change is expected to mainly affect the evapotranspiration term, resulting in a lower proportion of runoff and groundwater recharge in the future.

5.5.2 Groundwater Method 2 – Tier 1 Groundwater Quantity

Sustainable land use is a function of water availability and demand. Water demand must be appropriately apportioned to sustain the natural ecosystem, with excess capacity being allocated to various water stakeholders. The following simplified method is often used by planners to estimate the availability of groundwater supply for subdivisions or light industrial developments. If the development fails to meet these theoretical guidelines, more detailed assessment, including exploration drilling and testing, would typically be requested.

For the Pereaux River study area, the following information and assumptions are used:

- Total watershed area 7.82 km^2 from 1:10,000 scale topographic mapping (may also calculate based on unit areas (e.g., hectare, acre);
- Determine mean annual precipitation: Kentville CDA minimum, maximum and mean annual precipitation (1961-2006) was 837.9, 1575.6 and 1171.9 mm respectively;
- Determine percentage of main aquifer units from published geological mapping (Provincial Natural Resources); area of basalt/escarpment 22.7 %; Blomidon Shale aquifer 77.3 %.
- Determine probable recharge as percentage of minimum precipitation (may also use 85 percentile) for dominant aquifer beneath area of interest; est. 17 % for fractured basalt areas and 13.3 % for Blomidon sandstone and shale on the valley floor based on GSC 2006 modelling). A minimum recharge estimate is used (minimum precipitation) in this assessment to deal with potential dry years; and provides a good degree of conservativism in the estimates for an average water year.
- Determine per capita daily water usage (typical range from 60 to 100 igal/day (100 USgpd or 83 igpd default average).
- Assume 4 persons per residential unit (may range 2 to 4 typical).
- Determine current/project population of area (municipal, provincial census data); can also estimate from number of residential lots from PID mapping; and
- Calculate groundwater abstraction availability for current, future development. May also need to deduct other demands such as agricultural and stream flow maintenance.

Using a water balance approach (Eqn G3), the theoretical number of residential lots (N) that an area can support is based on the estimated minimum annual groundwater recharge and water demand as follows:

$$N = \frac{\text{Theoretical Groundwater Recharge } [m^3/d]}{\text{Theoretical Demand } [m^3/d]} \qquad \text{[Eqn G2]}$$

Blomidon Shale Bedrock Aquifer:

$$N = \frac{(0.8^{1})\ (\text{area } (m^2))\ (\%\ Rg^{2} \times \text{annual precipitation } (m^3))}{(\text{No. persons/lot} * \text{demand/person}^{3})\ (365\ d/yr)} \qquad \text{(Eqn G3]}$$

$$N = \frac{(0.8)\ 6044860\ m^2)\ (0.135)\ (0.838\ m/yr)}{(4 * 0.378\ m^3/d)(365\ d/yr)}$$

N = 991 lots for Pereaux Watershed (1.6 residential lots or 6.5 persons per hectare)

Similarly, for the basalt bedrock area on North Mountain:

$$N = \frac{(0.8)\ 1775140\ m^2)\ (0.17)\ (0.838\ m/yr)}{(4 * 0.378\ m^3/d)(365\ d/yr)}$$

N = 366 lots for Pereaux Watershed (2.1 residential lots or 8 persons per hectare)

The minimum lot size to provide the requisite 0.378 m^3/d (100 USgpd) per capita, assuming 4 persons per household, would be the inverse of N, or 0.5 hectares (1.2 acres) on the North Mountain and 0.6 hectares (1.5 acres) on the Valley Floor.

For example, assuming a historical low annual rainfall of 838 mm (ECAES, 2000 for Kentville Research Station), a conservative recharge coefficient of 17 % for fractured basalt with limited overburden, and 13.5 % for Blomidon sandstone and shale with thick sand and silt overburden on the valley floor, 4 persons per household, a conservatively high usage rate of 0.378 m^3/d (100 USgpd) and a 20 % factor of safety, a one hectare development area could theoretically support 1.6 residential lots on the Valley Floor, and 2 lots on the North Mountain basalt areas, and the entire 7.82 km^2 watershed could theoretically support up to 1357 lots with up to 5428 persons, assuming no other water users. There is therefore plenty of reserve capacity for the current and near future projected population of 308 persons in Pereaux watershed.

Using the recharge component of the equation, a commercial, subdivision or industrial applicant could theoretically abstract 3.1 to 4.1 m^3/day per hectare (0.5 to 0.6 igpm for dry and average recharge years) on a continuous basis. Additional abstraction would require recharge from undeveloped areas of the watershed. Most Industrial and some commercial applicants would therefore be required to proceed to a groundwater investigation to determine sustainable well yields. Wells developed in permeable overburden deposits would be expected to provide approximately double the above values.

The default water recharge value can be varied based on site-specific recharge values, either average for a watershed, or for specific aquifers (require site specific groundwater modeling), and for an average, wet or dry year; dry year predictions are preferred.

As discussed in Section 3.x, climate change is predicted to reduce the amount of groundwater recharge slightly due to increased temperatures, with resultant increased evapotranspiration and length of drought periods in the summer months. Increased evapotranspiration would theoretically reduce the proportion of infiltration passing though overburden to bedrock. The factor of safety in the above equation can be increased as needed to account for this.

Groundwater Method 3 – Tier 1 Groundwater Quality and Assimilative Capacity

The assimilative capacity for wastewater flows from a typical residential home are calculated in a manner similar to Method 2. However, wastewater will be discharged to the overburden aquifers, in the Study area. The mean annual infiltration rates for the overburden are used in the calculation.

- Select a dilution ratio (1:3 to 1:4);
- Determine infiltration rate of overburden in area of interest;
- Determine percentage of each overburden unit in study area (estimated)
    - Coarse Sand and gravel (15 %)
    - Fine sand (10 %)
    - Silty till (60 %)
    - Marine clay 15 %)
- Determine infiltration rate from published reports (129 to 430, mean 312 mm/year or 10 to 36.6, mean 26.6 % of annual precipitation);
    - Coarse Sand and gravel 350 mm/yr (30% of P)
    - Fine to sand 250 mm/yr (20 % of P)
    - Silty till 50 to 75 mm/yr (5 % of P)
    - Marine clay <50 mm/yr
- Assume 75 % of water demand is wastewater (e.g., 0.378 m^3/day (75 USgpm)

Method:

1. Calculate effluent per capita:
   0.75 x 0.3781 m^3/d (100 USgpm) = 0.2836 m^3/d (75 USgpm)

2. Calculate effluent per lot:
   0.2836 x 4 for four persons = 1.13 m^3/d

3. Calculate infiltration volume needed for 4x dilution of domestic septic effluent:
   1.13 m^3/d x 4 = 3.4 m^3/d

4. Calculate available infiltration for each overburden unit (bedrock unit if no overburden):

Unit	**Mean Precip (mm)**	**% Area**	**Infiltration (mm)**	**(% P)**	**Area (m^2)**	**Mean Infiltration Recharge m^3/yr**	**m^3/d**	**m^3/d/ha**
Sand/gravel	1171.9	15	350	0.299	1173000	410550	1124.8	9.59
Sand	1171.9	10	250	0.213	782000	195500	535.6	6.85
Sandy Till	1171.9	60	75	0.064	4692000	351900	964.1	2.05

marine clay	1171.9	15	50	0.043	1173000	58650	160.7	1.37
Total watershed					7820000	1016600	2785.2	19.9

5. Estimate Number of persons and residences per unit area:

Unit	**Effluent /capita m^3/d**	**Effluent/ Lot m^3/d**	**People /ha**	**Ha /perso n**	**Acres /person**	**Lots/ Water-shed**	**Lots/ Hectare**	**Lots /acre**
Sand/g ravel	0.284	1.13	33.8	0.03	0.07	992	8.5	3.4
Sand	0.284	1.13	24.2	0.04	0.10	472	6.0	2.4
Sandy Till	0.284	1.13	7.2	0.14	0.34	850	1.8	0.7
marine clay	0.284	1.13	4.8	0.21	0.51	142	1.2	0.5
						2455		

A 4x effluent dilution ratio was used for septic effluent assimilation. This should effectively reduce most septic concentrations to within guidelines (e.g., chloride from 500 to 125 mg/L). The above suggests that there is more than adequate assimilative capacity for the existing 308 population of the Pereaux Watershed. Only the marine clay areas located on the seaward end of the watershed might approach the 4x dilution ratio in dry periods.

The above suggests that up to 2455 additional homes could be developed based on septic assimilative capacity; compared to 1357 lots based on dry season bedrock groundwater recharge; the groundwater availability therefore controls development in this watershed. Homes located over the sandy terrain have the greatest dilution potential, having the greatest recharge potential. However these areas are also most prone to contaminant transport to nearby streams. Conversely, while the clay and silt terrain has less potential for dilution, groundwater transport would be expected to be slower, thereby offering some retardation of possible contaminants along the flow path.

With respect to climate change, this tool is not likely to be affected much. As previously discussed, temperatures will remain relatively consistent on an annual basis, and slight increases in temperature are likely to reduce overall recharge component due to increased evapotranspiration.

5.5.3 Conclusion

The above groundwater tools are relatively easy to apply on an annual basis. Required information is readily available from local climate stations, stream gauging stations, or government regional assessments. On a monthly or seasonal basis, assessments of water balances are more difficult, require considerable data collection and manipulation, and will require the resources of a qualified hydrological or hydrogeological consultant.

With respect to climate change on groundwater resources, only temperature is considered to be an issue on an annual scale. Increasing temperature is expected to significantly change the distribution of groundwater recharge over the water year. In the normally frozen winter months when limited recharge historically occurs due to frozen ground conditions, higher temperatures will likely result in less ground freezing and more frequent thaws and recharge events than in previous years. This benefit will be offset in part by longer drought periods in the summer when evapotranspiration exceeds net precipitation.

5.6 Risk Assessment and Cost/Benefit Analysis Tests

5.6.1 Annapolis Royal Flood Risk Assessment

Due to ocean level rise, crustal subsidence, and tidal amplification in the Bay of Fundy as it approaches resonance, the town of Annapolis Royal will be increasingly susceptible to flooding. We will consider here four alternative strategies that the town can adopt in light of the risk of flooding:

1. do nothing: spend no additional money protecting the town against floods, but pay for flood damages as they occur;

2. floodproof individual buildings threatened by the flood: floodproofing involves raising small buildings and the closure/sealing of basements and ground floors of larger buildings (see Table 5.?.2 for floodproofing costs);

3. construct a levee around the town to protect against a 5.4 m flood (see below for a description), or

4. construct a levee around the town to protect against a 6.5 m flood (see below for a description).

We will assume that all strategies are aimed at a design life of 100 years (after which time a similar analysis can be repeated). We will also ignore the time value of money in the following analysis (partly because we don't know when the flood damage will occur, although this could be handled probabilistically in a more detailed analysis).

Two projected flood levels will be considered for Annapolis Royal over the coming century;

5.4 m flood: this includes the projected 100-year return period storm surge combined with high tide (4.6 m) plus climate change effects (ocean rise, 0.5 m) plus crustal subsidence (southern Nova Scotia is gradually sinking, 0.2 m) plus tidal amplification in the Bay of Fundy (0.1 m). We will model the occurrence of these floods as a Poisson process. We will also assume that the storm surge duration is of the order of 12 hours, so that the storm surge is sure to coincide with a high tide. We note that the recurrence period of the 5.4 m flood really only becomes 100 years towards the end of this century, i.e. after ocean level rise, crustal subsidence, and tidal amplification has taken place. However, we take a conservative approach here and assume that the recurrence period is currently 100 years and will remain at that rate throughout the coming century. In other words, the mean rate at which the 5.4 m flood occurs is $\lambda = 1/100$ per year.

6.5 m flood: this includes all of the components of the 5.4 m flood except that the storm surge now corresponds with the Highest Astronomical Tide (HAT). The HAT has a return period of about 1.5 years. If the storm surge lasts for 12 hours (a conservative estimate), then the probability that the storm surge does coincide with the HAT is equal to 1 over the number of

12 hour intervals between occurrences of the HAT. Thus, the mean rate of occurrence of the 6.5 m flood per year is:

$$\lambda = (1/100)\left(\frac{1}{1.5 \times 365.25 \times 2}\right) = 9 \times 10^{-6}$$

which, as with the 5.4 m flood, will be assumed to be the current rate and to hold throughout the coming century.

Figure 5.7 shows various possible flood levels at Annapolis Royal, broken down into the contributing components of the flood. In this risk assessment, we are considering the floods listed in the fourth and fifth columns because these involve significant numbers of inundated buildings, while still having reasonable probabilities of occurrence.

Figure 5.8 Possible flood levels at Annapolis Royal

	Flood Levels							
Attributes	50-Year without CC	50-Year with CC	100Year without CC	100/121-Year with CC	100/121-Year with CC & HAT	100/121 Year with CC & HAT & Wave Run-up	200-Year without CC	200-Year with CC
Elevation	4.7 m	4.9 m	4.8 m	5.4 m	6.5 m	7.5 m	5.1 m	5.7 m
Number of buildings	0	1	0	42	116	131	2	69
Square m of all buildings together	0	212	0	12,672	23,182	24,918	820	18,629
Any high priority properties for EMS? (fire, police, hospital, nursing home, schools, etc.)	N	N	N	Y School	Y School FD isolated, some downtown areas.	Y Areas in Downtown St. George St, Prince Albert Rd, and St. Anthony St	N	Y School. FD isolated, some downtown areas.
Metres of roads flooded	0	0	0	1,300	2,460	2,954	30	1,810

Damage Costs per Flood and Floodproofing Costs for Annapolis Royal

Regarding the construction of levees, we shall assume that the levee will have a 3 m wide crest (to accommodate heavy equipment) and 3.5H:1V side slopes. We shall also provide a 3 m freeboard above the required flood elevation to avoid overtopping (and subsequent erosion) by wave actions, which are sure to accompany a storm surge. The average elevation of the land around the town on which the levee would be placed is about 5.0 m and the levee would need to be approximately 900 m in length. The details of the two levees being considered are as follows:

for the 5.4 m flood, a 3 m freeboard brings the upper surface of the levee to an elevation of 8.4 m. The constructed height of the levee is thus $H = 8.4 - 5.0 = 3.4$ m having a cost of about \$2,600/m. The total cost of this levee will therefore be $900 \times 2,600 = \$2,340,000$.

for the 6.5 m flood, a 3 m freeboard results in a constructed levee height of $H = 9.5 - 5.0 = 4.5$ m having a cost of about \$4,200/m. The total cost of this levee will therefore be $900 \times 4200 = \$3,780,000$

Risk Assessment

We shall first consider the expected failure costs, $\mathrm{E}\left[C_f\right]$, associated with flooding for the "do-nothing" case. This is just equal to the cost of flood damage times the number of floods expected to occur during the design life of 100 years.

The 5.4 m flood has a (conservative) mean recurrence rate of $\lambda = 1/100$, so the expected number of such floods in t = 100 years is $\lambda t = 1$. The expected failure cost for the 5.4 m flood is thus:

$$\mathrm{E}\left[C_f\right] = 1 \times 4,044,902 = \$4,044,902$$

The expected number of 6.5 m floods in t = 100 years is (conservatively) $\lambda t = \left(9 \times 10^{-6}\right)(100) = 0.0009$. The expected failure cost of the 6.5 m flood is thus:

$$\mathrm{E}\left[C_f\right] = 0.0009 \times 8,304,000 = \$7474$$

We see immediately that the best option with respect to the 6.5 m flood is to "do nothing". The chances of the storm surge occurring at the same time as the HAT is so small that the risk is negligible compared to the initial costs of floodproofing or constructing a levee.

For the 5.4 m flood, we compare the following expected total costs:

The expected total cost of the "do-nothing" option is \$4,044,902,

The expected total cost of the floodproofing option is the sum of the floodproofing cost and the expected failure cost of the 6.5 m flood (we assume that floodproofing will certainly protect against the 5.4 m flood), $2,545,288 + 7474 = \$2,552,761$.

The expected total cost of the levee construction option: $2,340,000 + 7473 = \$2,347,473$

The lowest expected total cost is option 3. This suggests that the town should construct a levee to protect against the 5.4 m flood.

We note, however, that options 2 and 3 are have very similar total expected costs, so the two options are quite competitive. Some detailed comments about the risk assessment are as follows:

- we assume that both the floodproofing and 8.4 m levee provide sure protection against the 5.4 m flood. Because of the 3 m freeboard, this is probably largely true of the levee, pending a more detailed study of likely wave heights accompanying the storm surge. However, in the opinion of the author, floodproofing provides less certain protection unless properly maintained and implemented (i.e. are all doors adequately sealed against water ingress at the time of the flood?). Thus, the actual expect total cost of the floodproofing option may still include a significant flood damage cost.

- floodproofing can be applied on a building-by-building basis, which may lead to cost savings (e.g. only protect the important buildings, or those buildings which would be most heavily damaged by a flood – garages, for example, may suffer very little damage in a flood).

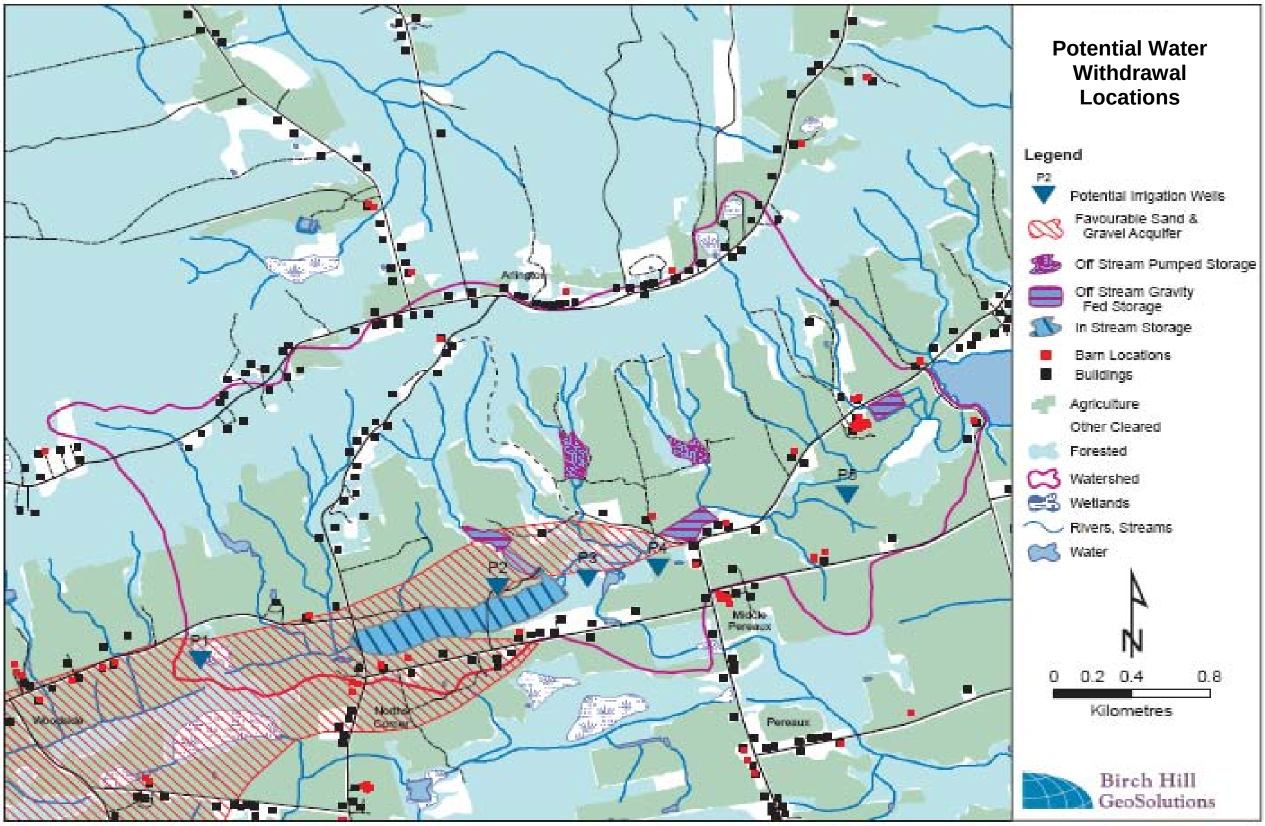
- the above analysis is simplified by assuming that only two flood levels are possible, 5.4 m and 6.5 m. In actuality, of course, there is a continous range of possible flood levels. A more detailed risk analysis would consider separately the expected number of floods from, say, 5.0 to 5.5 m, the expected number of floods from 5.5 to 6.0 m, and so on. However, the individual probabilities of occurrence of floods on such a detailed level would be quite difficult to estimate on the basis of past records and even more difficult to predict with any accuracy for the future. The refinement would probably not be justified.

5.6.2 Pereau Watershed Crop Failure Risk Assessment

In this section, we present an example risk assessment which can be viewed as a methodology to incorporate uncertainty into the decision making process. The scenario is that of an apple orchard farmer who needs to make decisions about how to plan for future droughts in the Annapolis Valley. Although, in general, drought lengths are not expected to significantly change in the Annapolis Valley over the next 100 years, we need to bear in mind that the GCM predictions are first of all mathematical models whose accuracy has yet to be determined, and second of all are based on assumptions that may or may not be accurate. In other words, although predicted drought lengths are not particularly changing, it is well known that world-wide climate changes are happening, and so we must be prepared. This example risk assessment presents one tool to enable us to be prepared. The methodology presented can be used similarly at any farm world-wide.

This tool is not intended for use by a farmer; rather, it is intended for use by an engineer, as input to a Land Use Planner, agricultural engineer, provincial department, agricultural organization, etc., in making decisions regarding agriculture as a land use. For example: Where should the boundaries of an agricultural zoning district be drawn? Where should new irrigation sources be developed? What crops are viable in the face of increased drought? And most importantly for this tool: What are the drought risks of climate change to a hypothetical apple orchard, and what are the costs of adapting to this risk by building a new irrigation pond?

Figure 5.9 Recommended Water Supply and Withdrawal Locations



Source: Adapted from CBCL Limited and Jacques Whitford, 2003

We start by considering a typical apple orchard farm in southern Nova Scotia. We will assume that this farm uses well water for irrigation in the event that rainfall is insufficient and that there is sufficient well water for 7 days of irrigation. The Ontario Government article “Establishing the high density supported apple orchard” states that a moisture equivalent of 25 mm of water per week from rain and/or irrigation is usually adequate to avoid drought stress (http://www.omafra.gov.on.ca/english/crops/facts/hdapch1.htm).

Our precipitation model assumes that any precipitation less than 0.5 mm in a day constitutes a “dry” day, and certainly as far as the orchard is concerned, a week of such ‘dry’ days would at most deliver 3.5 mm of precipitation, which is well under the required 25 mm/week suggested above. We will thus assume that a week of dry days will lead to the start of drought stress and that more than 14 dry days would lead to loss of the apple crop.

In other words, because 7 “dry” days can be covered by irrigation under the current conditions at the farm, we will assume that drought stress only begins for droughts in excess of 14 days in duration, and the complete crop will be lost if the drought extends past 21 days. If N_d is the number of dry days in a row (i.e. the drought length), then, the probability of a drought lasting for more than 21 days is (assuming that the farm has similar weather to Greenwood, NS):

$$\mathrm{P}\left[N_d > 21\right] = \mathrm{P}\left[N_d = 22\right] + \mathrm{P}\left[N_d = 23\right] + \mathrm{P}\left[N_d = 24\right] + \cdots = p_d\, p_{11}^{21}\left(1 + p_{11} + p_{11}^2 + \cdots\right)$$

$$= \frac{p_d\, p_{11}^{21}}{1 - p_{11}} = \frac{0.05435\left(0.71528\right)^{21}}{\left(1 - 0.71528\right)} = 0.000167795$$

and the probability that the drought last for between 14 and 21 days is:

$$\mathrm{P}\left[14 < N_d \le 21\right] = \mathrm{P}\left[N_d > 14\right] - \mathrm{P}\left[N_d > 21\right] = \frac{p_d\, p_{11}^{14}}{1 - p_{11}} - \frac{p_d\, p_{11}^{21}}{1 - p_{11}}$$

$$= \frac{p_d\, p_{11}^{14}}{1 - p_{11}}\left(1 - p_{11}^{7}\right) = \frac{0.05435\left(0.71528\right)^{14}}{1 - 0.71528}\left(1 - 0.71528^{7}\right)$$

$$= 0.00158386$$

We will assume that the apple orchard is worth \$400,000 annually to the farmer, and this amount is then lost when a drought in excess of 21 days occurs during the growing season (April 1 to September 30). For drought lasting between 14 and 21 days, we shall assume that 50% of the crop is lost, for a financial loss of \$200,000.

Taking these potential losses into account, we shall consider the case where the farmer has the following two design options;

1. do nothing and take the losses as they are dealt out by nature, or
2. build a retention pond of some size to allow for additional days of irrigation in the event of an extended drought.

We shall assume that the design life of the retention pond is 100 years, and will determine the best option for the farmer to take over this time span. We will do so by finding the option which gives the smallest *expected* total cost, including construction and maintenance costs, and *expected costs of failure* (i.e. loss of crops due to extended drought). For simplicity, we will ignore the time value of money – that is, we will assume constant dollar value.

The cost of constructing a water retention pond is suggested in http://www.kalamazooriver.net/pa319new/docs/handouts/pond_costs_loads.pdf to range from \$0.50 to \$1.00 per ft^3 of retained water – we will use the low end of this range and assuming a water depth of 1.5 m in our pond, the construction cost is approximately \$2700 for each 100 m^2 of pond. We will also assume a cost for design and permits equal to 30% of the construction cost (\$810 for each 100 m^2) and a maintenance cost of about \$17 per 100 m^2 per year (or \$1700 per 100 m^2 over the 100 year design life).

Based on current irrigation amounts, it is estimated that the farm will require approximately 150 m^3 of water for each ‘dry’ day. This means that one day of irrigation from the pond will require a pond area of 150/1.5 = 100 m^2. For x days of irrigation, then, the pond area will need to be 100x having a total cost, C_p, over the 100 years design life of

$$C_p = \left(2700 + 810 + 1700\right)x = 5210x$$

in dollars.

For the expected costs due to crop failure, we must compute the expected number of droughts of length in excess of 21 days over the 100 year design life. During this period, there are approximately

100(365/2) days during the 100 growing seasons. If N_{21} is defined to be the number of droughts in excess of 21 days, and N_{14} is the number of droughts of length between 14 and 21 days, over the next 100 years, then their expectations are:

$$E\left[N_{21}\right]=100(365.25/2)P\left[N_d>21\right]=(18262.5)\frac{p_d\,p_{11}^{21}}{1-p_{11}}=(18262.5)(0.000167795)=3.06$$

and

$$E\left[N_{14}\right]=100(365.25/2)P\left[14<N_d\le 21\right]=(18262.5)(0.00158386)=28.93$$

So the expected total cost of crop failure over the next 100 years will be the cost of 3.06 complete crop losses (at \$400,000 each) plus 28.93 partial crop losses (at \$200,000 each). If C_f is the total loss due to crop failure in the next 100 years, then:

$$E\left[C_f\right]=400,000E\left[N_{21}\right]+200,000E\left[N_{14}\right]=400000(3.06)+200000(28.93)=\$7,010,000$$

If a water retention pond is built that provides an extra *x* days of irrigation, above and beyond that provided by well water, then our critical drought lengths are increased to $(14+x)$, for partial crop loss, and $(21+x)$ for complete crop loss. Now the expected number of droughts of duration $(21+x)$ becomes

$$E\left[N_{21+x}\right]=100(365.25/2)P\left[N_d>21+x\right]=(18262.5)\frac{p_d\,p_{11}^{21+x}}{1-p_{11}}$$

Similarly, the expected number of droughts of duration between $(14+x)$ and $(21+x)$ becomes

$$E\left[N_{14+x}\right]=100(365/2)P\left[14+x<N_d\le 21+x\right]=(18262.5)\left[\frac{p_d\,p_{11}^{14+x}}{1-p_{11}}-\frac{p_d\,p_{11}^{21+x}}{1-p_{11}}\right]$$
$$=(18262.5)\frac{p_d\,p_{11}^{14}}{1-p_{11}}\left(1-p_{11}^{7}\right)p_{11}^{x}$$

The total cost, including costs associated with the retention pond and future losses, will be

$$C=C_p+C_f=5210x+400,000N_{21+x}+200,000N_{14+x}$$

The expected total cost will therefore be

$$\begin{aligned}
E\left[C\right]&=5210x+400,000E\left[N_{21+x}\right]+200,000E\left[N_{14+x}\right]\\
&=5210x+400,000\left(18262.5\right)\frac{p_d\,p_{11}^{21+x}}{1-p_{11}}+200,000\left(18262.5\right)\frac{p_d\,p_{11}^{14}}{1-p_{11}}\left(1-p_{11}^{7}\right)p_{11}^{x}\\
&=5210x+200,000\left(18262.5\right)\frac{p_d\,p_{11}^{14}}{1-p_{11}}\left(1+p_{11}^{7}\right)p_{11}^{x}\\
&=5210x+200,000\left(18262.5\right)\frac{0.05435\left(0.71528\right)^{14}}{1-0.71528}\left(1+0.71528^{7}\right)p_{11}^{x}\\
&=5210x+7,010,000\,p_{11}^{x}\\
&=5210x+7,010,00\left(0.71528\right)^{x}
\end{aligned}$$

in terms of the number of irrigation days, *x*, available from the retention pond. The following table expressed the expected total cost (at constant dollars) over the next 100 years.

x (days)	Expected total cost, $
0	7,010,000
1	5,019,000
2	3,597,000
3	2,581,000
4	1,856,000
5	1,339,000
6	970,000
7	708,000
8	522,000
9	390,500
10	298,000
11	233,000
12	188,250
13	157,660
14	137,270
15	124,160
16	116,270
17	112,110
18	110,617
19	111,033
20	112,814
21	115,570
22	119,030
23	122,980

From the above table, we see that the minimum expected total cost occurs when we construct a retention pond able to provide 18 days of irrigation. The pond must then be of size 18 x 100 m^2 = 1800 m^2, with an estimated initial cost of $\left(2700+810\right)(18)=\$63{,}180$ and a maintenance cost (at constant dollars) over the next 100 years of $30,600 (at $306 per year).

5.8 Land Use Mapping Analysis Tools Tests

5.8.1 Introduction

The project examined the use of integrated GIS tools to assist in bottom up decision-making with respect to climate change impacts. These tools, ArcView GIS and the CommunityViz extension are being reviewed in the context of scenario planning to enable the community to actively explore different land use planning options as they relate to flooding scenarios within the Town of Annapolis Royal. A case study approach is undertaken, focusing on the entire area within the town boundary between the Annapolis River on the north and west and Allains Creek to the south.

As mentioned in Chapter 3, ArcView GIS is a desktop mapping software that provides a cost effective GIS solution. Software extensions add greater functionality and CommunityViz is specifically designed to provide scenario-based land use analysis functionality. The 3-D capabilities of CommunityViz were not reviewed for this project.

Data for the project was provided under agreement by the Annapolis District Planning Commission and included a host of information: systems infrastructure (water, sewer), roads and other transportation features (trails, sidewalks), buildings, property data and coded future and existing land use, zoning and development potential. This data is quite substantial for a small municipality and was an effective base for doing further analysis without collecting further information. Potential and known flood levels were produced by the project team.

Planning scenarios for the Tool test were designed by a Planner and carried out by an experienced GIS analyst. ArcView lends itself to providing an out of the box solution and no other additional tools were used during the assessment. Two methods of analysis were conducted – one only using ArcView GIS functionality and methodologies and the second using the CommunityViz extension.

5.8.3 GIS Tools Only

ArcView by itself does provide some geoprocessing capability, such as buffering and union analysis. Buffering was used to determine setbacks form wetlands and watercourses. The union function computes a geometric intersection between two input features. The analytical tool is limited by two input features which makes for multiple processing sessions to achieve the desired result. Data management of interim files is critical. This process was used to develop weighted constraint maps for development potential. Union also can fill gaps if the two overlaying polygon features do not intersect.

ArcView has model building tools that allow the user to automate geoprocessing steps preserving a set of tasks, or a workflow, that one can execute multiple times. These models were used to test tools and process the union and coding of data.

The difficulty with doing weighted analysis in ArcView GIS is the limited geoprocessing functionality. Only being able to union two files per analytical session is time consuming when we needed to union approximately 7 layers to achieve or development potential scenario. Other methods of processing data was also hindered by the lack of specific tools that are available on the more advanced platforms, however, operator experience in this instance was able to overcome the software's short-comings by doing workarounds. Knowing what the perceived data requirements are and the components of a weighted analysis, enabled the GIS analyst to construct the data by other more tedious methods to achieve the same results that the ArcInfo platform would achieve with a single command.

Weighted overlay analysis a technique for applying a common scale of values to diverse and dissimilar input to create an integrated analysis. Geographic problems often require the analysis of many different factors. For instance, choosing the site for a new housing development means assessing such things as land cost, proximity to existing services, slope, and flood frequency. Typically this information would exist in a raster layer and not a vector-based layer. ArcView has neither access to the tools to create a raster from vectors nor to the weighted overlay analysis tool. Typically, the rasters would have different value scales: dollars, distances, degrees, and so on. You cannot add a raster of land cost (dollars) to a raster of distance to utilities (meters) and obtain a meaningful result.

Additionally, the factors in your analysis may not be equally important. It may be that the cost of land is more important in choosing a site than the distance to utility lines. Thus, on a overall scale of 1 to 9 the weighting of values to make land cost more prominent would be 8 and the distance to utilities is 3 - values at the end of the scale represent the extremes of suitability.

By coding each polygon layer with a weight to that layer's significance in relation to other layers and then adding the weights between layers, the analyst was able to achieve a similar result to the weighted analysis tool. This new data layer then was used in conjunction with other layers, building and property, to determine what the potential costs of future development are and the loss that could be associated with a flood event.

5.1.1 CommunityViz Extension to GIS

CommunityViz makes the process of determining suitability less cumbersome. The extension works in conjunction with ArcView by adding further analytical capability to the GIS. Suitability analysis provides a planner with locations that may be appropriate for future development based on a set of assumptions such as distance from features, likelihood (or weighting) of an particular event (flooding in this case), pre-existing conditions and future development plans.

An assumption is an input value to an analysis that is usually changeable and always apply to an entire scenario. Assumptions can express subjective inputs, such as how much weighting to give to a particular community value like open space or economic development. Output values that depend on a particular assumption are automatically updated when the assumption is changed. They can be expressed as a numeric value or as a choice (number, text, or Logical – yes/no) associated with a defined set of valid values. A numeric assumption can be any number, rate, or standard (number of stories, distance from a type of feature, weighted constraint) while a "choice" may represent a type attribute (dirt, gravel, paved road) or a time frame (1990, 2000, 2010).

CommunityViz is able to analyze data in such a way that one or more alternative scenarios or viewpoints are developed. Each point of view has it's on specific input features. The extension allows the user to do a build-out analysis. Build-out represents a theoretical maximum that allows planners to estimate the amount and location of future development for an area. Based on assumptions such as building density, physical constraints to development, and land-use regulations that define the size and placement of structures for that area, a build- analysis provides an answer to the question "how many buildings could be built in this area according to current land-use regulations?" without implying how many structures will actually be built.

Planners have traditionally performed build-out analyses by using spreadsheets associated build-out assumptions on a hard copy map. GIS improves this technique by associating the current and future land-use and development plans with a database of associated attributes and by automating the whole process.

The same assumptions that were used in the ArcView only process were used. Land use were assigned density variables and properties with buildings were not considered under a predefined size. Only land with a use class of residential was considered for future development.

Suitability analysis provided similar results as the ArcView only test, but with less intensive GIS Analyst involvement. The data preparations steps for the flooding levels was considered to be equal for both testing scenarios although data was only worked up once and a copy made for both analysis methods.

Summary

Both ArcView and CommunityViz are viable tools for investigating climate change impacts. These tools do however, require a large amount of data to function properly. Both are cost effective solutions for data analysis and use of the extension is currently only available on the ArcGIS platform. The GIS-only methods could be done on similar competitor software with the same effect.

A considerable amount of expertise is required to operate the GIS and extension at this level of geoprocessing. Although the extension does make step-by-step processing easier and in an ordered and well documented format, it is recommended that a well trained GIS Analyst or GIS-trained Planner undertake the analysis. The intricacies of "planning" language alone could be cumbersome for an Analyst and thus would require direction from a Planner to operate.

5.2.2 GIS Mapping Analysis

As explained in Chapter 3, our GIS mapping analysis of climate change impacts has been designed to be incorporated into the existing framework of GIS Land Sensitivity Analysis modeling commonly used in municipal planning departments. Our two main foci on coastal flooding in Annapolis Royal, and the competing land uses of agriculture and future residential development for scarce groundwater resources in the Pereau watershed, have been successfully tested with our GIS mapping tools. Basically, if the necessary climate change impacts data is obtainable in a municipality (i.e., if there is funding available to use our analysis tools to assess potential climate change impacts), then our GIS mapping tools can be easily used by municipal Planning Department GIS analysts to incorporate climate change locational adaptations, such as additional development setback distances from coastlines and rivers.

Annapolis Royal GIS Flood Mapping

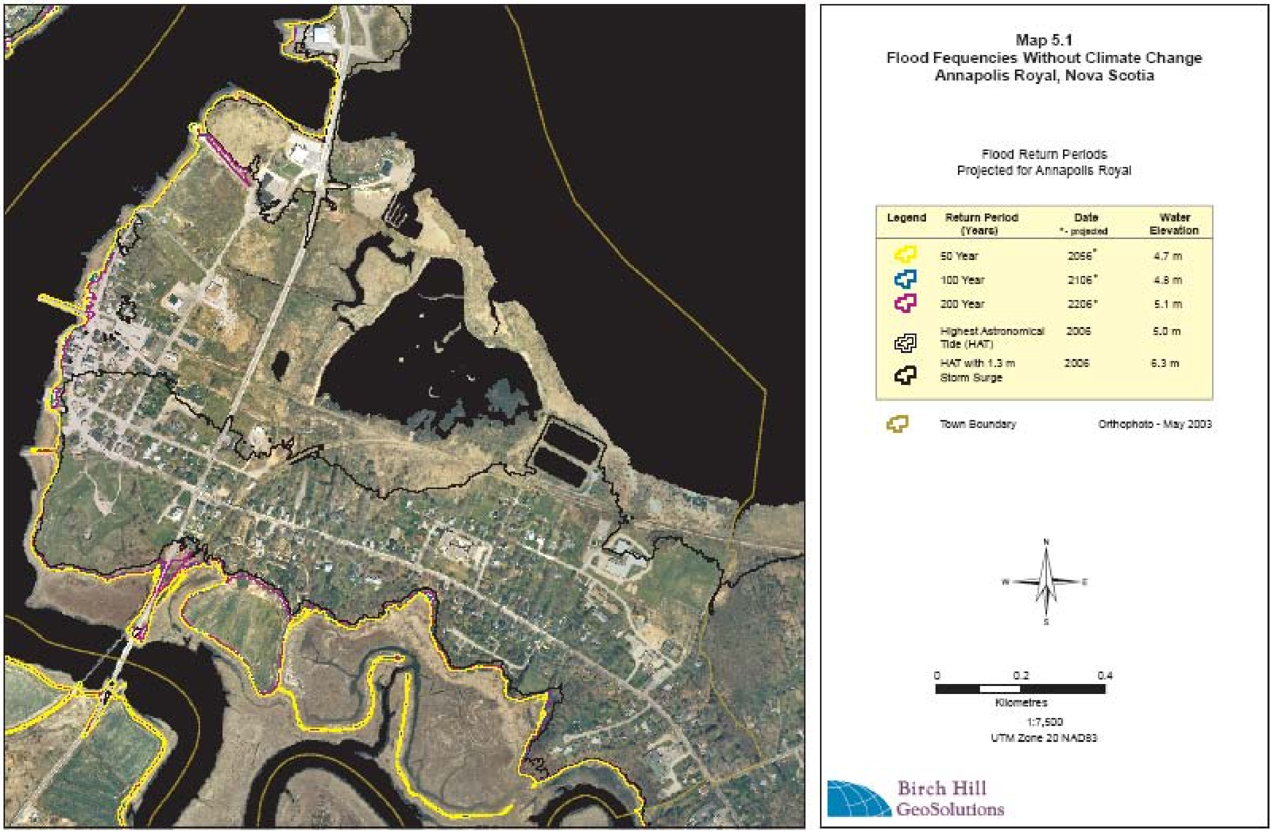
Our tools tests of GIS mapping in Annapolis Royal focused on coastal and riparian floodplain mapping in Annapolis Royal, and how this affects the common existing GIS Land Use Tools of Land Sensitivity Analysis and Build-Out Analysis. These resulting maps are summarized below.

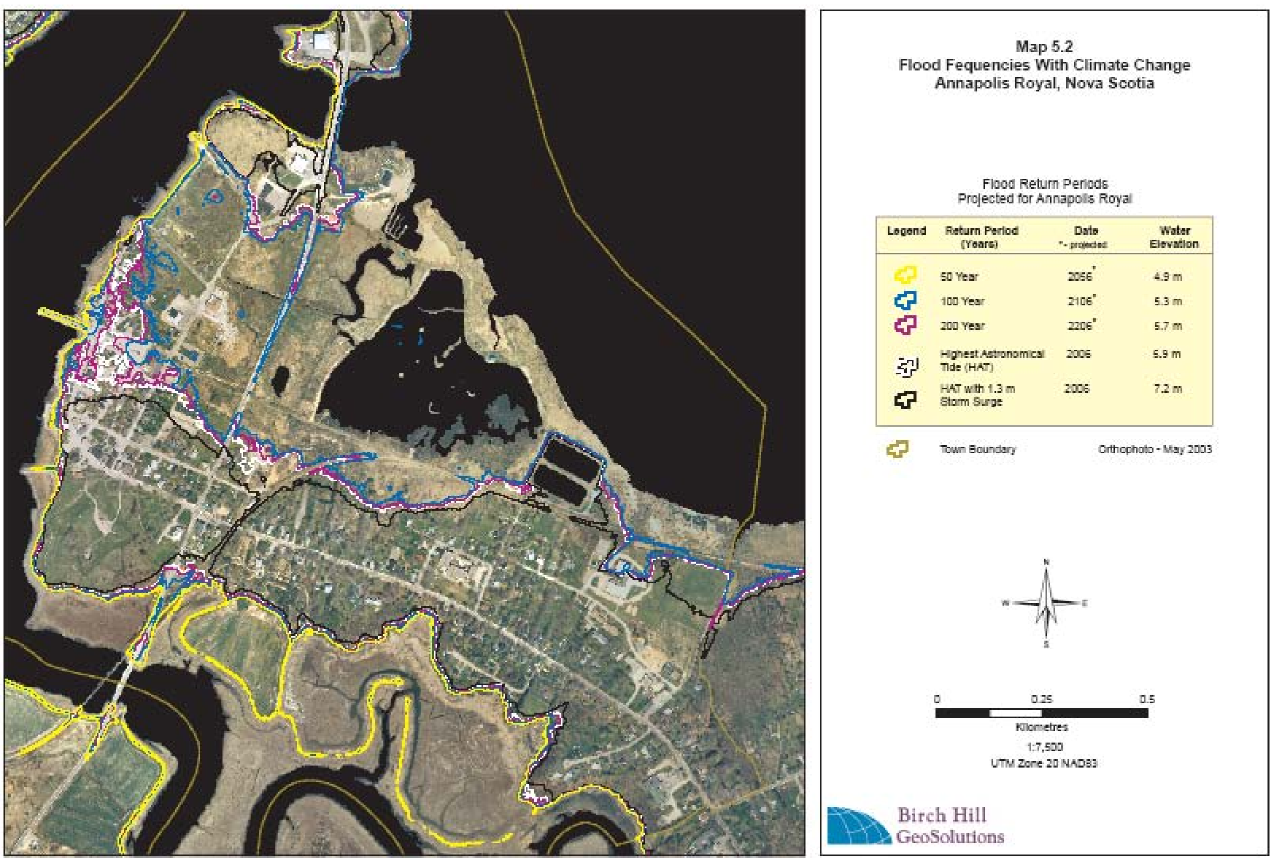
Map 5.1 was constructed using the flood frequencies data generated by our Water Modeler tool. This map shows the 50, 100 and 200 year flood return periods we modeled *without* incorporating climate change impacts on coastal flooding. We then incorporated climate change impacts on coastal flooding, and remapped the same flood return periods, which are shown in Map 5.2. The greatest difference was in the 100-year flood, which covered far more area when climate change impacts on coastal flooding were included. The flood return periods were mapped together on these two maps to show the differences between these commonly used flood return periods.

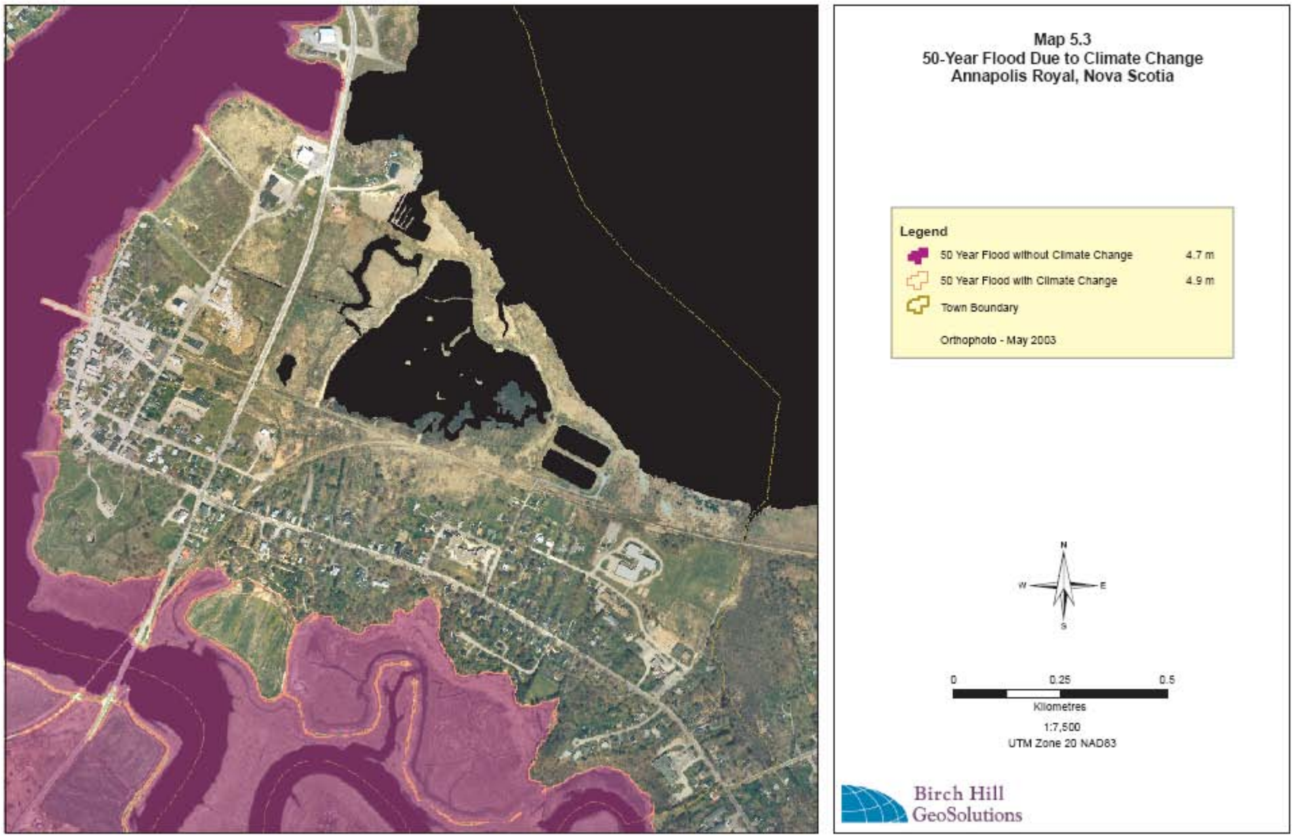
These flood return periods are illustrated in a different way in Maps 5.2 through 5.6. Map 5.3 shows one return period only, the 50-year flood, with and without climate change impacts. There is not a large difference. However, in Map 5.4 of the 100-year return period flood with and without climate change impacts, there is a large difference. With climate change factored in, the 100-year flood covers a substantial more area of the town, including the constructed wetland (large black area on map) used to treat effluent from the town sewage lagoons (the two black rectangular areas on the map). With climate change, the 100-year flood covers the main road, essentially isolating the town fire department from the rest of the town.

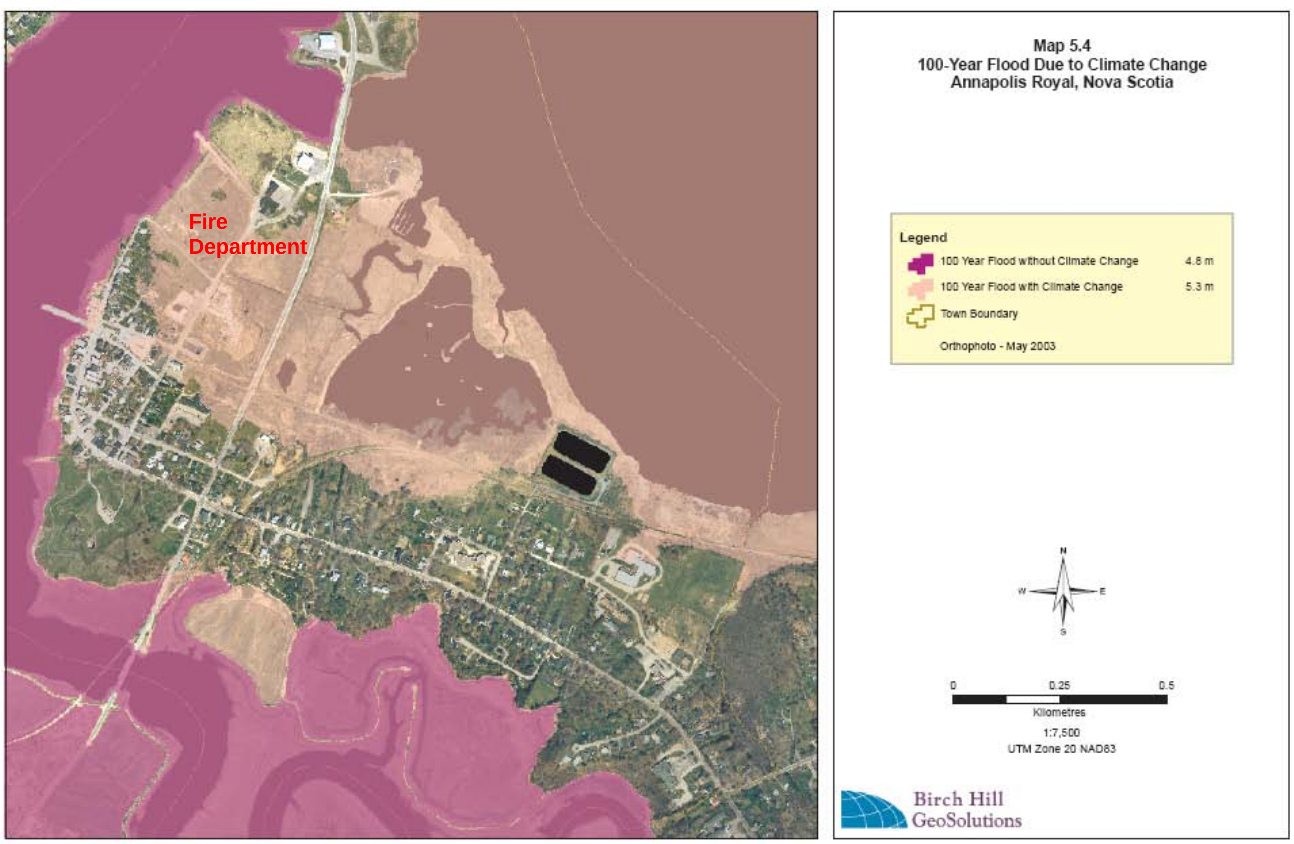
Map 5.5 illustrates this same comparison of flooding with and without climate change impacts for the 200-year return period flood. The 200-year flood with climate change essentially puts even more land area under water.

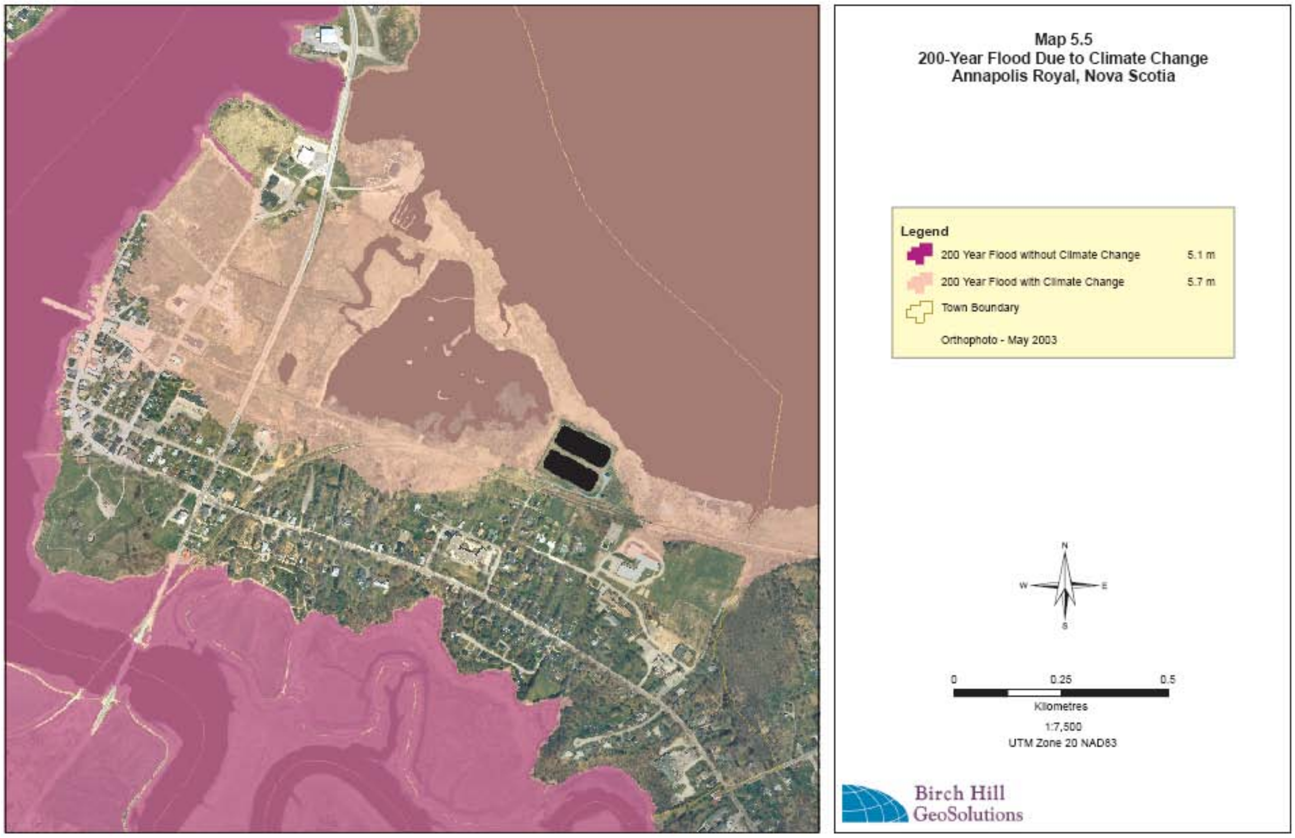
Map 5.6 shows flood levels from the “Ground-Hog Day Storm”, which occurred on February 2, 1976. This is the highest flood of record in Annapolis Royal, for which we were able to accurately document and ground-truth flood levels. (The Saxby Gale flood, which occurred in the late 1800s was higher, but not as readily mapped since it was not as well documented.) Using LIDAR analysis and ground-truthing, we were able to map the different flood level components we needed to compare. This is explained in detail in the Technical Appendix. As can be seen from Map 5.6, when wave run-up was added in, the water level reached 7.5, which now covers the sewage treatment lagoons, and leaves only a dry spine of land down the southern edge of the town. Map 5.4, our *projected* 100-year flood with climate change factored in, shows an average flood elevation of 5.3 metres, while Map 5.6, the *actual* 121-year flood of 1976, has an average water level of 5.4 metres. Note that climate change that has occurred since the 1976 storm has essentially added another 20 years to the projected flood return period.

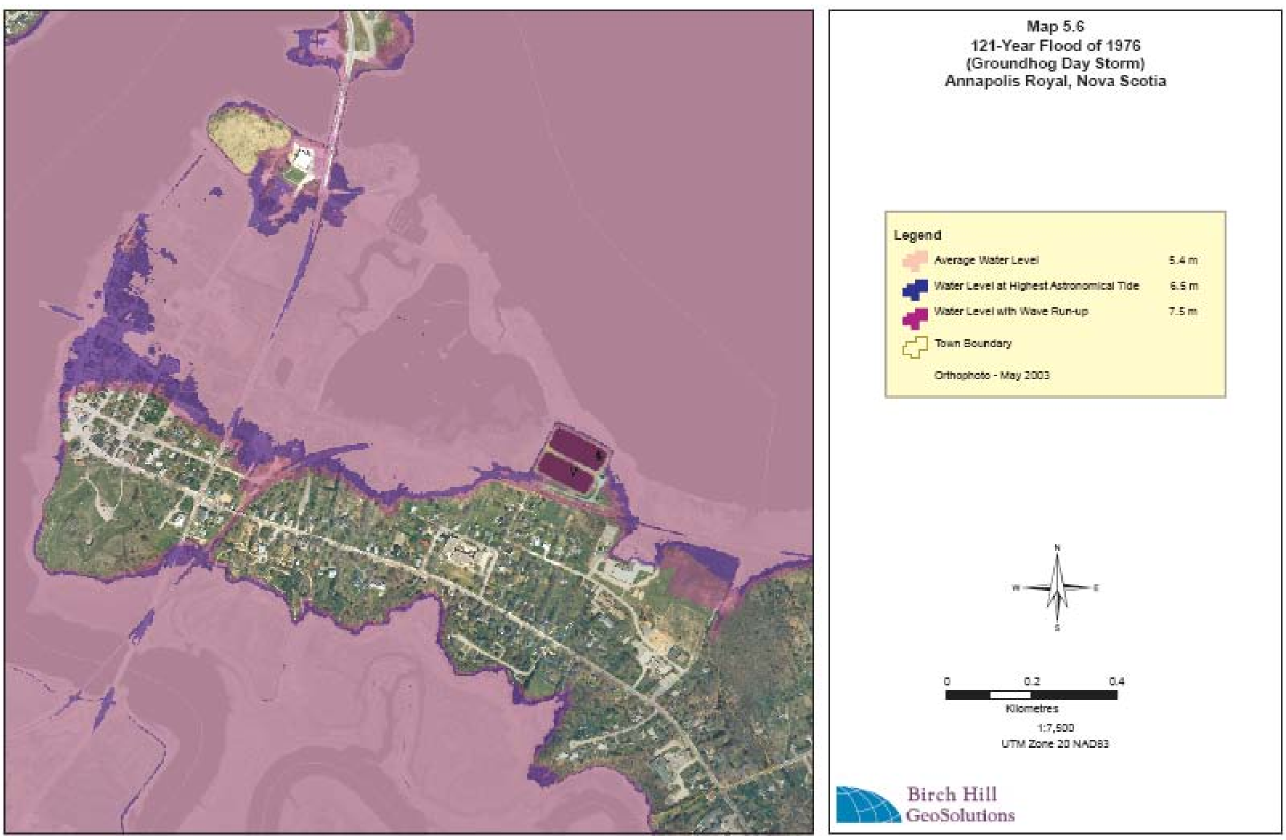

Map 5.1
Flood Fequencies Without Climate Change
Annapolis Royal, Nova Scotia
Flood Return Periods
Projected for Annapolis Royal
Legend
Return Period (Years)
Date *- projected
Water Elevation
50 Year
2056*
4.7 m
100 Year
2106*
4.8 m
200 Year
2206*
5.1 m
Highest Astronomical Tide (HAT)
2006
5.0 m
HAT with 1.3 m Storm Surge
2006
6.3 m
Town Boundary
Orthophoto - May 2003
N
W
E
S
0
0.2
0.4
Kilometres
1:7,500
UTM Zone 20 NAD83
Birch Hill
GeoSolutions


Map 5.2
Flood Fequencies With Climate Change
Annapolis Royal, Nova Scotia
Flood Return Periods
Projected for Annapolis Royal
Legend
Return Period (Years)
Date *- projected
Water Elevation
50 Year
2056*
4.9 m
100 Year
2106*
5.3 m
200 Year
2206*
5.7 m
Highest Astronomical Tide (HAT)
2006
5.9 m
HAT with 1.3 m Storm Surge
2006
7.2 m
Town Boundary
Orthophoto - May 2003
N
W
E
S
0
0.25
0.5
Kilometres
1:7,500
UTM Zone 20 NAD83
Birch Hill
GeoSolutions


Map 5.3
50-Year Flood Due to Climate Change
Annapolis Royal, Nova Scotia
Legend
50 Year Flood without Climate Change 4.7 m
50 Year Flood with Climate Change 4.9 m
Town Boundary
Orthophoto - May 2003
N
W
E
S
0
0.25
0.5
Kilometres
1:7,500
UTM Zone 20 NAD83
Birch Hill
GeoSolutions

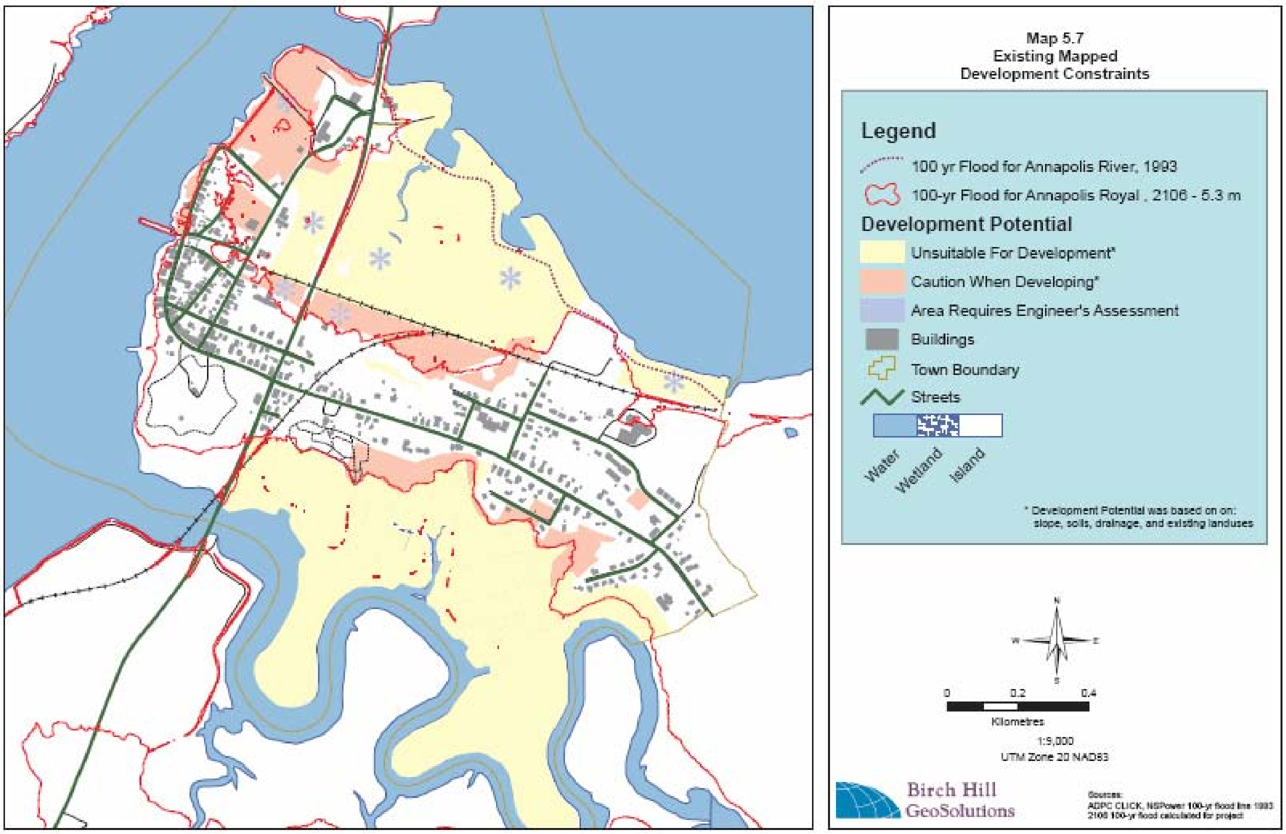

Fire
Department
Map 5.4
100-Year Flood Due to Climate Change
Annapolis Royal, Nova Scotia
Legend
100 Year Flood without Climate Change 4.8 m
100 Year Flood with Climate Change 5.3 m
Town Boundary
Orthophoto - May 2003
N
W
E
S
0
0.25
0.5
Kilometres
1:7,500
UTM Zone 20 NAD83
Birch Hill
GeoSolutions


Map 5.5
200-Year Flood Due to Climate Change
Annapolis Royal, Nova Scotia
Legend
200 Year Flood without Climate Change 5.1 m
200 Year Flood with Climate Change 5.7 m
Town Boundary
Orthophoto - May 2003
N
W
E
S
0
0.25
0.5
Kilometres
1:7,500
UTM Zone 20 NAD83
Birch Hill GeoSolutions

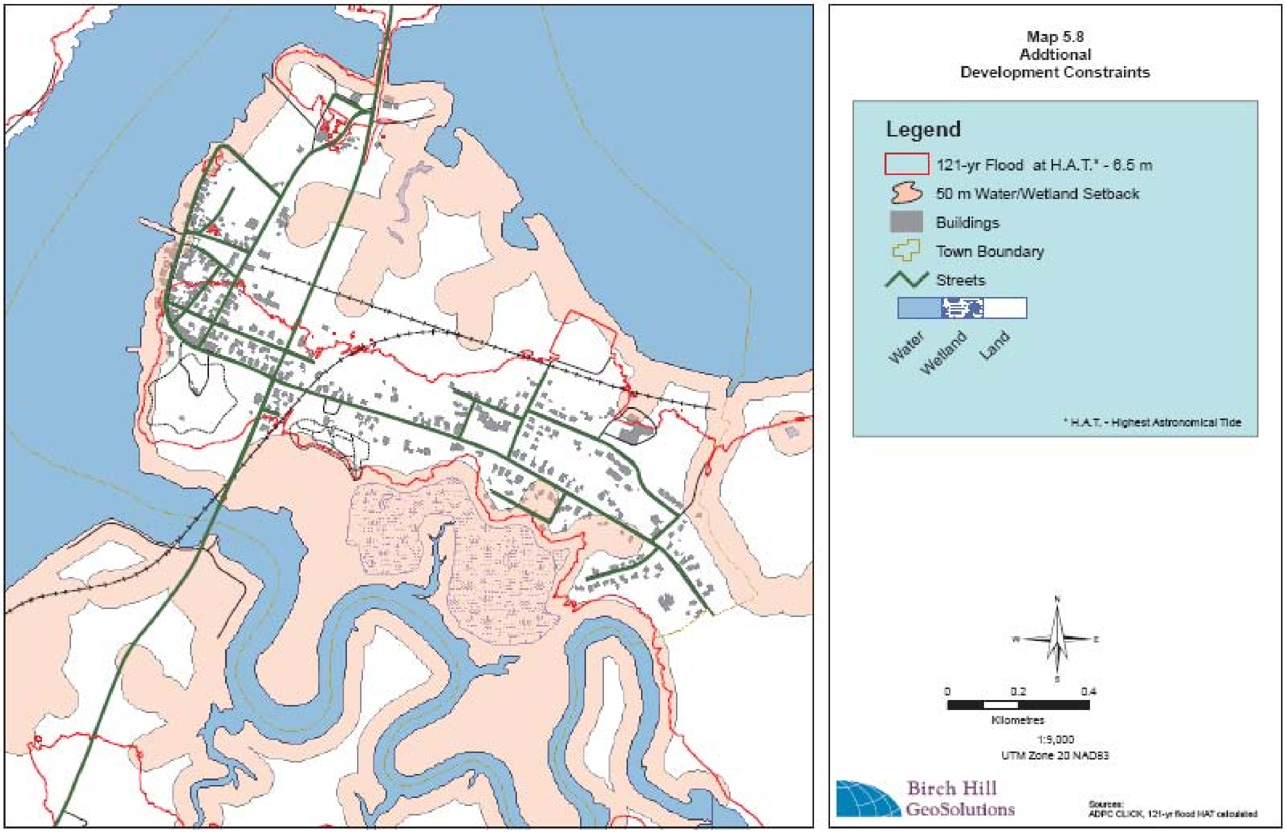

Map 5.6
121-Year Flood of 1976
(Groundhog Day Storm)
Annapolis Royal, Nova Scotia
Legend
Average Water Level 5.4 m
Water Level at Highest Astronomical Tide 6.5 m
Water Level with Wave Run-up 7.5 m
Town Boundary
Orthophoto - May 2003
N
W
E
S
0
0.2
0.4
Kilometres
1:7,500
UTM Zone 20 NAD83
Birch Hill GeoSolutions

Annapolis Royal Land Sensitivity Analysis

After calculating and mapping flood return periods with climate change factored in, we then went to the next step, adding our projected 100-year flood with climate change, with a 5.3 metre average water level, to Annapolis Royal's existing mapping Development Constraints map, shown in Map 5.7. The projected year is 2106, since the 100-year flood, by definition, is *projected* to occur once in the next 100 years. Of course, it is a well-known fallacy to expect that this is exactly what will actually occur. Two 100-year floods can occur in consecutive years, or not at all during the time period projected.

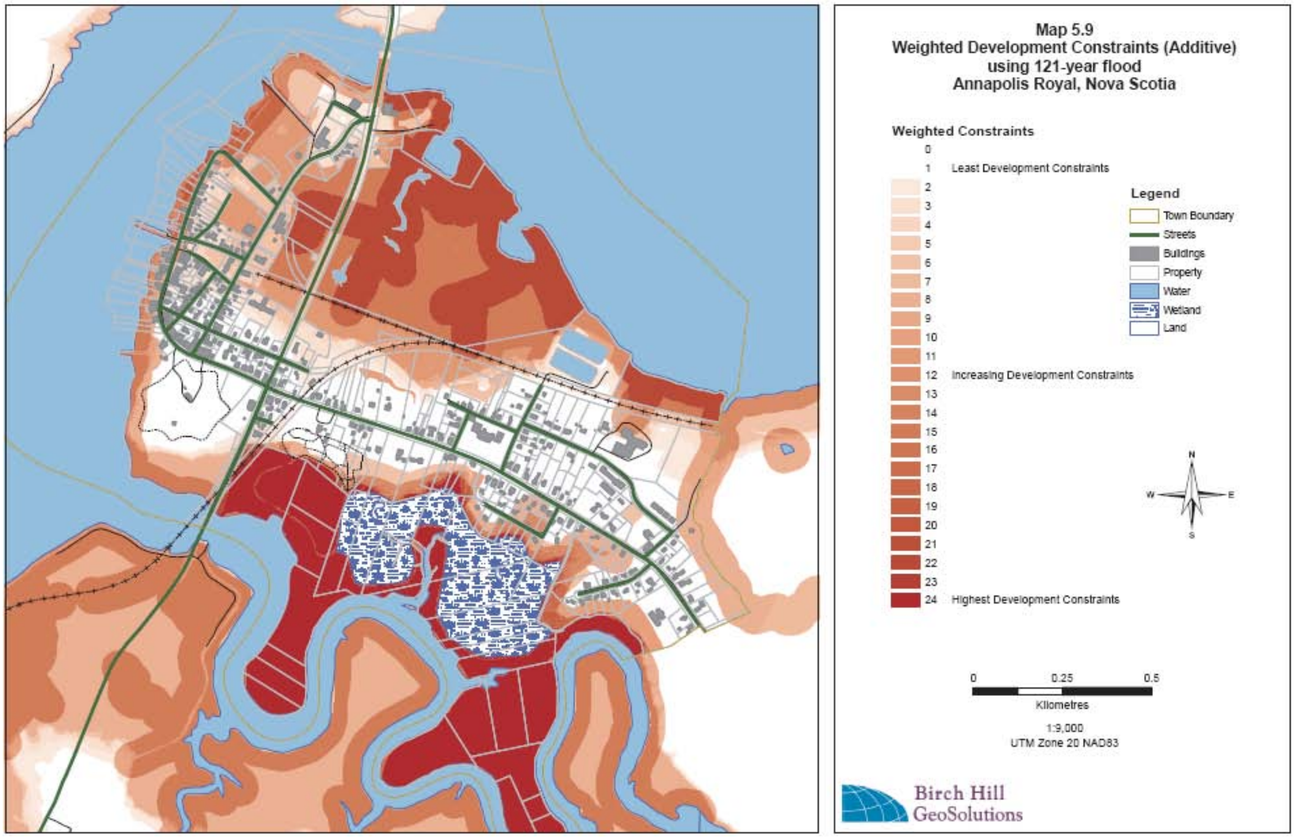


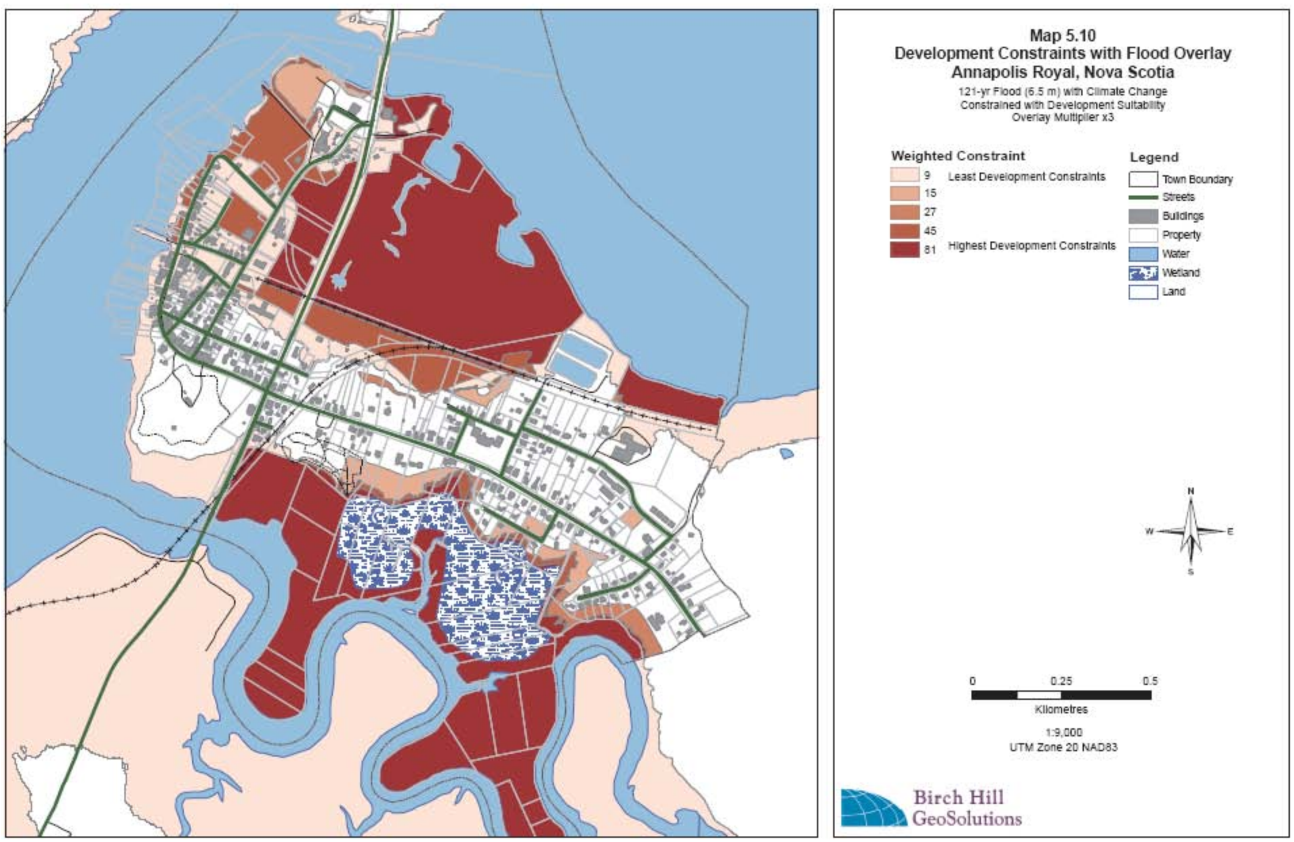
To complete our concept of what land use planning factors should be included in Annapolis Royal's existing Development Constraints map, we mapped additional Development Constraints in Map 5.8. These are a 50 metre development setback from water and wetlands, and the additional level of flooding from our thoroughly analyzed 121-year actual storm of 1976 at highest astronomical tide, with a flood level of 6.5 metres.

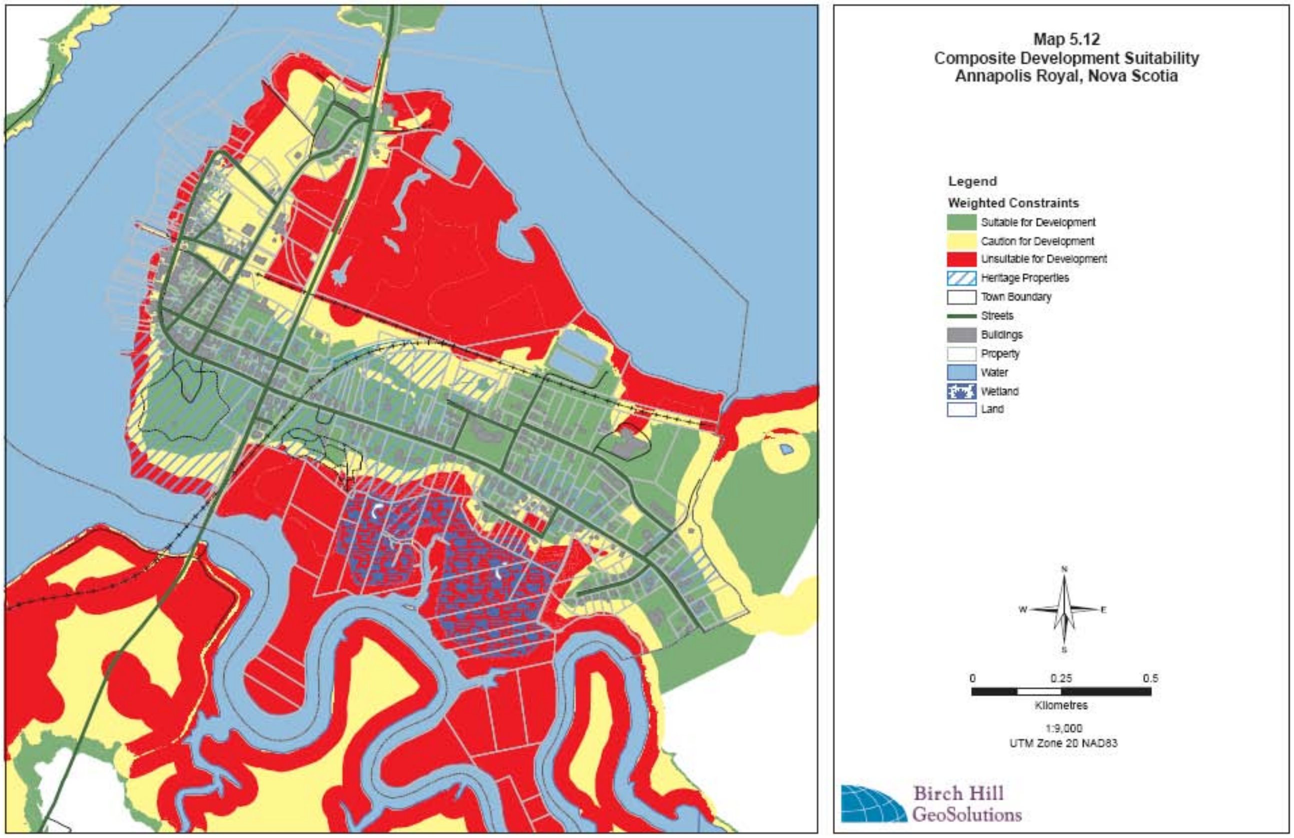


Our next step was to weight these development constraints in Map 5.9, using our GIS modelling tools, since for land use planning purposes, all constraints are not considered equal in terms of future development locations. For an explanation of how weighting can be done in Land Sensitivity Analysis, see the Technical Appendix. In Map 5.10, we used the 50-year flood instead of the 100-year flood, for the sake of comparison, and used a different weighting technique. In Map 5.9, our GIS modelling tool *added* up the overlapping polygons of values of development constraints, and then assigned colours to the numbers.

In Maps 5.10 and 5.11, we tested our GIS tool using overlay *multipliers.* In using an overlay multiplier, municipal planners and engineers would use their expertise to assign a constant value weight to an overlay factor, in this case projected flood levels, which the GIS modelling tool then multiplies by the values of the underlying development constraint polygons, which in this case are the existing development constraints already mapped for Annapolis Royal by the Annapolis District Planning Commission. In Map 5.10 we used the 121-year flood and 5.11, we used 50-year flood projections, which will affect the most critical developed and undeveloped parcels along the waterfront. We kept the multiplier at 3 times for both of these maps, and we kept the colour values coding the same, so that the only variable that is different is the flood year. The differences in mapped values between these two maps caused by the different flood projections with climate change can be clearly seen.


Map 5.9
Weighted Development Constraints (Additive)
using 121-year flood
Annapolis Royal, Nova Scotia
Weighted Constraints
0
1 Least Development Constraints
2
3
4
5
6
7
8
9
10
11
12 Increasing Development Constraints
13
14
15
16
17
18
19
20
21
22
23
24 Highest Development Constraints
Legend
Town Boundary
Streets
Buildings
Property
Water
Wetland
Land
N
W
E
S
0
0.25
0.5
Kilometres
1:9,000
UTM Zone 20 NAD83
Birch Hill
GeoSolutions


Map 5.10
Development Constraints with Flood Overlay
Annapolis Royal, Nova Scotia
121-yr Flood (6.5 m) with Climate Change
Constrained with Development Suitability
Overlay Multiplier x3
Weighted Constraint
9 Least Development Constraints
15
27
45
81 Highest Development Constraints
Legend
Town Boundary
Streets
Buildings
Property
Water
Wetland
Land
N
W
E
S
0
0.25
0.5
Kilometres
1:9,000
UTM Zone 20 NAD83
Birch Hill
GeoSolutions



In Map 5.12, we simplified the results from all of the preceding maps into a Composite Development Suitability map. The resultant "weightings" are a simplified three-pronged planning land use decision tool: 1. Suitable for Development; 2. Caution for Development; and 3. Unsuitable for Development. These are standard classifications in Land Use Planning. For land use planning purposes, the more finely divided classifications we used to arrive at this simplified end product would be too unnecessarily complicated to implement through revised land use by-laws. Also, a finer level of detail is not clearly supported by the rather subjective weighting and scaling values assigned to the mapped variables by municipal Land Use Planners and Engineers. This is basically our land use adaptations map, since it provides the locational classifications needed to guide implementing legislation of municipal land use controls (zoning and subdivision by-laws). Since our climate change flooding constraints on future development have been combined with the existing Annapolis Royal mapped development constraints, this represents a now complete amended Development Suitability Map, which can now be used to help guide future land use development decisions (adapatations to *all* environmental development constraints, including climate change impacts on flooding), in Annapolis Royal. Existing heritage properties are included, since these properties are enourmously important to the culture and tourism industry in this very historic town. The location of these properties with respect to environmental constraints, especially flooding, is important in terms of structural adaptations to flooding.

The methodology used in constructing our final Annapolis Royal Map 5.13, Build Out Analysis, has been previously explained in this chapter. Our GIS modeling tool was used to perform calculations based on this map, which will be of use to Annapolis Royal in their planned upcoming build-out analysis. There are 200 lots in Annapolis Royal which are not gray, i.e., do not have existing maximum development and/or are not unsuitable for development. This map will need to be further refined in the future, with input from the Annapolis Royal Town Council and the Annapolis District Planning Commission, since there are road access issues, potential amendments to zoning by-laws, and other factors that should be factored in, but were beyond the scope of this project. Our GIS modeling tool calculated the total area of these lots, superimposed on the existing Annapolis Royal zoning map, to arrive at total land areas for each existing residential zoning district in green (suitable for development) and in yellow (caution for development).

Suitable for Residential Development:

Residential 1 district: 81,235 m2

Residential 2 district: 27,900 m2

Residential 3 district: 10,980 m2

Waterfront 2 district: 0 m2

Caution for Residential Development:

Residential 1 district: 121,850 m2

Residential 2 district: 54,645

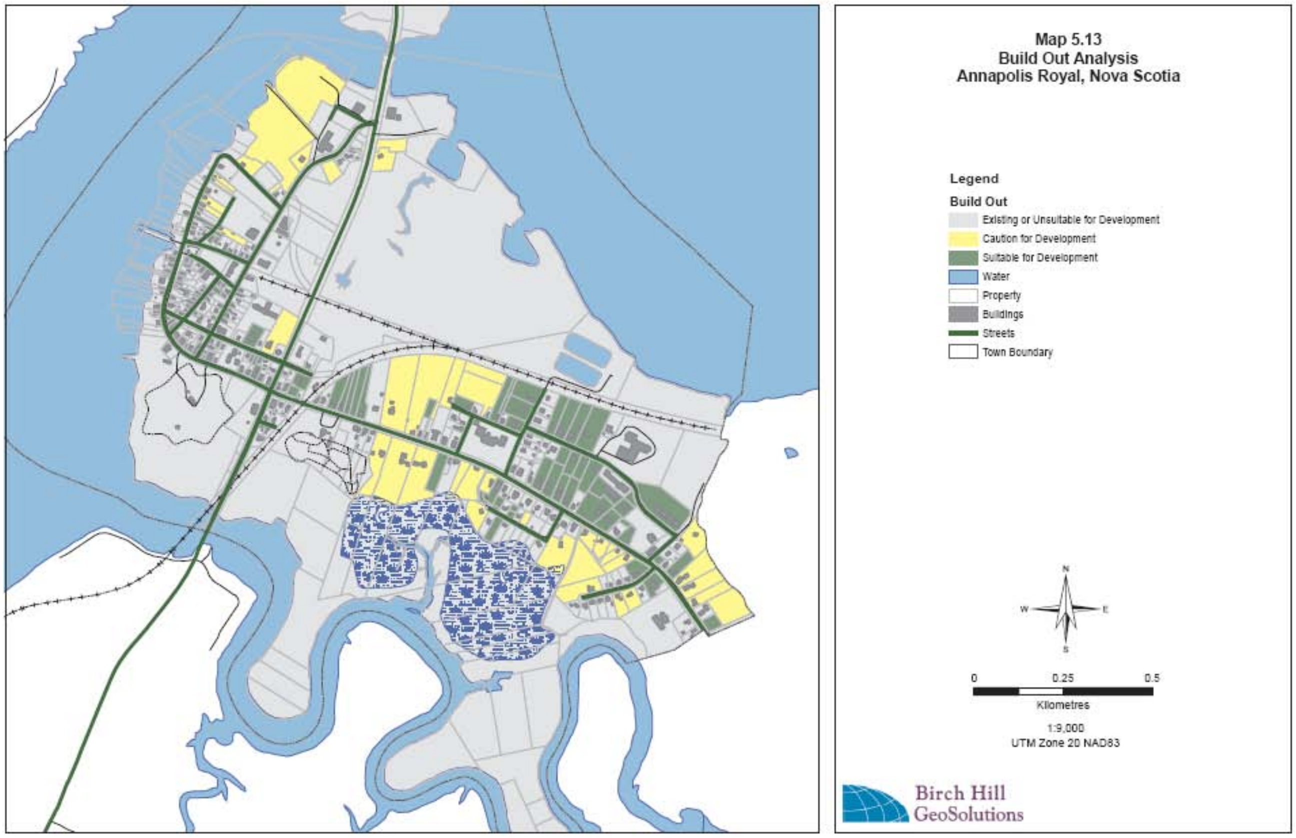
Residential 3 district: 0 m2

Waterfront 2 district: 62,077 m2

The reason we focused our analysis solely on *residential* development, is that Annapolis Royal now has approximately half of its original population of the approximately 1,000 residents it had when the Town obtained municipal status (1,000 residents is required for this), and so is very actively searching for new residential development locations. The most likely additional residential development possibilities are not the lots with existing buildings, which would require complicated revisions to the Land Use and Subdivision By-laws for further development, but rather the few larger undeveloped parcels, most of which will be subject to increased flooding from climate change.

We further tested our GIS tool to calculate the mean assessed values of buildings on the Build Out map up to 150 m2, since this is important information in terms of potential reduction of values due to the impacts of increased flooding from climate change. The mean assessed value of the 27 buildings is $65,810, with a minimum of $11,800 and a maximum of $295,500. For buildings of 150 -1,250 m2, the mean value of the 22 buildings is $128,720, with a minimum value of $11,600 and a maximum value of $305,400. The school building is 3,755 m2, with an assessed value of $4,904,000. The county assessor has requested results of our flooding impacts analysis, since he feels this is important information that should be included in his assessments. The impacts this could potentially have on property values is a politically and economically difficult issue, which we are still discussing with Annapolis Royal Council. In addition, property flood insurance rates for non-residential buildings (since residential properties are not covered by property insurance in Canada), could be affected.

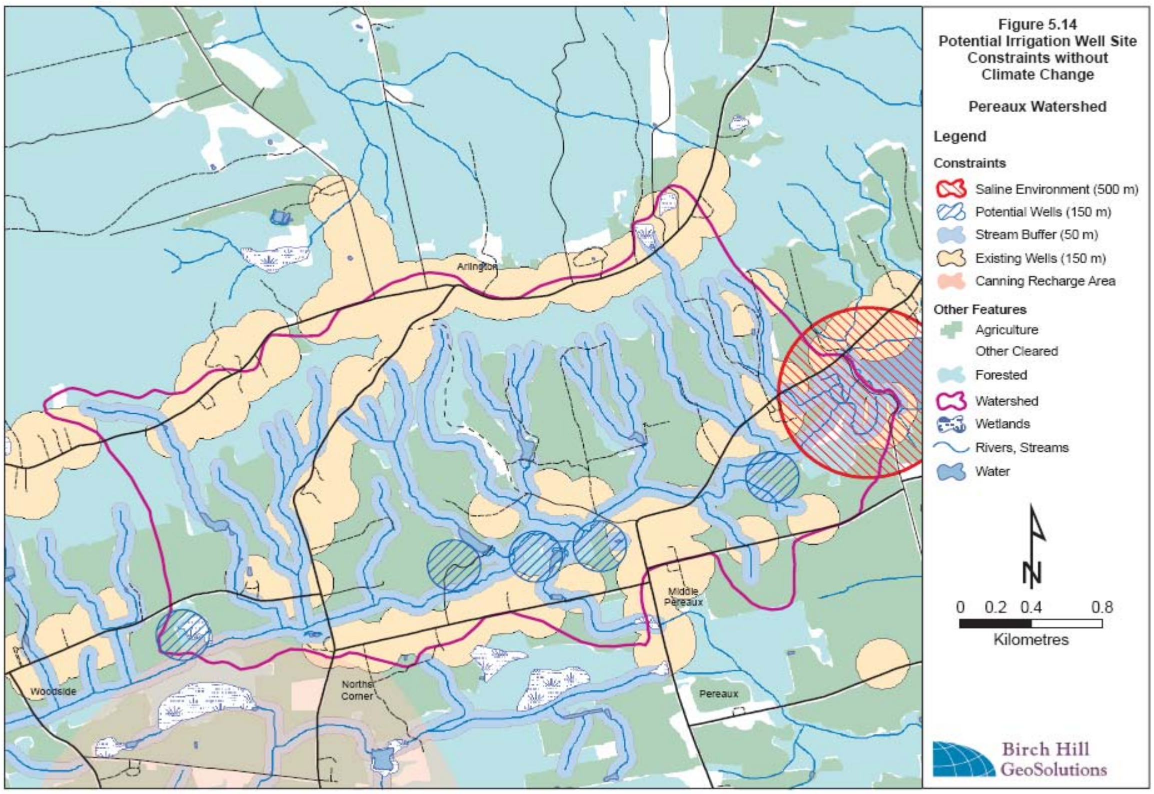
These analyses illustrate the number of ways in which our climate change flood impacts GIS modeling tool can be used to assist municipal Land Use Planners in various planning analyses.



One of the new subdivision developments, which Annapolis Royal is currently negotiating with developer, is going to be a "green development". Annapolis Royal is very interested in including our climate change flooding impacts and adaptation analysis in this new development.

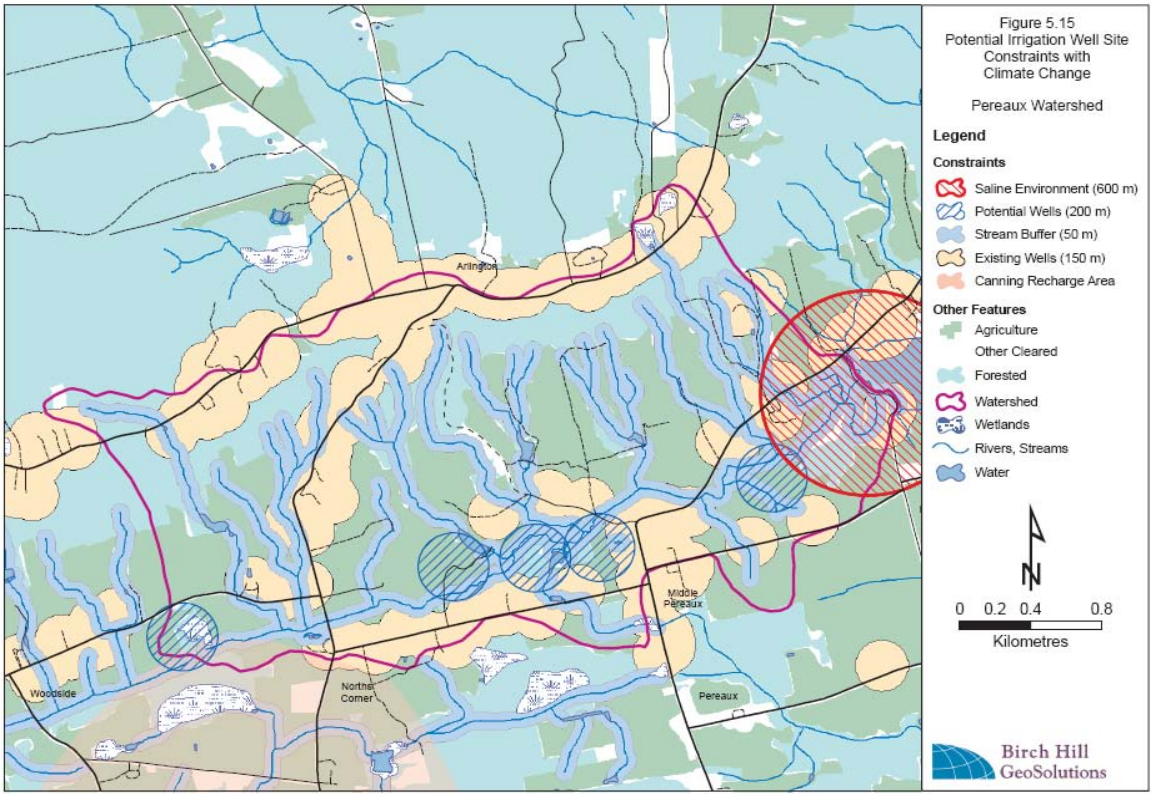
Pereau Watershed GIS Mapping

Our Pereau watershed test case site was evaluated primarily for climate change impacts on potential exacerbation of agricultural drought, and future residential development. While we interviewed all farmers in the watershed, this did not shed much light on climate change impacts and adaptations, which have been well covered scientifically in pervious sections of this report. Also, our drought risk and cost/benefit analysis tools were developed and applied scientifically, without information from the farmers, since none of the farmers had done much in the way of calculations of crop losses due to droughts in the past. Our GIS mapping of climate change impacts on agricultural drought is thus, limited to Maps 5.14 and 5.15, which are our subjective assessments of the impacts of climate change on an increase in the area of saline environment in the dykeland and near-shore agricultural areas, and an increase in the protection area of well buffers (from development), that will be needed due to climate change impacts on drought.



Source: Adapted from CBCL Limited and Jacques Whitford, 2003

Since it is difficult to project climate change impacts on hydrogeology, these two maps are rather subjective in their climate change impacts. What we really have mapped here is an adaptation to climate change via increasing well buffers.



Source: Adapted from CBCL Limited and Jacques Whitford, 2003

Relationship to Land Use Planning of Subdivisions

Dealing with these water supply concerns is a major issue for planners. Many residents will not admit to poor water supply capacity due to fear of reduced property values. When the Municipality tries to connect the affected areas to municipal services, many owners will not sign on due to onerous frontage charges applied by the municipality, especially if their wells can still provide adequate yield, resulting in enclaves of on-site serviced lots within an urban boundary. This situation is to be avoided, as urban impacts to groundwater quality will adversely affect the groundwater quality.

When it comes to regional and urban development, the water supply source, be it groundwater or surface water, cannot be considered to be infinite. In the case of groundwater sources, the water supply is limited to a balance between site-specific hydrogeology that controls recharge and storage, and demand. Areas with thick glacial deposits overlying fractured sedimentary bedrock tend to have much greater groundwater supply development capacity than areas with thin or nonexistent overburden overlying tight fractured crystalline bedrock. Planners therefore need to consider the hydrogeology when assessing groundwater availability.

Chapter 6 Recommendations

Some recommendations are included in the individual sections of this report, and are not repeated here. Below are general recommendations for Land Use Planners.

6.1 Linear Progression for Including Climate Change Impacts in Land Use Planning

1. Consider results from this project's analysis maps, including:

- **Flood frequency maps** in updating the existing Annapolis Royal Development Suitability Map.
- **Composite Development Suitability Map** in updating the existing Annapolis Royal Future Land Use Map, and in writing policies in the Strategic Plan update.
- **Build-Out Analysis Map** and table in updating the existing Annapolis Royal Future Land Use Map, and in writing policies in the Strategic Plan update. Develop the additional detail that may be needed for individual potential new lots.

2. Based on the above, make recommendations in the plan update for updating the Annapolis Royal Land Use By-law, and the Zoning map, with regard to development types, locations, and densities.

3. Based on the **Risk/Cost/Benefit Analysis** from this project, consider further which flood-proofing measures the Town might want to undertake for existing development. Also, educate residents, though distribution of a brochure, in the costs and benefits of flood-proofing and storm-proofing measures they might want to undertake.

4. Incorporate **climate change adaptation best practices** into municipal public works practices and engineering designs, such as best practices for stormwater management, sump basin design and maintenance, new infrastructure design and location, etc.

5. Consider building **climate change adaptations into new subdivisions** in the Town, and into the Town's Subdivision By-law. This would include: greener stormwater management, flood-proofing as necessary, increasing wind resistance, using energy efficient building to help adapt to more extreme high and low temperatures, and decreasing the "ecological footprint" in many ways to help adapt to climate change, such as channeling runoff to infiltration basins, using permeable, frost-resistant paving, leaving a natural buffer along water courses, etc.

6. Consider starting a local flood **monitoring program** to track flood levels and frequencies. Results of this will help determine whether our projections need to be updated 25, 50, 100 years from now.

7. During construction of new subdivisions and their associated infrastructure, keep track of **costs to build green** for climate change adaptation and mitigation, versus costs for traditional development. Based on the risk/cost/benefit analysis of this project, do a more detailed risk/cost/benefit assessment to address the full-life-cycle costs of green versus traditional subdivision design and construction. After construction of the "green subdivision", write a brief report on the success or

lessons learned from implementing municipal and residential flood-proofing, the costs and benefits of energy efficiency, and other green practices, and make it available for distribution by the climate change hubs in Atlantic Canada, as well as through the Atlantic Institute of Planners, the Gulf of Maine Times, and local stewardship groups.

6.2 Tools Summary

Tool 1: Climate Change Modeling
Our stochastic modelling tool proved to be an effective method of downscaling climate change to local conditions. It has the added advantage of being useful in risk analysis as well. Its use is limited by the expertise of the user, and would require assistance from the model's creator, Dr. Gordon Fenton. Further analysis of this tool for use on a regional or provincial level is highly recommended.

Tool 2: Coastal Flooding
Our coastal flooding tool using Water Modeler was very successful. Its use may be limited by the expense of using LIDAR, and the skill level of the user. This would be an excellent tool for provinces to use in mapping coastal flooding projections due to climate change. Further analysis of this tool for use on a regional or provincial level is highly recommended.

Tool 3: Inland Flooding
Existing hydrology tools for modelling inland flooding can be easily adapted to incorporate climate change, since climate change affects the parameters of the models. However, climate change impacts on these parameters can be difficult to assess. Further analysis of this tool for use on a regional or provincial level is highly recommended.

Tool 4: Groundwater Modeling
As with hydrology tools, existing tools for modelling hydrogeology can be easily adapted to incorporate climate change, since climate change affects the parameters of the models. However, climate change impacts on these parameters can be difficult to assess. We highly recommend that these tools be used in developing densities and lot sizes in municipal planning applications.

Tool 5: Risk Assessment
Existing risk assessment techniques can be adapted to climate change, as we have demonstrated in our model. Although this may not practical for an individual landowner to do, on the municipal or regional level this tool can be quite useful in assessing the impacts of climate change. We highly recommend that these tools be used at a regional level in assessing the viability of agriculture in the face of climate change.

Tool 6: GIS Modeling
Our GIS models are easy for a GIS analyst to use to incorporate climate change into the municipal land use planning process. However, the use of these tools is limited by the availability of climate

change flooding projections. We highly recommend that this tool be used in municipal land use planning when the climate change data is available.

Tools 7: Implementation

The numerous implementation tools we reviewed all are effective implementation of climate change adaptations. While none of these tools were designed for climate change adaptations implementation, we highly recommend that climate change factors be incorporated when the data is available.

6.3 Recommendations Already in Progress

1. Our team analyzed climate change impacts on Nova Scotia’s proposed new Septic Regulations, and submitted these recommendations to the Province during the public comment period. We do not yet know if any of our recommendations are going to be used.

2. Our team analyzed climate change impacts on Halifax Regional Municipality’s (HRM) Growth Management Plan, and submitted them to HRM during the public comment period. These have mostly not been incorporated into the new Growth Management Plan. Our recommendation to include mass balancing (sustainable yield) analysis in designing minimum lot sizes in rural areas not on public sewer and water systems has been incorporated, but most likely would have been anyway. Our recommendation to include assimilative capacity analysis (groundwater quality protection) was not used, but should have been, since this is usually a more limiting carrying capacity factor than safe yield.

3. Our team is currently working with the Federation of Canadian Municipalities (FCM) on revising their Green Municipal Fund Guidance Document to include climate change impacts and adaptation factors, which work will be on-going during the coming year. This is a very important implementation tool for our research, since it is a *major* source of funding for municipalities to do sustainable Land Use Planning research and construction. In addition, FCM has a very active sustainable development program, to which we are also contributing climate change impacts and analysis recommendations.

4. To implement our recommendations for sustainable development with respect to climate change impacts, we are actively in negotiations with several subdivision developers in Nova Scotia, as well as one in Fredericton, New Brunswick, to include climate change impacts and adaptations in their proposed “green” subdivisions.

5. With regard to development of new potential shared agricultural irrigation wells in the Pereau Watershed, we do not expect much to happen, since the funding to construct this infrastructure is lacking. However, we have made recommendations to the individual farmers we have interviewed in regard to water conservations strategies.

6. Our team is currently working with the Nova Scotia Department of Fisheries and Aquaculture on putting together a major project on coastal watershed protection in Nova Scotia, and this project will include climate change impacts and adaptations.

6.4 Recommendations for Future Research

1. Preparation of Model municipal By-laws to include climate change impacts and adaptations would be enormously useful, if funding to write these can be obtained.

2. More detailed analysis of municipal budgeting capabilities in terms of their capacity to include climate change impacts and adaptations is needed, since municipalities in Nova Scotia are already required to update their municipal plans every five years, and thus, climate change impacts adaptations could be included at that time. Other funding sources are summarized in the Technical Appendix.

3. We will follow up this study with a detailed table of data sources, costs, and timeframes to assist municialities in implementing our toolkit.

Aboiteau: (French) A one-way sluice, or gate, devised for allowing water to drain from a dyked agricultural field, while preventing salt water from entering at high tide.

Adaptability: The degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate; adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions.

Anthropogenic: Changes caused or produced by human actions or interventions.

Aquifer: A subterranean porous water-bearing formation capable of yielding–usable quantities of water.

Best Management Practices (BMPs): In natural resources management, refers to a set of standards that have been designed for an activity, and often a region, to protect against degradation of resources during management operations.

Catchment: A region having a common outlet for its surface water runoff, i.e., a sub-watershed or drainage basin. Also, an engineered sump structure designed for receiving stormwater runoff.

Climate Change (UF Global Warming): Human activities are altering the chemical composition of the atmosphere through the build-up of greenhouse gases that trap heat and reflect it back to the earth's surface. This is resulting in changes to our climate, including a rise in global temperatures, rising sea levels, and more frequent extreme weather events. The gradual change in global climatic conditions due to either natural influences (volcanoes, changes in solar radiation, etc.) or anthropogenic actions (burning of fossil fuels, deforestation, alteration of bodies of water). These phenomena cause the build-up of greenhouse gases in the atmosphere, thus trapping more heat, leading to wider fluctuations in weather patterns and more frequent and extreme weather events.

Datum: a reference point or surface against which position measurements are made, and an associated model of the shape of the earth for computing positions. Horizontal datums are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system. Vertical datums are used to measure elevations or underwater depths.

Dendritic: The tree-like branching form of the drainage pattern of a stream and it's tributaries, with the main trunk, branches, and twigs corresponding to the main stream, tributaries, and subtributaries, respectively, of the stream.

Diurnal Climate: A climate with uniform fluctuations of temperature throughout the year.

Ecosystem: The sum of the plants, animals, environmental influences, and their interactions within a particular habitat.

Environmental Assessment: Carrying out an environmental assessment means determining or estimating the value, significance or extent of damage to a particular ecosystem or aspect of it. An environmental investigation that will estimate the outcome of a certain course of action on a particular ecosystem or aspect of it.

Estuary: An area encompassing the confluence of salt and fresh water. They are usually located at the mouth of rivers that flow directly to the ocean or an arm thereof.

Evapotranspiration: Loss of water from a land area through transpiration (e.g., water vapour loss through leaves) of plants and direct evaporation from the soil.

Flooding: The overflowing of a body of water beyond its normal confines, especially over land. Flooding may occur as a result of heavy rainfall, obstructions in its watercourse (ice) or, in spring, as the result of a sudden melting of ice and snow.

Geodetic: Referring to the shape and dimensions of the earth.

Geoid: the equipotential surface of the earth (a surface of equal gravity potential) which most closely matches mean sea level. An equipotential surface is normal to the gravity vector at every point.

G.I.S.: Geographic Information System – a computer-based analysis and mapping system for spatially linked data sets.

Groundwater Recharge: The process by which external water is added to an aquifer's saturation zone, either directly into a formation or indirectly through another formation.

Habitat: The immediate environment occupied by an organism, in forestry, habitat usually refers to the animal habitat.

Hindcast: A way of testing a model. Realistic inputs for the past are fed into the model to see how well the output matches reality.

Hurricanes: Hurricanes are rotating air masses of tropical origin (occurring in the northern hemisphere), with wind speeds of at least 118 kilometres per hour (64 knots). The winds in a hurricane rotate inwards to an area of low barometric pressure. This relatively calm centre is called the "eye". In the southern hemisphere, these rotating air masses are called typhoons.

Infiltration: The flow of water through the soil surface into a porous medium (e.g., aquifers).

Infrastructure: The basic installations and facilities upon which the operation and growth of a community depend; these include: structures and buildings such as schools, electric, gas, and water utilities; transportation and communications systems; and so on.

Kinematic: The branch of mechanics concerned with the motions of objects without being concerned with the forces that cause the motion.

Nutirification: Water pollution caused by runoff of nutrients, such as nitrate, causes the proliferation of algal blooms and weed growth in receiving waters. When such vegetative growth in water dies and decomposes, oxygen in the water is consumed, resulting in a reduction of dissolved oxygen for fish and other organisms. Also, high nitrate levels in drinking water is harmful to human infants, causing the "blue baby" syndrome.

Orthometric: Refers to the height of an object or point above the Earth's surface along a plumbline, as determined by gravity.

Orthophotography: In aerial photography there are displacements of images due to tilt and relief. Orthophotography is the process of removal of these displacements.

Potential Production: estimated production of a crop under conditions when nutrients and water are available at optimum levels for plant growth and development; other conditions such as day length, temperature, soil characteristics, etc., determined by site characteristics.

Precipitation: Any form of water, such as rain, snow, sleet, or hail, that falls to the earth's surface.

Preparedness (environmental emergencies): Readiness to respond to an environmental emergency is crucial to minimizing the harmful effects it could have on the environment.

Prevention (environmental emergencies): A variety of strategies to help prevent environmental emergencies from occurring, whenever possible. These include education, regulations and other legal instruments governing the handling of all hazardous materials.

Riparian: relating to or living or located on the bank of a natural watercourse (as a river) or sometimes of a lake or a tidewater.

Risk Assessment: A risk assessment is an estimate of the chance that environmental or health problems will result from a particular activity. Risk assessments play an important role in determining controls for the manufacture, use and transportation of all hazardous materials, including toxic chemicals.

Runoff: water (from precipitation or irrigation) that does not evaporate or seep into the soil but flows into water courses such as rivers, streams, or lakes, and may carry sediment.

Salinization: The accumulation of salts in soils and water. De-Salinization is one of the methods used to produce potable water in regions that lack sufficient natural fresh water.

Sedimentation: Deposition of sediment, i.e., soil particles, in a water body.

Soil Erosion: The process of removal and transport of topsoil by either water ~~and/~~ or wind.

Stakeholders: Person or entity holding grants, concessions, or any other type of value which would be affected by a particular action or policy. Also, people or entities that could be affected by certain actions or policies.

Storms: Atmospheric disturbances manifested in strong winds accompanied by rain, snow, or other precipitation and often by thunder and lightning.

Susceptibility: probability for an individual or population of being affected by an external factor.

Sustainable: a term used to characterize human action that can be undertaken in such a manner as to not adversely affect environmental conditions (e.g., soil, water quality, climate) that are necessary to support those same activities in the future.

Sustainable Development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In other words, development is essential to satisfy human needs and improve the quality of human life. At the same time, development must be based on the efficient and environmentally responsible use of all of society's scarce resources - natural, human, and economic.

Theodolites: a surveying instrument for measuring horizontal and vertical angles, consisting of a small telescope mounted on a tripod.

Total stations: an optical instrument used in modern surveying. It is a combination of an electronic theodolite, an electronic distance measuring device (EDM) and software running on an external computer.

Urbanization: the conversion of land from a natural state or managed natural state (such as agriculture) to urban (cities or towns) use.

Vulnerability: the extent to which climate change may damage or harm a system; it depends not only on a system's sensitivity, but also on its ability to adapt to new climatic conditions.

Water-use Efficiency: carbon gain in photosynthesis per unit water lost in evapotranspiration; can be expressed on a short-term basis as the ratio of photosynthetic carbon gain per unit transpirational water loss, or on a seasonal basis as the ratio of net primary production or agricultural yield to the amount of available water.

Wetlands: Wetlands are land where the water table is at, near or above the surface, or which is saturated for a long enough period to create such features as wet-altered soils and water-tolerant vegetation. They include bogs, fens, marshes, swamps and shallow open water. Wetlands are threatened by human development and water pollution.

Xeric: Plants requiring only a small amount of moisture.

References cited in the document are listed in scientific notation, with full references here, listed by chapter of the report. However, when the reference is for a website, it is "in-line" in the document, and is not repeated here. References cited in the Technical Appendices are at the end of each chapter. A list of additional resources, including websites and documents, can be found in the Technical Appendix.

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