CONSIDERATION OF THE IMPACT OF CLIMATE CHANGE ON LAKE LEVELS IN THE MANAGEMENT PLAN OF TRIBAL FISHERIES AND CULTURALLY IMPORANT SITES

GREAT LAKES WATER LEVELS INTEGRATED ASSESSMENT
PHASE 1 REPORT

AUTHORS:

FRANK J. MARSIK[1]
KYLE P. WHYTE[2]
RICKY B. ROOD[1]
ELLIE MASTERS[3]
BARBARA DOYLE[1]

[1] UNIVERSITY OF MICHIGAN, ANN ARBOR, MI
[2] MICHIGAN STATE UNIVERSITY, EAST LANSING, MI
[3] OBERLIN COLLEGE, OBERLIN, OH

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EXECUTIVE SUMMARY

Coastal wetland ecosystems provide spawning grounds, food sources, and protective habitat for numerous fish species in the Great Lakes. While water level fluctuations within the Great Lakes are actually key to maintaining the biodiversity of coastal wetland ecosystems (Environment Canada & Wilcox 2002), long-term and sustained trends in water levels can result in a reduction of wetland biodiversity, placing considerable stress on the fish communities that depend up on these wetland ecosystems. Environmental drivers such as temperature, precipitation, run-off and evaporation play important roles in modulating Great Lakes water levels and are likely to experience changes in light of a warming climate. Considering that Great Lakes fisheries support a broad range of commercial, subsistence and recreational activities, communities which depend upon these fisheries must assess the implications of our changing climate on Great Lakes water level trends.

A number of unique challenges are faced by Indigenous Tribes within the Great Lakes Region with respect to the development of climate adaptation planning for their communities. The sovereignty and jurisdiction of Tribal governments, Tribal economic capacity, as well as cultural and spiritual considerations must be applied in any strategy that seeks to protect the Indigenous ways of life in the face of a changing climate. For this reason, Indigenous Tribes represent important collaborators in the Graham Sustainability Institute's Great Lakes Water Levels Integrated Assessment Plan (Graham Sustainability Institute 2014), a comprehensive effort to "develop information, tools and partnerships to help decision makers address the challenges and opportunities posed by the variability in Great Lakes water levels."

Through this project, we are working collaboratively with two federally-recognized Indigenous Tribes within the State of Michigan, the Little Traverse Bay Bands of Odawa Indians (LTBB) and the Grand Traverse Band of Ottawa and Chippewa Indians (GTB), to include the consideration of the impact of climate change on lake levels in the management plan of Tribal fisheries and in the protection of culturally important sites. An exciting element of this collaborative effort is that it provides a unique opportunity to address this topic with a blend of "western science" and "Indigenous science" approaches. Traditional Indigenous approaches to understanding natural science involve the observation of nature and the relations of elements of the natural system with other elements within the system, as opposed to the more linear measurement and theoretical approaches often applied as part of "western science".

The stated goal of Phase 1 of the Graham Sustainability Institute's Great Lakes Water Levels Integrated Assessment Plan is to provide an overview synthesis of the status, trends, causes and consequences of changing water levels as they relate to key issues in a particular locality. As such, this document provides a summary of our analyses to-date with regards to recent trends in atmospheric drivers, lake levels and observed impacts on the communities of our Tribal collaborators, with particular emphasis on the Tribal fisheries. In particular, we will discuss the promising linkage between the climate-related shrinking of the wintertime polar cold pool, the maximum extent of Lake Michigan ice coverage, Lake Michigan water levels and their subsequent impact on Tribal fisheries. We believe that this linkage will help guide the establishment of a set of plausible future climate scenarios, which can serve to direct our collaborative efforts in the development of adaptation plans to support future management of Tribal fisheries.

INTRODUCTION

Fishing is of great economic, recreational and cultural importance to the Indigenous Tribes within the State of Michigan. Tribal fishing activities are regulated the 2000 Federal Consent Decree (United States 2000), which details how fishing in the 1836 Treaty waters will be allocated, managed and regulated by State of Michigan and the following federally-recognized tribes within the State of Michigan: the Bay Mills Indian Community, the Sault Ste. Marie Tribe of Chippewa Indians, the Grand Traverse Band of Ottawa and Chippewa Indians, the Little River Band of Ottawa Indians and the Little Traverse Bay Bands of Odawa Indians. The 2000 Federal Consent Decree will expire in 2020. The 2020 Federal Consent Decree likely will dictate how fishing in the 1836 Treaty waters will be regulated through the next 20 years, a period which is expected to experience potentially significant climatic changes within the 1836 Treaty area (GLISA 2014). Currently predicted changes in our regional climate will have the potential to impact coastal wetland ecosystems and thus the number, species diversity and distribution of fish species within Great Lakes fisheries, important considerations for the Indigenous Tribes as they enter negotiations associated with the 2020 Federal Consent Decree.

While our average global climate is expected to continue to warm through the end of this century (IPCC, 2014), the anticipated regional patterns in temperature and precipitation are more complex. Efforts to understand the impact of these anticipated patterns on future Great Lakes water levels have required scientists to use the information provided by coarse-resolution global climate models in concert with fine-scale regional-scale models, the latter of which more explicitly describe the environmental drivers believed to control Great Lakes water levels (e.g., Angel and Kunkel, 2010; Hayhoe *et al*., 2010). Given the differences in the assumptions used to develop these regional models, in particular the description of potential evapotranspiration (PET), the predicted impact of future climates on Great Lakes water levels derived from these regional models varies considerably in both magnitude and direction (Lofgren et al., 2011). At best, it would appear that these different predictions can be looked upon as “plausible” futures, without regard to selecting any single result as “most likely”.

The stated goal of Phase 1 of the Graham Sustainability Institute’s Great Lakes Water Levels Integrated Assessment Plan is to provide an overview synthesis of the status, trends, causes and consequences of changing Great Lakes water levels as they relate to key issues in a particular locality. Given that the uncertainties associated with the calculation of PET in regional global models, our analyses includes consideration of the relationship between lake levels and large-scale atmospheric phenomenon (e.g., Arctic Oscillation, North Atlantic Oscillation), which might be more easily predicted by climate models. In part, this approach was inspired by studies such as Fyfe et al. (1999) and Gillette et al. (2002), which have investigated the trends in such large-scale phenomena in a changing climate. Later, our analyses were directed by the work of Martin (2015) who investigated the shrinkage of the wintertime Northern Hemisphere polar cold pool over the past six decades. We then extended Martin’s analysis to look at the potential linkage between the climate-related shrinking of the Northern Hemisphere, lower-tropospheric, wintertime cold pool and trends in the maximum extent of Lake Michigan-Huron ice coverage and Lake Michigan-Huron water levels

Long-term and sustained trends in water levels can result in a reduction of wetland biodiversity, placing considerable stress on the fish communities that depend up on these wetland ecosystems. For this reason, this document includes a discussion of the observed trends in coastal wetland ecosystems for the counties associated with our Tribal collaborators: the Little Traverse Bay

Bands of Odawa Indians (Harbor Springs, MI) and the Grand Traverse Band of Ottawa and Chippewa Indians (Peshawbestown, MI). Based upon the relationship that we developed between the wintertime Arctic cold pool extent and Lake Michigan-Huron water levels, we begin the process of using this information to suggest potential "plausible future climate scenarios for use in the development of potential climate adaptation strategies and we provide an example of the potential consequences of one plausible future: increasing potential for extreme low water levels.

STATUS AND TRENDS

Monthly Lake Michigan-Huron Water Levels

Given that the ultimate goal of the Graham Sustainability Institute's Great Lakes Water Levels Integrated Assessment Plan is to help communities develop plans to address the impacts of changing Great Lakes water levels under plausible future climates, a necessary step is to assess the past trends in these levels. For our project, trends in both the mean and variability of Lake Michigan-Huron water levels are of importance. Derived from Master Gage data provided by the Great Lakes Environmental Research, Figure 1 presents the monthly average water levels for the Lake Michigan-Huron system. The dotted read line in the figure represents the linear trend over the period shown (R^2=0.21, P<0.01, two-tailed). As can be seen, while there is considerable variability, the overall trend is one of decreasing water levels, particularly after 1986, which was the start of a nearly two year period of El Nino conditions.

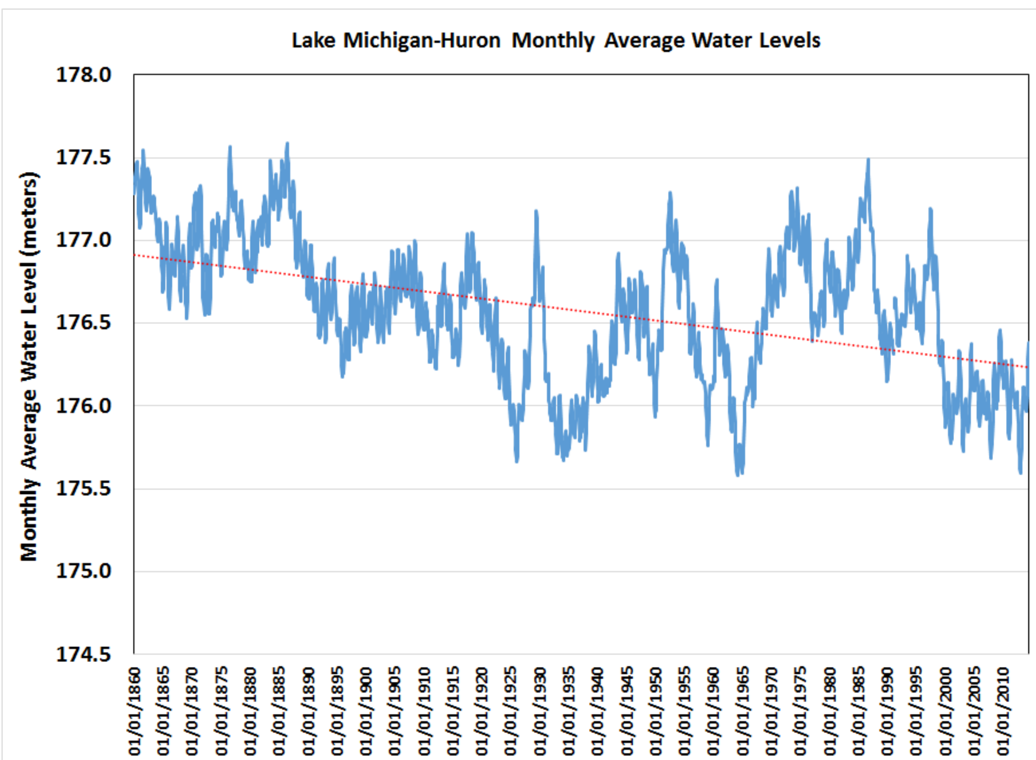

Figure 1. Lake Michigan-Huron Monthly Average Water Levels (Master Gage Data, Great Lakes Environmental Research Laboratory)

Using 30-year climatological periods, the average water levels for the system are as follows: 1861-1890 (177.05 meters), 1891-1920 (176.60 meters), 1921-1950 (176.25 meters), 1951-1980 (176.55 meters) and 1981-2010 (176.46 meters). In a similar manner, the variability (as expressed by standard deviation) over these same sequential 30-year climatological periods was calculated, and are as follows: 1861-1890 (0.23 meters), 1891-1920 (0.19 meters), 1921-1950 (0.32 meters), 1951-1980 (0.41 meters) and 1981-2010 (0.40 meters).

This analysis therefore suggests that the Lake Michigan-Huron system has experienced a decrease in monthly average water levels of approximately 1.5 meters over the period of record, with a general increase in the 30-year period variability from approximately 0.20 meters at the beginning of the past century to approximately 0.40 meters over this same period. For this report, we did not perform an analysis in the periodicity of water level variability.

Seasonal Maximum/Minimum Lake Michigan-Huron Water Levels

The seasonal variation in Lake Michigan-Huron Water levels are highlighted using the period of 2001-2010 as an example. In general, the annual minimum water levels typically occur during the winter, following the period in which seasonally cold air moves over the relatively warm waters of Lake Michigan, leading to unstable conditions in the marine boundary layer and resulting in enhanced evaporation from the lake surface. The onset of ice cover results in the end of this enhanced period of evaporation. In contrast, the annual maximum water level typically occurs during the late spring/early summer, as this time period follows the end of winter snowmelt and spring rains.

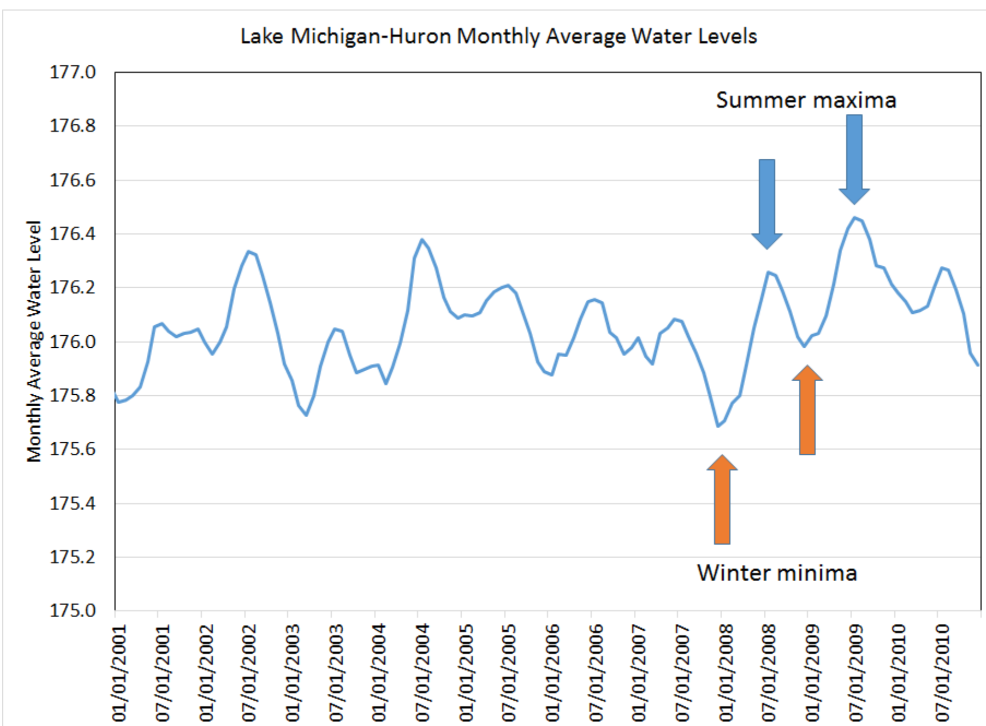

Figure 2. Lake Michigan-Huron Monthly Average Water Levels for the Period 2001-10. (Master Gage Data, Great Lakes Environmental Research Laboratory)

The Great Lakes Integrated Science Assessment (GLISA) Center notes that by mid-century, the average frost-free season across the study area (the Lower Peninsula portion of the 1836 Treaty Area) is likely to increase by an average of 24 to 30 days (GLISA 2014). One result of such a trend would likely be the shift in the timing of the seasonal spring snowmelt to an earlier date. Given the warming that has already been observed over the climatological periods highlighted in GLISA (2014), from 1951-1980 to 1981 to 2010, we have plotted the average month of the observed water level minimum and maximum for these periods to determine if a shift in the timing of the these events is already evident. In Figure 3, one can see that the months of July and August are typically when the maximum monthly average water levels are observed. From the period 1951-1980 to 1981-2010, there does appear to be a shift to an earlier occurrence of the maximum lake levels (in terms of frequency of occurrence in a given month).

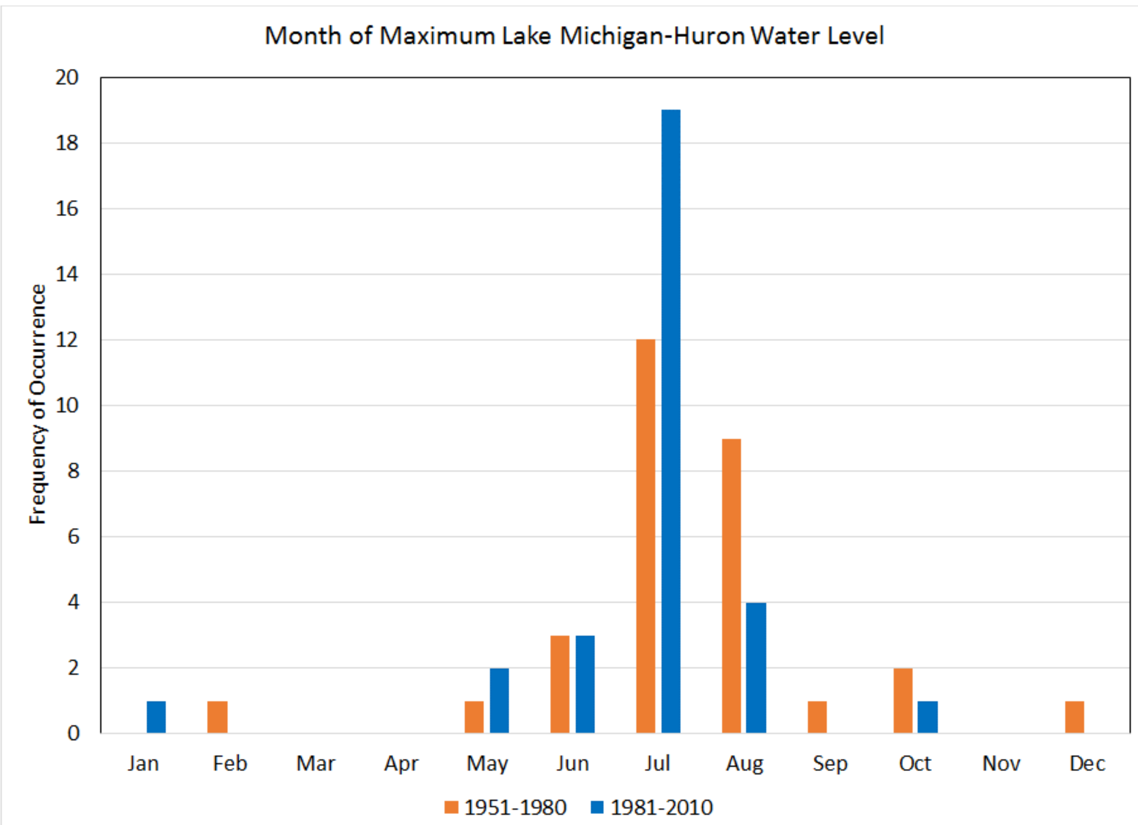

Figure 3. Frequency of Occurrence of the Month of the Annual Maximum Lake Michigan-Huron Water Level for Periods 1951-1980 and 1981-2010. (Master Gage Data, Great Lakes Environmental Research Laboratory)

To further understand the potential significance of this trend, we extended the analysis to include the period from 1921-1950 (not shown in Figure 3). Given that this latter period was not included in the GLISA (2014) analysis for the 1836 Treaty Area, we compared the annual average temperature for the State of Michigan for the climatological periods 1921-1950, 1951-

1980 and 1981-2010 (Data Source: National Center for Environmental Information). The state average temperatures for these three periods were determined to be 43.6˚F (6.4˚C), 43.6˚F (6.4˚C) and 44.9˚F (4.2˚C), respectively. Despite the similarities in the statewide average temperatures for the 1921-1950 and 1951-1980 climatological periods, the frequency of occurrence for the month of maximum Lake Michigan-Huron water levels for 1921-1950 was more consistent with that observed for the period of 1981- 2010. These results suggest that warming temperatures alone (and assumed subsequent earlier snow melt) is insufficient to predict the timing of maximum lake levels in the future.

Coastal Wetlands

According to the document "Climate Change Adaptation Plan for Coastal and Inland Wetlands in the State of Michigan" (Christie & Bostwick, 2012), a 2003 inventory by the Great Lakes Coastal Wetland Consortium estimated there to be approximately 275,748 acres of coastal wetlands in the State of Michigan, an estimated decline of 25% from the 369,000 acres of coastal wetlands that were believed to have existed historically. From this inventory, it is estimated that 28% of this total, or approximately 77,000 acres are found along the Lake Michigan coast. Rutherford (2008) Despite the fact that these wetlands consist of only 1% of the surface area of Lake Michigan, they provide spawning, nursery and foraging habitat for between 40-90% off Great Lakes fish species at some stage in the life cycles of these species (Rutherford, 2008).

Mortsch *et al*. (2006) report that the primary types of wetlands found along the Great Lakes coastline include:

Lacustrine – open to the lake, and affected by water level fluctuations and shoreline currents

Riverine – occur near the mouth of tributaries and connecting channels associated with the lakes

Barrier-enclosed – occur behind sandbar barriers form by coastal processes; depending on structure can have varying amounts of conductivity with the lake and thus influence by lake levels.

All three of these types of coastal wetlands be found in association with the Lake Michigan shoreline areas of interest for the Little Traverse Bay Bands of Odawa Indians and the Grand Traverse Band of the Ottawa and Chippewa Indians.

To date, we have not found information quantifying the loss of coastal wetlands for the Michigan counties that are associated with our Tribal collaborators. However, trends in loss/gain of county-wide wetland habitats obtained through the use of the State of Michigan's web-based Wetlands Status and Trends Tool (http://www.mcgi.state.mi.us/wetlands/reportTool.html) indicate that total losses of wetlands across these counties include: Charlevoix (4%), Emmet (7%), Grand Traverse (20%) and Leelanau (25%). Other excellent information pertaining to Michigan coastal wetlands can be found in the document "Best Practices for Climate Change Adaptation: Spotlight on Michigan Coastal Wetlands (Great Lakes Commission, 2014).

CAUSES AND CONSQUENCES

Lake Michigan-Huron Water Levels

Environmental Drivers

As described earlier, the primary environmental drives for the water levels in the Lake Michigan-Huron system are precipitation, run-off and evaporation. Using data from the Great Lake Environmental Research Laboratory (GLERL), we have analyzed each of these parameters to obtain a better understanding of the potential reasons for the long-term trend in mean water level decrease for the system. While the length of the data periods vary, we can still obtain a substantive view of trends in these parameters.

In Figure 4, the annual over-lake precipitation (in mm) for the Lake Michigan-Huron system, we can see that there has been statistically significant trend of increasing precipitation over the lakes. The dotted read line in the figure represents the linear trend over the period (R^2=0.17, P<0.01, two-tailed).

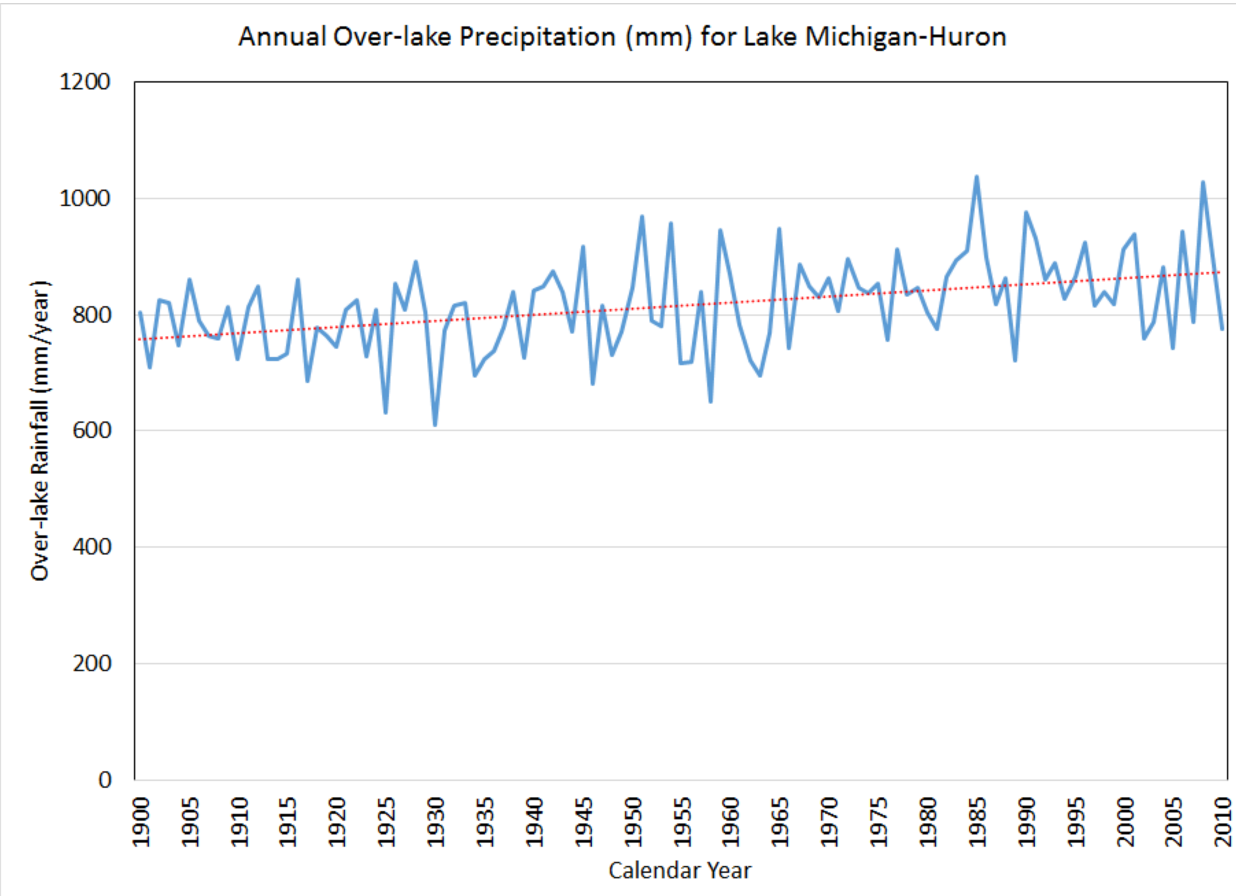

Figure 4. Annual Over-lake Precipitation (mm) for Lake Michigan-Huron.

As might be expected under a regime of increasing precipitation, the reported run-off for the two lake system has also been increasing (Figure 5). The dotted read line in the figure represents the linear trend over the period (R^2=0.05, P<0.10, two-tailed). Despite the long-term increase, it would appear that the rate of increase as slowed since around 1990.

The increases in precipitation and run-off into the lakes are counter to the observed general decrease in water levels for the system. Though not plotted, GLERL data for flow from Lake

Huron to Lake St. Clair does show a slight increase over the period. The flow data from Lake Michigan-Huron to Chicago, again not plotted here, is significantly lower in volume.

The last major environmental driver to consider is over-lake evaporation, which is presented in Figure 6. The dotted read line in the figure represents the linear trend over the period (R^2=0.13, P<0.01, two-tailed). As can be seen, though the overall trend in the predicted over-lake evaporation has shown a statically significant increase, much of this increase appears to have occurred since around 1980. The timing of this increasing rate of over-lake evaporation is consistent with the observed significant decrease in average lake levels for the Lake Michigan-Huron system over this same thirty-year time period, underscoring the important role for evaporation in explaining the recent trend in decreasing lake levels.

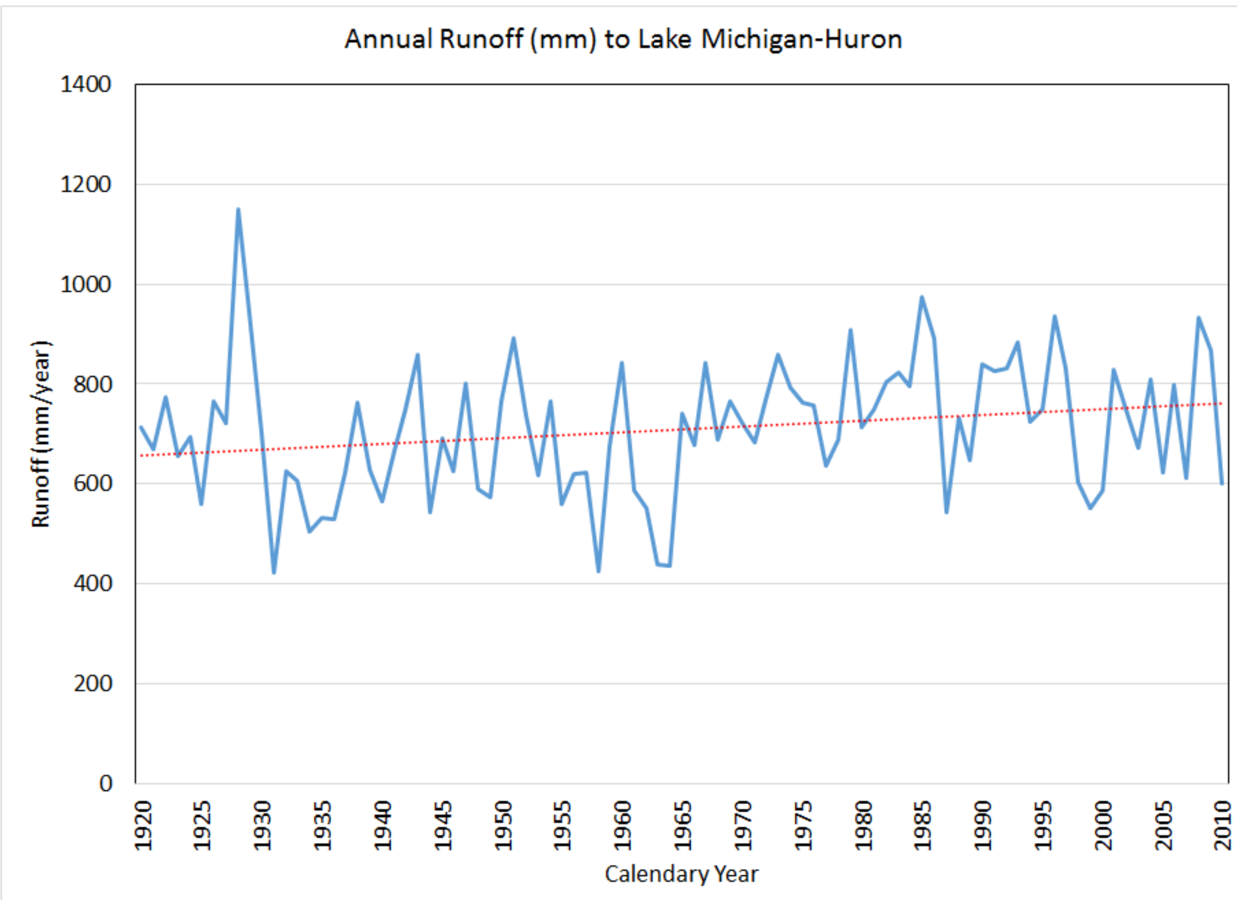

Figure 5. Annual Run-off (mm) for Lake Michigan-Huron.

As with the other drivers, there is considerable year-to-year variability in the observed times-series. Lenters et al. (2014) provide an extensive discussion on the complexities of such a lake level/evaporation relationship and how the timing of early season meteorological conditions can greatly impact overall seasonal evaporation. For example, conditions leading to strong evaporation during the early fall could help to cool the surface water temperatures sufficiently to limit evaporation in the late fall due to a reduced air-water temperature difference. Or in contrast, warmer temperatures during early fall in another year, might result in a delay in the cooling of surface waters and onset of seasonal lake ice, leading to significant evaporation occurring during the late fall when increasingly cold air moves through the region.

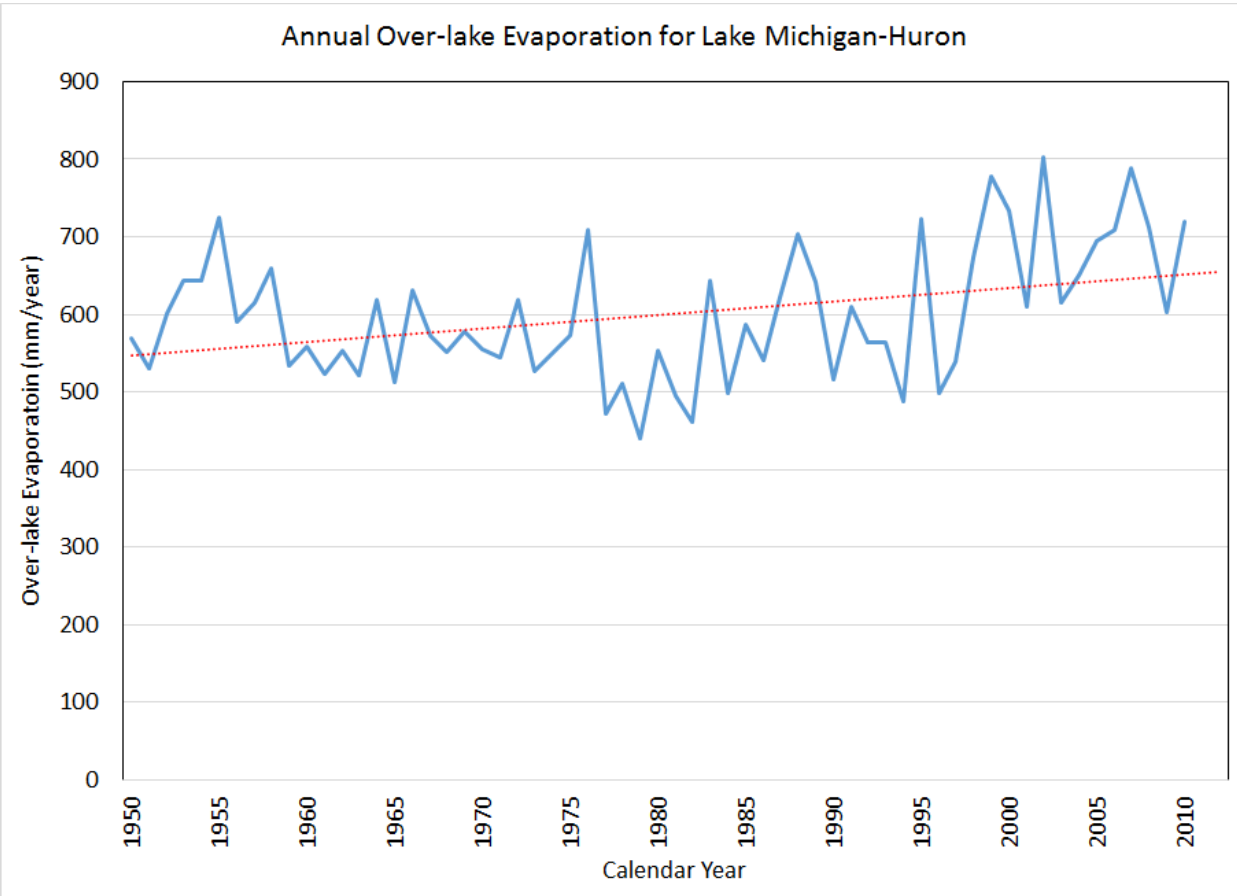

Figure 6. Annual Over-lake Evaporation (mm) for Lake Michigan-Huron.

Large-scale Influences on Environmental Drivers

<u>Teleconnections</u>

A major goal of this project will be to develop a set of "plausible climate scenarios" to use in the development of adaptation strategies for our Tribal collaborators. Given the important role of evaporation as a key driver in the determination of lake water levels, a logical next step in the process would be to use regional climate models to project potential trends in evaporation (and other important environmental drivers of lake water levels) under future plausible climates. However, as noted above, the approaches used to describe/quantify the evaporation process in regional climate models are currently debated and these different approaches lead to distinctly different projections for future water level scenarios.

Our group discussed that an alternate approach for determining plausible climate scenarios might be to link these historical variations in lake water levels with larger-scale atmospheric signals such as atmospheric teleconnections (El Nino/Southern Oscillation, Arctic Oscillation, North Atlantic Oscillation, etc.) that influence the important drivers of evaporation. First, we performed a set of simple correlations analyses using both Lake Michigan-Huron water level data, ice cover data and teleconnection indices data from GLERL data portal. Given that the period of October through May captures occurrences of ice on the Great Lakes, we used these months to define what was, admittedly, an extended "winter season" range in our comparison of lake water levels, maximum ice coverage and teleconnection indices. Additionally, when comparing the teleconnection indices against the Lake Michigan-Huron water levels, we used two measures of lake water levels: (a) the average Lake Michigan-Huron water levels during the same October through May period used to determine maximum ice coverage and average teleconnection values, and (b) the average Lake Michigan-Huron water levels for the entire Calendar Year which included the end of a given "winter season". For example of this latter category, for the "winter season" covered by October 2000 to May 2001, the comparison was made with the average water levels during Calendar Year 2001. This Calendar Year water level variable was used to acknowledge that there is often a lag in the impact of winter season conditions and observed lake water levels.

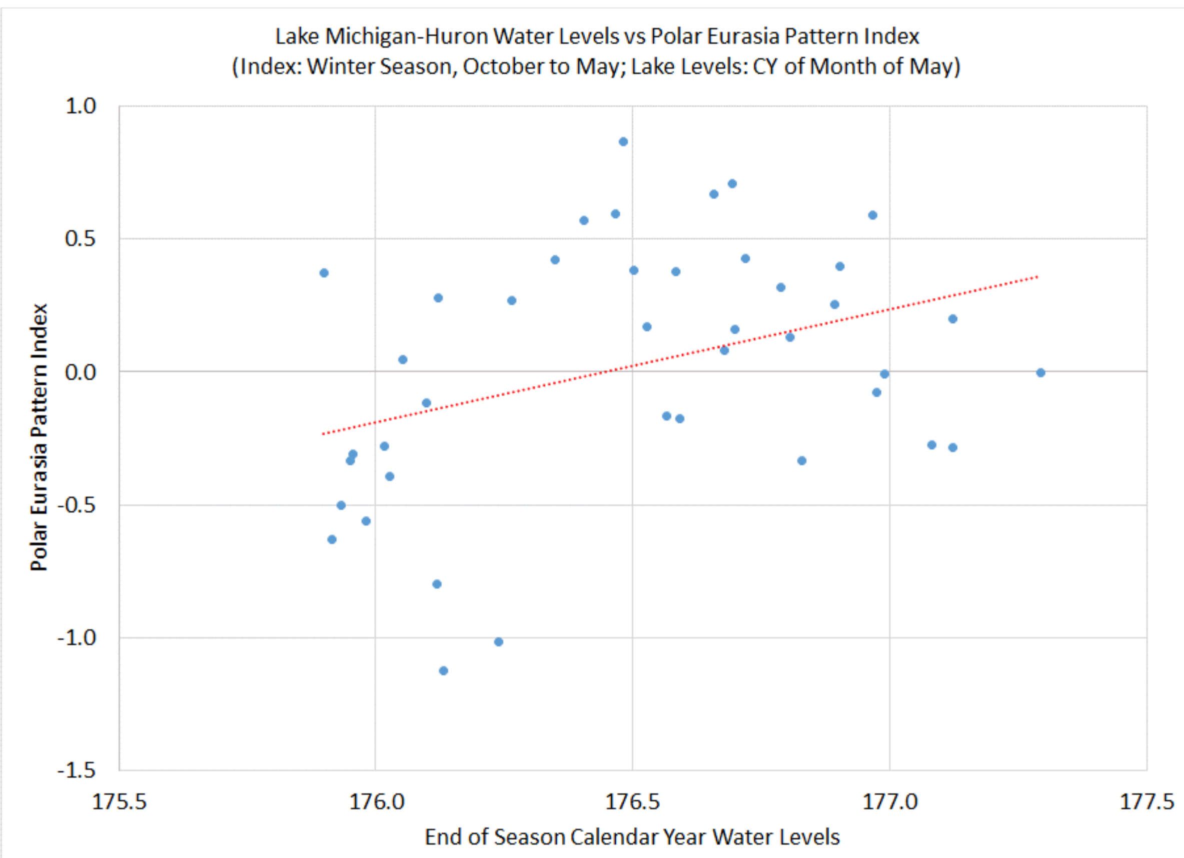

Figure 7. Annual Over-lake Evaporation (mm) for Lake Michigan-Huron.

In our analyses, we found statistically significant correlations between the Pacific Decadal Oscillation (PDO) (R^2=0.13, P<0.05, two-tailed) and Polar Eurasia (PE) (R^2=0.10P<0.05, two-tailed) indices for a given October through May "winter season" and the Lake Michigan-Huron water levels for the given October through May "winter season". The PDO is a shift in the temperature patterns of the North Pacific Ocean which occurs on a 20-30 year cycle. The PE is related to anomalies in upper level height patterns which impact the strength of the polar vortex. We also found statistically significant correlations between a given October through May "winter season" PDO (P<0.05, two-tailed) and PE (P<0.05, two-tailed) indices and the Calendar Year Lake Michigan-Huron water levels. Statistically significant correlations were also found between the PE and Lake Michigan and Huron maximum "winter season" ice extent (P < 0.01 for each, two-tailed). Unfortunately, Mantua and Hare (2002) note that the mechanisms which cause variability in the PDO, as one example, are not well understood. As a result, even if significant correlations can be found, it may be some time before the long-term prediction some teleconnection patterns can be accomplished with sufficient confidence that such predictions can be used to infer potential lake level futures.

A number of researchers have performed more detailed analysis on the relationships between Great Lakes water levels and atmospheric teleconnection patterns (e.g., Fyfe *et al*., 1999; Gillette *et al*., 2002; Ghanbari & Bravo, 2008; and Dogen, 2015). For example, Ghanbari and Bravo (2008) found significant correlations between frequencies of variations in Great Lakes water levels and the frequencies of variations in a number of traditional teleconnection indices. Dogan (2015) found statistically significant relationships between changes in *trends* of water levels and other environmental drivers and the timing of changes in the trends of the North Atlantic Oscillation (NAO). According to the Climate Prediction Center, the NAO is associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track relates the patterns. Despite the positive direction of such research, we felt that the complex nature of the published relations between Great Lakes water levels and teleconnection indices would not necessarily provide us with strong predictive capabilities upon which to develop a set of plausible climate futures.

Shrinking of Polar Ice Cover

We believe that a recent study reported by Martin (2015) could provide us with a very promising set of relationships which could be used to develop a set of plausible climate futures upon which to base our further work. This approach is attractive in that the relationships are rather straightforward and based upon temperature, a variable easily predicted by global climate models.

In his work, Martin (2015) sought to investigate trends in the areal extent of the Northern Hemisphere, lower-tropospheric, wintertime cold pool over the past 66 years. Using model reanalysis data, Martin determined the areal extent (in square kilometers) that would be enclosed by series of temperature contours (centered about the North Pole) at the 850-mb level (approximately 1000 to 1500 meters above the ground). An example of the areal extent encompassed by a -5˚C contour during a typical winter day is provided in Figure 8 below.

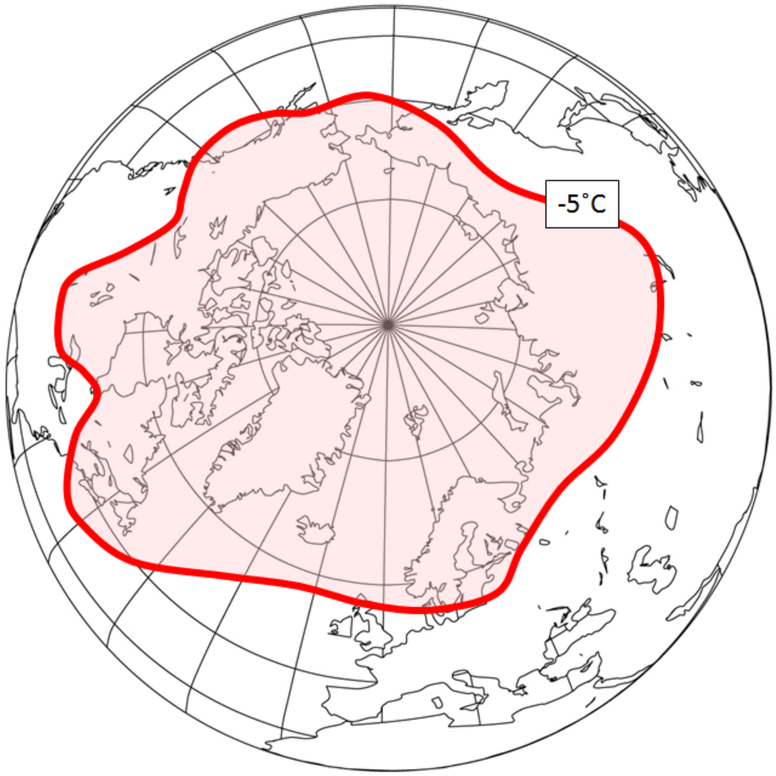

Figure 8. Example of the areal extent of region covered by a typical -5˚C contour at the 850-mb level during the Northern Hemisphere winter season.

The value of this analysis to our project is as follows. Air masses obtain the characteristics of the surfaces over which they form and reside for long periods of time. The Bergeron classification scheme, the most widely used form of air mass classification, typically characterizes and air mass based upon temperature and moisture content. The winter-time air masses which are most likely to drive strong evaporation from the Great Lakes waters are those that are cold (creating a strong temperature gradient with the relatively warm waters) and dry (creating an obviously strong moisture gradient). Air masses with these characteristics are generally termed continental polar (cP) and continental arctic (cA), forming north of approximately 66˚N latitude in the region where there is no/limited sunlight during the winter and where there is extensive snow and ice cover. In recent years, the extent of Arctic Sea ice has been decreasing, a likely result of our warming global climate (Figure 9). Thus, if the future trend is for a warming climate, then (a) the Arctic Sea ice extent will likely continue to decrease, (b) the reduction of Arctic Sea ice extent will likely lead to less cooling of the Northern Hemisphere, lower-tropospheric, wintertime cold pool, (c) the smaller areal extent will likely result in fewer cold outbreaks across the Great Lakes region during a given winter season, (d) the reduction in maximum lake ice extent will likely contribute to a subsequent increase in evaporation from the lakes and finally (e) reduction in Great Lakes water levels.

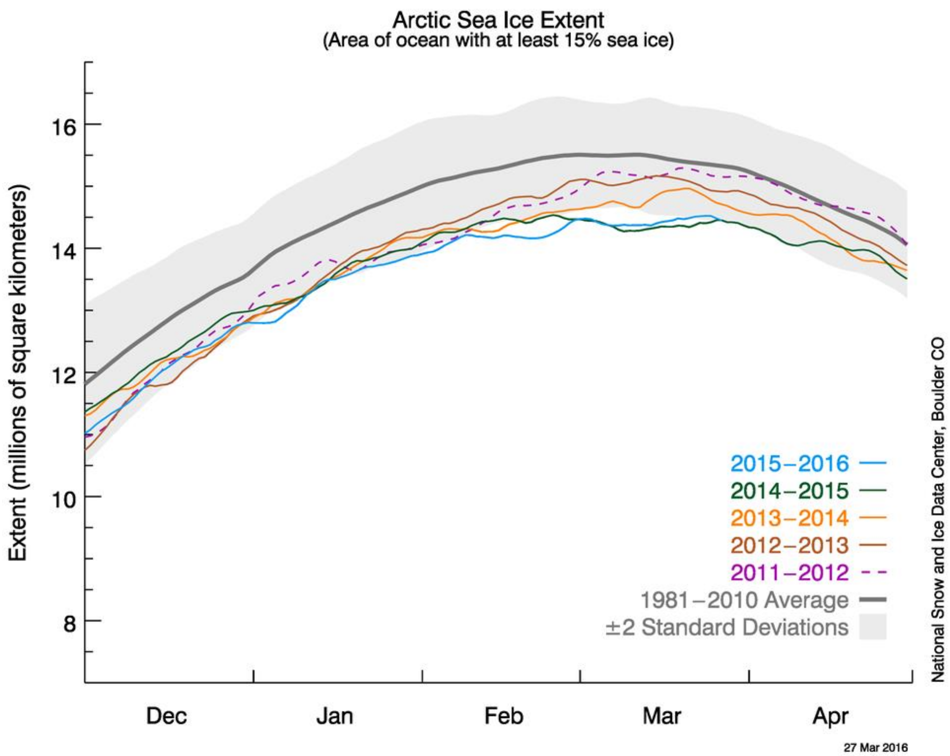

Figure 9. Areal extent of wintertime Arctic Sea Ice.

Estimating the areal extent values for the -5ºC isotherm (as shown in Figure 1 of Martin (2015)), we plotted the areal extent values versus the winter season maximum ice extent for Lake Michigan (Figure 10), and Lake Michigan-Huron water levels (Figure 11), for the respective winter seasons. As can be seen in Figure 10, the general trend is for decreasing maximum ice cover with decreasing areal extent of the -5˚C isotherm. The trend was found to be statistically significant ($P<0.05$, two-tailed). In Figure 11, the general trend is for decreasing Lake Michigan-Huron water levels with decreasing areal extent of the -5˚C isotherm. The trend was found to be statistically significant ($P<0.05$, two-tailed). Taken together, these results support the notion that when the Northern Hemisphere, lower-tropospheric, wintertime cold pool is smaller in areal extent, and thus less likely to impact the Great Lakes, the ice cover is typically lower, evaporation is likely greater and thus the water levels tend to be lower. In contrast, these results suggest that when the Northern Hemisphere, lower-tropospheric, wintertime cold pool is larger in areal extent, and thus more likely to impact the Great Lakes, the ice cover is greater, evaporation is likely less and thus the water levels tend to be higher.

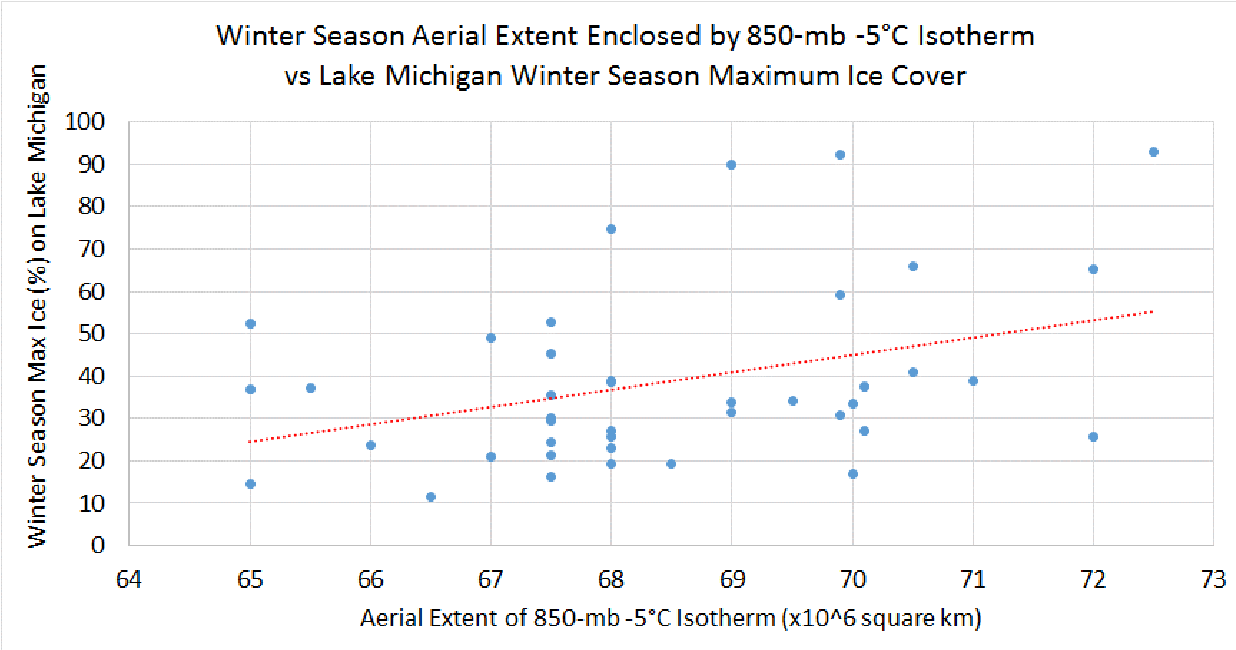

Figure 10. Winter season (DJF) areal extent enclosed by 850-mb -5°C Isotherm vs. Lake Michigan Winter Season Maximum Ice Cover.

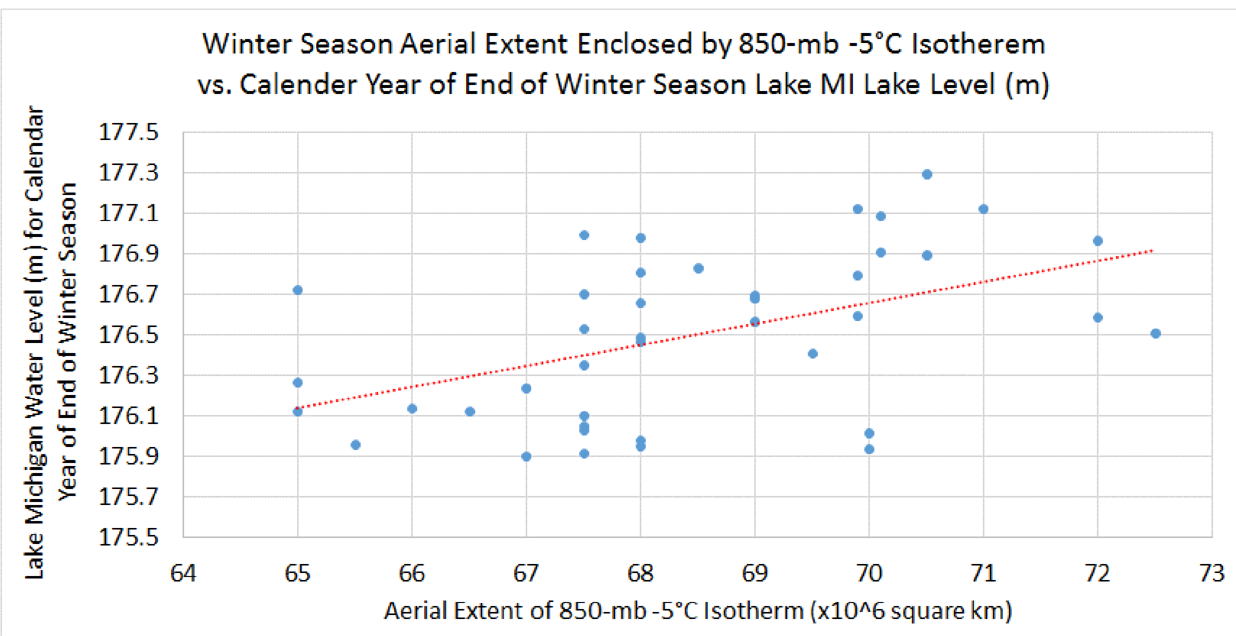

Figure 11. Winter season (DJF) areal extent enclosed by 850-mb -5°C Isotherm vs. Lake Michigan-Huron lake level for the following calendar year.

This interpretation is consistent with Assel *et al.* (2003) who noted that above annual maximum ice concentration on the Great Lakes is associated with wintertime flow patterns which enhance the transport of polar and Arctic air masses into the region. One would expect that a season characterized by a wintertime flow pattern with enhanced cold air advection would also be a winter season with a larger average area extent of the Northern Hemisphere, lower-tropospheric, wintertime cold pool.

Needless to say, there is still considerable variability in the data, with some values of the areal extent of the cold pool being associated with a wide range in lake level values. This variability underscores the complexity of the factors which contribute to ice extent and lake levels.

We acknowledge that trends are often not the best approach to project future conditions, namely because trends often mask the factors leading to the trend in question. In this particular case, however, the factors are fairly well-understood (warming temperature, reduced Arctic Sea ice, reduced cold pool) and thus we can make the assumption that in a climate that is projected to continue to warm through the end of this century, the trends of decreasing lake ice and lake water levels are reasonable projections based upon the observed data presented here. Based upon the relations shown, one might project that future water levels over the next few decades may be *tending toward* an average near 176.0 meters for the Lake Michigan-Huron system.

Potential Impacts on Coastal Wetlands

In this section, we consider the potential impacts of a plausible future of lower lake levels on Great Lakes coastal wetlands.

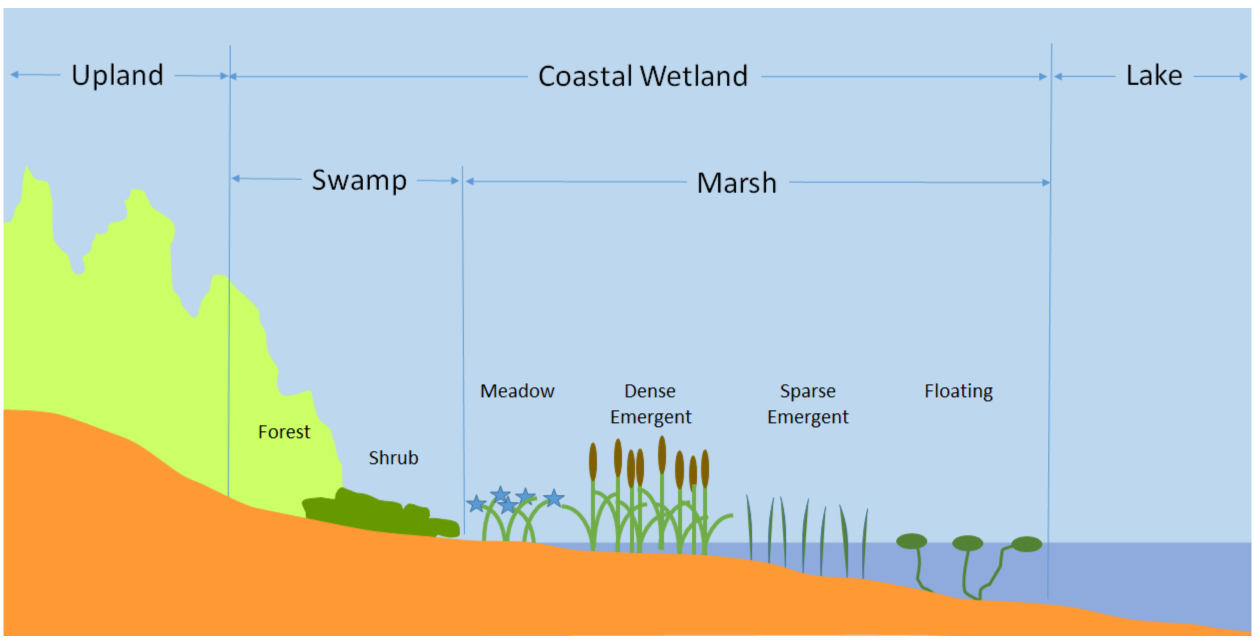

Figure 12. Typical lacustrine coastal wetland ecosystem gradient, after Wilcox (2002, *Where Land Meets Water: Understanding Wetlands of the Great Lakes*)

As described earlier, there are a variety of types of wetlands within the Great Lakes. For now, we will focus on the more common open-shoreline wetland. As shown in Figure 12, open-shoreline wetland communities have diverse vegetation communities ranging from forest and shrubs in the drier portions of the ecosystem and meadows, emergent and floating vegetation as one moves toward the water. Naturally, not all open-shoreline coastal ecosystems follow the textbook structure shown in Figure 12. As an example, Figure 13 shows a typically open-shoreline coastal wetland along Suttons Bay in the northwestern portion of the Lower Peninsula of Michigan, which was taken during the Fall of 2015. Mortsch (1988) notes that stable water levels are not beneficial to coastal wetland ecosystems. Rather, occasional flooding and then drying maintain wetlands at productive, intermediate stages of development. During low water level periods, the vegetation communities shift downward toward the land-water interface, while during high water level periods, the vegetation communities shift in the upland direction. During prolonged low water periods, perennial forest and shrub communities can take foothold in locations formerly occupied by meadow and emergent communities. Invasive species, such as phragmites, can also take hold in a wetland ecosystem during such dry conditions. When water levels rise, these regions may no longer viable ecosystems for diverse fish species, taking several years to return to their original states which are more favorable for supporting diverse vegetation and thus fish communities.

Figure 13. Typical lacustrine coastal wetland ecosystem along Suttons Bay, MI (September 2015).

The extent to which a coastal wetland community will see significant changes under decreasing water levels depends, in part, upon the shoreline bathymetry. As such, some coastal wetland ecosystems will be more vulnerable to negative consequences than others. As an example of a coastal wetland that could see considerable changes, we can look at the Wilderness State Park, an important fishing area for the Little Traverse Bay Bands of Odawa Indians.

As noted earlier, one plausible climate future under a warming climate would be one in which the average Lake Michigan-Huron water levels could approach 176.0 meters. If one makes the assumption that the currently inter-annual variability for lake levels remains unchanged over the next few decades, then extreme low Lake Michigan-Huron water levels could approach 175.2 meters in the future. This value represents the plausible future mean of 176.0 meters, minus two standard deviations using the current lake level variability. The coastal conditions for the current historical average lake water levels for the Lake Michigan-Huron system is shown in the top image of Figure 14 using the NOAA Lake Level Viewer (https://www.coast.noaa.gov/llv/). The lower image in Figure 14 represents the predicted conditions under our preliminary low lake water level scenario of 175.2 meters. The Lake Level Viewer suggests that the island chain that is part of Wilderness State Park may actually become connected via a land bridge.

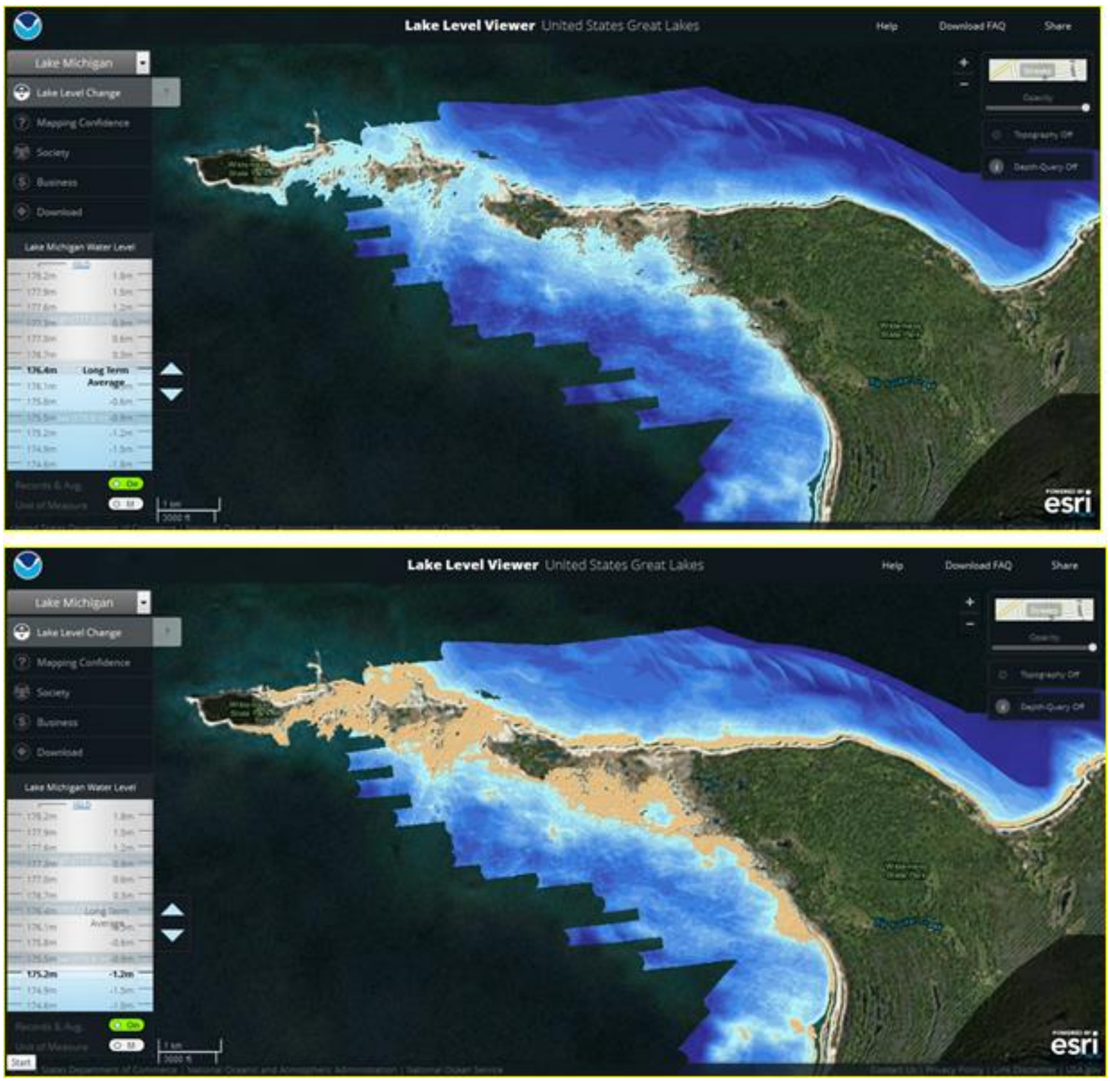

Figure 14. Spatial extent of exposed land for Wilderness State Park, MI, for two plausible future lake levels: 176.4 meters (top) and 175.2 meters (bottom).

Again, these results simply represent the potential conditions that could arise under one plausible low lake water level scenario. However, these results do suggest one location where the fishing activities of the Little Traverse Bay Bands of Odawa Indians would be vulnerable under a plausible future climate. Clearly, not all coastal areas along the Lake Michigan-Huron shoreline will see such dramatic exposure of land in a future with lower lake water levels. However, even receding waters could adversely impact areas that are currently suitable as spawning, nursery or otherwise protective habitats for some fish species. As noted by Cott *et al.* (2008) water level fluctuations can alter fish behavior, distribution and growth, resulting in fish to compete for more limited acceptable resources.

Currently Observed Impacts on Tribal Collaborators

We are only now beginning to explore potential plausible climate futures with our Tribal collaborators. We are hoping to work with our collaborators to engage Tribal Elders to obtain more extensive information on the relationships between past high/low lake level periods and the observed vulnerabilities of the Tribes during these periods. For now, we will simply list some of the observed impacts that have been discussed to date:

1. During the low lake level period around 2012, Tribal community members indicated that the low levels provided challenges to their ability to launch fishing operations from traditional launch points. If one plausible future climate scenario is one in which the long-term (30-year) lake levels are lower than at present, challenges to the ability of Tribal fishing captains/recreational fishers to launch fishing operations may persist. Such conditions will likely require a long-term solution to insure the capability of commercial/subsistence/recreational fishing.
2. Again, during the low lake level period around 2012, ancient Tribal burial grounds were exposed due to receding lake-shoreline interface. Ancient artifacts were also exposed.
3. Tribal fisheries staff at the Little Traverse Bay Bands of Odawa Indians have noted a strong correlation between shoreline ice extent and spring larval fish population of Lake Whitefish. During the spring following winters with extensive ice cover (recently, the Spring seasons for 2014 and 2015), a larger larval fish population was found along the northern shores of Lake Michigan and Huron, when compared to the observed larval fish populations following winters with relatively less ice cover. This relationship is likely linked to the role of shoreline ice in the protection on whitefish eggs which are deposited on rocky shoals near the shoreline (Lynch et al., 2010). During winters with significant lake ice, the ice helps to dampen the effect of storm winds/waves, thus protecting the eggs that were laid during the fall spawning season. In contrast, during winters without significant lake ice, rougher waters can lead to the eggs being dislodged from where they were laid, thus reducing their survivability. This is one area where we hope to engage Tribal Elders to determine if this lake ice/larval fish population relation was observed in the distant past, even if these observations are more qualitative in nature than quantitative.

ADDITIONAL CONSIDERATIONS

Much of the information provided within this Phase I report has been derived from publicly available data sources, and in person visits/emails/phone conversations with our point-of-contacts for both the Little Traverse Bay Bands of Odawa Indians and the Grand Traverse Band of Ottawa and Chippewa Indians. We are in the process of setting up on-site visits with each Tribe which will involve a broader group of Natural Resources staff (fisheries, wetland and aquatic biologists). At these meetings, we will share the results of this report with this broader audience and work to better understand detailed examples of observed vulnerabilities of each Tribe. We also hope to begin discussion on how best to engage the non-Tribal communities as we move through the next phases of the project.

In the coming month, we will be attempting to find additional larval and adult fish survey data for coastal areas outside of the fishing areas associated with our collaborating Tribes. This will allow us to more easily put the result of this work into context inter the broader Great Lakes region, and it will also allow us to more easily generalize the results of this work to enhance its transferability. Also, we have also begun to look at information provided by the Michigan DNR regarding stream fish populations, as a number of important fish species use these streams, the hydrology of which change with varying lake levels and changing precipitation/runoff. Finally, while we have found information pertaining to the potential influence of a changing climate on the lake/tributary interface (and potential impacts on nearby fisheries), we have not been able to find an adequate way to quantify this impact and will continue to pursue this.

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APPENDIX I:

LIST OF EVENTS AND PARTICIPANTS

1. 27 January 2016:

    a. General project meeting with Carolan Sonderegger, Aquatic Biologist and Climate Adaptation point of contact, Grand Traverse Band of Ottawa and Chippewa Indians.
    b. Participants: Carolan Sonderegger, Frank Marsik, Ricky Rood, Barbara Doyle

2. 30 March 2017:

    a. Education Outreach planning meeting (conference call) with Jannan Cotto, Education Director, Little Traverse Bay Bands of Odawa Indians
    b. Participants: Jannan Cotto and Frank Marsik

3. 30 March 2017:

    a. General project meeting with Jon Mauchmar, Environmental Specialist, Little Traverse Bay Bands of Odawa Indians
    b. Participants: Jon Mauchmar and Frank Marsik

APPENDIX II:

ONLINE MAPPING RESOURCES

Great Lakes Aquatic Habitat Framework
http://glahf.org

Great Lakes Coastal Wetland Mapping Tool
http://www.mtri.org/coastal_wetland_mapping.html

Great Lakes Environmental Research Laboratory Dashboard Project
http://www.glerl.noaa.gov/data/dashboard/portal.html

NOAA Digital Coast Lake Level Viewer
https://coast.noaa.gov/digitalcoast/tools/llv

U.S. Fish & Wildlife Service National Wetlands Mapper
http://www.fws.gov/wetlands/Data/Mapper.html

RESOURCES RELATED TO TRIBAL CLIMATE ADAPTATION PLANNING

Center for Indigenous Environmental Resources
http://www.yourcier.org/

Tribes & Climate Change website
http://www7.nau.edu/itep/main/tcc/

A Tribal Planning Framework – Climate Change Adaptation Strategies by Sector
http://tribalclimate.uoregon.edu/files/2010/11/Tribal_CC_framework_April_2013-25wov2q.pdf

Tribal Climate Change Adaptation Planning Toolkit
https://toolkit.climate.gov/tool/tribal-climate-change-adaptation-planning-toolkit

OTHER RESOURCES

Michigan Department of Natural Resources Stream Fish Population Trend Viewer
http://www.mcgi.state.mi.us/fishpop/#

APPENDIX III:

LIST OF PUBLICATIONS AND PRESENTATIONS

1. 05 May 2016

   a. Presentation: Inclusion of Climate-Change Effects on Lake Levels in Management Plans of Tribal Fisheries

   - University of Michigan, North Campus Sustainability Hours (Presenter: Frank Marsik)

APPENDIX IV:

REMAINING TIMELINE OF PROJECT ACTIVITIES

NOTE: The following timeline is based upon the assumption that the funding for this specific project will extend only to December 31, 2016 (which was the case as of this writing).

- May 2016:
  - The PI will travel to Harbor Springs, MI and Peshawbestown, MI for in person meetings with Natural Resources Division staffs for the Little Traverse Bay Bands of Odawa Indians and Grand Traverse Band of Ottawa and Chippewa Indians. Meetings will involve presentation of analyses performed as part of Phase 1, plus discussion of plausible future climate scenarios to use in balance of project.
  - Meeting with the LTBB will also involve continued discussion of activities associated with the Student Climate Ambassador position. Activities will relate to working with LTBB summer program, plus development of educational/information outreach materials for both the LTBB and non-Tribal community.
- May 2016 through June 2016, the project team will work with the LTBB and GTB to develop final list of plausible climate scenarios to be used in vulnerability analysis.
- July through September 2016, the project team will with the LTBB and GTB natural resources staffs to develop climate adaptation strategies. For the GTB, this work may also involve holding of a town hall meeting with the Tribal community to gauge the type of climate adaptation actions which would be supported by the Tribal community. The LTBB has already held their town hall meeting in October 2015.
- Over the period of October 2016 through December 2016, the project team will with the Graham Sustainability Institute and other project teams to synthesize all team reports into the final, overall Integrated Assessment Report.

APPENDIX V:

LIST OF STUDENTS INVOLVED

During Planning Grant Phase:

Ellie Masters, Oberlin College

During Phase 1:

Barbara Doyle, University of Michigan

NOTE: During Phase 1, our team advertised for the position of "Student Climate Ambassador", which will result in the employment of an undergraduate student who is a member of the LTBB or other Indigenous Tribe within the State of Michigan. Applicants for the position are currently reviewed as of the time of this writing. A description of the position is given below:

Climate Ambassador – Paid Summer Position

"Climate" refers to the slowly varying aspects of the Earth-atmosphere system. From a scientific perspective, climate is often described in terms of average conditions over periods of 30-years or longer. From the human perspective, climate is thought of in terms of the conditions experienced long ago by past generations, or over the lifetime of current generations.

Scientific data, and our personal experiences, tell us that our climate is changing. While it is not possible to predict exactly what our climate will be like in the future, we can explore and consider certain "plausible" climate futures. These considerations can guide our preparations to insure that we can protect various customs and practices of great importance to our Tribal community, practices which may become vulnerable under the environmental, economic and social pressures associated with a changing climate. The ability to educate ourselves, and our community, will play in important role in our ability to be prepared to adapt to whatever our future climate may be.

This summer, the Little Traverse Bay Band (LTBB) of Odawa Indians will be working with the University of Michigan and Michigan State University to conduct a summer program that will engage the youth within the LTBB community to explore our changing climate. To assist in this effort, a Student Climate Ambassador position has been established that will provide an opportunity for a college-aged student to work with the youth within the LTBB community to explore climate change, its impact on their lives and those of the Tribal community, as well as their role in shaping the Tribe's response to plausible future climates.

This position will support all aspects of summer program including providing appropriate adult support to children and youth ages 6-18, supporting positive youth development, providing a safe and empowering environment for youth, planning and supporting land-based indigenous science activities in an outdoors classroom, assisting staff with set-up and break down of activities, assisting with food service, appropriately managing behaviors utilizing best practices, and interacting positively with families and guests. We require familiarity with Native communities (previous experience working with Native youth is preferred), some knowledge of or coursework in child development, ability and willingness to work outside, and ability to lift 25 lbs.