GLISA

A NOAA RISA TEAM

Annual Report to NOAA Climate Program Office, Climate and Societal Interactions, Regional Integrated Sciences and Assessments

Award Title: Great Lakes Regional Integrated Sciences and Assessments Center

Award Number: NA15OAR4310148

Performance Period: June 1, 2017 – May 31, 2018

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Team Members

The Great Lakes Integrated Sciences and Assessments (GLISA) is housed jointly at the University of Michigan (UM) and Michigan State University (MSU), in the School for Environment and Sustainability (formerly the School of Natural Resources and Environment) and at the Center for Global Change and Earth Observations, respectively. GLISA's team includes an interdisciplinary group of Principal Investigators, staff and researchers, and graduate students at both institutions.

Principal Investigators

Team Member	Title	Institution
Jeffrey Andresen	Co-Director; Co-Principal Investigator	Michigan State University
Maria Carmen Lemos	Co-Director; Principal Investigator	University of Michigan
Thomas Dietz	Principal Investigator	Michigan State University
Kenneth Frank	Co-Principal Investigator	Michigan State University
Richard Rood	Co-Principal Investigator	University of Michigan

Staff & Researchers

Team Member	Title	Institution
Laura Briley	Climatologist	University of Michigan
Kim Channell	Research Associate	University of Michigan
Omar Gates	Climatologist	University of Michigan
Jenna Jorns	Program Manager	University of Michigan
Frank Marsik	Research Scientist	University of Michigan
Edward Waisanen	Research Associate; *left 9/2017*	University of Michigan
Angela Wilson	Research Associate; *left 9/2017*	University of Michigan

Students

Team Member	Institution	Department
William (B.J.) Baule, PhD	Michigan State University	Geography, Env. & Spatial Sciences
Samantha Basile, PhD	University of Michigan	Climate, Space Sciences & Eng.
Katherine Browne, PhD	University of Michigan	School Env. & Sustainability
Jennifer Carmen, PhD	University of Michigan	School Env. & Sustainability
Tingqiao Chen, PhD	Michigan State University	Counseling & Educational Psychology
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Thomas Hercula, MEng	University of Michigan	Climate, Space Sciences & Eng.
Matthew Irish, MEng	University of Michigan	Climate, Space Sciences & Eng.
Xiaolong Ji, MEng	University of Michigan	Climate, Space Sciences & Eng.
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New Areas of Focus and Partnership

Annual Climate Trends and Impacts Summary for the Great Lakes Basin

Team Leads: *Jeff Andresen, B.J. Baule, Kim Channell, Jenna Jorns*
Partners: Heather Arnold, Sylvain Deland, Wendy Leger, Nancy Stadler-Salt, Frank Seglenieks, and Robert Whitewood, Environment and Climate Change Canada; Beth Hall and Jonathan Weaver, Midwest Regional Climate Center; Meredith Muth and Douglas Kluck, NOAA; Brent Lofgren, NOAA Great Lakes Environmental Research Laboratory (GLERL)

Under the Great Lakes Water Quality Agreement (GLWQA), the Annex 9 Extended Subcommittee on Climate Change Impacts identified a need for an annual climate synthesis product for the region to address an information gap at the annual timescale. A pilot product for 2017, titled '*2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin,'* aims to provide a timely and succinct summary of the past year's climate trends, notable climate-related events, and relevant new research, assessments, and activities in the context of the Great Lakes. The United States and Canada coordinated on synthesizing existing information and developing a short and easy-to-understand document, intended to be replicated each year if the product is found to be useful to GLWQA annexes, the Great Lakes Executive Committee, and policy and decision makers at all levels in the Great Lakes. With funding from the NOAA Great Lakes Regional Collaboration Team, GLISA served as the coordinator for the project, leading the climate overview section, compiling the draft document, and managing the incorporation of feedback. GLISA staff are presenting the product this summer to the Great Lakes Executive Committee, the International Association of Great Lakes Research, and the American Association of State Climatologists to solicit feedback on the summary's utility.

Organizing and Hosting the 2018 Great Lakes Adaptation Forum

Team Leads: Jenna Jorns, Jessica Worl
Partners: Beth Gibbons, Rachel Jacobson, and Dawn Nelson, American Society of Adaptation Professionals

Building off of the success of the 2014 and 2016 fora, the 2018 Great Lakes Adaptation Forum (GLAF) will bring together practitioners and scholars from across the Great Lakes region for three days of sharing strategies and approaches to climate adaptation in an engaged learning program from September 24 to 26 in Ann Arbor, Michigan. GLAF 2018 is co-hosted by GLISA and the American Society of Adaptation Professionals (ASAP). The Forum's program approach will break down silos between these sectors, creating ample opportunity for practitioners to share best practices, lessons learned, and work jointly to produce solutions to climate challenges facing our region. The 2018 GLAF will focus on equity in climate adaptation and accelerating action through innovation and technology. GLISA and ASAP are working with an Advisory Board to develop the Forum approach and session tracks, and with a Program Committee to review session programs and determine the agenda. We have also separately engaged partners in Indigenous Tribes and community-based organizations to ensure the Forum approach and program are attractive to these groups. Finally, to further strengthen our network in this space, we have regularly communicated and collaborated with other regional fora planners, including the Carolinas Integrated Sciences & Assessments (CISA).

Great Lakes Ensemble Stakeholder Working Group

Team Leads: Laura Briley, Rachel Dougherty, Richard Rood
Partners: see membership list (below)

GLISA's Great Lakes Ensemble project has made great progress in the last year to assess the credibility of climate model data for the region and bring practitioners the highest quality of information for planning. We convened a Stakeholder Working Group to co-develop climate information products for the Ensemble to ensure they meet the needs of the communities and sectors we serve. More specifically, this group provides feedback on existing GLISA products to improve usability, co-develops new products with GLISA, investigates how to scale products to larger audiences, and provides guidance on GLISA's overall program direction. The group convened for a kickoff call this spring, followed by individual conversations to learn more about each member's needs and interests. The group is already actively involved in co-developing a climate scenario guide for practitioners and a climate model consumer report for the Great Lakes region. The climate scenario guide will be a collection of information about the premise, creation, use, and expert-driven recommendations for radiative forcing, climate, and impact scenarios. The guide will explain how all three types of scenarios are related to one another and what their individual functions serve from a stakeholder perspective. We plan to highlight specific stakeholder applications of the three types of scenarios and expert guidance for new stakeholders who are interested in incorporating scenarios in their own work. The Working Group is composed of the following members: Dr. Tim Boring, Michigan Agribusiness Association; Devon Brock-Montgomery, formerly with the Bad River Band of Lake Superior Chippewa Indians; Eric Clark, Sault Ste. Marie Tribe of Chippewa Indians; Dr. Ankur Desai, University of Wisconsin-Madison; Rebecca Esselman, Huron River Watershed Council; Edmundo Fausto, Amec Foster Wheeler; Elizabeth Gibbons, American Society of Adaptation Professionals; Christopher Hoving, Michigan Department of Natural Resources, Michigan Climate Coalition; Michele Richards, Michigan Army National Guard, Michigan Climate Coalition; Dr. Greg Mann, National Weather Service.

Lac du Flambeau Tribe Climate Change Resilience Plan

Team Leads: Omar Gates, Frank Marsik
Partners: Sascha Petersen and Ellu Nasser, Adaptation International; Eric Chapman and Patricia Moran, Lac du Flambeau Tribe of Lake Superior Chippewa Indians; Mike Steinhoff and Fei Mok, ICLEI Local Governments for Sustainability; Missy Stults, Independent Consultant; George Haddow, Bullock & Haddow LLC

GLISA previously worked with Adaptation International on the Climate Change Vulnerability Assessment and Adaptation Plan for the 1854 Ceded Territory, including the Bois Forte, Fond du Lac, and Grand Portage Reservations in Minnesota. Following this successful partnership, Adaptation International reached out to GLISA to partner on a new project to develop a climate change resilience plan for the Lac du Flambeau Tribe of Lake Superior Chippewa Indians in northern Wisconsin. As a subcontractor to Adaptation International, we are leading the climate change analysis, providing a custom analysis of historical observations and future projections for a geographic area defined by the Tribe. Preliminary findings were presented during a site visit in May 2018, when additional topics of interest were added to our role including writing up a climate summary, identifying climate thresholds for the Climate Change Vulnerability Index (CCVI) for species of interest, and providing relevant literature on groundwater, ice cover and pollen. The climate analysis portion of the project is expected to be completed by the end of 2018 with another site visit planned for fall, but GLISA will continue to consult as the project team completes the vulnerability assessment and identifies adaptation strategies in 2019.

Bad River Band FEMA Pre-Hazard Mitigation Plan

Team Leads: Laura Briley, Kim Channell, Omar Gates, Frank Marsik
Partners: Devon Brock-Montgomery and Nathan Kilger, Bad River Band of Lake Superior Chippewa

After attending the Tribal Climate Workshop in 2017 (co-hosted by GLISA and the Inter-Tribal Council of Michigan) and learning about GLISA, the Climate Change Coordinator for the Bad River Band of Lake Superior Chippewa Indians reached out to GLISA for support developing the Tribe's Pre-Hazard Mitigation Plan for FEMA. The Tribe suffered $25 million in damages to roads and public infrastructure after a historic 2016 flood from a heavy precipitation event. As a result, the Tribe's Natural Resources department began an analysis of current and future risks to a variety of weather events and was interested in including regionally downscaled climate projections for their location. GLISA worked with the department to define a suite of custom variables and thresholds of interest, including temperature, precipitation, snow, extreme precipitation, and frost-free season. These were presented to the Tribe in the form of figures, tables, a written summary, and a power point presentation. We also provided basic evaluation information for the underlying global climate models used for the projections and a comparison of the underlying models, per request. As a result, Devon Brock-Montgomery has joined our Ensemble Stakeholder Working Group.

Collaborative Assessment of Stormwater Runoff on Tribal Lands in Michigan

Team Lead: Maria Carmen Lemos, Frank Marsik
Partners: Robin Clark, Inter-Tribal Council of Michigan; Keweenaw Bay Indian Community; Lac Vieux Desert Band of Lake Superior Chippewa Indians; Grand Traverse Band of Ottawa and Chippewa Indians; Little Traverse Bay Bands of Odawa Indians; Saginaw Chippewa Indian Tribe of Michigan; Graham Sustainability Institute, University of Michigan

GLISA and the Inter-Tribal Council of Michigan (ITCM) worked together to co-host a Tribal Climate Workshop in 2017 to address concerns about increases in heavy precipitation events. During the workshop, GLISA presented a demonstration of the U.S. EPA's National Stormwater Calculator (SWC), which provides a quantitative assessment of stormwater runoff in a community as well as the potential effectiveness and cost of low-impact development options to reduce runoff. These critical assessments are, however, time- and cost-prohibitive for many Tribal natural resources departments. GLISA received a Catalyst grant from the University of Michigan Graham Sustainability Institute to apply the SWC on the lands of five tribes in Michigan. Using the SWC, we will work with each Tribe to develop a report of the magnitude of precipitation runoff in vulnerable areas of their lands for current and plausible future climates. The assessments will allow participating tribes to identify vulnerabilities, develop management practices specific to their infrastructure and aquatic resources, and to provide quantitative information valuable for seeking funding to implement management practices. We will present results to other ITCM-members tribes via webinar and to other Tribal representatives in the region at the 2018 Great Lakes Adaptation Forum.

Synthesis of Ice Cover in the Great Lakes

Team Lead: Laura Briley
Partners: Drew Gronewold, NOAA GLERL; Amy Sacka, Photographer and National Geographic writer

This work started from a request for historical ice cover data for the Great Lakes from Amy Sacka, a Detroit-based photographer who was working on a piece for National Geographic under a National Geographic Explorer grant. The original project idea was to document ice fishing communities and the impact of climate change on the culture and pastime in Lake St. Clair. However, after many conversations with local fishermen and reviewing data on GLISA's website, Ms. Sacka expanded the focus to Lakes Erie, Michigan, and Huron. To respond to this request, GLISA developed a narrative summary of Great Lakes ice cover including ice cover data, trends, and recent literature that address the observed decline in ice cover, mechanisms behind that decline, and context for thinking about the future of Great Lakes ice cover. The analysis is being finalized to share on our website and is intended to be used in future GLISA projects that require ice information.

Apostle Islands National Lakeshore Climate Change Vulnerability Assessment

Team Leads: Laura Briley, Alexia Prosperi, Richard Rood
Partners: Stephen Handler, Northern Institute of Applied Climate Science (NIACS); Peggy Burkman, U.S. National Park Service

Continuing a long engagement with the National Park Service and the Apostle Islands National Lakeshore in northern Wisconsin, we began a new project to support the Park's climate change vulnerability assessment for terrestrial ecosystems. Building on the scenario planning process conducted in 2015, we updated and refined the original scenarios with downscaled climate data, end-of-century projections, and new information on several requested variables (i.e., lake ice, lake levels, arctic cold spells, wind speed, wave action, strong storms, snowfall, lake-effect show, lake currents). We also conducted an analysis of historical trends and presented this alongside the new scenarios at an in-person workshop at the Park in spring 2018. Working with partners at NIACS, we are authoring a chapter on climate drivers for the assessment, including a discussion on climate models, uncertainty, and statistical versus dynamical downscaling.

Expansion and Automation of Web-based Station Climatologies

Team Leads: Jeff Andresen, B.J. Baule, Laura Briley, Omar Gates
Partners: Beth Hall and Michael Timlin, Midwest Regional Climate Center; David Mudie, University of Michigan Graham Sustainability Institute

One of the primary resources GLISA has developed in partnership with cities are our station climatologies. These have proven essential in our work, and we recently released a new suite of web climatologies for over 200 stations. However, we currently have only 21 station climatologies publicly available in PDF form with a customized climate narrative (i.e., overview and geography of location, summary of observed changes). We have been working on an interactive online version for all stations, but need support with: a) better automating this process to allow for annual updates, b) developing the capability to generate printable versions from the website, and c) to continue developing climate narratives for additional stations. To expedite this process and expand our capacity to accomplish these goals we formally established an agreement with the Midwest

Regional Climate Center (MRCC). MRCC and GLISA have collaborated in the past on the development of station climate summaries for select areas across the GLISA spatial domain. In the agreement, MRCC will leverage GLISA's existing climatology code and output products to build and finalize the interactive web version. MRCC will then develop a process for users to export the web version to a PDF. MRCC and GLISA are working together to select at least 20 new stations for which to develop climate narratives, aiming to fill spatial gaps in the Great Lakes region (in the U.S. and Canada) and to respond to stakeholder requests. If feasible, Canadian data will be integrated into the new and updated climatologies for Canadian stations.

Projected Changes in Frequency of Major Tree Fruit Disease in the Central Great Lakes

Teams Leads: Jeff Andresen, B.J. Baule
Partners: Aaron Pollyea, Michigan State University Department of Environment & Spatial Sciences

Tree fruit production in the Great Lakes region is a significant factor in the region's agricultural economy. The modification and moderation of regional climate, particularly in the areas leeward of the lakes, allows for the commercial production of specialty crops not common in other areas of similar latitude. Previous studies in the region have identified significant trends of several hydro-climatic variables over the past several decades with both over-land and over-lake measurements, and there is concern in the agricultural industry that these trends may continue in the future. In this study, we consider the potential impacts of a shifting climate on three major tree fruit diseases - fire blight, cherry leaf spot, and apple scab - for the historical (1980-2017) and projected future (2040-2059 and 2080-2099) time frames. The frequency and severity of these diseases are heavily dependent on diurnal variations and combinations of air temperature, humidity, and precipitation. Future climate projections were obtained from multiple General Circulation Models dynamically downscaled through a Regional Climate Model. See Key Research Findings for preliminary results.

Development of Teaching Case for Great Lakes Climate Adaptation Network

Team Leads: Katie Browne, Jenna Jorns, Maria Carmen Lemos
Partners: Michigan Sustainability Cases, University of Michigan School for Environment and Sustainability; Matthew Gray, Office of Sustainability, Cleveland (OH); Jeffrey Meek, City of Indianapolis (IN); Rebecca Esselman, Huron River Watershed Council

GLISA is partnering with Michigan Sustainability Cases (MSC), a program at the UM School for Environment and Sustainability, to develop a teaching case about the challenges of coproduction and sustaining partnerships between producers and users of climate information. The case will highlight the establishment of the Great Lakes Climate Action Network (GLCAN) as a model of sustainable coproduction. Forming in part as a result of the Great Lakes Adaptation Assessment for Cities (GLAA-C) project, GLCAN was created in 2015 as a regional network of the Urban Sustainability Directors Network to unite Great Lakes cities with universities in the region. Last year, GLISA and partners worked with five cities in GLCAN to develop a common vulnerability assessment template, which the cities could use to mainstream adaptation planning. The partnerships between GLISA, GLCAN, HRWC, and the cities of the Great Lakes illustrate GLISA's boundary chain model of stakeholder engagement and points to ways in which coproduction of usable climate information can be sustained even when funding has ceased. To develop the case, we will utilize MSC's innovative multimedia platform to pair the development of a case study with video and podcast production (i.e., three three-minute videos with practitioners, a one-hour podcast with GLISA's climatologists, and an interactive diagram of the boundary chain model of coproduction). Practitioners will not only participate in on-camera interviews, but will also review and contribute to the case study itself, ensuring that their perspective is accurately captured. We anticipate that the case will be completed by the end of 2018, when it will be used as a teaching case by GLISA Co-Director Maria Carmen Lemos in her courses. The case will also be featured on MSC's open access platform, where sustainability educators and practitioners will be able to use it worldwide.

New or Tailored Regional Climate Services

Previews of each formal product discussed are in Appendix C, and links to pages on GLISA's website with the full materials are hyperlinked in the text, below, where available. Details on other services are available upon request.

Annual Climate Trends and Impacts Summary for the Great Lakes Basin

States: All (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin), and the province of Ontario

Please see the project description in New Areas of Focus and Partnership and Appendix C for the complete document. The final summary, available in both English and French, is available on GLISA's website and will soon be available on binational.net.

City Climatologies for Vulnerability Assessment Template

Team Leads: Kim Channell, Omar Gates, Jenna Jorns
States: Illinois, Indiana, Michigan, Ohio
Partners: Rebecca Esselman, Huron River Watershed Council; Missy Stults, Independent Consultant

In 2017, GLISA partnered with five Great Lakes cities (i.e., Ann Arbor & Dearborn (MI), Evanston (IL), Indianapolis (IN), and Cleveland (OH)), the Great Lakes Climate Adaptation Network (GLCAN), and HRWC to develop a comprehensive vulnerability assessment template. The project-based template mainstreams the adaptation planning process by integrating climate-smart and equity-focused information into all types of city planning. For each city, GLISA developed a city-specific climatology as well as an overall climatology for the Great Lakes region. The content and format of the climatologies was co-developed with the project partners to include historical observations and future projections for several variables of interest. The data was presented qualitatively and quantitatively in tables and verbal summaries (see Appendix C), to facilitate use by different decision makers (i.e., qualitative for city leadership, quantitative for municipal staff). This project was funded by the Urban Sustainability Directors Network (USDN) and is a continuation of GLISA's work with Great Lakes cities as part of the Great Lakes Climate Adaptation Network. These cities are already using the templates to plan for the future. For example, Cleveland (OH) is updating their Climate Action Plan and performing a social and climate vulnerability assessment based on the template. Indianapolis (IN) also made use of information from the template in creating their Climate Action Plan that covers sustainability, resilience, and hazard mitigation.

Detroit's Climate Action Plan

Team Leads: B.J. Baule, Omar Gates
State: Michigan
Partners: Detroiters Working for Environmental Justice

Continuing a long-standing relationship with Detroiters Working for Environmental Justice (DWEJ), GLISA provided updated, localized climate information to inform the development of the city's first-ever Climate Action Plan (see Narratives). While this information was provided in early 2017, the plan was finalized and released in fall 2017. Developed by the Detroit Climate Action Collaborative, an initiative of DWEJ, the plan outlines specific ideas and attainable goals. GLISA Climatologist Omar Gates was invited to present at a press conference to announce the report release. In his remarks, Gates drew attention to the potential impacts of warmer temperatures on vulnerable populations, such as youth and the elderly, and increased precipitation on the daily functions of the city.

Extreme Precipitation and Impact Scenarios for Michigan

Team Leads: Laura Briley, Omar Gates, Frank Marsik
State: Michigan
Partners: Inter-Tribal Council of Michigan

As part of GLISA's partnership with the Inter-Tribal Council of Michigan (ITCM) and the fall 2017 Tribal Climate Workshop, GLISA co-produced four extreme precipitation scenarios with ITCM in response to the tribes' interest in scenario planning for future heavy precipitation events (see Appendix C). These scenarios were presented at the workshop, revised to incorporate feedback, and shared with all workshop participants for use by environmental managers and other representatives from ITCM-member tribes in their climate adaptation planning.

Lac du Flambeau Climate Change Resilience Plan

State: Wisconsin

Please see the project description in New Areas of Focus and Partnership. While this project is ongoing, the Tribe is already using the climate information presented by GLISA in two presentations to the Tribe's Tribal Council and Tribal Climate Resilience Planning Committee (TCRP). The TCRP is using past observations and future projections to identify vulnerable species as part of their vulnerability assessment and implement this information into their Climate Resilience Plan.

Bad River Band FEMA Pre-Hazard Mitigation Plan

State: Wisconsin
Please see the project description in New Areas of Focus and Partnership.

Climate Adaptation Planning in Ohio Cities

Team Leads: B.J. Baule, Omar Gates
State: Ohio
Partners: Jason Cervenec, State Climate Office of Ohio; Dan Meaney, Cuyahoga County Planning Commission; Ramarao Venkatesh, Ohio State University

GLISA responded to two requests for information from cities in Ohio, Cleveland, and Columbus. For Cleveland, we provided information for Cuyahoga County based on the climate divisions to inform their first county-wide Climate Change Action Plan. For Columbus, we provided localized maps (i.e., projected changes in average temperature, observed percent change in number of days with extreme precipitation events) to inform their Climate Change Action Plan.

Case Studies of Climate Adaptation in Tribal Communities

Team Leads: Logan Dreher, Frank Marsik
States: All (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin)

In summer 2017, GLISA hosted an undergraduate student from Brown University as part of the UM School for Environment and Sustainability Doris Duke Conservation Scholar program (see Training of Students). The scholar conducted a review of adaptation planning in Indigenous communities across the United States, to inform our preparation for the Tribal Climate Workshop. The project culminated in a report (see Appendix C) that was shared with workshop participants, highlighting case studies in infrastructure, natural resource management, comprehensive planning, and integrating adaptation strategies. In particular, the report was shared the Midwest Tribal Resilience Liaison for the Northeast Climate Science Center, who expressed an interest in using it in her work.

Program Evaluation & Impact

GLISA has made it a priority to better understand how our resources and information inform decision making and build communities' capacity to respond to climate variability and change in the Great Lakes region. We continue to track the metrics we presented in our Phase I report for 2010-2016 - indicators on sectors engaged, number of entities engaged, number of organizations engaged at different levels of government, total grants awarded, and funds leveraged. We have expanded to track not only these metrics, but also a list of collaborations, our community network, reach, and early career professionals supported. The new additions are in response to the network-wide effort by the RISA teams to better quantify and communicate our collective impact. We continue to evaluate GLISA's small grants competition model and began two new evaluation avenues, evaluation of impact and sharing impact stories, all of which are described below.

Evaluation of Small Grants Competition

GLISA is continuing its evaluation of the first five years of the small grants competition, focusing on how recipients used the climate information provided and how effectively they partnered with other organizations. We have completed interviews with 20 of the grant recipients and collected network information from 16. Network data includes the number of organizations recipients collaborated with, the nature of the collaboration, and the type of information shared. The data indicate that while recipients collaborated with a wide diversity of organizations to use the climate information GLISA provided, the network contracted in the years in which funding ceased. This finding raises questions about the sustainability of the network and the supply-driven nature of coproduction. We have delivered presentations of these preliminary findings at three conferences and received valuable feedback. A manuscript is in development.

Evaluation of Impact of Adaptation Projects

While adaptation professionals and other decision makers are currently implementing numerous adaptation projects, tools to evaluate the effectiveness of these projects are scarce and difficult to access. Recognizing this need, GLISA has begun development of a new web-based adaptation evaluation tool: My Adaptation Evaluation Resource Assistant (MAERA). We are partnering with evaluation specialist Dr. Michaela Zint, who developed a similar tool for the Environmental Protection Agency (EPA) that has been used by over 25,000 environmental educators to conduct and improve evaluations of their programs. The MAERA tool will provide a step-by-step guide for learning about and conducting evaluations of adaptation actions. It will also provide explanations, guides, and examples for users with different levels of experience with program evaluation (from beginner to advanced). GLISA and our partners will organize a workshop at the 2018 Great Lakes Adaptation Forum to introduce the tool and solicit feedback from potential users on a beta version. We will also partner with the American Society of Adaptation Professionals (ASAP) to assess the program evaluation needs of adaptation professionals and design the tool to better meet their needs. The tool will be completed by the end of 2018 and launched soon after.

Development of Impact Stories

In an effort to better communicate successful engagements, we developed three impact stories for use in outreach to elected officials, funding organizations, and the general public. We aimed to highlight GLISA's work in different sectors, choosing to begin with case studies in cities, tribes, and infrastructure. These stories are included in Appendix B and are available on our website here. We have several projects targeted to develop additional impact stories in fall 2018.

Building Local and Regional Expertise

We continue to focus on deepening existing relationships in our three focus sectors: cities, tribes, and agriculture. We also continue to explore new ideas in the health sector, train students, and strengthen collaborations with other NOAA entities.

Urban Adaptation

GLCAN (see Development of Teaching Case for Great Lakes Climate Adaptation Network) continues to be the primary mechanism by which we interact with cities in the region, by providing financial support to the network, climate information to members, and by working on dedicated projects together. Having completed our first funded project together, we recently received funding from the NOAA Sectoral Applications and Research Program (SARP) to continue this work and apply the template with six new cities in the region. By applying the template to stormwater management projects using three test engagement methodologies, we will assess whether our boundary chain model can reduce transaction costs for scaling up sustained stakeholder engagement. By developing our first teaching case on our work with cities, we aim to disseminate the boundary chain model of stakeholder engagement to other regions and countries. In addition, we continue to give presentations in cities across the region on climate change and localized impacts (see Great Lakes Climate Change Presentations).

Tribal Engagement

Our growing portfolio of work with Indigenous communities in the region continues to lend trust and credibility with stakeholders in the Great Lakes. The successful completion of our 2017 Tribal Climate Workshop in Michigan (see Extreme Precipitation and Impact Scenarios for Michigan) led to a new collaboration with the Bad River Band of Lake Superior Chippewa Tribe (see Bad River Band FEMA Pre-Hazard Mitigation Plan). Our previous work with the 1854 Treaty Authority in Minnesota led to a new project with Adaptation International in Wisconsin (see Lac du Flambeau Tribe Climate Change Resilience Plan). Our new project with the Inter-Tribal Council of Michigan (see Collaborative Assessment of Stormwater Runoff on Tribal Lands in Michigan) is a first for GLISA, to train stakeholders on a specific tool. GLISA Climatologist Omar Gates was invited to attend the 2018 Rising Voices Workshop in Duluth (MN) where attendees discussed how to better engage Tribal partners in sustainability work and in the protection of their way of life. The discussions highlighted GLISA's work with The 1854 Treaty Authority. Furthermore, we have engaged a group of Tribal partners as we plan for the 2018 GLAF to solicit feedback on program development and outreach (see Organizing and Hosting the 2018 Great Lakes Adaptation Forum).

Agricultural Work

GLISA is working to strengthen our focus on the agricultural sector, conducting original research projects and providing usable climate information to the industry. Key areas of focus in the past year have been on: changes in heavy precipitation and its relationship to nitrogen management (See Key Research Findings), the measurement and forecasting of radiation freeze events in key fruit growing regions and applications for frost prevention systems in fruit orchards (see Narratives), and on the projected changes in the frequency of tree fruit diseases in a changing climate (see Key Research Findings). We continued engaging stakeholders in these areas through MSU Extension and through presentations at conferences and meetings (see Outreach and Communication Activities). Additionally, GLISA's collaboration with Purdue University and Ohio State University has continued to explore agricultural water management in the region and how strategies will likely need to evolve under climate change (see 2017-2018 Publications).

Human Health

GLISA's active work in the public health sector stems from our collaboration with the Michigan Department of Health and Human Services (MDHHS). We created a survey to learn how other state public health departments in the region are using climate information in their work to inform plans for future GLISA projects. Representatives from the MDHHS provided contacts for other states, and six departments (i.e., Illinois, Indiana, Michigan, Minnesota, New York, and Wisconsin) volunteered to participate in the survey via phone or email. The results showed that many states are already utilizing climate science in their work, especially in areas of extreme heat, extreme precipitation, and water- and vector-borne illnesses. Much of the climate information they received were from university partners, federal agencies, and the state's departments of natural resources. The results were presented at the 2018 American Meteorological Society Annual Meeting in Austin (TX).

Training of Students

GLISA has continued our relationship with the UM College of Engineering Applied Climate graduate program in the Department of Climate and Space Sciences and Engineering. Over the last year, GLISA has worked with six students on real-world, applied climate projects to contribute to GLISA's research efforts as well as to provide usable climate information for stakeholders in the region. The students contributed to much of the work highlighted in the report, including the Great Lakes Ensemble and engagement with Apostle Islands National Lakeshore. We hope these students will maintain the knowledge and skills gained in their work with GLISA, including their role as brokers of climate information, in their future careers as leaders and decision makers regardless of profession or sector. In addition, GLISA mentored our first undergraduate student in the last year, through the Doris Duke Conservation Scholars Program (see Case Studies of Climate Adaptation in Tribal Communities). The program aims to diversify the conservation workforce by funding and developing the next generation of land, water, and wildlife professionals among traditionally underrepresented groups. We are hosting a second scholar in summer 2018.

Maintaining Partnerships and Collaborations with NOAA-funded Great Lakes Organizations

GLISA has continued to meet regularly with other UM-based, NOAA-funded Great Lakes programs to strengthen our collaboration and leverage resources, including Michigan Sea Grant, The Cooperative Institute for Great Lakes Research, and The National Estuarine Research Reserve System Science Collaborative. We worked together to develop a common set of metrics we can report and showcase on a 'NOAA @ UM' web portal (in development). We often table together at University and regional events, notably including the University President's Tailgate for the UM/MSU football game and the Michigan Congressional Roundtable (see Congressional Outreach). Outside the University, we maintain an active relationship with the NOAA Great Lakes Environmental Research Laboratory, working together to respond to one-time requests for information from scholars and the media, and collaborating on projects including the Great Lake Ensemble, the Great Lakes Adaptation Data Suite, the 2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin, and development of a lake ice narrative.

Regional Leadership & Partnerships

As a regional convener and content expert, we are often invited to serve on a number of local and regional committees. The following activities allow GLISA to broaden our impact by communicating our work to a larger group of stakeholders and lend our expertise to new projects:

- Participate in the Michigan Climate Coalition
- Serve on Great Lakes Water Quality Agreement Annex 9 Subcommittee
- Serve on NOAA Great Lakes Regional Collaboration Team and Communications Sub-group
- Participate in UM Library's Public Science Initiative
- Participate in working group to establish a regional page of U.S. Climate Resilience Toolkit
- Co-authors on the Fourth National Climate Assessment Midwest chapter
- Administer & participate in Great Lakes Climate Adaptation Network (GLCAN)
- Participate in Flint Citizen Science Advisory Board

Greatest Accomplishment This Year

Our team's greatest accomplishment this year is leading the development, production, and dissemination of the first-ever Annual Climate Trends and Impacts Summary for the Great Lakes Basin (see New Areas of Focus and Partnership). GLISA was asked to act as the coordinator for this binational pilot product, leading the development of the climate overview section while also synthesizing information from other section leads in both countries, managing graphic design and integration of feedback from the Annex 9 Subcommittee and external review. The document underwent several iterations of review and feedback, with our team needing to incorporate and respond to detailed and technical feedback while maintaining the readability of a report intended for a broad audience (i.e., researchers, decision makers, general public). As part of this process, we strengthened our relationship with Annex 9 leadership, NOAA, and Environment and Climate Change Canada (ECCC). In particular, we benefited from working closely with ECCC colleagues, learning what datasets in both countries were compatible to produce maps representing the entire region. In presenting the synthesis at regional and national meetings, we have reached new audiences, such as the Great Lakes Executive Committee (GLEC). We are in the process of collecting feedback on the utility of the report. To-date, the initiate response has been overwhelmingly positive that the document is valuable, easy to understand, and appropriate for decision makers.

Key Research Findings

Great Lakes Ensemble

Team Leads: Laura Briley, Rachel Dougherty, Richard Rood, Haochen Ye
Partners: Joe Barsugli, NOAA Earth System Research Laboratory; Edmundo Fausto, Amec Foster Wheeler; Drew Gronewold, NOAA GLERL; Glenn Milner, Ontario Climate Consortium; Michael Notaro, University of Wisconsin Madison; Peter Snyder, University of Minnesota;

As part of GLISA's Great Lakes Ensemble project, we conducted a systematic evaluation of lakes in the Coupled Model Intercomparison Project Version 5 (CMIP5) climate models. Large lakes can have an impact on regional weather. In addition, they can be both sensitive to and contribute to regional climate changes. However, in the numerical models that are used to investigate future climate changes, lakes are often absent or overly simplified. At the regional scale, this can have strong implications for the quality of the model information about the future. We argue that there is a first order requirement that the underlying climate models simulate lake-atmosphere interactions for their future information to be relevant in regions where lakes modify the climate. However, we are aware of very little effort within the scientific community to make known how individual large lakes are represented in models and how those representations translate to the quality of the data for particular regions. One of the first barriers we faced in uncovering the treatment of large lakes was a lack of model documentation focused on the simulation of lakes. We relied heavily on the modeling experts in our Science Advisory Panel and other modelers in our network to increase our knowledge about the models and guide our investigation. The primary goal of this work is to share our framework for identifying how individual large lakes are represented in climate models. We have applied our framework to a large number of CMIP5 climate models with an emphasis on uncovering the treatment of the U.S. Great Lakes. We now know which CMIP5 models simulate the Great Lakes, so we can build a CMIP5 lakes Ensemble and compare this to other regional data sets. In addition, our outlined methodology (i.e., decision tree) can be used by applied scientists in other regions where large lakes drive climate processes to identify the models that may offer the most credible lake-atmosphere representations. Two manuscripts are in preparation from this work.

Heavy Precipitation and Nitrogen Management

Team Leads: Jeffrey Andresen, B.J. Baule
Partners: Michigan State University Extension

Changes in total annual precipitation and in the intensity and frequency of heavy precipitation events have occurred across the United States. These heavy precipitation events have become increasingly damaging to crops and often result in large financial losses and other damages from the resulting flooding. Establishing a quantitative, cause and effect relationship over time between heavy precipitation and crop losses has proven difficult due to heterogeneities in practices over several decades. Loss of nutrients is one such loss related to heavy precipitation and can represent a substantial financial risk to producers (e.g., the average price in the United States for a short ton of anhydrous ammonia was $847). Depending on application rate, crop requirements, and operation size, the excessive application of nitrogen fertilizer, and subsequent losses, represents a substantial economic impact to producers. Our work to-date has focused on quantifying and updating existing work on precipitation trends and patterns across the greater Midwest. Precipitation has exhibited changes in frequency and intensity at seasonal and annual timescales, resulting in more precipitation, in greater intensities, across the landscape. Exploratory results suggest that low frequency precipitation variability has a significant effect on nitrogen loss and crop yields across the Midwest. At present, field data on inorganic nitrogen is being collected at two locations in western Michigan to calibrate and validate crop models for the present climate and allow us to evaluate nitrogen cycling under climate change scenarios.

A Network Intervention for Natural Resource Management

Team Lead: Ken Frank, Tingqiao Chen
Partners: Alliance for the Great Lakes

Network analysis was used to visualize knowledge flows and collegial ties among those managing ravines along southwestern Lake Michigan. The visualizations were used to target professional development to modify the network. Efforts altered the network centrality of key actors who had either incorporated knowledge about climate change into their own practices or who were strategically located in the social network of those managing ravines, but knowledge flows explicitly about climate change did not change. This provides insight into the potential and limitations of network analysis for informing the management of natural resources. The key finding is that it was possible to leverage a visualization of the network to guide changes in the network. This is referred to as a network intervention, a relatively new strand in social network analysis. In particular, members of the Alliance for the Great Lakes were able to identify clusters in the network of those who managed ravines on southwestern Lake Michigan. Through intensive professional development, members of the Alliance then cultivated more network ties with those who had the potential to bridge between networks. The result was a more integrated, less siloed, network. The project also created two unexpected findings. First, members of the Alliance had to cultivate an identity within each network cluster before cultivating bridging ties between clusters. In this way they supported both bonding and bridging social capital. Second, while they were able to cultivate bridging collegial interactions, members of the Alliance were not able to cultivate direct knowledge flows about climate change. Such knowledge flows are the target of their current work. A manuscript on this work has been submitted to Ecology and Society.

Projected Changes in Frequency of Major Tree Fruit Disease in the Central Great Lakes

Please see the summary in New Areas of Focus and Partnership for the project rationale. Early results suggest overall changes of some types of plant disease risk in recent decades, and some decreases in risk in the future, due mainly to projected decreases in relative humidity. As this work matures, results will be applicable to planning for disease management on an annual time scale and orchard planning on longer time scales, given that orchards often produce for 30 years or more.

Ice Prediction for Apostle Islands National Lakeshore

Team Lead: Richard Rood, Xialong Ji
Partners: Drew Gronewold, NOAA GLERL; Houraa Daher, University of Miami

GLISA and collaborators are working to forecast the first date of solid ice in the Apostle Islands National Lakeshore (APIS), a U.S. National Park Service (NPS) site in northern Wisconsin on Lake Superior to support regional management planning decisions and to protect human health and safety. We developed a new statistical model that simulates the onset of seasonal ice cover along the APIS shoreline. Our model encodes relationships between different modes of climate variability and regional ice cover from 1972 to 2015, and successfully simulates both the timing of ice onset and the probability that ice cover might form at any point in a particular winter. We simulate both of these endpoints using a novel combination of statistical hazard and beta regression models. Our analysis of coastal ice cover along the APIS reinforces findings from previous research suggesting that the late 1990s signified a regime shift in climate conditions across North America. Before this period, coastal ice cover conditions at the APIS was often suitable for pedestrian access, while after this period coastal ice cover at the APIS has been highly variable. Our new model accommodates this regime shift, and provides a stepping stone towards a broad range of applications of similar models for supporting regional management decisions in light of evolving climate conditions.

Outreach and Communication Activities

Organizing and Hosting the 2018 Great Lakes Adaptation Forum

Please see New Areas of Focus and Partnership for the planning effort underway for the 2018 Great Lakes Adaptation Forum (GLAF). As part of our planning, we have deliberately engaged a diverse group of stakeholders to ensure the process and Forum are inclusive. This includes convening an Advisory Board monthly (membership roster here), composed of more than 30 practitioners and scholars in the region. Separately from this group, we have had several conversations with groups of Tribal partners and leaders in regional community-based organizations. By targeting these groups in particular, we hope to design the program format and content to appeal to their networks and increase their participation in the Forum. We have also established a Program Committee (membership roster here) who will review session proposals and set the Forum agenda.

Congressional Outreach

As part of the RISA Executive Committee, GLISA has been working with the other regional teams on a unified network strategy to engage elected officials. In preparation, we updated our one-pager with a new case study for Michigan and drafted several GLISA ‘songs,’ 1-2 sentence summaries of impact stories for use throughout the RISA network. On May 8, GLISA was invited to participate in the NOAA Great Lakes Regional Collaboration Team’s first-ever state congressional roundtable for Michigan. The event was hosted at GLERL and was attended by more than a dozen staffers from local Congressional offices. GLISA hosted a table and Co-Directors Lemos and Andresen attended the event to share GLISA's mission and work with the attendees. The event was a success and will serve as a model to host one or two more roundtables in the region in 2019. Notably, a staffer of Congresswoman Debbie Dingell reached out to GLISA to have a separate meeting on the same day to learn more about work in the Great Lakes. GLISA hosted this meeting at the UM School for Environment and Sustainability and talked more about our work alongside other UM partners.

Great Lakes Climate Change Presentations

As our reputation as a trusted expert continues to grow, GLISA is often invited to speak at workshops or community meetings on the topic of climate change in the Great Lakes region. Co-Director Jeffrey Andresen also serves as the State Climatologist for Michigan, increasing GLISA's reach and visibility through his presentations in this capacity. For each of these talks, we typically build our presentation from a standard slide deck prepared for general audiences and tailor the talk to any unique information needs or topics not already covered. Below is a list of meetings we participated in over the last year:

- Michigan Water Environmental Assoc. Technology Conference, June 2017, Boyne City (MI)
- North Central U.S. Monthly Climate and Drought Summary and Outlook, July 2017, webinar
- MSU Friendship House, August 2017, East Lansing (MI)
- Land Information Access Association (LIAA) community meeting, Sept. 2017, Bridgman (MI)
- North Central Extension Educators Cropping Academy, Sep. 2017, Hickory Corners (MI)
- NOAA Research Social Science Webinar, September 2017, webinar
- LIAA Resilient St. Joseph Project meeting, October 2017, St. Joseph (MI)
- Dearborn Water Fellows meeting, November 2017, Dearborn (MI)
- MSU Extension Climate Outreach Team, November 2017, webinar
- Ottawa County Water Quality Forum, November 2018, West Olive (MI)
- SmartAg Symposium, December 2017, East Lansing (MI)
- 2018 Dry Bean Conference, December 2018, Bay City (MI)
- Kalamazoo Math and Science Academy, January 2018, Kalamazoo (MI)
- Michigan Agribusiness Association, January 2018, Lansing (MI)
- MSU Extension Ag Action Day, January 2018 (via webinar), Kalamazoo (MI)
- Great Lakes Crop Summit, January 2018, Mt. Pleasant (MI)
- MSU Extension Macomb County Education Series, February 2018, Mt. Pleasant (MI)
- Michigan Crop Improvement Association, March 2018, Okemos (MI)
- MSU Fate of the Earth conference, March 2018, East Lansing (MI)
- Kalamazoo Valley Museum, March 2018, Kalamazoo (MI)
- MSU Extension Blueberry Meeting, March 2018, Fennville (MI)
- University Lutheran Church, April 2018, East Lansing (MI)
- Michigan Association of Planning's Resilience Summit, April 2019, Lansing (MI)
- LIAA Resilient Michigan, April 2018, Lansing (MI)
- Tip of the Mitt Climate Change Summit, May 2018, Petoskey (MI)
- City of Ann Arbor Sustainability Forum, May 2018, Ann Arbor (MI)

Presentations at Regional and National Conferences

GLISA team members have attended a number of local, regional, and national conferences to present and communicate our work to our stakeholder groups, including academic and federal researchers, adaptation practitioners, and NOAA collaborators:

- RISA Annual Meeting, June 2017, Washington (DC)
- American Meteorological Society 23rd Applied Climatology Conference, June 2017, Asheville (NC)
- Midwest Climate Services Workshop, September 2017, Champaign (IL)
- Forging University-Municipality Partnerships Toward Urban Sustainability, October 2017, New Haven (CT)
- American Geophysical Union (AGU) Fall Meeting, December 2017, New Orleans (LA)
- Resilience Ecosystem Workshop, January 2018, Washington (DC)
- Michigan Dept. of Natural Resources Annual Meeting, January 2018, Traverse City (MI)
- American Meteorological Society 98th Annual Meeting, January 2018, Austin (TX)
- Michigan University-Wide Sustainability & Environment Conference, February 2018, Ann Arbor (MI)
- University of West Virginia Extension Education Series, March 2018, Martinsburg (WV)
- Fourth National Climate Assessment All-authors Meeting, March 2018, Washington (DC)
- 6th Rising Voices Workshop, April 2018, Duluth (MN)
- Association of American Geographers, April 2018, New Orleans (LA)
- Climate Predictions and Applications Science Workshop, May 2019, Fargo (ND)

Media Interviews & Mentions

GLISA has interacted with the media several times in the last year, and has participated in a number of interviews, listed below. Information we have provided is often cited as well in articles, and the following list includes some examples of these.

- Earth and Space Science News, August 2017; Faculty Richard Rood interviewed for an article on the historic flooding on Lake Ontario
- The State Press, September 2017; Co-Director Maria Carmen Lemos quoted in an article on the dismissal of the National Climate Assessment sustained assessment committee
- Crain's Detroit Business, October 2017; Climatologist Omar Gates quoted in an article about Detroit's Climate Action Plan
- Great Lakes Echo, November 2017; Co-Director Jeff Andresen interviewed for an article on weather prediction and accuracy
- Brownfield Agricultural News for America, February 2018; Co-Director Jeff Andresen quoted in an article on a warmer and wetter Midwest
- Columbus Underground, February 2018; GLISA information quoted in article to justify potential policy implementation for climate change
- Farm and Dairy, February 2018; GLISA information quoted in an article about farmers adapting to climate change
- Farmers Advance, April 2018; Co-Director Jeff Andresen quoted in an article on winter flooding and spring planting
- National Geographic, forthcoming; Climatologist Laura Briley interviewed for an article on climate change and lake ice cover in the Great Lakes

2017-2018 Publications

Additional publications and abstracts for all those listed here are in Appendix A.

Peer-reviewed

When do Climate Change, Sustainability, and Economic Development Overlap in Cites?

Citation: **Kalafatis, S. E.*** 2017. When do climate change, sustainability, and economic development considerations overlap in cities? *Environmental Politics,* 27: 115-138.
*Scott Kalafatis was formerly a graduate student with GLISA and is now a postdoctoral scholar at the College of Menominee Nation.
Status: Published, https://doi.org/10.1080/09644016.2017.1373419

Vulnerability of Specialty Crops to Short-term Climatic Variability and Adaptation Strategies on the Midwestern USA

Citation: Kistner, E., O. Kellner, **J. Andresen**, D. Todey, and L. Morton. 2017. Vulnerability of specialty crops to short-term climatic variability and adaptation strategies in the Midwestern USA. *Climatic Change*, 146(1-2): 145-158.
Status: Published, DOI: 10.1007/s10584-017-2066-1

Modeled Climate Change Impacts on Subirrigated Maize Relative Yield in Northwest Ohio

Citation: Gunn, K.M., **Baule, W. J**., Frankenburger, J. R., Gamble, D. L., Allred, B.J., **Andresen, J. A.** and L. C. Brown. 2018. Modeled climate change impacts of subirrigated maize relative yield in northwest Ohio. *Agricultural Water Management,* 206: 56-66.
Status: Published, DOI: https://doi.org/10.1016/j.agwat.2018.04.034

Identifying the Potential for Climate Compatible Development Efforts and the Missing Links

Citation: **Kalafatis, S. E.*** 2017. Identifying the Potential for Climate Compatible Development Efforts and the Missing Links. *Sustainability,* 9(9): 1642.
Status: Published, https://doi.org/10.3390/su9091642

Non-peer Reviewed

2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin

Citation: Environment and Climate Change Canada and the U.S. National Oceanic and Atmospheric Administration. 2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin. 2018. Available at binational.net.
Status: Published, on GLISA's website (see Appendix C).

Narratives

Plans, Policies, Strategies, Tools, or Agreements Implemented as a Result of GLISA Work

City of Ann Arbor Hazard Mitigation Plan and Stormwater Management Fee Increase

The City of Ann Arbor and GLISA have been working together since 2011, stemming from our collaboration on the Great Lakes Adaptation Assessment for Cities (GLAA-C) project. As part of GLAA-C, GLISA developed a city climate fact sheet and has provided updated information since. In the last year, two planning efforts have resulted in part from the climate information GLISA provided. First, the City finalized its 2017 Hazard Mitigation Plan for FEMA that mentions climate 228 times (all based on GLISA data), a drastic increase in attention since the 2012 plan. Second, the City Council passed an increase in stormwater management fees to gradually scale up rates to increase the City's capacity to plan for the already observed increase in extreme precipitation events. The impetus for this increase was based on GLISA data summarized in the aforementioned fact sheet. In fact, the Mayor mentioned a GLISA figure, a 45% increase in annual precipitation in the last 60 years, in a news article justifying the fee increase. The fee increase will raise annual stormwater revenues by 28% (an average increase of $20 per resident) and will partially support the $160 million worth of potential projects identified to improve stormwater management.

Detroit Climate Action Plan

GLISA has worked with the Detroit Climate Action Collaborative for several years to develop customized, localized climate information to inform the group's climate action planning for the City of Detroit. In the last year, GLISA updated the city-specific Historical Climatology with information for days over 100°F, deaths due to heat-related events, and future projections maps based on high and low emissions scenarios for temperatures greater than 90°F and 95°F. These thresholds were identified by the stakeholders as specific areas of concern in Detroit. This data was used to inform the City's first-ever Climate Action Plan, that was released in fall 2017. Developed by the Detroit Climate Action Collaborative, an initiative of DWEJ, the plan outlines specific ideas and attainable goals. The Plan benefits the more than 672,000 residents of Detroit and the more than 4 million residents of the larger Detroit metro area, including 300,000 business and 11 Fortune 500 companies. GLISA's collaboration with Detroiters Working for Environmental Justice, the leader of the Collaborative, was featured in a news article in October 2016 and in a press conference in October 2017 to launch the Plan. The Plan is now featured on the U.S. Climate Resilience Toolkit.

Economic Return

Projected Changes in Frequency of Major Tree Fruit Disease in the Central Great Lakes Region

Tree fruit production in the Great Lakes region is a significant factor in the region's agricultural economy. The primary weather-related constraint for production of tree fruit and other perennial fruit crops in temperate climates is the frequency and severity of freeze events during the spring season. Unfortunately for fruit producers in the Great Lakes region, the frequency of these freeze events following initial phenological development has increased during the past few decades, as observed during the 2012 growing season when a record warm March was followed by a series of freeze events that resulted in severe crop damage and economic losses as high as $500 million. Following this event, many regional fruit growers installed frost/freeze protection devices in their operations that provide some protection, but they are expensive (typically on the order of $3500/acre for the equipment with an additional $200/acre per year in operating costs, and the technology has functional limits). GLISA is working with growers to help quantify climate-related production risks and the potential mitigation of the freeze events, and the estimated payback times for the technology in historical and projected future time frames. Results from the project should assist growers making strategic investment decisions associated with the technology.

Appendix A: Additional 2017-2018 Publications

Peer-reviewed

Comparing Climate Change Policy Adoption and Its Extension Across Areas of City Policymaking

Citation: **Kalafatis, S. E.** 2017. Comparing Climate Change Policy Adoption and Its Extension across Areas of City Policymaking. *Policy Studies Journal.*
*Scott Kalafatis was formerly a graduate student with GLISA and is now a postdoctoral scholar at the College of Menominee Nation.
Status: Published, https://doi.org/10.1111/psj.12206
Abstract: Public policies increasingly address complex problems such as climate change mitigation and climate change adaptation that require forging connections across existing areas of policy activity. Despite the emerging prominence of these types of policymaking challenges, more research is needed to understand policy responses to them. In this paper, I use survey responses from 287 cities and a hurdle model to comparatively examine the factors that underlie the adoption of climate change mitigation and adaptation as issues influencing city policymaking and their extension across areas of city policymaking. I find evidence that while social change, crisis, and conditions supporting nascent coalitions were associated with adoption, extension across areas of policymaking was associated with the city's prevailing political economy as well as the resources for expanding communities of interest. In the process, I offer empirical evidence for existing similarities and differences in cities' considerations about climate change mitigation and adaptation; particularly that the number of policymaking areas influenced by mitigation was associated with financial factors while the number influenced by adaptation was associated with socioeconomic ones.

When do Climate Change, Sustainability, and Economic Development Overlap in Cites?

Citation: **Kalafatis, S. E.*** 2017. When do climate change, sustainability, and economic development considerations overlap in cities? *Environmental Politics,* 27: 115-138.
*Scott Kalafatis was formerly a graduate student with GLISA and is now a postdoctoral scholar at the College of Menominee Nation.
Status: Published, https://doi.org/10.1080/09644016.2017.1373419
Abstract: Overlaps between economic development, sustainability and climate change objectives have both political and practical implications for the development of policies addressing climate change mitigation and adaptation. However, little empirical research has systematically investigated factors underlying these overlaps. Here, survey responses from 287 cities in the US are used to explore associations between the presence of such overlaps and these cities' policy actions and contextual conditions. Patterns in the presence of these overlaps are described, which help shed light on the political economy underlying policymakers' considerations about overlapping climate change mitigation and adaptation considerations with economic development or sustainability. Policymakers' considerations about the possible political co-benefits and political trade-offs of these objective overlaps will play a critical role in shaping interconnected policy responses to complex challenges like climate change in the years ahead.

Vulnerability of Specialty Crops to Short-term Climatic Variability and Adaptation Strategies on the Midwestern USA

Citation: Kistner, E., O. Kellner, **J. Andresen**, D. Todey, and L. Morton. 2017. Vulnerability of specialty crops to short-term climatic variability and adaptation strategies in the Midwestern USA. *Climatic Change*, 146(1-2): 145-158.

Status: Published, DOI: [10.1007/s10584-017-2066-1](10.1007/s10584-017-2066-1)

Abstract: While the Midwestern USA ranks among the world's most important corn-soybean production regions, the area also produces a variety of high-value specialty crops. These crops are an important component of the region's rural economy with an estimated value of $1.8 billion in 2012. More profitable per-acre than many row crops, specialty crops also have higher production-related risks. They are generally more sensitive to climatic stressors and require more comprehensive management compared to traditional row crops. Temperature and precipitation fluctuations across the Midwest directly impact specialty crop production quantity and quality and indirectly influence the timing of crucial farm operations and the economic impacts of pests, weeds, and diseases. Increasingly variable weather and climate change pose a serious threat to specialty crop production in the Midwest. In this article, we assess how climate variability and observed climatic trends are impacting Midwestern specialty crop production using USDA Risk Management Agency data. In addition, we review current trends in grower perceptions of risks associated with a changing climate and assess sustainable adaptation strategies. Our results indicate that weather-induced losses vary by state with excessive moisture resulting in the highest total number of claims across all Midwestern states followed by freeze and drought events. Overall, specialty crop growers are aware of the increased production risk under a changing climate and have identified the need for crop-specific weather, production, and financial risk management tools and increased crop insurance coverage.

Modeled Climate Change Impacts on Subirrigated Maize Relative Yield in Northwest Ohio

Citation: Gunn, K.M., **Baule, W. J**., Frankenburger, J. R., Gamble, D. L., Allred, B.J., **Andresen, J. A.** and L. C. Brown. 2018. Modeled climate change impacts of subirrigated maize relative yield in northwest Ohio. *Agricultural Water Management,* 206: 56-66.

Status: Published, DOI: https://doi.org/10.1016/j.agwat.2018.04.034

Abstract: Subirrigation is employed to supply water to crop root zones via subsurface drainage systems, which are typically installed for the purpose of excess soil water removal. Crop yield increases due to subirrigation have been demonstrated in numerous studies, but there is limited information regarding yield under future climate conditions when growing season conditions are expected to be drier in the U.S. Corn Belt. DRAINMOD was calibrated and validated for three locations with different soil series in northwest Ohio and used to investigate maize relative yield differences between subirrigation and free subsurface drainage for historic (1984–2013) and future (2041–2070) climate conditions. For historic conditions, the mean maize relative yield increased by 27% with subirrigation on the Nappanee loam soil, but had minimal effect on the Paulding clay and Hoytville silty clay soils. Maize relative yield under free subsurface drainage is predicted to decrease in the future, causing the relative yield difference between free subsurface drainage and subirrigation practices to nearly double from 9% to 16% between the historic and future periods. Consequently, the subirrigation practice can potentially mitigate adverse future climate change impacts on maize yield in northwest Ohio.

Identifying the Potential for Climate Compatible Development Efforts and the Missing Links

Citation: **Kalafatis, S. E. 2017**. Identifying the Potential for Climate Compatible Development Efforts and the Missing Links. *Sustainability,* 9(9): 1642.
*Scott Kalafatis was formerly a graduate student with GLISA and is now a postdoctoral scholar at the College of Menominee Nation.
Status: Published, https://doi.org/10.3390/su9091642
Abstract: Those examining climate compatible development and triple-win policy efforts that simultaneously negotiate sustainable development, climate change mitigation, and climate change adaptation considerations are on the cutting edge of exploring why and how policymakers address complex social problems that require balancing considerations about multiple, interrelated policy issues. Enhancing understanding of factors underlying the emergence of these efforts can help strengthen incentives for action, address implementation challenges, and anticipate inequities. This paper uses survey responses from 287 cities and logistic regression analyses to explore conditions and policy actions associated with potential climate compatible development efforts when economic development, sustainability, climate change mitigation, and climate change adaptation considerations overlap. It finds evidence that potential climate compatible development efforts were present in 10% of the cities studied. Adaptation was the issue most likely to act as the missing link when each of these other issues influenced city policy actions, and mitigation was the least likely. Contextual factors associated with these efforts included budget stress, leadership from a policy entrepreneur, higher college degree attainment rates, having an environmental department or commission, and the area of the city composed of water versus land. Examining factors associated with these issues acting as missing links revealed contradictions that highlight the necessity of further exploration of processes affecting the pursuit of climate compatible development.

Non-peer Reviewed

2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin

Citation: Environment and Climate Change Canada and the U.S. National Oceanic and Atmospheric Administration. 2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin. 2018. Available at binational.net.
Status: Published, on GLISA's website (see Appendix C).
Abstract: During the 2017 reporting period, several notable events and trends were observed across the Great Lakes basin including higher than average seasonal temperature and precipitation, flooding, and low ice cover. The majority of the region experienced a wet spring with persistent heavy rain and snowfall. Water levels in the five Great Lakes were above average, continuing a similar trend during the past several years. Due primarily to high spring rainfall, Lake Ontario reached its highest ever recorded water level in May 2017 resulting in shoreline flooding in New York and Ontario. Winter and fall warm spells led to record warm temperatures in parts of the basin. At just 15% areal coverage, Great Lakes maximum ice cover for the year was 40% below the long-term average.

Appendix B: Impact Stories

GLISA's three new impact stories are displayed on the following pages.

The Climate-Ready Infrastructure and Strategic Sites Protocol (CRISSP)

Partnership Snapshot

- **What is CRISSP?** A simplified municipal adaptation tool to help small and mid-sized cities understand and prepare for infrastructure vulnerability due to climate change.
- **Research Partners:** Great Lakes and St. Lawrence Cities Initiative (GLSCI), AECOM, and Gary, IN.
- **Numbers Engaged:** Two boundary organizations (GLSCI; AECOM) and three cities (Gary, IN; Evanston, IL; Traverse City, MI).
- C**ontinuing Impact:** After development and piloting of CRISPP in Gary, the Cities Initiative shared the protocol with 110+ municipalities through training workshops, webinars, and outreach.

More frequent extreme weather events have left Great Lakes municipalities looking for a way to identify and secure vulnerable infrastructure, such as water treatment plants and electricity transformers. Limited municipal resources and a lack of reliable data on anticipated weather changes due to climate change have complicated these efforts. To support municipal planning, Great Lakes Integrated Sciences and Assessments (GLISA) collaborated with the Great Lakes and St. Lawrence Cities Initiative (GLSCI) and other partners to develop an adaptation tool for small and mid-sized cities, CRISSP: the *Climate-Ready Infrastructure and Strategic Sites Protocol*.

The protocol gives municipalities a tool to plan for climate extremes by accessing vetted climate information (such as projected increases in rainfall, storm severity, and the number of extreme heat days) and providing a step-by-step guide to assess vulnerabilities and identify adaptation actions. This guide includes instructions for assembling a CRISSP team across municipal departments, conducting a self-assessment, and taking steps to safeguard critical infrastructure, facilities, and sites. The process was developed to be a quick and low-cost adaptation tool, combining climate data with municipal staff's own knowledge of their assets and existing city planning services.

In addition to supporting the project with a small grant, GLISA accessed and provided customized climate and weather information, coordinated research through state and federal agencies, and worked with project partners to develop the CRISSP technical guide and supporting materials. CRISSP was first piloted with the City of Gary, Indiana. As a result, Gary's annual capital investment planning now includes improvements to infrastructure identified as vulnerable to extreme precipitation.

"The CRISSP puts municipal staff in the driver's seat, helping them to understand how extreme weather could affect the operations of their facility or infrastructure.

By drawing directly on staff knowledge and experience, the CRISSP helped me secure staff buy-in and build a shared sense of responsibility to be prepared for the next storm."

Brenda Scott Henry
Director/MS4 Coordinator
City of Gary, Indiana Green Urbanism/Environmental Affairs

GLISA and partners shared the protocol and lessons learned from the pilot in Gary with GLSCI's 110+ member cities through training workshops, webinars, and outreach. Traverse City, MI, and Evanston, IL, have since implemented CRISSP. GLISA continues to promote CRISSP to small and mid-sized cities in the United States and Canada, through partnerships with the Urban Sustainability Director's Network (USDN) and the Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR). The CRISSP project continues to generate interest and attention. It was featured in a NOAA Vulnerability Assessment webinar in September 2017 and the protocol was recently updated to provide a more user-friendly format. The GLISA and GLSCI teams will continue to promote the tool in the future.

Great Lakes Climate Adaptation Network (GLCAN)

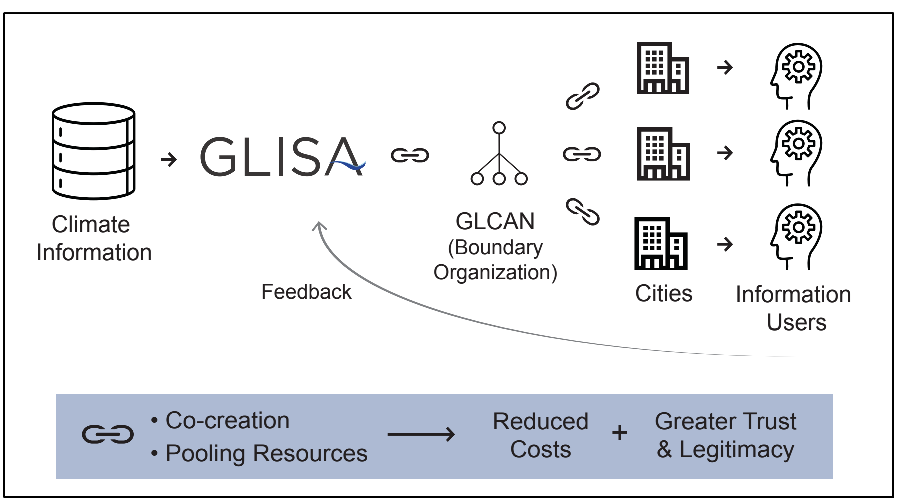
Partnership Snapshot

- **What is GLCAN?** A network of local government staff that collaborate to identify and act on climate adaptation challenges in the Great Lakes region.
- **Research Partners:** GLCAN and the Urban Sustainability Directors Network (USDN).
- **Numbers Engaged:** Two boundary organizations (GLCAN; Huron River Watershed Council) and five Great Lakes cities (Ann Arbor and Dearborn, MI; Indianapolis, IN; Cleveland, OH; Evanston, IL).
- **Continuing Impact:** After developing the Vulnerability Assessment template, pilot cities will improve adaptation planning while saving resources. The publically-available template will be further distributed to GLCAN's 26 member cities and through USDN's nine regional networks.

The Great Lake Climate Adaptation Network (GLCAN) is a peer-network of local government staff that work together to identify and act on climate adaptation challenges in the Great Lakes. GLCAN formed, in part, as a result of GLISA's work in the Great Lakes Adaptation Assessment for Cities (GLAA-C) project, funded in 2011-2014 by the Kresge Foundation and the Graham Sustainability Institute. The city partners in the GLAA-C project found great value in working across their cities and discussing common challenges and successes. GLCAN collaborates with GLISA to create climate information to support adaptation decision-making and build capacity for community resiliency efforts in member cities.

In this model of engagement, GLCAN and GLISA act as a *boundary chain* that moves climate information to and from producers at universities to users in cities. This model delivers usable information efficiently, minimizing transaction costs (such as human and financial resources) while building trust and legitimacy between partners (links in the chain). These types of interactions between producers and users play a critical role in increasing the integration and use of climate knowledge for adaptation.

In one example of the success of the boundary chain model, GLCAN and GLISA are currently working with the Huron River Watershed Council and five Great Lakes cities (Ann Arbor and Dearborn, MI; Indianapolis, IN; Cleveland, OH; Evanston, IL) to develop a universal vulnerability assessment template. The goal is to mainstream the adaptation planning process and integrate climate-smart and equity-focused information into all types of city planning. In addition to improving adaptation planning, the publically-available template will reduce municipal workloads and save resources by mainstreaming planning domains (e.g. natural hazards, infrastructure, climate).



The Boundary Chain

In a *boundary chain* model climate information moves through different *boundary organizations*, such as GLCAN, to connect science to users. By co-creating information and pooling resources, trust and legitimacy is built and costs decrease.

SEAS SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY UNIVERSITY OF MICHIGAN

GLISA A NOAA RISA TEAM

Tribal Adaptation Planning with Strategic Foresight Scenarios

Partnership Snapshot

- **What are strategic foresight scenarios?** Co-developed scenarios that combine indigenous knowledge with local climate trends for long-term planning.
- **Research Partners:** US Forest Service, College of Menominee Nation Center for First Americans Forestlands, Sault Ste. Marie Tribe of Chippewa Indians, Red Lake Nation, and Oneida Nation of Wisconsin.
- **Numbers Engaged:** Three Tribes in the Great Lakes region.
- **Continuing Impact:** Tribes are using scenarios to initiate climate change adaptation planning and to seek funding for planning activities. A sustained partnership with the Inter-Tribal Council of Michigan resulted in a Tribal Climate workshop focusing on extreme precipitation events.

Indigenous peoples in the Great Lakes region face many potential impacts to social, cultural, and economic resources from climate change. These include loss of access to culturally significant species as ecological conditions change and threats to marine and forest industries. For Tribes, it is critical that adaptation planning respect Tribal sovereignty and access to natural resources, while harnessing traditional ecological knowledge. The task of adaptation planning in this context is made difficult for Tribes by uncertainty about how climate change will impact the region at relevant scales.

To address these challenges, Great Lakes Integrated Sciences and Assessments (GLISA) teamed with the United States Department of Agriculture Forest Service and the College of Menominee Nation's Center for First Americas Forestland, providing a grant to explore the potential of strategic foresight scenarios to help Tribes adapt to climate change. Foresight scenarios are used to bring long-term perspective to policymaking and planning by outlining a set of possible future scenarios. These scenarios provide a starting point for adaption despite uncertainty around future conditions.

The College of Menominee Nation defines sustainability as the interaction of six interrelated dimensions.

Drawing on GLISA's existing relationships with three Tribes in the region (Sault Ste. Marie Tribe of Chippewa Indians, Red Lake Nation, and Oneida Tribe of Wisconsin), the team organized a Scenario Planning Workshop to bring together Tribal leaders and community members with climate specialists. Participants co-developed scenarios through a collaborative process, combining indigenous knowledge with localized climate impact profiles, customized by GLISA, that describe historical and future climate trends. In further meetings, Tribes used these scenarios to frame discussions about where additional capacity will be needed to adapt to future climate conditions.

These partnerships have produced valuable outcomes. Translating global and regional models has made them meaningful at finer scales relevant for Tribes. Having access to scenarios in narrative form has enabled institutions and communities within each tribe, which rarely communicate with one another, to share knowledge and insights through storytelling. Tribes are already using these scenarios to initiate new climate change adaptation planning activities, and to seek funding for internal and regional adaptation efforts. Sustained engagement with the Inter-Tribal Council of Michigan resulted in a Tribal Climate workshop in Bay Mills, MI, focusing on extreme precipitation events.

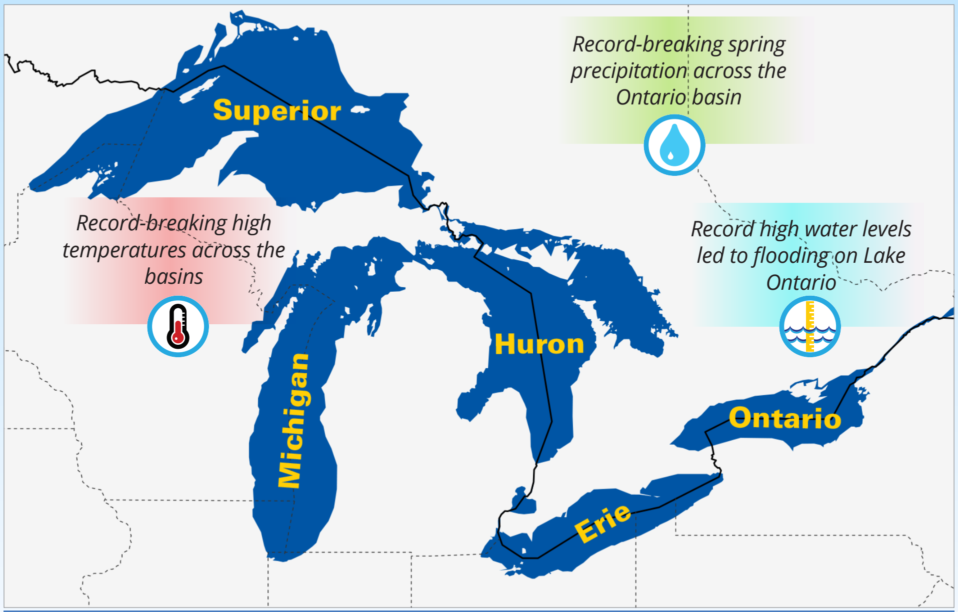
Appendix C: New or Tailored Regional Climate Services

The first pages of new or tailored climate services GLISA provided in the last year are included in the following pages:

- 2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin
- City Climatologies for Vulnerability Assessment Template (Great Lakes summary and example for Cleveland included)
- Extreme Precipitation and Impact Scenarios
- Case Studies of Climate Adaptation in Tribal Communities

2017 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

During the 2017 reporting period, several notable events and trends were observed across the Great Lakes basin including higher than average seasonal temperature and precipitation, flooding, and low ice cover. The majority of the region experienced a wet spring with persistent heavy rain and snowfall. Water levels in the five Great Lakes were above average, continuing a similar trend during the past several years. Due primarily to high spring rainfall, Lake Ontario reached its highest ever recorded water level in May 2017 resulting in shoreline flooding in New York and Ontario. Winter and fall warm spells led to record warm temperatures in parts of the basin. At just 15% areal coverage, Great Lakes maximum ice cover for the year was 40% below the long-term average.



Air Temperature	Basin Precipitation	Water Temperature	Ice Cover	Water Levels
↑	↑	↑	↓	↑

2017 Highlights: Record Breaking Year

High Precipitation

The entire basin experienced a wet winter and spring with portions of Ontario experiencing more than twice the normal amount of precipitation in April and May. Fall was wet in the central Great Lakes, with Michigan experiencing record October rainfall.

High Water Levels

Heavy winter and spring precipitation led to a record rise in Lake Ontario water levels from January to June. This caused major flooding on the shoreline of Lake Ontario and the St. Lawrence River in May 2017. The floods caused property damage, road and park closures, shoreline erosion, and untreated sewage dispersal.

High Temperatures

The winter of 2017 saw record-breaking warmth across the basin, with winter average temperatures 1 to 5°C above the long-term average. Fall warm spells in September and October also set temperature records in some eastern areas of the region.

Photo: *Greece, NY. Coastal Flooding Survey Project, Cornell University and New York Sea Grant*

Photo: *Kingston, ON. Environment and Climate Change Canada (ECCC), Wendy Leger*

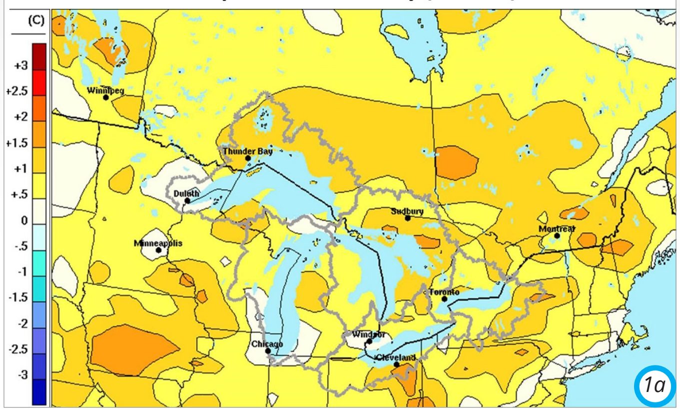
2017 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Climate Overview: December 2016 - November 2017

The December 2016 – November 2017 reporting period was overall warmer and wetter than normal, though there was substantial spatial and temporal variation across the region *(Figure 1)*. Mean annual temperatures were -1 to +2 °C below/above average across the region, with the largest departures from average temperature during the winter months. Precipitation was significantly greater than normal (10 to 50%), as seen by the green areas on the map, with some areas of the region setting new monthly and annual precipitation records. Given milder than normal temperatures during the cold season months, snow accumulations and snow cover duration were less than normal. Air temperatures over land in the basin were milder than normal, as were water temperatures.

Given heavy precipitation during much of the reporting period, basin-wide precipitation, runoff, and evaporation totals were also greater than normal. These numbers are generally consistent with observed long-term trends. Over the period from 1981-2010 across the region, air temperature (+0.26°C/decade), precipitation (+23.4mm/decade), evaporation (+19.9mm/decade), and water temperatures (+0.53°C/decade) have all increased. Runoff (-16.8mm/decade) has declined over the same time period. Highlights and links to additional data are given in the sections below.

**This report utilizes climatological seasons, which includes December from the previous year as part of the winter season.*



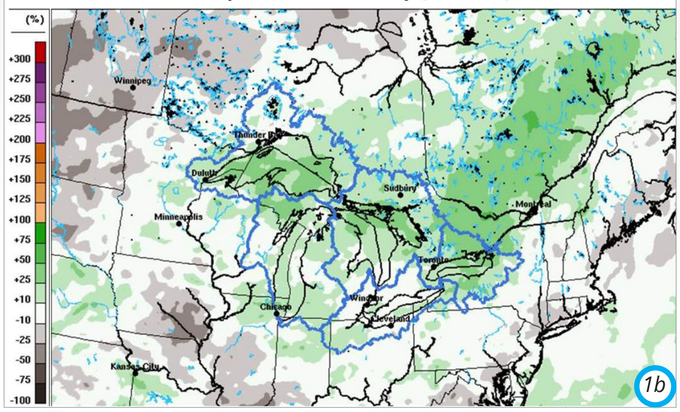


Figure 1. *Maps displaying annual anomalies for temperature (1a) and total precipitation accumulation (1b) in the Great Lakes region. Anomalies for temperature are departures from the 1981-2010 mean. Anomalies for precipitation are % departure from the 2002-2016 mean. Data for temperature are from ECCC model output and precipitation data is a merged dataset containing ECCC model and Numerical Weather Prediction (NWP) model data. Figures created by ECCC.*

		Superior		Michigan		Huron		Erie		Ontario	
		2017	LTA	2017	LTA	2017	LTA	2017	LTA	2017	LTA
Water Temps (Cº)	Max	16.4	16.0	21.5	21.3	21.1	19.9	24.0	23.9	23.2	22.2
	Min	1.3	1.0	2.4	1.5	1.1	0.9	0.7	1.1	2.7	1.8
	Avg	7.0	6.4	10.5	9.5	9.7	8.8	12.0	11.4	11.2	10.1
Ice Cover (%)	Max	18.7	48.6	18.2	28.8	35.4	51.7	35.5	70.1	6.8	20.5

		Superior		Michigan-Huron*		Erie		Ontario	
		2017	LTA	2017	LTA	2017	LTA	2017	LTA
Water Levels (meters)	Max	183.8	183.5	177.0	176.6	174.8	174.3	75.8	75.0
	Min	183.4	183.2	176.5	176.3	174.2	174.0	74.5	74.5
	Avg	183.6	183.4	176.7	176.4	174.6	174.1	75.1	74.8
Precipitation (mm)	Ann Sum	1032.8	711.6	883.6	794.4	963.0	842.4	1258.9	859.2
Evaporation (mm)	Ann Sum	764.8	556.8	843.9	504.0	972.5	896.4	745.0	650.4

Table 1: *Summary of hydro-climate variables by lake. **Long Term Average (LTA)** changes depending on variable: **Water Temps (°C)** - 2017: December 2016 through November 2017, LTA: 1992-2016; **Ice Cover (%)** – 2017: December 2016 through April 2017, LTA: 1973-2016; **Water Levels (meters)** - 2017: December 2016 through November 2017, LTA: Period of Record (1918-2016); **Precipitation (mm)** - 2017: December 2016 through November 2017, LTA: 1981-2010; **Evaporation (mm)** - 2017: December 2016 through November 2017, LTA: 1981-2010*

**Lakes Michigan and Huron are treated as one unit for water-levels, precipitation, and evaporation since there is no physical separation between the two lake bodies.*

2017 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Temperature Highlights: Very warm both in February and September

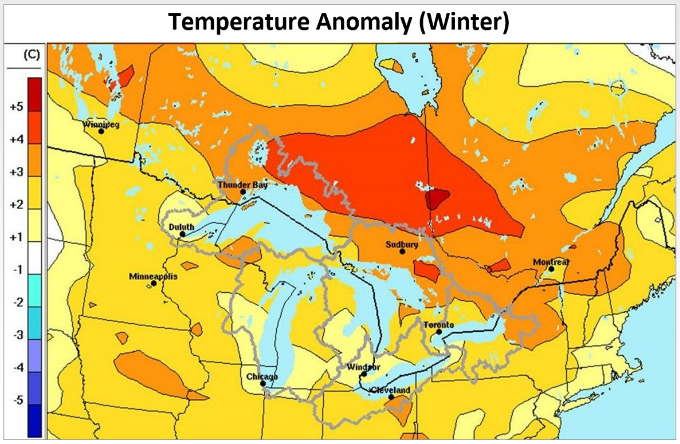


Figure 2. *Temperature anomalies (vs. 1981-2010 mean) for winter (December, January, February) 2016-2017. Figure created by ECCC.*

Winter temperatures averaged 1 to 5°C above normal *(Figure 2)*, with a below to near average December and very warm January and February. September and October were much above average, with record warmth in some eastern areas of the region.

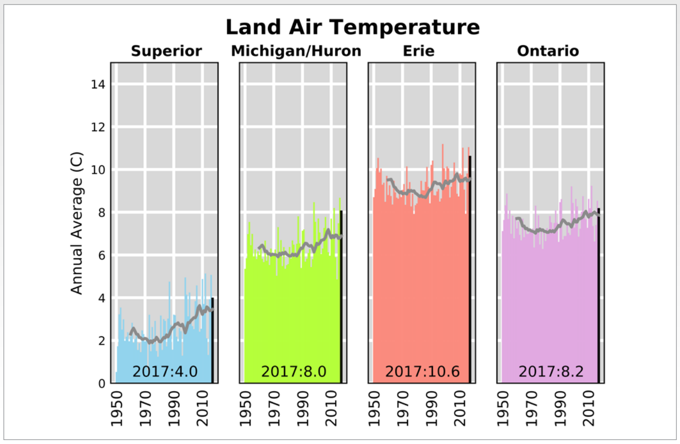


Figure 3. *Time series of over-land air temperatures by lake basin 1950-2017. The gray line is a 10 year moving average and the black line is the 2017 average.*

Annual air temperatures over land from December 2016 – November 2017 were above the historical long-term mean *(Figure 3)* and are consistent with the observed long-term increasing trend of air temperature, particularly in northern areas.

Hydrologic Highlights: Record Lake Levels on Ontario and Warm Water Temperatures

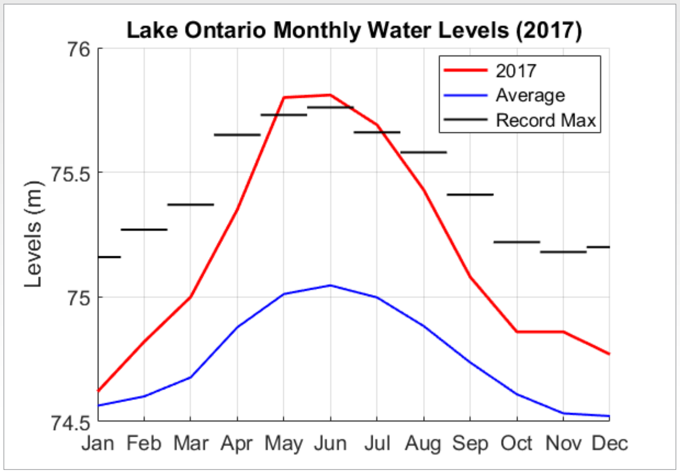


Figure 4. *2017, historical average, and record lake levels for Lake Ontario. Average levels based on 1918-2016 mean.*

In 2017, water levels on all 5 of the Great Lakes were higher than the long-term average. Record high water levels were observed on Lake Ontario in May, June, and July *(Figure 4)*.

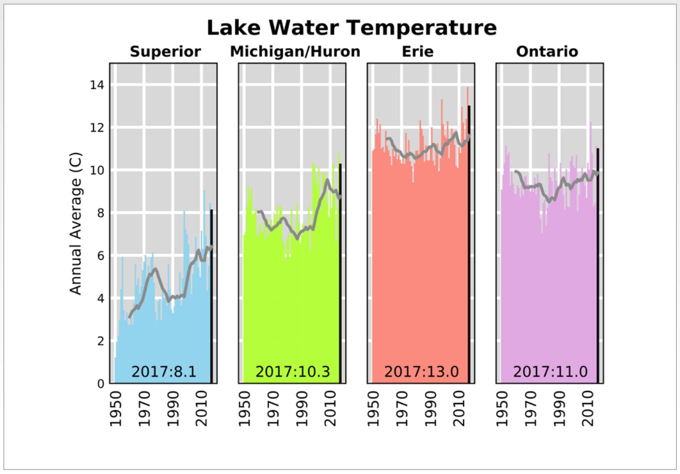


Figure 5. *Time series of water temperatures by lake basin 1950-2017. The grey line is a 10 year moving average and the black line is the 2017 average.*

Water temperatures on all of the Great Lakes were above average in 2017 and continuing an upward trend in surface water temperatures *(Figure 5)*, that has been particularly notable on the upper Great Lakes.

Precipitation Highlights: Wet Spring and Variable Summer Across the Basin

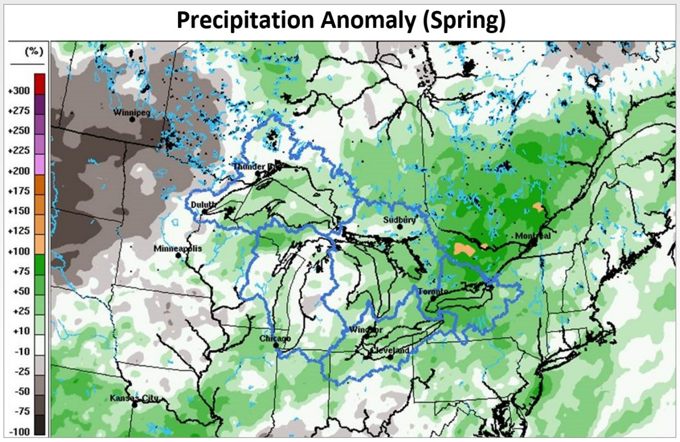


Figure 6. *Spring 2017 (March, April, May) precipitation anomalies (% departure 2002-2016 mean). Figure created by ECCC.*

In spring, much of the region experienced above average precipitation both over lake and over land, as seen by the green areas of the map *(Figure 6)*. Some areas in eastern Ontario and western Quebec saw more than twice the normal amount for this period, as seen by the gold areas on the map. Summer and fall precipitation was more varied across the region.

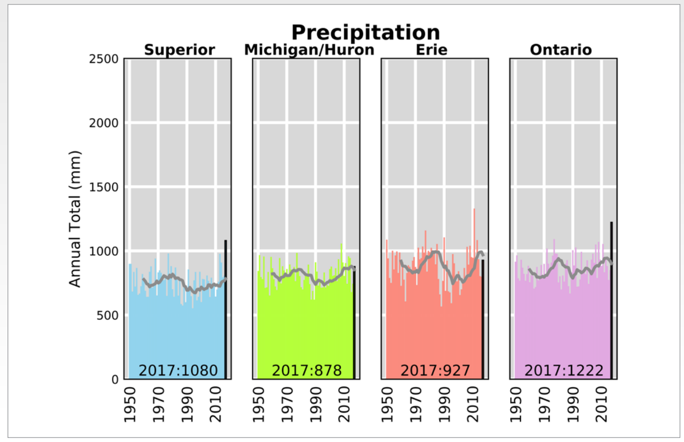


Figure 7. *Time series of precipitation by lake basin 1950-2017. The grey line is a 10 year moving average and the black line is the 2017 average.*

Annual precipitation accumulation for 2017 was above average (10% to 50%) for the region and continued a general upward trend observed in recent years *(Figure 7)*, though substantial inter-annual variability is common.

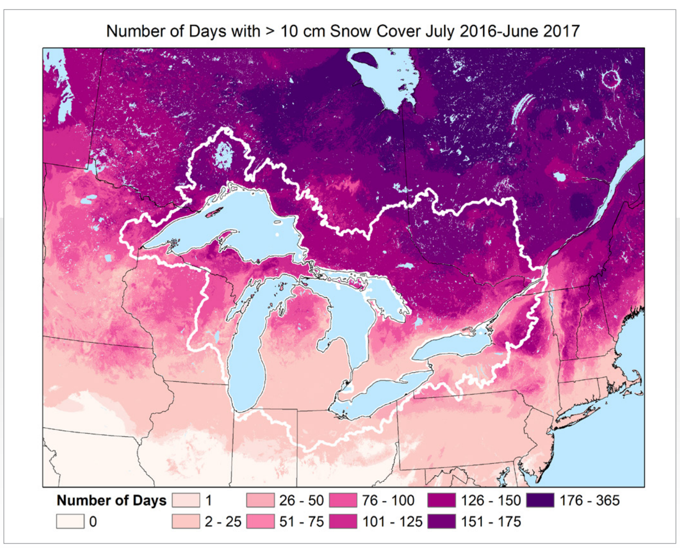


Figure 8. *Days with > 10 cm snow cover July 2016-June 2017. Estimated from the National Oceanic and Atmospheric Administration's National Operational Hydrologic Remote Sensing Center (NOAA NOHRSC) model output.*

Days with more than 10 cm of snow depth across the region ranged from 1 day in the extreme southern areas of the basin to more than 150 days in the northern reaches *(Figure 8)*. 2016-2017 was below the 2012-2017 average for all basins except the St. Lawrence, which experienced 6 more days of snow cover than average. The Lake Michigan basin experienced the largest departure of 16 fewer days of snow cover than average.

2017 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Major Climatic Events

Winter 2016-2017

- Entire Great Lakes basin experienced near-record to record-breaking warmth in January and February.
- Great Lakes only reached a maximum ice cover of 15% compared to the long-term average of 55%.
- Reduced ice cover forced existing ice near shores to erode coastlines in areas such as Erie, Pennsylvania.

Spring 2017

- Record-breaking or near-record precipitation during the spring caused significant flooding.
- Water levels on Lake Ontario experienced a record rise in spring, with May seeing the highest water levels recorded since records began in 1918.
- Widespread flooding and erosion occurred across New York, Ontario, and downstream in Quebec. Severe flooding closed Toronto Island Park from May 4th to July 30th.
- Freezing temperatures May 7-10 caused damage to vulnerable vegetation.

Photo: *Toronto Island Park. ©Toronto and Region Conservation (TRCA)*

Summer 2017

- Lake Ontario set new record-high monthly average water levels in June and July.
- High water levels and heavy precipitation resulted in several flash flood events across the basin.
- Flooding and cooler temperatures caused many issues for farmers.
- Western Lake Erie's harmful algal bloom was larger than average due to excessive spring and summer rain.
- In the western basin first freezes occurred more than a month before the median first freeze dates.

Photo: *Ellisburg, NY. Coastal Flooding Survey Project, Cornell University and New York Sea Grant*

Autumn 2017

- Late season heat wave impacted the basin in late September, with many areas getting above 35°C (95°F).
- Record precipitation in portions of the Great Lakes region during October.
- A rapid transition from above-normal to below-normal precipitation led to harvesting difficulties in November.
- Cold conditions in early November broke records in southern Ontario, Pennsylvania, and New York.
- Lake Ontario had the highest decline in water levels on record for the month of September due to a dry August and September.
- Near-record high monthly water levels for Lake Superior in October and November
- November saw the highest wave ever recorded on Lake Superior at 8.8m (28.8ft)

Photo: *Hamlin, NY. Coastal Flooding Survey Project, Cornell University and New York Sea Grant*

2017 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

New Research, Applications, and Activities

This section highlights research findings from across the region from the previous year. Findings from these efforts have implications for a wide range of sectors across the region, improve the understanding of regional climate, and show promise for informing planning efforts and policy implementation in the Great Lakes.

Regional Modeling

- Production of statistically downscaled temperature and precipitation datasets for the region based on Climate Model Intercomparison Project Phase 5 (CMIP5) global simulations *(Byun and Hamlet 2017).*
- Development of an ensemble forecasting system driven by CMIP5 scenarios by the U.S. Army Corps of Engineers and NOAA Great Lakes Environmental Research Lab to meet the needs of power generation authorities.
- Examination of regional and global precipitation projections under high emissions scenarios found general increases, concentrated in heavy rain events in the spring *(Basile et al. 2017).*
- Wind speed changes may be as critical as air temperature changes when determining the impact of climate change on water temperatures and stratification *(Magee and Wu 2017).*
- Improved methodologies developed for linking dynamical models of the lakes and atmosphere *(Xue et al. 2017).*
- Results of dynamically downscaling future climate scenarios in the Great Lakes basin *(Wang et al. 2017).*

Natural Resources

- Review of previous research regarding responses of fish to climate change finding that if food supplies are adequate, fish growth rates will increase with warming *(Collingsworth et al. 2017).*
- Historically observed shift toward diatom types with smaller cell sizes may be due to warming water *(Bramburger et al. 2017).*
- Projected future climate trends lead to higher fire weather indices (i.e., greater risk of wildfires) in the Great Lakes region and northeastern U.S. *(Kerr et al. 2017).*
- Die-offs of water birds due to botulism occur episodically and are associated with warm water with low levels *(Princé et al. 2017).*
- Of migratory birds in the basin, eastern meadowlark and wood thrush are quite vulnerable to climate change, while the hooded warbler is less vulnerable *(Rempel and Hornseth 2017).*

Planning and Engagement

- The United States Fourth National Climate Assessment held a regional engagement workshop in March 2017 for the Midwest region to provide stakeholders an opportunity to give input to and exchange ideas with the chapter author teams *(USGCRP 2017).*
- Under the Canada-Ontario Agreement Respecting the Great Lakes, the Ontario Ministry of Environment and Climate Change supported the Great Lakes Climate Change Adaptation Project 2016-18, led by ICLEI Canada. The project targeted municipal learning on climate change adaptation for 28 Ontario municipalities throughout the watershed. *(ICLEI Canada)*
- Strategies for introducing climate adaptation schemes in areas where political resistance may arise, using the Great Lakes region as a case study *(Rasmussen et al. 2017).*
- Public poll to find differences among communities in their attitude toward the threat of climate change based on their location *(Feltman et al. 2017).*
- Evaluation of potential financial consequences of climate change for hydropower producers and how to reduce risk, primarily those doing their generation on the Niagara River *(Meyer et al. 2017).*

For additional figures, information, and sources visit: glisa.umich.edu/resources/annual-climate-summary

About This Document

Coordinated by a partnership between climate services organizations in the U.S. and Canada, this product provides a synthesis report summarizing the previous years' climate trends, events, new research, assessments, and related activities in the Great Lakes Region. This product is a contribution to the U.S.-Canada Great Lakes Water Quality Agreement, through Annex 9 on Climate Change Impacts, and to the national climate assessment processes in the U.S. and Canada. It should be cited as: Environment and Climate Change Canada and the U.S. National Oceanic and Atmospheric Administration. 2017 Annual Climate Trends and Impacts Summary for the Great Lakes Basin. 2018. Available at binational.net.

Contributing Partners

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canada.ca/en/environment-climate-change

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Great Lakes Integrated Sciences and Assessments
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Great Lakes Water Quality Agreement
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3. CLIMATE CHANGE IN THE GREAT LAKES REGION AND CLEVELAND

A. Climate Change Profile for the Great Lakes Region

The climate of cities throughout the Great Lakes region is already changing. Rising temperatures are leading to more storm activity in our atmosphere, helping to fuel extreme weather and increased precipitation. While heat, drought, and other changes associated with climate change remain a concern for the future, many areas of the region are already facing challenges associated with more total precipitation and more frequent downpours.

Temperature

Great Lakes Regional Summary

- Average air temperature in the Great Lakes region has increased by 2.0°F since the 1900s.
- Average air temperature is expected to rise 1.8°F to 5.4°F by 2050.
- Total annual precipitation has increased by 11% since 1900 in the region with significant intra-regional variation.
- The total volume of rain falling in the most extreme events has increased 37% since 1951.
- Total annual precipitation will likely increase in the future, though types of precipitation will vary (i.e., more winter precipitation in the form of rain).

Average annual temperatures in the Great Lakes region have increased by 2.0°F since the 1900s, faster than the global and national rates. Most of this warming has been observed during the late spring and early winter, and in overnight low temperatures. The average temperature for the Great Lakes region is projected to increase in the future (1.8°F to 5.4°F by 2050), and many of the northern parts of the region will likely experience the most change with increases ranging from 4.5 to 6.0°F. The region is projected to see increases in the number of hot and very hot days, with projections indicating the southern portions of the region will see 15 to 35 more days over 95°F in an average year compared to the late 20th century.

Precipitation

The Great Lakes region has experienced changes in the frequency, amount, and form of precipitation. Total precipitation has increased by 11% since 1900 across the region, though this change varies within the region. Therefore, more local data should be used where available. In addition, heavy precipitation has increased rapidly throughout the region. Days seeing moderately heavy (1.25” or more) precipitation events have become 37% more frequent since 1951. Much of the region is projected to experience more average annual precipitation with total amounts ranging from an additional 2 to 6 inches per year by the mid-21st century. In addition, the Great Lakes themselves are projected to contribute more water vapor to the air. This increase in moisture combined with rising temperatures, which are necessary for storm formation, will likely produce more intense storms in the future.

Climate change will likely accelerate in the future.

The observed trends in temperature, precipitation, and seasonality are projected to continue or accelerate into the future. The rate of warming has been fastest during the winter, with some locations experiencing twice the annual warming rate of the Great Lakes region. Temperatures will continue to warm at a pace near or faster than the current rate, and precipitation will likely continue to increase, though variability and multi-year dry periods should still be anticipated. By mid-century, summer and spring temperatures may have greater increases compared to fall and winter.

Preparing for the next normal, not a new normal.

The climate system is dynamic and will continue to change rapidly due to greenhouse gas emissions and inherent feedback systems. The challenges, priorities, and risks of the current or next generation climate will continually change and will affect all sectors. Importantly, climate and weather conditions will not change to a new set of static conditions. This means long-term planning efforts in all departments should regularly evaluate climate and be as flexible and adaptable as possible. Assessing vulnerabilities of a city's assets is a first step toward this goal.

The following table summarizes how various climate risk factors in the Great Lakes region are expected to change in the future. The number and direction of arrows indicate the relative projected trend for mid-century and end of century. A single arrow indicates a projected moderate increase or decrease by mid-century, and two arrows indicate a substantial increase or decrease by end of century.

CLIMATE CHANGE IN THE GREAT LAKES REGION

RISK	BY MID-CENTURY	BY END OF CENTURY	SUMMARY
Convective Weather (Severe Winds, Lightning, Tornadoes, Hail)	Uncertain*	Uncertain*	While extreme precipitation has increased in the region, specific severe weather types (e.g., tornadoes and hail) have remained relatively stable over time.
Severe Winter Weather (Ice/Sleet Storms, Snow Storms)	Uncertain*	↓	Warmer, shorter winters will reduce the length of winter and winter-related impacts. However, some areas may see more ice, sleet, freezing rain, and wet snow with slightly warmer winter temperatures.
Extreme Heat	↑	↑↑	The number of extremely hot days, those over 95°F and 100°F, will likely increase, though not as fast as in areas farther south. Overnight lows have warmed faster than daytime highs, which may lessen opportunities for relief during heat waves.
Extreme Cold	↓	↓↓	The number of extremely cold days (i.e., days below 10°F) have decreased in the region and are projected to decrease even more in the future.
Dam Failures	↑	↑↑	Stronger and more extreme precipitation events coupled with aging dam infrastructure will increase the probability of dam failure, if appropriate measures are not taken.

CLIMATE CHANGE IN THE GREAT LAKES REGION			
RISK	**BY MID-CENTURY**	**BY END OF CENTURY**	**SUMMARY**
Flood Hazards	↑	↑ ↑	Stronger and more extreme precipitation events will be more likely to overwhelm stormwater infrastructure without appropriate adaptation efforts.
Wildfires	Uncertain*	↑	Summer drought and the number of consecutive dry days may increase in the future, despite more precipitation annually, increasing the risk of wildfires.
Drought	Uncertain*	↑	Summer drought and the number of consecutive dry days may increase in the future.
Infestation	↑	↑	With shorter winters and longer growing seasons, conditions may become more suitable for invasive species and pests currently found elsewhere and distribute vector-borne illnesses.

**Boxes labeled uncertain reflect either a lack of available data to discern a trend or no apparent trend from existing data.*

The arrows in this table reflect a qualitative assessment made by the project team based on the best available data for the Great Lakes region. While these trends hold true for projections for most of the region, they should not be assumed to hold true for any particular location. Data used to make this assessment is provided by the NOAA Technical Report NESDIS 142-3 and the Third National Climate Assessment.

B. Climate Change Profile for the Cleveland City

Cleveland City Summary

- Average air temperature in Cleveland has increased by 2.4°F since the 1950s.
- Average air temperature is expected to rise 3°F to 7°F by 2050.
- Total annual precipitation has increased by 24.6% since 1951.
- The total volume of rainfall in extreme events has increased 32% since 1981.
- Total annual precipitation will likely increase in the future, though types of precipitation will vary (i.e., more winter precipitation in the form of rain).

The following chart is a characterization of climate change at the city level. There will be trends in cities that may match or deviate from regional trends. This allows cities to consider unique challenges, vulnerabilities and opportunities associated with climate change.

Climate Change in the City of Cleveland

	Historic (1951-2014)	Mid-Century Projections (High Emissions)	End of Century Projections (High Emissions)	Change Mid-century/End of century	Percent Change* Mid-century/End of century
Average Temperature	50.8°F	53.8 to 57.8°F	55.8 to 61.8°F	3 to 7°F / 5 to 11°F	6 to 14% / 10 to 22%
Winter (1981-2010)	29.6°F	30.6 to 34.6°F	32.6 to 38.6°F	1 to 4°F / 3 to 9°F	3 to 14% / 10 to 30%
Spring (1981-2010)	48.6°F	49.6 to 55.6°F	51.6 to 59.6°F	1 to 7°F / 3 to 11°F	2 to 14% / 6 to 23%
Summer (1981-2010)	70.9°F	73.9 to 77.9°F	77.9 to 83.9°F	3 to 7°F / 7 to 13°F	4 to 10% / 10 to 18%
Fall (1981-2010)	53.6°F	56.6 to 60.6°F	58.6 to 66.6°F	3 to 7°F / 5 to 13°F	6 to 13% / 9 to 24%
Average Low Temperature	42.1°F	45.1 to 49.1°F	47.1 to 53.1°F	1 to 7°F / 5 to 11°F	2 to 17% / 12 to 26%
Average High Temperature	59.4°F	60.4 to 66.4°F	64.4 to 70.4°F	1 to 7°F / 5 to 11°F	2 to 12% / 8 to 19%
Days/Year Greater than 90°F	7.4 Days	19 to 43 Days	37.4 to 49.4 Days	12 to 36 Days / 30 to 42 Days	162 to 487% / 405 to 568%
Days/Year Greater than 95°F	2-4 Days	16 to 18 Days	Not Available	14 Days	350 to 700%
Days/Year Less than 32°F	108.5 Days	78.5 to 81.5 Days	Not Available	-23 to -30 Days	-21 to -27%
Total Annual Precipitation	39.1 in.	38.1 to 46.1 in.	40.1 to 46.1 in.	-1 to 7 in. / 1 to 7 in.	-3 to 18% / 3 to 18%
Winter (1981-2010)	8.2 in.	7.2 to 11.2 in.	7.2 to 12.2 in.	-1 to 3 in. / -1 to 4 in.	-12 to 37% / -12 to 49%
Spring (1981-2010)	10.1 in.	9.1 to 13.1 in.	8.1 to 14.1 in.	-1 to 3 in. / -2 to 4 in.	-10 to 30% / -20 to 40%
Summer (1981-2010)	10.4 in.	9.4 to 15.4 in.	8.4 to 14.4 in.	-1 to 5 in. / -2 to 4 in.	-10 to 48% / -19 to 39%
Fall (1981-2010)	10.5 in.	9.5 to 12.5 in.	9.5 to 12.5 in.	-1 to 2 in. / -1 to 2 in.	-10 to 19% / -10 to 19%
Heavy Precipitation Days(>1.25")	3.6 Days/Year	4.8 to 6.4 Days/Year	5.2 to 6.4 Days/Year	1.2 to 2.8 Days/Year / 1.6 to 2.8 Days/Year	33 to 78% / 44 to 78%

*Percent change is calculated as the difference between the projected values and the historic average, divided by the observation and multiplied by 100.

Data provided in this table is described in the "About the Data" section for "GHCN", "CMIP3", and "Dynamically Downscaling for the Midwest and Great Lakes Basin."

Temperature and Hot/Cold Extremes

Average Temperature

The average air temperature in Cleveland has risen since the 1950s, but has seen a moderate increase compared to other cities in the Great Lakes region. Annual average temperature has increased by 2.4°F from 1956 to 2012, with the current annual average temperature being 50.8°F. Average annual seasonal temperatures have also increased with spring experiencing the greatest increase of 1.7°F. Average temperatures in Cleveland are projected to increase 3.0 to 7.0°F by mid-century under a business as usual (i.e., high emissions) scenario, with the summer and fall having the greatest increases.

Hot Days

Days with temperature at or above 90°F are very common with multiple occurrences every year and no clear increasing or decreasing trend. Most years on record have experienced 2 to 4 consecutive days over 90°F, with events of 5 to 7 consecutive days occurring less frequently. By mid-century (i.e., 2050), models suggest an increase of anywhere from 12 to 36 more days per year over 90˚F, and an increase of 30 to 42 more days per year over 90°F by end of century. Models are not able, however, to tell us if those days will be consecutive or not.

Days with high temperatures at or above 95˚F have decreased since the 1930s. Events of consecutive days experiencing maximum temperatures over 95˚F have seen very little change and generally only occur every few years. These types of events are typically limited to 2 to 4 consecutive days, with a few occurrences of longer periods. By mid-century (i.e., 2050), models suggest an increase of 5 to 8 days over 95 and -4 to 16 days per year over 100˚F, and an increase of 8 to 28 days per year over 100°F by end of century. However, such hot days will not occur consecutively.

Heat waves can result from a combination of different drivers including high humidity, daily high temperatures, high nighttime temperatures, stagnant air movement, etc. In the future, models project an increase in the number of days experiencing high temperatures that could lead to additional heat waves, especially since air stagnation events are projected to increase. There is greater certainty that summer nighttime low temperatures will continue to increase, thereby making it more difficult to cool off at night during extended heat events. In addition, periods of future drought will also contribute to extreme heat

Cold Days

On average, Cleveland experiences 109 days per year that fall below freezing (32°F). Historical records show this number has decreased already. The city is projected to experience fewer nights below 32°F with decreases of 23 to 30 days by mid-century.

Days with temperatures at or below 10˚F are very common, but experienced a slight decreasing trend in the 21st century. There are frequent occurrences of 2 to 6 consecutive days at or below 10˚F, with some instances lasting 7 to 13 days less frequently. In the future, there are projected to be even fewer very cold days, so this type of event will be even rarer.

Precipitation and Flood/Drought Indicators

Average Precipitation

The amount of total annual precipitation in Cleveland has increased by 24.6% (8.7") from 1951 to 2014. An increase in precipitation was observed in all four seasons, with the winter seeing the greatest percentage increase of 23.4% (1.7"). Average precipitation in Cleveland is projected to increase by 2 to 4 inches by mid-century compared to current trends.

Precipitation - Historical

The frequency and intensity of severe storms has increased. Cleveland has seen a 16.3% increase in the number of heavy precipitation events (49 storms from 1961 to 1990 compared to 57 storms from 1981 to 2010). The northeastern part of Ohio is projected to experience on the order of 2 more days of heavy precipitation (events greater than 1.25") per year.

Flooding results when rainfall volumes exceed the capacity of natural and built infrastructure to handle precipitation. Stormwater managers look at several different "design" storms (inches falling over a certain length of time) when designing and managing their systems. These "design" storms are effectively the probability of any given amount of precipitation falling in a set period of time, based on historical experience. Monitoring over time shows that the volumes falling during these "design" storms are increasing. What this means is that the values used to build our existing infrastructure (Bulletin 71[56], used data through 1986, and NOAA Atlas 14[57] added 1987 to 2011) are dependent on fluctuating estimates of rainfall.

The table below helps illustrate this point by showing precipitation volumes in inches for both Bulletin 71 and Atlas 14 (Bulletin 71/Atlas 14) along with percent change between the two in brackets. This data shows how the "design" storm has changed over time.

Please note*: this table does not show projections for how the design storm may change in the future due to climate change.*

PRECIPITATION FREQUENCIES FOR THE CITY OF CLEVELAND

	1-YR	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
1-hr	0.96/0.984 [2%]	1.17/1.2 [3%]	1.46/1.51 [3%]	1.69/1.75 [4%]	2.06/2.07 [5%]	2.40/2.33 [-3%]	2.77/2.60 [-7%]
12-hr	1.77/1.68 [-5%]	2.17/2.01 [-8%]	2.70/2.52 [-7%]	3.13/2.94 [-7%]	3.82/3.57 [-7%]	4.45/4.11 [-8%]	5.12/4.68 [-9%]
24-hr	2.04/1.96 [-4%]	2.50/2.35 [-6%]	3.10/2.94 [-5%]	3.60/3.42 [-5%]	4.39/4.11 [-7%]	5.11/4.69 [-9%]	5.89/5.31 [-11%]

Precipitation – Future

In the Great Lakes region, projected changes in seasonal mean precipitation span a range of increases and decreases. In the winter and spring, the region is projected to experience wetter conditions as the global climate warms. By mid-century, some of this precipitation may manifest in the form of increasing snowfall, but projected warmer conditions by end of century suggests such precipitation events will most likely be in the form of rainfall (USGCRP, 2017).

Heavy precipitation events of more than 2" in a day (i.e., 24-hour period) are projected to increase by no more than one day (0.25 to 1 days) by mid-century and increase by slightly more (0.75 to 1.25 days) by end of century. Precipitation events of more than 3" in a day are projected to increase by less than half a day (0.15 to 0.45 days) by mid-century and increase by slightly more (0.3 to 0.75 days) by end of century.

There has been a slight decreasing trend in historic heavy hourly snowfall (events with snowfall over 1") with varying year-to-year conditions, and little to no change in hourly snowfall exceeding 2". Warmer temperatures in the future will cause some winter precipitation to transition from snow to rain over time. Annual snowfall is projected to decrease by 5" to 25" by mid-century, and decrease by 15" to 35" by end of century.

Drought, defined here as periods of 3 weeks with less than 0.45" of rainfall, has been highly variable year-to-year, with slight decreasing trends in summer and fall events and a slight increasing trend in spring events. In the future, even though more annual precipitation is projected overall, more is anticipated to fall in shorter, extreme events. Thus, there will be longer periods of time that experience no rainfall, increasing the potential for drought.

In the following chapter we look a local landscape features that influence our exposure and overall vulnerability to climate change in Cleveland

About the Climate Change in the Great Lakes Region and Cleveland Data

Coupled Model Intercomparison Project (CMIP) Version 3. The future (mid-century) climate projections for Cleveland are based on the Coupled Model Intercomparison Project Version 3 (CMIP3) A2 emissions scenario, representing "business as usual" high emissions scenario. These data were selected because they were used in the Third National Climate Assessment (Melillo et. al., 2014). More information is available at: https://www.wcrp-climate.org/wgcm-cmip

"Dynamical Downscaling for the Midwest and Great Lakes Basin." Future projections are based on the dynamically downscaled data set for the Great Lakes region developed by experts at the University of Wisconsin-Madison. There are a total of six downscaled models that represent how a variety of different variables are projected to change (mid-century, 2040-2059, compared to the recent past, 1980-1999). The ranges are comprised of the lowest and highest values from all six dynamically downscaled data sets. The regional data are available for download at: http://nelson.wisc.edu/ccr/resources/dynamical-downscaling/index.php.

National Oceanic and Atmospheric Administration National Centers for Environmental Information Global Historical Climatology Network Station Observations (GHCN). More information about this station located in Ann Arbor, MI from 1981-2010 is available at: https://glisa.umich.edu/station/c00200230

"National Oceanic and Atmospheric Administration ThreadEx Long-Term Station Extremes for America". ThreadEx is a data set of extreme daily temperature and precipitation values for 270 locations in the United States. For each day of the year at each station, ThreadEx provides the top 3 record high and low daily maximum temperatures, the top 3 record high and low daily minimum temperatures, the top 3 daily precipitation totals, along with the years the records were set for the date (NCAR, 2013). ThreadEx data for the Detroit area from 1966 to 2016: http://threadex.rcc-acis.org/

INTER-TRIBAL COUNCIL OF MICHIGAN, INC.

GLISA
A NOAA RISA TEAM

Michigan Extreme Precipitation

Summary

Intensity

The intensity of severe storms across the Great Lakes region has increased (Figure 1). In the State of Michigan, intensification of extreme precipitation events has been more pronounced over the Lower Peninsula (LP) compared to the Upper Peninsula (UP). Intensification of extreme precipitation events will likely continue in the future as the effects of climate change become more pronounced.

The amount of precipitation falling in the heaviest 1% of daily storms increased by 24% in the Great Lakes region from 1950-2010.

The amount of precipitation falling during multi-day events has increased dramatically over Michigan's LP.

Frequency

The frequency of severe storms across the Great Lakes region has increased. In the future, the frequency of heavier storms is projected to increase at a faster rate than storms that are less intense.

In the future, there may be a greater chance of both increased extreme precipitation events and prolonged dry periods.

Seasonality

Precipitation totals over Michigan's LP during the fall and spring have increased in most locations, while summer and winter precipitation totals have remained relatively stable. In Michigan's UP, fall precipitation has increased while all other seasons have experienced a decrease in precipitation.

Form

Annual lake effect snow has increased downwind of Lakes Superior and Michigan, and in the future lake effect precipitation is projected to increase although the LP may experience more rain than snow.

Historical data are based on NOAA's climate division data, US/Canadian weather station observations, and Kunkel, K.E., K. Andsager, and D.R. Easterling, 1999: Long-Term Trends in Extreme Precipitation Events over the Conterminous United States and Canada. J. Climate, 12, 2515–2527.

Historical Extreme Precipitation

Precipitation—especially extreme precipitation—observations can vary greatly over very short distances from one another making it difficult to collect a continuous record in space and time. In the map below, the circles represent locations of weather stations where the data records pass GLISA's quality control standards. The color of the circle indicates whether extreme precipitation events have become more (red) or less (blue) intense. The size of the cirlce indicates the magnitude of that change (bigger = greater change). Most stations across the LP indicate small to moderate increases in the amount of precipitation falling during the most extreme events. A few stations across central and in southwest MI observed larger increases, and the UP stations report very small decreases.

Observed Changes (%) in the Intensity of the 1% Heaviest Precipitation Days
(1951-1980 vs. 1981-2010)

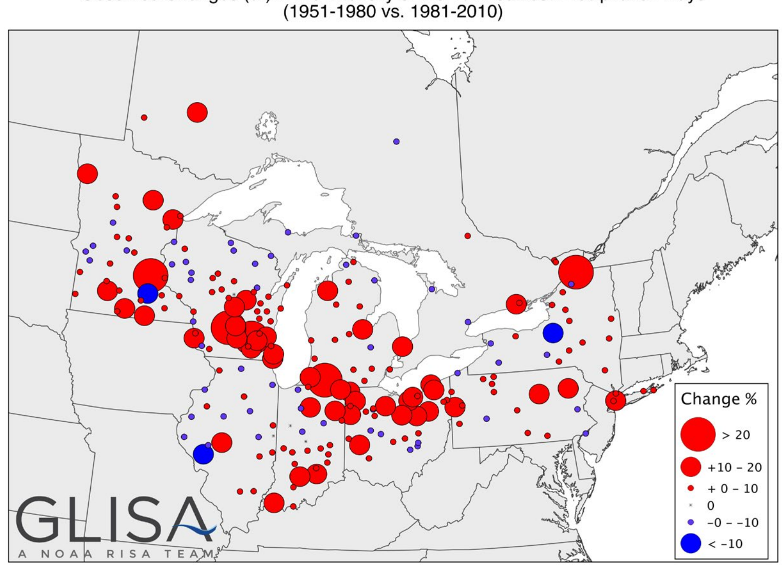

Figure 1: The change (%) in precipitation intensity (defined here as the amount of precipitation falling in one day) of the top 1% of heaviest precipitation days is mapped for the eight Great Lake states and Ontario at select weather station locations. Positive (negative) changes indicate daily extreme precipitation events have become even more extreme.

Glossary of Terms

Ensemble - A set of several climate model projections

Ensemble Mean - The average of several climate models

Precipitation Intensity - Rainfall rate measuring amount of rainfall over a given time period

Projection - Data representative of the future climate from a climate model simulation

Very Heavy Precipitation - The heaviest 1% of all daily precipitation events

Future Extreme Precipitation

In the future, more extreme precipitation events are anticipated. The change in days receiving one, two, and three-inches of precipitation by the mid-21st century are presented here. Since extreme events are, by definition, uncommon the numbers reported are in units of days per decade to avoid reporting fractions of a day.

The maps (Figure 2) of future projections are based on the average of an ensemble of six regional climate models.[1] The lower and upper range of the ensemble, which characterizes the difference between models, is reported in Table 1 for Michigan.

Table 1: Future change in number of days (per decade) with over 1, 2, and 3 inches of precipitation by mid-century for MI sub-regions. The reported range spans the lower to upper bound of projections in the ensemble. In every region at least one model projected a decrease in the number of days.

	1+ Inches	2+ Inches	3+ Inches
Western UP	-8 to 32 (days/decade)	-8 to 16	-8 to 8
Eastern UP	-8 to 24	-8 to 8 (up to 16 in far east)	-8 to 8
Northern LP	-8 to 24	-8 to 8	-8 to 8
Southern LP	-8 to 24 (up to 40 in southeast)	-8 to 16	-8 to 8

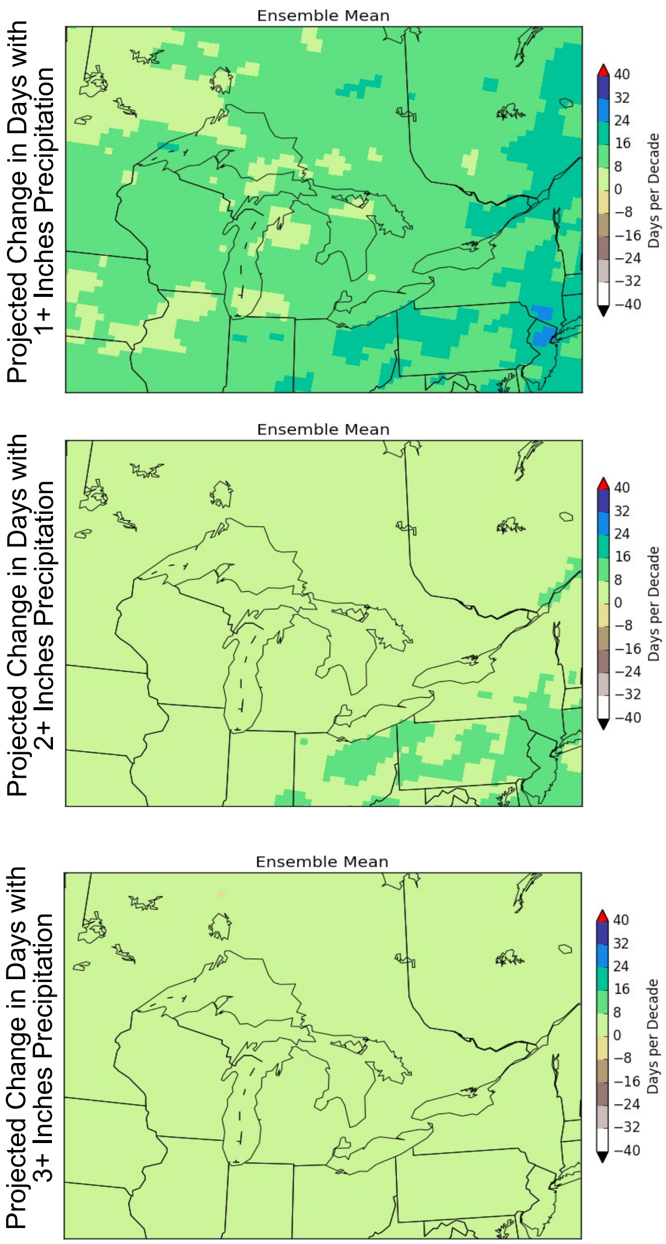

Figure 2: Maps of the projected change in days with 1+, 2+, and 3+ inches of precipitation by the mid-21st century (2040-2059 compared to 1980-1999). The Ensemble mean (average of 6 high-resolution regional climate models) is mapped.

Changes in Days/Decade with 1+ Inches Precipitation

On average, the State of Michigan is projected to experience more days with 1+ inches of precipitation by mid-century. In most parts of the State, 8 to 16 more days/decade are projected. In the northern LP and south western LP increases may be smaller (0 to 8 more days/decade). The western UP is one particular region where some models diverge - two of the six models project over 24 more days/decade receiving 1+ inches of precipitation, and one model projects a slight decrease (0 to 8 fewer days/decade).

Changes in Days/Decade with 2+ Inches Precipitation

On average, the State of Michigan is projected to experience up to 8 more days/decade of 2+ inches of precipitation by mid-century. Individual models indicate slightly more extreme precipitation in small pockets of the State, particularly southeast MI. Parts of the central LP show decreases and increases depending on the model.

Changes in Days/Decade with 3+ Inches Precipitation

On average, the State of Michigan is projected to experience up to 8 more days/decade of 3+ inches of precipitation by mid-century. There is very little variability among individual models indicating all would suggest a similar future change in extreme precipitation at the 3+ inches/day threshold. Two models suggest slight decreases of 3+ inch precipitation days in the central LP.

[1]The six models are the dynamically downdownscaled projections for the Great Lakes region available from the Center for Climatic Research, Nelson Institute, University of Wisconsin-Madison (http://nelson.wisc.edu/ccr/resources/dynamical-downscaling/index.php)

Extreme Precipitation & Impact Scenarios

GLISA and the Inter-Tribal Council of Michigan developed a set of extreme precipitation events and accompanying environmental conditions, as described in the four scenarios below, as a resource for the Tribes to use when thinking about how extreme precipitation may impact people and the environment at specific locations/regions. A list of general Tribal impacts is provided, and there is space for new impacts to be added to each scenario as specific concerns, issues, systems, etc. are considered.

Scenario 1
Extreme Precipitation Event During Dry Period in Spring/Summer

Event Description
The previous season experienced less than normal precipitation, and the ground is dry when the extreme rain or snow (in Spring) event occurs. The rain event may be an intense 1-day event or multi-day rain event with extremely high rain totals.

Specific Impacts

Scenario 2
Extreme Precipitation Event During Wet Period in Spring/Summer

Event Description
The previous season experienced more than normal precipitation, and the ground is saturated when the extreme rain event occurs. The rain event may be an intense 1-day event or multi-day rain event with extremely high rain totals.

Specific Impacts

Scenario 3
Extreme Rain Event Over Bare, Frozen Ground

Event Description
Winter conditions leave the ground frozen but without snowpack at the time of an extreme rain event. The rain event may be an intense 1-day event or multi-day rain event with extremely high rain totals.

Specific Impacts

Scenario 4
Extreme Rain Event Over Deep Snowpack

Event Description
The ground is covered in moderate to deep snow at the time of an extreme rain event. The rain event may be an intense 1-day event or multi-day rain event with extremely high rain totals.

Specific Impacts

General Impacts for All Scenarios
- Increased flooding & associated risks with infrastructure, damage to vegetation
- Erosion - major issue with coastal communities & developed areas, water quality, aquatic fish/plants/mussels
- Sedimentation & nutrient loading in surface waters, decrease water quality, cascading impacts on aquatic communities
- Interruption of pollination and food/medicine gathering, destroy gardens & wild gathered foods (depending on timing)
- Damage to budding vegetation, interruption of food/medicine gathering, interruption of pollination, reduced production wild/gathered foods, interruption in wildlife cycles, poor breeding outcomes among wildlife
- Stress on cold water fisheries
- Blockage or washout of main roads, inability to access healthcare (extreme case with dialysis), groceries, childcare/work
- Seiche on Great Lakes degrade shorelines, docks, buildings, parking lots, roads, gathering areas/beaches
- Risk of mold in homes

Case Studies of Climate Adaptation in Tribal Communities

Logan Dreher
July 2017

Climate change represents both a distinct challenge and opportunity for indigenous Tribes in the United States. Though most scholarship and literature often focus on the heightened vulnerability of Native American communities, Tribes are also uniquely equipped to adapt to a shifting and unstable environment. Indigenous communities in North America have weathered, and continue to resist, the long-reaching impacts of colonization. As a result, many Tribes have extremely resilient and adaptive cultures, practices, and knowledge systems.

Tribal communities have already emerged as domestic leaders in climate adaptation action, drawing on intergenerational environmental knowledge, "deep interpersonal and interspecies networks" and a seventh-generation mindset, where current leaders consider the impact of their decisions on seven generations into the future (Norgaard 2016). Federally-recognized Tribes can also leverage their sovereignty to act as laboratories to implement small-scale adaptation efforts, and to pressure a more robust national response to the warming climate.

This research intended to catalogue past and ongoing climate adaptation initiatives in Tribal communities in the State of Michigan in preparation for a climate adaptation workshop with the Great Lakes Integrated Sciences and Assessments (GLISA) and the Inter-Tribal Council of Michigan in the fall of 2017. Additionally, this report highlights particularly successful adaptation projects in four Tribal communities across the country to inform this workshop. These communities have not just responded to climate change, but used it as an opportunity to strengthen their government, restore traditional resource management practices, and encourage a re-examination of Western environmental practices and beliefs. Three of the case studies represent three broad categories of common adaptation projects: infrastructure, natural resource management, and comprehensive planning. The remaining example demonstrates how adaptation projects can integrate aspects of all three categories.

These four case studies identify successful strategies, tools, and funding opportunities potentially applicable to future adaptation efforts in the twelve federally-recognized Tribes in Michigan. The Michigan Tribal community has already demonstrated their resiliency through the diversity of their responses to the impacts of climate change in the region.[1] The success of Tribal governments in Michigan and across the country in spite of their limited capacity and ability to govern non-trust lands is exemplary of the determination of Native communities in the United States (US).

[1] While it is too lengthy to detail the breadth of projects here, see Appendix A for a more thorough discussion of adaptation efforts in Tribal communities across Michigan, and in other Great Lakes states.

Infrastructure

Energy Sovereignty: White Earth Nation (Minnesota)

Many Tribes have developed renewable energy technologies, which act as a mitigation tactic to decrease greenhouse gas emissions on Indian reservations. Green energy projects are also an adaptation strategy, as they provide a more resilient energy system during extreme weather and other emergency events. In addition, indigenous-owned energy projects are a way for Tribes to reinforce their sovereignty and better self-govern their land by controlling their own energy source and reducing reliance on fossil fuel produced off site. Tribal-owned renewable energy projects also have the potential to generate a profit through the sale of excess energy to surrounding public utility districts.

In the Great Lakes region, several Tribes have committed to a greener future by adopting the Kyoto Protocol, developing strategic energy use plans, improving energy efficiency, and conducting feasibility studies for the installation of renewable technologies (see Appendix A). One regional leader in renewable energy is White Earth Nation of Chippewa Indians in North-Central Minnesota, which was the first Tribe in the US to install wind turbines on an Indian reservation in 2003 (*White Earth Nation*). The Tribe estimates that members spend approximately one half of their income on food and energy costs, which are outsourced to off-reservation companies; by localizing both their energy and food system, White Earth Nation hopes to reinvigorate its economy while strengthening the reservation's resiliency to climate change (LaDuke et al. 2012). The Tribe also reinvests profits from green energy projects in local food initiatives to further stimulate its economy and preserve traditional ecological practices (LaDuke et al. 2012). Another distinctive aspect of White Earth's renewable energy initiative is their partnership with TWN Wind Power, a green energy company owned by a Canadian First Nation, the Tseil-Wauthuh Nation (White Earth Nation).

Figure 1. A child from White Earth Nation at a wind turbine construction site (Photo Courtesy of Honor the Earth).

Since the installation of its first wind turbine in 2003, White Earth Nation has completed two additional wind turbines and expanded to solar energy projects to develop a diverse portfolio of renewable energy technologies ("White Earth Nation"). Currently, the Tribe is installing solar photovoltaic systems in three community buildings, which will keep an estimated $8,000 of otherwise exported funds within the local economy, reduce annual energy costs by almost 30% and train four tribal members for employment in the renewable energy industry ("White Earth Reservation"). Throughout its renewable energy program, White Earth Nation has sustained a focus on training Tribal members to install and maintain its energy projects; in 2012, the Tribe trained ten members in wind-smithing and 25 others on solar panel installation (LaDuke et al. 2012). These trainings expand the Tribe's self-sufficiency to maintain their solar and wind energy facilities and improves the employability of individual Tribal members in the growing green energy industry.

In addition, White Earth Nation has begun to tackle both its members limited ability to purchase energy and the need for more efficient energy by providing solar thermal panels to residences free of charge. This decreases the cost of heating homes in the winter (LaDuke et al. 2013). In 2013, the Tribe began a feasibility study for a solar/wind hybrid distributed energy system, which is intended to provide power for the southwestern portion of the reservation (LaDuke et al. 2013). Once completed, excess energy from the hybrid system will be sold to a local power company. White Earth hopes to use the revenue to increase the scale of their sustainable agriculture programs (LaDuke et al. 2013).

Beyond its extensive renewable energy program, White Earth Nation has also been involved in the fight against the development of new fossil fuel infrastructure in the region. In 2013, the Tribe began a campaign against the construction of a new oil pipeline in Minnesota, which would run through wild rice lakes and other culturally important resources in treaty territories in the state (*Stop Line 3*). Along with the five other Minnesota Chippewa Tribes, White Earth is in the process of conducting an environmental impact assessment of the proposed pipeline to highlight the failure of the state to include indigenous voices in its own assessment ("Support the Tribal EIS"). White Earth also filed a petition to act as a formal intervening party in the permitting process of the pipeline (*Stop Line 3*). Both actions put pressure on the State of Minnesota to consider the specific impacts of the pipeline to Tribal communities and asserts the self-determination of Tribal governments. White Earth Nation's involvement in the permitting process spurred momentum for environmental groups and city governments to publicly oppose the construction as well, including the city of Grand Rapids, MN, the Sierra Club, and a group of 36 state legislators (*Stop Line 3*).

Table I. White Earth Nation Strategies and Funding Sources

Effective Strategies	Funding Sources
Employable skill training for Tribal members to increase Tribal capacity	○ USDA Rural Business Development Grants and Rural Business Opportunity Grants ○ Clean Energy Resource Teams Grants
Involvement in green economy through installation of renewable energy facilities on reservation	○ USDA Rural Business Development Grants ○ Department of Energy Anemometer Loan Program/Tribal Energy Grant ○ Congressional Appropriations ○ Blandin Foundation
Addressing energy poverty and high heating costs through installation of renewable energy technologies	○ Department of Energy Tribal Energy Grant ○ Northwest Area Foundation
Intervening in permit process of fossil fuel infrastructure	○ Honor the Earth
Inter-Tribal Collaboration	○ Honor the Earth
Synergistic adaptation projects	N/A

Natural Resource Management

<u>Eco-Cultural Resource Management: The Karuk Tribe (California)</u>

The Karuk Tribe is located in the Klamath Basin in Northern California, where they lack a formal reservation and hold less than one square mile of land in trust with the federal government (Diver 2016). Though the Tribe never agreed to cede their lands, as many other Tribal governments did through treaty negotiations in the nineteenth century, the US Forest Service acts as the primary manager of over 1.48 million acres of forestland that the Karuk claim as their ancestral land (Diver 2016). Today's Tribal members continue to harvest food for subsistence, hold cultural ceremonies, and conduct traditional resource management practices in the area, although their authority to do so most often goes unrecognized (Diver 2016).

In the face of their limited governance over the land in the Klamath Basin, the Karuk Tribe has worked to leverage federal trust responsibility to facilitate the use of traditional resource management practices and increase their involvement in regional environmental decisions (Norgaard 2014).[2] The Tribe has also asserted their right as co-tenants and co-trustees of the forest along with the federal government, a standing that court cases have granted to other Tribes who collaboratively manage fisheries with state governments (Norgaard 2014). Throughout the 1990s, the Karuk Tribe staged direct action protests on culturally important and sacred sites to assert their authority as resource managers to the US Forest Service (Diver 2016).

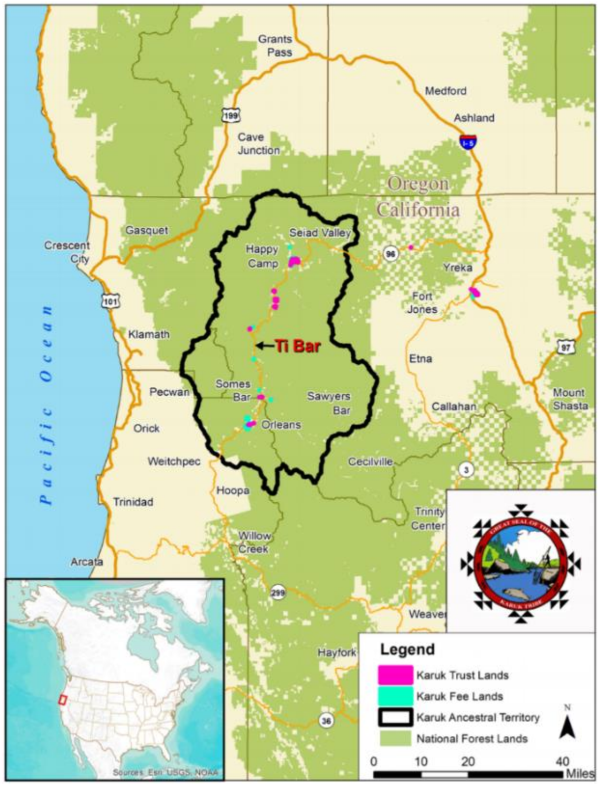

Figure 2. Map of Karuk Tribe land (Photo Courtesy of Diver, "Co-Management as a Catalyst").

In an attempt to reduce the conflict between the two parties, Tribal land managers and local Forest Service employees began to hold monthly meetings to discuss land management practices in the Klamath Basin (Diver 2016). In 1995, these meetings resulted in the creation of "cultural management areas" in which resource managers were required to adhere to the culture and customs of the Karuk Tribe. These requirements paved the way for increased Tribal involvement in forest management practices in the region. Throughout the late 1990s, Karuk Tribal land managers participated in the planning process for restoration projects in cultural management areas and acted as co-leads during their implementation. These co-management projects, which were authorized by an Interagency Agreement between the US Forest Service and the Bureau of Indian Affairs, allowed the Karuk Tribe to implement traditional ecological practices, particularly prescribed burns, while working with the US Forest Service (Diver 2016). Though co-management projects allowed the Karuk Tribe to deploy traditional land management practices, recently the Tribe has been hindered by turnover in local Forest Service employees, who have not had consistent interest in continuing such projects (Diver 2016). Therefore, the

[2] Federal trust is a legally enforceable obligation of the US to protect Tribal treaty rights, land, assets and resources based on promises the US government made in treaties with Tribal governments to protect land and resources for future generations (Norgaard 2014).

Tribe considers participation in co-management projects to be an interim strategy that builds Tribal capacity while the Karuk Tribe also works through other avenues to regain rightful authority over ancestral lands.

The Karuk Tribe has also worked extensively to research and publish institutional and legal barriers to Tribal participation and the inclusion of traditional ecological knowledge resource management. Partnering with the University of California Berkeley to increase their capacity for researching such topics, the Tribe published regional and national recommendations for improving intergovernmental cooperation between federal resource managers and Tribal authorities, as well as mechanisms to increase Tribal management of non-trust lands (Norgaard 2014). The Karuk Tribe's abundant research and scholarship on the topic emphasizes the importance of traditional practices as climate adaptation strategies, as they often help to stabilize and improve the resiliency of ecosystems. Prescribed burns, for instance, promote biodiversity, manage culturally important species, and limit the threat of uncontrollable wildfires by reducing the availability of forest fuels (Norgaard 2016). Other fire suppression methods are also often significantly more costly than prescribed burns (Norgaard 2014). In 2016, the Tribe also conducted a climate vulnerability assessment that focused on the importance of prescribed burns as an adaptation strategy to the impacts of climate change in the region (Norgaard 2016).

Figure 3. A forest floor after a prescribed burn (Photo courtesy of Lisa Hillman, Karuk Tribe).

The Karuk Tribe has been involved in a successful campaign to remove the Klamath River Hydro Project, a dam that blocks fish passage to their spawning grounds. The Tribe attempted to negotiate for better environmental regulations with the dam's operator, Pacific Corp, when the dam's operating license came up for renewal in 2007. When Pacific Corp did not address the concerns in their new licensing submission, the Tribe embarked on an intense media campaign to "Bring the Salmon Home" to educate the surrounding community on the importance of salmon to the ecosystem and to their culture (Hormel and Norgaard 2009). The Tribe gained the support of the then California Governor Arnold Schwarzenegger, as well Friends of the River, the Pacific Coast Federation of Fishermen's Association, and other environmental organizations in the state. Tribal members also travelled to Scotland to protest the stakeholder's meeting of the parent company of Pacific Corp where they dressed in traditional clothing, sang, chanted, and drummed to demonstrate the threat the dam poses to their culture (Hormel and Norgaard 2009).

The media scrutiny resulting from the Tribe's campaign eventually convinced the company that the dam was too costly to continue operation (Hormel and Norgaard 2009; Tucker 2017). Currently the dam is slated to be removed by 2020, and Pacific Corp awaiting approval for the removal from the Federal Energy Regulatory Commission (Tucker 2017). The Karuk Tribe's "Bring the Salmon Home" campaign is an example of the success of highly visible activism in Tribal communities, as well as the benefit of involving the larger community in protecting culturally important resources in Tribal communities.

Table II. Karuk Tribe Strategies and Funding Sources

Effective Strategies	Funding Sources
Strengthening relationships with local resource managers	○ Supported by internal funds
Education and outreach in local community	○ Fundraising
Public pressure and highly visible activism	○ Fundraising
Engagement with local universities for research	○ USDA National Institute of Food and Agriculture: Agriculture and Food Research Initiative Food Security Grant
Using traditional ecological practices as adaptation strategies	○ North Pacific Landscape Conservation Cooperative ○ US Bureau of Indian Affairs Tribal Climate Resilience Program ○ Humboldt Area Foundation
Assertion of co-trustee rights	○ US Bureau of Indian Affairs Tribal Climate Resilience Program

Comprehensive Planning

A Holistic Approach: The Columbia River Tribes (Idaho, Oregon, and Washington)

The efforts of the Columbia River Inter-Tribal Fish Commission (CRITFC) illustrate the way in which the unique culture of Tribal communities can motivate successful environmental action when little has been done in the outside community. The CRITFC is a collaboration of four of the tribes located along the Columbia River: the Nez Perce Tribe, the Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Confederated Tribes of the Warm Springs Reservation of Oregon.

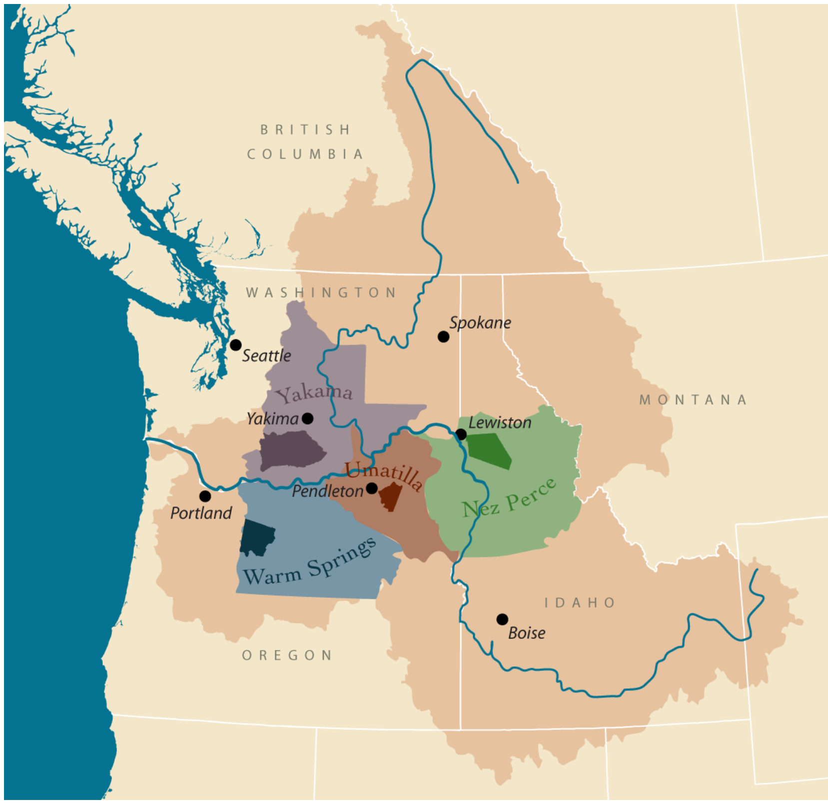

Figure 4. Map of CRITFC member territories (Photo Courtesy of CRITFC Website).

Salmon populations have declined dramatically in the Columbia River, as they have throughout the Pacific Northwest, throughout the twentieth century. Prior to European contact, 15-20 million fish were estimated to pass through the Columbia River annually; by 1995 there were 500,000 ("Spirit of the Salmon"). With little being done in the outside community, the CRITFC created the Wy-Kan-Ush-Mi Wa-Kish-Wit, or the Spirit of the Salmon Plan, to not only restore salmon and other fish in the region, but to strengthen its member Tribes' treaty rights, and to improve the health of the river system as a whole.

The cultural importance of salmon was at the heart of this action, and at the heart of the Tribal communities themselves. To the Tribes living along the Columbia River, salmon fishing is not a job, but a way of life handed down from generation to generation which makes the Tribes who they are (*Chinook Trilogy*). Among the Tribes salmon is considered a gift from the Creator that has cared for them since time immemorial. Spiritual leaders likened giving up on salmon to abandoning a family member in a time of need, and urged the region to care for the salmon as it had cared for them in the past ("Climate Change").

This cultural relationship motivated the Commission's initial action and undergirds the Plan's holistic approach to salmon restoration ("Climate Change"). The 1995 Plan blended traditional ecological knowledge and Western sciences through a "gravel-to-gravel" management plan where policies considered the needs of each habitat a salmon passes through in its lifecycle ("Spirit of the Salmon"). The inclusion of traditional knowledge also encouraged integrating the health of the entire ecosystem, rather than narrowly focusing on a single species; in Tribal culture, salmon cannot be divorced from the rest of its ecosystem, and is fundamentally in relationship with other organisms (*Chinook Trilogy*).[3]

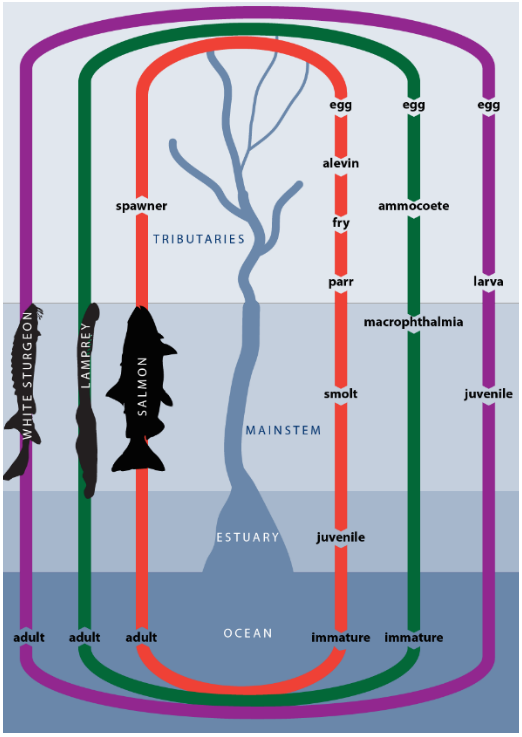

Figure 5. A visual representation of gravel-to-gravel management (Photo Courtesy of CRITFC 1995 Spirit of the Salmon Plan).

The Spirit of the Salmon Plan provided technical, institutional, and legal recommendations for governments and organizations within the Columbia Basin, which became a framework for other Tribal, state, and federal action in the region (*2014 Update*). The Plan's successful implementation hinged on coordination between state and federal wildlife authorities, local universities, environmental groups, the Columbia River Tribes, and other resource managers. Some of the critical outcomes of the plan include: the development of over 23 sub-basin watershed plans by state and federal fish and wildlife authorities with input and collaboration from CRITFC member Tribes; the creation of a formal dispute resolution process for CRITFC Tribes to address concerns about land and water use; new harvest regulations to more equitably share the salmon harvest between Native and non-native fisheries; revisions to Clean Water Act Standards for toxic chemicals to reflect the high fish consumption rates in Tribal communities; increased access to traditional fishing sites for Tribal members; and new employment opportunities in the fishing industry for Tribal members.

Most importantly, the implementation of the Spirit of the Salmon Plan successfully stopped the decline of salmon populations in the Columbia River in the twenty years since its adoption. In fact, data from the CRITFC indicates that salmon population is currently on an upward trend (*2014 Update*).[4] The plan's efforts to reduce existing stressors on salmon populations has also increased the species resiliency to the future impacts of climate change.

[3] See Table 1. in Appendix B for additional information on the application of traditional knowledge in the CRITFC's management plan.

[4] See Figure 8 in Appendix B.

The CRITFC has also worked to protect and secure floodplain and watershed habitats to better address the impacts of climate change on water ecosystems in the region (Gephart 2009). Increasing Tribal ownership of riparian zones ensures more consistent management practices and reduces the risk of development. The CRITFC identified their highest priority river corridors to purchase, using funding from a National Oceanic and Atmospheric Administration (NOAA) Fisheries grant and mitigation funding from a local power company. Between 2000 and 2008, the Commission acquired 3896 hectares of land to return to wetlands (Gephart 2009).

In a 2014 update to the Spirit of the Salmon plan, the CRITFC further addressed the impacts of climate change in the region. The update identified specific research needs, assessed the success of the recommendations of the previous plan, and issued new recommendations to local institutions and member Tribes. These include conducting a technical analysis of changes in water temperatures and flows to inform future water resource planning, tracking regional legislation related to climate change, and drafting a Strategic Climate Adaptation Plan for the Columbia River Basin (*2014 Update*). Since the update, two of the member Tribes have completed climate adaptation plans ("Climate Change"). In 2014, the CRITFC also participated in a review of the Columbia River Treaty, an agreement on hydropower and flood control between the US and Canada, to advocate for the inclusion of Tribal needs for climate adaptation planning in the renegotiation of the Treaty (*2014 Update*).

Additionally, in 2008 the CRITFC signed onto the Columbia Basin Fish Accords, an agreement between the Bonneville Power Administration, the US Bureau of Reclamation, and the US Army Corp of Engineers that dedicated $600 Million to salmon restoration on the condition that Tribal governments would not pursue litigation against hydropower and river operations for the next decade (*2014 Update*). By coordinating between regional governments and stakeholders, the Tribes were able to channel funding that would have otherwise gone into litigation directly into salmon restoration projects.

Table III. CRITFC Strategies and Funding Sources

Effective Strategies	Funding Sources
Land Acquisition for consistent land management practices	○ NOAA Fisheries Pacific Coast Salmon Fund ○ Bonneville Power Administration
Comprehensive planning and resource management	○ Bonneville Power Administration ○ County public utility districts in Columbia Basin ○ US Bureau of Reclamation ○ Congressional appropriation
Litigation to pursue federal trust rights	○ Supported by internal funds
Integration of traditional ecological knowledge and Western science in management practices	N/A
Partnerships with local institutions	N/A

Integrating Adaptation Strategies

Innovative Partnerships: Tulalip Tribes (Washington)

The Tulalip Tribes, a 22,000-acre Indian community in northern Washington composed of several smaller Tribal groups, are another example of the success of green energy projects in Tribal communities, as well as the power of integrating adaptation strategies to address multiple concerns ("*Tulalip Tribes"*).

Throughout the late twentieth century, the Tulalip Tribes were concerned about the impact of runoff and groundwater contamination from local dairy farms on declining salmon populations in the region ("*Tulalip Tribes"*). Like other Tribal communities in the Pacific Northwest, the annual salmon runs are an integral part of the Tribe's culture and food security. As a result, the Tribes had a contentious relationship with local farmers, who in turn often felt that the Tribes' treaty regulations inhibited their work and raised operating costs (Tulalip Tribe). However, after a series of floods in the region in 1990 inundated farmland across the region, a cattle rancher approached the Northwest Chinook Recovery, a non-profit dedicated to recovering salmon populations, for technical assistance in restoring a wetland on his property (Thompson 2012). A restored wetland would both minimize the threat of flooding during future storms and create a habitat for salmon to rear young (Thompson 2012; "*Tulalip Tribes*"). Positive press from the completed project in 1999 encouraged farmers and the Tribes to stop seeing each other as adversaries and instead seek additional mutually beneficial initiatives (Thompson 2012).

The resulting partnership spawned Qualco Energy in 2000, a nonprofit cooperatively managed by both the Tulalip Tribes, Northwest Chinook Recovery, and Sno/Sky Agricultural Alliance, an organization of farmers in the region. The shared energy collective diverts the manure produced on dairy farms from local water systems to power an anaerobic bio-digester, which generates methane gas that is burned and sold to the county's public utility district ("Tulalip Tribe"). The bio-digester facility began operating in 2008, and today generates a profit from what had otherwise been harmful waste threatening the salmon population (Thompson 2012; "Tulalip Tribe").

Figure 7. The bio-digester at Qualco Energy (Photo Courtesy of Qualco Energy).

The success of Qualco Energy became a foundation for further partnerships between the Tulalip Tribes and farm owners. More recently, the Tulalip Tribes helped to develop the Sustainable Lands Strategy, a partnership between the Tribes, Sno/Sky Agricultural Alliance, and other regional stakeholders dedicated to building regional resilience to flooding ("Tulalip Tribe"). The Sustainable Lands Strategy coordinated the creation of a comprehensive floodplain map that identified farmland at risk of flooding. As a result, farmers began to voluntarily sell or swap flood-prone land so that it could be returned to healthy riparian zones ("Tulalip Tribe"). Consequently, the initiative has implemented a novel approach to flood protection through work with Floodplains By Design, a public-private partnership in Washington State ("What is Floodplains"). The approach maximizes the benefits of natural infrastructure, utilizing setback levee systems that restore wetlands and marshes as riparian buffers and provide a habitat for wildlife. Coordinated planning between landowners and the Tribes in the region also led to the creation of flood bypasses and diversion channels in the case of extreme flooding events when dams and levees may potentially fail ("What is Floodplains"). By ensuring that regional environmental decisions were made through consensus, Sustainable Lands Strategy made a more diverse portfolio of resource management tools available.

As these projects illustrate, creative adaptation strategies can address multiple impacts of climate change simultaneously. Through work with the Sno/Sky Agricultural Alliance, the Tribes protected local wildlife, increased the resiliency of the region to future flooding, and developed a local source of green energy.

Table IV. Tulalip Tribes Strategies and Funding Sources

Effective Strategies	Funding Sources
Involvement in the green economy	○ USDA Rural Development grant ○ Department of Energy Tribal Energy Program National Renewable Energy Laboratory Grant ○ Sandia National Laboratories ○ Land donation from the State of Washington ○ US Department of Housing and Urban Development Native American Programs
Detailed floodplain mapping	○ Supported by internal funds
Voluntary buy-outs or land swaps to restore riparian buffers	N/A
Floodplains by Design integrated floodplain management approach	N/A
Strong local partnerships	N/A
Consensus in environmental decision-making	N/A

Conclusion

Though these examples and traditional knowledge systems are place-based, they illuminate successful strategies that could be applicable to climate adaptation initiatives in Tribal communities in the Great Lakes region. Federally-recognized Tribes in the US face common barriers in the adaptation planning process, particularly related to their limited governance over cultural and environmental resources on non-trust lands. Additionally, small Tribal government departments are often overburdened and limited in their capacity to address climate change in addition to the more immediate needs of their communities.

These case studies also shared some common threads, one of which was the importance of strengthening partnerships between local stakeholders and Tribal governments. As illustrated by the Sustainable Lands Strategy in Washington, and co-management projects between the Karuk Tribe and US Forest Service, building trust between Tribal governments and local stakeholders can grant Tribes greater input in regional environmental decisions. The CRITFC demonstrated that more comprehensive and coordinated management efforts require the participation of regional institutions and organizations, as well as the state and federal government. Education and outreach are essential tools in this process to strengthen relationships with regional stakeholders and facilitate a better understanding of Tribal culture.

An additional takeaway from these four case studies is the importance of traditional ecological knowledge in climate adaptation initiatives. Both the Karuk Tribe's traditional prescribed burns and the understanding of salmon in Tribal communities in the Pacific Northwest supported more successful and sustainable resource management. Traditional ecological practices such as these should be considered adaptation strategies, as they create more resilient habitats and ecosystems.

Climate adaptation projects within Tribal communities may not take the shape of traditional adaptation work. The ability of Tribal governments to respond to the challenges of climate change is reliant on a greater control of natural resources and more robust recognition of Tribal sovereignty. Addressing seemingly unrelated concerns such as chronic unemployment or poor health on the reservation allows Tribal governments to devote more time to consider the long-term impacts of climate change. The most successful adaptations strategies will address both problems simultaneously, as demonstrated by White Earth Nation's renewable energy projects.

Furthermore, it is important to note that the onus of responsibility cannot be on Tribes alone, as indigenous communities must also have better support and recognition from the US government to adequately adapt to climate change. Non-Tribal resource managers must also invest in identifying and removing barriers to Tribal participation in environmental decision-making processes to promote successful adaptation planning and implementation in Native American communities (See Resource 10 in Appendix C).

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