Final Report:

Evaluating the Impacts of Projected Climate Changes on the Grand Traverse Bay Region

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Abstract

This Integrative Assessment project for the Grand Traverse Bay region of Michigan evaluated changes in climate and land use based on data synthesis, statistical analysis and simulation modeling, with extensive stakeholder input throughout. Our project team found that climate for the region has become warmer and wetter over the last 100 years, with some local scale variation. We also found an increase in heavy precipitation events, with more of the annual rainfall budget falling during short intense storms than historical records. These climate shifts are concomitant with shifts in streamflow characteristics, with extended periods of lower streamflow, and greater frequency of high streamflow days. A shift to more extreme events accompanied by lower overall snowfall can increase the likelihood of flooding and affect the seasonal cycle of recharge to groundwater, where recharge is the amount of water percolating down to the water table.

Process-based simulation models were the primary tool used to quantify the likely impacts of projected climate changes and to evaluate the potential effectiveness of various adaptation strategies. Our project team helped regional stakeholders explore likely challenges for the region along with potential strategies to help mitigate these effects.

The project identified that the region is likely to experience increases to flood risk, which should be considered as improvements in infrastructure are planned. Green Infrastructure including pervious pavements may help reduce the effects of projected changes, but costs of such changes should be compared with alternative solutions including retention ponds. Aquatic ecosystems in the region are also likely to be affected due to projected lower summer flows and warmer water. Our project team demonstrated that process-based models can offer insights into the likely effectiveness of various possible mitigation and adaptation strategies.

Background

Residents of the Grand Traverse Bay (GTB) region consistently rank the natural environment among the top three characteristics of the area that contribute to a high quality of life. The reliance of the regional economy upon recreation and tourism also underscores the importance of the natural environment to economic health of the region. Characteristics of the region that are significant attractors of residents under current climate conditions, businesses and tourists could become detractors with changes in water quality, fisheries resources, and shorelines, among others. Regional economic analysis, coupled with stakeholder opinion studies, can provide evidence of potential vulnerability to climate change-induced changes in the natural environment of the region.

Water is pivotal to the economic vitality of the GTB region, which has 212 km of public beaches and many waterfront communities. The regional population doubled between 1975 and 2000 and can more than double seasonally due to mid-summer tourism (Boutt et al. 2001). Human development of the watershed has led to water quality threats including sedimentation, nutrient loading, toxins, hydrologic flow alterations, and increases in pathogens (U'Ren 2005). A 2009 study by the Watershed Center found that the number of macrophyte beds in Grand Traverse Bay tripled over an eleven year period due to increased nutrient inputs (U'Ren 2009). Aquatic plants and algae impact the bay's shoreline and have been linked to *E. coli* and avian botulism (Rediske 2010; Byappanahalli and Whitman 2009). Grand Traverse Bay beaches have been listed on the MDEQ impaired waters list due to pathogen occurrences. Grand Traverse Bay Watershed (GTBW) beaches are generally impacted shortly after storm events due to stormwater runoff in urbanized areas and increased nearshore turbidity from wind and wave action. The GTBW Protection Plan from the Watershed Center, approved by the US EPA and Michigan DEQ, identifies nutrients and sediments as top threats to the bay and its watershed. These issues threaten the economically vital uses of the GTBW, including water supply, aesthetics, fisheries, beaches, and boating.

Climate change has already impacted the GTBW. Regional annual average air temperatures over the last decade were approximately 1.5 degrees C warmer than the 1881-1920 average (GISS 2011). Due to this warming, from 1850 to 1995, GTB ice cover shortened by 23.2 days per century (Magnuson et al. 2000). Snowfall in the region has increased significantly over the last century (Burnett et al. 2003), likely due to reduced lake ice and thus more lake effect snow. Influenced by climate change, lake ice changes, widespread land use change, and increased water use, streams surrounding the GTB region with long-term (>60 years) records exhibit increasing median flow trends of +0.3% to 3.5% per decade (USGS 2011). Ensemble mean forecasts from the Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model dataset suggest temperatures will rise by 3.5 to 4 degrees C and precipitation will increase by approximately 10% by 2100 under the Representative Concentration Pathway (RCP) 6.0 emissions scenario.

To inform management of water resources in the GTBW and help stakeholders adapt to the impacts of projected changes in climate and land use, we conducted an Integrated Assessment (IA) of the region's risks and vulnerabilities to these changes. Numerous groups are working on pollution prevention and water quality enhancement projects across the region from academia (e.g., Michigan State University), non-profit grassroots organizations (e.g., the Watershed Center), local government departments, local health departments, and State government (e.g., DEQ). These groups have developed a wealth of data that provide insights into aquatic, microbial, environmental, and social processes. These data, along with hydrologic, sediment, and nutrient loading simulations under climate change scenarios have formed the technical basis for our team's IA of climate change risks for the GTB region. The focus, objectives, and suggested adaptation strategies within the IA were informed and influenced by multiple workshops and interactions with stakeholders.

We addressed the following questions in our IA: What are the risks and vulnerabilities of the GTB, its watershed, and its coastal communities to climate and land use changes, and what are potential mitigative or adaptive strategies to preserve designated uses?

During the project we worked with the stakeholders to prioritize our tasks based on our original objectives and identify others not specified in our proposed work. Therefore, some of our original objectives were not explored to the same degree as others. The technical assessment had the following original objectives (in parentheses we indicate if a portion of the original objective was not addressed):

1. Quantify historical changes in air and water temperature, precipitation, snowfall, lake ice cover, lake levels, streamflow, and water quality.
2. Qualitatively assess impacts of these changes on macrophytes and benthic algae, lake levels and shoreline alterations, and pathogen occurrence.
3. Simulate the likely local to regional impacts of climate change on nutrient and pathogen loading, sedimentation in streams and coastal areas, and stormwater runoff from coastal communities. (We did not address sedimentation or nutrient loading due to lack of sufficient information).
4. Assess the effectiveness and economic impacts of selected adaptation and management strategies for preserving highly valued uses critical to local economy. (We were unable to explore economic impacts of adaptation and management strategies because of the non-marginal nature of changes associated with the mitigation and adaptation strategies ultimately assessed.)
5. Develop adaptive management strategies and an integrated assessment report based on stakeholder recommendations.

Approach

Task 1: Engage stakeholders via interactive workshops throughout the IA process

Task 2: Assemble and QA/QC a multi-parameter database of historical climate and watershed data sets

Task 3: Synthesize data and analyze historical trends and relationships among change drivers and responses

Task 4: Assess possible impacts of climate variability on Grand Traverse Bay

Task 5: Simulate GTB watershed climate and land use change impacts, and adaptation strategies

Task 6: Prepare IA Report and help develop adaptive management plans

Stakeholder Engagement and Public Outreach

Throughout the course of the project, the team brought together scientists and stakeholders from the Grand Traverse Bay watershed at interactive workshops organized around the steps of the IA process. Our goal for stakeholder engagement was to integrate decision-maker and stakeholder input in all steps of the IA process to increase local knowledge, incorporate stakeholder questions and concerns in the research, and increase local capacity for implementing management options. We implemented a process to engage two types of stakeholders: 1) active and engaged water resource managers and decision-makers who served on a stakeholder working group and 2) the general public.

Stakeholder Working Group

The Working Group included key stakeholders who were selected based on their ability to address the local scientific and social implications of climate change on water quality. Our Working Group was comprised of representatives from the Michigan Department of Environmental Quality, the Watershed Center Grand Traverse Bay, local health departments, City of Traverse City, State and National parks, Grand Traverse region drain commissioners, local water quality laboratories, Michigan Sea Grant, the U.S. Army Corp of Engineers, and local lake associations and non-profit organizations. Their role in the project was to provide local knowledge and expertise, assist with assembling data resources, and to provide feedback and ideas for all components of the IA. We continually reached out to stakeholders to increase participation in the working group and to fill any gaps in representation. Our final Working Group meeting included participants from Cherry Capital Foods, Citizen's Climate Lobby, City of Traverse City Commissioners, Elk Rapids DDA, FLOW, Garfield Township, Grand Traverse Band of Ottawa and Chippewa Indians, Grand Traverse Conservation District, Grand Traverse County Commissioner, Grand Traverse County Health Department, Grand Traverse Regional Land Conservancy, Land Information Access Association, Leelanau Conservancy, Leelanau Conservation District, Leelanau County Drain Commissioner, MI Department of Environmental Quality, Michigan Sea Grant, National Resource Conservation

Service, Northern Michigan Environmental Action Council, SEEDS, and NMC's Water Studies Institute.

We hosted three workshops with our project team and the Working Group, one at each major stage of the IA (Table 1). The structure and design of the workshops was based on the Center for Water Sciences Water Fellows workshops (cws.msu.edu/waterfellows). We found this format, which combines presentations and facilitated discussions, to be successful for bringing diverse stakeholders together for shared learning, communication and developing a common vision (Dreelin and Rose, 2008). Each workshop began with a presentation by the research team and question and answer session with stakeholders. Following the presentation, the research team and Working Group had a series of facilitated discussions and exercises focused on the workshop topic and goals (Table 1).

Table 1. Overview of the Stakeholder Working Group meetings.

Meeting	Date	Number of Participants	Purpose	Outcome
1	May 21, 2013	30	Introduction to the project and discussion of questions, concerns, threats and opportunities	Refined and added research questions based on stakeholder input; identified additional stakeholders
2	March 24, 2015	30	Opportunities and implementation: explore effective implementation strategies and prioritize management options	Identified potential and desired adaptive management options to model; identified additional stakeholders
3	June 17, 2015	35	Review management options and provide feedback for final report	Refine analysis for final report; identification of preferred options

Stakeholder Input and Feedback

The science team engaged stakeholders so that their feedback could be incorporated into the technical components of the IA. At the first Working Group meeting, we asked stakeholders to identify topics and questions they would like to see addressed over the course of the project. Stakeholders identified a variety of topics that concerned them regarding climate change in the GTB region. The main areas of concern were:

- Water quality and water quality protection;

- Water levels;
- Adaptation, specifically how to adapt to climate change;
- Impacts to flora and fauna; and
- Extreme weather and stormwater runoff.

As for specific research questions, the main questions stakeholders were interested in answering were:

- What is the economic impact, by sector, of climate change?
- What will impacts to agriculture be? What changes are predicted?
- How will extreme events and stormwater change?
- How do we support native flora and fauna? Arrest invasion of new species?
- How much do we need to do? When do we stop?

In addition to these concerns and questions, the science team and stakeholders discussed the modeling capabilities of the team, what types of questions could be addressed, and what was beyond the scope of the current project.

Following the first meeting, the science team gathered available data and began modeling efforts. We hosted a second Working Group meeting once the science team had preliminary data regarding historical trends and future projections. Our goals for the second meeting were to identify what stakeholders considered acceptable in terms of change, what they were most concerned about given the preliminary results, and what climate adaptation strategies they thought were are acceptable and should be explored in the next phase of the study. In order to frame the discussion, we asked stakeholders to identify positive and negative changes given a "business as usual" future. This future scenario was based on current trends for the region. Stakeholders identified 14 positive and 17 negative characteristics of this "business as usual" future (Table 2).

Table 2. Stakeholders identified positive and negative changes in the "business as usual" future projections modeled by the science team.

Positive Aspects of "business as usual" Future Scenario	Negative Aspects of "business as usual" Future Scenario
1. Longer growing season	1. Lack action
2. Realistic scenario	2. Planning according to political boundaries
3. More solar energy in summer	3. Treat resources as commodities
4. Less snow removal costs	4. Dependence on fossil fuels
5. Lower heating costs	5. Impact on agriculture and forestry (fruit farming, disease)
6. Mild Spring transition	6. Weather volatility
7. Longer tourist season	7. Attract more tourists causing negative impacts
8. Earlier crop availability (cherries)	8. Loss of plant and crop species
9. New crops	9. Increase in insect-borne disease
10. Extended Fall season	10. Loss of quality fishing
11. Warmer, drier summer	11. Stormwater runoff – decreased water quality
12. Lively discussion	12. Increase energy requirement for summer
13. Wine and beer	

14. Species diversity	13. Lower baseflow and streamflow disruption-impacts on fisheries 14. More potholes 15. Invasive species 16. “Inappropriate” human reaction/responses 17. Shift in species composition

In order to scope the next steps of the IA, we asked the stakeholders to identify their top priorities for the science team to address. Stakeholders had time to discuss their views and then they were asked to vote for their top concerns for both positive (Figure 1a) and negative (Figure 1b) changes. The top priorities for both the positive and negative aspects of change reflect the stakeholders’ concerns regarding stormwater runoff and the resulting impacts on water quality, and impacts to agriculture. These results were then used in discussions regarding adaptation/mitigation strategies that could maximize potential positive changes while reducing negative changes.

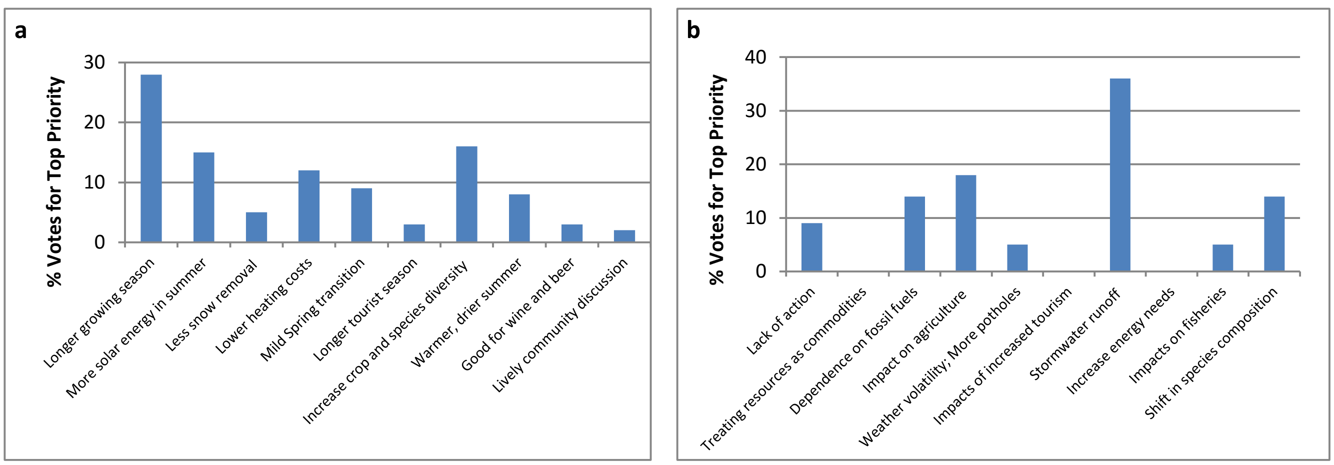


Figure 1. Voting results on top positive (a) and negative (b) changes in the modeled “business as usual” scenario.

The final discussion at the second stakeholder meeting focused on potential management actions for the science team to model. We asked the stakeholders to generate plausible scenarios for managing climate impacts. The whole group then discussed what was feasible for the science team to further assess given the capabilities of the model, the project budget, and project timeline. As a group, the stakeholders and science team identified the following scenarios to model:

- Use of green infrastructure to reduce stormwater runoff
- Use of low impact development practices, such as porous pavement, to reduce stormwater runoff
- Changing land use to mitigate impacts of a changing climate

In addition to these adaptation/mitigation strategies, stakeholders were also interested in how changes to agriculture could affect major crops in the region, how changes to snow and precipitation could affect tourism, and how changes to snow and precipitation that could affect condition of the region's roads. A survey of residents conducted during the same time frame as the IA (Norris, Feltman and Batanian 2015) was also used to assess residents' experiences with climate change impacts and degree of concern about climate change. A greater level of concern about climate change suggests that potential adaptive/mitigations may be received more positively than if concerns were lower. Following the meeting, the science team developed and modeled the scenarios for the adaptation/mitigation strategies and added future projections for impacts to agriculture, tourism, and roads.

During the third and final Working Group meeting, the results of the historical data analysis, future projections, and adaptation/mitigation scenarios were presented by the science team. We then asked stakeholders to discuss the following questions:

- How do the scenarios and projections impact your issues of interest?
- What do you think this means for your issues?
- What infrastructure can your community invest in to address climate change?
- What adaptation and mitigation options do you think are feasible going forward?
- What questions do you still have?
- What does this tell us about next steps?

Much of the discussion at the final meeting focused on how the stakeholders could use the results to move forward with action in the Grand Traverse Bay watershed. The stakeholders worked in small groups to discuss their concerns and identify their own next steps. These next steps included sharing the results with their own networks, using the results to advocate for adaptation and mitigation strategies, incorporating climate change into planning, and educating decision makers and the public about the potential impacts of climate change.

Incorporating Stakeholder Feedback in the IA

The science team used the input and feedback from the stakeholders to refine the research questions for the project, identify data sources, target analyses to topics of interest and relevance to stakeholders, and identify potential management scenarios. However, there were several topics and questions raised by stakeholders, such as impacts to specific native species and invasive species, that the team decided was beyond the scope of the project. The decision not to address certain specific stakeholder questions was discussed at the stakeholder meetings. The team also worked with stakeholders to refine areas that were initially too broad given the resources available to the team or were beyond the capabilities of the model. For example, impacts to agriculture are a main concern to stakeholders but not all agricultural commodities could be modeled. The team and stakeholders focused on tart cherries given the importance of the crop to the region and the data available. Stakeholders requested sector-specific information on the economic impacts of climate change, but economic information by sector is not available, nor are the modeling capabilities sufficient to address sector-by-sector impacts. Thus, a full sector-by-sector economic analysis was beyond the scope of the project given the limitations of existing data.

Despite these limitations, the IA team was able to address stakeholder-generated topics and questions throughout the IA (Table 3). Stormwater control was one of the main topics of discussion during all of our interactions with stakeholders. Stakeholders identified stormwater as a main concern because of the perceived negative impacts on water quality. Stakeholders also expressed a belief that the decision makers across the region could actively address stormwater control through policy changes. Consequently, much of the IA focused on changes to precipitation and flow and the potential adaptation/mitigation strategies that could reduce negative impacts from the projected changes.

Table 3. Stakeholder input and feedback was incorporated into all aspects of the IA. The issues and questions from stakeholders were gathered over three Working Group meetings.

Issue of concern for stakeholders	Stakeholder-generated questions	How the science team addressed input/feedback	Section of Report
Water levels	How will lake levels change?	Analyzed historical data and observed trends	
	How will stream flow change?	Analyzed historical data and observed trends Modeled future flows	
Stormwater runoff and water quality	How will precipitation and stormwater runoff change?	Analyzed historical trends in precipitation and extreme flows Modeled changes to hydrology	
	How will extreme events, such as large storms, change in the future?	Modeled changes in extreme events	
	What are the potential impacts to water quality?	Analyzed historical data available for beach closures	
Impacts on roads	How could climate change affect condition of the region's roads?	Modeled changes to precipitation and freeze-thaw cycles that could impact roads	
Impacts on tourism	How will changes in climate impact tourism, especially ski areas?	Analyzed historical changes in precipitation and snow pack Modeled changes in snowpack and ski season	
Impacts on energy use	How will the need for heating and cooling change?	Modeled heating and cooling degree days	
Impacts to flora and fauna	How do we support native flora and fauna?	After discussion with stakeholders, the IA team limited scope to agricultural	–

		crops (see below)	
	How do we arrest invasion of new species?	After discussion with stakeholders, the IA team decided this was beyond the scope of the project	–
Impacts to agriculture	What will impacts to agriculture be? What changes are predicted?	Modeled projected changes for bloom date, frost risk, longer growing season, and precipitation with focus on tart cherries	
Economic Impacts	What is the economic impact, by sector, of climate change?	Used economic data from the literature to provide examples of potential impacts	Incorporated into various sections where economic data were available
Adaptation/Mitigation Strategies	How could green infrastructure be used to reduce stormwater runoff?	Modeled three green infrastructure scenarios	
	How will low impact development practices, such as porous pavement, reduce stormwater runoff?	Modeled three porous pavement and stormwater retention scenarios	
	Would changing land use mitigate climate change?	Modeled how land use affects watershed hydrology	

Public Outreach

In order for any potential adaptation and mitigation options to be successful, the local community must have the will to take action. Cash et al. (2003) illustrates that scientific information is most effective in driving public response when the information appears credible, salient, and legitimate. Therefore, our team presented project results at the annual Freshwater Summit held in Traverse City every year of the project. The Freshwater Summit is an annual conference co-hosted by our local partner, The Watershed Center, which focuses on Great Lakes issues and draws scientists, managers, and concerned citizens from across Michigan. These presentations provided an opportunity to educate the public about the project, answer questions from the public, and notify the public of ways they could participate and provide feedback to the research team. We also held a public meeting at the conclusion of the project to share the results with the public and to gain their feedback on the research products. The meeting was held June 17, 2015 at the Great Wolf Lodge. Following the meeting, the MSU team provided the Watershed Center with a PowerPoint presentation of the project results so that they could give additional presentations to citizens in the GTBW.

Historical Data and Analyses

Our MSU team compiled extensive databases that included climate, hydrology and water quality information from public and private sources. This included a network of eight stream gages across the region, half of which are operated by the MSU Hydrogeology group and rest by the US Geological Survey; we then simulate hourly water fluxes using the Landscape Hydrology model for the entire region from 2009 to 2014 and average these values to create the colormap in Figure 2. The landscape hydrology model is a full energy balance, water balance code that ties to climate inputs from NLDAS; Details are discussed below and in (Kendall, 2009, Hyndman and Kendall 2007). We also continued to monitor groundwater levels in a network of wells that were installed by the USGS in the GTBW (Figure 2).

Our team used a combination of models and data to quantify the likely impacts of climate change to the timing and quantity of recharge, ecosystems, and crop yields. The first class of models that form a basis for our assessment are Global Climate Models (GCM), which simulate likely changes in temperature and precipitation under various assumptions of future greenhouse gas emissions. We also examined observed changes in climate variables from weather stations.

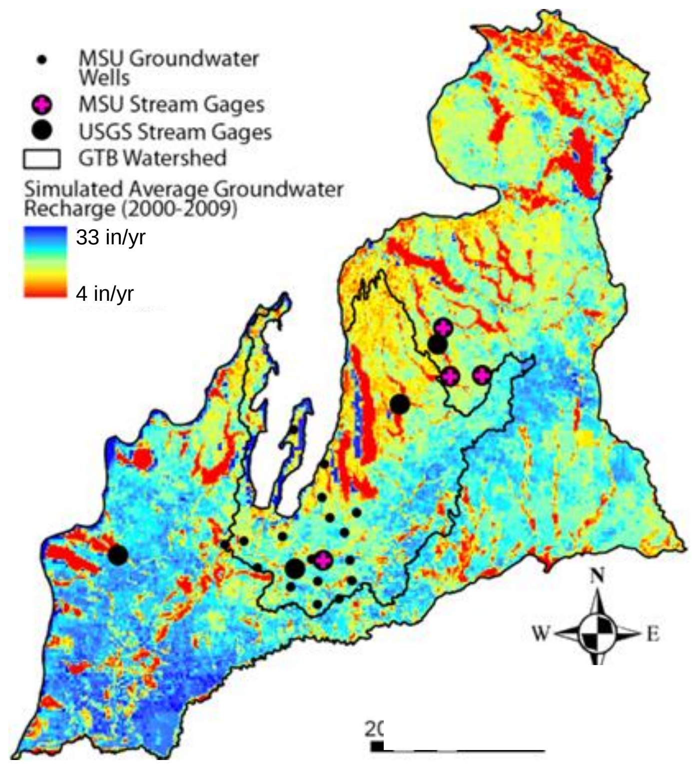


Figure 2. *Map of simulated average recharge across the study region, with stream gage and monitored water well locations.*

Temperature and Precipitation

Changes in climate have been observed over the last several decades. We analyzed trends in climate data from NOAA weather stations with a 50+ year record using regression. Figure 3 shows the weather stations included in the analysis, colored by the slope of the associated regression line. Temperatures have warmed across most of the region, with the highest increases in areas of higher elevations. A few areas near Lake Michigan have observed slight cooling or no increase in temperature.

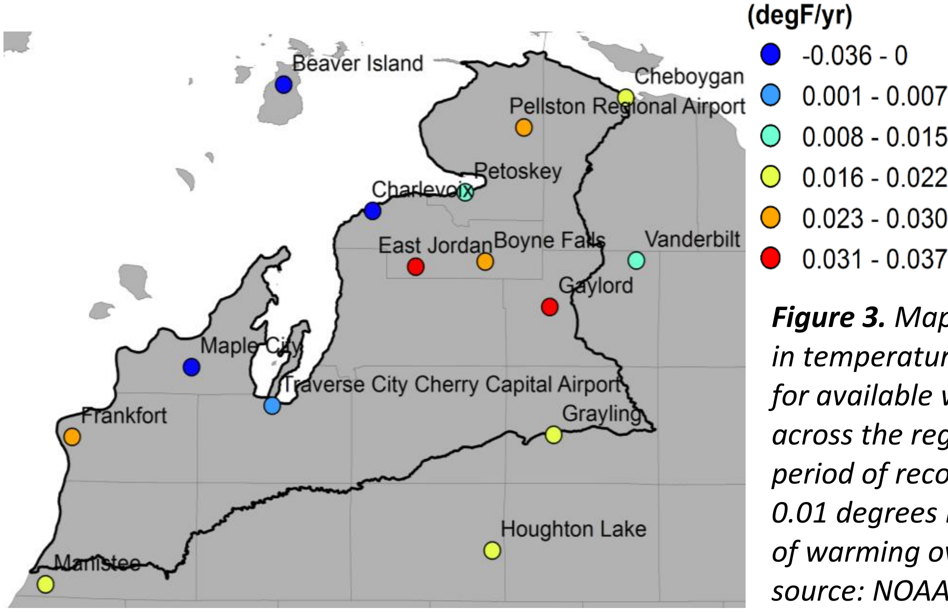


Figure 3. *Map of measured trends in temperature in degrees F per year for available weather stations across the region (for >50 year period of record). Note a slope of 0.01 degrees F/year means 1 degree of warming over a century. Data source: NOAA*

Observed precipitation has also increased across most of the region for the 23 stations in NW Michigan with more than 50 years of record (Figure 4a). Relative to trends in temperature, there is much more spatial variability in the observed changes in precipitation. For example, the Cheboygan area has experienced a significant (p-value <0.0001) increase in precipitation of 0.07 inches per year (or approximately 6.5 inches over 90 years) whereas Traverse City has experienced a much smaller increase (Figure 4b). The rise in precipitation is much more significant in the past decade (Figure 4c), with the Traverse City and Petoskey areas seeing more than an extra inch of rain per year on average in the past decade. This recent period is what people most commonly remember due to recent personal experience.

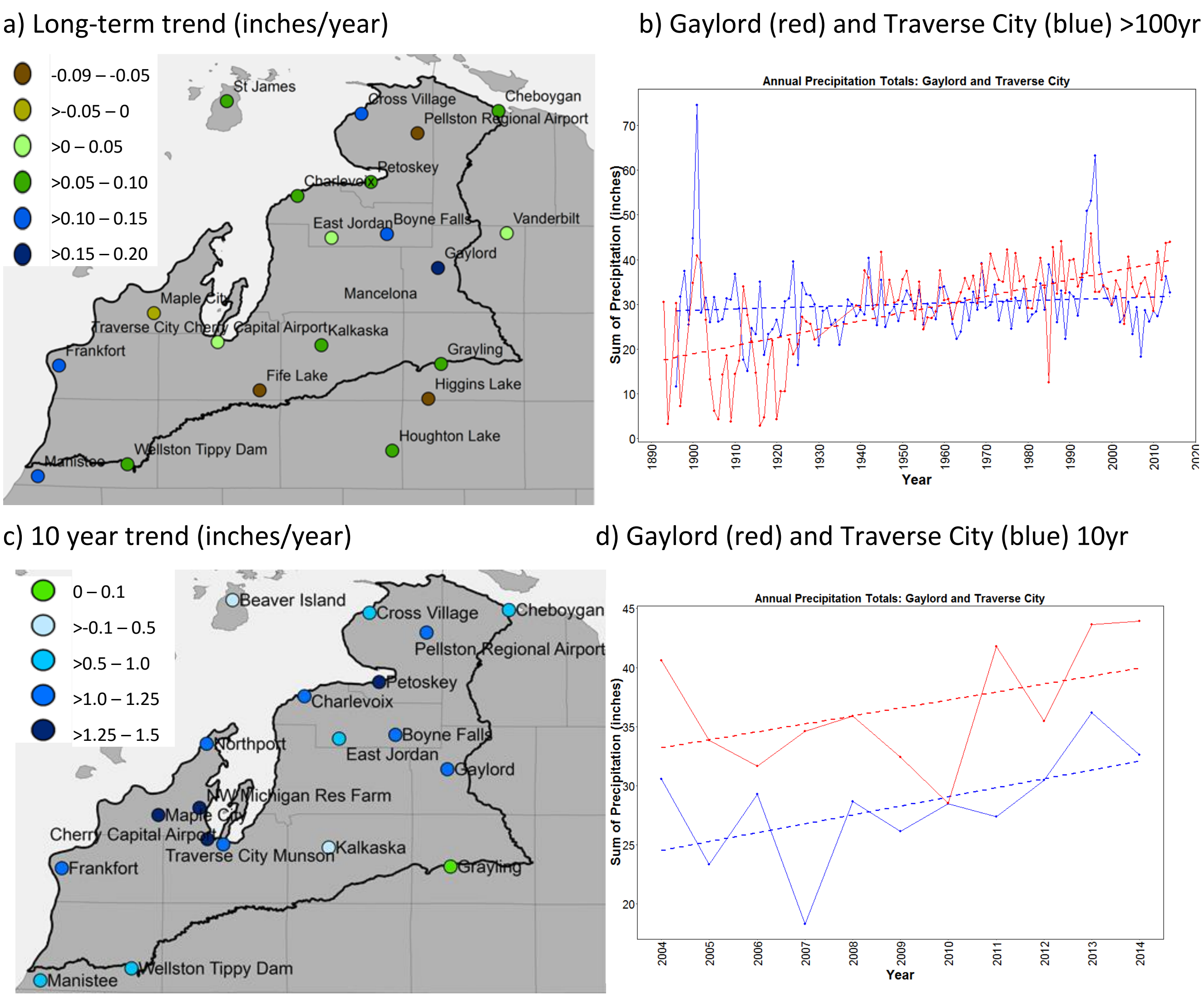


Figure 4. a) *Map of observed trends in precipitation in inches per year for available weather stations across the region (for stations with a period of record > 50 years),* ***b)*** *example changes in observed precipitation at Gaylord (red) and Traverse City (blue) gage since 1900,* ***c)*** *Map of recent observed trends in precipitation in inches per year from 2004 to 2014, d) example changes in observed precipitation at Gaylord (red) and Traverse City (blue) gages since 2004. Data source: NOAA.*

There has also been an increase in the number of heavy rain events (described as days with > 20 mm of precipitation) in some portions of the region (Figure 5), which will has the potential to increase the risk of flooding and may require enhancement of stormwater infrastructure. The projected increase in variance of precipitation may be the most concerning aspect of projected changes in climate, as more frequent heavy rain events will increase the risk of flooding while more dry and hot periods will likely lead to more extended and severe droughts.

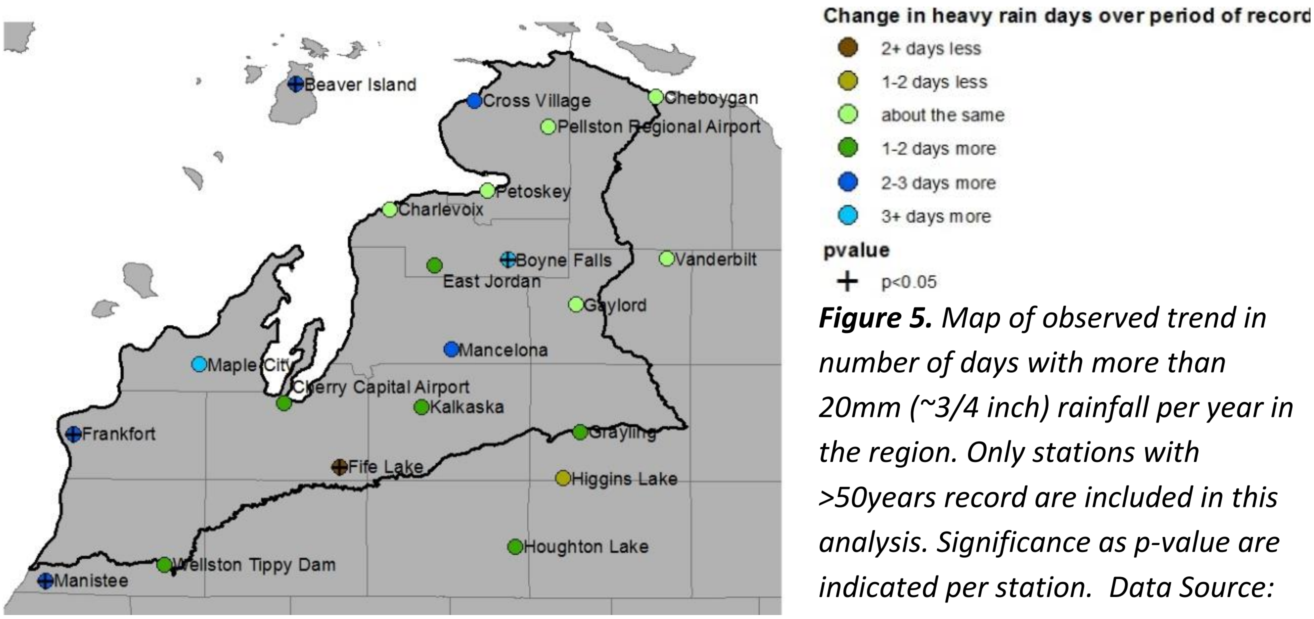


Figure 5. *Map of observed trend in number of days with more than 20mm (~3/4 inch) rainfall per year in the region. Only stations with >50years record are included in this analysis. Significance as p-value are indicated per station. Data Source: NOAA*

Some, but not all, areas in the GTB region have received increased annual snowfall since the early 1900's. The weather station in East Jordan, close to popular ski areas, has recorded a significant ($p<0.0001$) increase in annual snowfall of approximately 0.76 inches per year on average over the period of record; whereas, Traverse City has no significant long-term trend in annual snowfall (Figure 6). This is an important trend given the importance of snow for ski areas, groundwater recharge, and use of snow clearing equipment. It is important to note that this figure depicts snowfall, rather than snowpack, which is discussed later in this report.

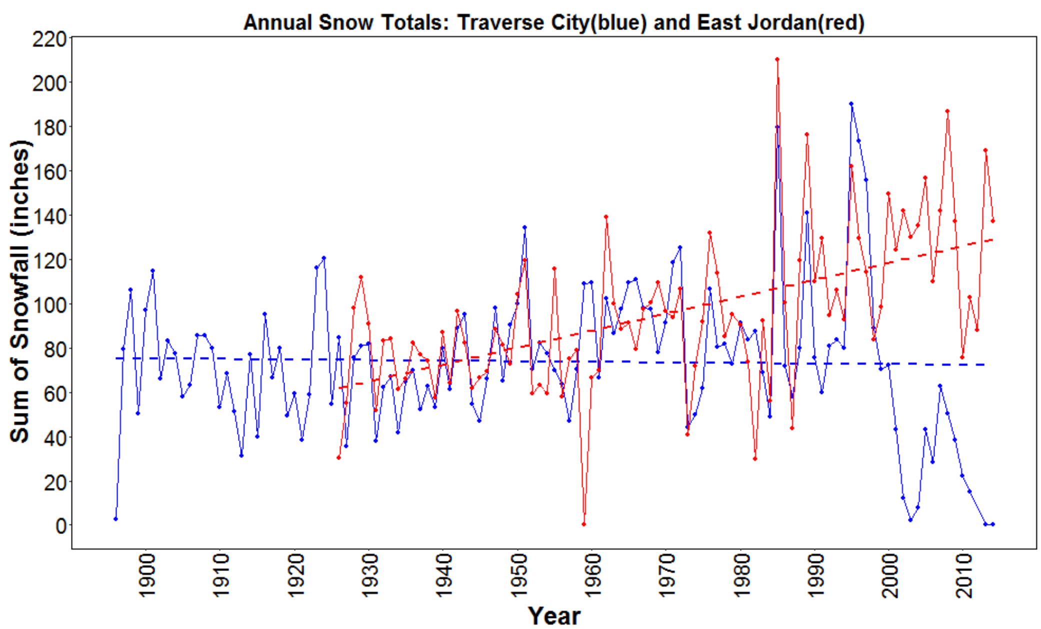


Figure 6. *Annual total snowfall in inches at Traverse City (blue) and East Jordan (red) weather stations. Data source: NOAA*

One climate change factor that is very evident to residents of the region is the decreasing levels of ice cover in Grand Traverse Bay. There has been a significant shortening of the period of ice cover in the Bay (Figure 7), which can be an indicator of less ice cover on the Great Lakes in general. This factor is important as less ice cover tends to cause more snowfall as the open water enhances lake effect snow, and also lower lake levels due to loss of water from the Great Lakes by evaporation in open water.

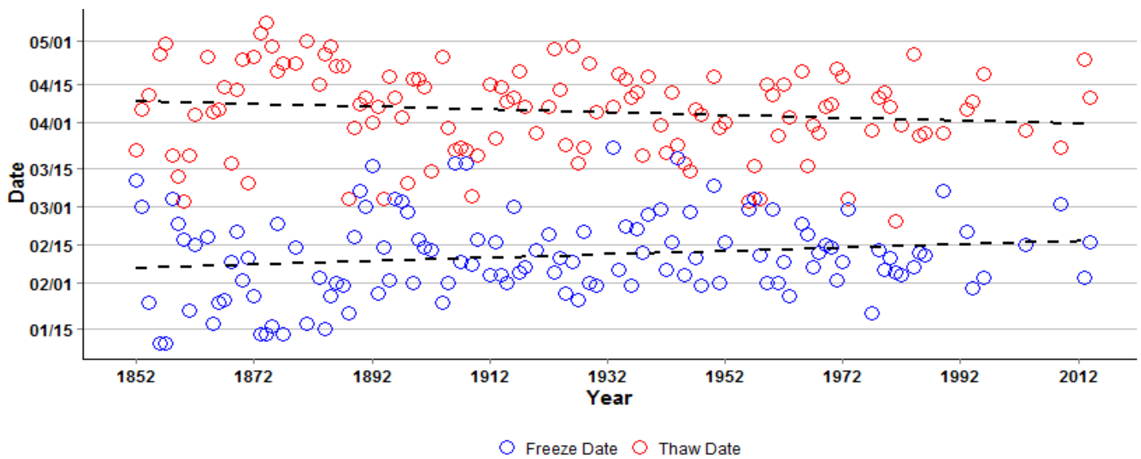
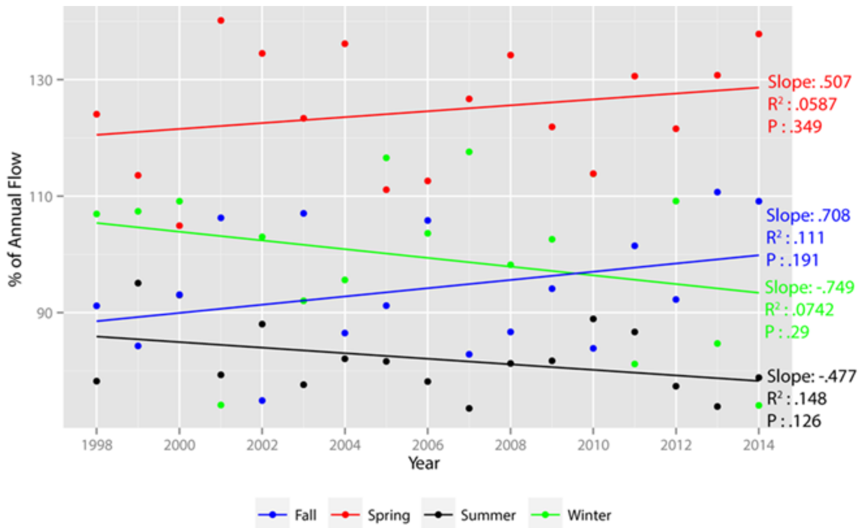


Figure 7. *Observed dates of freeze and thaw in the West Arm of the Grand Traverse Bay. The black dashed lines indicate a linear trend in these dates, which shows a decrease in the time that the bay is frozen (later freeze and earlier thaw). Freeze date is recorded when the waters are frozen out to Power Island for 24 hours. Thaw date is recorded when the ice is no longer frozen out to Power Island for 24 hours. Data source: The Watershed Center Grand Traverse Bay.*

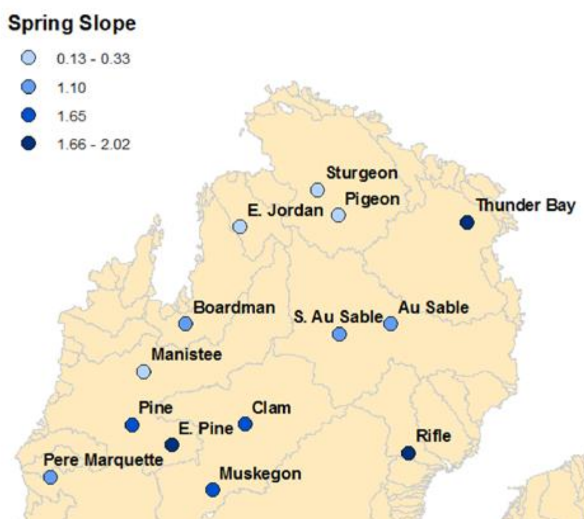
Streamflow

There also appears to have been a shift in the seasonality of streamflow for many of the streams in the region (Figure 8). All northwestern Michigan USGS streamflow stations are showing increasing spring flows and decreasing summer flows. This is consistent with rising temperatures causing early snowmelt, leaving less late spring recharge which feeds summer streamflows via groundwater flow which is a slow process. Groundwater is the source of the vast majority of streamflow in the region, thus earlier peak recharge is expected to cause declines in summer streamflow. Most groundwater in the region is stored in the highly permeable shallow glacial aquifer with groundwater at the land surface in zones where it discharges to surface water to depths of over 100 feet in areas with topography and away from streams. Lengthening of the growing season associated with climate change is also expected to lead to lower summer and fall streamflow as plant water demand occurs over a longer time. During seasons when vegetation is active and fully leafed out, most of the incoming precipitation becomes evapotranspiration (ET), while much of the annual recharge is derived during the period when vegetation is dormant or less active. Fall and winter streamflow tends to be variable across northwestern Michigan, with fall flows increasing for the Boardman and other rivers north of this location and decreasing south of this location. Winter flows show no consistent spatial trend.

a) Boardman River seasonal trends



b) Regional spring trends



c) Regional summer trends

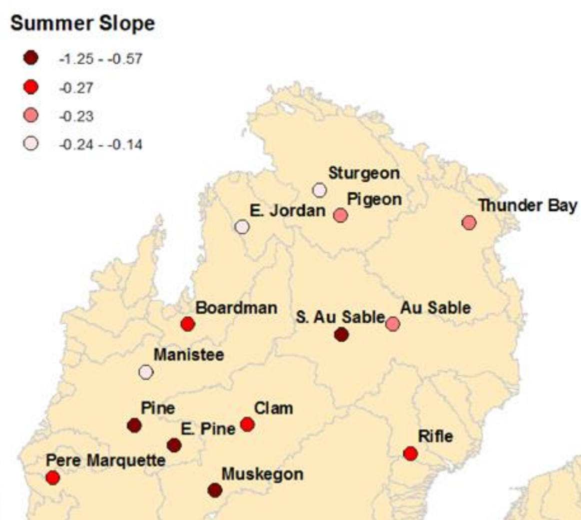


Figure 8. a) *Trends in seasonal streamflow in the Boardman River. Fall (blue) and Spring (red) streamflow have increased, whereas Summer (black) and Winter (green) streamflow have decreased as shown by the slope of the regression line.* ***b & c)*** *maps showing trend (slope) in seasonal streamflow across the Northern Lower Peninsula of Michigan (Data from USGS).*

High flow events have generally increased since 2012, as indicated by flows greater than the 95th percentile of recorded flow (Figure 9). If this trend continues, this indicates an increase in flood risk for the region. The most significant deviations are in 2013 and 2014, and the reason for such rapid changes are unclear.

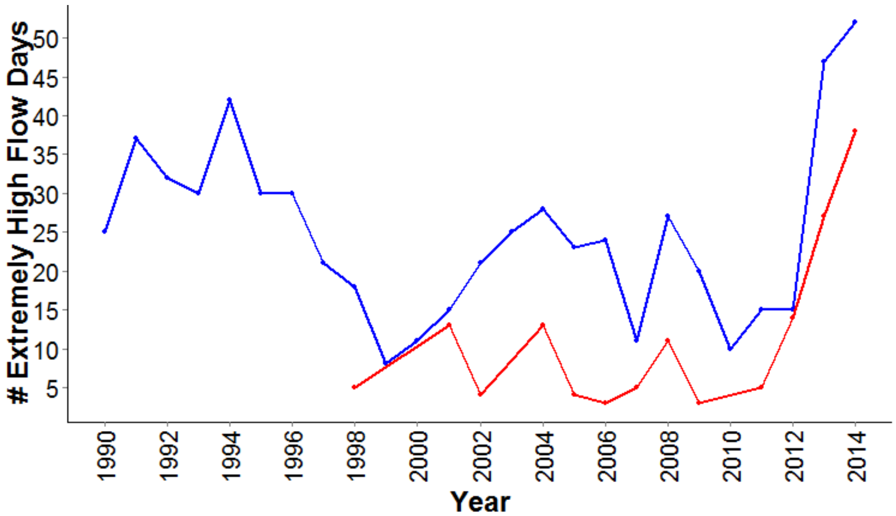


Figure 9. *Number of extremely high flow days per year (>95th percentile of daily flows over the period of record) for the Boardman River (blue) and the Jordan River (red). Data source: USGS*

Several factors contribute to changes in Great Lakes water level, including the input via precipitation and streamflow and losses due to outflow and evaporation (which is higher when the lakes have less ice cover). There is a significant ($p<0.0001$) positive correlation ($r=0.58$) between Lake Michigan level and the median streamflow in northern Lower Peninsula Michigan gages (Figure 10), especially prior to the last decade. Figure 10 shows the deviation from the median for both streamflow and Lake Michigan levels (Methodological Note: The median is more robust to the influence of outliers than the mean, which is why we present this data). Overall, when lake levels are above normal, stream flows have also been above normal, and vice versa.

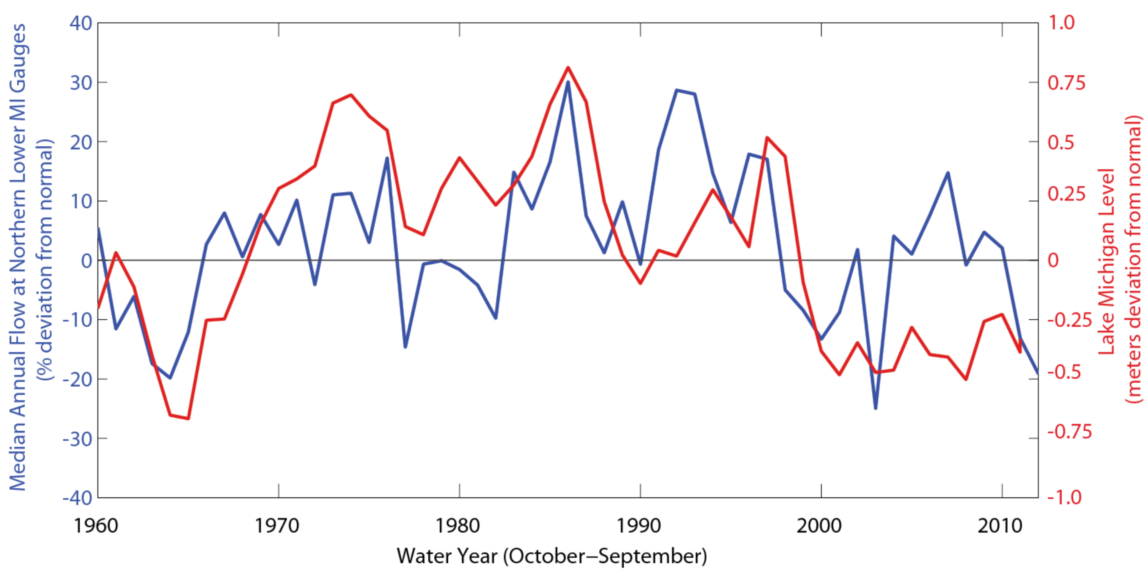


Figure 10. *Comparison between Lake Michigan Level (red) and the median annual flow at Northern Lower Peninsula stream gages (blue). Data source: USGS and NOAA*

Water Quality

There have been a number of beach closures across the region in the last decade, with the most common closures occurring near Traverse City (Figure 11). Most of the beaches stayed open across the region, but 53 closed at least one time between 2004 and 2014. Four beaches closed more than 6 times, half of which were in Traverse City.

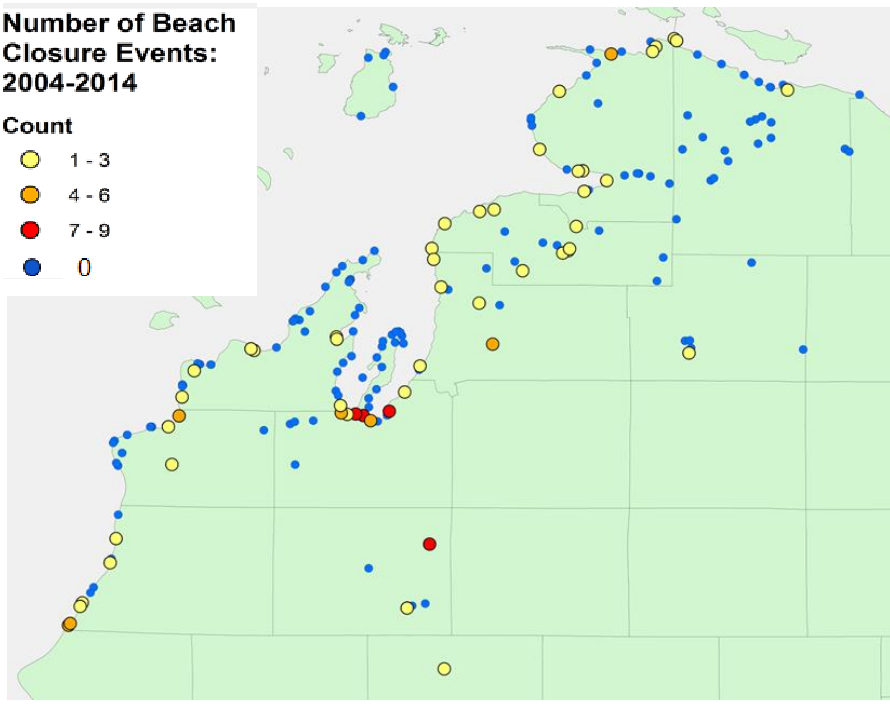


Figure 11. *Number of beach closure events between 2004 and 2014. Many monitored beaches did not close (blue). Several closed 1-3 times (yellow) and fewer closed 4-6 times (orange). Some beaches closed 7-9 times (red). Data source: Michigan DEQ*

Looking closer at the time series of beach closing data in comparison to select climate and streamflow data did not yield any significant correlations. Correlation coefficients were low between beach closing and annual precipitation (r = 0.10), number of days with heavy rain (r = -0.14), number of days with no rain (r = -0.23), August high temperature ($r < 0.00$), Lake Michigan level (r = 0.24), or average annual streamflow (r = 0.09).

Groundwater

The MSU hydrogeology group has been monitoring soil temperature and groundwater levels at a series of sites in the Grand Traverse Bay region for over a decade. As an example, the soil temperature data from site B3 indicate that the forested sites have significantly damped temperatures relative to those measured in the open sites (Figure 12).

a) Site map

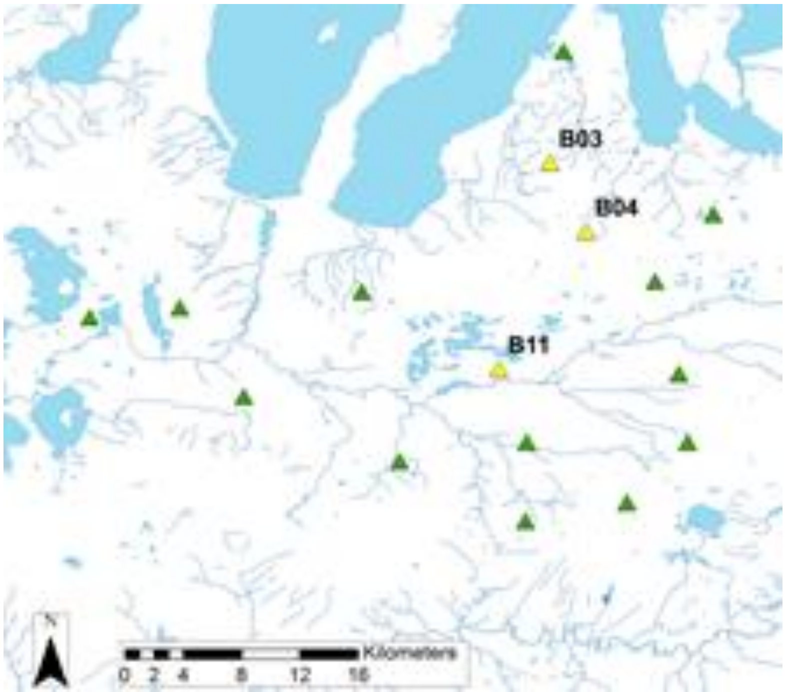
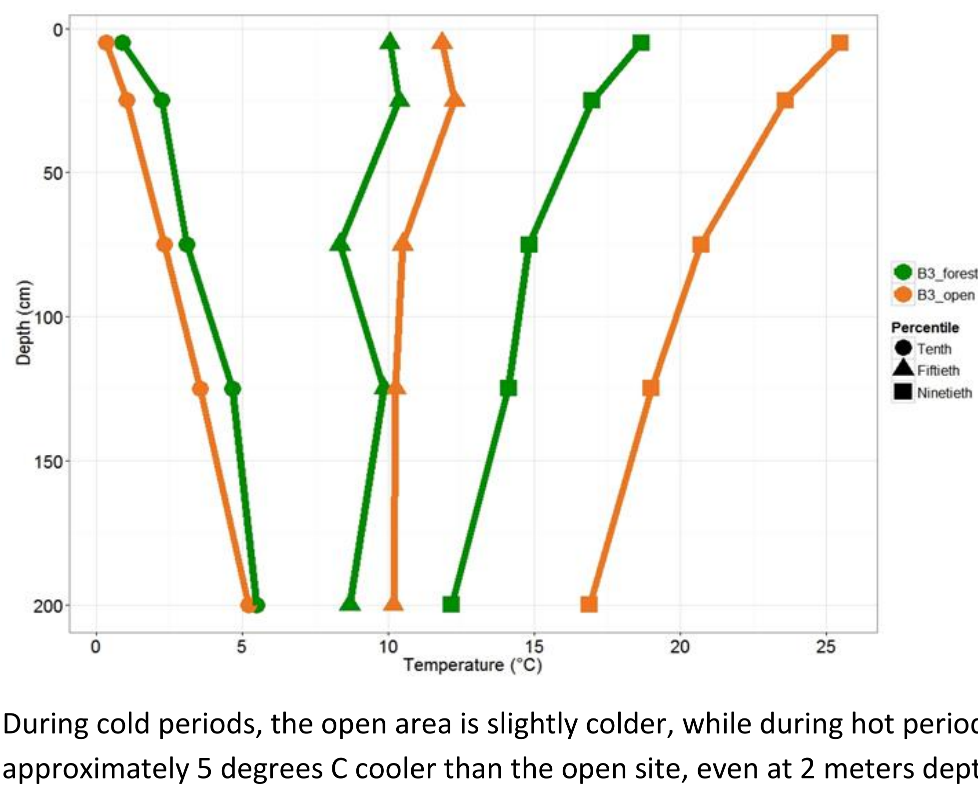


Figure 12. *MSU Hydrogeology groundwater monitoring* ***a)*** *Site map of soil temperature and groundwater sites across the GTBW region,* ***b)*** *Plot of the average annual 10th, 50th and 90th percentile of temperature distributions (see symbol shape) from 2010-2014 (water years) across sites from the Grand Traverse Bay Watershed (green lines and symbols are forest while orange is open area). Instrument depths range between 5-200cm. Data source: MSU.*

b) Groundwater temperature



During cold periods, the open area is slightly colder, while during hot periods the forested site is approximately 5 degrees C cooler than the open site, even at 2 meters depth. This indicates the importance of forest cover in moderating soil temperatures. It also indicates that reforestation may be a useful mitigation measure to help moderate increasing mean and variance of temperatures associated with climate change.

Groundwater observations across the region show annual cycles of rising groundwater levels during the spring due to recharge followed by declines during the growing season due to plant water uptake (Figure 13). Longer term trends show stable to declining water levels across the region from 2004 until 2012, followed by significant increases from late 2012 to 2015. This rising period corresponds with a period of cold winters and wetter than average years, and rising Great Lakes water levels. Trends across the three wells are correlated with each other, as would be expected for climate-driven fluctuations in water levels. Years with shallower groundwater levels, such as 2013 – 2014, in these monitoring wells also indicate shallower levels near streams and lakes in those years, which in general leads to higher flood risk as there is less room in the soils to store incoming precipitation.

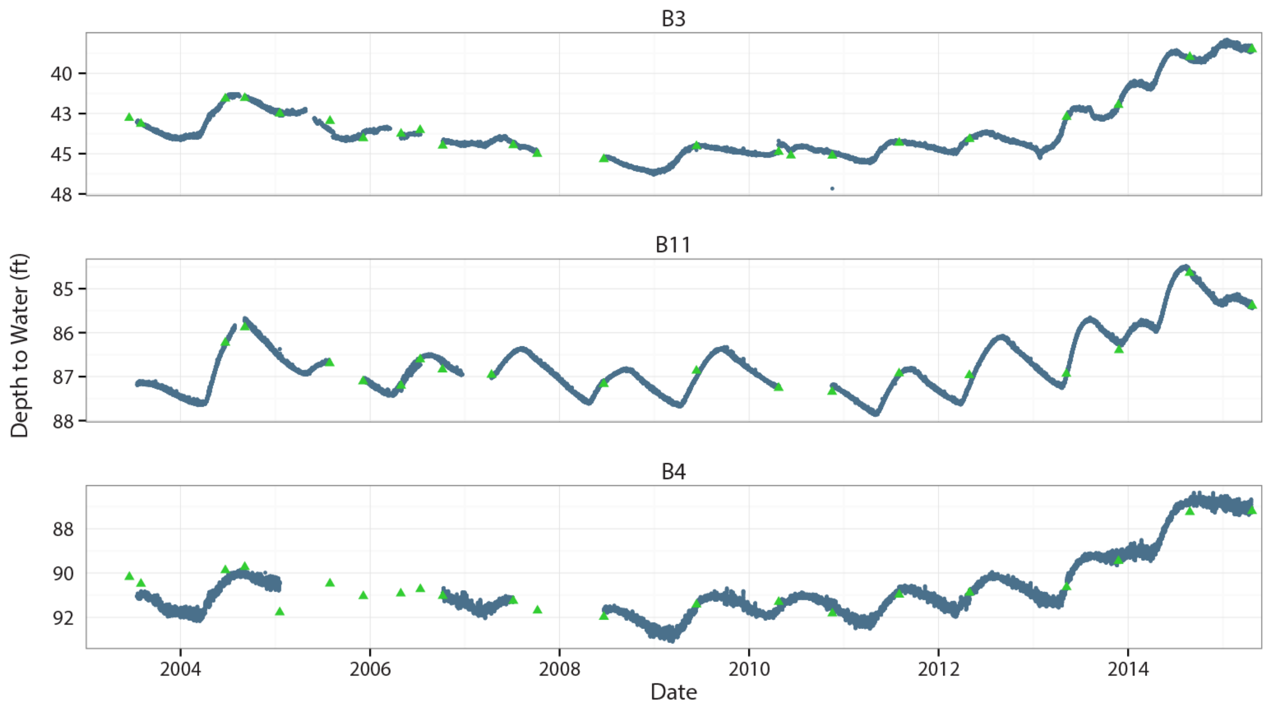


Figure 13. *Groundwater level observations from transducers (blue) and manual measurements (green triangles) - see site map in Figure 12b for the locations of the wells B3, B11, and B4. Data source: MSU.*

Model Simulations

Projected Climate Changes

For its Assessment Report 5 (AR5), the Intergovernmental Panel on Climate Change (IPCC) recently released updated estimates of projected climate change that were developed by synthesizing the results of multiple global climate model simulations (CMIP5). Global Climate

Models (GCMs), such as those used for the IPCC analysis, forecast climate change for a range of greenhouse gas emission scenarios, called “Representative Concentration Pathways” (RCP). These scenarios do a much better job describing spatial variability of climate across the Great Lakes region as they have much more sensitivity to land/open water (Figure 14a) than the previous generation of GCM runs for the IPCC AR4. This improvement is consistent with the fact that these models have increasing complexity and ability to incorporate important processes that influence climate, and they have more accurately matched measured climate conditions (Figure 15).

a) Regional prediction b) Scenario results

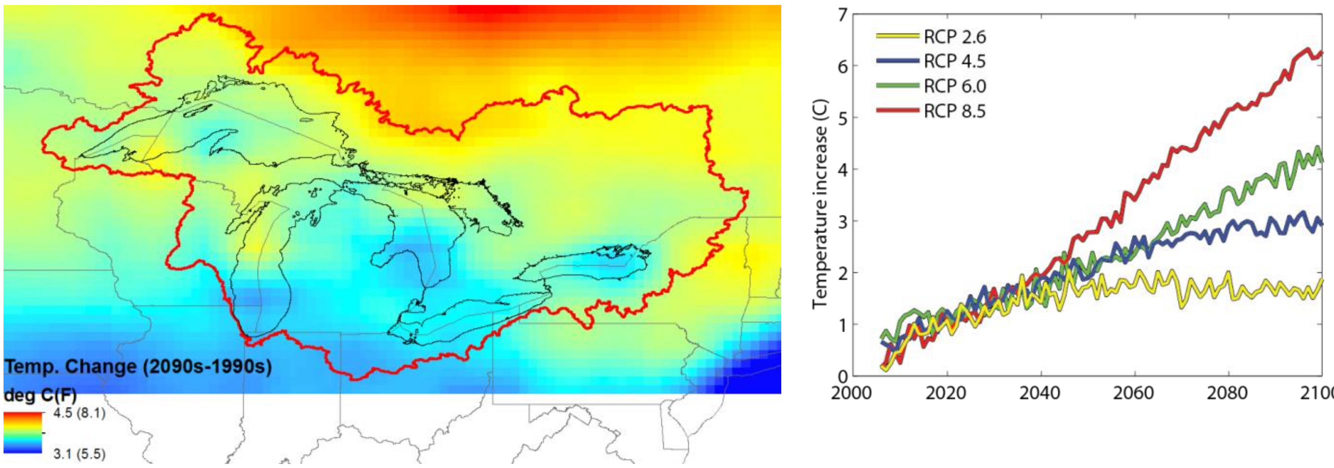


Figure 14. a) *Map of 2090 projected increases in temperature across the Great Lakes Region under the RCP 6.0 scenario represented as change from 1990’s,* ***b)*** *plot of projected increases in temperature for the region under the 4 main RCP scenarios considered by the IPCC AR5 (Model Data from IPCC).*

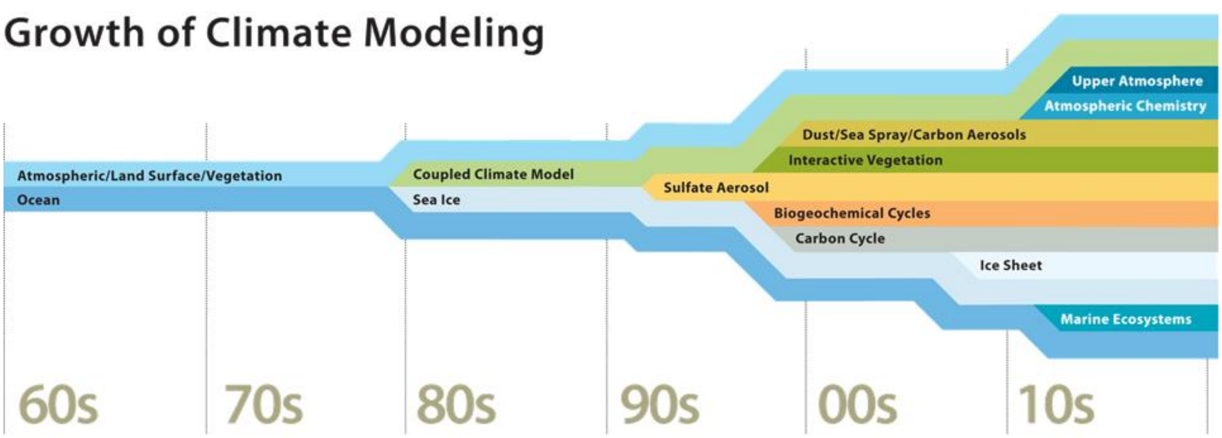


Figure 15. *Diagram illustrating the increasing complexity of GCM’s through the decades. (Image reproduced with permission from UCAR)*

Several greenhouse gas scenarios were examined for the GTBW region ranging from RCP 2.6 to RCP 8.5, in which the numbers indicate the radiative forcing effect of different levels of greenhouse gas emissions in Watts per square meter. Higher numbers indicate a greater amount of warming. The RCP 2.6 scenario assumes that greenhouse gas emissions are at or near a peak and that these will decline rapidly, which is not likely. The more likely RCP 6.0 and 8.5 scenarios have much more warming due to increases in greenhouse gas emissions through 2080 and the end of the century, respectively.

The average annual temperatures across the GTBW region is projected to increase by 2° to >6°C (3.5° to 10.5° F) by the year 2100 assuming future low to high emission scenarios respectively (Figure 14b). There is good agreement among a wide range of models in these estimates of temperature change.

Precipitation in the Great Lakes Basin is also projected to change based in the GCM simulations from the IPCC. Most of the Great Lakes region is projected to be slightly wetter. The northernmost regions of Michigan's Lower Peninsula have the highest projected change in the basin with approximately a 10% increase projected in the RCP 6.0 scenario by the end of the century (Figure 16). There is a significant spread across the different model predictions in terms of the projected precipitation change. Increase in variability (extreme events) is expected but difficult to predict.

a) Regional prediction

b) Scenario results

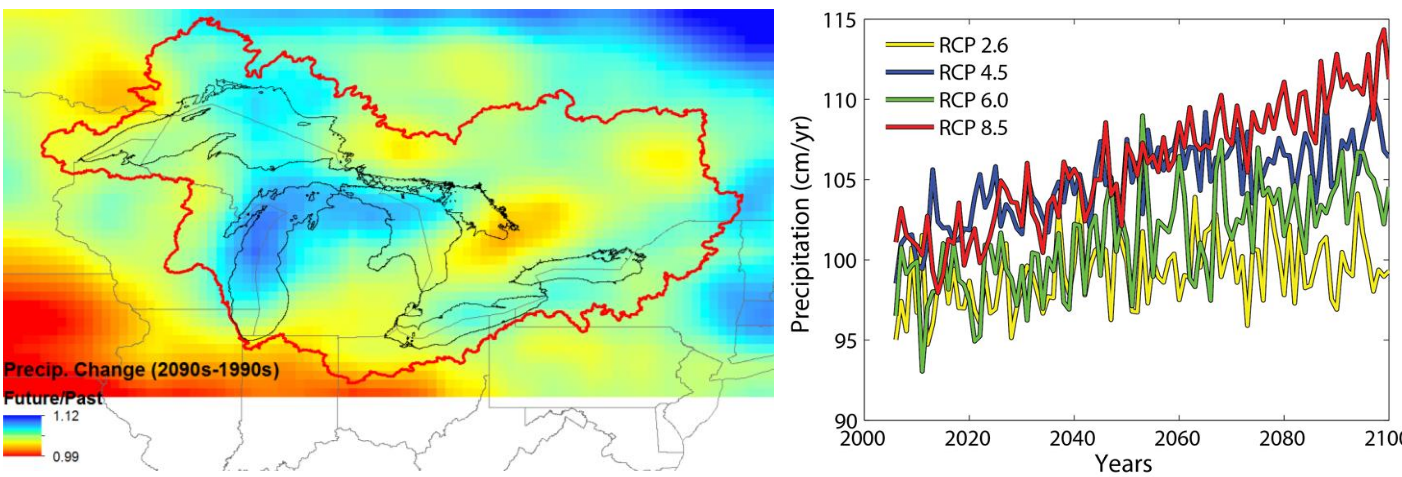


Figure 16. a) *Map of projected increases in precipitation across the Great Lakes Region under the RCP 6.0 scenario,* ***b)*** *plot of projected increases in precipitation for the region under the 4 main RCP scenarios considered by the IPCC AR5 (Model Data from IPCC).*

In addition to the longer term trends in projected precipitation and temperature, there are also significant changes in the projected seasonality of these factors within the study area (Figure 17). The largest increase in projected temperature are in summer months, especially by the end of the century when the rise at this time of year may be as much as 6° C. Precipitation is projected to decrease in the summer months and increase during the winter and spring.

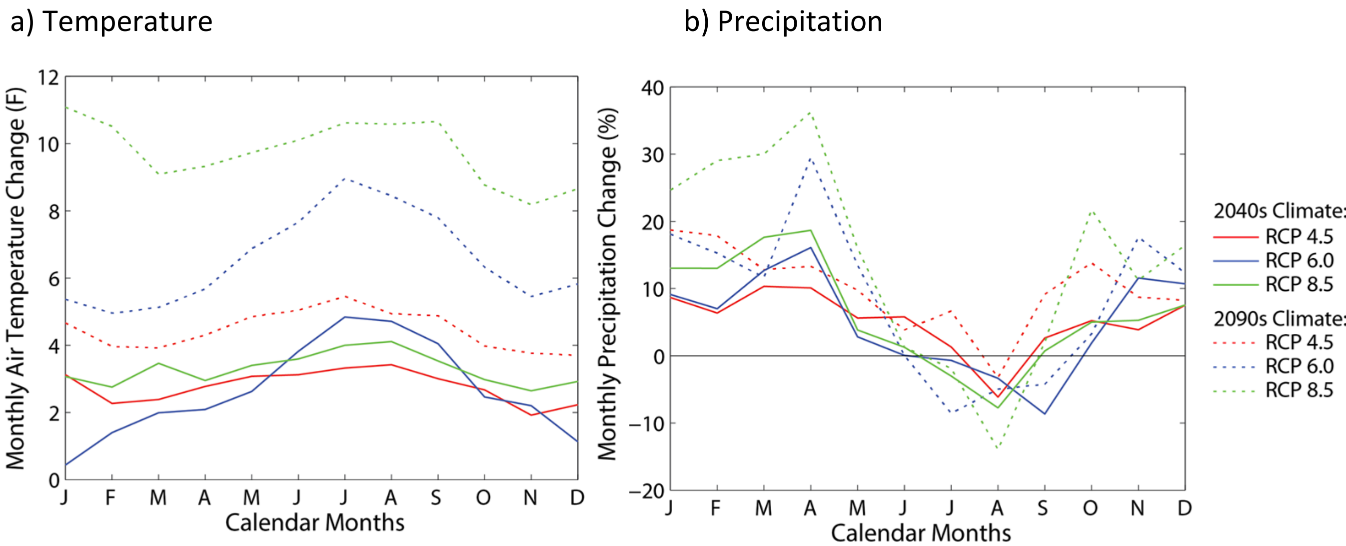


Figure 17. *Projected average increase in monthly temperature* ***a)*** *and precipitation* ***b)*** *at the middle of the century (solid lines) and near the end of the century (dashed lines) based on the IPCC CMIP5 scenarios. Values are represented as change from 2000-2014 baseline.*

Our project team took the projections of climate change shown above and simulated the hourly water cycle from 2000-2014 plus future projections with climate change (2045-2054 and 2089-2098) to quantify the likely impacts on hydrology, including stream flows. These simulations are based on the Landscape Hydrology Model (LHM) which simulates the entire energy and water balance hourly for large regions at fine resolution (Kendall and Hyndman *in review*, Wiley et al. 2010). LHM has been used to simulate the Boardman Charlevoix region and the the Muskegon River watershed to the south as shown in Figure 18.

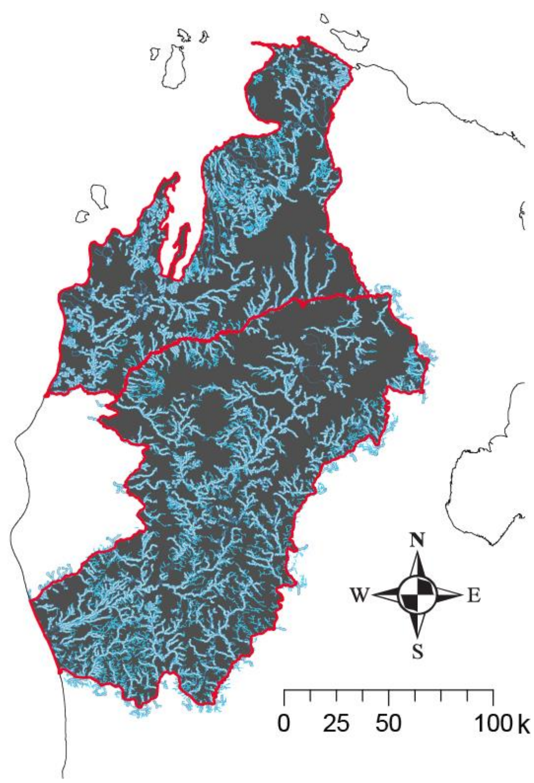


Figure 18. *Map of the LHM model domain incorporating the Boardman Charlevoix region to the north and the Muskegon River watershed to the south, with an overlay of blue rivers and streams.*

Models of Projected Impacts of Climate Change

Multi-decadal records show regional increases in temperature and precipitation, reduced ice cover on Great Lakes and inland lakes, as well as seasonal shifts in streamflow. In contrast, relatively short records are available for other important characteristics, such as groundwater levels and crop bloom dates. The Northwest Michigan Horticulture Research Center has been recording bloom date for several commercially important crops since shortly after establishment in 1979. These data show that bloom dates are getting earlier over this shorter period of record (Figure 19).

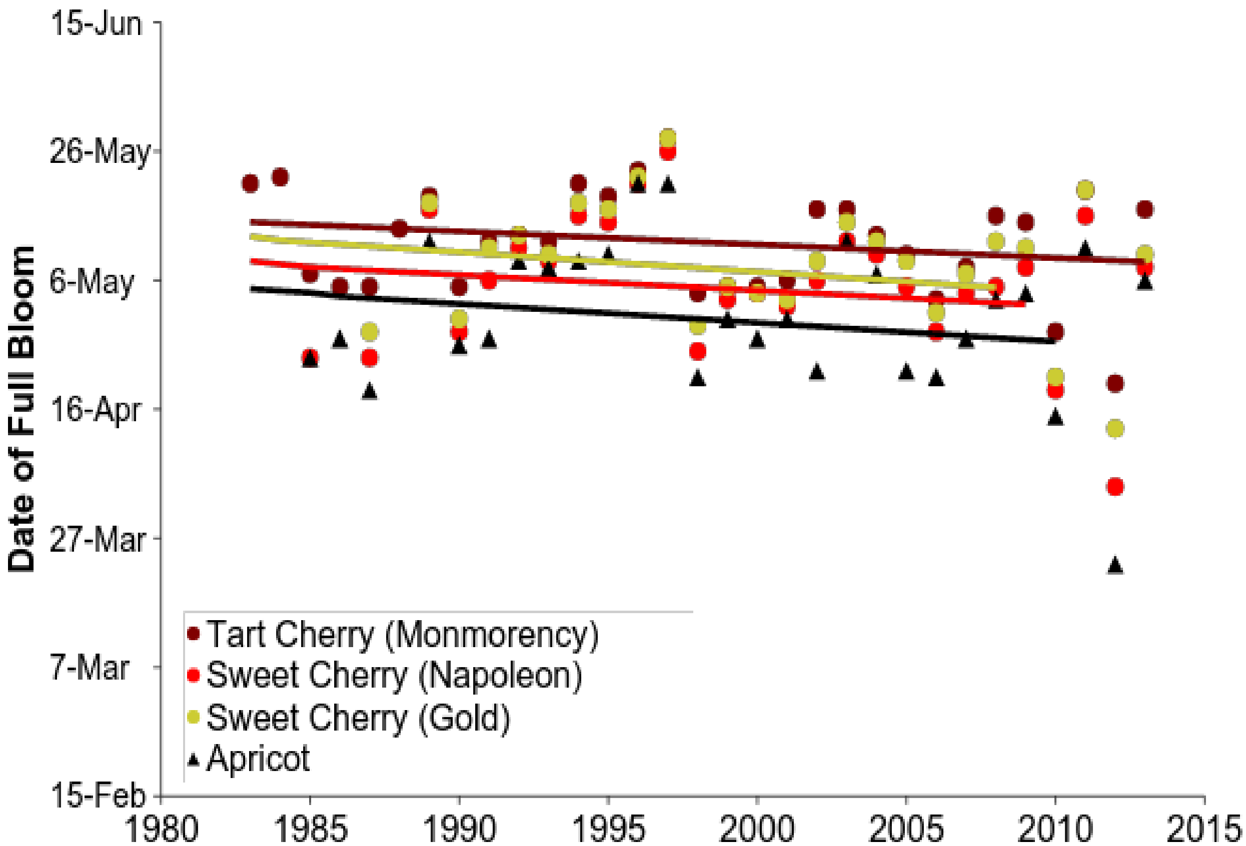


Figure 19. *Measured dates of full bloom for important fruit crop in Michigan.*

The most viable method of projecting the impact of climate changes into the future is using computer models. Direct measurements are often too short to establish trends. In a later section of this report, we simulate the projected changes in bloom date based on the IPCC simulations of climate change.

As we develop computer models, we verify these with observation data and then use the verified models to quantify the impacts of projected climate changes. Models thus provide powerful tools to quantify impacts of future changes. For example, they can provide reasonable assessments of the impacts of projected increases in temperature and changes in precipitation on streamflow, assuming the projected climate changes are correct.

We developed a conceptual model of climate change risk to explain the process of linking changes in projected climate to responses and impacts (Figure 20). In this model climate changes are primary drivers for direct physical and biological responses, which both cause human responses. Our actions at the regional scale have little impact on climate change but humans change their use of resources. For example, increasing irrigation due to climate change will impact groundwater levels and stream flows. The impacts of both direct and indirect responses on resource use generate societal and ecological impacts.

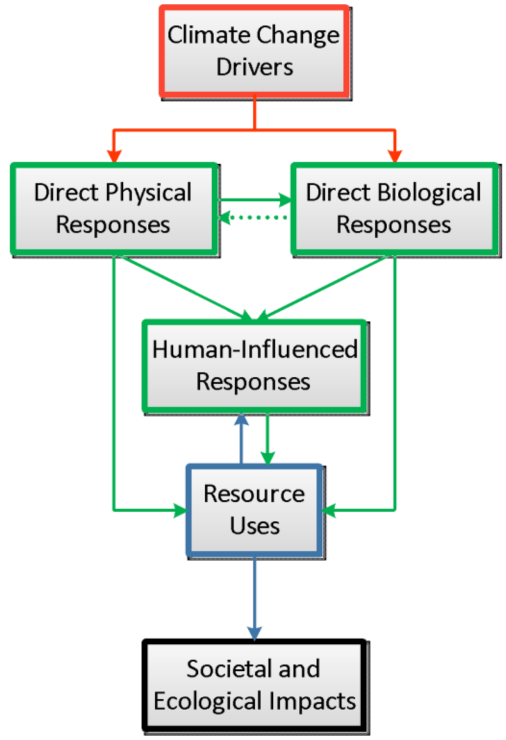


Figure 20. *Climate Change risk model*

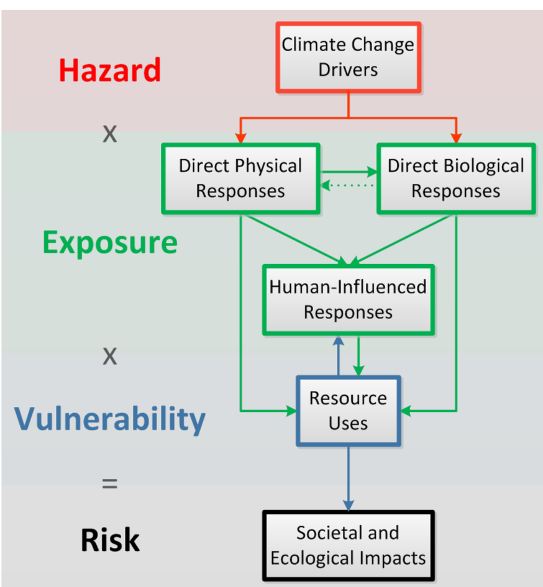


Figure 21. *Diagram of risk assessment associated with climate change.*

To understand risk, we first need to assess hazard, exposure and vulnerability as risk is effectively the multiplication of these factors (Figure 21). Climate change drivers are the hazard in this analysis, and humans are exposed via the responses mentioned above, while the vulnerability is related to resource use. These combine in terms of the associated risk, which is the actual ecological or societal impact.

For this integrative assessment we surveyed the historical record for **hazards** due to climate change, and **exposure** due to both direct and indirect responses. We also developed qualitative and quantitative forecasts and worked with stakeholders to identify **vulnerability** due to resource use. Finally, we examine the **risks** associated with climate change and examine the likely effectiveness of adaptation and mitigation strategies.

One of the most important areas of risk is associated with agriculture. The first step in evaluating such risk was to quantify the observed impacts of observed climate change on agriculture. For example, the bloom dates are earlier and more variable, which may increase crop loss due to frost. The warming trend alone may be beneficial for some agricultural sectors in the region, including vineyards. However the increase in variability may swamp positive outcomes with more loss of crops and even the vines themselves as happened in the last two years.

Forecasting Future Climate Thresholds

Stakeholders identified several important thresholds in climate variables which we examined during this project: Will potholes be more frequent? Will crop-loss increase? Will onset of fall colors change? Will the growing season change? Will heating/cooling costs increase?

To evaluate the influence of projected climate change on these thresholds, we used historical hourly weather data and future model projections from 1979-2099 for 3 scenarios (RCP 4.5, 6.0, and 8.5). To capture regional weather variability, we generated 340 million data points for each of the three scenarios, and thus over 1 billion total data points were created for this analysis. We then quantify the average changes across entire grid and analyze these changes by decade.

a) Heating Degree Days b) Cooling Degree Days

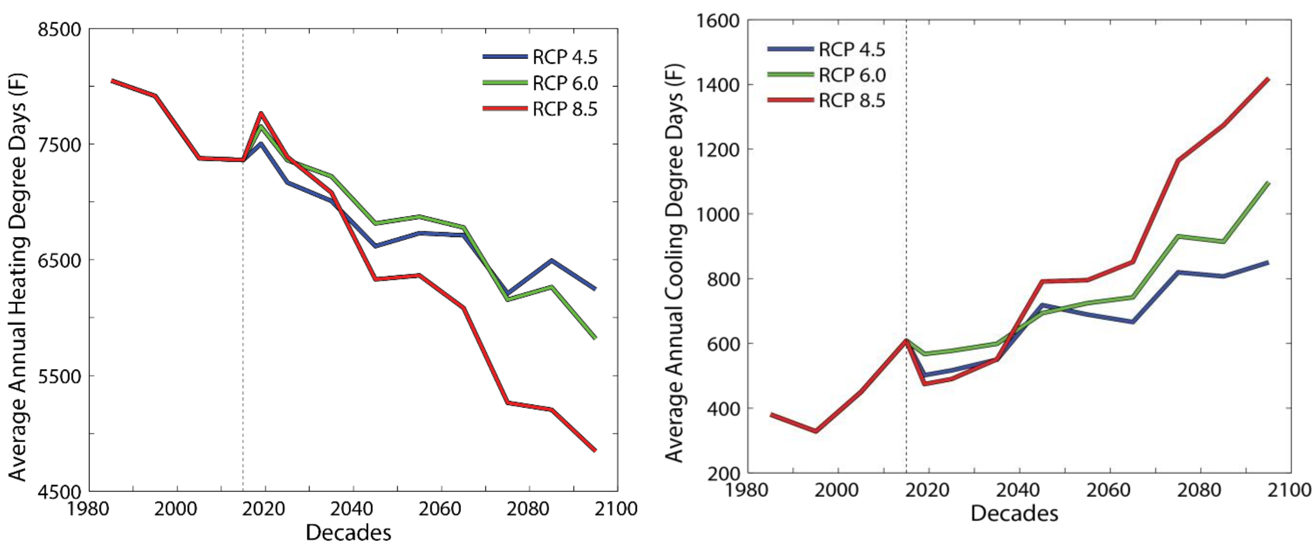


Figure 22. *Projected changes in* ***a)*** *heating degree days and* ***b)*** *cooling degree days for the three main RCP climate change scenarios from the IPCC AR5.*

One analysis involved changes in Heating/Cooling degree days, which is calculated by the number of degrees <65F multiplied by the number of days <65F, and vice versa. The projections indicate that the heating demand will decrease by 5 to 14% in the next 30 years and 14 to 41% in 90 years (Figure 22a). The energy savings associated with lower heating demand will be countered by increased energy requirements for additional cooling demand, which is expected to increase by 17-33% in the next 30 years and 41-133% by the end of the century (Figure 22b).

We also projected the start and end of the ski season across the study region based on the simple assumptions that the season starts after 7 total days where average daily temperature is below 34F, and ends with the last day where the average temperature is below 34F (a conservative assumption). This analysis indicates that it is likely that the ski season will start later and end earlier, resulting in a shortened season by about 3-4 weeks in the next 30-years and up to 2 months shorter by 2095 (Figure 23).

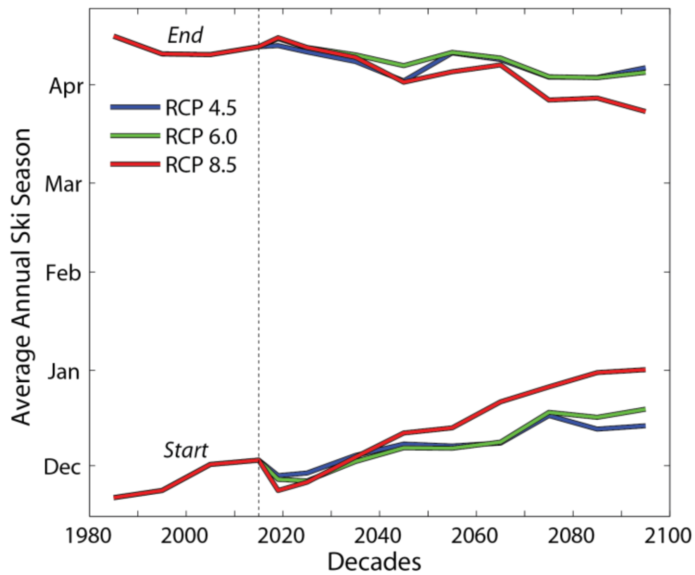


Figure 23. *Projected changes Ski season start and end date for the three main RCP climate change scenarios from the IPCC AR5.*

Agriculture in this region of Michigan on the other hand may benefit by the projected lengthening of the growing season. Our simulations estimate that the growing season will be approximately 27-41 days longer by 2045 and 30-55 days longer by 2095 than the recent 30-year average (Figure 24). Longer growing season along with warmer temperatures may allow new crops to be grown in Michigan, such as wine grapes that have not traditionally done well in the state. However, there is likely to be more variability in temperature including extreme events which may impart higher risk to such activities. As an example of this risk, the winters of 2013/14 and 2014/15 were extremely cold in the Grand Traverse region, causing major loss of grape vines.

In 2014, 77% of acres planted in major wine grape varieties were located in the northwest, west central and eastern regions of the state. Of those three regions, however, the northwest regions accounts for 86% of grape acreage.[1] Wine grape production is estimated to contribute $8.2 million annually to the state's economy, while wine tourism is estimated to contribute just less than $40.2 million (based on 2013 production data and 2012 winery visitor data) (Knudsen, McCole and Holecek 2014). The harsh weather of the 2013/14 winter reduced the state's wine grape harvest by 50%.[2] The hot and dry summer of 2012 resulted in high levels of production; however, the kind of drought that Michigan experienced during that summer will mean increased demand for irrigation.

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[1]https://www.nass.usda.gov/Statistics_by_State/Michigan/Publications/Michigan_Rotational_Surveys/mi_fruit15/fruit.html

[2]https://www.nass.usda.gov/Statistics_by_State/Michigan/Publications/Annual_Statistical_Bulletin/stats15/agstat15.pdf

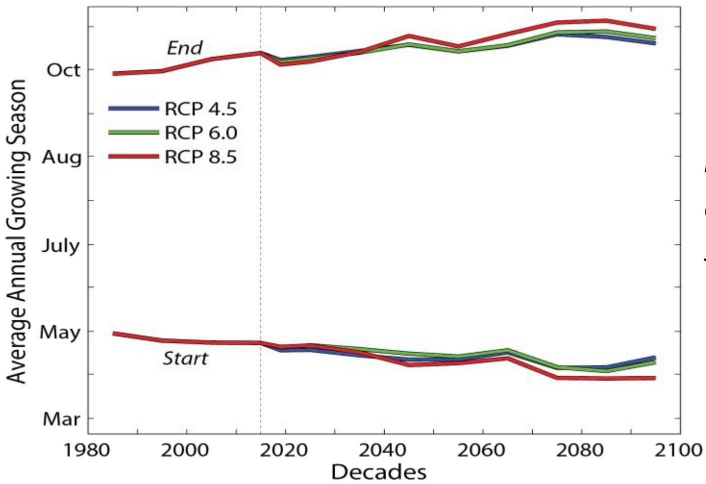
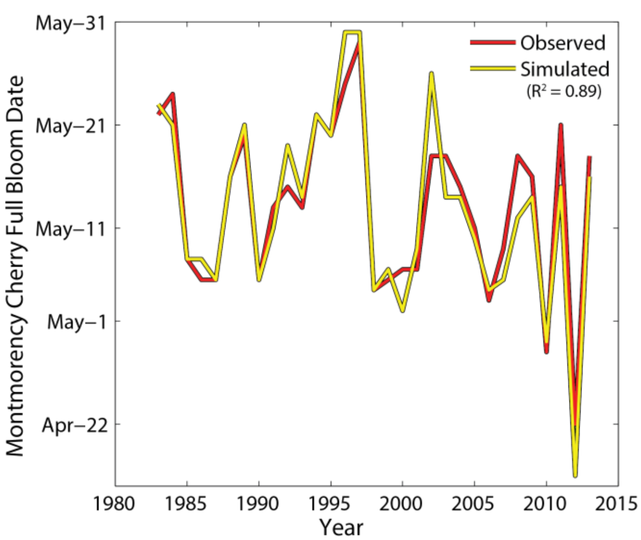


Figure 24. *Projected changes in growing season start and end for the three main RCP climate change scenarios from the IPCC AR5.*

To further evaluate the likely changes to orchards, we developed a simple tart cherry bloom date model. Our cherry model is a growing-degree day model, with a temperature threshold of 1.8 degrees C, and a bloom threshold 277.7 growing degree days. We optimized this model using bloom date data from 1983-2013 (shown in Figure 19). The model provided a good fit to the data with a R^2 value of 0.89 (Figure 25a). We then used this optimized model to project bloom dates under climate change scenarios into the future. The projection indicates that the bloom date will shift earlier by approximately 8 to 14 days by 2045 and 12-36 days by 2095 than the recent 30 year average.

a) Model calibration

b) Model projection



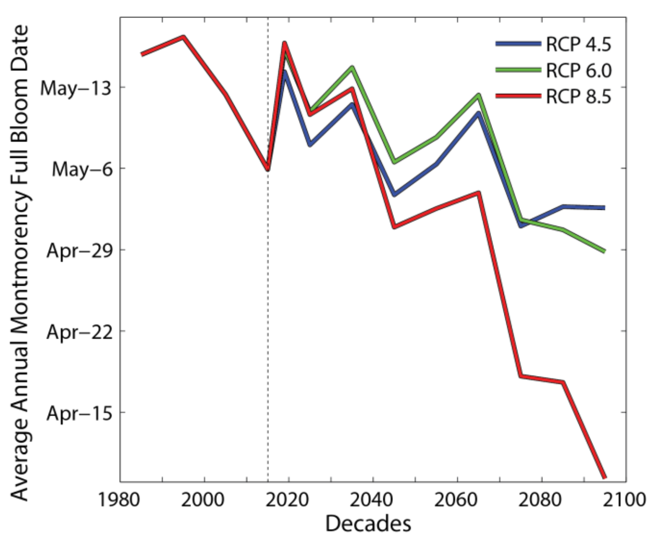


Figure 25 a) *Comparison between a simple 2 parameter statistical model (simulated) and observed data on tart cherry bloom date****. b)*** *Projected tart cherry full bloom date under projected climate change for the three main RCP climate change scenarios from the IPCC AR5.*

The increasingly early full bloom dates projected with climate change may increase the risk of crop loss as the risk of frost after bloom is likely enhanced with the earlier blooms. We estimated the risk of tart cherry crop loss due to freezing after bloom as a spatially-averaged likelihood of having a freeze event, defined as a minimum nightly temperature below 0 degrees C following the start of a bloom. This simple model shows the potential for slightly lower risk as climate warms, however it underestimates risk of crop loss after early budburst (Figure 26). A more complex model would be necessary to further evaluate this risk because the increase in variance of temperature may overwhelm this effect causing higher risk.

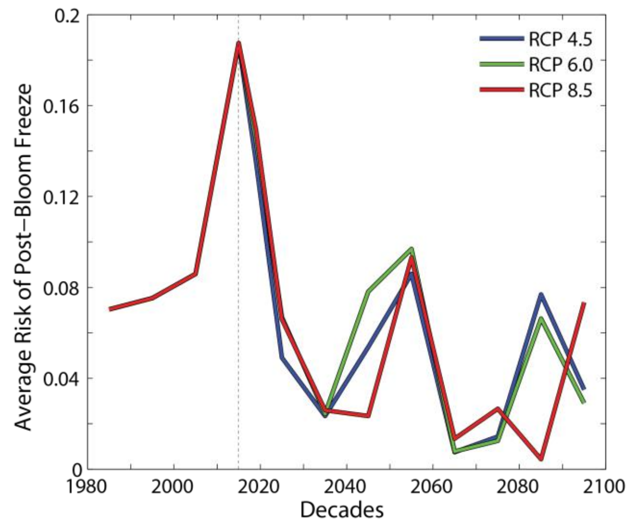


Figure 26. *Projected changes in the probability of post bloom freeze in the Grand Traverse region for the three main RCP climate change scenarios from the IPCC AR5.*

In both 2002 and 2012, early spring warming combined with late frosts devastated the tart cherry crop in Michigan. Until 2012, 2002 held the record for lowest tart cherry production year in Michigan, but that record low was broken by the 2012 crop year. Yield per acre in 2002 was 545 lbs and in 2012, 425 lbs. By contrast, the average annual yield over the 2003-2011 crop years was 6815 lbs/acre. In 2012, despite record high prices, the total value of 2012 tart cherry production was just under 28% of average annual value of total production for the 2003-2011 period.[3]

We also projected changes in winter freeze/thaw cycles using a temperature threshold model that assumes the ground freezes with 10 degree days <32 F and melts with 10 degree days above 32 F. This analysis indicated that the variability in cycles will likely be amplified by climate change (Figure 27). Such an amplification would likely result in more potholes in roads and thus increase road repair costs. This model could be compared with data on pothole occurrence.

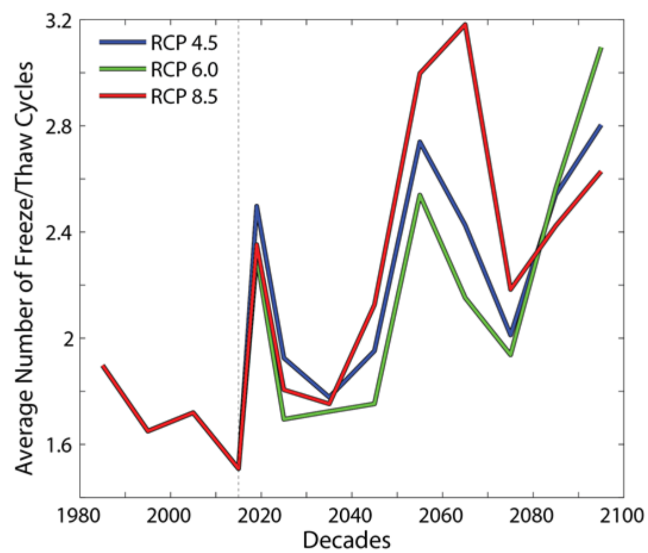


Figure27. *Projected changes in number of freeze thaw cycles for the three main RCP climate change scenarios from the IPCC AR5*

[3] http://www.nass.usda.gov/Statistics_by_State/Michigan/Publications/Annual_Statistical_Bulletin/stats03/statspdf.html and http://www.nass.usda.gov/Statistics_by_State/Michigan/Publications/Annual_Statistical_Bulletin/stats13/agstat13.pdf plus additional years for yield data 2003-2011.

Forecasting Future Hydrology

Forecasting changes in hydrology requires more complex models because simple statistical models can not represent the complex nonlinear dynamics associated with changes in the water balance through time. We developed a full water and energy balance hydrologic model that is robust to changes in climate and land use. The Landscape Hydrology Model (LHM), developed at Michigan State University, directly simulates surface- and ground-water processes, along with the energy balance associated with linkages between climate, plants and water (Figure 28). LHM is a full energy and water balance code capable of large-scale fine-resolution simulations. It is also modular and readily expandable. The code readily incorporates GIS, remote sensing inputs, facilitating development of models across broad regions using readily available data.

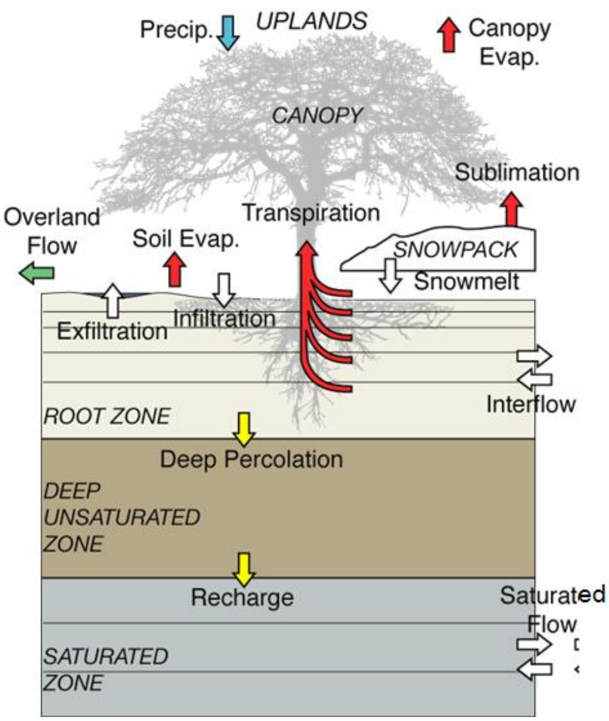
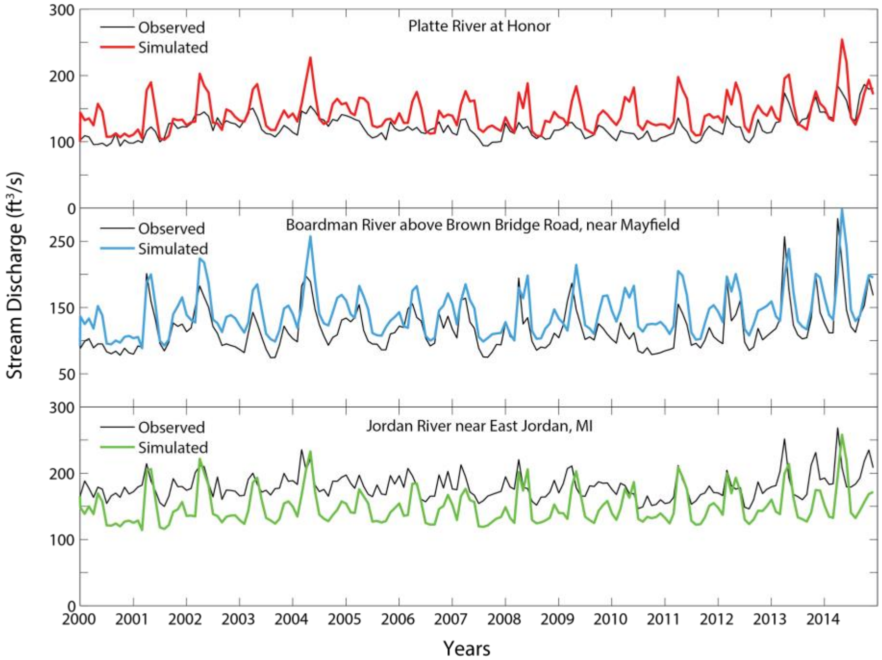


Figure 28. *Diagram representing processes described in LHM.*

LHM simulates the complete Landscape Water Cycle including: 1) canopy and litter interception of precipitation, 2) stored water in snow, 3) root zone soil moisture dynamics including variable root mass with depth, 4) water percolation through the rest of the unsaturated zone, and 5) groundwater flow in the saturated zone (based on the USGS code MODFLOW).

For this project, we developed models to explore the likely impacts of ensemble climate scenarios (RCP 4.5, 6.0, 8.5). In addition, we explore the following land use scenarios (current land cover, reforestation, and green infrastructure.

Once the model was parameterized, we compared modeled streamflow to data from USGS stream gages, serving as a comparison between simulated and observed flows (Figure 29). The model as presented here is not calibrated in any manner yet it provides a good representation of the measured streamflow across two of the three stream gages. The model underpredicts baseflow in the Jordan River. This particular river system has a much larger groundwater contributing zone (groundwater-shed) than surface watershed, which may be a reason for the underestimate.



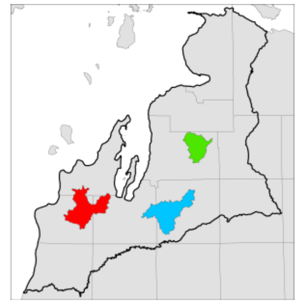


Figure 29. *Plot of measured stream flows relative to simulated flows from LHM. Locations of the watersheds are shown in the same color as the lines. Note these are completely uncalibrated simulations (Data from USGS).*

Looking closer, as expected, the LHM simulations show that smaller watersheds have lower summer flow, but similar spring flows from the Boardman and Elk River watersheds that are much larger (Figure 30). This is consistent with the smaller watersheds having much less groundwater storage. Somewhat surprisingly, peak flows are similar across watersheds with very different sizes. This is attributed to a much higher percent urban runoff in the small watersheds near Grand Traverse Bay. Peak flows and spring flows often load nutrients to the bay, thus this finding indicates the smaller flashy watersheds likely increase the risk of algal blooms in the bay.

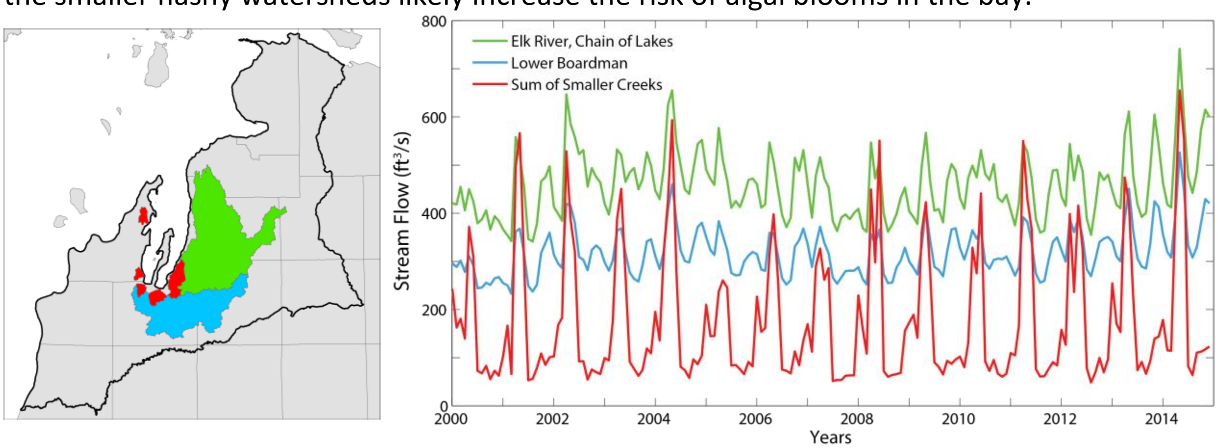


Figure 30. *Plot of simulated stream flows from LHM from two large watersheds relative to the sum of flows from small creeks that drain to Grand Traverse Bay. Locations of the watersheds are shown in the same color as the lines.*

A detailed analysis of monthly water fluxes in this simulation allows for differentiation of recharge, evapotranspiration and overland flow runoff components of the hydrologic cycle for this region. Recharge and evapotranspiration (ET) dominate the water balance of the region (Figure 31a). Evaporation and transpiration make up approximately 55% of the annual water budget while, groundwater recharge accounts for approximately 35%, leaving only approximately 10 percent for runoff on average. Although this is a small percent, it has the largest short-term impact due to flooding. Seasonally, there is a dominant recharge pulse, and a much smaller runoff pulse, related to snowmelt (Figure 31b). Evapotranspiration peaks during the growing season, as expected.

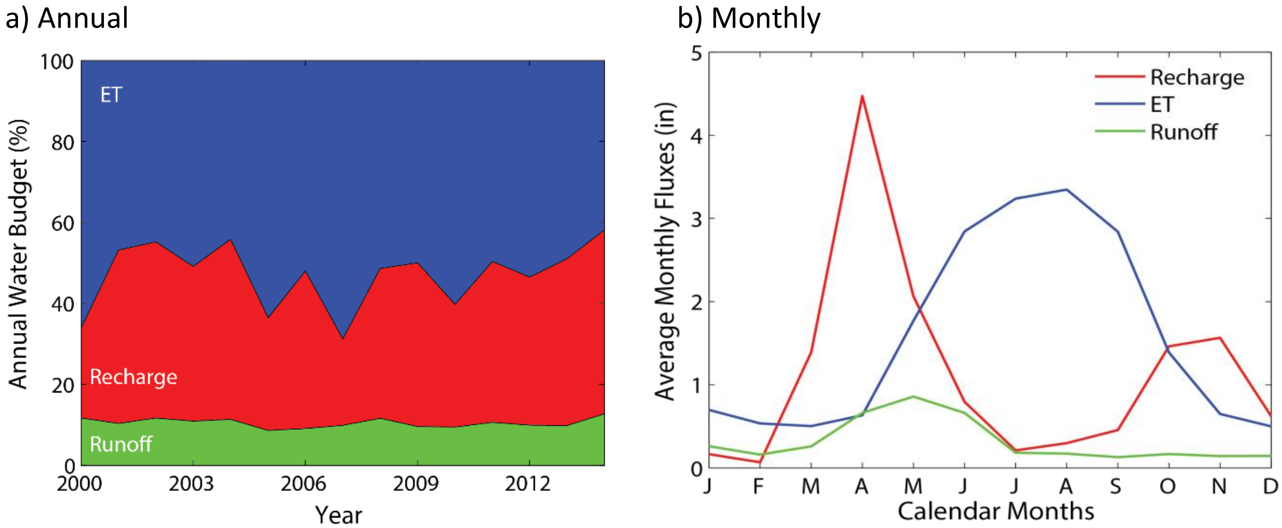


***Figure 31. a)** Annual hydrologic flux components as a percent of the total simulated annual water budget. **b)** Plot of monthly water flux components averaged across simulations from 2000 to 2014. Recharge represents the amount of water that percolates through the ground surface past the root zone into groundwater, Runoff represents overland flow, and ET is evaptranspiration.*

Changes in recharge varied spatially across the modelled area from as much as +/- 4 inches per year (Figure 32). There are large areas of decreasing recharge, which will be a significant challenge for agriculture. Groundwater dependent ecosystems, such as wetlands and cold-water streams, will likely have less available water.

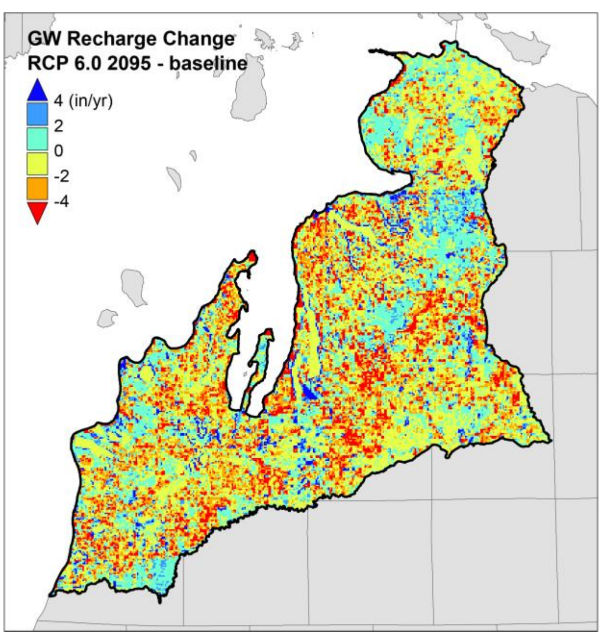


***Figure 32.** Modelled change in groundwater recharge under RCP 6.0 climate change scenario.*

Upland recharge is the most relevant measure for agriculture. Our model predicts that recharge in this important area will increase during winter months but decrease for the remainder of the year. Spring recharge decreases moderately under 2 of 3 scenarios of 2040s climate, and sharply in all 3 scenarios of 2090s climate (Figure 33a). Seasonality in recharge is thus accentuated and can drive changes in ecosystem behavior through changes In groundwater discharge to surface water bodies. This decrease is coincident with the months where evapotranspiration peaks (Figure 33b); the soil moisture also declines significantly in these projections (Figure 33c), which is linked to likely increases in risks to dryland farming in the region.

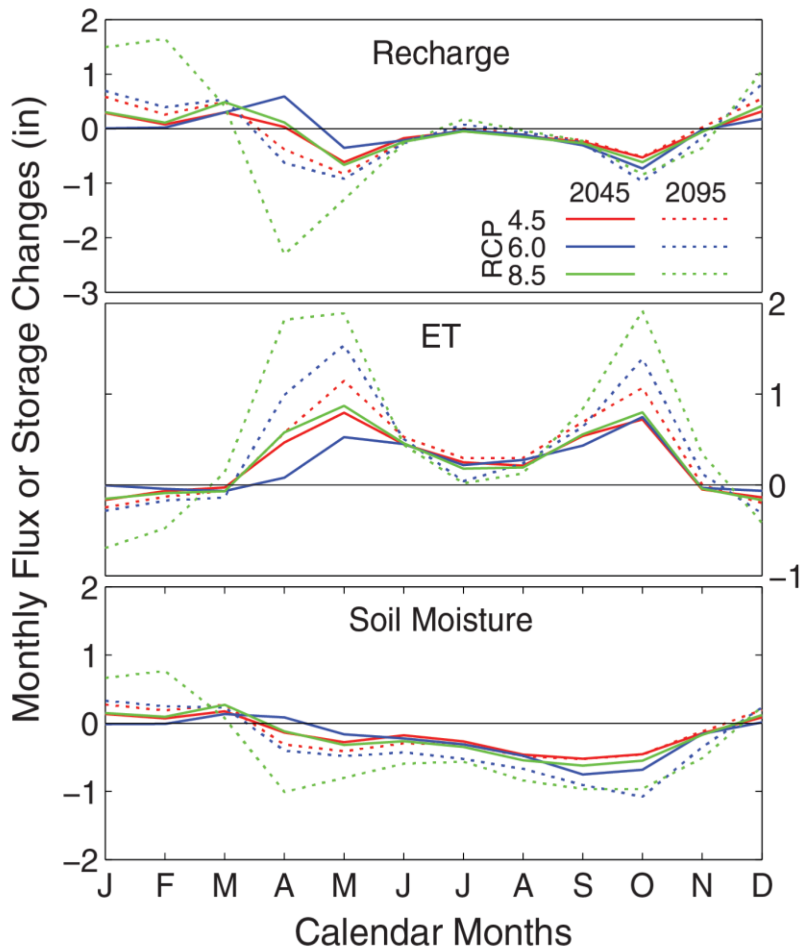


Figure 33. *Modelled change in monthly average groundwater recharge (Recharge), evapotranspiration (ET), and soil moisture storage (Soil Moisture) under climate change scenarios for 2040's solid lines and 2090's - dashed lines.*

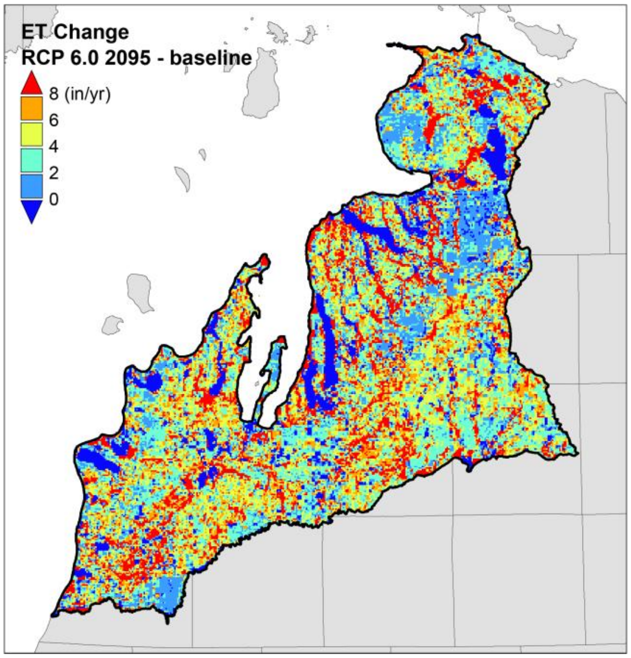
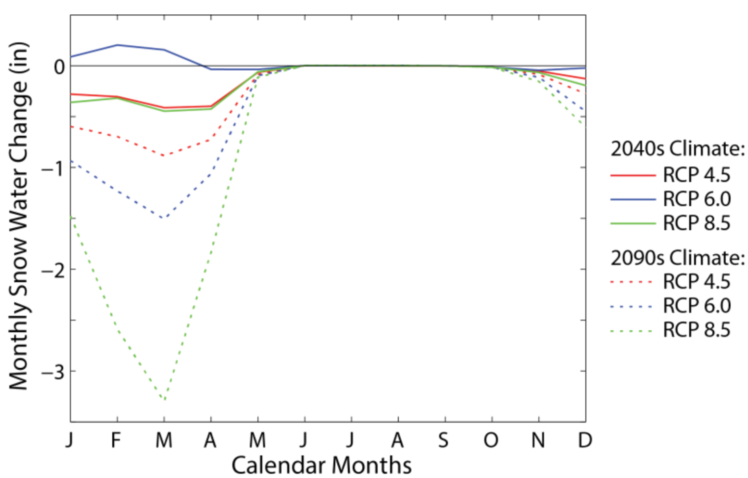


Figure 34. *Modelled change in evapotranspiration under RCP 6.0 climate change scenario.*

Evaporation and transpiration are expected to increase in all land cover types between 1 and 8 inches per year under moderate climate change scenario RCP 6.0 (Figure 34). Most of the region is expected to experience an increase of more than 2 inches per year. This shift from recharge to evapotranspiration means that more water returns to the atmosphere and less water goes into groundwater reservoirs to supply water to streams, lake, and wetlands in the area.

Snow is an important aspect of the water cycle in Northern Michigan. Climate change scenarios predict dramatic declines in snowpack, driven primarily by decreases in water content (Figure 35). A reduction in snow water content of 1 inch is translated roughly to a drop of 10 inches in snow pack thickness. Several major ski areas are located within the area with the highest decreases in snowpack. These changes in snowpack also relate back to previously discussed seasonal shifts in recharge due to spring snowmelt. Local increases in snowfall (discussed earlier) may mediate some of the projected declines in snowpack due to increasing temperatures.

a) Modelled seasonal changes



b) Map of projections

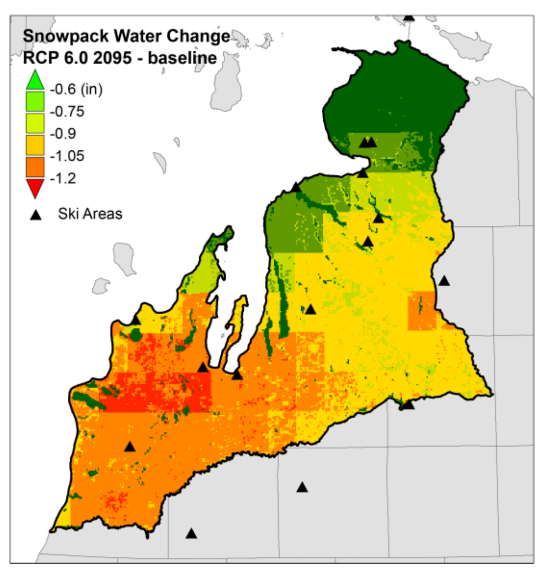


Figure 35. a) *Modelled seasonal change in snow water content under the main RCP climate change scenarios for 2040's and 2090's.* ***b)*** *Map of projected change in annual snow water content for the RCP6.0 projection by 2095 relative to the baseline*

condition with no climate change.

Streamflow is projected to change rather dramatically for smaller urban streams in the region for different climate change scenarios. By the 2090's, winter streamflow is projected to increase by 15 to 50 percent, due to intermittent melting of the snowpack. There is then a corresponding reduction in summer streamflow by 15 to 20 percent, since a significant amount of snow melted in the late winter and early spring rather than being stored for later recharge to sustain streamflow during the summer (Figure 36). The lower summer flows would also likely be linked to warmer stream water with less cool groundwater available to supply the streams under these projected conditions.

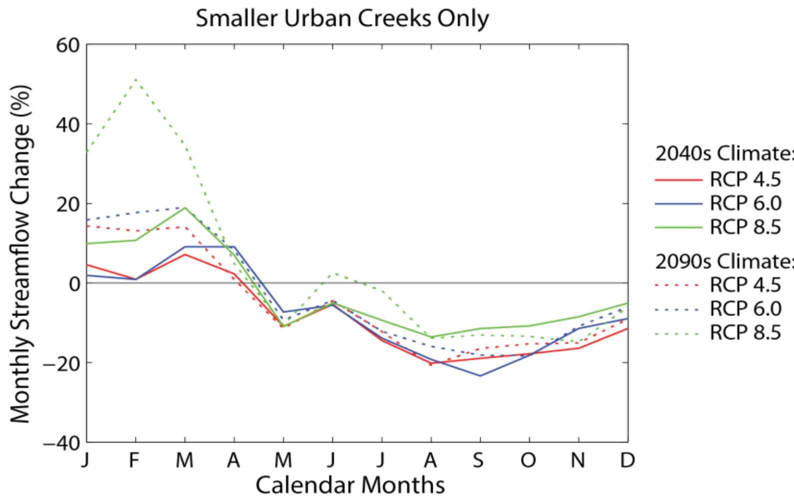


Figure 36. *Modeled change in monthly streamflow for smaller urban creeks under projected climate change conditions for the main IPCC climate change scenarios.*

Mitigating Land Use and Climate Change Impacts

Our research team explored what we can do to potentially mitigate some impacts of climate change. Mitigation reduces *exposure* to a hazard by altering physical or biological system responses. Examples include: planting riparian buffer strips helps to reduce sediment loads due to increased large precipitation events, and planting native grasses helps reduce lawn irrigation, reducing water use from surface and groundwater.

As a first step to evaluate the likely influence of mitigation measures, we simulated the impacts of two specific types green infrastructure on seasonal streamflows under current climate conditions (Figure 37). Reducing impervious area within the region is frequently mentioned as a potential mitigation strategy. We developed three corresponding scenarios reducing impervious surfaces by 5, 10, and 20% from current levels of imperviousness (as defined by the 2011 National Land Cover Dataset) in medium to high density urban areas. The result was the same land cover type with less impervious surface area. A second set of scenarios were designed to simulate expanded implementation of green infrastructure strategies that allow for on-site retention and infiltration of stormwater, such as bioswales. These were implemented within the model by expanding the catchment areas of on-site retention and infiltration basins for stormwater 150, 400, and 900 meters beyond existing coverage. .

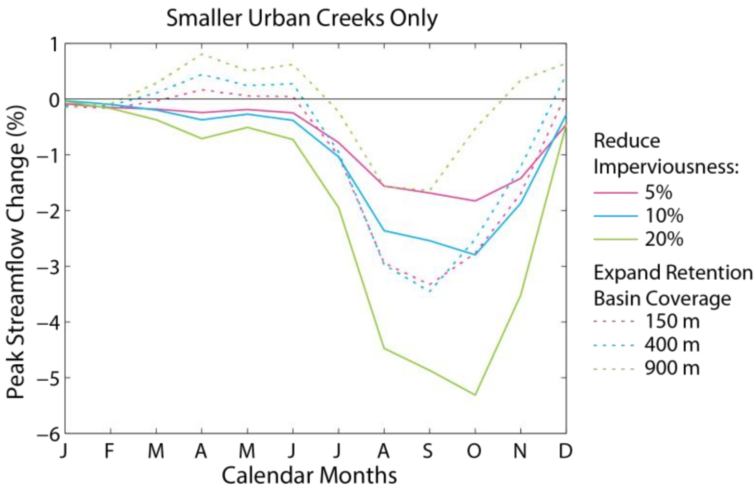


Figure 37. *Modeled effectiveness of mitigation options (reduce impervious surface areas or expanding retention basis) on their ability to change peak streamflow in small watersheds in the GTBW region under current climate conditions.*

Reducing imperviousness and expanding retention basins both reduced summer flows, while these two mitigation options had minor but opposite effects on simulated flows during the spring (Figure 37). The largest changes in streamflow are expected to be seen in late summer through fall, where both mitigation strategies reduce peak streamflow. Reducing imperviousness by 20% in the watershed decreased peak streamflow most throughout the year, with as much as a 4-5% decrease in the fall. All scenarios of retention basin expansion resulted in similar reductions of peak streamflow when compared with moderate reductions in imperviousness. Reductions in streamflow are most desirable during high-flow events, such as spring flooding, to decrease erosion. Unfortunately, our simulations show that green infrastructure is minimally effective during this time period but has larger impacts during critical low-flow periods.

When simulations combined land use changes with climate change scenarios, we found that the anticipated changes in peak streamflows are predicted to be much larger than the potential benefits simulated in our green infrastructure scenarios (Figure 38). Individual more highly urbanized catchments, such as Kids Creek or Mitchell Creek, may benefit more. This is likely due to the relatively small role that overland runoff plays in generating streamflow in this groundwater-dominated region.

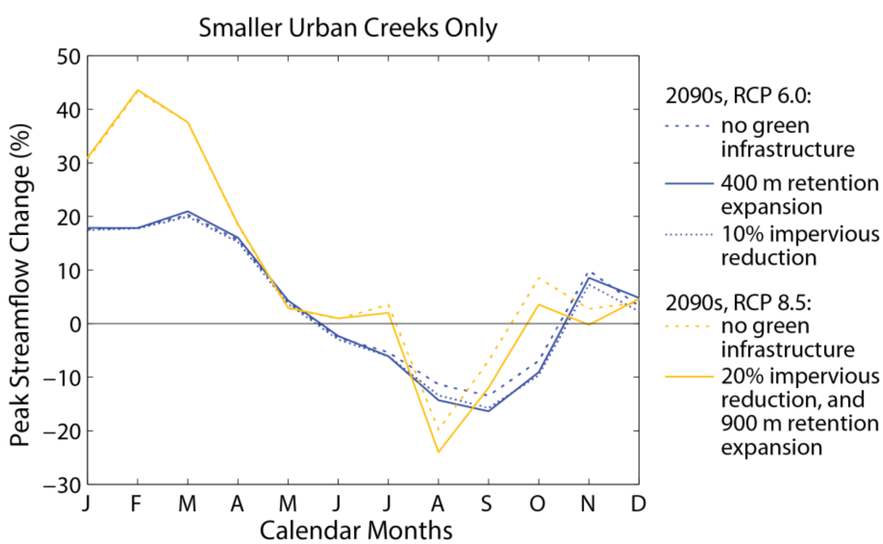


Figure 38. *Modeled effectiveness of various green infrastructure scenarios on their ability to alter peak streamflow in small watersheds in the GTBW region climate change scenarios.*

Another strategy to mitigate some effects of climate change are to reforest areas that have been converted to agriculture over the past 150 years. To illustrate the changes possible under an extreme scenario, we compared modeled recharge under a scenario depicting the largely-forested land use prior to European settlement of the region (Fig 39b) to that of current land use conditions (Figure 39a). Recharge patterns vary in response to climate, soil, and land use. In particular, regions with increased snowpack experience greater recharge (see Figure 2 for current land use). Similarly agricultural or grassland land uses experience greater recharge than forested areas, holding climate and soil conditions constant.

The effect of the current land use practice relative to pre-settlement (roughly 1820-1850) is to significantly increase groundwater recharge in agricultural belts, while decreasing recharge in urban centers. Returning areas under altered land use to pre-settlement conditions would reduce groundwater recharge, thus decreasing streamflows. One particular consequence of reducing streamflow would be to reduce sediment transport capacity (erosion) within the region's streams. Other consequences would result as well, including impacts on stream temperature and flows during critical ecological periods. Further modeling can be used to evaluate impacts of any particular land use management strategy in greater detail.

a) Current land use b) Presettlement Land use

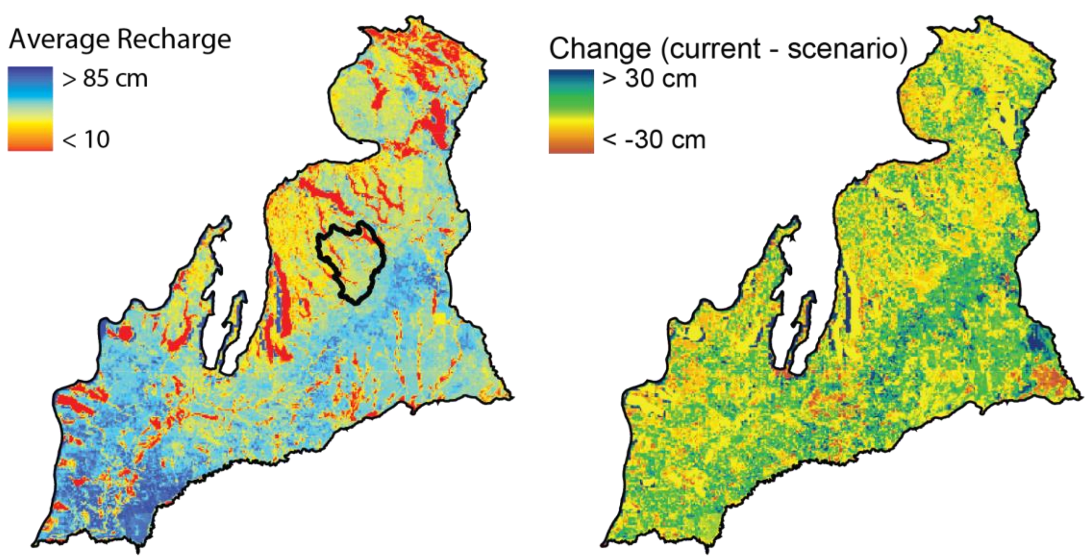


Figure 39. *Modeled annual groundwater recharge under* ***a)*** *current 2000 – 2009 and* ***b)*** *presettlement land use conditions.*

Adaptation can reduce the *vulnerability* to a particular hazard. Examples include: planting warmer-weather varietals and cultivars helps maintain yields during warmer summers, and upgrading road crossings to handle higher flows helps protect built infrastructure during more frequent flood events. While this study does not directly address adaptation strategies, there has been a significant research effort related to this, particularly related to agricultural practices (see, for instance, *Basso et al. 2015*)

Summary

This project demonstrated that significant changes in climate and land use across the Grand Traverse Bay region are likely to have impact recharge, stream flows, lake levels, crop yields, and ecosystems. The climate is projected to become warmer, wetter, and have more extremes with less snow. As a result, the region will likely have less streamflow, lower lake levels and have seasonal shifts in streamflow. This in turn is likely to lead to water quality problems including more e-coli issues.

Our main tools to evaluate these potential changes are process based models, which can quantify the likely impacts of projected changes, and to test the effectiveness of potential adaptation strategies. Through this IA process, our team worked with regional stakeholders to help understand and mitigate expected challenges that we discovered through the project.

We identified that climate change is likely to have significant effects on seasonal streamflow. One of the most significant concerns associated with these changes are the likely increases to flood risk. This should be considered as the region plans for projects where bridge crossings are designed or flood zones are evaluated. The costs of Green Infrastructure should be evaluated relative to costs of updating other urban infrastructure to deal with the projected changes in streamflow. In addition, the models used in this study indicate that the region is likely to experience lower summer flows and warmer water, which would have effects on aquatic ecosystems.

Through this project, we demonstrated that models can offer insights into types of mitigation and/or adaptation that can help avoid future problems. While a cost-effectiveness analysis was not feasible, given the types of mitigation and adaptation strategies ultimately simulated, the simulations nevertheless help communities across the region understand the potential impacts of infrastructure investments so that such an analysis could be conducted for particular locations and projects.

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Appendix 1. List of compiled data.

Data has been downloaded from multiple agencies covering topics including: surface water, water quality, and climate data.

- Surface water data has been gathered from six USGS streams gages (04126740, 04126970, 04127000, 04127499, 04127565, 04127800) and four USGS lakes (0443903085312101, 0445256085240001, 0450415085153501, 0451540084560301) in the area of the Boardman-Charlevoix Watershed. Data gathered from MSU operated gaging stations on the Jordan and Boardman Rivers have been used.
- Groundwater level and temperature from 17 MSU operated dataloggers installed in USGS well sites have been compiled. Several of these sites have accompanying soil moisture and temperature installations. Water level data from USGS GW station in Cheboygan has been downloaded.
- Climate data has been downloaded from the twelve Michigan State Enviroweather (previously MAWN) stations (arl, blk, bnz, eld, elk, epr, kal, kwd, mcb, nth, nwm, old) in Northwestern Michigan. Data downloaded from these stations includes daily maximum and minimum air temperatures, maximum and minimum soil temperatures, and solar radiation. Additionally, data has been downloaded from 98 NOAA NCDC weather stations in Northwestern Michigan collecting daily (at least) max temperature, min temperature, and precipitation. Data from the NCDC Storm Database has been compiled including reported hail, lightning, thunder storms, tornados, wind storms, as well as event wind magnitude and associated fatalities, injuries, and property damage.
- Water quality data has been downloaded from MiCorps. This data includes invertebrate, and habitat descriptions from 17 stream sites in the Boardman-Charlevoix watershed from 2006, as well as water clarity, phosphorus, chlorophyll a, temperature-dissolved oxygen profiles from 25 lakes some as early as 1975. Temperature, dissolved oxygen, specific conductivity, pH, nitrate, total nitrogen, and total phosphorus data from 73 lakes have been collected, compiled, and shared by Tip of the Mitt Watershed Council. Stream macroinvertebrate data from Tip of the Mitt Watershed Council and The Watershed Center Grand Traverse Bay have been shared and compiled. Data on macrophyte bed locations during 1992, 1998, and 2009 have been shared from The Watershed Center Grand Traverse Bay. All available EPA STORET data has been downloaded for the counties of the Grand Traverse Bay watershed area.
- Pathogen data has been downloaded from MiSWIM regarding E. coli levels at 22 public beaches. The occurrence of beach advisories and closures along with lab results were compiled from MDEQ for the counties covering the Grand Traverse Bay Watershed.
- Ice cover data have been compiled from Grand Traverse Bay, Elk Lake, Skegemog Lake.
- The Online Water Library of Northwestern Michigan College appears to be a promising resource for data and literature on water in this region. This resource has has not yet been thoroughly examined.
- Miscellaneous Other Data
    - Annual National Audubon Society Christmas bird count data for Traverse City beginning in the 1960's.
    - Number of holes and locations of golf courses in the Boardman-Charlevoix watersheds
    - Information on tart cherry farm numbers and acreage

- National level data on tart and sweet cherry yields beginning in 1997
- Date of full bloom for select fruit varieties beginning in 1983 from the Northwest Michigan Horticultural Research Center
- County level population beginning in 1990.

Appendix 2. List of organizations invited to stakeholder workshops.

Acme Township Supervisor

Antrim Conservation District

Antrim County Administrator

Antrim County Drain Commissioner

Antrim County Planner

Banks Township Supervisor

Benzie Conservation District

Benzie County Administrator

Benzie-Leealanu Health Dept.

Benzie-Leelanau District Health Department

Bingham Township Supervisor

Blair Township Supervisor

Cherry Capital Foods

Citizen's Climate Lobby

City of Traverse City - City Manager

City of Traverse City - Public Services Dept.

City of Traverse City Commission

City of Traverse City Manager

City of Traverse City Planner

Conservation Resource Alliance

East Bay Township Planning Commission

East Bay Township Supervisor

Elk Rapids Assistant Village Manager

Elk Rapids Chamber of Commerce

Elk Rapids DDA

Elk Rapids Planning and Zoning Adminitrator

Elk Rapids Planning Commisioner

Elk Rapids Township Supervisor

Elk Rapids Village Manager

Elk-Skegemog Lakes Association

Elk-Skegemog Lakes Association, President

Elmwood Township Supervisor

Executive Director, Leelanau Conservancy

Fife Lake Township Supervisor

FLOW

Garfield Township Supervisor

Grand Traverse Band of Ottawa & Chippewa Indians - Natural Resources Dept.

Grand Traverse Band of Ottawa and Chippewa Indians

Grand Traverse Conservation District

Grand Traverse Conservation District, MAEAP

Grand Traverse County Administrator

Grand Traverse County Commissioner

Grand Traverse County Drain Commissioner

Grand Traverse County Health Department

Grand Traverse County Planner

Grand Traverse County Soil Erosion Department

Grand Traverse Health Department

Grand Traverse Regional Land Conservancy

Grand Vision/Traverse Area Association of Realtors

Green Lake Township Supervisor

Inland Seas Education Association

Kalkaska Conservation District

Kingsley Village Manager

Land Information Access Association

Leelanau Conservancy

Leelanau Conservation District

Leelanau County Administrator

Leelanau County Drain Commissioner

Leelanau County Planner

Long Lake Township Supervisor

MDEQ

MDNR

Michigan Department of Environmental Quality

Michigan Department of Natural Resources

Michigan Land Use Institute

Michigan Sea Grant

Michigan State University

Michigan State University Extension

Milton Township Supervisor

National Resource Conservation Service, Antrim & Kalkaska

National Resource Conservation Service, GT &Leelanau

Networks Northwest

NOAA

Northern Michigan Chapter, Citizens Climate Lobby

Northern Michigan Environmental Action Council

Northwest Michigan Council of Governments

Northwestern Michigan College

Northwestern Michigan College - Online Water Library

NPS- Sleeping Bear Dunes

Paradise Township Supervisor

Peninsula Township Supervisor

Rotary Camps & Services

Rotary Camps & Services/Water Committee

Rotary Water Committee

SEEDS

Sleeping Bear Dunes National Lakeshore

Suttons Bay Township Supervisor

TC350

The Nature Conservancy

The Watershed Center Grand Traverse Bay

Three Lakes Association

Three Lakes Association, Executive Director

Three Lakes Association, President

Torch Lake Protection Alliance

Torch Lake Protection Alliance, President

Torch Lake Township Supervisor

Traverse Area Association of Realtors

Traverse City Area Chamber of Commerce

Traverse City Convention & Visitors Bureau

Traverse City DDA

Traverse City Tourism

Traverse Connect

US Geological Survey

USGS

Water Studies Institute

Water Studies Institute - Northwestern Michigan College

Whitewater Township Supervisor