

Climate Change Impacts and Adaptations for Land Use Planners

Executive Summary

1. Introduction

The purpose of this project was to research, develop, and test “tools”, i.e., methodologies, for Canadian communities to use in analysing climate change projections and impacts on land uses in their communities, and implementing adaptations to these impacts. The main text is geared toward Land Use Planners and other municipal officials. It is supplemented by more detailed descriptions for engineers in the Technical Appendix.

Land Use Planners, as their name implies, deal with the use and management of land. In order for a municipal Land Use Plan to be “sustainable” it must be environmentally, socially, and economically sound. There is already an existing need for more sustainable Land Use Planning in many communities across Canada. Since climate change is expected to increase environmental impacts on land uses in the future, there could be an even greater need for incorporating more scientific analysis into Land Use Planning policies and practices. Although there is still a great deal of uncertainty with regard to climate change projections and impacts, climate change policies that already meet an existing need, e.g., floodplain development restrictions, are “policies of no regrets”.

In this study 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. Our toolkit is geared toward rural municipalities in the Atlantic Provinces, and south-western Nova Scotia in particular; however, most of the tools we developed would also apply to coastal communities in other areas.

2. Methodology

Our research methodology followed the logical progression outlined below:

- climate change impacts background review (Chapter 1 and 2)
- analysis tools research and tool development (Chapter 3),
- implementation tools research (Chapter 4),
- testing our tools at two test sites in Nova Scotia’s Annapolis Valley area (Chapter 5), and
- recommendations for using our tools to assess and adapt to climate change (Chapters 3, 4, and 6).

Climate Change Impacts

Atlantic Canada is one of the more complicated areas in the world in terms of climate change, due to changing ocean currents and to changing sea levels. Thus, some areas of Atlantic Canada may become warmer and drier, while others may become cooler and wetter. While most of Atlantic Canada will experience sea level rise, some northern areas will experience a fall in sea level, due to crustal rebound from past melting glaciers. Potential climate changes include: sea level changes, sea ice changes, temperature changes, precipitation changes, wind changes, an increase in the frequency and severity of severe weather events, e.g., storms and droughts, and more climate variability. Each climate change element could, in turn, cause other impacts. For example, sea level rise and storm surge could cause flooding and coastal erosion. Precipitation falling in shorter, more intense bursts could cause more rapid runoff, thus more non-point source pollution and less infiltration to groundwater. We focused on two major impacts: coastal flooding in Annapolis Royal, and drought in Pereau River watershed.

Climate Change Adaptations

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 existing land uses to climate change impacts. 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 many adaptations appropriate to the specific use. For example, flood-proofing existing structures, or finding new irrigation sources for crops on droughty soils.

Climate Change Analysis Tools

After researching secondary sources on climate change impacts in Nova Scotia, and to a lesser extent, the rest of Atlantic Canada, we then reviewed the *analysis tools* that municipal and consulting engineers and scientists can use to inform Land Use Planners with regard to climate change impacts in local communities. We looked for tools that would help Land Use Planners answer the following questions:

- 1) **Climate Change Modeling Tools:** How will the climate change in my community?
- 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?
- 3) **Inland Flooding Hydrology Analysis Tools:** How will climate change impact inland flooding, and what tools can be used to determine safe setbacks from surface water for new structures and infrastructure?
- 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?
- 5) **Risk and Cost/Benefit Analysis Tools:** Once we know climate change impacts, how do we assess the risks and cost/benefits of these impacts on coastal flooding and agricultural drought?
- 6) **GIS Analysis Tools:** Once we know localized climate change projected impacts, and the risks and cost/benefits of it from the proceeding tools, how can we then incorporate this knowledge into community land use planning *locational* decisions for future land uses, and adaptations for existing land uses?

7) Climate Change Implementation Tools

Concurrently with our research on climate change impacts analysis adaptation tools, we researched climate change implementation adaptation tools. While some implementation tools are fairly obvious, e.g., municipal Land Use Planning policies and by-laws, where a Land Use Planner might have direct influence; others, such as federal or provincial legislation, and property insurance practices, are more indirect, although they are effective at influencing land uses. Thus, we researched both, which include the following:

- Engineering Codes of Practice,
- Regulations and Administrative Practices Related to Land Use Planning,
- Building Codes,
- Sustainable Buildings Adaptations, and
- Emergency Management.

Tools Testing

We tested all of our analysis tools at one of our two test sites, since neither of our two test sites by itself was a complete example of rural Land Use Planning. The small rural Town of Annapolis Royal is an excellent example of flooding problems, but is on public sewer and water and has little agriculture; whereas the Pereau River watershed is not on public sewer and water and has an agricultural base. Unlike our analysis tools, which could be tested in actuality at our two test sites, we could only test our implementation tools in *theory*. This is because in order to be implemented, legislation must be amended, or Best Practices have to change, etc. While we could make recommendations for these improvements, we could not actually implement them, since it is not within our purview to make these changes. After testing our tools, we formulated recommendations for their use, and in some cases, for further revision and testing. The remainder of this Executive Summary focuses on descriptions of the purpose and testing of our main tools, with our three main new tools described in more detail. These are Climate Change Modeling Tools, Coastal Flooding Tools, and Risk /Cost/Benefit analysis tools.

3. Climate Change Modeling Tools

Model Purpose

An important first step in our study was to develop a climate change tool that would help us downscale global models to our test sites. This would not only tell us how the climate was changing at our test sites, but would

also tell us the feasibility of a user-friendly model that could run on a personal computer. 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 existing models. Thus, we needed a model that goes beyond what is currently available, and would also enable us to directly compute risks.

Model Description

The model we developed for our study is a Stochastic Climate Model. We basically assume that the future *mean* behaviour is as predicted by Global Climate Models (GCM), but that weather *variability* is as seen in the past. This model allows for changes in the mean (temperature, precipitation, wind speed) and applies site specific past variability to predict future extremes. This is a "best estimate" approach to predicting future climate risk. Our model involved first of all analyzing past data and deciding what distribution would best model the data.

In this method, the detailed climate or weather in a particular region is treated as a random (stochastic) time varying process. The basic idea is that the random weather 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 temporal statistics of the random process (e.g. mean, variance, temporal correlation structure, each of which possibly vary in time). 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. From the analysis of past weather records for the site in question, the "random" weather process is characterized by estimating its distribution and time varying nature along with any deterministic components. Climate predictions of a GCM are then used to specify how the parameters of the random weather process will change in the future. The resulting process can be used to answer probabilistic questions and produce possible scenarios of weather in the region. Steps in using this model are:

- Step 1. Perform Statistical Analysis of *Historical* Data
- Step 2. Incorporate Information on How Parameters Will Change
- Step 3: Use Model to Generate Climate Change at Test Site

Model Testing

We tested this model on our test site areas. The weather variables we modelled were temperature, wind speed, and precipitation. The model worked well, and results were later used in our risk analysis. Climate change projections using this tool were as follows:

Temperature: *Past* data indicates that the trend in maximum daily temperatures shows a slight increasing of about 1 °C per century. The *future* GCM projection suggests an average daily temperature increase of about 4 °C per century. This increase in maximum daily temperature lengthens the growing season, which increases total evapotranspiration, thus, increasing irrigation demands.

Wind Speed: A careful study of the highs and lows from our model does not indicate any significant change in mean daily maximum wind speeds based on past data. Future wind speed predictions from GCM models are unable to resolve wind events at a spatial and temporal scale sufficiently small to say anything significant about how daily maximum windspeeds are liable to change at a particular site in the future. The most that the GCM models can provide is how the daily (and large-scale spatial) average is going to change in the future, and the predicted change is negligible.

Precipitation: Our model showed that the approximate length of a drought with a 100 year return period is approximately 20 days (based on both past data and future projections). Thus, that is what farmers need to plan for regarding irrigation. We used this information in our agricultural drought risk model.

Disadvantages and Advantages

- Disadvantage: 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 Statistical Downscaling Models, which is the only practical alternative). Such data is not always available.

- Disadvantage: It would require some time for someone not familiar with its use to learn.
- Advantage: It can produce multiple future scenarios of any duration.
- Advantage: It can downscale both spatially and temporally.
- Advantage: It allows for extreme value analysis since the climate is described by a distribution.
- Advantage: It allows for the direct computation of risk.
- Advantage: It can be performed on a personal computer by someone with a good knowledge of basic statistics, using weather data readily available.

Conclusions for Land Use Planning

The climate change modeling tool we developed not only provides information on mean changes in temperature, wind speed, and precipitation, but also allows the risks associated with climate extremes to be assessed. Both are very useful to Land Use Planners. In addition, engineers can use this information to interpolate climate change impacts on the many environmental factors which go into Land Use Planning, and affect land development/protection land use decisions. This in turn impacts Land Use Planning decisions for future land uses, and adaptations for existing land uses.

4. Coastal Flooding Analysis Tools

Model Purpose

The second group of tools employed in this project involved mapping areas at risk to flooding near Annapolis Royal under future climate change effects (storm-surge and sea-level rise). We use two tools together for flood analysis and mapping: LIDAR and Water Modeler.

LIDAR: 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. This remote sensing technique involves an aircraft equipped with a laser rangefinder that directs 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 Global Positioning System (GPS) and the distance to the earth's surface, land elevations can be determined.

Water Modeler: Another new tool employed in this study is the "Water Modeler" software package developed at the Nova Scotia Community College by Applied Geomatics Research Group, which was used to analyze the observed water level records from a tide gauge and calculate the return periods and probabilities of 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 is 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. For this reason we have used the results of the "Water Modeler" software for determining the return periods of water levels of future floods.

Model Testing

We tested this model at our Annapolis Royal test site. First we used historical analysis of past floods in the Annapolis Royal area. We used the LIDAR data and GIS techniques to map the flood inundation areas from the most severe past storm, in 1976, for which we had accurate information. Flood thresholds were determined from the LIDAR map including what water levels would be required to overtop the dykes and levees in the region.

Climate Change

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 1976 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. Because of the uncertainties with climate change and sea-level rise in the future, water levels were increased by 10 cm increments to provide flood maps for many different possibilities. We also modeled other parameters that could

impact such a flood as experienced in 1976, such as waves and tides. However, this information did not provide the probabilities (or return period) of such a storm or water level of reoccurring.

Water Level Return Periods and Probabilities

The return periods and probabilities of a given water level or storm-surge can be calculated from a time series of water levels. Currently, there are limited tools for planners to determine return periods of raised water levels. We utilized research conducted by Bernier and Thompson of Dalhousie University that focused on validating their storm-surge model. Bernier used historical wind records and inferred air pressure to drive the storm-surge model and compared it to observed storm-surge water levels for several sites around the northwest Atlantic. The wind information is reported on a 6 hour basis, therefore the hourly water levels were averaged to a 6 hour period for comparison to the model results. Because of averaging of water levels, the analysis under estimates water levels for some short lived extreme weather events such as hurricanes. Storm-surge water level return period curves were produced for several sites in Atlantic Canada, including Saint John, NB and were used as a conservative estimate. Saint John, NB was the closest site to Annapolis Royal, and we converted the data to our test site.

To calculate extremes and thereby, obtain flood probabilities, “Water Modeler” was used to analyze the hourly, not averaged 6 hour, observed water level records from Saint John, NB and calculate the return periods and probabilities of water levels associated with storms and sea-level rise. The results from this software had shorter return periods for a given water level but were comparable with the results from the Bernier study. The “Water Modeler” software allows different sea-rise rates to be applied and return periods and probabilities calculated. We calculated return periods of the 1976 storm and high water levels for return periods of 50, 100, 150, and 200 years based on water level time series from Saint John, NB and translated them to Annapolis Royal.

Disadvantages and Advantages

- Disadvantage: LIDAR is expensive compared to using standard topographic maps; however, the certainty of the areas at risk would be less, potentially adding confusion to the planning process.
- Advantage: The combination of LIDAR and the Water Modeler provided us an excellent set of tools to map flood risk from storm-surge and sea-level rise associated with climate change.
- Advantage: LIDAR information provided detailed land elevations to accurately predict flood inundation areas. If these data do not exist they are relatively expensive to acquire and process.
- Advantage: The ability of the Water Modeler software to generate return periods and the probabilities of re-occurrence of water levels allows us to associate a risk for a given water level.

Conclusions for Land Use Planners

This software is not yet commercial; however, that is planned and will be priced to be affordable to the planning community. Without this software, planners could estimate return periods from curves such as those produced in the Bernier study. This study has demonstrated that the tools exist in order to map areas at risk to storm surge and impacts of climate change in the future. This information is very important to include in land use mapping of development constraints and future land uses on the municipal and site level. Once applied to a region, these tools would also be of use to other stakeholders that influence land use planning, such as insurance companies.

5. Inland Flooding Analysis Tools

Model Purpose

Riparian flooding is also a very important factor impacting land uses, which will become even more of an issue with climate change. In much of Atlantic Canada, climate change is expected to result in more frequent and intense storms, of shorter duration. This means more precipitation will runoff, rather than recharging groundwater. It also means streams will become flashier, with occasional severe floods. There are a number of existing engineering tools currently being used for riparian flood level projections. We examined: 1) surveying tools and 2) flood routing analysis tools for their utility with respect to inland flood level projections. Surveying tools are currently used to project riparian flood levels, and climate change elements can be factored in.

Model Testing

An example of the application of these tools to the Allains Creek, which drains the southern half of Annapolis Royal, is in Chapter 5 of the main report. Allains Creek is a predominantly undeveloped small watershed, and

flood routing analysis of it was included primarily as an example of the use of these tools. Allains Creek does not contribute significantly to flooding of Annapolis Royal, which is primarily subject to coastal flooding. However, in *many* other watersheds, inland riparian flooding is one of the most significant impacts of climate change. Thus, engineers using these tools can provide important information to Land Use Planners with regard to projected flood level probabilities, which in turn, influence existing and future land uses.

Climate Change

Climate changes in the accepted vertical datums used in surveying will affect surveying, engineering, planning, and construction activities. Climate change will affect the parameters used in these models, such as precipitation and snow melt. Climate change can be factored into the model if projected changes in precipitation and temperature are known. Engineers will need to take climate change 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. There are a number of Best Practices use to improve channel capacity, and thus, reduce flooding.

Disadvantages and Advantages

- Disadvantage: Climate change factors that impact the hydrologic cycle are inter-related, making it difficult to predict, for example, how much runoff versus infiltration is likely to change.
- Disadvantage: These tools need to be used by a Hydrology Engineer, and since most municipal engineers lack this in-depth experience, consulting engineers would need to assist municipalities.
- Advantage: When the data (including downscaled climate change impacts) and expertise are obtainable, these tools will greatly aid in projecting riparian flooding, which in turn, has a significant impact on Land Use Planning decisions.

Conclusions for Land Use Planning

The implications for Land Use Planning are great, since land uses have historically been influenced by river corridor locations, before flooding implications were really understood. These models can be used to help include climate change in future land use planning decisions, and assess the risk of flooding and the adaptations to it, for existing land uses. Today we are stuck with the land use location choices of our forefathers, but new development can be cited with climate change adaptations in mind; and existing development can be flood-proofed, or otherwise protected, especially if we know how climate change will flooding problems.

6. Hydrogeology Tools

Model Purpose

As an integral component of the hydrologic cycle, groundwater would be expected to be affected by changes in precipitation and temperature attributed to climate change. Other climate change effects could include increased risk of saline intrusion to near shore aquifers due to sea level rise, and increased pathogen persistence in shallow aquifers due to higher groundwater temperatures. A Land Use Planner needs to know how climate change would affect three main aspects of hydrogeology: the hydrologic cycle, groundwater quantity, and groundwater quality, with respect to competing land uses for groundwater resources. Tools to address these issues are:

Hydrogeology Tool 1: Water Cycle 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.

Hydrogeology Tool 2: Groundwater Quantity Analysis

We used a simplified method of “mass balancing” to estimate the availability of groundwater supply for future development. This method balances groundwater recharge from precipitation with groundwater demand, to arrive at a theoretical carrying capacity of development for groundwater *quantity* for a particular geologic unit.

Hydrogeology Tool 3: Groundwater Quality and Assimilative Capacity

We used an “assimilative capacity” tool to model groundwater *quality*, in a similar way to modelling groundwater *quantity*, above. This tool looks at how much dilution (assimilative capacity), through precipitation, is necessary to dilute septic effluent to protect the water quality of wells and thus, surface water bodies.

Model Testing

We used the Pereau River watershed in the Annapolis Valley, Nova Scotia as a test case. The results of our stochastic climate change downscaling tool were used in this assessment. Using the 100 year forward predictions, the mean monthly hydrologic budget approach demonstrates that temperature increase is the main climate change factor likely to affect the groundwater component of the hydrologic budget. This is mainly due to slightly higher temperatures extending the growing season, which in turn increases evapotranspiration, which impacts groundwater. Using a 4 °C/century temperature increase (from our downscaling tool) an approximate 13% increase in evapotranspiration is predicted, which would reduce the amount of groundwater recharge and stream base flow available for irrigation during an extended summer dry period. Off-setting this potential loss is increased recharge during the predicted warmer winter months. Significant declines in groundwater levels could occur in shallow aquifers in the dry periods; smaller declines would be expected in deeper bedrock aquifers.

Climate Change

Changes in climate, especially precipitation and temperature, will impact the hydrologic cycle, and thus, the amount of precipitation that recharges groundwater. Reasonable recharge coefficients are needed for each planning area in order to reliably use these tools. These tools can be adjusted to account for climate change scenarios by modifying the annual precipitation, groundwater recharge percentage or the factor of safety.

Conclusions for Land Use Planning

Analysis of groundwater with regard to the land's carrying capacity for existing land uses, especially agricultural irrigation, and future land uses, such as conversion of farmland to residential, is important in rural land use planning. A hydrologic budget should be initially prepared by a qualified person for each planning area, and suitable groundwater recharge rates should be determined for each aquifer type. These default values could then be used by planners to assess groundwater availability and assimilative capacity these tools. Perhaps the greatest effect of climate change on groundwater resources will be increased demand for groundwater due to potential adverse quantity and quality effects on surface water resources. As groundwater becomes more important in sustaining stream flow and irrigation needs during hotter summers, the best strategy for the on-going assessment of climate change impacts to groundwater resources will include strategic monitoring of water levels, stream flows and water quality for each key aquifer within the planning area or specific watershed.

Disadvantages and Advantages

- Disadvantage: This approach is dependent upon availability of quality data and requires a knowledge of hydrological and hydrogeological processes, and may require the services of a qualified person.
- Disadvantage: These tools, as they are now, require a qualified hydrogeologist to use.
- Disadvantage: To use these tools to evaluate the impacts of climate change, the impacts of climate change on precipitation and temperature must be known, and for most communities, climate change models have not been downscaled to local conditions.
- Advantage: These tools are relatively easy to apply on an annual basis.
- Advantage: In an area with a significant projected change in precipitation, this tool would definitely show some changes due to climate change.

7. Risk and Cost / Benefit Analysis Tools

Model Purpose

We needed a model to help us assess the risks and cost/benefits of the two main environmental impacts at our test sites, coastal flooding in Annapolis Royal, and agricultural drought in the Pereau watershed, both of which will be exacerbated by climate change.

Model Research and Development

Existing methods of analyzing risk and cost/benefits were adapted to incorporate the climate change factors of coastal flooding and agricultural drought. 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.

How the Model Works

- Step 1. Assess hazard levels
- Step 2. Assess potential damage costs for the null alternative
- Step 3. Assess costs of adaptation alternatives
- Step 4. Assess potential damage costs for the adaptation alternatives
- Step 5. Choose optimal adaptation alternative

Model Testing: Annapolis Royal Flood Risk Assessment

Due to sea level rise, crustal subsidence, and tidal amplification in the Bay of Fundy, the Town of Annapolis Royal will be increasingly susceptible to flooding. We adapted risk and cost/benefit analyses to help us quantify four alternative adaptation 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 ;
2. floodproof individual buildings threatened by the flood.
3. construct a levee around the town to protect against a 5.4 m flood; or
4. construct a levee around the town to protect against a 6.5 m flood.

Results of our testing are: the best option with respect to the 6.5 m flood is the “do nothing” option, since the chance of the storm surge occurring at the same time as the highest astronomical tide 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, the lowest expected total cost is option 3. This suggests the town should construct a levee to protect against the 5.4 m flood.

Model Testing: Pereau Watershed Crop Failure Risk Assessment

Agriculture in the Pereau River watershed already suffers from occasional droughts, which we project will increase slightly with the impacts of climate change on evapotranspiration. We used an example of crop failure risk assessment, which can be viewed as a methodology to incorporate uncertainty into the decision making process. 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 Global Climate Model 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 testing our model we used a hypothetical apple orchard worth \$400,000, annually to the farmer, and this amount is lost when a drought in excess of 21 days occurs during the growing season.

Taking these potential losses into account, we considered two alternatives for the farmer:

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

Our hypothetical test case results show that the minimum expected total cost occurs when we construct an irrigation pond able to provide 18 days of irrigation. This model also includes the maintenance cost of the pond over the next 100 years.

Disadvantages and Advantages

- Disadvantage: It depends on climate change distributions generated with a stochastic climate model, since an assessment of risk is needed; so it may not be feasible for use with other types of downscaled climate change data (which may not include the distributions).
- Disadvantage: It can require additional risk assessment elements prior to use, such as flood frequencies generated by Water Modeler.
- Advantage: It allows land use planning decisions, which minimize total expected cost, to be made in the face of uncertainty.
- Advantage: Even if the above two disadvantages of dependency on other climate change data, apply to a particular site, the model could be used with a hypothetical climate change scenario, and ranges of costs/benefits of alternative adaptation actions could be assessed.
- Advantage: This tool, requires only a personal computer, and a user with knowledge of basic statistics.
- Advantage: It helps Land Use Planners and land users (e.g., residents and store owners in a floodplain, farmers in drought-prone areas) assess their best courses of action regarding climate change adaptations.

Conclusions for Land Use Planning

This model can help municipal Land Use Planners answer questions such as: For future land uses, where should development zones (in floodplains) and agricultural zones (in droughty soils) boundaries be drawn, considering the costs of flood protection and the costs of development of new irrigation sources? For existing land uses, what adaptations to flooding and agricultural drought, exacerbated by climate change, should be considered, in light of the costs of these adaptations versus the costs of no action?

8. GIS Land Sensitivity and Build-out Analysis Tools

Purpose of Model

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.

Model Testing

We tested this tool in our test site of Annapolis Royal NS. The results of Water Modeler flood probabilities were mapped in GIS, and then added to the Town's existing development constraints map, to create a Land Sensitivity Map, and then a "second generation" Composite Development Suitability map. We then analysed build-out scenarios, based on the Composite Development Suitability map, to determine feasible locations for new development with climate change factored in.

Disadvantages and Advantages

- Disadvantage: 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.
- Advantage: 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.

Conclusions for Land Use Planning

Incorporating climate change impacts, such as flooding, into the Land Sensitivity and Build-out Analysis processes is simply a matter of treating these parameters like any other development constraint. Thus, if the information is available, such as the probabilities of different flood levels, then it can be factored into GIS maps, which can then be used to inform Land Use Planning decisions, and their implementation via a Future Land Use map, and ultimately, zoning map revisions.

9. Implementation Tools

The numerous implementation tools we reviewed are all effective "implementation" of climate change adaptations. They fall into three main categories, summarized below.

Regulatory tool adaptations include legislation at all three levels of government; however, the municipal level is the most important level for local Land Use Planning. Environmental regulations that impact municipal Land

Use Planning are usually enacted on the federal and provincial levels, while provincial land use planning acts usually provide the guidelines for municipal Land Use Planning. While none of these regulatory tools include climate change impacts assessment and adaptations, they are appropriate tools to be amended to include it. Our analysis tools all lead up to impacts on development constraints at the local level, which can be incorporated into the Land Use Planning process through the GIS Modeling in Tool 6, and revision of municipal plans and by-laws. Changes to building codes, however, could be enacted at any of the three levels of government, although amending the National Building Code is recommended, since it is usually adopted by the provincial building code, which is adopted by municipal building codes.

Sustainable development adaptations, as with insurance, is more of a private adaptation, as are *some* Best Practices in construction. We recommend the inclusion of climate change adaptations in building practices, especially in the LEED process.

Emergency management adaptations are most effectively carried out at the local or regional level, since emergency service provision is primarily a municipal function. While none of these tools were designed for climate change adaptations implementation, we recommend that climate change factors be incorporated when the data is available.

10. Toolkit Recommendations

1. Write an instruction manual for our Climate Downscaling tool, Coastal Flooding tool, and GIS analysis.
2. Assess the availability of adequate weather data on a sub-regional level.
3. Assess the feasibility of municipal and provincial applications at sub-regional levels.
4. Investigate the feasibility of producing coastal flood maps for Atlantic Canada and north Pacific coast.
5. Test our inland flooding tool in a larger watershed, and where climate change may affect precipitation.
6. Test hydrology tools not used: time of concentration, and riparian flooding using Gumbel distribution.
7. Assess the feasibility of developing regional hydrogeology calculations that municipalities can use.
8. Test our risk/cost/benefit model on a larger scale with full-cost accounting and municipal fiscal impacts.
9. Link our risk/cost/benefit model with other adaptation tools being developed, e.g., infrastructure costing.
10. Assess the feasibility of data for mapping climate change development constraints on a regional basis.
11. Make recommendations at federal and provincial levels for including climate change in legislation.
12. Write model policies and by-laws for incorporation of climate change impacts and adaptations.
13. Make recommendations for incorporating climate change impacts and adaptations into LEED process.
14. Educate communities regarding the importance of planning emergency management for larger storms.